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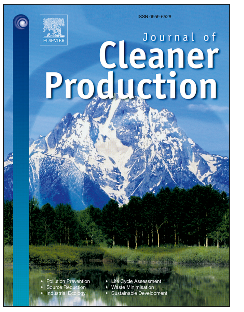

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Cradle-to-gate life cycle assessment of traditional gravel ballasted, white reflective, and vegetative roofs: a Lebanese case study

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Abstract

Lebanon, a Mediterranean country, lacks a clear sustainability plan as well as an infrastructure update and management, leading to road flooding, especially in urban areas. Therefore, the installation of Vegetative Roofs (VRs) could be an interesting option for Lebanon. To evaluate if VRs are truly superior to Traditional Gravel Ballasted Roofs (TGBRs) and White Reflective Roofs (WRRs), a cradle-to-gate Life Cycle Assessment (LCA) was performed. Potential environmental impacts of an existing Extensive Green Roof (EGR) were compared to three fictitious roofs of the same area: TGBR, WRR, and Intensive Green Roof (IGR). The functional unit used for comparison was: "providing a cover for a surface area of 834 sqm and for 45 years". Specifications of TGBRs and WRRs were provided by local technicians and civil engineers. Furthermore, specifications of VRs were provided by the United Nations Development Program (UNDP), Country Energy Efficiency and Renewable Energy Demonstration for the recovery of Lebanon (CEDRO) project. The SimaPro software and Ecoinvent library were used to model the systems considered. Results clearly indicated that EGR was the best option for all environmental impact categories. Rebar, concrete, and thermal insulation were the main contributors to the environmental impacts for TGBR, while rebar, concrete, thermal insulation, and waterproof membrane were the highest contributors for WRR. Sensitivity and uncertainty analysis were also performed to verify the robustness of the results.

Keywords: Life Cycle Assessment, vegetative roofs, reflective roofs, traditional roofs, Lebanon.

Introduction

Vegetative Roofs (VRs), also termed as garden roofs, are "roof systems that promote the growth of plants on rooftops" **[1]**. In addition to embellishing the roof surface, VRs offer many advantages. They protect the roof assembly from solar radiation and hail damages, hence lowering its temperature and reducing temperature fluctuations in spaces underneath it ranging from 1 to 3 floors **[2]**. Another advantage of VRs is the reduction of the building energy consumption through direct shading of the roof, evapotranspiration, and improved insulation values **[3, 4]**. If installed on broad surfaces, VRs might also attenuate the urban heat island effect **[5]**, which would decrease the energy consumption in urban areas **[2]**. From a water management perspective, VRs capture a fraction of the rainwater through their growing medium in order to be used by the plants and then returned to the atmosphere through the evapotranspiration process **[6]**. Therefore, these types of roofs can reduce water runoff and help manage flooding during heavy rain in urban areas **[7, 8]**. Many studies showed the influence of VRs on stormwater retention in different regions in the world **[9-13]**. Furthermore, the vegetation layer could remove airborne pollutants picked up by rain, thus improving the quality of the runoff **[14, 15]**.

The installation of VRs in Lebanon, a country in the Middle East, could be an interesting option, as the country lacks a clear sustainability plan as well as an infrastructure update and management, leading to road flooding in urban areas, amongst other things such as the electricity deficit and continuous need for heating/cooling systems **[16-18]**.

In addition, the installation of VRs could help manage flooding, which is also a major problem in Lebanon. The increase in concrete and asphalt surfaces, especially in urban areas, prevents the storm water absorption, which leads to roads flooding. This water picks up pollutants such as oil, heavy metals, and animal waste, and transports them to the underground water **[19, 20]**. VRs could help overcome this issue since the growing medium, vegetation, and drainage layer trap and store precipitation. In particular, the water can be used by the plants during drought periods or can undergo evapotranspiration. Also, the trapping process takes some time, which delays the drainage of rainwater compared to traditional roofs or any other impermeable surface **[21]**.

So far, only a total of five Green Roofs (GRs) have been installed in Lebanon. The one occupying the largest surface area is an Extensive Green Roof (EGR) installed at the Central Bank of Lebanon (834m^2). To determine if VRs are effectively superior to Traditional Gravel Ballasted Roofs (TGBRs) and White Reflective Roofs (WRRs) for Lebanon from an environmental perspective, the Life Cycle Assessment (LCA) methodology is selected. Based on the International Organization of Standardization (ISO 14040:44) LCA is an international