# The environmental impact assessment of Asphalt Rubber: Life Cycle Assessment

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***ABSTRACT:*** *Material and energy recovery from end of life tires are the two alternatives to accomplish the European legislation, which has progressively banned landfill disposal with EC Directive 1999/31/EC. Therefore, diversified solutions for end of life tires management should be available to provide a concrete way for reuse and to help to solve the problem of the huge amount of old tires to be treated yearly. Among the material recovery alternatives, road construction using crumb rubber modified binders, called Asphalt Rubber, is already world widely used and is considered an excellent solution to recycle old tires.*

*In order to support a policy disclosure to this recycled material, the evaluation of the environmental impacts connected to the life cycle of the asphalt rubber is essential and Life Cycle Assessment is a holistic tool which allows for the evaluation of the overall impacts of the road life cycle and of its critical spots.*

*In this paper, the life cycle assessment of a specific case study of a crumb rubber modified asphalt mixture prepared with the wet method, near Florence (Italy) was evaluated.*

*The results of the study clearly identify the main contributing steps to the environmental impacts in the life cycle of the rubber asphalt road and therefore, together with the technical and economical evaluation of this technology, will be useful for policy makers when setting the reference specifications in public tenders.*

***KEYWORDS:*** *Life Cycle Assessment, Asphalt Rubber, Crumb Rubber, Old tire*

## 1. Introduction

In general the main requirements for a road overlay are safety, shorter construction time, durability and lower construction and maintenance costs. Only in recent years the cost benefit ratio has been estimated by introducing some new parameters, such as the lower CO2 emissions, the raw material saving and noise reduction. These latter features help to define and quantify the benefits of the so called “green technologies”, for which the economic balance is enlarged to environmental sustainability.

Asphalt Rubber (AR) technology is already well established and considered to give environmental benefits connected to the potential of utilizing significant amounts of end-of-life tires, therefore providing a valid contribution to close the end of life tire (ELT) recovery chain [1]. The experiences obtained with the use of AR hot mixes in several countries showed the excellent structural and functional behavior of this type of material [2]. In general, improvements can be observed in the fatigue life of wearing courses, reduction of maintenance costs, increase of skid resistance, decrease of reflective cracking in overlays, and reduction of noise levels.

In addition to the improvement of mechanical behavior of asphalt hot mixes, AR is one of the available technologies that can contribute to solve environmental impacts of traditional ELT disposal, since AR binder incorporates to the conventional bitumen approximately 20%, by weight, of crumb rubber recycled from ground tires.

The evaluation of the environmental sustainability of the whole process is very important and should be carried out using suitable tools. The whole life cycle of the AR road pavement should be evaluated, in order to assess the total environmental burdens, from the construction of the road (including the production of materials used, transportation etc.), to the use and maintenance of the road over its life cycle, and finally to its end of life.

Life Cycle Assessment (LCA) is a holistic tool that can be used to evaluate the environmental performance of a product or a process over the entire life cycle according to standard impact categories, and is therefore a suitable approach for this purpose.

In this study, LCA tool was used to evaluate, under a life cycle analysis perspective, the environmental performances of two road rehabilitation cases, to actually quantify some of the environmental benefits especially in terms of energy savings, achievable through the application of AR hot mixes, compared to traditional hot mixes.

According to this principles, re-using common waste product such as rubber from end of life tire could play an important role in saving energy and natural resources, particularly in road pavements construction.

On one side, because its mechanical performances allows a significant reduction of thickness increasing pavement life, with a significant energy saving during the hot mix production, transport and laying phases; on the other side, because this kind of pavements presents a more regular surface, which reduces consumption of vehicles and related emissions.

The present study focuses on quantifying the savings during construction phase, in itself enough to convince of the environmental validity of AR solutions, and further evaluates the balance of the entire life cycle of a road pavement using AR hot mixes, from the transformation of ground tires in crumb rubber to the paving, and then its maintenance and end of life (i.e. performances of vehicles are not included).

The aim of the study is not only to evaluate the global environmental impacts, but also to highlight the phases within the life cycle of the road which have an high influence on the selected impact categories. In this way, it will be possible to have a realistic picture of the environmental burdens of the involved processes and put forward solutions in order to eventually decrease the environmental impacts associated to the different phases. Under this perspective, LCA plays a main role in supporting the eco-design approach to process or products [3] and in completing the knowledge that can be gained from a local environmental impact assessment perspective.

## 2. LCA methodology

LCA evaluates the environmental impacts of the phases of the life cycle of a product or a service, “from cradle to grave”, that is from the gathering of raw materials necessary to create the product to the moment when all materials are returned to the earth. This includes all the impacts, which are not considered in the traditional analysis (i.e., extraction of raw materials, transport of the materials, disposal etc.). The LCA analysis was performed according to the rules of international standards ISO 14040 [4]:

• ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework

• ISO 14044:2006 Environmental management – Life cycle assessment– Requirements and guidelines.

Goal and Scope Definition is the preliminary phase in which the goal of the study, the functional unit, the system boundaries, the amount and quality of data, the assumptions and limits are defined.

Life Cycle Inventory Analysis, LCI is the phase concerned on the study of the life cycle of the process, through the elaboration of a model of the real system under study, together with a data collection activity.

Life Cycle Impact Assessment, LCIA consists of the characterization of the environmental impacts of the process or product under study and is aimed at highlighting the environment modifications due to the resource consumption and pollutant emissions. In this step, the data calculated during the inventory step are elaborated to give an assessment of environmental hazard.

Life Cycle Interpretation is the final step of a LCA, with the aim to propose the eventual possible changes in the life cycle in order to reduce the environmental impacts of the examined processes or activities.

The LCA study includes four phases (Figure 1):

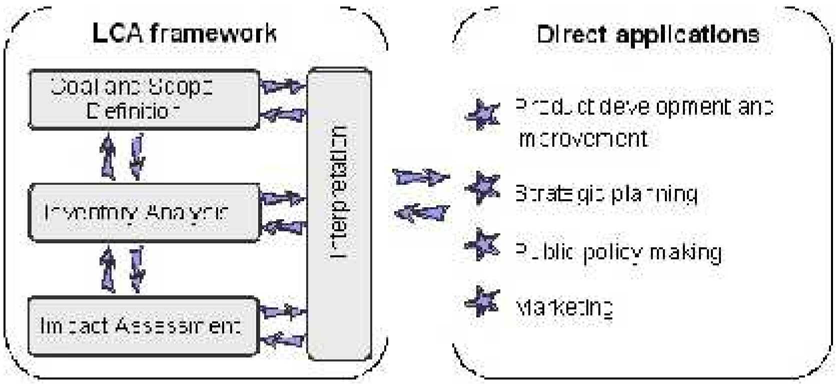



**Figure 1.** *Phases and main applications of a LCA study*

Specific data relative to the road construction and type and quantities of the materials used were provided by the Asphalt Rubber Italian producer [5] and, when not available, were obtained from the literature or Ecoinvent database [6]. Performance and environmental data were obtained from several field bench tests. Life cycle inventory data collected were elaborated with LCA software SimaPro 7.3.2 and the CML2000 method was applied for the impact assessment [7].

### 3. Goal and scope definition

This LCA analysis was carried out in order to evaluate the environmental benefit of rehabilitation using Asphalt Rubber technology with a parallel evaluation of analogous rehabilitation case with conventional hot mixes.

AR design solutions allow an immediate benefit in terms of energy saving, due to the reduction of raw materials and related processes necessary during the construction phase, besides the advantage due to the longer life of AR pavements.

To begin, an improving AR solution was defined to increase performance and to implement, at the same time, a thickness reduction of pavement rehabilitation layers, leading to money saving. A structural design method was applied to calculate and verify AR solution, determining the state of tension and deformation (extension) caused by applied traffic loads, verifying the failure criteria for the pavement and taking into account the following issues:

- AR hot mixes contribution by decreasing the extent of vertical compression at the top of pavement foundation;

- AR hot mixes contribution by reducing traction stress at the base layers of bituminous layers.

Considering lab tests with Italian AR road materials and characteristics of aggregates that are used in the present geographic zone and climatic database (max temperature of 45°C and minimum of – 15°C), it was assumed for respective AR Gap-graded Top layer (basaltic) and AR Gap-graded Binder layer (calcareous) hot mixes an Elastic modulus of 4200 and 4000 MPa [8].

Design solution, using common road design BISAR® software, that delivers the best performance in terms of expected life, is detailed below:

A) Asphalt rubber solution:

- 3 cm top layer AR Gap Graded (E=4200 MPa, with nominal maximum aggregate size of 12.5 mm): 8% AR bitumen (20% CRM) and 92% aggregates

- 6 cm binder layer AR Gap Graded (E=400 MPa, with nominal maximum aggregate size of 14 mm): 7.8% AR bitumen and 92.2% aggregates

- 10 cm base layer, conventional material (E=2500 MPa): 4% Bitumen 50/70 and 96% aggregates

For a total thickness of 19 cm.

B) Conventional solution:

- 4 cm SMA top layer (E=4000 MPa): 6% Bitumen 50/70 and 94% aggregates

- 6 cm binder layer (E=3500 MPa, calcareous): 4.7% Bitumen 50/70 and 95.3% aggregates

- 12 cm base layer (E=2500 MPa, calcareous): 4% Bitumen 50/70 and 96% aggregates

For a total thickness of 22 cm.

Applying the traffic forecasts provided, pavement expected life obtained using the same software, parameters and laws of fatigue to all solutions was estimated 20 years for the AR solution, with maintenance interventions on the top (3 cm) layer each 8 years, while the life time of the conventional solution is 8 years with maintenance intervention on the top layer (4 cm) every 5 years.

The production capacity and laying of the conventional hot mix and AR hot mix are considered to be equal.

**Figure 2.** *Rehabilitation using AR Gap graded, Pistoia*

### *3.1 Functional unit*

UNI EN ISO 14040 standard defines the functional unit as “the quantification of the service delivered by the investigated product system”. The purpose of the functional unit is to ensure comparability between different systems and, in a mathematical sense, it serves as a reference for inputs and outputs of the compared systems. In order to make the two road typologies comparable, we should refer the impacts to km per year, so as to include time in the functional unit.

Therefore, the functional unit is 1 km of road with 7 m width (2 lanes of 3,5 m each) per year **(1 km * year)**.

### *3.2 System boundaries*

The definition of the system boundaries consists in the selection of processes or operations (i.e., production of materials, transports, production of energy etc.) and flows (emissions, wastes, etc.) to be included in the analysis.

The system boundaries of this LCA study include:

**- Road construction:** Materials, such as crumb rubber material (CRM) from end-of-life/ground tires, gravel, bitumen, with relevant quantities, place of origin, transportation. Production processes include crumb rubber production, AR bitumen production, and road construction, with the relevant input materials and energy, output components, transportation of components. Road construction includes the follow phases:

- *Hot mixes production*: the known characteristics of the AR hot mixes plant, equipped with a two stage gas burner (580 kW), allows to determine the energy consumption associated with production;
- *Hot mixes transport*: it depends on the distance between production plant and yard; assuming an average distance equal to 50 km it’s possible to define the energy consumption associated with transportation;
- *Disposal of resulting materials*: materials milled and recycled are collected and transported away from the yard. Consumptions and emissions are calculated considering an average route equal to about 10 km, and taking into account the 15% increase in average volume that occurs between the stage of milling and the subsequent filling and stabilization;
- *New pavement laying*: in this phase, the energy balance has taken into account the power of every machine and the total use of each of them.

**- Road maintenance:** Pavement maintenance, including substituted material, energy consumption for the maintenance operations, transportation and disposal of the excavated material.

**- Road end of life:** Asphalt excavated from the site was considered to be transported and disposed in an inert material landfill.

The use of the road, with the emissions due to the vehicle passage on the surface, was excluded from this system.

## 4. Life Cycle Inventory

The life cycle inventory (LCI) step is the process carried out for the quantification of energy and raw materials consumed, atmospheric emissions, waterborne emissions, solid wastes and other releases for each process within the entire life cycle.

Specific data relative to type and quantities of the materials used for the construction of the roads were provided by Asphalt Rubber Italia [5]. Data relative to ELT pulverization process were obtained according to an Italian sector company. Background data were obtained from the Ecoinvent database integrated in the SimaPro software.

### *4.1 Crumb rubber powder production*

Currently, in Italy, the largest majority of crumb rubber powder is a sub-product of granulate rubber production. The energy consumption estimated for the granulation process is 0.406 kWh per kg of granulate/powder produced. Therefore, the impacts of the production process is to be allocated among the powder and the granulate production. Allocation was done on a weight basis.

### *4.2 Crumb Rubber modified bitumen*

AR binder is used in the top layer and in the binder layer of the AR road rehabilitation.

AR modified bitumen was described according to data provided by the company. Bitumen 50/70 is mixed with 20% w/w of crumb rubber powder in the AR plant, with a diesel consumption of 18L per ton of modified binder. The equipment was born to be a mobile equipment but, actually in Italy there’s a different system of producing AR (Figure 3).


**Figure 3.** *AR Italian plant*

One of the difficulties with using this material in Italy was the poor storage stability, so that the AR binder had to be produced near or at the hot mix plant, using mobile equipment for the production of AR. In the case of a small amount of material, which often happens in this phase of diffusion of this technology, this compounds significantly high costs. Thus, Asphalt Rubber Italia developed a delivery system using rubber modified bitumen tanks equipped with heating and stirring with diathermic oil (as in Figure 4). This system is particularly useful in the Italian reality of market in which there are today more than 650 companies that produce and sell asphalt hot mixes.


**Figure 4.** *AR binder mobile tank for transportation and deliver in all country*

Transportation of the materials is shown in table 1, where the minimum and maximum distances are shown between the refinery and the plant for bitumen transportation (50-150 km), between the CRM production plant and the AR plant for the CRM transportation (10-100 km). These distances are indicated according to the company experience.

**Table 1.** AR binder Transportation

| **AR bitumen production: transportation** | | | |
|---|---|---|---|
| **Material** | **Type of transport means** | **Distance min-max (km)** | **Origin and Destination** |
| Bitumen 50/70 | truck 30 t | 50-150 | refinery-plant |
| Rubber powder CRM | truck 30 t | 10-100 | plant/A.R.Plant |
| AR binder | truck 30 t | 0 | A.R.plant/A.R. plant |

### *4.3 Hot mix production*

Conventional hot mixes contains about 6% bitumen in the top layer and about 4 to 5% in the binder and in the base layer. With AR technology, the amount of AR bitumen for both the top and binder layers can be considered in average 8% (about 6.4% of bitumen 50/70 with 1.6% CRM).

Hot mix production process consists in mixing bitumen with aggregates in a discontinuous batch hot mixing plant, equipped with a two stage gas burner (power 580 kW). The energy consumption of this process is 0.160kWh/kg of produced hot mix and is the same for both AR hot mix and conventional hot mix.

Transportation distances for the materials used are listed in Table 2. Also in this case the minimum and maximum distances for the materials transportation are indicated according to the producer experience. The distance between the quarry and the plant for the aggregates transportation can range between 30 and 80 km.

**Table 2.** Transportation distances for materials

| **Material** | **Type of transport means** | **Distance min-max (km)** | **Origin and Destination** |
|---|---|---|---|
| Bitumen AR | truck 30 t | 0 | plant AR/plant AR |
| Aggregates | truck 30 t | 30-80 | quarry/AR plant |
| Bitumen 50/70 | truck 30 t | 50-150 | refinery/AR plant |

### *4.4 Road Construction*

The road construction phase can be divided into the following phases:

- AR hot mixes production;
- Hot mixes transport;
- Milling;
- Transport for disposal;
- New pavement construction.

The production capacity and laying of the conventional hot mix and AR hot mix are considered to be equal.

In the milling phase the specific consumption of the machine depends on the thickness of the milled layer: for the 22 cm thickness for the traditional road, the specific fuel consumption is 69 l/h , while for the 19 cm of the AR road the specific consumption is 61 l/h. The milling machine has a constant working capacity of 500 m2/h, and therefore, on a 7000 m2 surface (1 km length), the working time is of 14 hours.

Due to the difference in thickness of removed layer, there is a difference in diesel consumption as well as in removed material, which is then transported from the site to the landfill for inert material disposal. The distance between the construction site and the inert material landfill usually ranges between 10 and 50 km (Table 3).

**Table 3.** Transportation distance for milled materials

| **Material** | **Type of transport means (HP, kW, weight)** | **Distance (km) min-max** | **Origin/Destination** |
|---|---|---|---|
| Milled material (kg) | truck 30 t | 10-50 km | Yard job/landfill |

The asphalt laying process consists in the same operations for both cases and the specific consumptions for both cases are similar (Table 4).

**Table 4.** Consumptions during asphalt laying process

| **Asphalt Laying operations** | **Specific consumption (l/h)** | **Work capacity (m2/h)** |
|---|---|---|
| Paver (Marini 665WD) 118 power | 18,1 | 1000 |
| Bobcat | 4 | 16000 |
| Road Sweeper Bucher | 26,67 | 8000 |
| Roller Marini 100VS2 | 12,85 | 4000 |

### *4.5 Use and maintenance*

For the Asphalt Rubber technology, road life time was indicated to be of 20 years, and maintenance actions on the top layer (3 cm thickness) were foreseen every 8 years, therefore they take place 2.5 times over the lifetime of the road.

For the traditional technology, road life time was indicated to be of 18 years and maintenance actions on the top layer (4 cm thickness) were foreseen every 5 years, therefore they take place 3.6 times over the lifetime of the road.

In the milling phase, the specific consumption of the machine depends on the thickness of the milled layer: for the 4 cm thickness for the traditional road, the specific fuel consumption is 36 l/h , while for the 3 cm of the AR road the specific consumption is 35 l/h. The milling machine has a constant working capacity of 500 m2/h, and therefore, on a 7000 m2 surface (1 km length), the working time is of 14 hours. Therefore, different amounts of materials are substituted and also transported for this maintenance operations (Table 5).

**Table 5.** Milled material

| | **Type of transport means (HP, kW, weight)** | **Distance (km) min-max** | **Origin Destination** |
|---|---|---|---|
| Milled material (kg) | truck 30 t | 10-50 km | Site/landfill |

### *4.6 End of life*

The end of life of the road was described with a disposal process of the resulting inert materials in a landfill for inert materials situated in a range of 10 – 50 km from the rehabilitation site. The transport of the excavated materials is included in the process.

## 5. Life cycle impact assessment

In the life cycle impact assessment phase (LCIA), the potential environmental impacts of the life cycle of the road are calculated. The potential impacts are calculated according to the CML 2000 method, which elaborates on the problem-oriented (midpoint) approach. The following ten impact categories are included in the method:

- Ozone layer depletion (ODP)
- Human toxicity
- Fresh water aquatic ecotox.
- Marine aquatic ecotoxicity

- Terrestrial ecotoxicity
- Photochemical oxidation
- Global warming (GWP100)
- Acidification
- Abiotic depletion
- Eutrophication

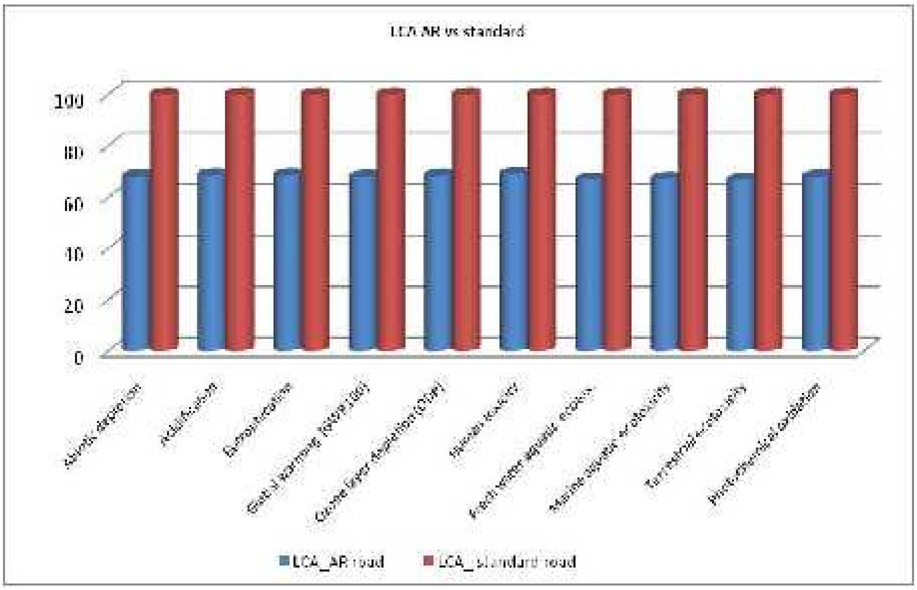
According to a life cycle perspective, results have to be considered phase-specific, but not time- and site-specific (i.e. no information are given about concentration of impacts in time and space).

### *4.2 LCA of asphalt rubber and conventional road*

The results of the analysis, referred to the functional unit (1 km*year) are listed in table 6 and show that the AR technology provides better environmental performances compared to the traditional technology over the entire life cycle: for all the impact categories, AR road shows improved performances of about 32% compared to the traditional standard road (Figure 5).

**Table 6.** Results of environmental performances AR road/conventional road

| **Impact category** | **Units** | **LCA AR road** | **LCA conventional road** |
|---|---|---|---|
| Abiotic depletion | kg Sb eq | 470,4820614 | 690,0650983 |
| Acidification | kg $SO_2$ eq | 200,6254185 | 292,4172741 |
| Eutrophication | kg $PO_4^{-3}$ eq | 40,77403416 | 59,41062426 |
| Global warming (GWP100) | kg CO2 eq | 31676,04318 | 46608,61182 |
| Ozone layer depletion (ODP) | kg CFC-11 eq | 0,008077139 | 0,011791892 |
| Human toxicity | kg 1,4-DB eq | 12503,81109 | 18077,84697 |
| Fresh water aquatic ecotox. | kg 1,4-DB eq | 4585,796209 | 6855,59203 |
| Marine aquatic ecotoxicity | kg 1,4-DB eq | 12698961,68 | 18886861,13 |
| Terrestrial ecotoxicity | kg 1,4-DB eq | 128,1745591 | 191,8532325 |
| Photochemical oxidation | kg $C_2H_4$ eq | 9,103604073 | 13,37387651 |




The main contributions to the environmental burdens derive either from bitumen production or electricity, used mainly in the hot mix production process, depending on the specific impact category. For instance, in the GWP category, the largest contribution for both AR and traditional technologies derives from electricity consumption with about $2x10^4$ and $3x10^4$ kg $CO_2$ eq., (65% and 67%) respectively, followed by bitumen production with $5x10^3$ and 7.5x $10^3$ kg $CO_2$ eq., (about 16%) respectively.

Following, inert material disposal contributes for about 8%, materials transportation for about 5%, and diesel consumption for 3% and 1%, respectively, and finally the aggregates excavation for about 3%. The impacts for the AR road are generally lower than those of the standard road, except for the diesel consumption, which is due not only to the asphalt laying phase but also to the AR bitumen production. Overall, the global balance is in favour of AR technology (Figure 6).

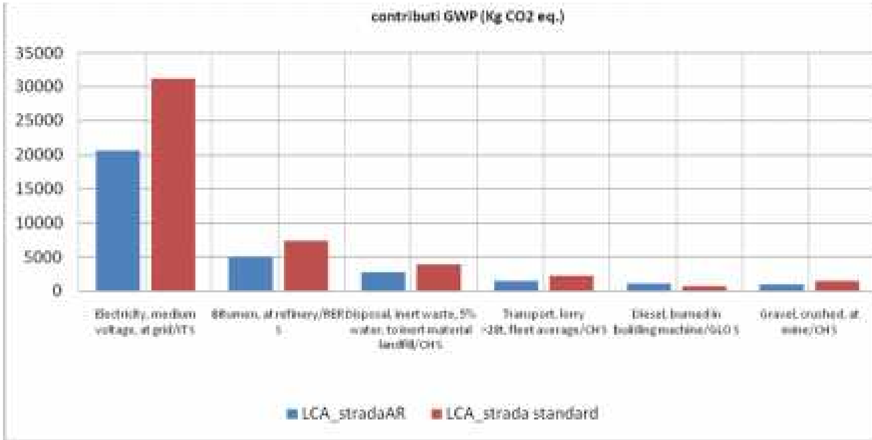



**Figure 6.** *Contribution of process phases of LCAs to the GWP impact categories*

If we look in more detail into the environmental impacts of the materials production processes, such as the hot mixes, we observe that the AR hot mix production has larger impacts than the traditional hot mix production, due to the impacts deriving from the AR bitumen production. This process includes the CRM production, the transportation of the rubber and bitumen to the AR plant, as well as the diesel consumption in the AR plant for the mixing of Bitumen and CRM (Figure 7). In particular, the rubber powder production contributes for about 10% to the GWP, the freshwater toxicity and the terrestrial toxicity categories, while the diesel consumption during the mixing phase contributes for 25% about to the GWP, eutrophication and human toxicity.

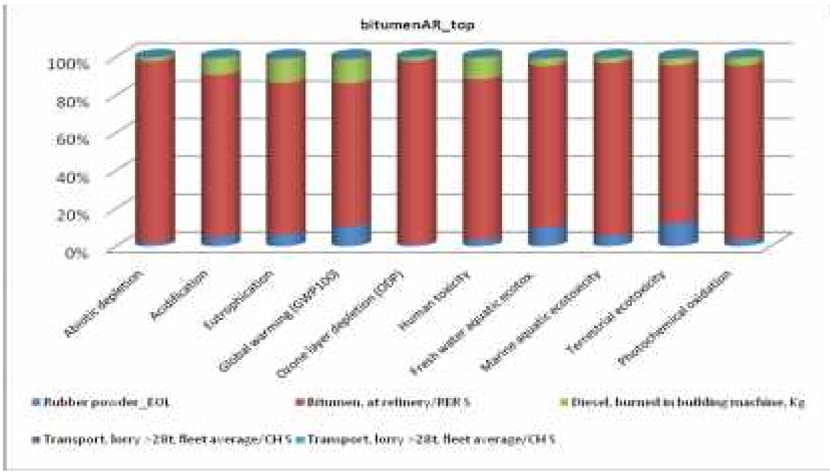



**Figure 7.** *Main contribution AR mix production to environmental impact categories*

Thus, the environmental burdens of the AR hot mix production are larger than those of the traditional hot mix production, in a range of 10 to 20%, depending on the impact category. For instance, for GWP, freshwater toxicity, terrestrial toxicity, AR hot mix environmental burdens are 10% larger, while for abiotic depletion, ozone layer depletion, human toxicity they are about 20% larger. For acidification, eutrophication and photochemical oxidation impact categories, AR hot mix yields environmental impacts 15% larger compared to traditional hot mix (Figure 8).

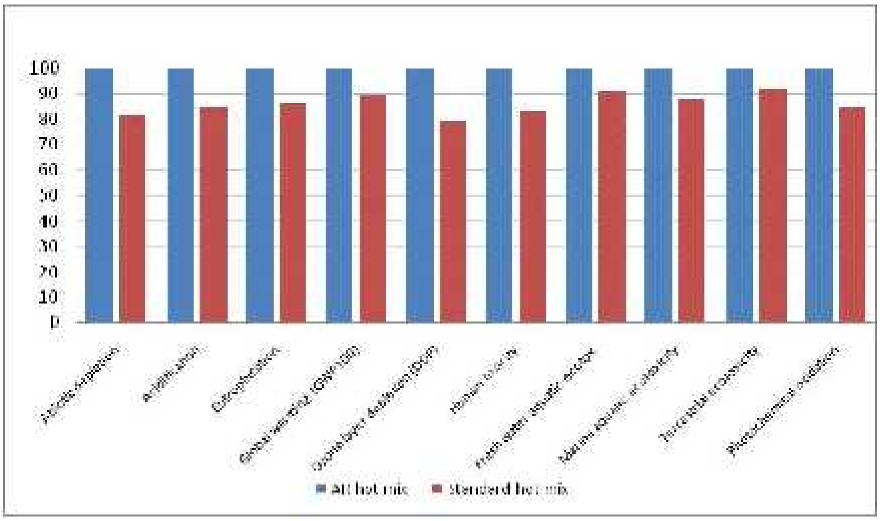



**Figure 8.** *Comparison of environmental performances of AR hot mix and standard hot mix production*.

If we focus on GWP, the larger impact of AR hot mix production is due to a larger consumption of electricity during the production process, a larger amount of bitumen used in the process, and diesel consumption in the AR bitumen production process. Transportation phase and aggregates production contribute in the same way to both AR and conventional hot mix production (Figure 9).

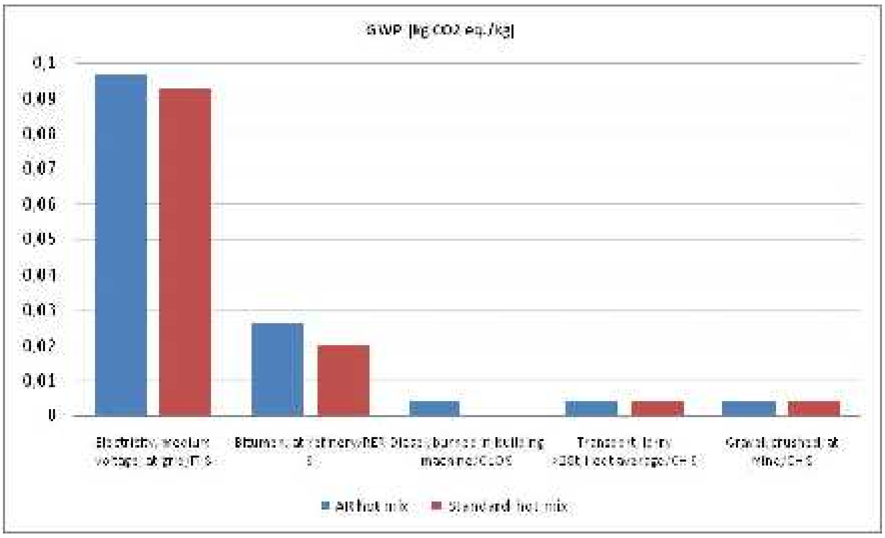



**Figure 9.** *Contributions of the hot mix production processes to the GWP impact category*

However, when we consider the road construction, the AR technology provides environmental impacts lower than conventional technology of about 5-10%, depending on the impact category. This advantage is achieved due to the reduced thickness of the AR road and the consequent saving of fuel, energy and materials in the construction process.

The environmental impacts were calculated on the basis of the shortest distances accounted for the transportation of the materials in the various stages of the life cycle. Upon a sensitivity analysis, carried out by modifying the distances for the transportation of the materials from the minimum to the maximum indicated by the company, we observe an incidence of the transportation contribution over the total impact of about 5 to 10%, depending on the impact category (Figure 10).

For instance, GWP, eutrophication and acidification impact categories, which are considerably affected by the transportation emissions, increase of about 10% upon increasing the distance of the transportation trips, while ozone layer depletion, human toxicity, freshwater toxicity and photochemical oxidation increase of about 7% upon increasing the distance. Finally, abiotic depletion, marine aquatic ecotoxicity and terrestrial ecotoxicity increase of about 5%.

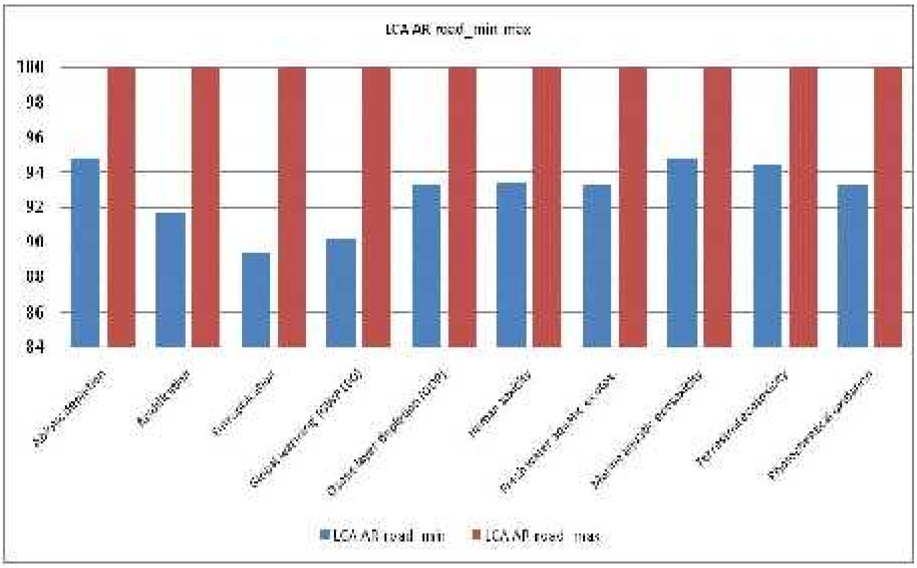



**Figure 10.** *Sensitivity analysis of the contribution of transportation phase to the life cycle global impacts*

### 6. Evaluation of the environmental advantages of AR versus conventional scenario

In order to evaluate the potential environmental benefit of the Asphalt Rubber technology also towards the End of Life tires recovery chain, two scenarios were compared, regarding only the top layer manufacture and including equivalent processes within the boundaries of each system.

1. The construction of a top Asphalt Rubber layer of 3 cm thickness, including hot mix production (with AR bitumen) the layer excavation and the hot mix laying operations. This process includes the production of CRM from ELT .

2. The construction of an equivalent conventional asphalt layer of 4 cm thickness, including hot mix production (with non modified bitumen) the layer excavation and the hot mix laying operations. In this process the landfill disposal of the amount of ELT, avoided in the previous scenario with the production of CRM used for the AR, is included.

Material and energy recovery from end of life tyres are the two alternatives to accomplish the European legislation, which has progressively banned landfill disposal with EC Directive 1999/31/EC but, even if there is a strict law with also heavy fines, unfortunately reality shows that in Italy we still have illegal dump, not to mention that we continue to cross ground tires in the slopes of our most beautiful landscapes. So this paragraph actually quantifies another type of environmental advantage, against scenarios still occurring to our reality, in 2012.

In both cases, the feedstock energy of the ELT is entirely allocated to the use phase of the tire, and thus it is excluded from our system boundaries. In this simplified analysis, the transportation of ELT from collection centres to landfill facilities or to recovery plants is excluded.

Figure 11 shows that environmental benefits are achieved for all the impact categories (although in different amounts) with the implementation of AR technology. For instance, the environemtnal performance improves of about 24% for abiotic depletion, acidification and ozone layer depletion, while of 30% for global warming potential and photochemical oxidation. The improvement reaches about 90% for eutrophication and marine ecotoxicity and even more for freshwater ecotoxicity category.

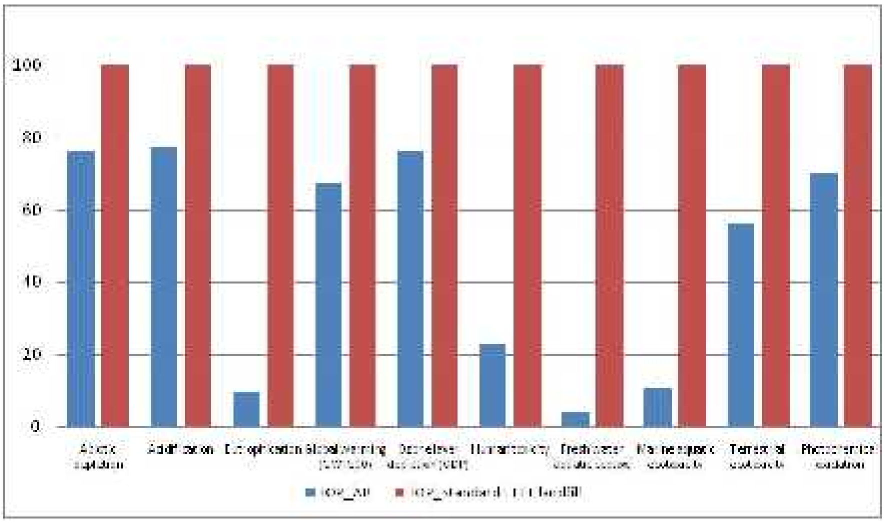



**Figure 11.** *Comparison of the environmental performances of AR scenario and standard scenario with landfill disposal of ELT*

Focusing on the global warming potential, a deeper look into the contribution of the different processes to the impact category shows larger impacts deriving from energy and material consumption due to the larger amounts of bitumen and aggregates used in the conventional top layer (4 cm thickness instead of 3 cm for the AR alternative). Moreover, a significant contribution comes from the landfill disposal of ELT, which is instead avoided in the asphalt rubber scenario (Figure 12).

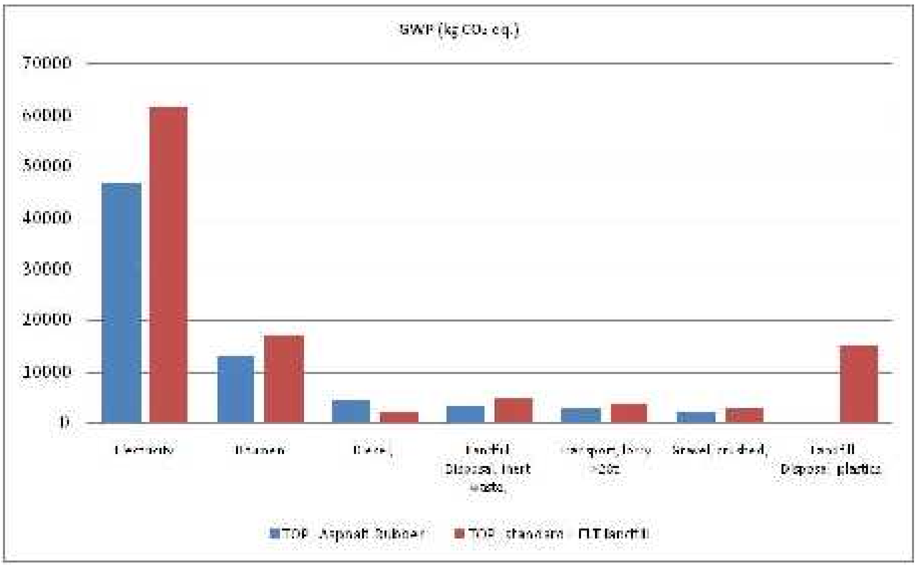



**Figure 12.** *Contribution of the two scenarios processes to the GWP impact category*

## 7. Summary of results

The LCA analysis of the two rehabilitation cases, one with conventional apshalt and the other one with AR technology, allows us to take some important main conclusions.

The AR technology represents a big improvement to what concerns environmental performance for all impact categories evaluated over the entire life cycle, when compared to a conventional alternative for road rehabilitation (and new construction). Under the adopted hypothesis the improvement achieved is of about 30% for all the evaluated impact categories.

The environmental impacts relative to AR hot mix production process are larger than the conventional hot mix production, due to larger impacts deriving from the AR bitumen production. This process includes CRM production and transportation and fuel consumption for the production process itself.

On the contrary, during the asphalt laying phase, the AR technology has lower consumption due to the smaller thickness of the asphalt layer and therefore to the smaller amounts of materials used and milled materials which are transported and eventually disposed. These energy and materials saving opportunities allow for an overall advantage of AR technology in the road construction. The consequent environmental benefits are in the order of 5-10% for all the impact categories.

The advantage of AR technology is further improved over the entire life cycle, if we consider the longer life time of the AR road and the lower number of maintenance operations needed. These features allow for an improvement of about 30% for all the impact categories, in comparison with the conventional technology.

It is evident that the environemntal performance of the technology is closely correlated to its technical performance.

The contribution of the main phases (construction, maintenance and end-of-life) to the overall impact of the life cycle is different for the two technologies: the road construction phase give always the largest contribution, about 66% for the asphalt rubber and 55% for the traditional road.

As for the maintenance phase, the environmental impacts due to the AR maintenance contribute for about 30% of the total, while for the traditional road for about 40%.

End of life of the road accounts for less than 4% for all the impact categories for both the analyzed cases (Figures 13 and 14).

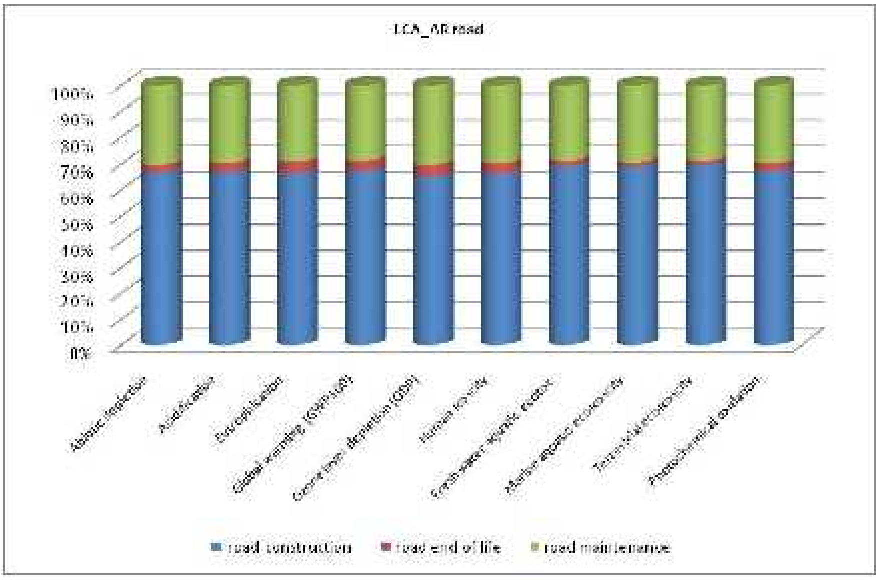



**Figure 13.** *Contribution of the main phases to the life cycle of the AR road*

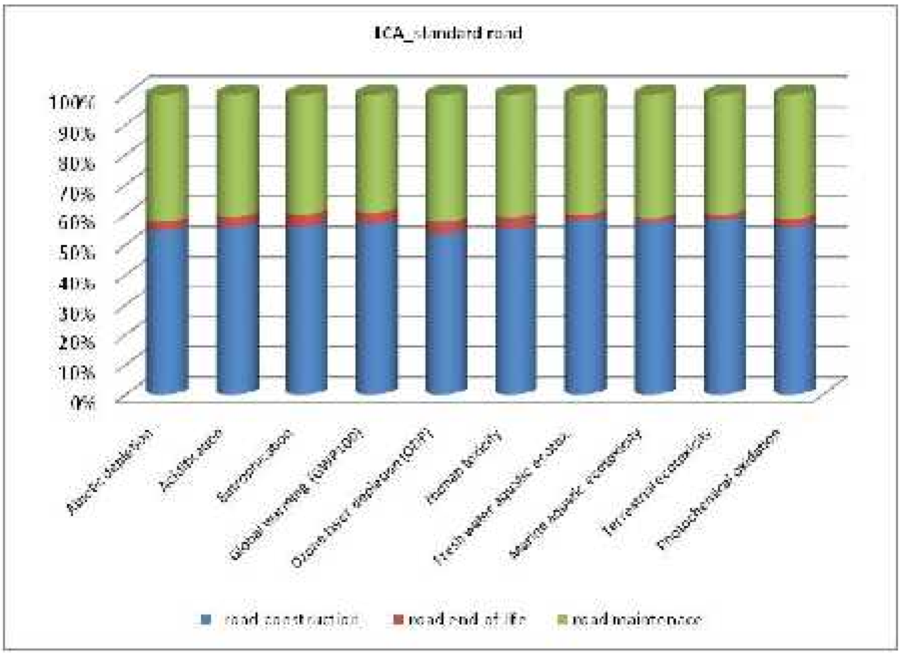



**Figure 14.** *Contribution of main phases to the life cycle of conventional road*

The sensitivity analysis on the influence of the transportation distances over the environmental impacts shows that transportation contribution to environemntal impacts can increase of up to 10% depending on the impact category. Therefore, in order to contribute to a reduction of the environmental impacts, the transportation distances should always be minimized when possible.

The adoption of the asphalt rubber technology affords also significant environmental advantages due to the avoided landfill disposal of the amount of ELT needed for the production of the CRM in the AR asphalt.

When including this aspect, we calculated that for the top layer of 1 km road, with the use of AR technology, the environmental performances are improved in a range between 25 and 90%, depending on the impact category, compared to a conventional technology.

## 7. Conclusions

In this paper results of a quantitative analysis of environmental benefits arising from the use tire recycling in road pavements are shown in terms of Life Cycle Assessment, highlighting the significant savings achieved under construction and maintenance.

AR hot mixes in rehabilitation processes and new constructions, as well as presenting better structural and functional performance, allow a significant reduction in environmental impact. The results of the analysis described in this paper quantify this benefit.

The environmental advantages achievable using AR solutions instead of pavement rehabilitations with traditional hot mixes are estimated to be about one third (33%) of the overall energy consumption and carbon dioxide emissions resulting.

Moreover, the AR solutions present better structural and functional performance than the original solution. They may, indeed, support more traffic than expected and have a longer expected life.

A significant noise reduction is also obtained with this alternative solution, due to the AR open graded sound absorption coefficient equal to 0.75, in addition to improved adhesion characteristics.

All this features should lead the pubblic agencies to consider the AR solution a so called “win-win” technical alternative for the pavement rehabilitation and new constructions. This is particularly relevant when considering the drive towards public tendering innovation that is at the heart of green public procurement and regional burder sharing initiatives.

This study has its limitations which open opportunities for future research. First, additional impact categories can be usefully investigated in order to gain further insights into time- and site-specific environmental impacts. Second, the functional unit can be usefully extended in order to gain further insights into environmental performances of vehicles. Improving the steps and methodology of the presented LCA analysis the environmental benefit obtained using Asphalt Rubber technology (33%) will increase.

## 8. Bibliography

[1] Antunes I., Way G.B., Sousa J., Kaloush K., “The Successful World Wide Use of Asphalt Rubber”, 16th Convegno Nazionale SIIV, Cosenza, 2006

[2] Rand, Dale, "Texas Asphalt Rubber Specifications and Safety 2011 Update (power point presentation)," Texas DOT Construction Division, Flexible Pavements Branch, San Antonio, February 8, 2011

[3] Lewandowska, A, Kurczewski, P, ISO 14062 in theory and practice-ecodesign procedure. Part 1: structure and theory INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT 15 (8), 769-( 2010)

[4] ISO 14040, 2006. Environmental Management e Life Cycle Assessment e Principles Framework. International Organisation for Standardisation.

[5] http://www.asphaltrubberitalia.com/

[6] http://www.ecoinvent.ch/

[7] Guinée JB, et al. Life cycle assessment: an operational guide to ISO standards. Kluwer, Amsterdam, 2001

[8] KALOUSH, K. E., WITCZAK, M. W., SOTIL, A. C., WAY, G. B. (2003) – "Laboratory Evaluation of Asphalt Rubber Mixtures Using the Dynamic Modulus (E*) Test" – Proceedings of the 82nd TRB Annual Meeting, Washington, D.C., USA.