Supporting producers in designing more efficient and low impact green roofs through the Life Cycle Analysis: environmental and energy performance

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Abstract

The environmental performance of six green-roof solutions currently available on the Italian market has been compared and a lack of information comes out, both on environmental and thermal issues that are necessary to run a consistent and specific assessment.

Life Cycle Analysis (LCA) could support producers in designing more efficient and low impact green-roofs, selecting materials based on their environmental profile over their life cycle and taking into account potential reuse of recycle at the end of life. This paper presents an environmental assessment 'cradle to gate', based on a 1 square meter functional unit (FU), according to European Standard EN 15804:2012+A1:2013. Five different scenarios, based on different "U-value" limits according to D.M. 26/06/2016, has been defined to run the comparison. Outcomes are expressed in parameters describing environmental impact and resources use. The results show that, despite a large interest in green-roofs, currently considered to be a sustainable and energy saving solution for both cold and warm climate, no specific information and data are in fact available for designers and LCA practitioner to assess the environmental and energy performance accurately. Moreover, the insulation layer is the primary responsible for both the energy and environmental performance of the green-roof and therefore, taking into account the LCA profile of the insulation material during the design stage is a crucial step to guarantee a low impact building. Moreover, the new vegetative substrates available on the market are generally presented as more sustainable when, in fact, LCA quarrels with that. Therefore, a comparison between 7 different media currently available on the market has been carried out; results have been significantly affected by a large lack of specific LCI data.

Keywords: green-roof, soil medium LCA, energy saving, thermal insulation, impact indicator

INTRODUCTION

Green roofs and walls are considered to be a valuable design solution in the urban context to mitigate the heat island effect, to reduce noise and pollution and to improve the rainwater management and increase air, water quality and biodiversity. (N.H., Wong, 2003). But considering the Net Zero Energy Building – Net ZEB concept, introduced by the EPBD recast Directive 2010/31/UE, energy saving, renewable energy sources and other strategies usually adopted to lower the building energy consumption and limit greenhouse emissions are not sufficient from now on. The energy used by the building during its life is combined by energy in production, energy in transportation to the building site, energy in use (for heating, cooling, lighting), energy for building maintenance, and, at the end, energy for demolition. Energy in use in buildings in the Mediterranean area, dating back to

50^{ies} and 60^{ies}, represents a 70-90% of total energy, while a 10-30% refers to building material extraction, process and production and 1% only to end of life processing (Sartori et al., 2007; Campiotti et al., 2013).

Net ZEB buildings, in fact, will have a near zero energy consumption in use but an increasing embodied energy in materials and technologies (Beccali et al., 2003). Therefore, assessing the energy and environmental performance of the building, throughout its full life cycle, including production, construction and end of life, and not just the use phase, becomes more and more relevant to assure a consistent evaluation. Thus, the sustainability certification and labeling for building materials becomes an urgent market request to that any conformity label includes quantified, replicable, comparable and harmonized environmental indicators (Gargari et al., 2016).

Standard EN15804:2013+A1 '*Sustainability of construction works-Environmental product declarations-Core rules for the product category of construction products'*, defines the Product Category Rules (PCR) to draw up a Type III Environmental Product Declaration (EPD), according to ISO 14020 and ISO 14025. Such an EPD, provides to the user quantified environmental information about a building product or service, that have been assessed in conformity to an harmonized and scientific method. A Product EPD is the primary source of data to perform an environmental assessment of a building. EPD provides also information about emissions to indoor air, soil and water during the use of the building, that can be potentially dangerous for human health.

MATHERIALS AND METHODS

The aim of this research is to improve the quality and consistency of environmental information about green roofs, currently available for designers. The LCA assessment result allows a clear comparisons of the environmental impacts and use of resource of 6 different green roof types on a standard clay block slab, as a function of the growing medium.

Six different intensive or extensive roof types have been designed based on 4 performing layers:

- a vegetative layer or *medium* where the specific *sedum* is planted
- a separating root inhibitor layer
- a drain and insulating EPS layer
- a waterproofing layer

The root inhibitor membrane has a 1126 kg m^{-3} density, the EPS has 25 kg m^{-3} density, the waterproofing layer is a 5 kg m^{-2} bituminous membrane.

The *medium* used in the different scenarios have been selected from the ones currently available on the European market:

- TYPE *a*: made of 75% Pumice, 15% Lapillus, 10% Compost
- TYPE *b*: made of 20% Pumice, 63% Lapillus, 2% Compost, 1% Zeolite, 14% Peat
- TYPE *c*: made of 10% Pumice, 80% Recycled bricks, 8% Peat, 2% Grass
- TYPE *d*: made of 25% Pumice, 60% Lapillus, 15% Compost
- TYPE *e*: made of 20% Pumice, 80% Compost
- TYPE *f*: made of 25% Pumice, 60% Lapillus, 15% Peat
- TYPE *g*: made of 45% Coconut fibre, 25% Expanded Perlite, 15% Pumice, 15% Gravel

Moreover, considering that green roof contributes to the environmental and energy performance of a building both in warm and cold climate, 5 different insulation scenarios have been designed for each of the 6 green roof types, when EPS layer thickness varies in order to relate the thermal performance to the environmental one.

Scenarios have been designed in order to satisfy the minimum thermal requirements for roofs as defined by the Italian Energy Regulation DM 26/06/15. The Life Cycle Assessment has been carried out in compliance with the modular approach as defined by the European standard EN 15804: 2012+A1:2013. The LCA analysis covered the production stage A only, therefore is a so called *cradle to gate* assessment.

The assessment has been carried out using the software GaBi® and secondary data have been selected from the GaBi® database.

System boundary

Impacts over the life cycle of the green roof have been calculated taking into account flows entering and exit the system during the manufacturing process as detailed below:

- A1, raw material extraction and processing, processing of secondary material input (e.g. recycling processes),
- A2, transport to the manufacturer,
- A3, manufacturing,

including provision of all materials, products and energy, as well as waste processing up to the end-of waste state or disposal of final residues during the product stage.

Module A1, A2 and A3 are declared as one aggregated module A1-3.

The reference service Life or durability of a the green roof, when properly maintained, is the same as the service life of the roof layer it is installed on.

LCA scenario and additional technical information

In order to refer the environmental performance of the green roof to the minimum energy performance required for roofs by DM 26/06/15, five different usage scenarios have been defined varying the thermal transmittance property of the roof layer, referring to values as in Table 2 Appendix A DM 26/06/15.

Thickness of the EPS insulation layer has been calculated assuming the green roof is installed over a 16+4 cm clay block slab: increasing thickness from 8 (default) -9-12-14 to 16 cm, the U-value decreases respectively from 0,33-0,31-0,24-0,21 to 0,18 W m^{-2} $°K^{-1}$, considering a ±5% tolerance. The functional unit has been defined as $1m^2$, including *medium*, the separating root inhibitor layer, the drain and insulating EPS layer and the waterproofing layer. Sedum is exclude as non relevant and the slab as other indoor layers (additional insulation or plaster) as invariant.

Green Roof Assessment

The environmental core impacts have been calculated according to EN15804:2012+A1:2013 and are detailed in Table 1.

Table 1. Comparison between LCA core impact categories of the 6 different green roofs solutions (default scenario) $1m^2$ FU

Impact Category	Extensive HD TYPE 1 medium a	Extensive LD TYPE 2 medium b	Intensive Recycled TYPE 3 medium c	Intensive HD TYPE 4 medium d+e	Extensive HD TYPE 5 medium f	Extensive Renewable TYPE 6 medium g
density	76 kg m^{2}	46 kg m^{2}	118 kg m^{2}	81 kg m^{2}	82 kg m^{2}	114kg m^{2}
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1,97E-005	2,20E-005	2,99E-005	1,96E-005	1,96E-005	1,96E-005
Abiotic Depletion (ADP fossil) [MJ]	1,51E+003	1,56E+003	1,64E+003	1,51E+003	1,61E+003	1,51E+003
Acidification Potential (AP) [kg SO2-Equiv.]	1,16E-001	1,03E-001	1,19E-001	1,74E-001	1,02E-001	1,01E-001
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,33E-002	9,83E-003	1,70E-002	2,89E-002	9,76E-003	9,39E-003
Global Warming Potential (GWP 100 y) [kg CO2-Equiv.]	5,45E+001	4,88E+001	4,37E+001	8,33E+001	4,83E+001	4,81E+001
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	3,21E-009	3,18E-009	3,77E-009	3,18E-009	3,18E-009	3,18E-009
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	2,63E-001	2,63E-001	2,64E-001	2,66E-001	2,63E-001	2,62E-001

RESULTS AND DISCUSSION

For almost all roof types, impact categories as well as resource use and emission to air are caused by the production of EPS. Therefore, increasing the thickness of the insulation layer form the default scenario of 8 cm to 16 cm, leads to an evident and obvious aggravation of impacts. But values of impact categories in others U-value scenarios increases not proportionally to the decrease of thermal transmittance. Relationship between U-value and impact categories values when the reference U-value changes are the same for all green roof type and are generically represented by Type 1 medium values, as in Table 2.

Table 2. impact categories for the 5 different U-value scenarios 1m² FU – Green Roof Type 1

Green Roof Type 1	8 cm	9 cm	12 cm	14 cm	16 cm
U value W °K^{-1} m^{-2}	0,33	0,31	0,24	0,21	0,18
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1,97E-05	2,16E-05	2,60E-05	2,92E-05	3,24E-05
Abiotic Depletion (ADP fossil) [MJ]	1,51E+03	1,72E+03	2,20E+03	2,54E+03	2,89E+03
Acidification Potential (AP) [kg SO2-Equiv.]	1,16E-01	1,29E-01	1,61E-01	1,84E-01	2,07E-01
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,33E-02	1,45E-02	1,75E-02	1,96E-02	2,17E-02
Global Warming Potential (GWP 100 y) [kg CO2-Equiv.]	5,45E+01	6,14E+01	7,75E+01	8,89E+01	1,00E+02
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	3,21E-09	3,63E-09	4,63E-09	5,34E-09	6,05E-09
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	2,63E-01	3,02E-01	3,94E-01	4,59E-01	5,24E-01

The LCA comparison of the 7 medium layers has been carried out based on the declared unit 1 m2, thickness 1 cm (Figure 1). In general terms, damage categories that mostly contribute to the medium environmental impacts are Abiotic Depletion (ADP fossil), Global Warming Potential (GWP 100 y) and Acidification Potential(AP).

Then, it becomes relevant for designers to analyse elements that, in any of the different medium, causes high values of these impact categories in order to combine a proper mix that satisfies technical performance requirements for green roof, minimizing, at the same time, its environmental impact.

Primary energy consumption (Figure 2) are extremely high in medium "c", "f", "g". Supposing that the high energy use from non renewable sources in medium "c" is due to the crushing of recycled bricks, in medium "f" it is caused by Peat extraction and in medium "g" by Perlite production. It has to be noted that the % of primary energy from renewable resources used in medium "c" represents the local scenario of the energetic mix used in the assessment.

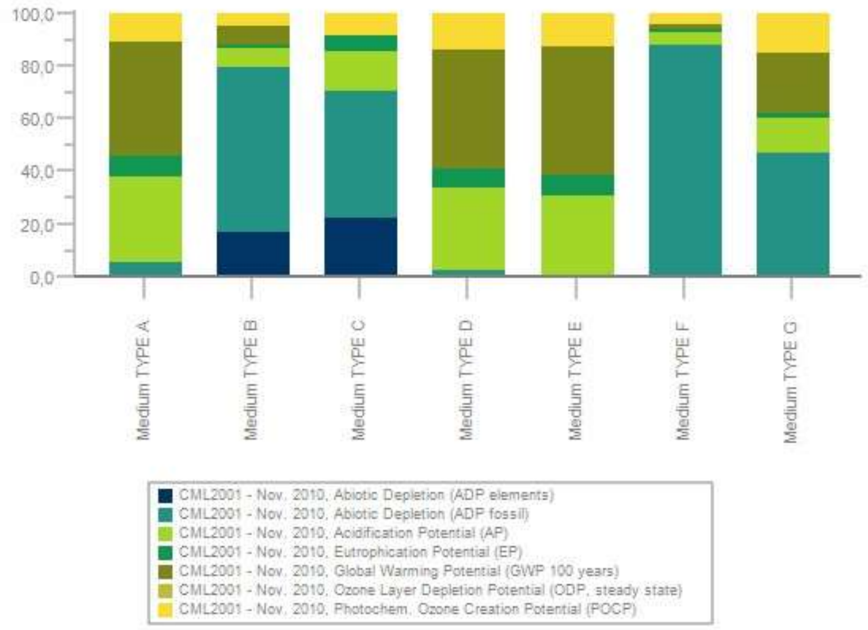

Figure 1. LCA comparison of 7 *medium*

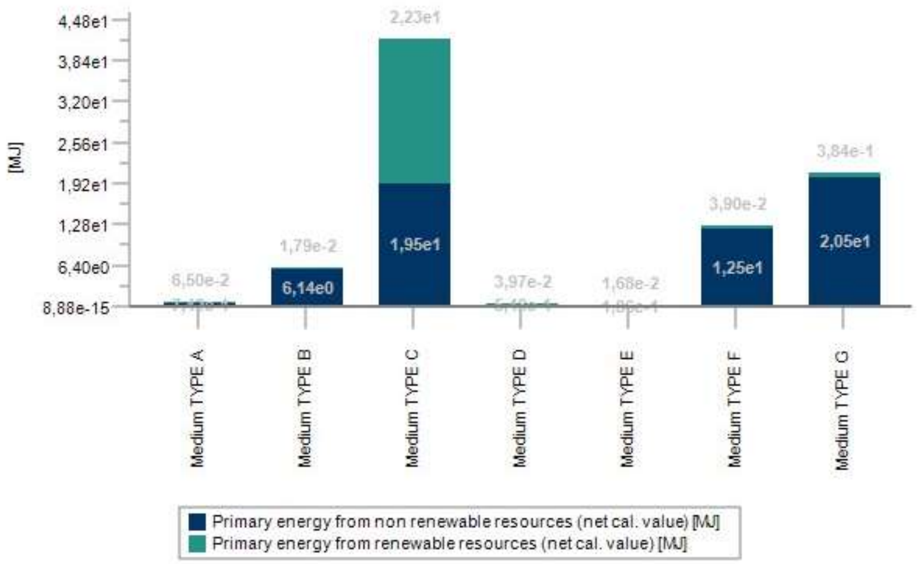

Figure 2. Primary energy use for the 7 different *medium.*

CONCLUSIONS

A preliminary investigation on availability of both generic and specific environmental information about materials and components for green roofing has confirmed a sever lack of data, pointed out by previous researches again and again (Gargari et al., 2016).

Despite several new studies on environmental impacts of green roofs have been published recently and, the first EPD of an extensive green roof has been verified and certified in May 2016 (KANUF, 2016), specific characteristics of vegetative substrate layers and its environmental and energy performances are still barely available.

Many of the national end European companies producing green roofs promote original mixes based on Pumice, Peat, Lapillus together with new and innovative materials as vegetal fibres, recycled elements, water absorbing particulates.

Such components are promoted and recommended because of their sustainability, water absorption and retention and release of nutrients to plants, but any detailed information about their specific chemical composition (mixes are almost secret company recipes) as well as any data referring to thermal performance under different humidity conditions are totally missing.

Therefore, from one hand the scientific research moves forward to demonstrate how much green roofs contribute to improve indoor comfort in buildings (and, more generally, environmental quality in urban spaces) and reduce energy consumption, form the other hand has not performed yet a consistent evaluation of technical parameters needed to calculate U-value and thermal capacity values of these substrates in use.

Density, thermal conductibility, and specific heat values of the medium mixes are hard to be found in literature or in technical and commercial documentation, especially when related to different humidity values or as a function of the RSL.

Then, it's pretty much complicated for designers to calculate thermo-hygrometric performances of a building with a green roof with a good level of accuracy. A tightly cooperation between research and industry is then needed to calculate, using accurate tools, performances of green roofs in use and, at the same time, monitoring and comparing results with data from a real 1:1 scale model.

Environmental specific data of substrates come to light because of the cooperation, can be collected and organized in a Life Cycle Inventory Database, supporting LCA studies on green roofs.

Furthermore, it's important to point out that a complete LCA, according to more recent PEF indication, must include other life cycle stages as end of life and recycle at least but, talking about green roof, the use stage should have a certain importance due to the large use of irrigation water, especially in warm/hot climate. Moreover, the use of fertilizers to feed plants has to be considered, together with a potential reuse or recycle of any of the different layers at the end of life.

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