

# Issues to be considered for an environmental, economic and social assessment of green roofs by a life cycle approach point of view

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**Abstract** Green roofs have been turning out a promising technology, according to the experts of this sector, not only for energy-efficient purposes but for the whole performance of buildings. This paper discusses on the application of three methods, life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (SLCA) on "green roof" product. This paper discusses on data required for performing an LCA of green roofs and identifies life cycle chain actors supposed to provide such data. Various cost components that need to be taken into account while assessing the life cycle cost of a green roof are reported too. The UNEP/SETAC guidelines approach for the SLCA is proposed for the SLCA of green roofs in this paper. An analysis of the potential social impacts of green roofs has been also done as well, since a standardized procedure SLCA has not been carried out yet at the best of our knowledge.

## 1 Introduction

Worldwide, there is a rising attention on the energy performances of buildings since this sector has been considered the main responsible of energy consumption, at least in developed countries. In this context, green roofs have been turning out a promising technology, according to the experts of this sector, not only for energy-efficient purposes but for the whole performance of buildings. Among these advantages, it must be noted that the shading action of the vegetation towards the solar radiation and the cooling effect of the microclimate surrounding green roofs due to evapotranspiration of plants contribute to reduce the building energy demand, mainly for cooling. This kind of roof is, in fact, obtained by adding high-quality layers of impermeable waterproofing membrane, an anti-root barrier, a

drainage layer, a lightweight substrate and plants on the top of a traditional roof. Green roofs, actually, do not only allow reducing the energy consumption in buildings but are also able to provide with several environmental, economic and social benefits. This could suggest the idea that such buildings components are always a more sustainable alternative with respect to the other roofing systems. In the attempt of measuring the life cycle sustainability (LCSA) of this product, the three following methods should be applied, according to the accepted definition of LCSA, that is:

- life cycle assessment (LCA);
- life cycle costing (LCC);
- social life cycle assessment (SLCA).

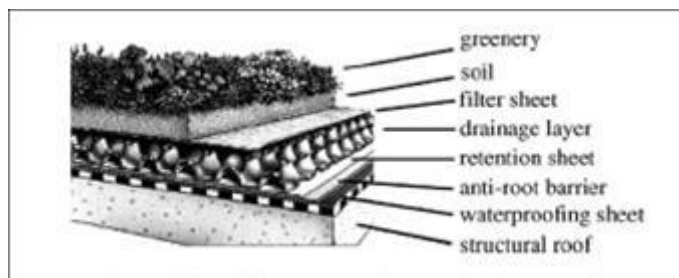
In the last years, several researches have been addressed to green roofs but it must be noted that most of them are mainly focused on one specific environmental benefit provided by use phase of green roofs. In other words, the life cycle approach seems to be neglected in the above mentioned researches. As a matter of fact, only two studies [1,2] adopting such approach for evaluating the environmental performance of green roofs, are currently available in journal papers. So far, little research has been done to evaluate the costs and benefits of green roof systems for urban applications. A short review (including only proceedings) regarding what has been already done from this standpoint has been carried out by Carter and Keeler [3]. While, if only journal papers are considered, only the study carried out by Wong et al. [4], about the Life Cycle Costing of green roofs can be found so far. Moreover, it has to be highlighted that little or none attention has been paid at the actual social impact of such technology throughout its life cycle so far. In the literature, only LCA and LCC applications [1,2,4] can be found. Therefore, applications of life cycle sustainability analysis (LCSA) on green roofs cannot be found in references so far.

This paper discusses on the application of three methods, above mentioned on "green roof" product, in other words, this article presents a study aimed at singling out the main issues to be considered for a LCA, a LCC and a SLCA of green roofs. Specifically, regarding the elements to be taken into account for a social evaluation of the life cycle of such technology, an analysis of the potential social impacts of green roofs has been also done, since a standardized procedure SLCA has not been carried out yet at the best of our knowledge.

## 2 Background

Green roofs are becoming an increasingly visible component of urban environments thanks to several environmental, economic and social benefits they can provide but also to several green roof policies which directly and indirectly encourage new green roof installations, promoting the fast expansion of the green roof market. An interesting review of what has been already done from the green roofs policies point of view concerned at the federal, municipal and local in several cities in Europe (and also in North America and United States) has been carried out by Carter et al. [5].

The most evident, although the most important, difference between a green roof and a traditional roof is the presence of a growing medium (soil) and vegetation as its outermost surface. In detail, such a kind of roof is obtained in general by adding a high-quality waterproofing membrane, a drainage layer, a lightweight growing medium and plants on top of a traditional roofing system. Sometimes, an anti-root barrier and/or a water storage layer can be added as well. Figure 1 shows more in detail different layers involved in green roofs.



**Fig.1: Different layers of a standard green roof (after [6])**

Generally, green coverings can be clustered in two main categories: intensive and extensive green coverings. The first ones are developed to be accessible for people (in fact, they are also known as accessible roof gardens). They are thicker and can support a wider variety of plants but they are heavier and require more maintenance. While, the second ones are not designed for public use (in fact, they are also known as inaccessible roof gardens). They have a much thinner profile which limits plant diversity on the roof but they can easily be retrofitted to an existing building and may be safely used on existing structures [7].

### **3 Towards a life cycle sustainability assessment of green roofs**

Green roofs, as it has been said earlier, are able to provide several environmental, economic and social benefits. This could suggest the idea that such building components are always a more sustainable alternative with respect to the other roofing systems. In the attempt of measuring the life cycle sustainability of this product, the Life Cycle Sustainability Assessment (LCSA) might be applied.

The LCSA is an assessment methodology that considers simultaneously the three pillars of sustainability. The accepted model for applying the LCSA is defined by equation (1):

$$\text{LCSA} = \text{LCA} + \text{LCC} + \text{SLCA} \quad (1)$$

where LCA is standardized environmental Life Cycle Assessment, the LCC is the Life Cycle Costing assessment and SLCA is the LCA procedure with the integration of social factors [8].

Below some considerations regarding the application of LCA, LCC and SLCA methods on green roofs are reported.

#### ***3.1 LCA of green roofs: main issues to be considered***

LCA is an already established approach with a standardized procedure (ISO 14040 [9] and ISO 14044 [10]), which aims to evaluate the environmental burden of products along their entire life cycle. It consists essentially of four steps, that is:

- Goal and scope definition
- Inventory analysis
- Impact assessment
- Results interpretation.

##### **3.1.1 The Functional Unit**

The first step, definition of goal and scope is one of the most critical parts of an LCA because it affects strongly the result of the LCA [11]. In the scope phase a functional unit (FU) has to be defined. Such FU being the reference to which all other data in the assessment are normalized, represents a key element of any life cycle assessment. Regarding the LCA of green roofs, a specific attention should

be paid on the choice of the FU: if the study, in fact, aims at evaluating the potential environmental burden of a green roof or at comparing the environmental impact of two green roofs in order to identify the best one, then in this case the choice of the FU seems quite easy because the roof unit surface could be the most reasonable and practicable FU. While, if LCA study aims at comparing different roof technologies including green roofs in order to identify the best one, then in this case the choice of the FU might be a little more complicated. In such case, in fact, since comparing the impact makes sense only for an equal product performance, identifying at least one parameter which has to be considered as a constant among different roof options investigated (it might be e.g. the overall roof thermal transmittance) would be needed first.

Therefore, the FU of the LCA study for “green roof” product is strongly dependent on the specific goal of the study.

### **3.1.2 Inventory analysis for the production phase**

To develop the LCA model an inventory analysis has to be created. In this paper it has been assumed to consider the whole life cycle of the "green roof" product, that means: raw material extraction, production, use/maintenance phase and disposal.

In this step, for modeling the production phase (meaning in this paper, pre-manufacturing, transportation of finished products to the construction site and manufacturing/assembling of different layers) information on green roof structure and transportation of finished products involved in the green roof to the construction site should be collected. This means, as the “green roof” product is particularly complex because obtained by assembling several products, that for each roof component, data about materials (type and amount per FU) needed for constructing each of them, have to be collected. Such data should be provided by the company supplier of green roofing system and should be reported in technical sheets of products. Data on resources consumption and relative emissions associated with acquiring the raw materials and manufacturing these roof products have to be collected as well. Manufactures of green roof products are supposed to provide such data. Therefore, primary data are supposed to reported in firm database in order to accomplish existing regulations, in water bills and electricity bills of the firm. Secondary data might be obtained by using available database in software for LCA.

The transportation distances between raw material extraction sites and manufacturing plants sites and between these last ones and the construction site are needed as well. Such data might be determined by knowing the location of

extraction sites, manufactures of products involved in the green roof. This information might be provided by manufactures.

The manufacturing of a green roof consists generally of assembling several products simply by overlapping. However, a certain energy consumption may occur during this stage; it depends mostly on specific products chosen for building up each layer of green roofing system (e.g. if the waterproofing membrane is made of synthetic material, then there is supposed to be an energy consumption due to using of specific equipments for welding several plies; while, if the waterproofing membrane is made of liquid bitumen layer that is cold applied, then no energy consumption occurs). A water consumption occurs as well, mainly because the testing stage after the waterproofing membrane installation and after putting the growing medium down. These data should be provided by the installation company or project responsible and might be determined by means of water and electricity bills. While, secondary data could be obtained by means of information provided by manufactures of equipment used, technical standards regarding installation of green roofs and technical sheets of green roof products.

### **3.1.3 Inventory analysis for the use/maintenance phase**

For modeling the maintenance phase, the life expectancy of such building component has to be considered.

Waterproofing membrane life span constitutes a driver element for determining this parameter. The average life span of conventional roofing system is usually 10-15 years before requiring replacement [2]. If a green covering is built up, the service life of the underlying waterproofing is doubled or even tripled due to the vegetative cover [12]. The Fraunhofer Institute calculated the life expectancy of a green roof to be more than 40 years [13]. However, values commonly assumed by authors in few published studies on this topic [1,2], range from 45 to 50 years. No replacement of the waterproofing membrane is required within the analysis period. For modeling such life cycle phase, the green covering type installed has to be considered: intensive or extensive (in fact, for example, in terms of resources material consumption, in extensive green roofs there is supposed to be only fertilizing, while in intensive ones also using of pesticides).

It seems remarkable to note that in order to get a real estimation of environmental burden of the use/maintenance phase, the potentiality of green roofs to remove some air pollutants [14] should be considered (e.g. the amount of NOX potentially removed by the vegetation during the green roof use phase [14] should be considered together with nitrogen oxides (NO and NO<sub>2</sub>) emissions coming from green roofs during their use phase, due to fertilized growing medium). Data

regarding potentiality of green roofs to remove some air pollutants might be obtained by field measures or by referring to values reported in available studies in references

#### **3.1.4 Inventory analysis for the end of life phase**

Regarding the end of life phase, information on waste treatments supposed for each product should be collected first. This could be done by collecting safety sheets from manufactures. Once the waste treatment is defined, emissions coming from the specific process should be determined. Primary data could be provided by end of life actors. Such data are supposed to be reported in firm database in order to accomplish existing regulations and in electricity bills of the firm. While secondary data might be obtained by using available databases in software for LCA.

It has to be said that not always such safety sheets provided by manufactures report clearly the type of waste treatment supposed for a given product. If this case regards the "growing medium" roof product, then choosing a reasonable disposal treatment for growing medium might turn out quite complicated mainly because such kind of product has not been classified in the Waste European Catalogue yet. This fact, on its turn, makes difficult to identify the best disposal treatment for such waste. A potential recycling/reusing, for example in agriculture, which might seem one reasonable end of life would need further analyses mainly because of the using of chemical compounds during the life span of the green roof. They, in fact, might modify the growing medium composition, so making it no longer suitable for agricultural purposes. So far, between disposal in landfill or incineration with energy recovery, the best solution would be the landfill because of the growing medium composition (inert fraction is definitely bigger than the organic part). Information about transportation to the disposal plants has to be collected too.

### ***3.2 LCC of green roofs: main issues to be considered***

Life cycle costing (LCC) is basically a compilation and assessment of all costs related to a product, over its entire life cycle, from production to use, maintenance and disposal, that are directly covered by any actors in the product life cycle (supplier, producer, user/consumer, end-of-life actor). The main aim of this technique is determining the most effective capital investment option for achieving technical-economic optimization of a system.

However, it has to be reminded that although a number of industry guidelines and references have been developed for conducting a LCC, still an ISO standard does not exist, unlike LCA.

A possible life cycle costing approach for green roofs might take into account initial cost of construction and other cost components such as maintenance cost and disposal cost incurred by building owner. Since green roofs are able to provide several economic benefits to the building owner, such as lower energy consumption especially for cooling, stormwater utility fee credit (they are able to retain stormwater for small events) and NO<sub>x</sub> emissions credits (they are able to improve air quality), in predicting the total cost associated with a green roof over its intended service life, other cost components might be actually included in such economic analysis (avoided cost due to reduced energy consumption, avoided cost due to reduced runoff to the stormwater system etc.). In this end see study carried out by Carter et al. [3]. For calculation of LCC of a green roof the equation 2 could be used:

$$\text{LCC} = \text{Ownership cost component} - \text{Using cost component} \quad (2)$$

where the first term includes costs incurred by the owner over the lifetime of the green roof (initial cost of construction, maintenance and disposal cost), while the second term considers savings gained by the owner during the use phase of the green roof. In this paper, this second term is not discussed.

Initial cost should include following cost components: materials cost, labor cost to build up the roof component used, transport costs to the construction site and installation costs.

As far maintenance cost, it depends mainly on the specific type of green covering analyzed: accessible green roofs (intensive) with more demanding plantings would require more maintenance costs than inaccessible garden (extensive).

Moreover, future maintenance and replacement costs of green roofs are supposed to be lower than those of traditional roofs; in fact, green roofs, as it has been said earlier and as several authors [15-18] claim, generally have longer lives than exposed roofs because the additional layers of substrates and vegetations act as protection for the roof membrane. A longer service life of roofing systems would mean fewer roof replacements during the life of the building, thereby reducing the maintenance cost.

As far the disposal cost at the end of the service life of the green roof, if there are not primary data, an estimation might be done by referring to the specific tariff system and prices for waste treatments involved in the waste scenario hypothesized in the study, that are currently applied in the region or country where



the green roof is located. In the calculation of LCC of the green roof, it is essential that the risks and uncertainties associated with statistical parameters such that discount rate, inflation rate, defect occurring frequency and duration of maintenance operation be properly considered.

### ***3.3 SLCA of green roofs: main issues to be considered***

So far, it has to be highlighted that little or none attention has been paid at the actual social impact of such technology throughout its life cycle. In the literature, only LCA and LCC applications [1,2,4] can be found. Moreover, despite several scientific works on SLCA are available in references and new guidelines have been recently published by a researchers group of UNEP SETAC for SLCA [19], there is not a complete and commonly accepted procedure for a SLCA.

#### **3.3.1 The pursuit of an approach for a SLCA of green roofs**

Therefore, one of the main issues to be dealt with first, is the identification of a possible procedure for a SLCA of green roofs. In order to do that, currently available approaches proposed by authors for carrying out the SLCA could be assumed as starting point towards the definition of ad hoc scheme expressly addressed to green roofs. Referring to the approach proposed by guidelines for the SLCA might turn out particularly useful in the view of an implementation of life cycle sustainability assessment on such building components, mainly because the methodological framework for the social impacts analysis suggested in it, is similar to that one for ELCA, already standardized by ISO 14040 [9,10].

#### **3.3.2 The pursuit of stakeholders categories to be considered in the SLCA of green roofs**

If the guidelines approach is assumed as a reference method, then main steps of SLCA are: goal and scope definition; life cycle inventory; life cycle impact assessment; impact interpretation. In the scope phase it needs to define:

- the stakeholder categories
- the subcategories.

Although UNEP SETAC guidelines propose a complete set of social and socio-economic subcategories (Table 3 of guidelines), for each stakeholders category identified (workers, consumers, local community, society and value chain actors,

not including consumers), it seems important to notice that the definition of stakeholders categories for green roofs to be included in the analysis and of social relevant characteristics to be assessed (and relative indicators for each stakeholders category ) should take into account the following consideration: the implementation of one green roof cause some social impacts, but also the implementation at large scale cause other social impacts. Then, which impacts SLCA has to assess? If SLCA aims at comparing two green roofs, stakeholder categories potentially affected and, in its turn that should be considered in the analysis, would be only “workers” and “consumers”. If SLCA aims at comparing two different roof technologies, e.g. "green roof" technology vs. “traditional roof” technology, “local community” and “society” should be included as well, with respective social indicators. Therefore, depending on the specific goal of the SLCA study, two different procedures for SLCA of green roofs should be designed, each of them with its own stakeholders categories and set of social indicators.

### **3.3.3 Which subcategories should be evaluated in the SLCA of green roofs?**

Although aware that UNEP SETAC guidelines propose a complete set of social and socio - economic subcategories for each stakeholders category identified, part of the work consisted of singling out by adopting a bottom up approach some potential social impacts caused by green roofs on following stakeholders categories: occupants, local community and society.

Table 2 reports synthetically for each of the above mentioned stakeholders categories, the potential impact.

## **4 Conclusions**

This work springs out mainly from the following question: are green roofs always a more sustainable alternative with respect to the other roofing systems, due to their several environmental, economic and social benefits?

So far, applications of life cycle sustainability analysis (LCSA) on green roofs cannot be found in references so far. In this work the application of three methods, LCA, LL and SLCA on "green roof" product has been discussed. This constitutes a first step towards the implementation of life cycle sustainability assessment (LCSA) on "green roof" product.

The results of this work might be useful in order to highlight which data different actors of the product life cycle chain should be pushed to provide with. This, on turn, could contribute to render easier the life cycle sustainability assessment of this product. Of course, some applications on suitable case studies, with the pertinent sensitivity analysis, will be needed in order to figure out the weight of each element here proposed, in the evaluation of the life cycle sustainability of this product.

**Tab.2: Potential social impact of green roofs on occupants, local community and society)**

Stakeholders categories	Potential social impact	Brief description
Building occupants	Well being and health	Improvement of indoor conditions. Supply of green areas for relax and social interaction.
Local community	Well being and health	Improvement of air quality. Mitigation of "heat island effect". Supply of green areas for relax and social interaction.
	Local economic development	Contribution to the improvement of the local agricultural production in urban and suburban areas.
Society	Job opportunities	The implementation at large scale of green roofs would cause a new market able to provide new job opportunities.

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