Synthetic sustainability index (SSI) based on life cycle assessment approach of low impact development in the Mediterranean area

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Abstract: Climate change and the processes of urbanization alter the hydrologic and hydraulic regime of runoffs formation in urban areas. Low impact infrastructure development (LID) contributes to achieving conditions of invariance hydrological and hydraulic. The purpose of this work is to identify an index of synthetic sustainability (SSI) based on life cycle assessment (LCA). Such LCA evaluates design alternatives through the comparison of the different values of the SSI. The proposed methodology allows the evaluation of the SSI attributing to the individual layers of the LID different weights and taking into account both of the influence that each of them perform on invariance hydrologic and hydraulic both of the LCA normalized output. In this paper is showed a methodological implementation obtained by the analysis of a green roof and a permeable pavement. This green roof has been realized, on real scale, in the Urban Hydrology Experimental Park in University of Calabria (Italy).

Subjects: Climate Change; Research Methods in Environmental Studies; Environment & the City

Keywords: climate change; LID; green roofs; permeable pavement; LCA; sustainability index

ABOUT THE AUTHORS

The DIATIC research group deals with Sustainable Water Management with specific reference to hydraulic mathematical modeling, to quantify the physical and hydraulic aspects that have an impact on the operational management of infrastructures. This group has a specific experience in sustainability indices elaboration (Maiolo et al., 2005, 2006). The DINCI research team deals with Sustainable Urban Hydraulics with specific reference to LID Field Testing. Collaboration in research activity between these two research groups was born in the Italian National Operative Project (PON) - Research and Competitiveness for the convergence regions 2007/2013—project: “Integrated and sustainable management of the water-energy cycle in urban drainage systems” and is continuing with the Italian National Project (PON)—Innovation and Competitiveness (I&C) MISE 2014/2020—project: “I-BEST—Innovative Building Envelope through Smart Technology”.

PUBLIC INTEREST STATEMENT

The research is based on the study of two major problems in urban context such as CO2 emissions and the reduction of flooding risk. The research focuses on environmentally friendly construction techniques (green roof and permeable pavement) at University of Calabria that contribute to reducing CO2 emissions and reduce the risk of flooding in urban environments. Both of these infrastructures are able to handle rainwater so they do not cause flooding, while plants on green roofs help extract CO2 from the atmosphere.
1. Introduction

In the modern society to oppose climate change is a major challenge, due both from the urbanization process, both from climate changes that make the hypothesis of stationarity of weather and climate conditions in the long term no longer valid (Krysanova et al., 2010; Maiolo, Mendicino, Senatore, & Pantusa, 2017; Milly et al., 2008). Climate change increase the frequency and intensity of weather related natural disasters and increase vulnerability urban ecosystem (Ibarrarán, Ruth, Ahmad, & London, 2009). This climate changes obey to the traditional conservation laws of physical system (Carini, Fatibene, & Francaviglia, 2007) based on vulnerabilities and resilience index (Ibarrarán, Malone, & Brenkert, 2010). The Mediterranean basin is perfectly corresponding to both of these trends for two aspects: it is observed a continuous increase in anthropic pressure, with a consequent increase in urbanization (Cudennec, Leduc, & Koutsoyiannis, 2007) and it is considered a “hot spot” with regard to climate change (Garcia-Ruiz, López-Moreno, Vicente-Serrano, Lasanta-Martínez, & Begueria, 2011; Giorgi, 2006). 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 determ flooding phenomena and uncontrolled sliding of the surface water which are destined to become more frequent and important (Carbone, Garofalo, Tomei, & Piro, 2014; Piro, Carbone, Garofalo, & Samsalone, 2007). 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 (Maiolo & Pantusa, 2016; Maiolo, Pantusa, & Colica, 2008; Ni, Liu, Ren, & Yang, 2014; Zhao, Liu, & Zhao, 2011) or using analytical environmental criteria that guide design choices towards sustainability (Carini, Maiolo, Pantusa, Chiavavalloti, & Capano, 2017; El-Halwagi, 2012; Foo, 2011; Maiolo & Pantusa, 2015, in press; Maiolo et al., 2005, 2006). The analyses of these scenarios requires the use of sustainable solutions, as an alternative to conventional techniques capable of restore, as far as possible, the natural hydrological pattern of populated areas (Cannata, Ciccone, & Valentinielli, 1994). Today the combination of these types of sustainable interventions are identified as Best Management Practices (BMPs), among which are distinguished sustainable solutions with low environmental impact (Low Impact Development - LID) 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 (Piro, Carbone, Nigro, & Garofalo, 2014). Among the LID types appear to have a greater potential for spreading the green roof and the permeable pavement associated with bioretention cell. Green roofs and permeable pavements use an urban areas otherwise unused to ensure many environmental benefits on surrounding context (Carbone, Brunetti, & Piro, 2014; Mentens, Raes, & Hermy, 2006; Polla et al., 2015; Schmidt, 2005). It is clear that the LIDs are useful infrastructure solutions to make sustainable urban environments.

There is a need to have available a methodology capable of providing an accurate estimate of their sustainability. Indeed this assessment can not only be linked to environmental benefits related to lifetime, but assessments are needed on the steps which precedes and follows them. A valid criterion for sustainability verification of a product/system is the life cycle assessment (LCA) (Maiolo, Carini, Capano, Nigro, & Piro, 2017). This method accounts for the material and energy flows entering and leaving the system analyzed and provides an assessment of the environmental cost of the analyzed system (Berger & Finkbeiner, 2010; ISO, 2006). One of the fundamental principles of LCA is the concept of functional units. The functional unit is a very sensitive aspect because it ensures the comparability of results of LCA application (Kirk, Roseen, & Etner, 2006; Van Haaster, Ciroth, Fontes, Wood, & Ramirez, 2017). In the literature there are many studies based on LCA application to LIDs with very different approaches (Table 1), but most of them offer qualitative assessments (Brudler, Arnbjerg-Nielsen, Hauschild, & Rygaard, 2016). In Table 1 the interaction between alternatives and impact categories produces LCA estimates which identifying the specific study (dependent on the functional unit and LCA objective). These aspects are able to quantify the impact of multiple design solutions through the impact categories. Therefore, the choice of alternatives and the impact categories, referring to the Table 1 studies, is linked to the need to correlate some types of emissions
Table 1. Literature synthesis with LCA applications on LIDs

| Reference          | Functional unit     | N. Alternatives | N. Impact categories |
|--------------------|---------------------|-----------------|---------------------|
| Kirk et al. (2006) | Roof area           | 4               | 9                   |
| Kosareo and Ries (2007) | Roof area   | 3               | 15                  |
| Spatari et al. (2011) | Area            | 2               | 2                   |
| Flynn (2011)       | Area               | 2               | 11                  |
| Chenani et al. (2015) | Roof area    | 2               | 10                  |
| O’Sullivan et al. (2015) | Water volume | 3               | 18                  |
| Brudler et al. (2016) | Area             | 2               | 8                   |
| Gargari et al. (2016) | Roof area    | 5               | 7                   |
| Xu and Zhang (2016) | Nutrients quantity removed | 6       | 4                   |
| Xu et al. (2017)   | Treatmet area      | 8               | 18                  |

with different types of environmental impact on a global scale and for this reason it is variable from case to case. The main difference between these is based on the choice of functional unit that can be related to system types (Chenani, Lehmävirta, & Häkkinen, 2015; Kosareo & Ries, 2007; O’Sullivan, Wicke, Hengen, Sieverding, & Stone, 2015) or area types (Spatari, Yu, & Montalto, 2011; Xu, Hong, Jia, Liang, & Xu, 2017; Xu & Zhang, 2016). Many LCA applications to LIDs are comparative type (Gargari, Bibbiani, Fantozzi, & Campiotti, 2016; Kirk et al., 2006; Kosareo & Ries, 2007). The LCA, therefore, can be considered a useful way to direct decision-making during the design phase and helps to choose design alternatives based on prospects and priorities (Brudler et al., 2016). The proposed document is based on the need to analyze stratigraphic materials, because it is a detail that can have a great impact on the sustainability of LIDs (Chenani et al., 2015; Flynn, 2011; Kirk et al., 2006; O’Sullivan et al., 2015; Xu et al., 2017), and propose an expedited index (SSI) comparison between design alternatives, very useful for specialized technicians.

Sustainability assessments using LCA provide impact estimates sensitive to many variable parameters. To correlate these assessments with water management objectives and reducing climate change, it is inevitable to use qualitative methodologies such as synthetic indices linked to sustainability development. These sustainability indices are complex to evaluate because they are related to dynamic processes whose characteristic parameters are complex to be integrated into a single evaluation. In the literature there are many sustainability indices that are used for surveying and planning in environmental policies (Chaves & Alipaz, 2007) and most of them are living planet index (LPI), ecological footprint (EF), city development index (CDI), human development index (HDI), environmental sustainability index (ESI), environmental performance index (EPI), environmental vulnerability index (EVI), index of sustainable economic welfare/genuine progress index (ISEW/GPI), well-being index (WI), genuine savings index (GS), and environmental adjusted domestic product (EDP) (Böhringer & Jochem, 2007; Mori & Christodoulou, 2011). For example, the ESI index, a tool for controlling and managing natural resources, is classified through indicators and sub-indicators and facilitates comparative analysis (Esty, Levy, Srebotnjak, & De Sherbinin, 2005). Integrating LCA analysis through the use of performance indices is a common technique in the literature (Nakano, 2015). In this paper an SSI index was identified that allows as orienting technical choices and facilitates comparative analysis between different low impact design solutions, linked not only to operational phase.

2. Materials and methods
To assess the sustainability of the life cycle of the Unical green roof materials and permeable pavement is chosen to identify a significant synthetic index. The synthetic index will be used to compare the environmental performance of the Unical green roof and permeable pavement. This methodology allows the evaluation of a synthetic sustainability index (SSI) of a LID intervention through a calculation procedure base on scores and weights. The scores used are correlated to several layers
of the LID (permeable pavement and green roof) and each is attributed a weight that summarizes its ability to contribute to hydrological and hydraulic invariance.

Among the parameters that can give synthetic information to estimate hydraulic and hydrological invariance there is the runoff coefficient, for its dependence on duration, intensity, dry weather and other conditions at the outline of the stormwater event as the climate conditions. The runoff coefficient is a very important tool in hydrology (Gottschalk & Weingartner, 1998). Runoff analysis, an important aspect to describing the operating conditions of a LID, is strongly bound to the superficial layers, particularly in a green roof (Berretta, Poë, & Stovin, 2014; Garofalo, Palermo, Principato, Theodosiou, & Piro, 2016).

In this paper the assessment of the runoff coefficient can be made on the basis of the collected data of the equipment of the Unical Urban Hydraulic Park. The runoff coefficient analysis, referring to pre-determined rainfall events, reported partially in (Carbone, Garofalo, Nigro, & Piro, 2015), show the different potentiality of the layers to retain water, also with reference to the dry weight and weight of saturation (Piro, 2015).

In order to ensure the hydraulic and hydrological invariance, the criteria to attribute the stratigraphy weights evaluates according to this runoff coefficient analyses. The relative weight of each layer is assigned as show Tables 2 and 3. The proposed method attaches a “weight” variable between 1 and 5, where 1 value indicates a bad capacity to contribute to the runoff, as opposed to the 5 value.

To define the scores, which has allowed to evaluate the environmental impact of LID realization, even for the steps that precede and follow the implementation step, is used the Life Cycle Assessment (LCA) method. Scores are assigned according to the values assumed by LCA assessment, evaluated throughout LID stratigraphy. The LCA scheme application is explained below. In this analysis, the objective of the LCA is the assessment of environment impacts on climate change associated to the materials of sector 1 stratigraphy of the green roof and the permeable pavement. The analysis is carried out in reference to the functional units of 1 m³ of the single 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 impact evaluation is done using the IMPACT2002 + method to the main interest to the climate change. The IMPACT 2002 + method is based on combined midpoint/damage-oriented approach (Jolliet et al., 2003) and is specified by midpoint categories (human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, terrestrial acidifica-tion/nutrification, aquatic acidification, aquatic eutrophication, land occupation, global warming, non-renewable energy, mineral extraction) and damage categories (human health, ecosystem quality, climate change, resources) as show in Table 4. In this paper the interest is related to the Global Warming impact category, but will be presented with an overall assessment of the two LIDs through the seventeen impact categories of the chosen method.

| Table 2. Weights associated with the sector 1 of the green roof |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Layer           | Anti-root barrier (ARB) | Water storage layer (WLS) | Drainage layer (DL) | Filter layer (FL) | Culture layer (CL) | Vegetated layer (VL) |
| Weight         | 3                | 3                | 5                | 3                | 5                | 4                |

| Table 3. Weights associated with permeable pavement stratigraphy |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Layer           | Impervious geotextile (IGT) | Protection layer (PL) | Sub-base layer (SBL) | Base layer (BL) | Geotextile (GT) | Bedding layer (BL) | Wear layer (WL) |
| Weight         | 4                | 4                | 5                | 4                | 3                | 2                | 1                |
Some of the important steps in applying the LCA method are characterization and normalization, which make the stage of interpretation easy and clear. Characterization factors for each substance are obtained by multiplying the potential of the midpoint with the factors characterizing the damage of the reference substances. The normalization factor is determined by the ratio of the impact per unit of emission divided by the total impact of all substances of the specific category (Humbert, Margni, & Jolliet, 2005). This factors are assigned on the basis of the impact assessment method (Table 4). The normalization process is useful in defining the intensity of the environmental impact of the system studied compared to the average human induced impact in the chosen geographic area. To estimate this assessment detail is used the methodology Impact 2002 + implemented in SimaPro 8.2.0 software. The scores associated to LID layers are shown and explained in detail in the Results section of this paper.

The sum of the products of the score and the weight given to each layer allows the evaluation of the SSI refers to LIDs:

$$SSI = F_1 F_{1w} + F_2 F_{2w} + \ldots + F_n F_{nw}$$

where the subscript “r” indicates the score and the subscript “w” indicates the weight. The equation shows that the SSI is directly proportional to the value of the impacts associated with the LCA evaluation of the individual layers. This demonstrates that higher values of the SSI index have greater environmental impacts associated with the life cycle of the LID layers. As it depends on numerically positive quantities, the SSI will be a positive value that correlates environmental compatibility and hydrological-hydraulic performance of the stratigraphy.

### 3. Experimental site and data used

To make an experimental verification to full-scale, have been carried out at the University of Calabria a series of pilot plants with low environmental impact, associated to traditional hydraulic control infrastructure. These experimental installations are the “Urban Hydraulics Park” of the Vermicelli basin. The Vermicelli basin extends for about 27.80 ha, and about 30% is constituted by impermeable surface; the downstream part of this basin is characterized by the presence of the complex of buildings and road infrastructure related to the Engineering Departments of the University of Calabria (Unical), while the upper part is mostly natural.

The Urban Hydraulics Park, for the sustainable management of stormwater, is composed of several solutions related to BMPs and LIDs, such as a green roof, a permeable pavement, a bioretention cell and a conventional treatment plant, consisting of a tank sedimentation and a filtration unit arranged in series. The park is also equipped with a complex system of monitoring and data acquisition can acquire real-time and continuously, information on climate parameters, hydrologic, hydraulic and water quality of urban runoff. The experimental green roof of extensive type, is divided into four sectors, hydraulically independent, each with an area of approximately 50 m² and a slope of 1%. The stratigraphy consists in: waterproofing membrane antiroot, mechanical protective layer of the state.
antiroot, integrated layer drainage/ ventilation/accumulation, filtering layer, state culture, plant essences (Carbone, Garofalo, Nigro, & Piro, 2014a).

The permeable pavement was carried out on a portion of about 380 m² within a pre-existing area parking, with an overall extension of approximately 2,700 m². The experimental installation is divided into two parts: the first, of about 150 m², is bound to permeable pavement; the second part, with bitumen paved, extends 230 m² and was left impermeable for the comparison of the superficial outflows between the two different types of flooring. During intense events, automatic samplers for the collection of samples for the qualitative characterization of surface runoff and sub-surface waters (Piro, Carbone, Nigro, & Garofalo, 2015).

The bioretention cell is installed downstream of the impermeable portion of the permeable pavement; runoff that forms on the impermeable side of the parking area is collected in a channel, measured, and finally discharged into the bioretention cell through a trench in gravel specially crafted. The comparison between the flow rate of runoff input to the bioretention cell (monitored with a device weir), and the output (conveyed in a final delivery cockpit, instrumented for the measurement of sub-surface flow), allows you to monitor the quality of filtered water and the hydraulic efficiency of the work.

The last experimental installation of the Urban Hydraulics Park is the treatment plant consists of a sedimentation tank and a filtration unit; these are among the traditional treatment systems, which are used in the urban environment in order to reduce the polluting substances present in the stormwater, such as particulate material (MP), nutrients, hydrocarbons and heavy metals (Piro, Carbone, Garofalo, & Samsalone, 2009). Downstream of the treatment by sedimentation, operated with the tank, the filtration unit is installed, which is responsible for handling requests for smaller size particles (diameter < 20 mm) escaped the primary sedimentation (Le Coustumer, Fletcher, Deletic, Barraud, & Lewis, 2009; Piro, Carbone, & Garofalo, 2010). The filtration unit is used to remove part of the pollutants of stormwater runoff, such as MP, organic matter, hydrocarbons and heavy metals. The filtering layer is constituted by a layer of polyurethane, with the function of blocking the light coarse material escaped the previous sedimentation treatment, and a second part consisting of agricultural processing waste material -that mainly influences the operation of filtration and makes the only system of its kind (Carbone, Garofalo, Nigro, & Piro, 2014b) - with the function of filtration of smaller particles, it is not retained by sedimentation. The research carried out confirm that, among the types LIDs, the green roof and the permeable pavement appear to have considerable potential for dissemination. The green roof analysis, located on the cover of the Cube 46/C of Unical, is carried out with reference to the sector 1, whose stratigraphy (Figure 1), from the bottom upwards, is listed below:

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

Figure 1. Green roof stratigraphy.
The stratigraphy of the permeable pavement of the Hydraulics Urban Park of Unical (Figure 2) proceeding from the bottom upwards, is as follows:

- geotextile,
- sand with Anti-puncture function of the underlying geotextile,
- gravel for drainage with a larger diameter grains,
- gravel for drainage with a smaller diameter grains,
- geotextile,
- mixture composed of traditional sand, glass sand and zeolite,
- Porous paving (concrete).

4. Results
Scores are assigned in reference to the LCA normalized output values, evaluated with respect to the total contribution of climate change on the global assembly of the stratigraphy. The analysis is based on this damage category for two reasons:

1. an overall assessment shows a higher impact associated to climate change compared to the other damage categories (Figure 3),
2. seeing that the climate change mitigations effect of the LID is known (Zahmatkesh, Burian, Karamouz, Tavakol-Davani, & Goharian, 2014), is evaluated if a LID, in the life cycle of constituent materials, preserves the Low Impact characteristic.

Below is an overview of LCA impact assessments for each green roof layer and permeable pavement. Impacts are expressed as a percentage (percentage impact of each individual layer of the total impact of climate change on the globe stratigraphy). The stratigraphy of the sector 1 green roof is evaluated as follows:

4.1. Score determination for ARB
The environmental cost of such a layer, referred to climate change, 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 realization of the
product. 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.

4.2. Score determination for WSL
The environmental cost of such a layer, referred to climate change, is approximately equal to 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.

4.3. Score determination for DL
The environmental cost of such a layer, referred to climate change, is approximately equal to 18.7%. This value represents the highest value in the stratigraphy of the green roof sector 1. The impact associate to polymeric materials, also present in WSL and FL, is due to production processes specially the energy costs. This aspect is also linked to the 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.

4.4. Score determination for FL
The environmental cost of such a layer, referred to climate change, is approximately equal to 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.

4.5. Scores determination for CL and VL
The environmental cost of such a CL layer, referred to climate change, is approximately equal to 13.8 and 13.5% for VL layer. Compared to previous layers, these have very low impact values linked to the remaining damage 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 CL layer with respect to the materials constituting the previous stratigraphy. The sum of the products of score and weight given to each layer indicator parameter, allows the evaluation of the SSI of green roof:

\[
SSI = A_{RB} A_{RBw} + DL_{DLw} + WSL_{WSLw} + FL_{FLw} + CL_{CLw} + VL_{VLw} = 0.11
\]

Scores are assigned in reference to the LCA normalized output values, evaluated with respect to the total contribution of climate change on the global assembly of permeable pavement stratigraphy.
4.6. Score determination for IGT
The environmental cost of such a layer, referred to climate change, is approximately equal to 14.6%. This value is lower than only to the percentage of Resources category. Specifically, the production of this type of polymer materials is almost entirely related to the impact Carginogens, being harmful to human health. A considerable contribution is related to road transport and the use of non-renewable energy.

4.7. Score determination for PL
The environmental cost of such a layer, referred to climate change, is approximately equal to 10.9%. This is not the traditional sand, indeed this value is second only to the percentage of the Resources category. This is not the traditional sand, this figure is second only to the percentage of Resources category damage. This will determine the greater contribution compared to compound layers from material found in nature, due to the processing technologies and therefore the energy use. Also in this case it is evident the emissions contribution associated with road transport.

4.8. Scores determination for SBL and BL
The environmental cost of such a SBL layer, referred to climate change, is approximately equal to 6.8%, the same value is obtained for the BL layer. These layers, analogues for structural composition, exhibit very low impact values related to all damage categories. Higher values are associated with the climate change and Resources categories. Being materials found in nature is justified to associate the environmental cost mainly to the transport phase on the road by lorries, whose energy class is not particularly competitive. The effect due to this aspect is greater because greater volumes are required for the transport of these materials compared to those that make up the previous stratigraphy.

4.9. Score determination for GT
The environmental cost of such a layer, referred to climate change, is approximately equal to 14.7%. Being polymeric materials, the previous impact category is only comparable to the Resources category, as opposed to Human health and Ecosystem quality which have significantly lower contributions. The environmental costs associated with such layer are related to the use of non-renewable energy, the functional phase “from cradle to gate” of material. A considerable contribution is related to road transport.

4.10. Score determination for BDL
The environmental cost of such a layer, referred to climate change, is approximately equal to 34.8%. Percent of this can be compared with the output of the other damage category, except for Ecosystem quality. The impact is due to the extraction mechanisms of zeolite and to the transport phase on the road by lorries, whose energy class is not particularly competitive. Useful is to specify that it is a layer consisting of three phases: traditional sand, glass sand and zeolite. A drive up the percentage of impact contributes in large part the zeolite used, which comes from Australia.

4.11. Score determination for WL
The environmental cost of such a layer, referred to climate change, is approximately equal to 11.2%. Percent of this can be compared with the output of the other damage category, except for Ecosystem quality, which registered one of the lowest percentages of the average. This value settles approximately on average for this stratigraphy, indeed, is dependent on the concrete processing techniques forming the roach. Even in this case the transport requires larger volumes with impact on the final impact percentage. The sum of the products of score and weight given to each layer indicator parameter, allows the evaluation of the SSI of permeable pavement:

\[ SSI = WL_w + BDL_w + GT_w + BL_w + SBL_w + PL_w + IGT_w = 0.10 \]

The LCA analysis results, referred to climate change, among these LIDs are illustrated synthetically from the underlying histograms (Figure 4).
5. Discussion

The LCA application has highlighted that there are substantial contributions also for the layers consist of natural material (sand, gravel), which have an impact on the total due to the use of transport type on the road. Observing the two histograms (Figure 4) it can see the peak level associated with BDL layer. It may be noted, moreover, that the life cycle of polymeric materials is equal for both LIDs, certainly due to non-renewable sources of energy supply (this aspect show the importance of Resource Damage Category in Figure 3) and types of transport by lorries whose energy class is not particularly competitive. A confirmation of this fact is to be observed that the contribution of carbon dioxide, due to the gas emissions, has a higher percentage than the other emissions from methane and dinitrogen monoxide (Figure 5).

This observation fully justifies the relevance of climate change on the others damage categories of the method used. It is well known in the literature that low environmental impact infrastructures counteract CO₂ emissions in the air (Demuzere et al., 2014; Ismail, Samad, Rahman, & Yeok, 2012; Nordbo, Järvi, Haapanala, Wood, & Vesala, 2012). For this reason, it is interesting to evaluate the sustainability of their life cycle through the LCA to quantify the impact in terms of kg CO₂ into air. Possible advances can be the calculation of the difference between CO₂ entering the atmosphere associated with the life cycle and the CO₂ extracted from the atmosphere following the operational phase of these infrastructures. This estimate will enable the effective sustainability of the LIDs related to the interaction between inbound and outbound CO₂ flows to be precisely defined.

Compared to other studies in the literature (Table 1), the methodology proposed in this paper emphasizes the structure of LIDs whose functionality is mainly related to stratigraphy. Using a single stratigraphic volume, the environmental cost of climate change linked to two different types of LIDs was assessed making an only the Global Warming impact category. Unlike what is in the literature, the SSI index does not require a comparison of alternatives of the same type, but it compares
different solutions (green roof and permeable pavement) that share a similar purpose related to the nature of LIDs.

The showed LCA analysis has specific validity for the case study and therefore does not allow absolute evaluations. This evaluation has constituted a valid basis for the SSI formulation, especially for the possibility of using, as input, the reliable data coming directly from the experimental sites of the Unical. The synthetic indices obtained for the two LIDs are excellent methods of evaluation between design alternatives, because allow to choose the best solution based on environmental consideration. The SSI index, used as an estimate of the LIDs sustainability, allows to identify the most economically advantageous design solution relatively to environmental costs, highlighting any critical issues related to the life cycle of the constituent materials. The numerical comparability between the calculated SSI indices shows that the analyzed LID infrastructures are green technologies that adequately reflect the Low Impact aim.

6. Conclusions
The use of LIDs in urban contexts contributes to the fight climate change effects and improves water runoff management. To quantify the sustainability of a LID infrastructure and to have analytical support in choosing alternative projects, it is used the SSI based on the LCA methodology. This index includes environmental (LCA) and hydraulic-hydrological (runoff coefficient) considerations. To synthesize the environmental aspect, the life cycle analysis of the materials present in each layer of the two LIDs was used. The synthesis of hydraulic-hydrological efficiency is done by estimates on the runoff coefficient supported by information on the water retention capacity of each layer.

This index able to compare the life cycle sustainability of materials that made the green roof sector 1 and permeable pavement at University of Calabria. The proposed methodology is based on simple analytical considerations but is capable of providing expeditious support in evaluation technical. An intrinsic benefit linked to this paper is the utilization a method to obtaining an approximate estimate of the climate change associated to the analyzed processes. In order to obtain a more reliable estimate, it is envisaged to advance the research to calculate the difference between the CO₂ extracted and returned in the air. In this perspective, the SSI index is a valid indicator of limit scenarios because it selects potentially critical design solutions through a conjunct interaction between sustainability and efficiency.

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