Asphalt Rubber: how to successfully overcoming the barriers towards greater sustainability

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ABSTRACT. *Noise reduction, higher safety, durability, shorter construction times, lower maintenance costs, reduced carbon footprint , higher cost benefit ratio, saves natural resources and it is an alternative to reconstruction:the list of benefits associated to Asphalt Rubber technology exceeds the highest level of performance requirements and it is also environmentally friendly. Not only words but a fifty years old history of successful use.*

It's been twenty years since Mac Donald's patent rights expired.

Why isn't Asphalt Rubber a worldwide success yet? Especially when we look at the current market situation for oil, not to mention the almost global financial crisis.

What policy disclosure should adopt a promoter of this technology?

This paper focus on the steps to follow to actually create an important slice of market for this technology in Italy, through a global strategy which strongly involves recycled rubber producers, scientific entities, local agencies and Asphalt Rubber producers. So that this "innovation" becomes a shared tradition.

KEYWORDS: *Asphalt Rubber, waste tire, crumb rubber*

1. Introduction

The last two decades have been characterized by a widespread growth of environmental awareness. Recent climatic events (and beyond), on a global scale, have confirmed –if necessary - the need for a rapid change toward a more sustainable development. Indeed, the word "sustainability" is more and more frequently used worldwide (and often abused) to indicate *the long-term maintenance of responsibility, which has environmental, economic and social dimensions, and encompasses the concept of stewardship, the responsible management of resource use. Moving toward sustainability is a social challenge that entails, among other factors, international and national laws, urban planning and transport, local and individual lifestyles*[1]. Nowadays, the reappraisal of good old practices (like re-using and recycling used things) and the development of new technologies that save resources are topics of common interest to many sectors. The development of these so-called "green technologies" brings to the possibility of computing, case by case, the energy, CO2 and cost savings that are related to the diminished consumption of non renewable resources.

The road has been edging in that direction for many years, through the rational use of recycled materials in many diverse technical solutions. The use of RAP, secondary aggregates and crumb rubber has the undeniable advantage to save resources by recycling valuable materials that –usually- are generated not far from the road construction site. In the era of carbon emission constraints, the possible mitigation of the freight transports' footprint should not be dismissed when assessing the road construction impacts.

The Asphalt Rubber (AR) technology was developed in a time when "sustainability" was far from being a trending topic; nevertheless it is a green technology that –over time- has demonstrated to provide very good mechanical performances in all climatic conditions, to last longer than conventional asphalts and to require less maintenance. Last but not least, its mix design allows to reduce noise emissions and to optimize acoustical absorption [1].

Most of the "road construction and maintenance best practices guides" share the sustainability principles that aim to optimize the use of precious resources. It is commonly agreed that a wearing course made of poor aggregates and less than 4% of bitumen won't last long in time. It's common knowledge that its maintenance/replacement costs won't justify the initial savings.

In a moment in which most of the agencies have problems with funding because of a lack of money, a road material that presents such high performance and durability and that actually can solve several problems should be welcomed with great enthusiasm. But it is not.

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[1] wikipedia

Indeed, notwithstanding the outcomes of many local trials that confirmed the excellent performances of the AR mixes, in Italy, rubberized asphalts continue to be considered as “a new technology” and, as so, its acceptance from the Public Administration is made difficult by the disbelief of many.

Nowadays - in a time of budget restrictions – public decision makers prefer not to abandon the “old way”, even if this means the use of poor quality products that need continuous maintenance. Fortunately, there are always a few “witty spirit” and the European funding programs that push Public and Private Organizations to think different.

The former are moved by curiosity, will to explore and to test unconventional solutions to solve the usual old problems. They are the innovators that make possible a slow but unrestrainedly process of diffusion of the new technologies. On the other hand, the European programs catalyze the stakeholders’ clustering and spur the participants to propose projects that are specifically “Life Cycle Oriented”.

The development and implementation of policies that ensure the sustainable management of natural resources and waste, is one of the most recurrent themes among those covered by the EU funding programs. Scrap tires can be recycled in many ways but none of the mainstream methods suffice to recover the entire quantity generated in developed nations. Diverting waste tires from being stockpiled or illegally dumped is a priority to avoid the risk of fire and mosquito infestation (Figure 1). Nevertheless, each recycling method should be evaluated taking into account the potential energy costs and savings that are related to the whole recovery process (from cradle to grave).

Figure 1. *Discarded tires in a poorly managed landfill*

2. Asphalt Rubber in Italy

In the wake of the excellent feedback and increasing performance knowledge about this innovative and sustainable technology, the company Asphalt Rubber Italia Srl decided to introduce in 2006, first in Italy, the technology of modified binders with rubber from recycled old tires, called wet method [2] (Figure 2). Before this, several experiences were carried on with the dry method, some with good results, but the national (and European) panorama required a controlled technology that could ensure a given performance (higher) constant in time.

Figure 2. *Crumb rubber from ground tires used to produce Asphalt Rubber binder*

Following the Arizona Department of Transportation (ADOT) specification, in Italy, the AR producer began experimenting with two asphalt rubber mixes: an open graded mixture (ARFC) and a gap graded mixture (ARAC) [3]. To fully utilize AR properties, two aggregate gradations, that would provide a high voids in the mineral aggregate (VMA), have been adopted. The main effort to manage the production of AR in Italy consisted in adapting the consolidated AR technology knowledge from abroad to the Italian reality (raw materials, weather, environment, specifications, etc), starting by mixing several bitumen-base (virgin asphalt) with several type and size of crumb rubber, before finding the “optimal” blend to be tested in an industrial scale [4].

In recent years, the EU interest is directed to move toward a “recycling society”, to mitigate the urban noise and to reduce road deaths and injuries caused by car accidents. Because of the local initiatives and/or driven by EU funding opportunities, the Italian projects that study, develop and utilize the rubberized asphalts as a “sustainable resource” have recently multiplied.

Among the most recent ones, it's worth mentioning the "Progetto Leopoldo" (Regione Toscana and Università of Pisa), that assessed and optimized the safety features and the environmental sustainability of certain road pavements. Rubberized asphalts (dry and wet) have been studied and a thin friction course was optimized to provide a high friction coefficient (+10÷20% with respect to the traditional ones) and road noise reduction (from 3 to 6 dB with respect to DGHMA) [5].

The acoustic properties of rubberized asphalts (gap / open) have been analyzed in a growing number of pilot tests performed in the last 4 years. The main methods used for noise measurements have been those of "pass-by noise" or "close proximity" (CPX – ISO 11819-2). Tests carried out with measurement boxes fixed at about 4 m high to lamp-posts along the road side have shown a reduction in noise, depending on traffic speed, between 3 dB(A) and 6 dB(A) with respect to the reference road; for Open Graded mixtures a peak in the acoustical absorption can be detected, corresponding to 630 Hz (Figure 3) [6].

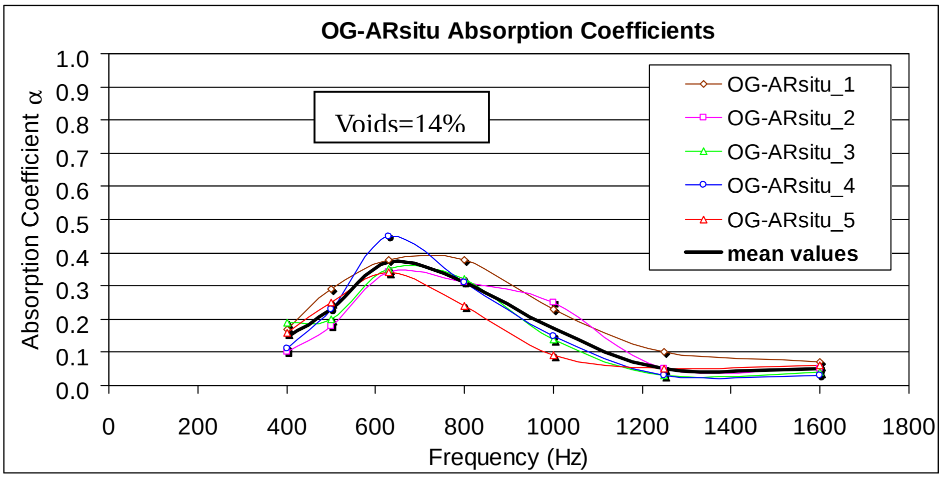

Figure 3. *Absorption coefficients of Open Graded AR mix*

One of the most interesting projects on noise reduction under progress is the "HUSH" (Harmonization of Urban noise reduction Strategies for Homogeneous action plans) project which has the aim to harmonize, at a European level, the national norms on noise management. Also in this case, rubberized asphalts have provided outstanding tire/road noise mitigation [7].

To assess the relationship between increasing vehicle speed and noise emission spectra in urban environment, an important study was carried out by Vienrose [7], that used the SPB (Statistical Pass-By Method) to gather information on vehicles transit at speeds lower and greater than 45 km/h in the same measurement location.

Acoustic data were reported on a "LAFmax-Speed" (maximum noise level) graph as shown in Figure 4. The blue lines refers to the noise emissions of vehicles on the asphalt rubber open graded pavement, the green line to those passing on conventional pavement, the red line to those related to the gap graded pavement. AR open and gap graded show a significant noise reduction, with differences that exceed 5 dB (A): an excellent result in urban environment.

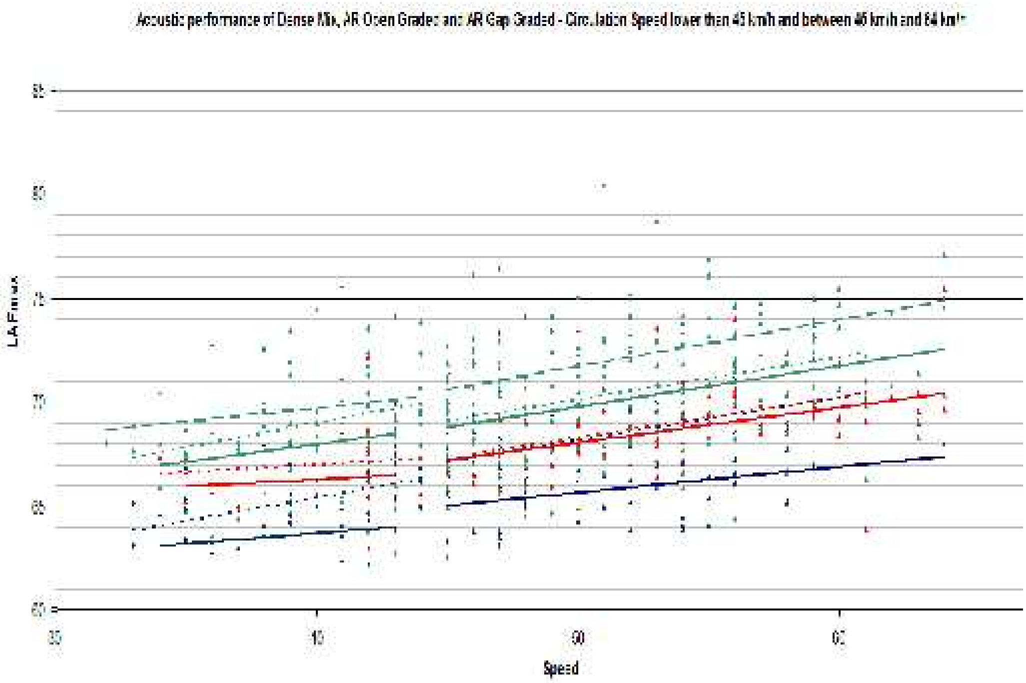

Figure 4. *Vehicle noise emission below and above 45 km/h with SPB method for Gap graded (red line) and Open graded (blue line) Asphalt Rubber Hot mixes compaired with "traditional" Dense mixes (green lines)*

Moreover, the exceptional mechanical properties of the AR mixtures have been studied by Università Politecnica delle Marche that have recently confirmed superior fatigue resistance, reduced moisture sensitivity and excellent thermal cracking sensitivity [8,9,10].

In 2009 the Province of Torino, with the scientific support of the University of Torino, has launched a development project with the aim to evaluate the use of rubberized asphalts in the roads under their administration. The project has brought to a detailed rheological analysis of asphalt rubber binders and an extensive characterization of a Gap Graded mix which has been utilized to pave, so far, 16.000 m2 of highway [11]. Notwithstanding the positive project results, the experimental phase has not yet been followed by a regular use of the tested materials. For the time being, the size of the pilot trials is far from being relevant for statistics on the "rubberization" of the italian highway network (about 5.700 Km).

Indeed, all the above mentioned studies confirmed the excellent performance of the AR technology, both in urban and highway scenarios. The Italian studies present a complete systemic approach for an evaluation aimed at the characterization of Italian Asphalt Rubber mixes and give immediate answers for producers and applicators.

Nevertheless, since 2006 till today (more than 6 years), AR has been exclusively used to make "test-sections". Never in the history of the Italian engineer, a road materials has been under such attention. Specially a "new technology" fifty years old.

But, what makes the AR hot mixes so remarkably different from the conventional asphalts? Both are made of mineral aggregates and bitumen..

..the rubber makes the difference.

3. Extended producer responsibility in Italy

In 2011, the enacting of the national Decree 82/2011 has dramatically changed the management of End of Life Tires (ELT) in Italy.

Indeed, following a consolidated European trend, the "free market" system has been replaced by a product stewardship scheme that puts the waste management under the tire manufacturers' responsibility.

Since the 7th September 2011, the tire manufacturers and importers are under the obligation to provide for the management of the quantities of ELTs equal to those put on the replacement market and intended for sale on the national territory. To comply with that obligation, the manufacturers and importers may provide for the collection and recovery of waste tires, individually or in associated forms. To this aim, the six major manufacturers/importers operating in Italy decided to associate and –in 2009- they established Ecopneus, a nonprofit company that manages about 300 Ktons ELT/year on their behalf [12].

The shift from the free market system to the EPR is mainly justified by a better control of the waste streams and is unique opportunity to encourage more sustainable recovery paths.

Until recently, about 100 Ktons/year of waste tires (25% of total ELT arising) were lost in unknown routes: sometime the ELTs were traded for being re-used abroad and very often huge quantities of ELTs were dumped and abandoned in illegal stockpiles [12].

Besides, most of the remaining ELTs (about 300 Ktons/year) were shredded or grinded to produce Tire Derived Fuel and recycled rubber (granulates and powder).

Unfortunately, the lack of a sound environmental awareness among many institutions has hampered the growth of the Green Public Procurements thus shrinking the market volumes for recycled rubber goods.

Also because of that, most of the rubber granulates and powders are sold-out abroad and the export of shredded tires to the east-Asian markets has dramatically grown in recent years (Figure 5) [13].

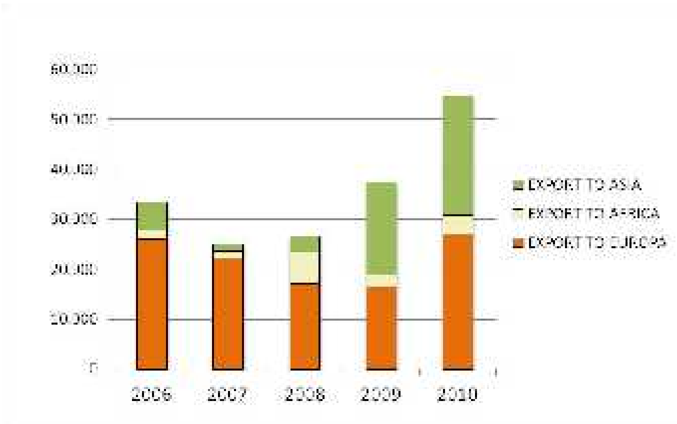

Figure 5. *Export of shredded tires from Italy (tons/year)*

As a consequence of that, most of the recyclers have lost in profitability and cut off most of the investments in Q&A, R&D and marketing actions; not surprisingly, the domestic market for recycled rubber has almost completely annihilated.

For the reasons above, the waste tire management in Italy is still driven by demand and does not show evidence of developing in a market-driven economy.

With regard to economics, the collection and treatment costs of the waste tires are not counterbalanced by the sales revenues of the recovered materials that are undersold abroad (mainly in Asian markets) and the green-fee paid by the consumers is inadequately high.

Moreover, the competitive price of the imported recycled rubber goods cannot be matched by the domestic industry and many “green products” that are currently sold in Italy are not made in Europe although they are made of recycled European rubber.

Useless to say that from an environmental standpoint, the current situation is not sustainable.

As an example, the export of 100.000 tons/year of tires (shredded tires and/or rubber fraction) from Italy to the far east, has a carbon footprint equal to 20.800 ton CO2/year. The carbon footprint is double if the recycled rubber goods are sold in the European market.

Apart from the responsibilities that have been explained above, the tire manufacturers and importers are also under the obligation to provide for R&D and training activities in order to optimize the management of end of life tires. The national legislator has recognized the need for an overall improvement of the sector and indicated the research and training as important tools for developing a green market from scratch.

3.1 Scrap tire markets, the Italian overview.

The Italian tire recycling industry is mainly composed of SMEs (Small and Medium Enterprises) with less than 25 employees and an annual turnover that does not exceed 5 millions €. For the reasons mentioned in the previous chapter, most of the Italian enterprises have invested in grinding machineries for producing crumb rubber at ambient temperature, but the production of tire derived fuel-TDF prevails in most of the cases (Figure 6) [12].

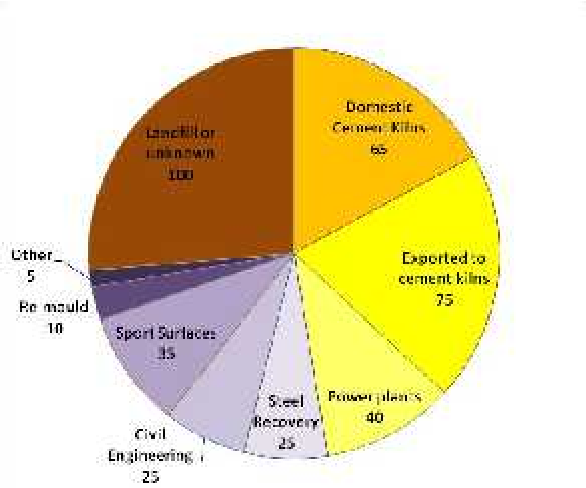

Figure 6. *Scrap Tire Markets in Italy 2010 (tons/year)*

The recovery of waste tires as a secondary fuel in cement kilns and power plants is the predominant market in Italy (more than 170 Ktons/year) and it has the highest potential for growth over the next years.

Among the other markets, the use of crumb rubber in artificial sport surfaces (artificial turf) is the most important way to valorize the recycled rubber.

Until recently and under the previous “free market”, a relevant quantity of ELTs was lost through a series of poor if not illegal practices that have spread over time in several areas of the country, causing severely negative economic and environmental consequences. In fact, to avoid paying disposal fees, huge quantities of tires have been illegally dumped for many years by individuals or by criminal organizations that collected ELTs at very competitive prices.

To overcome the problem, Ecopneus has set up a door to door collection system that is free of charge for the tire dealer or any other professional activity that generates waste tires.

3.2 The long way toward a robust and sustainable management

The new collection system introduced by Ecopneus, has rapidly increased the quantity of ELT convoyed into correct recovery paths. Unfortunately, the markets that have been developed so far for the crumb rubber are not strong enough for utilizing larger quantities. In the short term, the only possible solution is to recover most of the ELTs as secondary fuels (Figure 7) [12]. Nevertheless, based on the lessons learned over time in USA and in many other European states, a more balanced material/energy ratio is necessary for a robust and long-lasting ELT management.

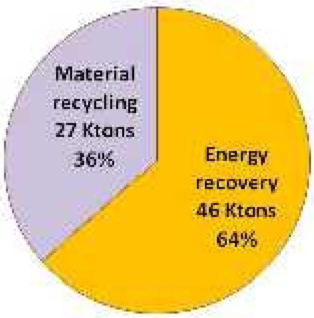

Figure 7. *Material/Energy recovery: Sept – Dec 2011*

To achieve such a market development, it is necessary to stimulate a great number of stakeholders and institutions whose actions may deliver a change.

Indeed, the weakness of the current situation has demonstrated that uncoordinated markets, driven by self-interested parties, may be unable to pursue the most sustainable solutions.

To this aim, the business networking undertaken by Ecopneus is oriented to encourage the growth of domestic markets for recycled rubber.

The “waste hierarchy” introduced by the Directive 2008/98/Ce, has indeed defined a higher rank for the material recycling that should be preferred to energy recovery. However, the hierarchy has been widely discussed and criticized as unrealistic in many cases.

In fact, only the analysis of the environmental impacts (LCA) associated with waste recovery or recycling is the proper tool for defining the most sustainable solution on a case by case basis.

Adapting the national management of End of Life Tires on the basis of case by case analysis may be difficult if not impossible and more general guidelines must be followed.

As a matter of fact, an increasing number of LCA (Life Cycle Assessment) carried out in recent years at international level have demonstrated the environmental benefits (or saved impacts) associated with the use of tire recycled rubber in substitution of other elastic materials.

Nevertheless, the assessment of the environmental impacts of Rubberized Asphalt in comparison with conventional ones lacks sometimes in consistency and the final results are affected by too many parameters for bringing to general conclusions.

Moreover, most of the Italian public investments in road works are restricted to the replacement of the top 3 cm of wearing course; therefore, the use of reduced thickness RAC overlays cannot help to demonstrate the economic and environmental favorability of the AR technology.

The greater durability of AR mixes makes it possible to save energy, resources and money even without reducing the thickness of the AR friction course but the soundness of the base layers cannot be given for granted in many situations and, as so, the expected life span is virtually unknown.

For all the above reasons, the Life Cycle Assessment of Asphalt Rubber Pavements in comparison to conventional mixes, may be misleading when the positive externalities of the tire rubber recycling are not adequately taken into account.

Nevertheless, it may be quite difficult to consider all the foreseeable changes that may happen in the development phase of a complex sector like the tire recycling industry. Few companies might grow over time causing the disappearance of small, non-efficient enterprises; the entire supply chain could be restructured as a consequence of that.

The following LCA tries to assess the “extended positive impacts” associated with the use of AR mixes by means of a comparison between the “business as usual scenario” and the possible diversion of waste tires from being exported for being recycled in Asphalt Rubber.

4. Life Cycle Assessment of an Asphalt Rubber scenario in comparison with the current ELT export scenario

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, according to the rules of international standards ISO 14040 [13]. LCA is often used to evaluate the environmental performances of two alternatives in order to support one in comparison to the other, provided the two systems are perfectly equivalent.

To compare the environmental performance of the AR technology versus a business as usual scenario, an LCA has been performed taking into account the impacts of the transboundary movement of ELTs that are not recovered in Italy. The *Business As Usual* scenario (BAU) consists of conventional asphalt paving, plus the export of the same quantity of ELTs that should be used for producing the CRM (crumb rubber modifier) in the AR scenario.

In fact, nowadays, due to the lack of domestic demand, ELTs processed in Italian facilities are often exported to east asian countries, where it can be further processed to produce ‘green’ goods, which are often sold back to the Italian market (Figure 8 and Figure 9) [13]. The energy for processing the ELTs is assumed not to be affected by the place of grinding (Asia or Italy).

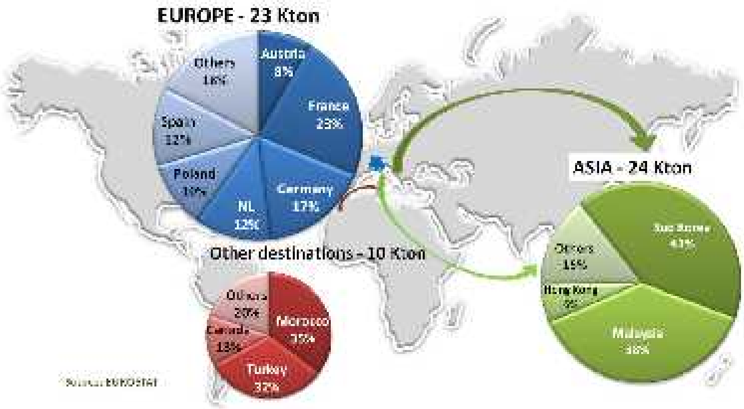

Figure 8. *Export of shredded tires in 2010*

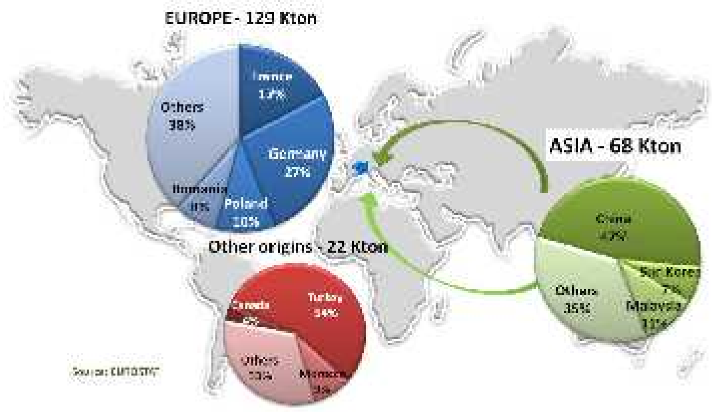

Figure 9. *Import of rubber goods in 2010*

The comparison was carried out taking into account the worst case scenario: the substitution of a conventional top layer (3 cm thick) with an AR gap graded (3 cm). The expected lifespan is 20 years for both cases and the only advantage considered is a less frequent maintenance of the AR pavement: an analysis period of 20 years was used, but the life of a treatment is 8 or 5 years, before further treatment is required.

In these conditions, the use of AR technology affords apparently only limited advantages, ranging between 5 and 10% depending on the impact category and mainly deriving from the transportation phase to and from east Asian countries. However, this finding is useful to support the development of national chain management in order to close the chain in the national territory (Figure 10).

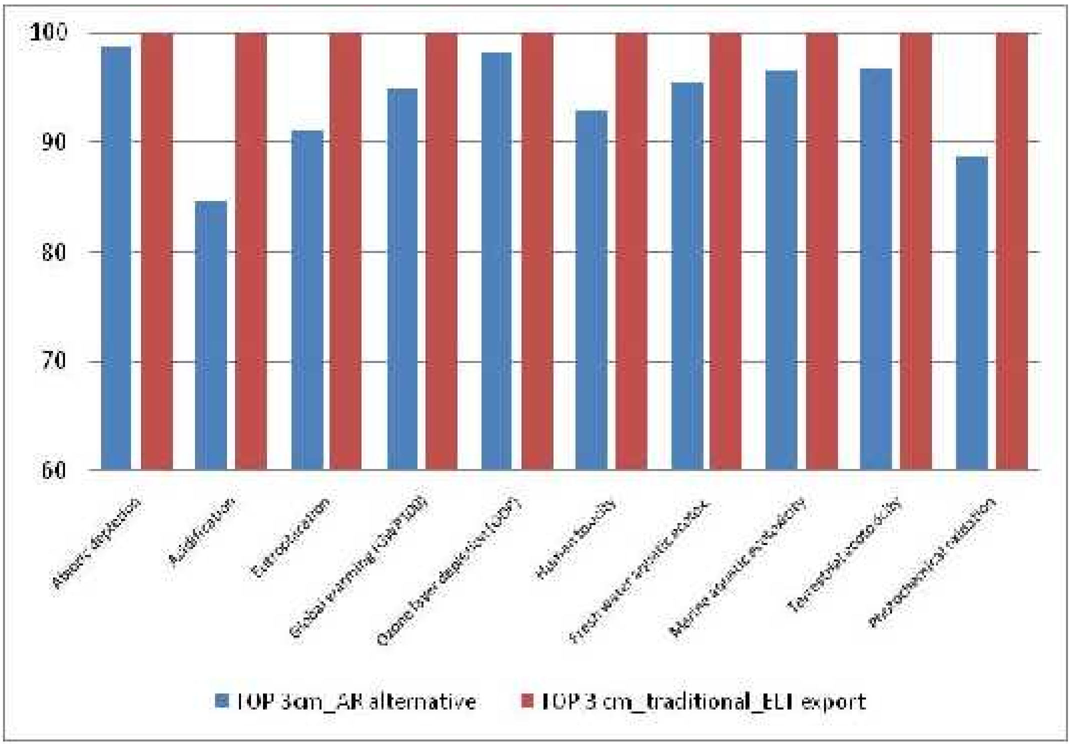

Figure 10. *Comparison of the 2 scenarios*

As shown in Figure 10, focusing on the global warming potential and acidification, which are two of the most significant environmental impact categories, since both connected to the use of fossil fuels, a deeper look into the contribution of the processes within each scenario shows larger impacts in the traditional/ELT export scenario due to the overseas transportation (transoceanic freight).

Even in the worst case scenario, when all the direct benefits of rubberized asphalts are reduced to almost zero, the positive externalities of an increased domestic utilization of the tire rubber make the AR technology an environmentally sound option.

If 1.000 lane-Km of italian roads were paved with AR mixes, the avoided transboundary movements of ELTs would result in more than 5.000 tons CO2 eq of saved emissions.

Obviously, the use of the Asphalt rubber technology offers wider advantages.

Indeed, the use of AR allows significant reduction in thickness and increases pavement life (with lower maintenance), allowing significant savings of raw materials, energy savings during the production, transportation and laying and consequently permits the reduction of VOC emissions and greenhouse gases.

Since 2006 the greenhouse gases (namely CO2) have become a greater environmental concern. This was first recognized in the Kyoto treaty and more recently ruled upon by the United States Supreme Court in a decision where CO2 was judged to be a pollutant [14, 15].

In addition to the energy and CO2 savings directly associated with the construction of thinner AR pavements, previous studies have demonstrated that AR pavements can be smoother over time; if other conditions are unchanged, the vehicles fuel consumption is lower on smooth pavements, therefore providing lower CO2 emissions from traffic [16].

5. From saving the environment to the costs saving, across the road

The following analysis considers the rehabilitation process of a road assuming that AR hot mixes are placed at approximately half the thickness of conventional hot mixes. This assumption is, anyway, conservative.

In order to illustrate the environmental benefits associated with the use of AR hot mixes, the energy and CO2 emission savings must be quantified during the whole road construction process, which consists in [17, 18]:

a) Hot mixes production (tire shredding, granulation, crumb rubber transportation, production of AR binder and blending in a hot mix plant), assuming a 3 cm thick layer of AR in spite of 6 cm of conventional dense hot mix and a plant with a 580 kW gas burner installed;

b) Hot mixes transportation. Energy savings in this phase are essentially due to the reduction of thickness of the surface layer;

c) Milling. The total fuel consumption of a typical cold milling machine must be evaluated taking into consideration the removed surface thickness;

d) Disposal of resulting materials, assuming a 10 km average distance from the job site to the landfill;

e) Natural bitumen is taken from a refinery 100 Km maximum far from the hot mix plant and aggregates from an average distance of 20 Km;

f) New pavement laying, taking into account the nominal power of each utilized machinery.

Energy costs are referred to the mass unit (kg); the density of typical AR hot mixes is considered about 2300 kg/m3, with rubber in 1.7% by weight (40 kg/m3), bitumen in 6.8% (160 kg/m3), aggregates in the remaining 91.5% (2100 kg/m3). Energy balances per m3 of surface layer have been estimated by adding real power costs tested in an existing plant; the crumb rubber modifier (CRM) production and transportation impacts have been considered in the computation, assuming that 10% on weight of the ELTs is converted in CRM.

In Table 1 the energy consumptions and savings in kWh/m3 are reported together with the related CO2 emissions, (conversion factor: 0.58 kgCO2/ kWh).

Table 1. Energy and CO_2 impacts and savings per m^3 of AR hot mix layer [17]

		Energy consumption [kWh/m^3]	**CO_2 emissions [$kgCO_2/m^3$]**	**Energy saving [kWh/m^3]**	**CO_2 emission saving [$kgCO_2/m^3$]**
CRM production and transportation	Tire transportation	56.6	32.8	-56.6	-32.8
	Shredding + Granulation	256.8	148.9	-256.8	-148.9
	CRM transportation	6.5	3.8	-6.5	-3.8
	Steel recovery	-221.4	-128.4	+221.4	+128.4
AR Hot mixes production		6.2	3.6	7.4	4.3
Aggregate saved		---	---	5683.8	3296.6
Asphalt saved		---	---	3152.7	1828.5
Hot mixes transportation		13.1	7.6	15.7	9.1
Hot mixes laying		2.9	1.7	3.0	1.7
Milling		17.7	10.3	1.9	1.1
Transport for disposal		-1.5	0.9	0.8	0.5
TOTAL		**139.89**	**81.138**	**2939.8**	**1705**

Nowadays, the oil cost per barrel (166 liters) has reached the $105. Considering that the oil low end of heat value is 40 MJ/kg (11.1 kWh/kg) and a density of 0.8 kg/m3, the energetic cost is about $18/GJ ($0.06/KWh), in the hypothesis of exploiting the whole chemical energy stored in molecular bonds and assuming no charges in cost due to oil transportation.

This means that, by using Asphalt Rubber in spite of traditional technologies, we actually can save 176 $/m3 (134 €/m3).

Moreover, two other important features should be added in the computation of energy and money savings [1]:

1. Since the skid resistance increases of about 25%, the incidence of accidents per kilometer reduces of about 20%; as a consequence, a more detailed estimation could be carried out by computing energy related to reduction in breakdown services and crashed car removals.

2. Assuming a longer lifespan of the AR pavement (+ 20%), all energy savings estimated must be increased of the same factor.

This means that AR hot mixes, in particular in rehabilitation processes and new constructions, as well as presenting better structural and functional performance, allow a significant reduction in environmental impact but also allow a considerable cost saving: actually more than 176$/m3.

6. Conclusions

Recycling of waste materials in Engineering is not a "matter of fashion": the scientific community is more and more spurred to develop technical solutions and models aimed at a reintegration process in the production of materials otherwise landfilled or stockpiled.

Traffic engineering field, more than any other, is suited to this mission, as the construction of transport infrastructures often involves large movements of materials, with volumes not easily found in other types of works.

In this paper, after a summary of the state of Asphalt Rubber technology in Italy, results of a quantitative analysis of environmental benefits arising from ground tire recycling in road pavements are shown also in terms of energy balance and CO2 savings.

The main conclusion is that: to what concerns the recycling of ground tires in road construction, environmental protection is no longer a burden but a resource.

In particular Asphalt Rubber technology provides the opportunity to improve the road network in terms of performance, service capabilities and support to local and national economies, reducing both environmental and economy costs.

Moreover, the utilization of CRM in domestic markets permits the diversion of End of Life Tyres from being exported abroad thus reducing the freight transportation impacts.

Progress in the use of recycled materials has been appreciable in the Italian community over the last 20 years. However, further developments depend on a more intense cooperation among various disciplines: industry and government, highway engineers and environmental specialists. So that Asphalt Rubber technology actually become a shared tradition.

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