LCA approach for the C&D waste management system in different countries of the world

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Abstract

The main problem with the recovery of construction and demolition (C&D) waste is the huge amount of recycled aggregates that remain unsold, due, maybe, to the lack of trust by sector operators. Carry on an environmental assessment would be a useful method to reveal the advantages in the use of the secondary resources. Through a literature review, this paper will analyze the application of Life Cycle tools for evaluating circular strategies in C&D waste management to compare different scenarios, hypotheses, and approaches adopted in life cycle assessment (LCA). The comparison will be done between four scientific articles from different countries (Italy, Spain, Denmark, and Brazil), in which an LCA analysis regarding C&D waste management has been carried out.

1. Introduction

The huge generation of mineral waste from construction and demolition (C&D) activities sets its gaze on the opportunity of a possible recovery. In Italy, most C&D waste is already sent for recovery (ISPRA, 2019) but despite the good performances in terms of recycling rate there are still obstacles that prevent the widespread use of the secondary resources produced in the recycling activities. This is, probably, caused by the low landfilling fees, the high availability and/or low price of natural aggregates, the lack of or inefficient waste sorting at source and, above all, the lack of trust in the use of recycled aggregates (RAs). The main problem with the recovery of C&D waste is, therefore, the huge amount of RAs that remain unsold (Collivignarelli et al, 2018). Among the various possible solutions, to push the sector operators to use them, one could be the environmental and economic evaluation of the advantages of the use of RAs compared to natural ones, and this can be done by applying the life cycle methodologies as the Life Cycle Assessment (LCA) and the Life Cycle Costing (LCC). The LCA is a methodology to evaluate the potential environmental impacts of a product or a system by accounting for the environmental exchanges (e.g. emissions, consumption of reagents and energy) over the entire life cycle of the product or system for several so-called "impact categories", such as e.g. climate change, resource depletion, and toxicity. The LCC, instead, considers all the costs that will be incurred during the lifetime of the product, work or service, e.g. acquisition costs, operation costs, disposal costs, maintenance costs. The following article focuses on the LCA of the C&D waste management system which takes into attention all the phases, from the generation of inert waste in the demolition site to recycling in dedicated plants and the production of RAs up to the recovery in new constructions (buildings or roads). Various LCAs have already been carried out in Europe and worldwide. Four scientific articles on the topic will be investigated to compare the applied methodologies and the results obtained.

2. Literature review of LCA studies applied to C&D waste management

Through a literature review, four scientific papers were examined. The articles were chosen from the ones where the LCA methodology has been applied in the common field of C&D waste management but in different countries. Accordingly, the four papers are: Borghi et al. (2018) from Italy; Mercante et al. (2012) from Spain; Butera et al. (2015) from Denmark; Rosado et al. (2019) from Brazil. For simplicity, from now on, the publications will be indicated with the country of origin: Italy, Spain, Denmark, Brazil. The analysis of the four articles will put in relation four countries such as Italy (with Region Lombardy as a case study), Spain, Denmark, and Brazil (with São Paulo State as a case study) to find some correlations between the assumptions, the input data, and the environmental impacts assessments.

The first comparison that can be made concerns the amount of C&D waste produced in a year in the different countries and the fate of those waste (recycling, landfill or incineration).

In Italy, about 0.83 tonnes per person of C&D waste was generated in 2014, of which the majority has been sent for recycling. In Lombardy Region the mixed waste (EWC 170904) is the main flow, accounting for approximately 80% of C&D waste. The 90.7% of C&D waste was sent to recycling, 3.3% was disposed of in landfills and the remaining 6% was stored in transfer stations without being subjected to any further treatment within the same year. In Spain, about 0,75 tonnes per person of C&D waste are produced every year; reduction or prevention is the first management choice, followed by re-use and recycling, valorization (including energy recovery) and lastly deposit in sanitary landfills (Rodríguez et al, 2014). Relating to Denmark, the article does not give data on the quantity of C&D waste generated but the recovery rate (mostly in road construction) is already over 80% as the landfilling of the C&D waste is not practiced in Denmark (Butera et al., 2014). In Brazil, the data reveals the production of 0.48 tonnes per person per year. In Paulo State the 30% of the C&D waste generated in each municipality is sent to illegal storage area and then sorted, and disposed of into inert or sanitary landfills, depending on their composition. Only seven municipalities out of the 58s of the São Paulo State recycle 20% of the mineral fraction.

2.1. Step 1. Goal and Scope definition

The first step in the LCA is to define the goal and scope of the study.

2.1.1 Goal

All the articles share the same main objective which is to evaluate the environmental impacts relating to the end of life phase of the mineral fraction of C&D waste. The Spanish case study also combines the goal to draw a proper

LCI (Life Cycle Inventory) of C&D waste management in Spain based on primary data collected directly from some Spanish companies.

2.1.2 Functional unit

The choice of the right functional unit is the most important phase of the LCA because everything that will be evaluated later will be referred to it. Italy, Spain, and Denmark and Brazil have chosen the tonnes of C&D waste as functional unit, demonstrating a certain unity in the way of thinking.

2.1.2 System boundaries and different scenarios

All the studies included in the system boundary all the treatment processes, starting from waste entering the management system until when it leaves the system as an emission (solid, liquid or gaseous) or as secondary material. The activities/ processes considered are:

- On-site storage
- Collection and transport
- C&D waste recycling and transfer
- Valorization (if any)
- Final disposal

However, the most interesting part is the different scenarios assessed in each paper, hypothesized to find the best-case scenario and what to improve to take the maximum advantage from the waste management. Italy (Table 1) and Brazil (Table 2) assessed the larger number of sensitivity scenarios by changing a certain assumption from time to time.

Spain considered two different kinds of recycling plants:

- Type I: These plants process mixed C&DW. They have a treatment capacity of 500-650 t/day and an installed power of 150-160 kW.
- Type II: These are larger facilities with two lines. The first one processes mixed C&DW with a production capacity of 3,000-4,500 t/day. The second one handles concrete waste, separately and independently from the mixed one. This second line, with a capacity of 2,500 t/day, produces secondary aggregate with better quality and more uniform composition.

Denmark analyzed two parallel end-of-life scenarios which are the utilization of the RAs in road construction and the C&D waste disposal in a mineral landfill.

Table 1: Scenarios considered in Italy case study

Sensitivity scenarios	Parameters that change
Base case scenario	11.6% of C&D waste is sent to the storage, 85.1% to recycling and 3.3% to disposal.
Scenario analysis on the method for calculating the replacing coefficient[8]	The replacing coefficient is replaced by R* that is based on economic considerations: $R^*=P_{RA}/P_A$ where P_{RA} and P_A are the average market price of RAs and of the avoided natural materials.
Scenario analysis on the management system	1. The storage operations were removed, the waste is directly sent to recycling and landfilling; 2. All the managed C&D waste is disposed of in landfills.
Scenario analysis on the recycling plants	1. Plants powered by electricity; 2. Plants fueled by diesel.
Scenario analysis on the transport distance	1. C&D waste delivery distance: between 20 km and 35 km; 2. RAs selling distance: between 10 km and 30 km; 3. NAs selling distance: between 30 km and 60 km.
Scenario analysis on the replacing coefficient[91]	1. R=0; 2. R1=0.97 and R2=0.86.
Scenario analysis on the RAs quality	The amount of avoided NAs was calculated by setting R=1 assuming that the quality and the performance of RAs is equal to that of NAs (Q=1) and that the market is stable and well-developed for high-quality RAs (M=1).
Best Case scenario	All the C&D waste is sent to recycling; The plants are powered by electricity; Transport distance is at the minimum value with NAs selling distance unchanged; 90% of the produced RAs are considered of high quality and R=1.

[8] The calculation of the replacing coefficient is: R=Q1*Q2*M in which Q1 considers the quality of RAs, Q2 the technical characteristics of RAs compared to those of the substituted material in relation to the specific application. M is the market coefficient, M=0 when all the produced RAs are unsold and M=1 when RAs are totally sold (Borghi et al., 2018).

9

Table 2: Scenarios considered in Brazil case study

Sensitivity scenarios	Parameters that change
Base case scenario	30% of the C&D waste generated in each municipality is sent to illegal storage areas. The waste removed from these areas is then sorted, and disposed of into inert or sanitary landfills, depending on their composition. Seven municipalities out of 58s recycle the 20% of mineral fraction using different facilities obtaining different RAs quality.
Scenario analysis on the municipalities' recycling rate	All municipalities recycle the mineral fraction: 1. The recycling rate is 20%; 2. The recycling rate is 100%.
Scenario analysis on the quality of facilities and RAs	All stationary recycling facilities utilised by the municipalities has the best configuration, obtaining a larger fraction of medium quality RAs. 1. The recycling rate is 20%; 2. The recycling rate is 100%.
Scenario analysis on the transportations	1. Consider that all the mineral fraction is transported to the existing recycling facilities, regardless of the recycling rate, following the same approach adopted in the other scenarios; 2. Consider the transport of the mineral fraction that will be effectively recycled to the recycling facility (recycling rate 20%), the transport of the remaining mineral fraction to the inert landfill, and the environmental burdens of inert landfilling.

2.2. Step 2. Life Cycle Inventory and quality of data

This step involves the compilation and quantification of inputs and outputs for a product or a system throughout its life cycle. In general, the primary data used to model the recycling of C&D waste, the products avoided, the transport distance and the storage operations, are collected from field visits and direct interviews with recycling plants' operators. Italy collected primary data, related to C&D waste recycling plants, during technical visits performed at nine recycling plants. All consumptions reported are average values weighted on the amount of C&D waste treated by each facility considered in the analysis. Data about the energy and material consumptions for the extraction of the natural raw material and the production of NAs were calculated based on official data provided by the 12 Provinces of the Region. Moreover, some road construction companies operating in the territory have been contacted to understand which natural materials RAs can substitute and how RAs perform compared to NAs. Transport distances have been evaluated analyzing the MUD (Modello Unico di Dichiarazione ambientale) database. Spain collected data directly from Spanish enterprises involved in the life cycle of the C&D waste management: two firms that manufacture containers and bags, that are used to store the C&D waste on demolition/construction sites, two companies responsible for the temporary storage of waste and transporting it, five firms devoted to sorting and treating C&D waste and two enterprises that operate inert landfills. The plants provided annual data on inputs (waste, water, electricity, and fuel) and outputs (emissions into the air and water, and solid waste). Denmark paid particular attention to the leaching data for C&D waste, which was obtained from lysimeter experiments on five samples. Data for capital goods of the C&D waste treatment facility and operation of the crushing machinery was retrieved from literature. In Brazil, a general questionnaire was elaborated to gather primary data about the C&D waste management as well as interviews and technical visits, where specific data have been obtained.

Italy, Spain and Brazil modeled the inventory data with the support of SimaPro software while Denmark used EASETECH (Turconi er al, 2013) a model for LCA of waste and energy systems developed by the Technical University of Denmark. All of them, instead, took ecoinvent database as a reference to configure the inventory of minority materials, fuel, and electricity.

2.3. Step 3. Life Cycle Impact Assessment

The third step is aimed at evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (associating inventory data with specific environmental impact categories and category indicators). In table 3 all the impact categories that each country has chosen to estimate are indicated.

Table 3: Impact categories considered in the four studies

Impact categories	Climate Change	Ozone Depletion	Human toxicity Non-cancer effects	Human toxicity cancer effects	Ionizing radiation	Particulate matter	Photochemical ozone formation	Acidification	Eutrophication	Eutrophication freshwater	Eutrophication	Freshwater ecotoxicity	Water resource depletion	Mineral, fossil & ren resource depletion	Energetic impact	Natural resource consumption
Italy	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Spain	x	x					x	x	x	x	x					
Denmark	x	x	x	x	x	x	x	x	x	x	x	x		x		
Brazil	x	x	x	x	x		x	x	x					x	x	x

Italy chose two different characterization methods for the impact assessment:

- ILCD 2011 method considering all the recommended impact categories except the land use and the ionizing radiations.
- CED method (Cumulative Energy Demand) to evaluate the energetic performance.

Spain and Brazil applied the characterization factors proposed by CML (Guinée et al, 2002) to the selected impact categories, while Denmark as Italy included the ILCD-recommended midpoint categories.

2.4. Step 3. Results and Interpretation

In the final step of the LCA procedure, the results are summarized and discussed as a basis for conclusions, recommendations, and decision-making having in mind the goal and scope of the study. In Italy, the result showed that under the current scenario, for most impact categories, the benefits associated with C&D waste recycling (due to the substitution of natural resources) cannot balance the burdens generated from the other management phases (mainly from transport). A good part of the assessed scenarios showed no or quite small advantages in respect to the current scenario. The scenarios in which some improvements are encountered are those with plants powered by electricity and in which there is a reduced delivery distance for C&D waste. The maximum advantage is, instead, found when all the RAs produced are of high quality and the total amount is sold. The best-case scenario shows a negative sign in most of the environmental impact indicators. The study conducted in Spain revealed that for all impact categories, the consumption of fuels and energy by transport, sorting and landfilling, make a net contribution to the environmental impact. Moreover, the scope of the Spanish study included the burdens due to the manufacture and use of bags and containers for the temporary storage of C&D waste. The result showed that the net contribution of the containers is lower than 1% of the global impact for all impact categories. The savings are due to the recycling of plastics, metals, aggregates, cardboard, and wood for all the impact categories, except for climate change for wood and cardboard which emissions, due to recycling, are bigger than those of the corresponding virgin products. In Denmark, the LCA modeling demonstrated that the utilization of C&D waste in road construction as a replacement material for natural gravel was preferable to landfilling for most environmental impact categories. Also here, transportation of C&D waste and avoided transport of natural aggregates were the most important processes for most non-toxic categories and one toxic category (carcinogenic human toxicity), accounting for 60–95% of total impacts. Leaching played a major role in freshwater eutrophication, as well as human and ecosystem toxicity. In these impact categories, landfilling disposal may be a better solution than road utilization due to the lower Liquid/Solid ratio in the landfill scenario, and the included leachate collection and treatment. In Brazil, the results highlighted the importance of the avoided impacts from recovered materials, mainly those related to steel, glass and plastics recycling. The results of the alternative scenarios indicate that the increase of recycling and the production of medium quality RAs improve significantly the impact categories of Acidification and Respiratory Inorganics compared to the base-case scenario. However, although the mineral fraction represents a large quantity of C&D waste, its recycling does not appear remarkable for the avoided impacts. Conversely, its contribution to the impacts of transportation was significant, accounting for the consumption of 76% of the total crude oil used throughout the management system.

3. Discussion

In conclusion, in all the papers, the LCA of the C&D waste management system was carried on following nearly the same approach. The goal and scope, the way to collect data, and the impact categories are very similar. In all of the LCAs similar results were obtained and all of them have concluded that recycling is not always the best environmental choice due, especially, to the high emissions deriving from the C&D waste transportation and to the emissions of the recycling plants. The key points recommended by the Countries to improve the environmental performances of the system, so, are: the increase of the demand of recycled aggregates, supporting their use in the construction sector; the reduction of the waste transportation distance (shorter than 40 km) by, for example, localizing the recycling plants properly across the regional territory, and promoting the connection between recyclers and constructors. However, to have a wider view on the life cycle process the LCAs studies should have added to the boundary system the first phase of the demolition. One suggestion by Italy, Spain and Brazil is, indeed, the adoption of selective demolition in civil construction and demolition works but they did not include it in the system studied. Instead, one study that assess the environmental performances of the selective demolition was carried by Rigamonti and Pantini in 2019: the results show that the environmental sustainability depends a lot on the characteristics of the building to be demolished as well as on the local markets for recycled materials and selective demolition alone cannot solve the problem because it must then be followed by a good waste management system (i.e. there must also be recycling plants, good secondary materials must be produced and these must then be really used in replacement of something). Waste legislation and policy of the EU Member States in the waste management hierarchy put as a priority the prevention (European Commission, 2008). The correct management from the generation phase is a key element to allow compliance with the hierarchy of waste, ensuring the waste reduction and the optimization of the recovery of materials.

4. Concluding remarks

We can conclude that, in all the reviewed papers, the LCA of the C&D waste management system was carried on following nearly the same approach.

Recycling is not always the best environmental choice due, especially, to the high emissions deriving from the C&D waste transportation and to the emissions of the recycling plants.

Sensitivity and scenario analyses, where the influence on the results of the variation of one or more parameters and assumptions is evaluated, is useful to help the final decision-making phase and to make more direct recommendations about what to improve. Both Italy and Brazil analyzed a good number of scenarios, while Denmark and Spain assessed only the two different cases of recycling and landfilling.

The demolition step should be included in LCAs of C&D waste management systems as it determines the quality of the waste flows sent to recycling plants.

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