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Life Cycle Assessment of a Sustainable and Innovative Solution for Unpaved Rural Roads †

Leonardo Urbano [1], Lucia Tsantilis [1,*], Pier Paolo Riviera [1], Orazio Baglieri [1] and Ezio Santagata [1,2]

1 Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy; leonardo.urbano@polito.it (L.U.); pierpaolo.riviera@polito.it (P.P.R.); orazio.baglieri@polito.it (O.B.); ezio.santagata@polito.it or ezio.santagata@qu.edu.qa (E.S.)
2 Department of Civil and Architectural Engineering, Qatar University, Doha 2713, Qatar
* Correspondence: lucia.tsantilis@polito.it
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Abstract: The use of recycled aggregates, including waste materials and by-products, has attracted increasing interest in the last decades as a sustainable and cost-effective solution for the construction and maintenance of road pavements, due to the reduction of excavation operations and depletion of natural resources. Life cycle assessment (LCA) represents a valuable methodology for the evaluation of the environmental sustainability of technologies involving the use of such materials. This paper deals with the LCA of an innovative emulsion-based cold recycled mixture specifically conceived to be used as a sustainable solution for the surface finishing of unpaved rural roads. Two scenarios entailing the employment of recycled or virgin materials were analyzed with the assessment of global warming potential (GWP), energy requirement, and water consumption. Results obtained confirmed that the scenario entailing the use of recycled materials represents the most sustainable and environmentally friendly solution.

Keywords: life cycle assessment; sustainability; reclaimed asphalt; mineral sludge; unpaved roads; rural roads

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1. Introduction

The growing concerns regarding environmental issues and climate change have led the pavement construction industry to move towards increasingly sustainable solutions to preserve natural resources [1]. In this context, the recycling of by-products in paving mixtures represents a valuable option since it allows for the replacement of large volumes of virgin aggregates, thus contributing to reducing the depletion of raw materials [2–4]. The recycling of by-products appears to be especially suitable for rural roads, for which lower performance is generally required compared to high-volume highways and arterials [5].

Reclaimed asphalt pavement (RAP), obtained from the milling of existing asphalt pavements, and mineral sludge (MS), derived from industrial washing of natural aggregates in crushing plants, may be effectively used as alternative aggregates in the construction of pavement layers due to their large availability and problems faced in their stockpiling and/or disposal [6–8]. In fact, a previous research study conducted by the authors showed that RAP and MS can be successfully employed in large quantities in the production of emulsion-based cold recycled mixtures (CRM) for the surface finishing of unpaved rural roads [9].

In this paper, the environmental benefits related to the use of CRM were assessed using the life cycle assessment (LCA) methodology. To this purpose, the global warming potential (GWP), energy requirement, and water consumption related to the production, construction, and maintenance stages of the innovative mixture were analyzed and compared to a reference in which the use of only virgin materials is considered.

2. LCA: Scenarios and Results

Figure 1 shows the cross sections (4.50 m width and 30 cm thick) corresponding to the two different scenarios compared based on LCA.

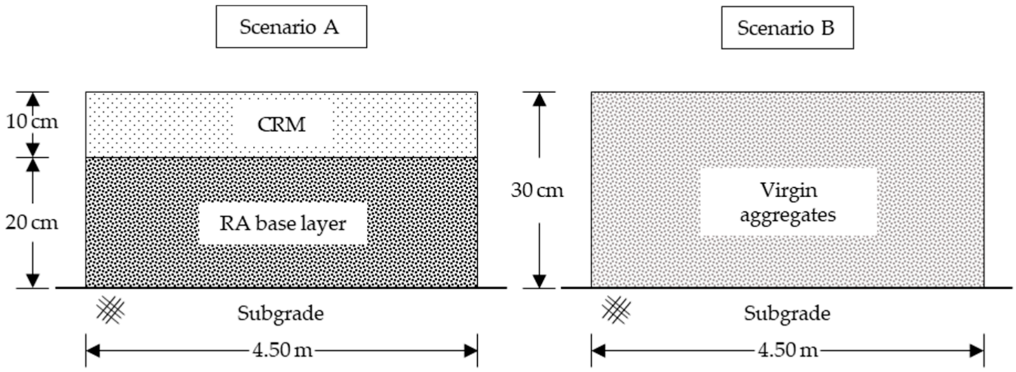

Figure 1. Cross-sections corresponding to the considered scenarios.

Scenario A refers to the innovative proposed solution consisting of a 20 cm thick RA base layer covered by a 10 cm thick CRM finishing surface layer. Scenario B refers to the typical solution currently adopted in northern Italy for low-volume unpaved rural roads, consisting of a single 30 cm thick crushed virgin aggregates layer.

The LCA was performed using the PaLATE tool, properly customized in order to account for the reference geographic context analyzed in the present study. The system boundaries included materials production, construction, and maintenance operations, according to a cradle-to-gate approach. The in-service phase was kept out of the analysis, due to its negligible impact in comparative terms and uncertainty in the forecast of traffic spectra. The end-of-life phase was also excluded from the system boundaries since all materials have the potential to be fully reclaimed without requiring landfill disposal. The functional unit consists of 1 km of road with a service life of 10 years.

The life cycle inventory was based on both primary and secondary data. Primary data were collected through interviews with local companies, while secondary data were collected from the available literature [10–13]. The inventory of equipment and trucks employed in the production, construction, transportation, and maintenance activities (Table 1) was based on primary data, while emission factors were obtained from the literature.

Table 1. Equipment and trucks considered in the analysis.

Equipment/Trucks	Activity
Crushing Plant	Crushing of virgin aggregates
Mobile Crushing Device	Crushing of RA
Wheel Loader + Blender	Production of CRM
Dump Trucks	Transportation of granular material
Tanker Trucks	Transportation of fluid material
Paver and Roller	Pavement construction

The analyzed impact categories were global warming potential (GWP), energy requirement, and water consumption.

The results of the analysis obtained for the two scenarios are given in Table 2. It can be highlighted that the adoption of the technical solution proposed for scenario A led to an overall reduction of the environmental burdens, which was particularly relevant when considering water consumption and GWP.

A comparison between these two solutions is also provided in a graphical form in Figure 2, where the relative impacts in terms of GWP, energy requirement, and water consumption values are expressed as a percentage of those found for reference scenario B.

Moreover, for each normalized impact, the relative contributions of materials production (MP), transportation (T), and construction/maintenance (C&M) phases are also provided.

Table 2. GWP, energy requirement and water consumption for scenarios A and B.

Impact	Scenario A	Scenario B
GWP (Mg of CO_{2eq})	18.7	24.0
Energy (MJ)	253,169	263,651
Water (m^3)	327	6701

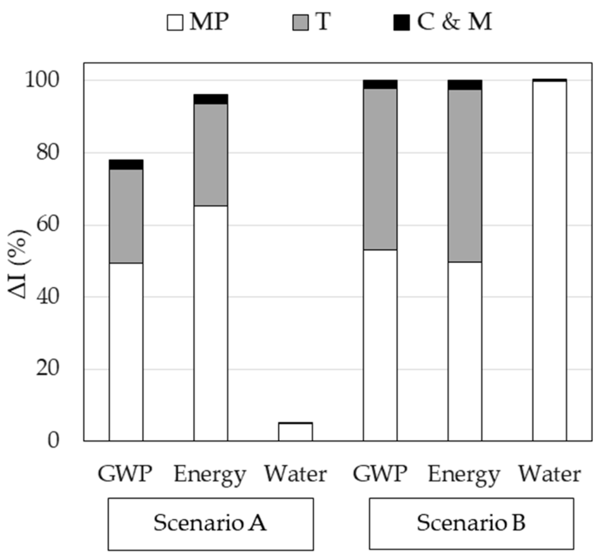

Figure 2. Normalized impacts (ΔI) of GWP, energy, and water expressed as a percentage of the results of reference scenario B, with relative contributions of materials production (MP), transportation (T), and construction /maintenance (C&M) phases.

It is interesting to observe that pavement construction and maintenance activities played a marginal role, as proven by contributions that were found to be always lower than 3%, regardless of the analyzed scenarios. The highest impacts were found to be those related to materials production. In particular, based on the comparison of the two solutions in terms of GWP and energy requirement, it was demonstrated that savings related to the use of a less amount of virgin aggregates were almost or totally offset by the innovative technical solution. This is due to the environmental burdens caused by the industrial production of the emulsion, the treatments of RAP, and the in-field preparation of CRM. On the other hand, relevant reductions in terms of water consumption were yielded by the dramatic decrease in the use of virgin aggregates. When focused on transportation, it can be noticed that the technical solution proposed in scenario A produced a reduction of more than 40% in the GWP and energy impact categories. Such a significant saving can be attributed to the use of in-place recycled materials that required fewer transportation distances with respect to solutions based on the use of virgin aggregates, as well as by the lower maintenance activities that are needed when bitumen-bound materials are used for wearing courses.

3. Concluding Remarks

In the present study, the environmental performances of two technical solutions for low-volume unpaved rural roads were evaluated and compared using LCA.

It was observed that the most critical stages are those related to materials production and transportation, while negligible impacts derive from construction and maintenance operations.

The outcomes of this LCA demonstrated the benefits, in terms of environmental impacts, associated with the considered innovative solution. Based on the assessment of GWP, energy requirement and water consumption related to materials production, transportation, construction, and maintenance operations, the proposed solution (which entails the use of large quantities of RAP and MS) outperformed the reference solution currently adopted for unpaved rural roads in northern Italy.

Further studies are certainly needed to extend the analysis to other impact categories and to widen the system boundaries.

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