Life Cycle Assessment of building end of life

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Abstract

The paper deals with how the buildings' end of life is assessed in LCA, throughout a study based on European Standard and literature review. End-of-life modelling is becoming more important within circular economy policies that improve the extension of buildings' service life (through regeneration and refurbishment processes) and building's components reuse or recycling. The paper highlights different assumptions and different approaches taken in LCA modelling of the building end of life: functional unit, system boundary, allocation method, inventory of quantity and data collection. Moreover the uncertainty and limits of modelling are analysed.

1. Introduction

In the last two decades, many LCA studies of buildings have been conducted, but a lot of them do not include an in-depth analysis of the end-of-life phase (asserted by Paleari et al., 2015). The omission is mainly caused by the lack of information and the difficulty in predicting future scenarios (Oregi et al., 2015). Many studies about building's LCA, in fact, are focused on the product phase (A1-3) and the operational energy use stage (B6); instead the end of life is modelled choosing simplified assumptions, such as an average distance between the building and the place of disposal and landfill for demolition waste of the whole building. In this way, the impact of end-of-life stage, in comparison to the whole life cycle, is less than 1% for the life cycle energy use, so the end-of-life stage loses its relevance (Oregi et al., 2015).

The simplified assumption about landfill for demolition waste of the whole building is no longer possible under the Waste Framework Directive (WFD) 2008/98/EC, which establishes that almost 70% of construction and demolition waste (CDW) have to be reused, recycled or recovered. Hence, the LCA studies from 2008 assume a rate of recovery/reuse/recycle of material over 70%, in order to respect the WFD. Moreover, the circular economy point of view is changing the concept of 'end of life', therefore also the evaluation of it. Circular economy policies aim at efficient use of natural resources and at reduction of waste generation (COM 398, 2014; COM 614, 2015). It is possible to state that, in this context, the promoting routes are:

- remanufacturing / reconditioning of products, which increase the lifetime of products by rebuilding and repairing them;
- a closed-loop system, which transforms products, that have reached the end of their useful life, into something new, by process of reuse and recycling of components.

In the building sector the actions, that respect these two routes of circular economy, are:

- the regeneration of buildings, in order to give back a new function and extend the service life of buildings; in this context the practices of repair, replacement and refurbishment are incentivised;
- the management of construction and demolition waste in order to reuse and recycle waste as secondary materials, avoiding landfill and the extraction of raw materials.

Nevertheless, improper management of refurbishment practices or CDW recycling should result in considerable environmental impacts and recycling processes might cause indirect environmental impacts (JRC, 2011; Mousavi et al., 2016). Within the life cycle thinking approach, it is important to evaluate the impacts of every circular action through scientific methodologies like the internationally standardized procedure of Life Cycle Assessment. In this context, the evaluation of the end of life phase, that has been little treated in the LCA studies, becomes crucial. In fact, with the support of LCA it is possible assess the impact of repair, replacement, refurbishment processes and CDW management: in the EN 15978 (2011) these phases are identified in the Module B3, B4, B5, C1-C4. Moreover EN 15978 sets a module D in order to quantify the environmental benefits or loads resulting from reuse, recycling and energy recovery processes.

The EN 15978 defines the limit between the end-of-life stage and module D. The end-of-life stage starts from the activity that produces waste, and considers the management for waste, as a “multi-output process that provides a source of materials, products and building elements that are to be discarded, recovered, recycled or reused”. The impacts assigned to end-of-life stage regard the waste management and disposal until the landfill (considering also the impacts of landfill), if it is the final destination of waste, included the impacts of transports (from building to landfill). But the situation changes when the waste stops being ‘waste’ to became a second-hand material usable in other processes by recycling or energy recovery. The secondary materials leaves the system, and its burdens are divided between end-of-life stage and module D. The process of collection and transport until the sorting plant of secondary materials are part of the waste processing of the building, so the burdens are assigned to the end-of-life stage; instead the further processes (e.g. recycling process) concern another product system. So the processes’ burdens and avoided impacts are assigned to module D (beyond the system boundary), in according to the ‘cut-off’ approach.

End-of-life modelling needs allocation methods to divide environmental impacts and benefits between the first and second life of products. There are different approaches and different methods of allocation and the debate is open especially in the context of defining the PEF (Giorgi et al., 2016). But, in the case of the building, the EN 15978 sets out a ‘cut-off’ approach. However in literature there are many building LCA studies that use other types of allocation, because of different goals and scope of the studies. Moreover, many methodological choice still remain without rules, and debates are still ongoing in areas like the definition of (temporal) system boundaries, life cycle inventory generation, selection and use of environmental indicators, and interpretation and communication of the LCA results (Saner at al., 2012). According to Sandin at al. (2014) the four factors that can mainly change the result of LCA are: the type of approach used in modelling between consequential and attributional approach, the end-of-life phases considered, the type of disposal that is chosen among reuse, recycling, incineration or landfill and the impact of technology assumed. This paper shows how some authors have treated LCA in case studies about buildings' end of life, which methods are assumed and which limits have been found.

2. Different goals and scopes in end-of-life modelling

In literature, LCA studies which take into account the end-of-life stage are conducted with different 'goal and scope'. The scientific papers analysed treated the end of life in three different way. Some studies use an approach of whole-LCA modelling in order to assess the entire environmental impact of building considering all stages of life, hence the end-of-life stage, too (e.g. Oregi et al., 2015; Blengini et al., 2010). Other studies regard a LCA which takes into account just few stages of building life. They want to evaluate the impacts of deep refurbishment of a building and assess the treatment of waste produced during the works (e.g. Ghose et al., 2017a). Moreover these studies compare buildings' intervention strategies which minimize the waste to aid decision making (e.g. Ghose at al. 2017b). Other studies consider only the end-of-life stage modelling to assess the impact of management of waste generated from building demolition. The goal of these LCA studies is to evaluate the environmental impacts related to end of life of the different fraction of construction and demolition waste in order to assess the best type of disposal or recovery (e.g. Butera at al., 2015; Sandin at al. 2014, Vitale et al., 2017), considering, also, the quality of recycling of materials. Moreover, studies want to evaluate different alternatives of demolition scenarios and management of waste generated (e.g. Martinez et al., 2013). Different 'goal and scope', brings different approaches and different assumptions in LCA, such as functional unit, system boundaries, data collection, data source and allocation approach.

2.1. Functional unit and system boundary in end of life modelling

According to ISO 14040, the functional unit is a measure of the function of the studied system. The functional unit changes in relation to different studies because it also depends on the reference performance chosen. Whole-LCA studies, focused on whole-life-cycle impact assessment, use a functional unit referred to the entire building and the design requirements, such as thermal comfort. So, results are expressed per unit of useful heated floor area and per year (1 m^2/years) (e.g. Oregi et al., 2015; Blengini et al., 2010; Ghose et al. 2017a; Ghose at al. 2017b). The studies that consider only end-of-life waste management, instead, take into account a functional unit aimed at management of waste generated by demolition activities. The functional unit is expressed in weight (e.g. tonnes) of waste generated, for assessing environmental impacts and benefits of the different scenarios of the management system (e.g. Butera et al., 2015; Vitale at al., 2017).

The Standard EN 15978 states that the system boundary of end of life has to consider the process of selective demolition/deconstruction, collection of waste materials of the building and the processes of on-site sorting, transport to plants for recycling/recovery and/or disposal of waste in landfill. According to the 'polluter pays' principle, loads, (e.g. emissions) from waste disposal are considered part of the building life cycle. However, the benefit of reuse or recycling (for example the energy generated form waste incineration or the benefit of use of secondary materials in the other productions' system) are assigned to module D.

In some studies different scenarios are assessed, hence different system boundaries are analysed in order to choose the most sustainable routes, considering different management processes for the same type of material. Blengini et al. (2010) in whole-LCA modelling consider the phases of: 'pre-use and maintenance', which include structure, finishes and equipment material (quantities estimated from building drawings and field measured data), transportation (average distances estimated from personal communication with designer and contractor), construction stage (estimated from field measured data, personal communication with designer and constructor, literature), maintenance activities (estimated from literature and personal communication with designer and constructor); 'use', which considers energy use for heating, ventilating and DHW, energy use for cooking, washing, lighting and use of appliances (calculated with the software); 'end of life', in particular, which considers three stages (estimated data from literature): selective disassembling of re-usable/recyclable materials and structures (windows, steel, aluminium and roof), controlled demolition of the structure by hydraulic hammers and shears, CDW treatment and recycling, reuse or landfill. In particular, CDW generated from the building process and during maintenance operations was considered: the mineral fraction, such as concrete, mortar, bricks, ceramics, etc., was assumed to undergo a recycling process for the production of secondary aggregates; metal and glass separation and recycling; wood incineration and mixed rubble recycling.

Ghose et al. (2017b), in LCA for different refurbishment assessments, consider three scenarios of different rates of recycling. The first scenario is 'business as usual scenario' which analyses conventional activities from production of refurbished components (without recycling content), transport to construction-site, construction-site activities and transport of waste to treatment site, waste management considering parts of waste to landfill and a little rate of material to recycling (considering, through consequential approach, the avoid loads of production of new materials using the waste as secondary materials and the avoid loads of a avoid landfill). The second scenario regards the 'waste minimization', it considers a rate of materials reused at construction-site and it assumed an higher rate of materials recycling than first scenario. The third scenario regards the ‘reduce demand of primary production’, it consider the use of material with recycled content in the production of refurbishment component phase and it assumed the same rate of materials recycling than first scenario. The fourth scenario regards a waste ‘minimization and reduce demand of primary production’, it consider both the use of material with recycled content in the production of refurbishment component phase and an higher rate of materials recycling than first scenario.

Vitale et al. (2017) analyse with more detail the CDW management, including all activities of selective demolition, collection, sorting, transportation, material and energy recovery, and landfill. It consider, through a system expansion, a system about the building demolition, sorting in situ and transportation, and the recycling chains for metals, plastics and glass, a waste-to-energy chain for combustible materials, and landfill disposal for residual waste.

However the assessment of waste are influenced by the perspective chosen and the assumptions made about material recycling and energy recovery. Therefore, in LCAs of alternative waste treatments, such as studies with ‘gate-to-grave’ system boundaries, the option of waste prevention (such as avoiding demolition) is rarely considered because the functional unit is commonly defined as a certain amount of waste to be treated (Laurence Hamon in Saner at al., 2012).

2.2. Data collection and scenario assumptions

Regarding to quantification of waste in a building refurbishment or demolition, the quantity of waste can be estimated through site measurement and by a model developed with a software, that gives a bill of quantities of material. Ghose et al. (2017a) declare that the estimating of material quantities based on models developed with software (like CAD) is a fairly trustworthy data collection method when bills of quantities of detailed building design are unavailable, and other studies also demonstrate this (Malmqvist et al., 2011).

Otherwise, the quality of secondary materials for recycling is difficult to forecast because it depends on the demolition process (if it is a selective or traditional demolition). Poor quality of recovered material affects its recyclability. In fact, Intini e Kuhtz (2011) explain, through an example of recycling PET, that the mechanical impurities represent the main issue affecting quality in the recycling stream, because manufacturing processes were originally designed for virgin raw materials only. Hence, efficient sorting, separation, and cleaning processes become very important in order to obtain high quality recycled material. Also, Ghose et al. (2017b), referring to a study of Graedel and Reuter (2011), show the importance of material recovery rate and recycling efficiency, which are the two main factors that determine the benefits of recycling. They show, that a low recovery rate (75%) with high recycling efficiency (98%) per kg aluminium scrap results in 0.74 kg of avoided primary aluminium production; instead an high recovery rate (100%) with a low recycling efficiency (70%) per kg aluminium scrap results in 0.70 kg of avoided primary aluminium production.

Moreover the end of life of building does not fall at present but it will occur at a later time. Generally refurbishment assessment studies take a reference life of about 50 years, and new building assessment studies take 100 years as reference life. Consequently, the technologies and processes of recovery should be more efficient than current ones. So, this is another assumption to choose within an end-of-life LCA. In the case study of Sandin at al. (2013), two assumptions of technology are assumed: one assessment takes today's technologies and the other one takes today's low-impact technologies which are representative for the average future technologies (wind power is assumed to replace diesel as energy source in demolition).

Moreover the regulations can modify the recovery rate. For example, the waste management scenarios have changed with WFD, which has changed the landfill scenarios to a rate of 70% recycling of CDW.

In end-of-life modelling, also distances of transport between building and recycling plants are estimated. The distances to recycling and deposit plants are calculated as an average distance of the current plants per region, in the LCA conducts by Martinez et al. (2013). In Butera et al. (2015), the distance from demolition site to landfill is assumed 50 km, while the distance to treatment facility is hypothesized 30 km. Moreover the avoided transport from place of extraction of virgin materials to production place is assumed 50 km. Generally, in every studies, the impacts of transports are a high contribution in a buildings' end-of-life LCA, so the assumption of distance play a crucial role.

2.3. Modelling methods

The great difference in end-of-life LCA studies regards allocation method assumed between attributional and consequential. The first (attributional model) sets the goal towards the analysis and description of the current and real situation. Attrubutional approach "consider the flow in the environment within a chosen temporal window", hence it counts all impacts as a current snapshot of a certain product or service. The second (consequential model) "consider how the flow may change in response to decision", so it hypothesizes the consequences, counting impacts that could be produced or avoided in a future situation (Ekvall, 2016).

It is interesting to note that, generally, the studies which want to predict the environmental impacts in decision-making phase, use a consequential approach with avoided impacts, and all benefits of avoided extraction material and avoided landfill are considered in the counting. Otherwise, other studies choose an attributional approach, calculating the impacts until waste disposal in case of landfill, or until the transport in sorting plant in case of recycling. In case of attributional no avoided impacts or benefit of recycling are considered in LCA results. Blengini et al. (2010), wants to assess the effectiveness of recycling process, so they choose a consequential approach of avoided impacts including the whole recycling chain. All activities and processes from waste collection to substitution of virgin products, are taken into account in order to assess the use of recycled products in comparison to the correspondent virgin products. In the study, the environmental burdens corresponding to manufacturing of new product with second materials are subtracted from the system. So, the environmental balance between impacts and gains can be negative, if the impacts avoided are higher than induced impacts. Attributional approach is adopted by Ghose et al. (2017a), because they want to avoid the risk of double-counting, so no benefits are given for the provision of recyclable materials, analysis the current situation. Instead, Ghose at al. (2017b) in order to assess a situation with future-oriented perspective, adopt a consequential LCA with an approach of avoided burdens. Butera at al. (2015) have the objective of studying the consequences caused by the changes in the modelled system, so they use a consequential LCA. Differently, in the study of Vitale et al. (2017) the allocation problem in the LCA modelling has been avoided by utilizing the system expansion methodology, because the study aim to quantify the contributions of each stage of the end-of-life phase, with a particular attention to the management of the demolition waste, without the problems of allocation.

3. Uncertainty of data

All studies analysed declare that uncertainty of data is the major limit in the assessment of end of life. The limited availability of buildings' end-of-life studies is caused by the lack of data on demolition, recovery and recycling of materials (Blengini et al., 2010). Generally, literature-based data and secondary data (such as international EPD, database) are assumed, but also the database assumption can change the LCA results.

Regarding database, some authors highlight the great lack of flexibility in a life cycle inventory (LCI) before ecoinvent v3. According to Ghose at al. (2017) the earlier versions of the ecoinvent database based on attributional modelling represented a lack of consistency and transparency in the consequential modelling approach. In 2013 the development of consequential datasets in the ecoinvent v3 database has reduced the uncertainty.

4. Conclusions

Recent circular economy policies give a new relevance to buildings end of life decisions so the modelling of this final stage need more careful analysis. The paper take into account different end-of-life LCA studies and the limit of assumptions and the uncertainty of data are stressed. The end-of-life LCA is highly uncertain in building sector, because generally many data are supposed, also because the end of life of building occurs in the future. To calculate benefits and loads there is the need to take into account several assumptions about, for example, types of treatment, distance to plants of treatment, the quantity of materials analysed, the efficiency of material recycling and the efficiency of technology and practices (existing or future). Many discussion are still open, such as about the type of modelling between consequential and attributional, the end-of-life phases to be considered, and the poor of data quality.

Hence, there is the necessity to improve the end-of-life assessment, in order to provide better support in the end-of-life decisions and waste management with LCA. At first, waste prevention, which is the first pillar of waste hierarchy, has to be considered also in end-of-life LCA, then differences among scope definitions, time perspectives and boundaries, and the use of different allocation procedures for waste treatment and recycling have to be minimized, furthermore, data quality must be improved.

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