Waste Management Value Chain Factor Identification of Household Involvement

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Abstract

Circular economy approach means to increase the reuse of once acquired natural material in economy. Both environmental protection supporting initiatives and increasing awareness of pollution problematic is helping to increase recycled waste ratios. Main consumers in economy are Households and as result also main actor in generating waste. Literature analysis identifies the household role Sort a Source (SAS) as applicable approach, while limited information on recognized process components for household sorted waste habits with environmental impact assessment.

Challenges for efficient waste management:

1. Different implementations require different levels of household involvement in sorting processes for various sorted waste types.
2. Waste management is closely linked to infrastructure and introducing changes are both costly and lengthy, thus defining efficient processes is one of key long term aspects.
3. Various products sold have different lifecycle for their components (ex. Packaging vs actual product, more complex in case of replaceable parts), including recyclability, thus analysis of value chain has to be split to component lifecycle analysis (LCA) and recycling possibilities.

Keywords

Circular economy, Value chain activities, Waste management, Household and Sort-At-Source (SAS).

1. Introduction

A waste sorting and further recycling is basis for Circular economy. Society also is getting more aware of long term beneficial impacts of waste sorting and sorted waste ratios are increasing. Consumption of different products can be grouped by three main groups with different characteristics: industrial, commercial and household. Each of identified groups have different work processes and different waste management value chains with specifics attributes. In this article authors are focusing on household sorted waste analysis to identify factors, what are influencing waste sorting efficiency and identifying some challenges for efficiency analysis.

Households are critical as sorting at a source is one of most efficient approach to reduce total costs in waste recycling value chain, still there are some common aspects, what was not identified, and analysed in reviewed literature for full lifecycle costing. Analysis traditionally focuses either on Operator as waste or recycling system manager, also representing governance and normative regulation, while analysing household behaviour focuses on behavioural aspects. In this article authors assesses household role in product lifecycle focusing on waste management aspect and identifies elements, what are directly connected, with waste sorting with environmental impact, and what are external cost for operator service. Sorted waste processed are directly linked with implemented into particular area solution and defined requirements by waste operator. More convenient sorted waste processes *(value chains) would increase higher sorting rates with reduced rejected sorted waste ratios.

Secondary problem: In literature, the generalized model is referenced as analysis scope, giving result with granularity which is to low, to derive detailed conclusions for analysis for household level and directly use as input in CAD models for calculations.

Discussion items:

- Value chain elements identified in waste management process for Household
- Granularity of data necessary for detailed analysis - Household effort and materials consumed as part of process (granularity).

Separate topic for further analysis – Regulative/normative requirement changes to support sorted waste management process, but not recognizing Households as unpaid primary resources for Recycling operators.

Problem identified with initial analysis: Household role and actual environmental cost elements (Trade-offs: Effort and cost)) are poorly identified in the sorted waste process analysis or no available in sufficient details.

1.1 Methods

Methods used was literature overview for set scope for more detailed analysis, and further developed a simplified model with a LCA as approach analysis to assess the Household waste sorting process activities. Both theoretical and empirical literature on waste management is critically reviewed.

1.2 Objectives

Problem for research: Household role and actual environmental cost elements (Trade-offs: Effort and cost)), to identified as part of sorted waste process environmental impact assessments.
Research subject: Waste management process (Value chain)
Research object: Household role in waste management process.
Research question: Household role in waste management process activities potentially identify components.
Research objectives:

1. Analyse Literature and materials on Value chain and recycling, assess effort spent on waste sorting;
2. Identify Waste recycling value chain household related activities and develop simplified model;
3. Analyse Waste sorting activity for household;
4. Identify gaps and possible improvement approaches.

This analysis would identify potential gaps in assessments of total environmental impact for sorted recyclable waste, research and analysis approach used in literature criticism.

2. Literature Review

Waste produced is primal source of recyclable waste and is becoming more important to plan as general awareness of pollution problem is growing, especially in cities where population density is high. There are EU level initiatives and target set as KPIs to meet in recycling of waste generated (reducing landfill depositing unsorted unrecycled waste) concept to move toward circular economy are discussed (Hollins et al. 2017). Process for collection and actual recycling efficiency has huge impact on overall level" efficiency. Authors expressed with quotes as there as per researches literature analysis omits there is absent indication of inclusion of the significant components/elements thus potentially not covering full process. Models analysed for recycling often are analysis on recycling company processes with primary focus on solid waste component for recycling, omitting needed "pre-processing" phases or steps like transportation as logistic and effort done in households as impact. Identification of all process steps, their elements and stakeholders is required step to achieve actual TCO (Total Cost of Ownership) values for every process including waste management.

2.1 Waste sorting as incentives related to circular economy model

Circular economy as and approach views waste as and input for next cycle of manufacturing thus increasing sustainability with reducing need of primary resources. Better sustainability can be achieved by to decrease the negative environmental impact with initiatives in both directions: reduction of un-needed consumption and indirect environmental impact together with increased recycling of extended product usable life, by increasing options for sorting of recyclable waste and environmental awareness of households. Thus increasing circular economy conditions as also supporting a synergy for economies with optimal integration in infrastructure (Geipele et al. 2018).

Overall least damaging method for environment is reduce use as is analysed in researched articles and literature sources. Still in regards to view produced materials from sustainable point of view there can be identifies several main classifications for material circulation, while material circulation is a foundation of economy, thus "not use" at all is not possible. Ranking those views in most to least preferable several levels can be named as identified in **Figure 1.** Schematics of a waste hierarchy model (Rousta 2018) for sorting at a source assessment or on household level when viewing households waste management value chains. Note, there can be also analysed Waste management value chains originating in manufacturer sites, but it is outside this research still related costs in full TCO would be considered.

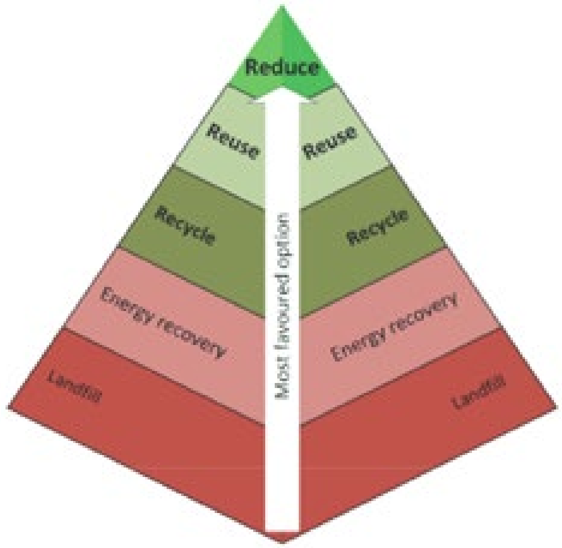

Figure 1. Schematics of a waste hierarchy model(Rousta 2018)

Approach represented in **Figure 1.** Schematics of a waste hierarchy model (Rousta 2018) is also basis for this research as can be linked and identified related value chains on household levels, where product purchased proceed, with product there also have to be viewed that un consumer side there are splitting point, like most cases packaging is removed upon actual use of good purchased, thus removed packaging (Some might be used in household for some period – like temporally storing food in opened packaging, example milk, but eventually packaging is split as waste). Households are also most important resource in view of recycling process as sorting upon use, what is recognized as "Sorting-At-a-Source" (SAS) is efficient as brings significant cost saving in recycling process in comparison to sorting later unsorted waste un Operator site. There can be viewed 2 general approached – fully centralized of fully decentralized for processes, but for waste specifics fully decentralized means returning to not managing waste (US EPA 2019). There can be also considered various options for decentralisation, and introducing even feasible cost machinery for households or small recyclers. Minimising a waste have highest impact to saving toward environment as not require further activities related with recycling (Sabiini and Rishmany 2019). Mainstream implementation if with centralized waste operators and recycler. Still author has hypothesis that household effort and also cost is not recognized in Waste recycling processes (Unpaid work) thus leading to underestimation valuation of total recycling impact (missing to identify and recognize all relevant environmental costs) see also **Figure 2**. Generalized Waste management value chain.

2.2 Waste management analysis with value chain model

The waste management processes can be analysed with Value chain method. Household living space is planned and constructed while building process, and it determines a household infrastructure options, what are available for particular household. Construction of value chain approach assessed is defined in applicable standards (ISO 14040:2006 n.d.), while infrastructure lifecycle analysis is covered with another standard reference to ISO15686-5:2017(en) Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing (ISO15686-5 2017). Considering both would lead to integrated model for analysis of processes.

There can be developed several models focusing on particular aspects for analysis and process diagrams with different depth of activities identified (for example to use likewise activity breakdown structure in line with and mapping BIM LOD levels/process vs. sub-process and activity levels) to analyse particular process aspect. Generic High level process diagram presented in **Figure 2.** Generalized Waste management value chain high level ISWA technical guide model (ISWA 2019).

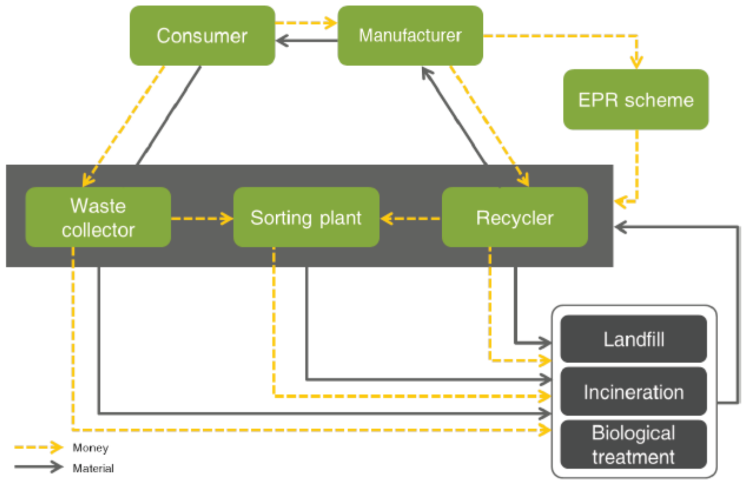

Figure 2. Generalized Waste management value chain high level model (ISWA 2019)

Primary waste sorting is a task placed on the shoulders on the households, thus waste sorting requires to adapt household or for a person performing particular task as a daily routine taking into account the available options (what are available) of infrastructure for sorted waste disposal. In other words, from the LCCA viewpoint, spending household personal resources to assure a more environmentally friendly and green lifestyle, on a daily basis includes additional effort and cost for actor, as discussed in article by Akil "Towards sustainable solid waste management: Investigating household participation in solid waste Management"(Akil and Ho 2014)**.**

Waste management operations should be viewed as 'more-or-less integrated' systems of collection and treatment for recycling. Within the considerably varied spectrum of systems in existence, however, a varying degrees of fragmentation can be identified in the collection system, but due the implementation and waste material being collected. When planning a waste management operator's infrastructure questions to consider are:

1. Which materials are collected separately?
2. How are they collected, and how does this affect collection of residual waste?
3. How effective are schemes at capturing the targeted materials? (Jean-Jacques 2014).

Covered scope of materials and processes would directly link to service costs. Infrastructure representing largely fixed costs part while service operation variable (recyclable materials). Also with consideration of recyclable materials there can and identified incentives (Hollins et al. 2017), both for household and waste Operator or particular materials recycler.

Waste management is often used with operators focus not fully recognizing other stakeholder interests, like households. This approach is applicable for operator services cost and price for clients calculation while limiting assessment to the cost and value chain aspect of operator and primarily internal, what also can be justified as internal of directly controllable costs are manageable for operator with high extent (Boskovic et al. 2016) **Figure 3.** Collection route.

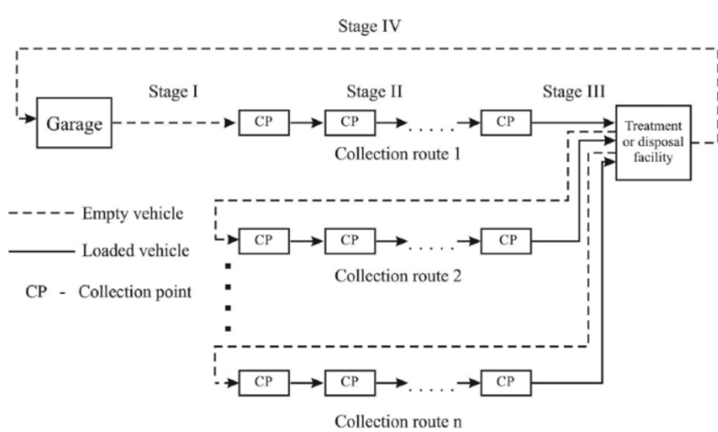

Figure 3. Collection route.(Boskovic et al. 2016)

Operator centalized analysis recognizes manufacturing and costs for household as external. That aslo simlifies calculations, thus not including in service fee calcualation, althought for TCO of LCA product this would be aplicable. Also for waste management viewing different large number of ōriginal products would not provide value as Waste service operator is not original product owner or manufacturer.

While the separation of materials (waste) that make up a product has been modelled as a measure of product complexity, this does not take into account the benefits and considerations in recycling products. In article, an approach to prioritize the recycling of products was developed based on a recycling desirability index, that composes a product, has to been modelled to include product complexity, this does not take into account the benefits and considerations in recycling products. In article published by Sultan el al. an approach to prioritise the recycling of products, was developed based on a recycling desirability index discussed in "What should be recycled: An integrated model for product recycling desirability" (Mohamed Sultan, Lou, and Mativenga 2017). Still in article focus to discuss product end of life recycling approach, while authors view, that more detailed and in-depth approach for detailed and parameterized analysis is needed for full understanding to TCA of full lifecycle. While in simplest implementation assigning a recyclability index enables to assess and compare products for a household decision maker and also would allow to select products with longer usable life, thus providing savings in primarily manufacturing resources and overall value chain by replacing less frequently of with less environmental impact and would be improvement.

2.3 Waste sorting effort in household

Sorting waste requires effort and resources. Within SAS model in a household a person performs the waste sorting, thus also contributing time. Different households have different habits and attitude to waste sorting what have been analysed in literature. Main arguments supporting waste sorting identified for example in article by Czajkowski et al. listing:

1. A stronger desire for a positive self-image leads to a preference for more home sorting of wastes as recycling behaviour may be observable by neighbours, family and friends;
2. Individuals may believe that home sorting of wastes is more effective than collective sorting. If people believe that more "waste" should be transformed into useful secondary materials, then a belief in the superior effectiveness of home sorting over collective sorting would also motivate a preference for home sorting, even when it is privately costly in terms of time and effort.
3. Individuals may feel that they have a moral duty to self-sort recyclables, and so prefer choice options with more self-sorting (Czajkowski, Kadziela, and Hanley 2014).

To authors understanding, there are need to analyse efficiency as resources used in household might be not fully attributed to actual waste management process on regional or national levels measurements.

General approach is to charge household /waste service client for waste. General economic theories us supply and demand considers that higher price (Charges) wold lead to less demand. In respect to environmental protection this negative relation with higher charges could be used as an incentive to reduce waste (Choe and Fraser 1998). In article there are discussed and concluded, that monetary terms can be part of motivation, but also indicates that there are relation to other factors like increase of awareness have significant positive impact. Article also consider to view as integral part of the waste management system options: deposit-refund, option, or implementation with upstream taxes, what would be interesting incentives and appropriate for manufacturers or service providers. One of main conclusions is that waste management costs have demand –price elasticity, thus when considering implementation a paying power should be taken into account as in generic models the waste management costs are defined for particular area and operator to assure high sorted waste interest.

This Literatures sources are presenting effort estimates for waste sorting activities thus this aspect has been analysed, for reference a survey results are presented as **Figure 4.** Time spent on sorting waste (Bruvoll, Halvorsen, and Nyborg 2000).

Table 1. Time spent on sorting waste. Minutes per week per person and hours per year per household. Average

How many minutes extra du you on average use per week for ...	Average for those who sort	Average for entire sample
... cleaning sorted waste	9	9
... folding, sorting and carrying sorted household waste	14	13
... transporting sorted waste to central depot. Disregard return deposit	7	6
Total	30	28
Total time spent per household per year in hours	44	41

Number of respondents: 1084 (those who source separate) and 1162 (entire sample)
Source: Omnibus Survey fourth quarter 1999, Statistics Norway.

Figure 4. Time spent on sorting waste (Bruvoll et al. 2000)

For using data, a comparative analysis need to be performed and for calculation estimates recalculated to indicate expected effort within particular waste operator service area (note: in this survey data is measured in minutes without additional cost elements assessed), as actuals effort required would differ for different instances (Operators/ areas) also a parameter. Limits of this survey, that, there are no information of process details and also person demographic data what would be relevant, who performs related waste sorting activities (for example, information adult vs children effort variance considerations).

Additional considerations, logistics and transporting to operator sorted waste collection points, also would be directly related to sorted waste infrastructure in particular area for household, with impact of total effort estimation/actual as sorted waste bins might be located in close vicinity and in distance. Actual and model representation of implantation would have to included estimated/calculated distance to sorted waste disposal as a modelling parameter.

3. Results and Discussion

To assess identified research topic main process stakeholders are identified, in process for this analysis are Households, Operators and Manufacturers (Service providers), each representing separate role in waste management process. Household are main actors as are consuming product of service thus also indicating usable life end for consumer products or services. Discussion of governance aspects in depth is outside this research as implementation is considered to be included by Operators in Waste management value chain supported with Manufactures implementation of Product /service in manufacturing value chain.

The waste sorting by manufacturers are not analysed as waste management on manufacturers processes (ISWA 2019), could be assured with high waste homogeneity input for waste sorting and homogeneous waste management thus reaching better efficiency and are managed directly as imposes direct environmental costs (environmental/pollution related taxation/ regulative incentives).

3.1 Overall simplified value chain for sorted waste analysis

For analysis purposes a simplified value chain model by authors of the lifecycle assessment, was developed Simplified model indicates 2 (Two) main outcomes of waste sorting, waste sorted for recycling. This process also covers considerations and approach as long lasting product can be used multiple times. is presented **Figure 5.** Simplified one cycle Lifecycle model with waste sorting in household. Product use considers multiple use of main product, while each use has environmental impact, by using energy of consumables during operation which Further detailed representation on activity level with indication of components is further depicted in **Figure 6.** Environmental factors in Activity level.

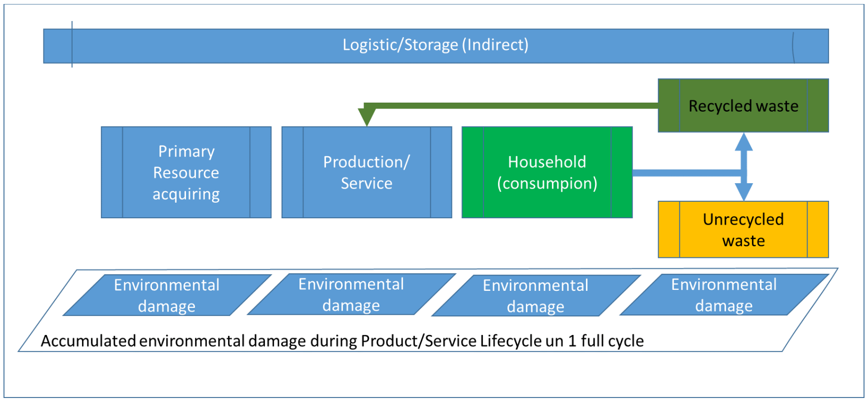

Figure 5. Simplified one cycle Lifecycle model with waste sorting in household (authors)

Such approach also contributes to identify a carry-over principle to next stage an environmental impact for a product what could be also assessed as sum of environmental impact by all component for product/service. A special assessment if needed for logistic impact assessment as logistics can be attributed by estimates of with particular instantiation (Location /waste management operators service area/ Operators value chains implemented together with infrastructure) and what is recognized as sorted waste (In Latvia, food packaging, has to be wasted clean before storing to operator sorted waste bins, thus introducing additional impact to environment).

3.2 Activity model of household for sorted waste components

Identified Household specific characteristics of activity each have environmental effect or price for decision as Trade-off (price of choice), thus a contributing to summary environmental impact for a product.

Waste sorting in household's specific characteristics for process modelling identified:

- Small amounts of specific waste per sorting event;
- Need to store specifics waste separately before delivery to operator separated waste bin;
- Knowledge and environmental awareness:
  - Knowledge, what and how to be sorted;
  - Who sorts (an Adult or a child washing food packaging);
  - Materials split to components.
- Effort for sorting largely differs with:
  - Packaging (before 1st use);
  - Primarily product type (specific types: industrial, food);
  - Product complexity.
- Usable life length of product;
- Consumables needed for operation event (Multiple);
- Household storage space for sorted waste allocation;
- Sorted waste bin location distance (Logistic);
- Waste management service infrastructure in area.

Identified aspects would be analysed for particular waste operator as provided infrastructure are limiting gains of waste sorting (Like long distances to disposal of specific waste introduces additional environmental costs for logistics (what can be justified for specific types of waste, example toxic/dangerous waste (batteries, chemicals, medicine related waste and similar).

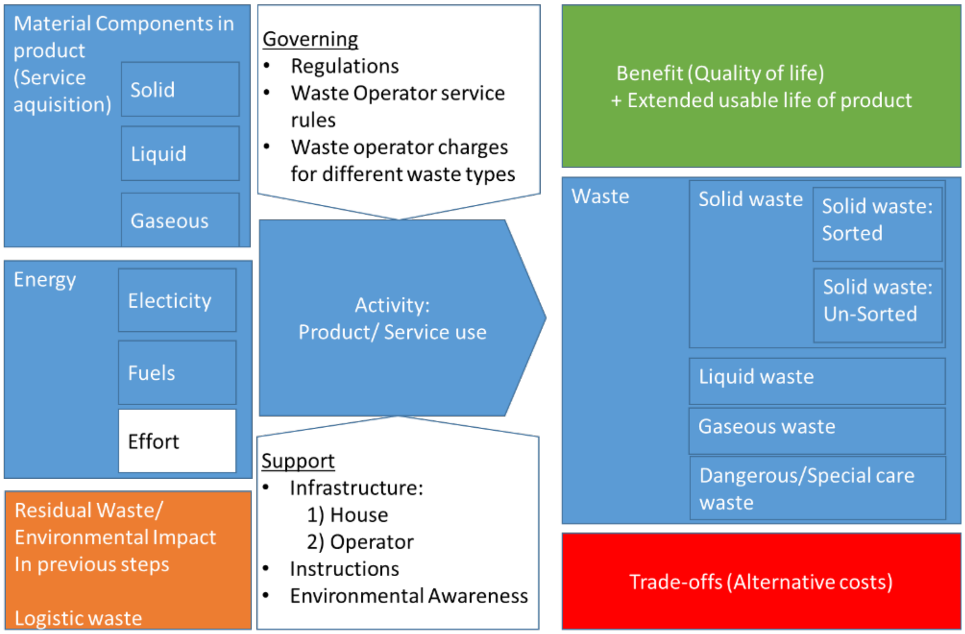

Figure 6. Environmental factors in Activity level.

An activity model for analysis of the household is presented in **Figure 6.** Environmental factors in Activity level, what identifies main components identified as process assessment parameters. Model indicates several categories for analysis, primarily indicated as inputs: Materials (also product) with split to components (solid, liquid, gaseous), Energy (electricity, fuels, effort) and Residual Waste (environmental impact in previous steps carried over, and Logistic waste). Product also can have attributed evaluation of waste management complexity as in literature indicated recycling desirability index which could be expanded to all consumer products and calculated by manufacturer/seller like appliance energy class index or plastic recyclability.

Governing aspects indicating all related regulative norms, waste operator's services rules together with Waste operator's charges for different sorted waste as they are forcing households to particular behaviours in waste management process. Strengthening governance stricter can be linked to McGregor theory of X and Y to authoritarian (Theory X), while authors suggest to approach with increasing motivation aspect with proper infrastructure developments and incentives with increasing environmental awareness.

Output section includes Benefits (or using / receiving primary purpose of product) also would indicate reuse of product ass separate instances due environmental cost associated differences first and then continuing use and potentially some maintenance (Like household appliances have common perception of estimated usable life 10 years and during each use have environmental effect which accumulated to total impact together with initial environmental impact of manufacturing and delivery).

Activity model components identified and presented there, are not exclusive and for particular analysis additional relevant components or groupings might be more efficient, while maintaining overall concept to evaluate and analyse potential implementation with least total environmental impact (represented in mathematical terms asses to minimize TCO).

3.3 Main results

Household involvement is critical for efficient consumer waste management approach, while manufacturing and product distribution processes including packaging solutions are decided and planned before household. Decisions on production and distribution are setting baseline for waste sorting and limits efficient resource use for recycling together with implemented infrastructure for sorted waste. Waste management processes LCCA evaluation together as full lifecycle LCA considering a SAS vs centralized or centralized for specific waste (unsorted/ hard to sort for Households) in respect of household

Potentially high impact and contribution to customer awareness would be to add relevant requirements in manufacturing guidelines to reflect and carry forward (over) information in for all stages of manufacturing environmental impact information and indicate values for households (consumers) to provide the product recyclability index representing total summary environmental impact or damage also a potential for recyclability as information for purchase decision.

Parameters identified are no exclusive and for particular service area considering infrastructure, more parameters could be identified of grouped while maintaining principle to minimize total costs of ownership for households (not operator primarily LCCA analysis).

3.4 Discussion items and analysis challenges

Discussion items open – In depth assessment model methodology for complex multiple stage manufacturing, representing logistic (component delivery for assembling sites) and infrastructure, with environmental cost contribution methodology. Methodology and models present and analyse environmental impact as in each stage there are limited information available for full lifecycle and thus proceed assigning estimated effect to particular activity indicating potential for recycling (Manufacturing and distribution phase). Also due the different infrastructure support implemented (Instantiation) in different areas, actual efficiency is closely related with options for waste sorting (Waste management Operator and Recyclers). On area /region or even national level further to proceed review and inclusion in relevant metrics for reporting (Area/National level).

Challenge in analysis – approach definition, waste as process or waste as output leading to different models: Sample composed waste accounting in waste processing have to be analysed separately as household identification there needs to split further, to rural and several urban by accessible infrastructure options). These aspects are aligning in Figure 1. presented concept that most efficient is to reduce unneeded consumption, what would be applied with reducing some components, what are hard to recycle with components what have better recyclability.

3.5 Proposed Improvements

Main improvements for further analysis and implementation can be identified:

1. For future assessment of waste recycling, recognize all components in product or service lifecycle together with available sorted waste infrastructure in area (also environmental costs in producing and logistics before consumption);
2. Recognize household effort and resources used in waste sorting as process “cost” with environmental impact (also as one of process parameters for implementation: a minimizing costs and effort in a household in recyclable waste process service infrastructure planning);
3. Consider to introduce recyclability index also in complex items *(product with packaging at a sales point), what is directly related with product /component recyclability and accumulated environmental impact (Sample of non-conformance food packaging (Indicating Recyclable plastics) requiring washing before it can be recognized as recyclable waste) – This improvement requires further research due complexity in practical implementation.

4. Conclusions

1. Literature analysis confirms and is providing insights for waste management as a value chain, indicating sorted waste as definite process
   a. Carry-over (*forward) principle is critical of full evaluation of the environmental impact for total product waste assessment as basis for total LCA of product or service environmental impact rating as TCO (Total Cost of Ownership);
   b. Develop and with relevant methodology included in normative based and implement a product a rating - Waste recyclability index, representing of total effort needed for recycling, note, for products, not rated - define Default value as baseline for evaluation as a baseline;
   c. Further developments and coordination on policies would be needed to consider as Household actually is last stage of direct product use lifecycle and in case used materials in whole value chain are not recyclable, thus limit whole process efficiency for recycling;
   d. Potentially assessing with indexes at a Point of sale a consumer goods, indicating summary estimated environmental impact for full lifecycle (consider ref. to equipment energy rating scale);
   e. Potentially introducing recyclability indexes can be linked to increasing of planned usable life for products as savings of environmental impact would offset additional costs on manufacturing or distribution value chain elements;
   f. Index also could be used to increase awareness /contribute for environmental aspects;
2. Confirmed and elaborated the identification of sorted waste as particular input of product/service value chain activity according circular economy concept.
3. Analysis result a simplified model and an activity model for household waste sorting was developed and discussed.

4. There were several gaps and improvements identified:
   a. Reflect all resources and value chain activities in waste sorting (Product lifecycle analysis and consider resources utilized upon sorting waste);
   b. Consider to minimize both effort and costs for household when planning waste management service implementation;
   c. There could be considered incentives to motivate household with bonuses with sorted waste what also would help to increase awareness and participation to increase overall recycling on SAS does require effort and cost at household.
5. General consideration - important aspect to support whole process is indicated a – relevant Infrastructure is one of key elements to increase recycling levels but for actual recycling level all related environmental cost elements would have to be reflected and included.

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Biography

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