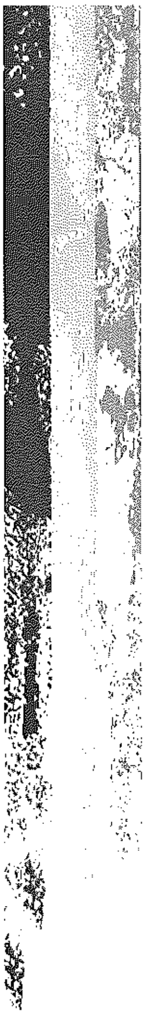

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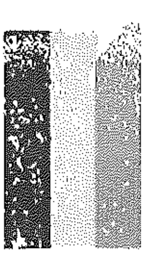

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ASSESSING THE ENVIRONMENTAL IMPACT EXERTED BY ROADS IN "OPERATIVE" CONDITIONS - A HIGHWAY CASE-STUDY

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ABSTRACT

The work arises from the consideration that the environmental impact of a road cannot be limited to the analysis of materials constituting it, even if correctly analyzed in their life cycle, because roads are designed mainly to accomplish well-established requests of transportation demand of people and freights. These considerations must be properly taken into account, when analysing the environmental performance of the road infrastructures, by properly accounting for the vehicles' pollutant emissions.

On the other hand, a given road is comprised of the pavement and subgrade; it also includes several different components and accessories (e.g. road marking, drainages, safety barriers, etc.) that contribute to set a road infrastructure in operative conditions. As a matter of fact, apparently, unlike pavement materials and traffic flow, only a limited attention has been paid in the scientific literature to roadside components. In the present work the environmental pressure of these components, and especially safety roadside installations (i.e. guardrails), is presented and critically compared with the one exerted by pavement materials and traffic flow, in order of establishing their relative contribution. To accomplish this task, an application referring to a segment of a typical Italian highway is proposed.

By means of the inclusion of the other accessories, a general assessment of roads can be achieved, that is more useful for administrations for better matching the current sustainability standards and guidelines.

INTRODUCTION

Transportation scenarios are turning toward greener features [1, 2, 3] due to the increasing concern about the planet environmental constraints. This is well evident in roads design, maintenance and management [4, 5] approaches.

In any case, more comprehensive perspectives are needed in the assessment of the pressure exerted by roads on the natural environment, that range from the climate change analyses [6], to the ecosystem preservation [7], with a constant attention to the sustainability footprint impacts [8, 9].

The life cycle assessment (LCA) approach [10, 11] is recognized and accepted as one of the most effective tools for correctly assessing the potential burden exerted on the environment by roads infrastructures and transportation systems [12], since it avoids misinterpretations deriving from a time and space limited analysis of this sector [13].

Actually, contractors, policy planners and road management organizations are interested in having reliable but manageable methods for assessing the overall environmental pressure exerted by roads in their actual configurations, that are also able to take into account the impact of materials used for the road construction, the operations related to the maintenance and the emissions released by the actual vehicles' flow. This approach could enable policy makers to compare different scenarios in the early design stages and/or introduce remediation actions for suitably modifying the overall environmental performance of road infrastructures.

Talking of overall environmental pressure exerted by roads in "operative conditions" (i.e. when the road equipped with all of the accessories and therefore ready to be used), it might be regarded as determined by the concurrent pressures exerted by the road infrastructure, the traffic flow and the road components (i.e. safety installations, etc.), despite the scientific literature seem to be interested in analyzing only the first two issues.

Clearly, other calculation components such as all the functions needed for operating the infrastructure (such as cleaning, salting, trim hedge, for example) could be considered as well in this aim. Anyway, it was decided to limit the analysis to only the three above mentioned.

Starting from these considerations, in this work the environmental impact of a typical road safety component, i.e. the guardrail, is investigated. Its environmental effects are also compared with those produced by the road pavement and the traffic flowing in the same road.

Road infrastructure

Generally, road infrastructure is comprised of pavement and subgrade. As regards the pavement, its construction and maintenance are the main concerns of environmental studies present in literature [14, 15, 16, 17, 18, 19] in which the importance of a life cycle approach has been pointed out. Clearly, asphalt and concrete pavements are mostly investigated because they are subjected to a higher wearing compared with the one of the deeper road's layers (subgrade).

The use of recycled materials has also received an increasing attention [13] due to their importance in limiting the environmental pressure exerted by such infrastructures: the use of secondary materials, in fact, avoids the recourse to primary materials and therefore prevents their depletion. It is relevant that such approaches pay a specific attention to the transportation of materials because, not rarely, noticeable distances are involved that imply significant pollutant emissions.

Traffic flow

The traffic emissions released by the vehicles' flow [20] represent one of the most important components of the environmental impact of roads. Several analyses and methods have been produced [21, 22, 23] for assessing the vehicles' emissions, depending on their age, volume capacity, type of fuel and mean velocity. Clearly, the application of these comprehensive methods requires the knowledge of detailed data concerning the fleets of running vehicles and their yearly change.

In addition, the effect produced by the road's maintenance activities on the disrupting of the traffic flow, along with the involved increases of the pollutant emissions is another important element to consider [24].

Road components

Apparently, unlike pavement materials and traffic flows, only limited attention has been paid in the scientific literature to roadside components, despite their importance in setting a transport infrastructure in "operative" conditions. In addition, the current roadside components-related literature is mainly aimed at the selection of materials that are the most suitable in reducing the environmental impact for realizing a given component. Within this context, pavement marking [25], streetlights [26] and highway guardrails [27] have mainly been investigated. In other words, the road equipment has been analyzed as a separate element, and not in comparison with the road pavement, thus missing the general perspective of the environmental impact of transport systems.

On the contrary, in the present work the environmental pressure of components will be evaluated and compared with the pavement materials, to establish their relative contributions. The result will be useful to rank the most significant elements of roads in light of a sustainable management of transportation systems. By this point of view, this work tentatively provides a contribution for a simple but reliable environmental assessment of roads, in their "operative" conditions.

CASE STUDY

The case study concerns the Italian Highway A20 belonging to a new two levels road intersection, which was planned near the municipality of "*Gioiosa Marea*", in Sicily. The pavement is made of asphalt and not concrete as the majority of the Italian roads. For the road section under analysis, the Average Annual Daily Traffic (AADT) value, which was obtained by means of a traffic survey, is approximately 13,600 veh/day [28].

To ensure reasonable levels of protection against serious ran-off-road crashes, in accordance to an Italian decree [29], proper lateral and median guardrails, denominated "H4", have been installed (see Fig. 1).

The study presented here was developed by considering a 20 years period of utilization of the infrastructure. Although this assumption clearly represents a conventional hypothesis, it still allows to catch the effects produced by the main three elements here considered, i.e. pavement, traffic and safety barriers. In fact, in a period of 20 years the wearing course will reasonably have to be replaced by utilizing the same materials and working techniques; the fleet of vehicles will obviously change, but some reliable estimations concerning its composition and its modal changes can be assessed, safety barriers will have to be substituted because of the possible crashes produced by statistically-evaluated accidents that will occur in the analyzed segment of the road.

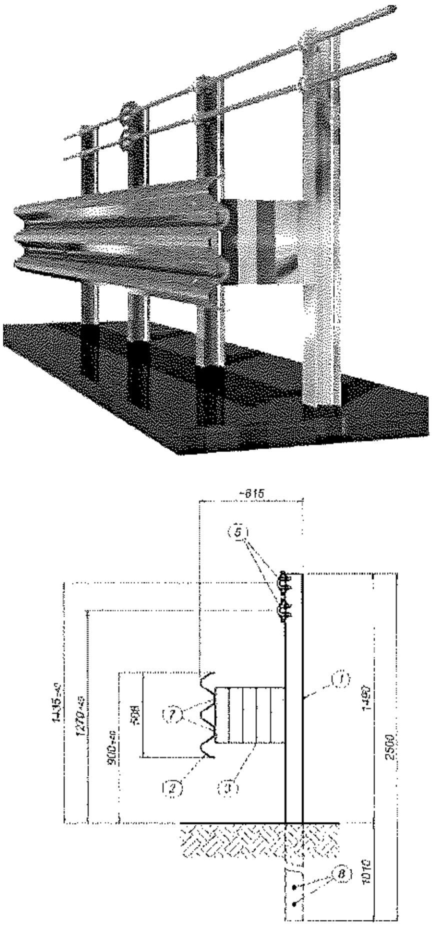

Fig. 1 –*Sketch of the guardrail under analysis*

It is remarkable that in this study 20 years do not represent the lifespan neither of the road nor the guardrail under analysis.

In Fig. 2 the production, replacement and maintenance operations hypothesized in the selected observation period, are reported.

In this study, a classical Life Cycle Assessment (LCA) methodology was applied to assess the potential environmental impacts of a highway's guardrail and pavement. The LCA method is a well-known standardized procedure that consists of four steps: goal and scope definition, life cycle inventory analysis, impact assessment, and interpretation of results [10, 11].

Data used for this LCA study were evaluated using a well-known software, i.e. SimaPro©, v. 8.01 [30]. Primary data were used, but when they were not available, data needed for the LCA were obtained from the Ecoinvent database featured in SimaPro©. The potential environmental impacts were calculated through classification and characterization, and obtained using the Impact Assessment Method "CML – IA baseline V3.00/EU25".

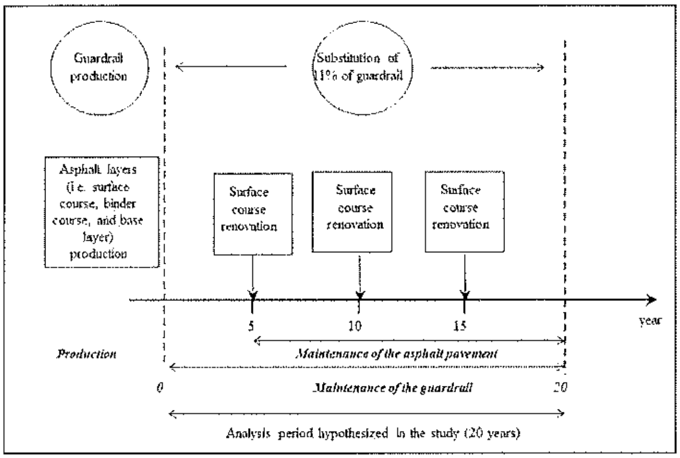

Fig. 2 –*Schedule for production and maintenance activities of guardrail and pavement.*

In the present study, we analyzed four main impact categories, in accordance with the Product Categories Rules (PCR) for the assessment of the environmental performance of UN CPC 53211 (highways and safety installation for roads) [31]. These impact categories, i.e. global warming potential (GWP), photochemical ozone creation potential (POCP), acidification potential (AP) and eutrophication potential (EP), allow to estimate and compare the burden exerted by each component of a road.

The additional environmental load due to the occupation of land by the road infrastructure during the considered analysis period was not included in the study.

Impacts exerted by the guardrail

The guardrail's typology was selected, on the base of three main parameters, i.e. daily average traffic, percentage of heavy vehicles, and typology of road. This is fully in accordance with the Italian standard concerning the definition of the typology of guardrail to be installed.

The functional unit selected here is defined as 1 km of guardrail.

The system boundaries for the LCA of the guardrail include raw material extraction, production, maintenance and transportation from the manufacturing plant to the construction site. As for the end of life, that is related to the material deterioration, it seems reasonable to assume that in 20 years the material preserves its properties. This implies that the analysis period selected does not correspond to the service life of the guardrail.

As for the production, it is made of zinc-coated steel; the steel product manufacture and the zinc coating process occur in the same plant. Data on the guardrail dimensions, amounts of materials and transportation distances from the manufacturing plants to the construction site, are specific to the case-study. Primary data on the energy consumption of the machinery used to install and dis-install the guardrail (i.e. a pole driver), were not available; therefore, they were not included in the study, although this could represent an underestimation of the environmental burden of this component.

As for the maintenance, generally, in Italy a guardrail during its service life, is being replaced when it loses its safety-aimed structural properties due to accidents.

In this study approximately 11% of the guardrail was assumed to be replaced in 20 years. This value was determined carrying out a statistical analysis on accidents that could occur in the highway's segment analyzed. The average number of annual encroachment frequency and their severity (2.2 enc/km/yr) have been estimated referring to the Cooper study [32, 33]. Then, the length of longitudinal safety barriers that need to be changed each year (22 m/yr) was appraised.

Another important assumption of the study is that 100% of the steel from the dis-installed guardrail is sent to recycling, while the zinc is supposed to be totally disposed, as it is allowed by the current technologies.

Results obtained in terms of pressure exerted on four relevant environmental impact categories, are reported in Table. 1.

Table 1 . Environmental impact of the guardrail (1 km)

Impact category	**Environmental indicator**	**Initial construction**	**Maintenance**	***Total***
GWP	Kg CO_2 eq	454,966,23	30,918,46	485,884,69
POCP	Kg C_2H_4 eq	204,619	11,155	215,774
AP	Kg SO_2eq	2.670,19	220,30	2,890,49
EP	Kg PO_4-eq	1.060,55	95,12	1.155,67

As observed in Table 1, during 20 years the initial construction phase (which includes here: raw material extraction, production of the finished product) is the largest contributor to GWP, POCP, AP and EP in respect to the maintenance. In fact, 0.94% of the GWP, 0,95% of the POCP, 0,92% of the AP, and 0,92% of the EP are caused by this life cycle stage.

In terms of process, the global warming potential, the photochemical ozone creation potential and the eutrophication potential are mainly related to the production of primary steel. In fact 254.000 kg CO_2eq (52%), 136 Kg C_2H_4 eq (63%), and 629 Kg PO_4-eq (54%) comes from this process. While the process to make a semi-manufactured steel product into a finished steel product contributes significantly to the acidification potential (1.190 Kg SO_2eq).

Impacts exerted by the road pavement

The functional unit chosen is defined as 1 km of highway, although other quantities could be indicated for a road, like the number of passengers per km.

The highway section is constituted by two lanes and an emergency lane (on each carriageway) for a total width of asphalt pavement of 21,00 m.

The system boundaries for the LCA of the road pavement include the raw material extraction, production, maintenance and transportation, being the disposal phase included in the maintenance one. The end of life of the asphalt pavement (reasonably 25 years), that could be either landfilled, recycled, or simply remain in place and serve as part of the underlying structure for another pavement layer [34], was not included in the study that refers to a period of 20 years.

The product system investigated accounts for the asphalt layers, i.e. surface course, binder course, and base layer. The subgrade is not included in this study (Fig. 3).

These three layers were assumed to be made of virgin materials (bitumen and aggregates). They are manufactured with hot mix asphalt (HMA), and each layer is characterized by different percentage of bitumen and aggregates.

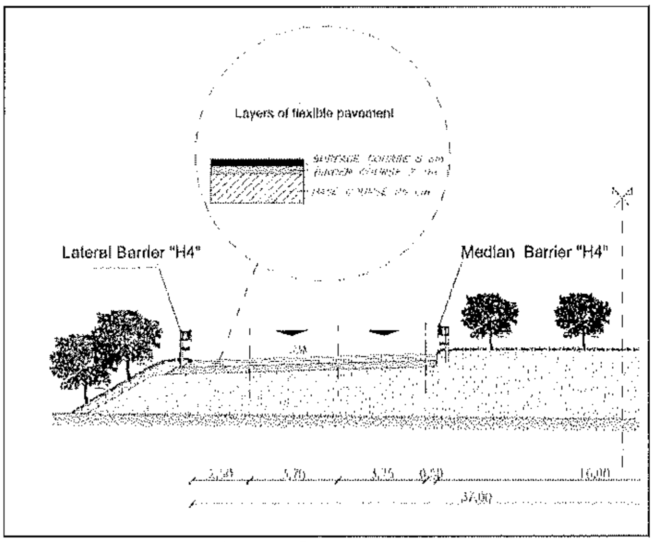

Fig. 3 –*A20 Highway semi-cross section*

The maintenance activities during the analysis period here considered (i.e. 20 years), involve only the surface layer: more specifically, this layer was assumed to be renovated three times in full through 20 years.

This assumption is based on the above-described working hypotheses (Mediterranean climatic conditions, traffic flows, and materials used), that lead to a lifespan of this layer of approximately 5 years. The pavement's maintenance consists of a whole dismissing of the materials constituting the rolling surface and their transportation in a landfill. Moreover, the replacement of the new surface is realized in this study by adopting virgin materials.

As regards the life cycle inventory of materials, primary and secondary data were used. Specifically, the amounts of materials and fossil fuel (diesel) involved in the construction of the road pavement, as well as the transportation distances from the manufacturing plants to the construction site, are specific to the case study. Input data related to the machineries used (i.e. pavers, bitumen sprayer, tandem rollers, machine) were obtained by summing the pertinent fossil fuel consumption.

Table 2 shows an overview of the results obtained from the pavement's LCA in terms of pressures exerted on the four relevant environmental impacts categories here considered.

Table 2 . Environmental impact of the road pavement (1km)

Impact category	Environmental indicator	Initial construction	Maintenance	Total
GWP	Kg CO_2 eq	1.110.172,32	736.350,78	1.846.523,1
POCP	Kg C_2H_4 eq	831,37	422,54	1.253,90
AP	Kg SO_2-eq	9.543,18	5.590,08	15.133,26
EP	Kg PO_4-eq	889,62	704,47	1.594,09

As observed in Table 2, during 20 years the production phase is the largest contributor to GWP, POCP, AP and EP in respect to the maintenance. In fact, 0,60% of the GWP, 0,66% of the POCP, 0,63% of the AP, and 0,56% of the EP are caused by this life cycle stage.

In terms of process, the global warming potential, the photochemical ozone creation potential, the acidification and the eutrophication potential are mainly related to the production of bitumen. In fact 824.000 kg CO_2eq (45%), 1.110 Kg C_2H_4 eq (89%), 11.300 Kg SO_2eq (75%) and 762 Kg PO_4-eq (48%) comes from this process.

Impacts exerted by traffic flow

Concerning the environmental impact of the traffic flow during the selected observation period, some hypotheses are needed about the change in the composition of vehicle fleet and the traffic volume.

The future increase in traffic volume, $AADT_n$, is simply calculated as shown in Eq. (1):

$$AADT_n = AADT_1 * (1 + i/100)^n \qquad (1)$$

where:

$AADT_n$ is the average annual daily traffic volume at the *n-th* year

$AADT_1$ is the average annual daily current or base yearly traffic volume

i is the annual percentage of traffic growth

n is the number of years in the life cycle.

The evaluation of traffic pollutant emissions has been carried out using the Copert IV© software [35]. The method takes into account several traffic and vehicular parameters, such as: vehicle age and engine volume, fuel, yearly mileage (km/year) and mean fleet mileage (km).

The methodology allows the calculation of the emissions affecting the considered impact categories.

With reference to the baseline year, the daily traffic volume $AADT_1$, the free flow speed, v, and the annual percent traffic growth, i, were estimated to be 13,600 veh/day, 120 km/h, and 2%, respectively.

By means of the Copert IV© Software, the emissions were computed and utilized for assessing four main environmental impact categories, using the characterization factors reported in www.environdec.com (see Table 3).

Table 3. Environmental impact of traffic flow

Impact category	Environmental indicator	Total (in 20 years)
GWP	Kg CO_2 eq	23.347.060
POCP	Kg C_2H_4 eq	7.36.530
AP	Kg SO_2-eq	4.277.093
EP	Kg PO_4-eq	16.139

These results are consistent with the fleet of running vehicles hypothesized in the study, as it is possible to find in several literature studies

RISULTS AND DISCUSSIONS

Results obtained from the analysis of the considered safety barrier need to be compared with the impacts exerted by the road pavement and traffic flow, in order of establishing their relative contribution to the burden of the whole transportation system.

In this aim the environmental impacts exerted by the components of the transportation system analyzed (i.e. pavement, traffic flow and guardrail) have been evaluated and critically compared (see Table 4).

To compare these components properly, the potential impacts exerted by 1 km of guardrail were multiplied by four, because 4 km is the total length of guardrail to be installed on both sides of 1 km of highway.

As shown in Table 4, that reports the contribution of each of the three calculation components, traffic flow obviously resulted to be the greatest contributor. In fact, approximately

86% of the total GWP, 100% of the total POCP, 100% of the total AP and 72% of the total EP is determined by the traffic emissions.

Table 4 Comparison of the environmental impact of the transportation system components here analyzed.

Impact category	Enviromental indicator	Pavement	Guardrail	Traffic
GWP	Kg CO_2 eq	1.846.523,10	1.943.538,77	23.347.060,00
POCP	Kg C_2H_4 eq	1.253,90	863,10	7.336.530,07
AP	Kg SO_2-eq	15.133,26	11.561,98	4.277.093,40
EP	Kg PO_4-eq	1.594,09	4.622,67	16.139,00

A quite interesting result is that, when comparing only the calculation components "pavement" and "guardrail", the total environmental impact caused by the production and maintenance of the guardrail during the analysis period is almost comparable with that of the production and maintenance of the pavement, as illustrated in Fig. 4.

It seems remarkable that, as observed in Table 4, the eutrophication potential of the barrier resulted approximately three time-higher than the one of pavement. In terms of process, the production of primary steel and manufacturing of semi-finished steel product into a finished one resulted to be the main responsible for this outcome (86% of PO4-eq emitted come from these two processes). Such a result certainly requires further analyses to understand deeply which activities within the production process of steel are mainly accountable for this impact.

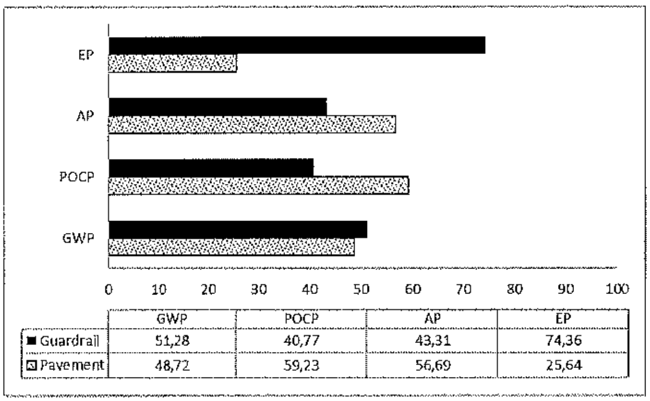

Fig. 4 –*Percentage comparison between the pressures exerted by pavement and guardrail.*

The result obtained by comparing the potential environmental impacts of the road pavement and the guardrail certainly confirms the importance of including these safety roadside components within LCA of highways and roads, unlike current LCA studies of roads do.

CONCLUSIONS

This study aims to provide a new tentative approach for life cycle assessment of roads, according to which in a life cycle assessment of a road not only the pavement and traffic (which are usually considered in the current LCA studies of roads) but also all of the road equipment should be featured.

In the present work a typical safety roadside component, i.e. guardrail, was investigated to evaluate its contribution to the whole environmental impact of a road during an analysis period of 20 years. To evaluate the significance of its impact, the environmental burden of a road pavement and traffic flow were computed as well.

From the application to 1 km of an existing Italian highway the traffic flow turned out to be the greatest contributor to the environmental impact of roads, as expected.

The comparison between the barrier and the pavement has unexpectedly shown interesting outcomes instead. In fact, the only pressure caused by the safety-barrier resulted to be comparable with that of the asphalt pavement. This confirms the importance of including these safety road components into LCA studies of a road, unlike current LCA studies of roads do.

Furthermore, in this case, for example, the pressure exerted by the safety barrier on the eutrophication potential is remarkably higher than the ones exerted by the pavement (three time higher).

While carrying out the study, some difficulties have been encountered regarding data required for this type of analyses. For example, neither primary nor secondary (obtainable from current LCA databases) data on the zinc recycling from the zinc-coated steel (guardrail) was available. This asks for more detailed and sector-specific databases, and, in turn, obviously requires an "in field" analysis aimed at enriching pollutant emissions and embodied energy data, on the basis of the actual working chain of roads materials and components.

It's evident that the results here presented could be affected by the observation period here selected for the analysis, that is 20 years. In fact, despite during this period several maintenance actions take place, the impacts related to the dismissing phase have not been encountered for.

In addition, based on the obtained results, in order to achieve a more comprehensive environmental impact of the life cycle of a road, it would therefore be necessary to extend the analysis carried out here also to the other safety road components (horizontal marking, noise barriers, etc) and the rest of the road equipment such as traffic signals, street lights, control points, for example.

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