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Environmentally appraising different pavement and construction scenarios: A comparative analysis for a typical local road

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ABSTRACT

The aim of this work is to carry out a comparative analysis of environmental impacts for different scenarios of a typical local road. Life Cycle Assessment (LCA) is the modeling tool used to quantify and characterize comparative environmental impacts. In carrying out this specific application of the LCA, different road construction techniques were considered with regards to the whole structure and compared in order to identify the best alternative in terms of environmental sustainability.

So far, in fact, typical LCA frameworks of roads have focused on recycled materials for pavement layers only, thus neglecting study of the materials used in the embankment or in the subgrade. In this study, these materials were included too, in order to prove the environmental benefit of using a sustainable technique such as in situ stabilization of fine soils with lime (typically dumped clayey soils) in order to reduce the need for virgin material for embankment and subgrade construction.

When using different percentages of recycled materials (such as reclaimed asphalt pavement – RAP) in the bituminous layer or in the foundation, the analysis of the functional unit studied shows a significant reduction of energy consumption and pollutant emissions mainly due to transportation of materials involved, in this way increasing the environmental performance of the road.

Another important consideration is that the use of fine soils stabilized with lime "in situ", instead of dumping it, not only is a good technical solution for improving soil mechanical properties, but it also produces a reduction of energy consumption and of pollutant emissions. It is noticeable that this technique results in a significant reduction of pollutant emissions due the transportation of involved materials, increasing the environmental performance of the road.

Introduction

Transportation infrastructures represent key elements for characterizing the level of development (Herranz-Loncán, 2007; Rietveld, 1994) and welfare (Knaap and Oosterhaven, 2011) of a given country. Although balance and coordination

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among different transportation means are normal concerns of planners (Sonstegaard, 1992), roads must be considered leading components of transport infrastructures, since they are responsible for a remarkable portion of the whole mobility of people and freights.

With increasing concern about planet environmental constraints, transportation scenarios are turning toward greener features (Girod et al., 2013) This is very evident in approaches to road design, maintenance and management (Fürst and Oberhofer, 2012; Oxley et al., 2012). This new concern has also resulted in a large number of researches and studied devoted to evaluate the environmental impact of road infrastructures (Barros et al., 2013; Mayer et al., 2012) mainly based on classical or hybrid LCA approaches (Eriksson et al., 1996; Huang et al., 2009b; Milachowski et al., 2011; Santero et al., 2011b, 2011c). More general visions are also considered in the assessment of the pressure exerted by roads on the natural environment, ranging from climate change analyses (Stanley et al., 2011), to ecosystem preservation, with frequent attention to sustainability footprint impacts (Amekudzi et al., 2009).

However, due to the intrinsic complexity of such analyses, the role of materials constituting infrastructures and their maintenance is usually separated from evaluations regarding the impact of vehicles moving on them. Some studies try to approach the question in an integrated way, introducing the need to include the supply chain in the analysis of passenger transportation or providing an LCA analysis (Milachowski et al., 2011; Mroueh et al., 2001) of a generic motorway with a hypothetical traffic flow of cars and heavy goods vehicles affected by standard fuel consumption, considered as the European average for this kind of vehicles. However, these studies do not take in account the effects of the traffic delay induced by maintenance operations (Santero et al., 2011a) and do not properly consider emissions from the vehicles for which the roads have been designed and realized in a given territorial and traffic context.

Currently, contractors, policy planners and road management organizations are interested in reliable but manageable methods for assessing the overall environmental pressure exerted by roads in their operative configurations, that is taking into account the impact of materials for road construction, operations related to the maintenance and emissions from the vehicle flow. This approach could enable policy-makers to compare different scenarios at the design stage and/or introduce remediation actions that could suitably modify the overall environmental performances of road infrastructures.

On the other hand, when undertaking an environmental impact assessment analysis of such infrastructures there is often scarce availability of primary data concerning the embodied energy pertinent to and the pollutant emissions released by the materials constituting the analyzed roads. The fact is that these material could either be absent in the current database on which the LCA procedures rely or refer to working chains that are significantly different from those of the materials involved. For example, a frequent case is that of materials for which data have been obtained in other countries with different operations concerning the extraction, production and transportation phases.

With the aim of making a contribution to overcoming these problems, in this work an integrated method of evaluation of the whole impact of road infrastructures is proposed that, in addition the materials constituting the infrastructure and the maintenance operations, at the same time accounts for the traffic flow foreseen in the design phase for the road considered. Pollutant emissions are computed on the basis of the European defined categories of vehicles (in the Corinair database) (Eggleston et al., 1991).

Moreover, for evaluating the impact of materials for which databases are lacking, an indirect method of evaluation is proposed, based on the amount and types of energy sources involved in the working chain of these materials.

In this way, an eco-profile of the operative conditions of roads is drawn, constituting the integrated parameter of the whole environmental performance of the considered road.

Methodology

The environmental impact of a road is measured by the aggregation of impacts over its life cycle, beginning with extraction of raw materials and culminating in various end-of-life scenarios (Santero, 2010).

This work aims at quantifying the environmental impacts of a typical Italian rural road using an LCA methodology according to ISO 14040 and ISO 14044 (ISO, 2006a, 2006b). By definition, an LCA study comprises four phases which affect one another (Fig. 1): goal and scope definition, inventory analysis, impact assessment and interpretation.

The goal and scope definition determines the guidelines to be followed during the rest of the study by specifying the reason for conducting the study, the intended use of the results, intended audience, the system boundaries, the functional unit, the data requirements and the study limitations (Vidal et al., 2013). In the inventory analysis (LCI) all the inputs (energy and resource requirements) and the outputs (environmental emissions) are collected and defined. In the assessment phase, the environmental effects of the system components are assigned to different impact categories. In the final phase the results are interpreted and evaluated in order to obtain deductions and to provide some recommendations.

Different road construction techniques (with regards to both the pavement and the subgrade) were considered and compared in order to identify the best alternative in terms of environmental sustainability.

The scenarios analyzed includes road construction techniques based on the use of virgin material only, reuse of discarded materials (such as Recycled Asphalt Pavement, RAP) as well as in situ stabilization with lime of fine-grained soils.

In particular, lime stabilization of clayey soils (otherwise unsuitable to be used for construction purposes) was selected for this study since it is not only a good technical solution for improving soil strength and stiffness properties (Celauro et al., 2012a, 2012b), but, due to the volumes of material involved in construction, maintenance and rehabilitation of