Research Article

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Life Cycle Assessment (LCA) for Water re use System of a Green Roof

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Abstract

In urban contexts climate change and urbanization alter the correct management of outflows. The need to reduce CO2 emissions and increase the green areas presence is linked to forecast targets to facilitate the correct management of urban risks. To achieve these objectives the new technologies are available, such as green roofs, which are useful for reducing the impacts of climate change in urban areas and for the proper management of outflows, indeed, the green roofs can be connected to rainwater reuse systems. The collection and reuse water system can be studied using the Life Cycle Assessment (LCA) methodology. In this paper a sustainability estimate of the green roof and reuse water system is proposed in the Urban Hydrological Experimental Park at the University of Calabria (Italy).

Keywords: Green roof, Water reuse, Life Cycle Assessment, Sustainability

Introduction

In urban contexts, the need to oppose the effects of urbanization and climate change is increasing [1,2]. Drainage water, in the urban systems, is the component most affected by the combined effect of climate change and urbanization. The natural water cycle in urban context produces the flooding phenomena and uncontrolled sliding of the surface water which are destined to become more frequent and important [3,4]. For these reasons, it is necessary to manage urban water resources in a sustainable way, through appropriate procedures to optimize the allocation of water resources or using analytical environmental criteria that guide design choices towards sustainability [5-13]. Today the Best Management Practices (BMPs), among which are distinguished sustainable solutions with low environmental impact (Low Impact Development, “LID”), are identified as intervention which aimed to minimize the impervious surfaces, restoring the natural hydrological cycle in an urban environment through the use of vegetated systems and infiltration. For the urban rainwater management, low impact sustainable solutions offer many advantages as reduction of the polluting load of the first rain water and the reduction of the flow rates and volumes of the peaks relating to urban drainage system [14]. Among the LID types the green roof is frequently used in urban context because it uses unused urban areas to guarantee many environmental benefits as promote energy saving in buildings, pollutants concentration [15].

The rainwater management is one of the most important functions of a green roof. This characteristic has an important potential in a context of water resource scansity [16,17]. For thisreason, the collection and treatment of rainwater is a design solution considered in the presence of vegetated roofs [18]. These technologies, whose efficiency in terms of the collected water quality also depends on the materials present [19], contribute to increasing the sustainability of the low impact infrastructures such as green roofs, increasing their known benefits.

The green roof and water reuse system (GRWRS) represents an element which contributes to increasing the vegetated roofs sustainability.Thereforeit makes sense to discuss its sustainability level. Indeed this estimate cannot be linked only to the operational phase, but to the entire life cycle. A valuable tool that estimates the sustainability is the Life Cycle Assessment (LCA) - a useful method to support decisions. LCA is an objective method that defines the ecological budget of a product or system, because it considers all product or system information linked to the life cycle. In the literature there are many studies based on LCA application to LIDs and LCA application to pipeline [20-30].

Studying the reuse system sustainability is useful to show that environmental impacts depend not only to the operational phase, but also on the complex life-cycle structure of the product and the materials that make up it.

This paper proposes a LCA application to a GRWRS, using the University of Calabria green roof and a generic structure of water reuse system. This work aims to highlight that the involved materials life cycle has a bearing on the sustainability of the entire system life cycle. The sustainability analysis proposed, through LCA, focuses only on the materials study, without making technical evaluations concerning the system performance.

Material and Methods

This section will be divided into two parts:

- Explanation of the LCA methodology applied to the stratigraphy of the University of Calabria green roof
- Explanation of the LCA methodology applied pipelines for reuse system

The GRWRSis decomposed into two sections which regain the roof stratigraphy and the reuse system, proposed in several alternatives among the most used.The LCA procedure application is different between the two sections up to the inventory definition (Life Cycle Inventory phase - LCI), but the calculation method for the Life Cycle Impact Assessment (LCIA) is similar in order to compare the results.

Life Cycle Assessment of the green roof

The University of Calabria is located in the southern Italy and it is surrounded in a Mediterranean climate. The green roof is part of the "Urban Hydraulic Park," which also includes a permeable pavement, a bioretention system and a sedimentation tank connected to a treatment unit. An extensive green roof was installed on the existing rooftop of the Department of Mechanical Engineering and it was divided into four sectors. Two sectors are vegetated with native plants and differ from each other by the drainage layer. Another sector is characterized by bare soil with only a few spontaneous plants. The last sector is the original impervious roof. The green roof is divided into square elements of 50 by 50 cm with alternating vegetated and non-vegetated areas. In this study, only one vegetated sector – sector 1 - of the green roof was considered. The green roof analysis is carried out with reference to the stratigraphy shown in Figure 1 and here detailed from the bottom to the top

- antiroot bituminous membrane layer, with a high content of elastomeric and plastomeric polymers,
- water storage layer, with indestructible felt in polyester/polypropylene fibers,
- drainage layer, ventilation and drainage with expanded polystyrene,
- filter layer, with filter mat made of polypropylene,
- culture layer, with Mediterranean mineral soil,
- vegetated layer, withCerastium, Diantus, Carpobrotus.

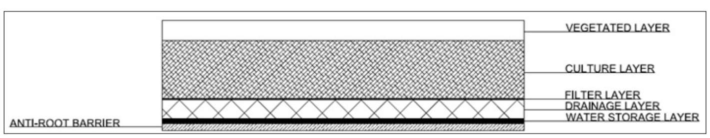

Figure 1: Sector 1 stratigraphy

To evaluate product sustainability with the LCA method, it is necessary to evaluate the requests of water and energy linked to extraction techniques, production operations, transport and disposal. This analysis provides information on how each phase of the process affects the sustainability. The method structure related to the study case is summarized following. In this analysis, the objective of the LCA is the assessment of environment impacts associated to the materials of sector 1 stratigraphy of the green roof. The analysis is carried out in reference to the functional units of 1 m3 of the stratigraphy. The system boundaries include the phases of extraction of raw materials, production processes, transport from the supplier to the installation place and energy consumption related to the transformation. The data quality is guaranteed by the experimental site of the University of Calabria and by the possibility of using the Ecoivent database.

Life Cycle Assessment of the re use system

In this analysis, the objective of the LCA application is to evaluate the impacts associated to the life cycle of different types of pipes. Seven test pipes of a different materials are analyzed, chosen from the most popular ones on the European market (Gres, Steel, Iron cast, PE, PP, PRFV, PVC). The functional unit is 100 linear meter of the pipe of the material selected with the same diameter (nominal diameter 300 mm). In this work, the functional unit is independent of the hydraulic considerations because the LCA application is only intended to compare the environmental performance of the materials. The system boundaries include the phases of extraction of raw materials, production processes, transport from the supplier to the installation place and energy consumption related to the transformation.

Input data does not refer to specific pipelines, but represents average European values of some manufacturers (Ecoinvent database is used).

Life Cycle Impact Assessment

For the Life Cycle Impact Assessment (LCIA) it is possible to use many methods, which differ in purpose and structure of analysis. In this work, among the various LCIA methods available in the software (such as SimaPro, which is used for this application) is chosen. The Impact 2002+ method specifies the impact in damage categories (human health, ecosystem quality, climate change, resources) and impact categories (human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidification/nutrification, aquatic acidification, aquatic eutrophication, land occupation, global warming, non-renewable energy, mineral extraction). The operation criterion of this method, reported in, is summarized below [31,32]. The IMPACT 2002+ method is formulated by the methodologies combination based on both the midpoint approach, which refers to the impact categories, both on the endpoint, based on the damage categories. In the Impact 2002+ method, the assessments are made primarily at the midpoint level and at the normalized damage level. In the first case, the evaluations are obtained by means of the midpoint characterization factor and are expressed in equivalent kilograms of the reference substance. In the second case these assessments are calculated by means of the normalized damage factor and expressed in "points", which correspond to "pers • yr" with reference to Europe. The normalization factors for the Impact 2002+ damage category are show in Table 1.

Table 1: Impact 2002+ normalization factors related to Western Europe [32].

Damage categories	Normalization factor referring to Q2.2 version	Unit
Human Health	0,0071	Disability-Adjusted Life Year DALY/point
Ecosystem Quality	13,700	Potentially Disappeared Fraction of species over a certain amount of m2 during a certain amount of year PDF. m2.y/point
Climate Change	9,950	kg CO_2 into air/point
Resources	152,000	MJ/point

In this method the normalization factors are the impact ratio per unit of emission divided by the total impact of all substances in the specific category [32].

Impact 2002+ is used to LCIA phase for the GRWRSas impact assessment methodfor the interest towards the Climate Change and because the new criteria for the comparative assessment of the Human Toxicity and Ecotoxicity categories have been developed in Impact 2002+.

Results and discussion

Life Cycle Assessment of the green roof

The impacts associate to the functional unit choice are shown in Figure 2 and detailed in the following list [33]. It is important to note that the impacts evaluated are expressed as a percentage (percentage impact of each individual layer of the total impact of Climate Change on the globe stratigraphy), to highlight the Climate Change importance on the total.

- Antiroot bituminous membrane layer - The environmental cost of such a layer is approximately equal to 17.4%. This value is only comparable to Resources damage category, while Human health and Ecosystem quality impacts are approximately equal to half compared to the previous values. The environmental load is associated with the processing techniques of the raw materials needed for product realization. The Climate Change and Human health impacts grows considerably due to the emissions derived from the means of transport by road, whose energy class is not competitive.
- Water storage layer - The environmental impact associated to Climate Change, is about 18,2%. In this case are involved polymeric materials which, with the same energy costs linked to the production stage compared to the anti-root layer, have major impacts due to the distance between the retrieval location of the material up to the city of Rende. The damage category that registers the least damage is the Ecosystem quality, being synthetic materials.
- Drainage layer - The value is approximately equal to 18,7%. This percentage represents the highest value in the stratigraphy of the sector 1 of the green roof. The use of polymeric materials, also present in the water storage and filter layers, has a certain impact due to production processes and to the considerable energy costs associated with them, as well as inability to find these materials near to installation place. The impact quantification is only comparable to the Resources damage categories, but Ecosystem quality and Human health are identified by significantly lower values.
- Filter layer – The environmental cost for this layer is about 18,3%. Specifically, the polymeric materials production is the almost totality relative to Carginogens impact, resulting mainly harmful to Human health, while a contribution is almost nil on Ionizing Radiation.
- Culture and vegetated layer - The environmental cost of such a two layers is respectively equal to 13,8% and 13,5%. Compared to previous layers, these have very low impact values linked to the remaining damage's categories. Being materials phase on the road by lorries, whose energy class is not particularly competitive. The impact due to this aspect is increased by higher volumes required for the transport of culture layer with respect to the materials constituting the previous stratigraphy.

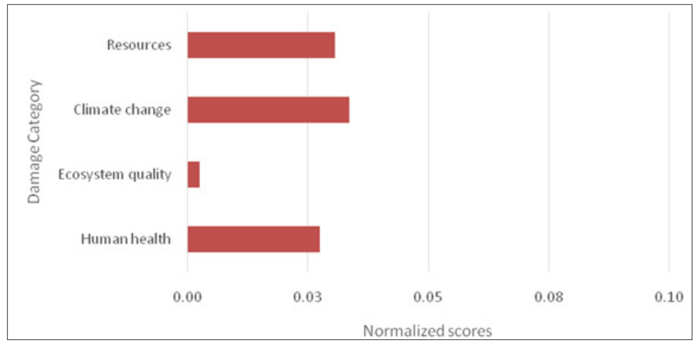

Figure 2: Life cycle assessment output for green roof sector 1.

The LCA application has highlighted that there are substantial contributions also for the layers consist of natural material, which have an impact on the total due to the use of transport type on the road. The polymeric materials life cycle is due to the non-renewable sources of energy supply used (this aspect show the importance of Resource Damage Category in Figure 2) and types of transport by lorries whose energy class is not particularly competitive.

Life Cycle Assessment of the reuse system

In the Figure3 is evident that the greatest contribution is related to human health [34]. It is associated a high environmental cost to polymeric materials (PRFV and PVC), whereas the iron cast and gres pipes have smaller impact. Figure 3 shows a low overall contribution of the damage category Ecosystem quality and the comparable total related to Climate change and Resources. Related to Human health, the impact associated with the test materials has similar values, excluded Steel, PVC and PRFV which have the greater impacts. Concerning Ecosystem quality category, the impact associated with the test materials assumes a values similar, excluded Steel. With regards to Climate change, the impact values associated with the test materials are similar excluded gres and iron cast which present the lower impact. Regarding Resources, the impact associated with the test materials has a comparable values excluded Steel, PVC, PRFV, PE and PP, which have the greater impacts.

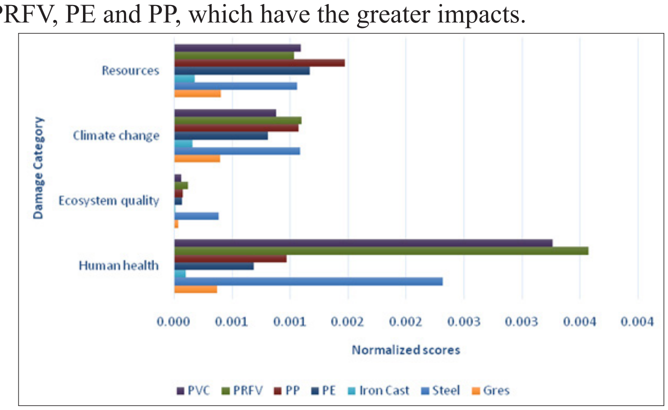

Figure 3: Life cycle assessment output for reuse system.

Conclusion

To carry out the sustainability estimate for the GRWRSthe LCA method is used. This evaluation is focused on materials analisys to demostrate that the sustainability level of LID depending also from the materials life cycle study. The impacts details of this analysis depend on the choices made and for this reason cannot be considered an absolute assessment for the GRWRS. With this work it has been shown that the sustainability level of the low-impact infrastructure does not depend only on the operational phase, but also on what is before and after this step.

References

1. Krysanova V, Dickens C, Timmerman J, Varela-Ortega C, Schlüter M, Roest K, et al. (2010) Crosscomparison of climate change adaptation strategies across Large River Basins in Europe. Africa and Asia. Water Resour Manage 24: 4121-4160.
2. Maiolo M., Mendicino G, Senatore A, Pantusa D (2017) Optimization of drinking water distribution systems in relation to the effects of climate change. Water: 9: 803.
3. Carbone M, Garofalo G, Tomei G, Piro P (2014) Storm tracking based on rain gauges for flooding control in urban areas. Procedia Engineering 70: 256-265.
4. Piro P, Carbone M, Garofalo G, Samsalone J (2007) CSO treatment strategy based on constituent index relationships in a highly urbanized catchment. Water Science & Technology 56: 85-91.
5. Maiolo M, Pantusa D (2016) An optimization procedure for the sustainable management of water resources. Water Science and Technology: Water Supply 16: 61-69.
6. Maiolo M, Pantusa D, Colica F (2008) Optimization problems in the sustainable management of water resources. L'ACQUA 4: 55-66.
7. Ni J, Liu M, Ren L, Yang SX (2014) A multiagent q-learning-based optimal allocation approach for urban water resource management system. IEEE Transactions on Automation Science and Engineering 11: 204-214.
8. Zhao K, Liu N, Zhao L (2011) Optimization allocation of water resources in Hengshui City based on sustainable development. Journal of Water Resources & Water Engineering 5: 137-140, 144.
9. Carini M, Maiolo M, Pantusa D, Chiaravalloti F, Capano G (2017) Modelling and optimization of least-cost water distribution networks with multiple supply sources and users. Mathematics research.
10. El-Halwagi MM (2012) Sustainable design through process integration: Fundamentals and applications to industrial pollution prevention. Resource conservation, and profitability enhancement. Butterworth – Heinemann.
11. Maiolo M, Martirano G, Morrone P, Pantusa D (2005) A sustainability synthetic territorial index (SSTI) to assess the sustainable management of water resources. In 3rd Dubrovnik conference of sustainable development of energy. Water and environment systems, Dubrovnik, 5-10 June.
12. Maiolo M, Martirano G, Morrone P, Pantusa D (2006) Assessment criteria for a sustainable management of water resources. Water Practice & Technology 1.
13. Maiolo M, Pantusa D (2015) A methodological proposal for the evaluation of potable water use risk. Water Practice & Technology 10: 152-163.
14. Piro P, Carbone M, Nigro G, Garofalo G (2014) A modelling approach to assessing variations of total suspended solids (TSS) mass fluxes during storm events. Hydrological Processes 28: 2419-2426.
15. Maiolo M, Carini M, Capano G, Nigro G, Piro P (2017). Life cycle assessment of a bitumen antiroot barrier in a green roof in the Mediterranean area. International Journal of Petrochemistry and Research.
16. Maiolo M, Pantusa D (2017) A proposal for multiple reuse of urban wastewater. J Water Reuse Desal 2017.
17. Maiolo M, Pantusa D (2017) Combined reuse of wastewater and desalination for the management of water systems in conditions of scarcity. Water and Ecology 4.
18. Parizotto S, Lamberts R (2011) Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil. Energy and Buildings 43: 1712-1722.
19. Mendez CB, Klenzendorf JB, Afshar BR, Simmons MT, Barrett ME, et al. (2011) The effect of roofing material on the quality of harvested rainwater. Water research 45: 2049-2059.
20. Kosareo L, Ries R (2007) Comparative environmental life cycle assessment of green roofs. Building and Environment 42: 2606-2613.
21. Spatari S, Yu Z, Montalto FA (2011) Life cycle implications of urban green infrastructure. Environmental Pollution 159: 2174-2179.
22. Flynn KM (2011) Evaluation of Green Infrastructure Practices Using Life Cycle Asessment (Doctoral dissertation). Villanova University.
23. O'Sullivan AD, Wicke D, Hengen TJ, Sieverding HL, Stone JJ (2015) Life Cycle Assessment modelling of stormwater treatment systems. Journal of Environmental Management 149: 236-244.
24. Xu X, Zhang Q (2016) Life cycle assessment of bioretention systems for nutrient management. StormCon 2016, Indianapolis, IN, August 22–25, 2016.
25. Brudler S, Arnbjerg-Nielsen K, Hauschild MZ, Rygaard M (2016). Life cycle assessment of stormwater management in the context of climate change adaptation. Water Research 106: 394-404.
26. Xu C, Hong J, Jia H, Liang S, Xu T (2017) Life cycle environmental and economic assessment of a LID-BMP treatment train system: A case study in China. Journal of Cleaner Production 149: 227-237.
27. Dennison FJ, Azapagic A, Clift R, Colbourne JS (1999) Life cycle assessment: Comparing strategic options for the mains infrastructure—Part I. Water SciTechnol 39: 315-319.
28. Du F, Woods GJ, Kang D, Lansey KE, Arnold RG (2012) Life cycle analysis for water and wastewater pipe materials. J Environ Eng 139: 703-711.
29. Lemos D, Dias AC, Gabarrell X, Arroja L (2013) Environmental assessment of an urban water system. J Clean Prod 54: 157-165.
30. Barjoveanu G, Comandaru IM, Rodriguez-Garcia G, Hospido A, Teodosiu C (2014) Evaluation of water services system through LCA. A case study for Iasi City, Romania. Int J Life Cycle Ass 19: 449-462.
31. Jolliet O, Margni M, Charles R, Humbert S, Payet J, et al. (2003) IMPACT 2002+: A new life cycle impact assessment methodology. The International Journal of Life Cycle Assessment 8: 324.
32. Humbert S, Margni M, Jolliet O (2005) IMPACT 2002+: User guide. Draft for version, 2.
33. Maiolo M, Carini M, Capano G, Piro P (2017) Synthetic sustainability index (SSI) based on life cycle assessment approach of low impact development in the Mediterranean area. Cogent Engineering 4: 1410272.
34. Maiolo M, Capano G, Carini M, Pantusa D (2018) Sustainability criteria for the selection of water supply pipeline. Sustainability (Submitted ID- 250948).

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