Analysis of environmental sustainability in the rehabilitation of existing pavements using Asphalt Rubber hot mixes

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ABSTRACT. Asphalt Rubber is by definition a green technology, not only because it uses a recycled material but also because its mechanical performance allows pavement thickness reduction, saving natural resources and money and reducing CO_2 emissions.

This paper quantifies the main parameters connected to the study of the environmental sustainability related to the production and laying of AR hot mixes.

After a brief summary of the state of AR technology in Italy, results of a quantitative analysis of environmental benefits arising from the use of this technology are shown in terms of energy balance, highlighting the significant savings achieved under construction, in addition to the benefits of longer duration and less maintenance required for AR pavements.

Finally, it is reported, as a study case, the set of improvements solutions adopted for the rehabilitation of the Florence - Pisa – Livorno highway, where the choice of using AR technology as a rehabilitative solution was made after a detailed analysis of the environmental benefits.

KEYWORDS: Asphalt Rubber, Wet process, Energy saving, GHG saving, CO_2 emissions reduction.

1. Introduction

Noise reduction, safety, durability, shorter construction time, lower maintenance costs, lower CO_2 emissions, higher cost benefit ratio and natural resources saving: the list of benefits connected to the use of Asphalt Rubber technology exceeds the most innovative material.

The present paper focuses the environmental sustainability of this technology, since nowadays environmental factors have an increasingly decisive role in the choice of road materials.

By re-using common waste products such as rubber from old tires it is undeniable that there are numerous environmental advantages in saving energy and natural resources. Also, experience has shown that by properly combining the waste product of ground tire rubber with asphalt at high temperatures the resultant binder will make a hot mix with superior engineering properties, including reduced fatigue and reflection cracking, greater resistance to rutting, improved aging and oxidation resistance and better chip retention due to thick films [1 - 3] . Plus, Asphalt Rubber pavements have demonstrated to have lower maintenance costs, higher noise absorption, reduced splash and spray and better night-time visibility due to contrast between pavement and striping [2, 5].

From above it can be deduced that environmental benefits of AR technology are connected to several aspects during the entire pavement life cycle:

- On one side, the use of AR allows significant reduce in thickness and increases pavement life (with lower maintenance), allowing a significant saving of raw materials, saving energy during hot mix production, transport and laying, and reducing emissions of pollutants and greenhouse gases;

- On the other side, there is the recycling of old tires, the fact that AR pavements present more regular surface, which reduces consumption of vehicles and related emissions. AR friction course and open graded mixes can actually reduce noise, which can avoid the current environmental impact of sound-absorbing panels. Moreover, AR is a recyclable hot mix, whose production does not produce more fumes than traditional solutions [3].

2. The state of Asphalt Rubber technology in Italy

While in other European countries crumb rubber modified hot mixes are now commonly used, in Italy, AR technology is still considered to all affects a new technology and most of old tires are destined for burning, especially in cement industry.

The fact that the European Community since 2006 prohibits the accumulation in landfill of used tires, has revived the interest for their possible recycling in road pavements and several agencies have started to recommend the use of AR as a sustainable engineering solution.

With regard to the regulatory developments that are following the technological evolution of AR in Italy, Asphalt Rubber binder (wet method) is part of the environmental directive: "Information concerning the recycled materials and goods and articles made with recycled materials from rubber"- as the DM 203/2003 - G.U. No 173, 27 July 2005, which encourage the reuse of recycled materials in new constructions.

Since the first applications in the Italian network, in the end of 2006, AR pavements have been studied and monitored and environmental expectations by increasing the application of AR in Italy confirm the aspects introduced in the preceding paragraph.

Regarding noise, tests have demonstrated that an AR Open graded surface leads to a reduction, depending on traffic speed, of: -3 dB for speeds <50 km/h, 4 dB for speeds between 50 and 90 km/h, 6 dB over the 90 km/h [11]. Since a noise barrier is able to obtain a reduction of about 1 dB for every 60 cm in height, it’s possible to reduce or even eliminate them, with a substantial reduction of environmental impact. These considerations, already tested and proven in the U.S. and Europe, have been measured in Italy: the CIRS (Centro Interuniversitario di Ricerca Sperimentale Stradale) measured a reduction of 4.5 dB for an average speed of 40 km/h. This result was confirmed by analysis conducted by local Environmental Agency (ARPA of Tuscany), which has led to define a sound absorption coefficient equal to 0.75 for AR Open graded hot mix [11].

3. Energy quantification of environmental benefits using Asphalt Rubber hot mixes for the rehabilitation of existing pavements

To actually quantify some of the environmental benefits listed in the introduction, it is presented the environmental improvements in terms of energy savings achievable through the application of AR hot mixes, compared to traditional hot mixes.

The 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. Since this second type of benefit has already been examined in several studies, the present study only quantifies the savings during construction phase, in itself enough to convince of the environmental validity of AR solutions.

In order to illustrate energy and CO_2 emission savings, the study quantifies the energy balance of an entire rehabilitation process of a road pavement using AR hot mixes.

During the rehabilitation process it’s assumed that AR hot mixes (gap graded or open graded) are placed at approximate half the thickness of conventional hot mixes. This assumption is, anyway, conservative [1].

3.1 Overall energy balance during the rehabilitation process

In this paragraph it’s shown the analytical energy balance of the yard. The whole construction process can be divided into the following phases:

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

For each of the steps listed, consumptions and energy resources and materials are detailed, taking as reference a pavement rehabilitation with 3 cm AR Open Graded (with nominal maximum aggregate size of 12.5 mm), 4 cm AR Gap Graded (with nominal maximum aggregate size of 14 mm), SAMI in Asphalt Rubber and 30 cm recycling with foamed bitumen. This type of pavement structure as been applied several times in Italy.

The following charts illustrate each aspect of the process, highlighting their energy consumption per m³ of AR hot mix.

- *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;
- *Cold milling*: knowing the consumption of a typical cold milling machine as a function of milling thickness (as shown in Figure 1), it’s possible to determine the total consumption of fuel and, therefore, the equivalent energy consumption and CO_2 emissions;

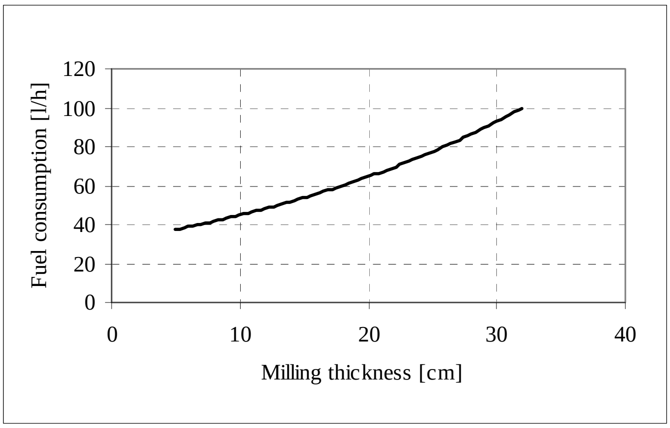


Figure 1. *Typical fuel consumption function of a cold milling machine*

- *Stabilization and recycling*: as for the milling machine, knowing the fuel consumption as a function of operating conditions, depending on the thickness to be recycled and stabilized it's possible to find the total energy consumption and associated CO_2 emissions;
- *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.

The results obtained are summarized in Table 1 and Figure 2.

Table 1. *Energy balance of the yard per unit of AR hot mixes*

Process	Energy consumption [kWh/m³]	CO_2 emissions [kg CO_2/m³]
AR hot mixes production	6.206	3.600
Hot mixes transport	13.185	7.647
Milling	17.651	10.237
Stabilization and recycling	19.214	11.144
Transport for disposal	1.953	1.133
Hot mixes laying	2.960	1.717
TOTAL	61.169	35.478

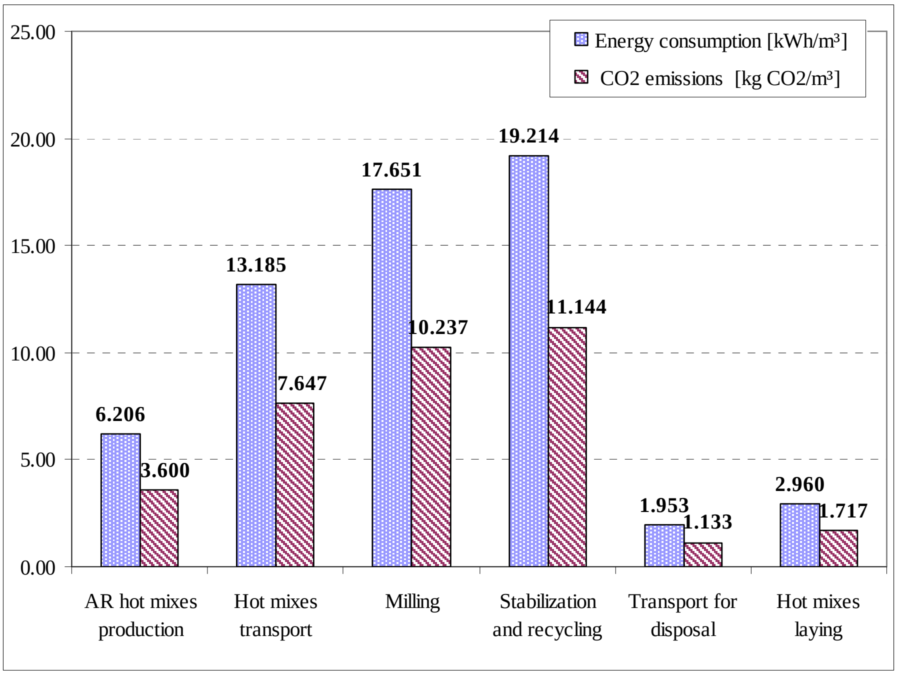


Figure 2. *Energy balance per unit of AR hot mixes*

For the entire rehabilitation process, therefore, energy consumption amount to 61.169 kWh for each m³ of AR hot mixes finally obtained, and the corresponding value of CO_2 emissions is equal to 35.478 kg CO_2/m³.

3.2 Energy saving associated to AR solutions for pavement rehabilitation

The main items that, during pavement rehabilitation, conduce to a substantial energy saving of AR applications compared with traditional solutions are:

- *Reduced hot mixes production*: this affects both in terms of production and transportation. Production was estimated assuming a plant with a 580 kW gas burner. Transport is estimated assuming, again, a 50 km average distance between plant and construction site;
- *Reduction of milling thickness*: the reduction of thickness presents the double advantage of reducing, at the same time, milling process and the amount of resulting materials. In order to calculate energy saving during milling, it was quantified the fuel saving analyzing the relative curve of consumption (as shown in figure 1). To taking into account the energy saving associated to disposal needing, it was considered a 10 km average distance from construction site and disposal landfill.

Results obtained are summarized in Table 2 and Figure 3.

Table 2. *Energy savings achieved for each m³ of AR hot mixes*

Process	Energy saving [kWh/m³]	CO_2 Emission saving [kg CO_2/m³]
Hot mixes production	7.378	4.279
Hot mixes transport	15.674	9.091
Hot mixes laying	2.960	1.717
Milling	1.873	1.086
Transport for disposal	0.766	0.444
TOTAL	28.651	16.617

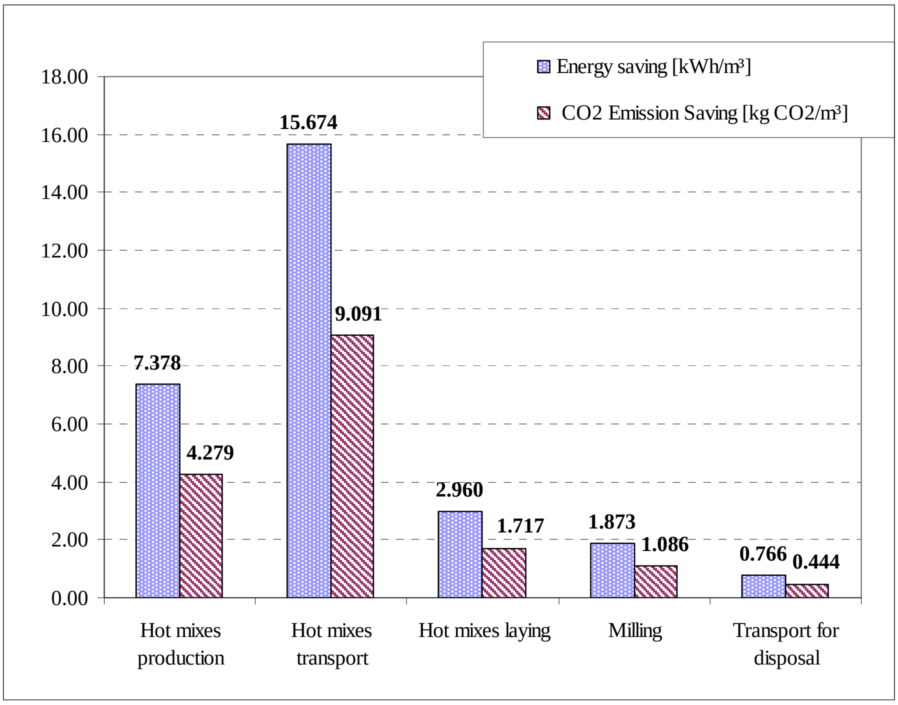


Figure 3. *Energy saving and CO_2 emission saving per unit of AR hot mixes*

Overall, using AR hot mixes instead of traditional design solutions, energy savings amount to 28.651 kWh for each m³ of AR hot mixes finally obtained, and the corresponding reduction in CO_2 emissions is equal to 16.617 kg CO_2/m³.

That savings, compared to overall energy consumption associated to the rehabilitation process, allow energy savings equal to 47%.

4. An Italian case study: the Florence-Pisa-Livorno Highway

The present case study regards the pavement rehabilitation along about 3+3 km of Florence–Pisa–Livorno highway in Tuscany.

Designed and built over many years, this highway doesn't present uniform road section characteristics along its path, but road surface width is sufficiently constant and equal to about 18.60 m.

The measures provided are aimed at improving road safety raising the performance of infrastructure. Interventions originally planned with traditional solutions consisted in:

- Removal of the existing pavement for a thickness equal about to 25-35 cm;
- Lime and/or cement stabilization;
- 30 cm of cold recycling (with foamed bitumen);
- 9 cm of traditional dense hot mix with modified bitumen (SBS medium)
- 5 cm of traditional binder hot mix with modified bitumen (SBS medium)
- 4 cm of traditional open graded hot mix with modified bitumen (SBS hard)

An improving AR solution was defined to increase performance and to implement, at the same time, a significant thickness reduction of pavement rehabilitation, with correspondent money saving.

Several researches [6 - 8] have demonstrated that, at intermediate and high temperatures, rubber stiffens the binder and increases elasticity (proportion of recoverable deformation) with the consequent reduction of temperature susceptibility and improvement in resistance to permanent deformation and fatigue.

The properties conferred to bitumen by the use of rubber as modifying agent clearly reflect on bituminous mixes manufactured with Asphalt Rubber in terms of rutting and cracking resistance compared with conventional bituminous mixtures, as showed by several studies [9, 10].

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.

The structural analysis was performed using BISAR® software by Shell Research. To find the optimal design, several possible solutions have been evaluated, choosing for the surface AR open graded hot mixes, which presents high noise-reduction characteristics, to be applied instead of the open graded hot mix originally planned. The chosen pavement solution also includes an AR SAMI that provides a durable waterproof membrane that has the necessary flexibility to withstand heavy traffic, foundation settling and climate changes. The best advantage is the increased resistance to the propagation of cracking: it allows the sealing of cracks on the existing pavement and prevents the spread to new surface layers, since it reduces the stress transmitted to the upper layers.

This SAMI membrane is formed by the application of the hot asphalt rubber mix (185º), at the rate of 2.5 Kg/m², and also by the application of chips at a rate of 10 to

12 Kg/m². The thickness of this membrane is about 1.2 to 1.5 cm, and can be considered effective for the pavement's design thickness calculation.

Considering experience with Italian road materials and characteristics of aggregates that are used in the present geographic zone and climatic database (max temperature oh 45°C and minimum of – 15°C), it was assumed for respective AR Gap-graded and Open-graded hot mixes an Elastic modulus of 4,000 and 1,700 MPa. SAMI was considered as a 15 mm layer with 3500 MPa of E modulus.

Granulometric specifications for AR materials are shown in Table 3 and Table 4.

Table 3. *Granulometric specifications for AR Gap Graded.*

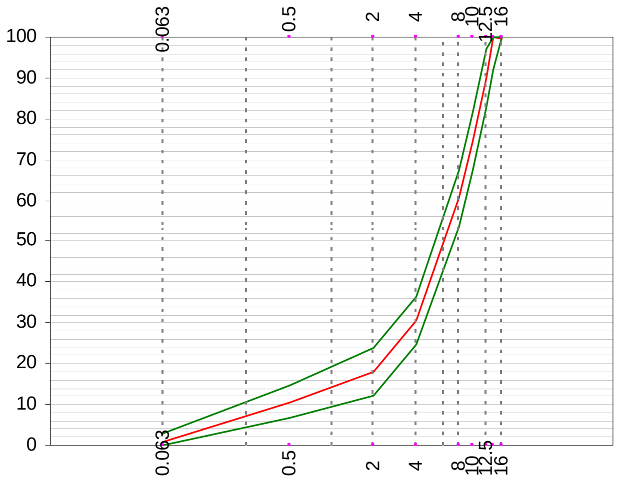
<table>
<tr><th colspan="3">Asphalt Rubber Gap Graded</th><th>MD</th><th>12.5</th><th>B</th><th>AR</th></tr>
<tr><th colspan="7">Mix (UNI EN 13108-1)</th></tr>
<tr><th colspan="3">Granulometric Composition (EN 12697-2)</th><th>Dimension (mm)</th><th>Limit (min)</th><th>Limit (max)</th><th>Regular Value</th></tr>
<tr><td colspan="3" rowspan="9">
</td><td>16</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td>14</td><td>92</td><td>100</td><td>100</td></tr>
<tr><td>12.5</td><td>83</td><td>97</td><td>90</td></tr>
<tr><td>10</td><td>68</td><td>82</td><td>75</td></tr>
<tr><td>8</td><td>54</td><td>68</td><td>61</td></tr>
<tr><td>4</td><td>25</td><td>37</td><td>31</td></tr>
<tr><td>2</td><td>12</td><td>24</td><td>18</td></tr>
<tr><td>0.5</td><td>7</td><td>15</td><td>11</td></tr>
<tr><td>0.063</td><td>0</td><td>3</td><td>1</td></tr>
<tr><td>AR BINDER CONTENT</td><td>§ 5.3.1.3</td><td>UNI EN 12697-1/39</td><td>%</td><td>MIN</td><td>7.5-8.5</td><td>8</td></tr>
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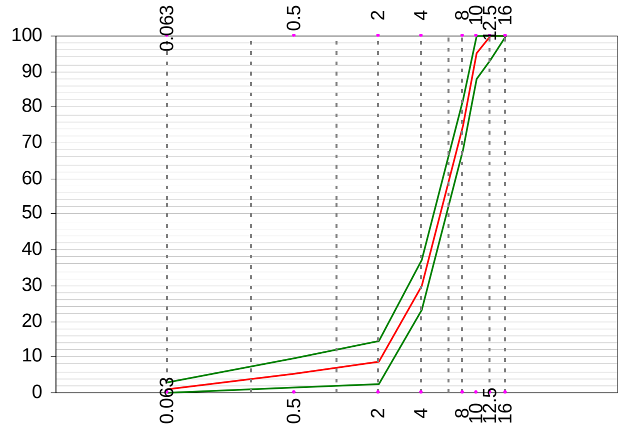
Table 4. *Granulometric specifications for AR Open Graded.*



Asphalt Rubber Open Graded			MD	12.5	B	AR
Mix (UNI EN 13108-1)						
Granulometric Composition (EN 12697-2)			**Dimension (mm)**	**Limit (min)**	**Limit (max)**	**Regular Value**
			16	100	100	100
			12.5	93	100	100
			10	88	100	95
			8	68	82	75
			4	23	37	30
			2	3	15	9
			0.5	2	10	6
			0.063	0	3	1
AR BINDER CONTENT	§ 5.3.1.3	UNI EN 12697-1/39	%	MIN	8.5-9.5	9

Design solution that delivers the best performance in terms of expected life, cost-benefit analysis and noise reduction is detailed below:

- Removal of the existing pavement for a thickness equal about to 30 cm;
- Lime and/or cement stabilization;
- 30 cm foamed bitumen cold recycling;
- AR SAMI;
- 3 cm of calcareous AR Gap Graded hot mix;
- 3 cm of basaltic AR Open Graded hot mix.

Performance comparison of original and alternative solutions considered is shown in Table 5.

Table 5. *Performance comparison of original and alternative pavement solutions performed using BISAR® software by Shell Research.*

Solutions	Total Thickness (m)	Fatigue		Permanent Deformation		Fail	Na (Shell)	Expected life [years]
		e_t	N_f	e_v	N_v			
		$*10e^{-6}$	Shell	$*10e^{-6}$	Shell			
Original solution: 4 cm Open mix + 5 cm binder SBS + 9 cm dense SBS + 30 cm Recycling + 150 Mpa	0.430	**52.7**	1.16E+08	**111.3**	6.84E+08	**Fatigue**	**1.16E+08**	**30**
Alternative 1: 3 cm AR open + 3 cm AR gap + AR SAMI + 30 cm Recycling + 150 MPa	0.375	**43.8**	6.07E+09	**149.0**	2.13E+08	**Perm. def.**	**2.13E+08**	**35**
Alternative 2: 3 cm AR open + 4 cm AR gap + AR SAMI + 25 cm Recycling + 150 MPa	0.335	**50.2**	3.09E+09	**169.8**	1.26E+08	**Perm. def.**	**1.26E+08**	**35**
Alternative 3: 3 cm AR open +5 cm AR gap + AR SAMI + 25 cm Recycling + 150 MPa	0.345	**55.5**	1.87E+09	**162.8**	1.49E+08	**Perm. def.**	**1.49E+08**	**35**

As one can see from the table, applying the traffic forecasts provided, pavement expected life obtained using the same software, parameters and laws of fatigue to all solutions was:

- 30 years for the original solution;
- 35 years for all the three alternative solutions in AR.

Considering the first AR alternative solution shown above, overall energy balance of the yard was calculated assuming the following conditions.

- Hot mixes production plant has a capacity equivalent to 220,000 kg/hours and it's powered by a two stage burner with a thermal power up to 581 kW.
- Production plant is about 65 km far from rehabilitation yard. Considering the average consumption of each truck and the ratio of CO_2 emissions of fuel (diesel), it is possible to calculate energy savings and correlated CO_2 emissions.

Results are summarized in the Table 6 and Figure 4.

Table 6. *Overall energy balance for rehabilitation yard*

Process	Energy consumption [kWh]	CO_2 Emissions [kg CO_2]
AR hot mixes production	7,894	4,579
Hot mixes transport	16,771	9,727
Milling	28,402	16,473
Stabilization and recycling	31,663	18,365
Transport for disposal of milled material not recycled	2,580	1,496
Hot mixes laying	5,006	2,903
TOTAL	92,316	53,543

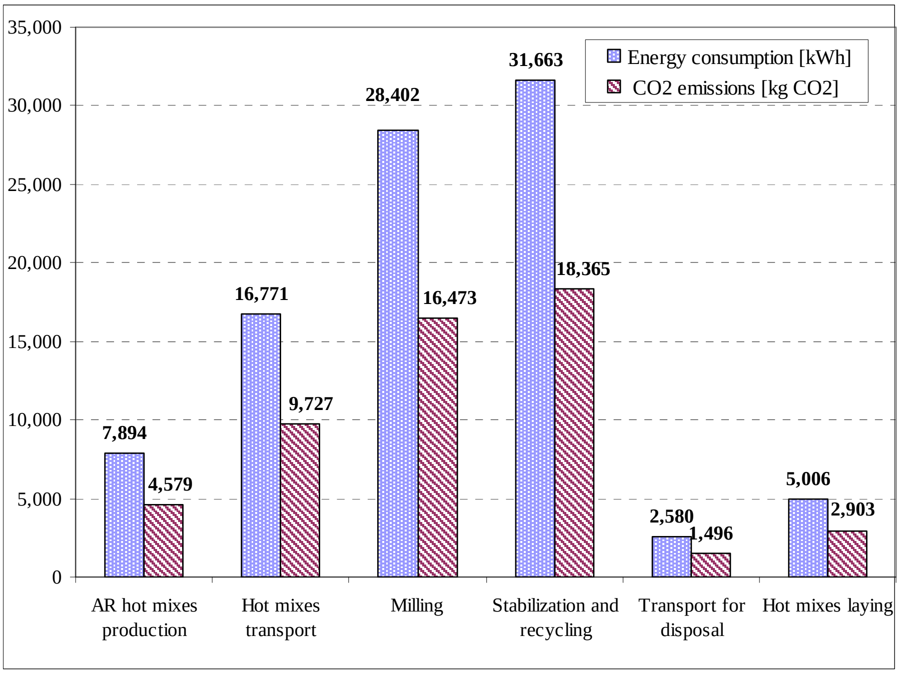


Figure 4. *Overall Energy balance for the yard*

Major savings in terms of materials quantities to be produced, transported, lay and/or disposed, are related to thickness reduction of the pavement, which allows a significant cutback in the conglomerate to be applied and in milling depth.

The respective reductions, compared with traditional solutions, of such materials quantities are:

- reduction of hot mixes produced, equal to 2,435 m³;
- reduction of milled material to be disposed of, equal to 1,793 m³.

Such production and disposal reductions lead to energy savings quantified as reported below. For example, considering the typical fuel consumption function of a cold milling machine, shown in Figure 1, it is possible to quantify energy savings resulting from the 3 cm reduction in milling thickness, as shown in Table 7.

Table 7. *Energy savings achievable by reducing the milling thickness.*

Thickness reduction (cm)	-3.0
Fuel savings per hour (l/hours)	8.0
Milling machine work capacity (m²/hours)	500
Total milling surface (m²)	21,200
Overal work time (hours)	42
Overall fuel savings (l)	340
Energy savings (kWh)	*1,551*
CO_2 reduction (kg CO_2)	*900*

Moreover, the relative reduction in the amount of milled material allows further energy savings on the transport for disposal, estimated in Table 8.

Table 8. *Energy savings achievable by reducing transport for disposal of milled material.*

Milled material reduction (m³)	636
Distance from yard to landfill [km]	10
Fuel consumption [km/l]	2.5
Overall fuel savings [l]	283
Energy savings (kWh)	*1,290*
CO_2 reduction (kg CO_2)	*748*

Overall energy savings, obtained using AR hot mixes as a more efficient alternative to traditional hot mixes, has led to the following results shown in Table 9 and Figure 5.

Table 9. *Overall energy savings achieved using AR hot mixes*

Process	Energy consumption [kWh]	CO_2 Emissions [kg CO_2]
Hot mixes production	10,526	6,105
Hot mixes transport	22,361	12,969
Hot mixes laying	5,006	2,903
Milling	1,551	900
Transport for disposal	1,290	748
TOTAL	40,734	23,626

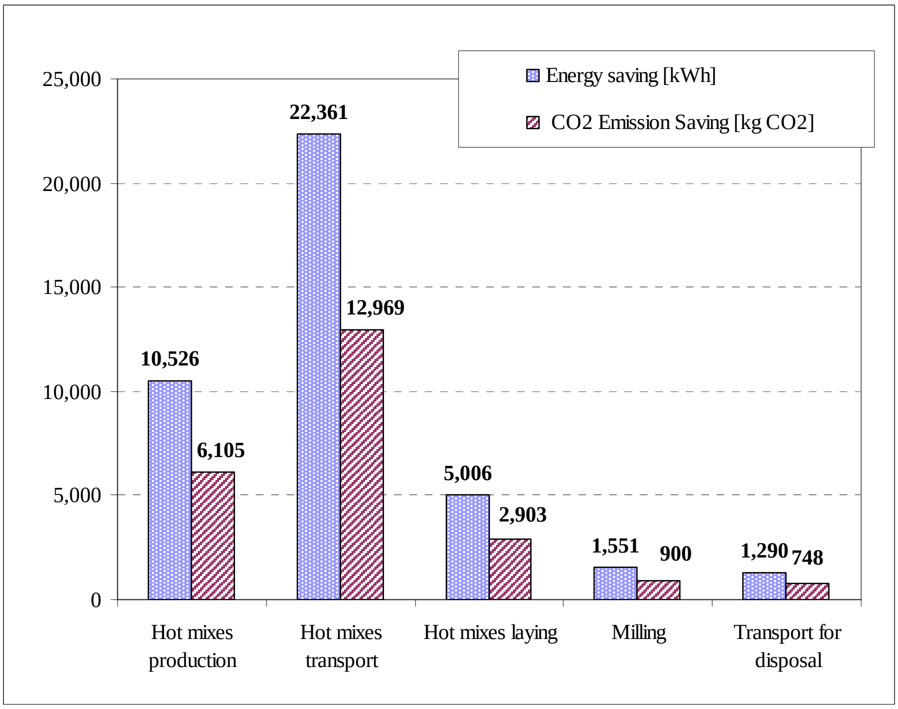


Figure 5. *Overall energy savings achieved using AR hot mixes*

Therefore, AR optimal design solutions allow energy savings equal to about half of total energy consumption resulting from the rehabilitation yard energy balance.

5. Conclusions

AR hot mixes in rehabilitation processes, as well as presenting better structural and functional performance, allow a significant reduction in environmental impact. Results of the analysis described in this article show energy savings that amount to 28.651 kWh for each m³ of AR hot mixes finally obtained, and a corresponding reduction in CO_2 emissions equal to 16.617 kg CO_2/m³.

Regarding the case-study presented, that is 3+3 km of an Italian highway, the overall energy balance for the rehabilitation yard shows a total comsumption of 92,316 kWh and a corresponding value of CO_2 emissions equal to 53,543 kg CO_2. The corresponding energy savings are equal to 40,734 kWh and the reduction in CO_2 emissions is equal to 23,626 kg CO_2, which is the equivalent of about 40,000 heavy (10%) and light (90%) vehicles emissions that travels in that highway

Therefore, the savings achievable using AR solutions instead of pavement rehabilitations with traditional hot mixes are equal to about half (44%) 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.

The alternative solution also allows a significant noise reduction due to the AR open graded sound absorption coefficient equal to 0.75, in addition to improved adhesion characteristics.

Pavement maintenance expected in the medium to long term of this package will consist in the restoration of the surface layer (3cm) where necessary, and not earlier than 8 years.

All this features lead the pubblic autority that manages the Firenze-Pisa-Livorno highway to consider the AR solution the best technical alternative for the pavement rehabilitation.

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