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## Environmental impact of Green roofing: the contribute of a green roof to the sustainable use of natural resources in a life cycle approach

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### Abstract

Even if several studies and researches have demonstrated that green roofs significantly contribute to energy saving, indoor thermal comfort, urban heat island mitigation, rain-water management and air pollution reduction, environmental benefits of green roofs mainly depend on use of primary energy, natural resources or raw materials used in the construction.

A green roof is usually a more or less complex aggregation of different layer addressing each one to a specific characteristic and performance.

Results of previous LCA researches, based on a cold climate scenario, have demonstrated the highest influence that some specific layers have on the overall impact of the green roofs and to what extent the global impact changes when insulation and the substrate layers vary in density and quality.

Starting from results of these similar EU researches, this study aims to evaluate the variation of the overall impact in hot climates where insulation is less strategic than heat capacity.

LCA has been applied to assess and compare the environmental impacts of four different green roof solutions compared to a standard clay pitched roof, based on the functional unit of 1m<sup>2</sup> with the same reference service life, where layers have been selected according to local practice and market. Despite a general equivalence in environmental impacts of all the roofing elements, results have highlighted a general lack in specific life cycle inventory information that leads to a potential inaccuracy

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of the assessment especially when recycled material are used in the growing medium or when disposal scenario includes recycle processes.

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**Keywords:** Green roof; Life Cycle Assessment; Environmental impact

## Nomenclature

GWP	Global Warming Potential
AP	Acidification for soil and water
EP	Eutrophication
ODP	Ozone Depletion
POCP	Photochemical ozone creation
[ADP-element]	Depletion of abiotic resources-element
[ADP_fossil fuels]	Depletion of abiotic resources – fossil fuels
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
RSL	Reference Service Life
DSL	Design Service Life
FU	Functional Unit

## 1. Introduction

Green roofs are considered as a solution to many urban issues including urban heat island mitigation, noise and air pollution reduction, storm-water management and support of biodiversity and are quite often addressed as the best building choice to increase the environmental sustainability in an urban setting. Recent initiative at European level (CEN TC 350 WG1) also promote a benefit for those building covered by a green roof as a reduction in Land use impact.

Generally speaking, it is now quite clear that green roofs can be used to reduce or mitigate issues as urban heat island effect, water runoff, air and water quality (Liu et al., 2003; Wong et al., 2003).

Most of the reasons that stop building owners in building a green roof lay in the idea that beside the initial costs, cost form maintenance of green roof during the life cycle of the building are quite high. In fact, some studies have demonstrated that intensive or deep soil roof systems have a higher life cycle cost (LCC) than conventional practice (Wong et al., 2003), but this is not always true for extensive green roof system that might cost less than a conventional roof.

Moreover, considering that the European Regulation on Energy Efficiency 31/2010 drives to nearly zero energy building, energy and resources consumption in buildings are in a near future primarily due to the building material. More than the energy consumption in use, the environmental impact of the building materials becomes therefore an urgent performance to be evaluated in a life cycle perspective. Even environmental impacts due to energy consumption during the use phase of the building have been drastically reduced in the last 10 years, compared to data by Saiz et al. (2006), the estimation that the use represents approximately 80% to 90% of the life-cycle energy use, while 10% to 20% is consumed by the material extraction and production, and less than 1% through end-of-life treatments (Sartori et al., 2007) is still not so far from the reality, especially in Mediterranean climate where conventional building dates back to '50es and '60es.

## 2. Case study

A single-floor social housing building, located in Pisa (Lat 43°40' N Long. 10°23' E) has been selected as case study. The building is E-W oriented and it has insulated brick masonry walls ( $U=0.32 \text{ Wm}^{-2}\text{K}^{-1}$ ) and a pitched clay roof.

Aims of the study were to assess the potential environmental benefits or loads, over the life cycle of the building, when the standard pitched roof is replaced by different types of green roofs. The energy performance of the building is not taken into account since the use phase B6 (operational energy in use) is not part of the assessment.

Therefore, building elements others than the roof floor, as external and internal walls and floors, have been not considered in the life cycle assessment (LCA) since they are invariant.

Five roof types have been evaluated, as described in **Errore. L'origine riferimento non è stata trovata..**

Table 1. Roof types used for the life cycle assessment (LCA).

Pitched roof	Extensive Green roof HD	Extensive Green roof LD	Intensive Green roof HD	Intensive Green roof RC
	Sedum	Sedum	Sedum	Grass
	Medium A 80 mm	Medium B 80 mm	Medium C 150 mm	Medium D 150 mm
Clay roof tiles	Filter layer	Filter layer	Filter layer	Filter layer
Ventilated air cavity 60 mm	Drainage/insulation layer	Drainage/insulation layer	Drainage/insulation layer	Drainage/insulation layer
Thermal insulation EPS 80mm	EPD 80mm	EPD 80 mm	EPD 80 mm	EPD 62 mm
	Root barrier	Root barrier	Root barrier	Root barrier
Light concrete screed 40 mm	Light concrete screed 40 mm	Light concrete screed 40 mm	Light concrete screed 40 mm	Light concrete screed 40 mm
Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm
Plaster 15 mm	Plaster 15 mm	Plaster 15 mm	Plaster 15 mm	Plaster 15 mm

The green roofs differ because of the depth and type of medium soil, that distinguish from an extensive type and an intensive type. An extensive green roof system is characterized by its vegetation, ranging from sedums to small grasses herbs and flowering herbaceous plants (maximum high 25cm), which need little maintenance and no permanent irrigation system. The growing medium depth for an extensive green roof system is typically 3÷15cm, and is not considered as a walk area. These systems are ideal for efficient storm water management with low maintenance needs.

An intensive green roof system is characterized by its variety of vegetation ranging from herbaceous plants to small trees with professional maintenance and a regular irrigation system. A typical growing medium depth of an intensive green roof is 15÷30 cm. Intensive green roofs offer a great potential for design and biodiversity, and the plant selection, and design greatly affect the maintenance required for the upkeep of these roofs.

The quality of the medium (density, grain size, mix) strongly influences the whole the green roof performance: a green layer on a roof slab is exposed to extremely hard conditions (solar irradiation, high temperature, wind, heavy rainfalls, etc.) and a wrong medium selection could compromise a reliable and long-lasting performance, with reference to drainage, waterproofing, thermal insulation/thermal mass, quality of greenery, and maintenance costs. The medium is the layer where the plants take the nutrients from, and it is the fundamental element of the green-roof system.

That's why this research focuses on the growing medium soil taken as the variable parameter of the system, in order to evaluate the relevance of different types of medium on the environmental impact of a green roof.

The four varieties of medium used during the assessment are described in **Errore. L'origine riferimento non è stata trovata..**

Table 2. different types of medium soil.

Medium A	Medium B	Medium C	Medium D
878 kg m <sup>-3</sup>	500 kg m <sup>-3</sup>	904 kg m <sup>-3</sup>	1000 kg m <sup>-3</sup>
Pumice 75%	Pumice 20%	Pumice 25%	Expanded clay 10%
Lapillum 15%	Lapillus 64%	Lapillum 60%	Recycled bricks 80%
Compost 10%	Zeolithe 0.5%	Compost 15%	Compost 10%
	Peat 14%		

## Compost 1.5%

The growing medium layout description refers to technical information provided by commercial companies directly, but it is mostly based on literature (Bozorg Chenani et al., 2015; Peri et al., 2012) since the original recipe of the medium is part of the company strategy and is generally confidential.

### 3. LCA method and inventory

The LCA methodology as stated by the recent European standard EN 15804 (2012) , Annex A1 (2013) has been used to assess the environmental impacts of different types of green roof compared to a standard pitched roof, over a Reference Service Life (RSL) of 40 years (Roofscapes, 2002).

The RSL has been defined according to the shortest life span of the materials used (primary the waterproofing membrane), assuming then that none of the green roof layers (the root barrier, the protection layer, the drainage/water retention layer, the filter layer, and the substrate) are replaced during the service life and that they fulfill their basic functional requirement all over the life span. We assumed the same for all the pitched roofs materials.

Therefore the Functional Unit FU has been defined as the vertical projection of 1 m<sup>2</sup> of roof with a RSL of 40 years.

In order to compare the flat green roof and the pitched roof, an 1 m<sup>2</sup><sub>equivalent</sub> unit has been calculated for the pitched roof, so to consider the tilt angle of the pitched roof (16°).

According to the modular approach introduced by the standard, the life cycle assessment has been carried out per modules and, specifically:

- Module A1-A3 Production
- Module A4 – Transport to building site
- Module C2-C4 End of life

Module A1 to A3 includes all the info and LCI data related to the raw material extraction and processing, processing of secondary material input, transport to the manufacturer, manufacturing.

Module A4 describes the environmental impacts related to the transport to the building site.

Use phase from B1 to B7 have been not considered, even if phase B7 *Operational water use* could be relevant in assessing the resource use impact of green roofs in very hot and dry climate. In the LCA includes module B, during the use phase, extra growing medium added due to the natural run-off and the use of fertilizers shall be also considered in stage B2 *Maintenance*, including relative emissions from the substrate (Akiyama et al., 2000; Ciarlo et al., 2008) and potential leakage to water.

Module C2 to C4, after the demolition stage, describe transport to waste processing, waste processing for reuse, recovery and/or recycling and or final disposal.

Moreover, module D "Benefit and loads beyond the system boundaries" has been not considered due to the difficulties of defining a real scenario of reuse o recycle for most of the materials. This could lead to potentially underestimate benefit of choosing a pitched roof (clay roof tiles can be 90% recycled) but has no consequence for the green roof comparison since there are no significant differences in the four cases concerning recycle beyond the end of life stage. Even the incineration of some of the green roof layers involves an energy recovery process, there are no substantial variances in quantities that could lead to specific potential impact reduction.

The five LCA roofing scenario are described in following **Errore. L'origine riferimento non è stata trovata., Errore. L'origine riferimento non è stata trovata., Errore. L'origine riferimento non è stata trovata., Errore. L'origine riferimento non è stata trovata., and Errore. L'origine riferimento non è stata trovata..** The clay block slab layout is not reported in the tables even it has been considered in the LCA assessment.

Table 3. Pitched Roof - LCA scenario.

Pitched roof	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Clay roof tiles	Clay roof tile / LATERLIFE	10 km	8 km	Recycling clay roof tiles
Ventilated air cavity 60 mm	--			
Wood Frame 60 mm	Soft wood, planed, air dried	10 km	25 km	Disposal, wood untreated to municipal

Waterproof barrier	Polymeric membrane HDPE / LATERLIFE	10 km	25 km	incineration /LATERLIFE	Disposal polyethylene to municipal
Thermal insulation EPS 50 mm	Thermal insulation EPS LD / LATERLIFE	10 km	25 km	incineration /LATERLIFE	Disposal polystyrene to municipal

Table 4. Extensive Green roof Low Density medium - LCA scenario.

Extensive Green roof LD	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario	
Sedum					
Medium B 80 mm	Pumice, at mine Zeolite /ETH U Peat, at mine /NORDEL U Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill	
Filter layer 1.30 mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene incineration	to municipal
Drainage/insulation layer EPS 80 mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene incineration	to municipal
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene incineration	to municipal

Table 5. Extensive Green roof High Density medium - LCA scenario.

Extensive Green roof HD	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario	
Sedum					
Medium A 80 mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill	
Filter layer 1.30 mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene incineration	to municipal
Drainage/insulation layer EPS 80mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene incineration	to municipal
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene incineration	to municipal

Table 6. Intensive Green roof High Density medium - LCA scenario.

Intensive Green roof HD	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario	
Grass					
Medium C 30 mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill	
Medium C 150 mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill	
Filter layer 1.45 mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene incineration	to municipal
Drainage/insulation layer EPS 62 mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene incineration	to municipal
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene incineration	to municipal

Table 7. Intensive Green roof medium with recycled materials - LCA scenario.

Intensive Green roof RC	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Grass				
Medium C 30mm	Pumice, at mine Compost, at plant/CH U Expanded Clay	35 km 10 km	12 km	Disposal, inert material to sanitary landfill
Medium D 150mm	Recycled bricks /LATERLIFE Compost, at plant /CH U	8 km 17 km	12 km	Disposal, inert material to sanitary landfill
Filter layer 1.45mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration
Drainage/insulation layer EPS 62mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene to municipal incineration
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration

SimaPro<sup>®</sup> software has been used to calculate the life cycle impact and two databases have been used: The international Ecoinvent system processes and Industry Database 2.2 and the Italian LCA database LATERLIFE developed by the Italian National Association of Brick Industries ANDIL LCA group of the University in Florence and running under the LATERLIFE software available at [www.laterizio.it](http://www.laterizio.it). All the processes in the Ecoinvent have been revised in accordance to the standard's requirements in terms of system boundaries and allocation rules.

### 3.1. Production phase scenario

Several difficulties occurred in collecting the LC inventory data and mostly for the production phase A1-A3 due to the lack of both specific and generic data in the database used for the assessment. Despite the database of building materials is quite complete, especially the LATERLIFE one, no information are promptly available about the growing medium or the substrate components. Inert substrate is usually a mix of volcanic materials, mainly made by Lapillus and Pumice and organic materials as compost or peat, where NPK fertilizers are added.

Largest approximation in the assessments is due to the fact that lapillus record misses from any database. Therefore pumice has been selected to represent both volcanic materials. While compost and peat are present in Ecoinvent, specific NPK fertilizer data have been modeled starting from title information and other technical information provided by producers. In order to evaluate the impact reduction potential due to the use of recycled aggregate in the growing medium, the Medium type D has been modeled using recycled bricks. These could be modeled as scraps from the primary clay brick production or waste processed at the end of life. Since there is no LCI data in SimaPro<sup>®</sup> software, a new record has been modeled considering the energy needed for sorting and crushing bricks after the demolition stage, as well as the emission in air during these phases but excluding any other impact related to the manufacturing process, including provision of virgin material.

### 3.2. Transport scenario

Building materials (bricks, concrete, wooden frame, plaster, expanded clay...) are supposed to be provided by a single supplier as well as all the green roof layers, that comes from a company retailer in the area.

As regard the transportation to disposal, several waste processing and disposal site (landfill) are located close to the town of Pisa so the end of life scenario is based on a short distance from the building site (within 25 km). A road

transport by truck has been considered for both. Transport scenarios to/from the building site are described in the previous Tables.

### 3.3. End of Life scenario

Defining the end of life scenario is the most sensitive and crucial part of the assessment. It is a quite difficult task due to the fact that most of these materials are not classified in the Waste European Catalogue and there are no specific and consistent data available about the collection, treatment, recycle and reuse of construction materials in Tuscany.

Scenarios for end of life and waste processing have been defined according to the real market contest near Pisa and have been derived from Romani (2014). Bricks and concrete scraps, from the roof slab, are recycled and both energy use and emission in air during the sorting and crushing operations have been taken into account. Sorting and crushing waste produced during the recycling process go to landfill. Two specific processes, one for bricks one for concrete scraps have been modeled in SimaPro<sup>®</sup> software since there were no generic data available. Data have been derived from different Ecoinvent processes: *Disposal, building, cement fiber slab to recycling* and *Disposal, building, brick to recycling*. These processes present a high level of uncertainty because the operation of demolition, transport to the sorting plant, handling and sorting are combined, and the modular approach proposed by EN 15804 has been ignored. Therefore is not possible to separate, as example, emission due to demolition and transport from emissions released during sorting. The crushing phase is missing and it has been derived from the Ecoinvent process *Limestone, crushing and washing*. The polymeric membrane and the thermal insulation panel are treated in a incinerator for energy recovery and waste-specific air and water emissions from incineration, auxiliary material consumption for flue gas cleaning, short-term emissions to river water and long-term emissions to ground water from slag compartment (from bottom slag) and residual material landfill (from solidified fly ashes and scrubber sludge) as well as the process energy are considered. Light concrete screed and plaster are sorted and then disposed to landfill.

Regarding the green roof layers, there are no regulations regarding the reuse of green roof soils in agriculture. As reported by Peri et al. (2012), incineration is excluded because the large amount of inert, and the sanitary landfill is the only waste processing available due to the potential/real presence of peat; thus, the different impact of disposal for the growing mediums comes only from different quantities.

## 4. LCA Life Cycle Assessment

The life cycle assessment has been carried out using the CML –IA version 4.1, dated October 2012, according to EN 15804 Annex C, so to express the environmental impacts through the 7 parameters or core indicators as stated by the standard: *Global Warming Potential (GWP)*, *Ozone Depletion (ODP)*, *Acidification for soil and water (AP)*, *Eutrophication (EP)*, *Photochemical ozone creation POCP*, *Depletion of abiotic resources-element (ADP-element)*, *Depletion of abiotic resources – fossil fuels (ADP\_fossil fuels)*.

Moreover, the standard introduces 10 parameters describing the resource use, based on the Life cycle Inventory LCI. In order to simplify the assessment, only two parameters *Total use of non renewable primary energy resources* and *Total use of renewable primary energy resources* have been calculated. The parameter *Net use of fresh water* is particularly relevant during the use phase of the life cycle of the green roof and in hot climate especially, where a regular daily irrigation is necessary to assure the vegetation survival and the thermal performance of the green roof. Since stages B1-B7 *Use phase* are not part of the assessment, this parameter has been not calculated.

## 5. Results and impacts

Comparison of the 5 different roof types shows that, despite any general comments, environmental impact of the different green roof solutions don't differ too much one from the others.

For almost all the impact categories excluded the two ones referring to the use of resources, all the indicators have the same magnitude, as shown in Fig. 1.



In general, green roofs have a lower impact compared to the clay pitched roof, especially on categories such as ADP-fossil fuels (- 20÷30%), and ODP (5-6%) while the average impact reduction amount to 5% for all the other impact categories, apart POCP (1%) and GWP ( 2%) (see Fig. 2).

For all the roof elements, the highest impacts come from the production phase.

For the clay tiled roof, impacts primarily comes from clay bricks and tiles and concrete because of the use of non renewable primary energy in the furnace and the use of natural resources that lead to high environmental impacts in ADP, GWP, AP and QDP (see **Errore. L'origine riferimento non è stata trovata.**).

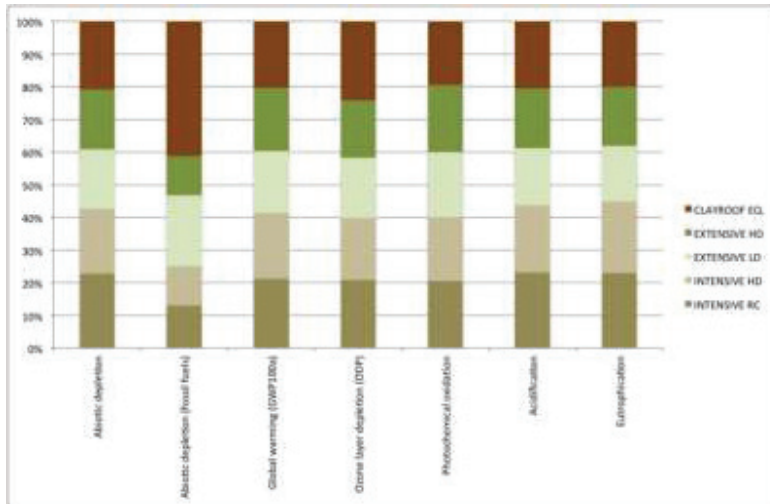


Fig. 1.. LCA assessment. Comparison of results per roof type - LCA modules A1-A3, A4, C1-C3.

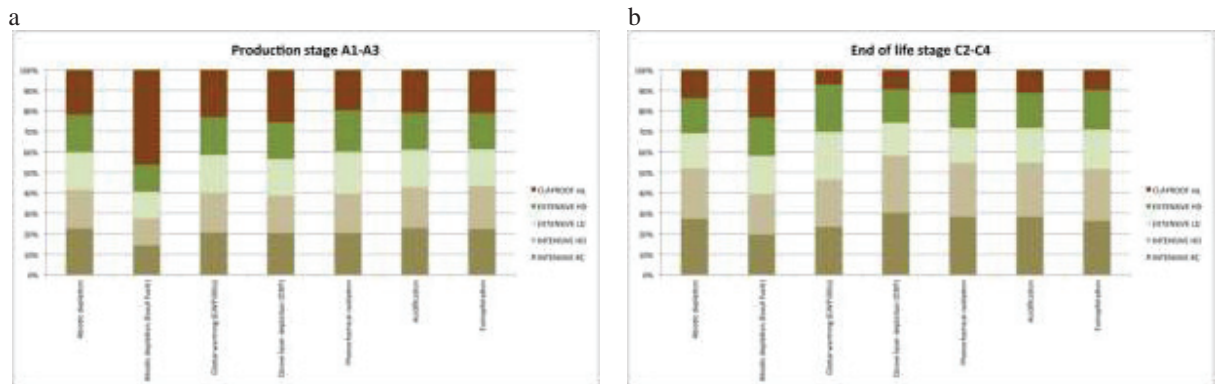


Fig. 2. LCA assessment. Comparison of results per roof type – (a) LCA modules A1-A3 Production on the left; (b) LCA modules C1-C3 End of life on the right.

Table 8. LCA assessment impact indicators. Comparison of global impacts - LCA modules A1-A3, A4, C1-C3.

	Unit	INTENSIVE RC	INTENSIVE HD	EXTENSIVE LD	EXTENSIVE HD	CLAYROOF EQ.
Abiotic depletion	kg Sb eq.	2.63E-05	2.30E-05	2.10E-05	2.10E-05	2.41E-05
Abiotic depletion (fossil fuels)	MJ	1.18E+01	1.08E+01	1.96E+01	1.08E+01	3.73E+01
Global warming (GWP100y)	kg CO2 eq.	1.16E+02	1.10E+02	1.04E+02	1.05E+02	1.12E+02
Ozone layer depletion (ODP)	kg CFC-11 eq.	7.99E-06	7.21E-06	7.05E-06	6.71E-06	9.21E-06





Low maintenance costs of a clay roof should be also considered, because no replacement of the tiles are needed during the Design Service life of the roof, since the clay roof tiles have a 150 years life span. Replacement of insulation and waterproofing layer of a standard roof requires low energy and a very simple procedure.

Therefore, considering the benefit of a green roof in terms of comfort and energy saving but also taking into account the maintenance operations that are required to let the green roof perform in years at best, as described above (water consumption, use of fertilizers, replacement operation over 40 years, emissions to air and water), a proper design of the growing medium soil seems to be the most relevant and key element of a good green roof design.

This conclusion leads to a general request for more complete information about the growing medium available on the market since, without a detailed description of the formula, of the thermal and water retention properties, and the disposal requirements, a precise LCA or LCC assessment cannot be completed. Information about the chemical composition of the medium are brief and not specific and one of the most relevant material generally used for substrate, the lapillus, doesn't exist on the Ecoinvent database, so that any assessment is affected by a evident uncertainty due to the substitute process used instead of the proper one.

Different mix in substrate could lead to completely different impacts, so a deep study of present product is the base for the develop of new and more sustainable ones.

There is a large chance of improvement in the sustainability of green roof, especially during production and disposal phases and LCA could easily support the industries in defining lower impact solutions, in order to increase the amount of recycled materials that could be used for the growing medium and the membrane.

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## References

- Akiyama, H., Tsuruta, H., Watanabe, T., 2000. N<sub>2</sub>O and NO emissions from soils after the application of different chemical fertilizers. *Chemosphere Global Change Science* 2, 313-320.
- Bozorg Chenani, S., Lehvavirta, S., Hakkinen T., 2015. Life cycle assessment of layers of green roofs. *Journal of Cleaner Production* 90, 153-162.
- CEN TC 350 WG1 Environmental performance of buildings in developing a TR WI 00350023 - Additional indicators.
- Cheryl, R., Boyer, G. B., Fain, C. H., Gilliam, T. V., Gallagher, H., Allen, T., Sibley, J. L., 2008. Clean Chip Residual: A Substrate Component for Growing Annuals. *HortTechnology* 18.
- Ciarlo, E., Conti, M., Bartoloni, N., Rubio, G., 2008. Soil N<sub>2</sub>O emissions and N<sub>2</sub>O/(N<sub>2</sub>O+N<sub>2</sub>) ratio as affected by different fertilization practices and soil moisture. *Biology and Fertility of Soils*. 44, 991-999. <http://dx.doi.org/10.1007/s00374-008-0302-6>.
- EN15804:2012 + A1:2013 "Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products".
- Fantozzi, F., Bibbiani, C., Gargari, C., 2015. Simulation of the thermal behaviour of a building retrofitted with a green roof: optimization of energy efficiency with reference to italian climatic zones. Florence "Sustainability of Well-Being International Forum". Food for Sustainability and not just food, Florence SWIF2015 Proceedings.
- Kohler, M., Schmidt, M., Grimme, F.W., Laar, M., de Assuncao Paiva, V.L., Tavares S., 2002. Green roofs in temperate climates and in the Hot-Humid tropics- far beyond the aesthetics. *Environmental Management and Health* 13(4).
- Kokogiannakisa, G., Darkwa, J., 2012. A simulation-based framework for a mapping tool that assesses the energy performance of green roofs. *IEEA 2012*, 17-18, Singapore.
- Lisa, K., Robert, R., 2007. "Comparative environmental life cycle assessment of green roofs", *Building and Environment* 42, 2606-2613.
- Liu, K.K.Y., Baskaran, B., 2003. Thermal performance of green roofs through field evaluation. *Proceedings for the first North American green roof infrastructure conference, awards, and trade show*, Chicago, IL, May 29-30. pp. 1-10.
- Peri, G., Traverso, M., Finkbeiner, M., Rizzo, G., 2012. Embedding "substrate" in environmental assessment of green roofs life cycle: evidences from an application to the whole chain in a Mediterranean site. *Journal of Cleaner Production* 35, 274-287.
- Ray, S., Glicksman L., 2010. Potential Energy Savings of Various Roof Technologies. *Buildings XI Conference -- Proceedings ASRAHE*.
- Romani, M., 2014. Valutazione della sostenibilità economica degli interventi di riqualificazione energetica secondo la metodologia LCC (Life Cycle Cost): applicazione a un edificio di edilizia sociale. Degree thesis, University of Pisa, Faculty of Engineering, 2014 Tutors: Fabio Fantozzi, Caterina Gargari, Massimo Rovai.
- Roofscapes. Green roof Benefits. 2002. <http://www.roofmeadow.com/PDF/Benefits.pdf> (July 9, 2002).

SimaPro software. <http://www.simapro.co.uk/index.html>

Saiz, S., Kennedy, C., Bass, B., Pressnail, K., 2006. Comparative Life Cycle Assessment of Standard and Green roofs. *Environ. Sci. Technology*.40,4312-4316.

Sartori, I., Hestnes, A.G., 2007. Energy use in the life cycle of conventional and low energy buildings: A review article. *ENB*, 39, 249-257.

Wong, N.H., Chen, Y., Ong, C.L., Sia, A., 2003. Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment*.38,261-270.

Wong, N.H, Tay, S.F., Wong, R., Ong, C.L., Sia, A., 2003. Life cycle cost analysis of rooftop gardens in Singapore. *Building and Environment*.38,499-509.