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# TOWARDS THE DEVELOPMENT OF A SIMPLIFIED LCA-BASED MODEL FOR BUILDINGS: RECYCLING ASPECTS

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## ABSTRACT

The building sector identified as a main contributor of energy and resources consumption contributes to many environmental impacts such as resources depletion or climate change. The identification, quantification and analysis of the main flows of matter, energy and pollution through the building system by means of appropriate methods can help to provide knowledge and tools for decision making.

The Life Cycle Assessment (LCA) is, in this context, a method which can be applied to study the environmental impacts of buildings. Several LCA-based environmental analysis tools have been developed over the past few years. However, the relevance of such tools is often questioned. The methodological choices seriously influence the results of the analysis particularly in terms of data quality, type and number of environmental indicators, recycling take-account, modelling of the end of life (EOL) and more widely the chosen system boundaries. As a result of all of these shortcomings, the LCA studies are often seen as being too complex for application in the design process.

In this article, we present the current LCA models characteristics for buildings. Then, we focus the analysis on the recycling and EOL of products by presenting the current practices.

It has been found that current LCA models do account for material, recycling and end of life aspects but in a way so that it is not an easy task to evaluate the design choices for these aspects. Through the adopted methodology, main recycling criteria of LCA models were identified and consequences of defining a proper boundary system for a LCA model are discussed.

We conclude by discussing the challenges of improving the LCA methodology for buildings.

## INTRODUCTION

The environmental impacts of buildings have become an issue of interest since the building sector is identified as a major contributor to the environmental impacts resulting in many pollution, energy consumption and waste generation among others. Even if much work has been done in this area, there is still a major way for research to improve the methodology of LCA tools for buildings. The detailed analysis of some hidden flows in current LCA model such as the material and recycling flows and end of life aspects become relevant as the use phase of a LCA of buildings is of less magnitude in new types of buildings (green buildings, low energy, and passive buildings). By reviewing the literature about environmental assessment tools for buildings, several tools were identified. However, even if state-of-the-

arts are available [1], no proper detailed analysis on the LCA model characteristics is proposed. Dealing with the recycling and end-of-life (EOL) aspects, they are often poorly addressed even if some authors tried to propose improved methodology in this field [2]. The objectives of the work underlining the article are to first present the basis of LCA models for buildings. Based on the current limitations, we discuss the recycling aspects and the relevant criteria to account for.

#### METHOD: SURVEY OF CURRENT LIFE CYCLE ASSESSMENT MODELS

The construction of a LCA-based model of buildings refers to a systemic approach of mass flow balance. It enables the quantification of diverse environmental impacts of a system (material, product or building) from the extraction of raw materials until the end of life and possible reuse or recycling [3, 4]. As a result and contrary to other environment assessment tools such as Mass Flow Analysis (MFA) or Environmental Impact Assessment (EIA) which model the flows within a given period of time (*e.g.* a year), intrinsic key parameters in a LCA are the evaluation of a function across a certain period of time. It means that the scope of usual LCA study encompasses different periods of time between the extraction of raw materials until the end of life inevitably resulting in using scenarios. This argument is especially justified for long-lived system such as buildings where the life cycle is generally model within 50 to 100 years depending on its use [5]. These key parameters enable to distinguish the LCA of buildings (resp. building products) from the LCA of other manufactured products with short life cycle.

The survey literature on recycling aspects is taken both in current LCA models description [1] and some from the existing literature [2, 9].

#### RESULTS OF THE ANALYSIS

Table 1 presents five different models currently implemented in LCA models except the construction product model [9]. The analysis of recycling modelling is split between different criteria as shown in table 1 and in the following paragraph.

Existing recycling approaches	Type of evaluation	Type of recycling model	Type of recycling allocation / characteristics	Recycling process allocated in FAB	EOL included?	EOL activities included	Recycling process allocated in EOL
Cut-off [1]	Comparative	Open or closed loop	Full bonus of recycling at the fabrication phase	x			
Metallic recycling methodology [1]	comparative	Open or closed loop	Full bonus of recycling at the fabrication phase	x	x	x	x
Bonus method (avoided impact) [1]	comparative	Open or closed loop	Half bonus at the fabrication phase and half at EOL	x	x	x	x
Value substitution [1]	comparative	Closed loop only	Decrease of the quantity of matter in entry and quantity	x			
Construction products model [9]	Absolute (flow)	Open or closed loop	Bonus for using SRM** in the life cycle system studied	x	x	x	
Stock flow [11]	Absolute (flow)	Open loop only	Assessment of an effective flow	x	x	x	

\*\* : secondary raw materials

Table 1. Criteria of existing recycling approaches.

- INTRODUCTION IN EOL MANAGEMENT AND RECYCLING TYPE:

Considering the building sector specificity, we differentiate closed-loop which corresponds to a recycling within the same system and for the same function *e.g.* recovered steel in a steel production plant from open-loop recycling which deals with different life cycles upstream and downstream the life cycle of interest. The last type of recycling is usually encountered in the building sector [10]. Whereas the closed-loop recycling allocates the recycling process within its boundary, in open-loop recycling, the recycling process is not readily allocating, remains unclear and lead to define boundary conditions depending of the objectives the model should follow.

As mentioned previously, one key assumption in every LCA model is the time parameter. Usually no time differentiation is considered and it is assumed that the impacts occurring at the end of life are the ones occurring at the time the assessment is carried out by lack of having forecasted data on end of life.

- USUAL PARAMETERS TO CONSIDER:

In the recycling modelling, usual parameters are the incorporation (at fabrication), recycling (at EOL) rates and the distances of transport between recycling facilities and the building site.

- ALLOCATION OF RECYCLING PROCESSES:

Current bonus method, as shown in table 1, credits a material being recycled with half of the bonus (impacts of recycling minus impacts of the avoided fabrication thanks to recycling) at the fabrication and the other half at the EOL phase, often resulting in negative values at this stage (see for instance results from figure 2). Yet, crediting a bonus at the EOL phase is actually relying on a major assumption which can lead to a major drawback: one may credit a product for a recycling that may not happen. On the other hand, 90% of steel elements are recycled at EOL whereas this proportion is only around 40% during fabrication, so that the bonus method may be more appropriate for such materials.

As a result, the stock flow model, currently implemented in the French environmental data, enables to be in accordance with environmental product declaration (EPD) and databases specific to construction products [7]. The main criteria for this model are to date: the allocation of the recycling process at the fabrication phase which enables to always evaluate current recycling technologies. This type of allocation in a recycling model adapted to the LCA of buildings has been little discussed in the literature. Vieira *et al.* proposes a similar method to take into account the end of life impacts of buildings (and as a result the recycling aspects) by allocating the recycling process at the fabrication stage [2]. Besides, this model does not consider the EOL treatment and draws the system boundary until the EOL activities *i.e.* selective dismantling and transportation to the end of life (with specific distances according to the assumed end of life scenario: landfill, incineration or recycling). As a result, one key point of this recycling model is that it decreases uncertainty due to technological forecasting by always assessing effective recycling flows at the fabrication stage.

- EVALUATION OF THE RECYCLING BENEFIT:

One aim of every LCA study or LCA-model is to be as transparent as possible that is to clearly show the methodological hypothesis taken in the model. In the recycling issue, a LCA practitioner would straightforward apply the recycling at the inventory step whereas the output of the LCA model is very often expressed as environmental indicator.

In the different recycling models analysed, it has been noticed a difference between all the models as some calculate the recycling benefit as a function of the current flows *e.g.* incorporation of secondary raw materials (SRM), recycled waste generated whereas others do it by means of a difference between a virgin material compared to a recycled material.

To make clearer the situation, there is a need to explore more the relationship between the input (environmental data representing inventory of several flows), the methodological choices (does the building's LCA model include a recycling model) and the environmental indicators as an output (which indicator is suitable and affected by the integration of the recycling flows).

It is every time possible to consider three scenarios of recycling rates (null, current, maximal rates). For example, the incorporation of the steel as secondary raw material (SRM) is currently in France about 40% whereas the recycling rates are still high, around 90%. This discrepancy may be explained by the fact that there is not obvious correlation between these two recycling parameters because they rely on technological processes for the recycling, material structure after a life cycle which may lead to use more process to incorporate it as a SRM in a new life cycle, and a last parameter which we define as the degree of separability. It means that even if a material is potentially recyclable at the end of life, due to its incorporation within other materials and as a whole within a building will not automatically ensure its recycling at the end of life due to its 'degree of separability'. By taking again the example of steel, it is stated that a steel product entirely made by steel material will be more recyclable than another product incorporating steel linked to other materials. As a result, incoming work should define precisely the concept of the degree of separability by identifying for different building products a value of this innovative parameter. Current recycling models either define a bonus (difference between recycled and non recycled product) or a flow with an effective recycling (at fabrication and EOL phases). Generally the recycling rates at EOL do not properly address this degree of separability as data may not always be available.

By emphasis on this last parameter, it enables to identify one of the major differences between product specific LCA databases [7, 11] and generic LCA databases.

- RECYCLING PARAMETERS INFLUENCE:

The different models were tested in order to see how they influence the results of the analysis. A simplified application on a reinforced concrete building enables to emphasize the importance of the production phase. Its influence decreases if the incorporation rates are maximized except in the bonus method where negative values occurred when assessing the EOL impacts which significantly differentiate this model from the other ones under study. It has been also found that the transportation distances are usually of less relevance than key parameters such as the recycling rates. Yet, these transportation distances can play a key rule at the EOL. As some models *e.g.* stock flow do not account of recycling processes at EOL, the only parameters of recycling at EOL are the dismantling impact and transportation distances. As a consequence, it may result in assessing a better environmental impact for landfilling or incinerating scenario compare to the recycling scenario as the transportation distances to recycling facilities are often higher than the distances to landfill scenario due to the presence of local landfill opportunities [12].

This is illustrated in figure 1 where a distance of transport to recycling facilities ranging from 0 to 500 km was assessed. Results show the increasing discrepancy between the allocations approaches depending on the inclusion of the recycling process and the associated recycling rates. Data were taken in the LCI database ecoinvent [6] and the impacts are expressed in cumulative energy demand [6] for a functional unit of 1000 kg. The default scenario was considered as landfilling of concrete by taking a 30 km distance according to the french EPD database [11]

The impacts for recycling at EOL are for the 'no recycling process' scenario only the dismantling and the transportation distances corresponding to an increased function of transportation distances whereas the other scenario do include the recycling process, it results

in having negative values (recycling offsets) up until a critical distance about 400 km. The offsets for the stock flow approach are of less magnitude as the model does not include the recycling process and the critical distance is thus shorter and about 80 km.

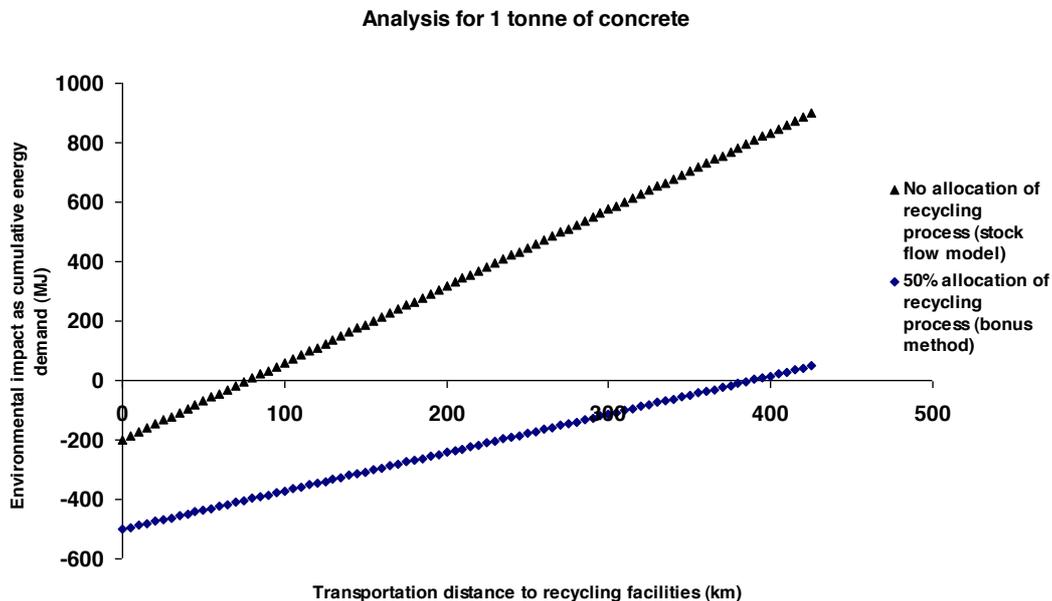


Figure 1. Analysis of EOL impacts as a function of transportation distances

#### DISCUSSION IN RECYCLING MODELING WITHIN LCA MODEL OF BUILDINGS

The recycling and end-of-life inclusion is currently modelled in different manner leading to possible high differences especially if the assessment is done phase by phase (*e.g.* production, transport, on-site... EOL). As a result, we recommend that the inclusion of recycling at the EOL should be first guided by the objective of the study. If the goal is to favour building design for recycling, then the EOL recycling processes should be taken in the analysis. The concept behind is the precautionary principle and the incentive to influence the building design as early as possible to take into account of recyclability at the EOL.

However, the study of the stock flow model revealed another way about dealing with recycling. First, this model does not deal with recyclability but only effective recycling. By allocating the recycling process at the new product (fabrication stage), it ensures to always assess current technologies which deals only with an effective recycling flow. From a LCA methodology point of view, it enables the reduction of uncertainties due to technological forecasting. The other approaches reported in the table either are closed loop approaches (value substitution) and then not properly deals with the effective recycling in the building sector or do not account for the EOL (cut-off approach) meaning that the material flows leave the system without any environmental impacts. In a view of developing a simplified LCA model for building, it would be interesting to study some probabilistic scenarios at the EOL as it would encompass some of the shortcomings of the different current models namely account for the uncertainty and include the recycling process at EOL.

#### CONCLUSION

Different recycling approaches were assessed according to different criteria. Current limitations are of many magnitudes and it was not in the aim of this article to present all of them in details. The recycling and end-of-life inclusion seems to be either portly handled or in

different manner leading to possible high differences especially if the assessment is done phase by phase (*e.g.* production, transport, on-site... EOL impacts). A sensitivity analysis would be needed in the incoming work in order to estimate the main parameters of a LCA of buildings as we only isolate the recycling parameters from the rest of the LCA model. However, for the purpose of defining proper boundary conditions in a LCA model for buildings, the purpose of the model needs to be defined first in an attempt to assess an effective flow in a way of decreasing uncertainty of impacts that are far from the time the assessment is conducted. The other possibility is to include EOL recycling process in a way of designing building for recycling.

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