Action 2.3

Environmental evaluation of the use of crumb rubber from ELTs in road paving technologies in comparison with standard solutions

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Introduction

The present work intends to evaluate the environmental impact performances of innovative bituminous conglomerate, containing rubber powder recycled from End of Life Tyres (ELTs), in comparison with the traditional ones. The study is performed applying the Life Cycle Assessment (LCA), in accordance with the ISO 14040/44, on the dry and wet technologies and, for this latter, two different typologies, open-graded and gap-graded, are taken into account.

Goal and scope definition

The goal of the LCA study is to evaluate, from the environmental impacts, the production of bituminous conglomerates for road pavements. In particular, the focus is the comparison of the bituminous conglomerate, produced with rubber powder recycled, with the standard ones. The LCA study has been performed according to the ISO 14040/44.

Case study

Three different typologies of asphalt rubbers, one dry technology and two different wet solutions, have been evaluated and then compared to a standard one. Politecnico of Turin provided to CRF all specifications of these solutions in accordance with previous pavements. Table 1, Table 2, Table 3 and Table 4 show all the information of the reference pavements respectively for the standard, dry, wet (gap-graded) and wet (open-graded) technologies.

STANDARD		
Road pavement location	SP 177 Alpignano	
Paved surface	280 m long; 3,25 m wide; 4 cm thickness	
Conglomerate quantity	85775,6	kg
Plant location	Settimo Torinese (To)	
Aggregates quantity	81072,8	kg
Aggregates location	Settimo Torinese (To)	
Bitumen quantity	4702,8	kg
Bitumen location	Volpiano (To)	
Bitumen percentage	5,80%	

Table 1: standard solution

DRY		
Road pavement location	SP 177 Alpignano	
Paved surface	280 m long; 3,25 m wide; 4 cm thickness	
Conglomerate quantity	85090	kg
Plant location	Settimo Torinese (To)	
Aggregates quantity	79553,4	kg
Aggregates location	Settimo Torinese (To)	
Bitumen quantity	4741	kg
Bitumen location	Volpiano (To)	
Rubber powder quantity	795,6	kg
Rubber powder location	San Maurizio Canavese (To)	
Bitumen percentage	5,90%	

Table 2: dry solution

WET (gap-graded)		
Road pavement location	A5 - Settimo Torinese	
Paved surface	80 m long; 5 m wide; 3,3 cm thickness	
Conglomerate quantity	28718	kg
Plant location	Cuorgnè (To)	
Aggregates quantity	26665	kg
Aggregate location	Cavaglià (To)	
Base bitumen quantity	1673	kg
AR location	Agliana (Pt)	
Base bitumen location	Livorno (Li)	
Rubber powder quantity	380	kg
Rubber powder location	Terni (Tr)	
AR bitumen percentage	7,70%	

Table 3: wet (gap-graded) solution

WET (open-graded)		
Road pavement location	A5 - Settimo Torinese	
Paved surface	80 m long; 5 m wide; 3,9 cm thickness	
Conglomerate quantity	31880	kg
Plant location	Cuorgnè (To)	
Aggregates quantity	29355	kg
Aggregate location	Cavaglià (To)	
Base bitumen quantity	2058	kg
AR location	Agliana (Pt)	
Base bitumen location	Livorno (Li)	
Rubber powder quantity	467	kg
Rubber powder location	Terni (Tr)	
AR bitumen percentage	8,60%	

Table 4: wet (open-graded) solution

Besides, starting from the Eurobitumen dataset [1], Politecnico of Turin updated and then shared to CRF the bitumen eco-profile.

Functional unit

The Functional Unit is the quantity of bituminous conglomerate needed to pave the upper layer of the road, the wearing course, long 1 km, wide 5 m and with a variable thickness on the basis of the technology. In summary, the thicknesses are: 4 cm for the traditional and dry technologies, 3,3 cm and 3,9 cm respectively for the gap-graded and open-graded wet technologies.

System boundaries

The analysis follows a "cradle to gate" approach taking into account only the production process of the materials used for paving the wearing layer. Figure 1 shows the simplified system boundaries.

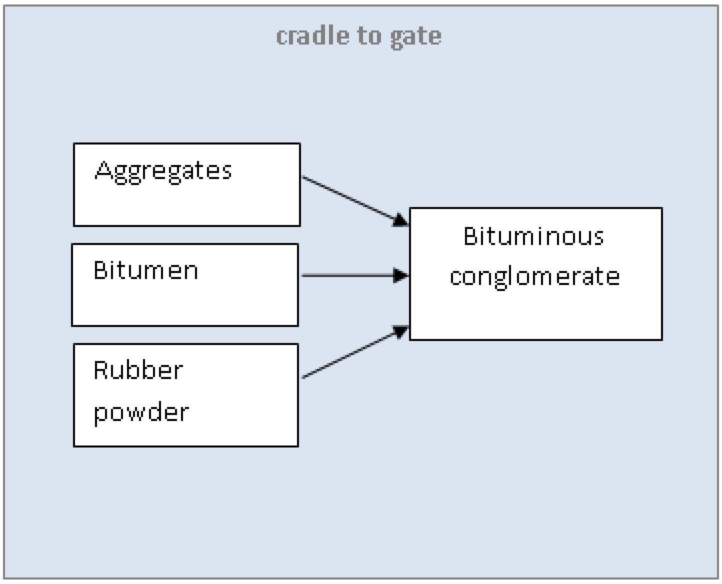

Figure 1: system boundaries

The system boundaries include the raw material extractions, production of bitumen, rubber powder recycled from ELTs, production of Asphalt Rubber (AR) bitumen and production process of bituminous conglomerate. Besides, for each step, emissions and waste management is evaluated as well.

In particular, the bitumen production process is drawn in Figure 2.

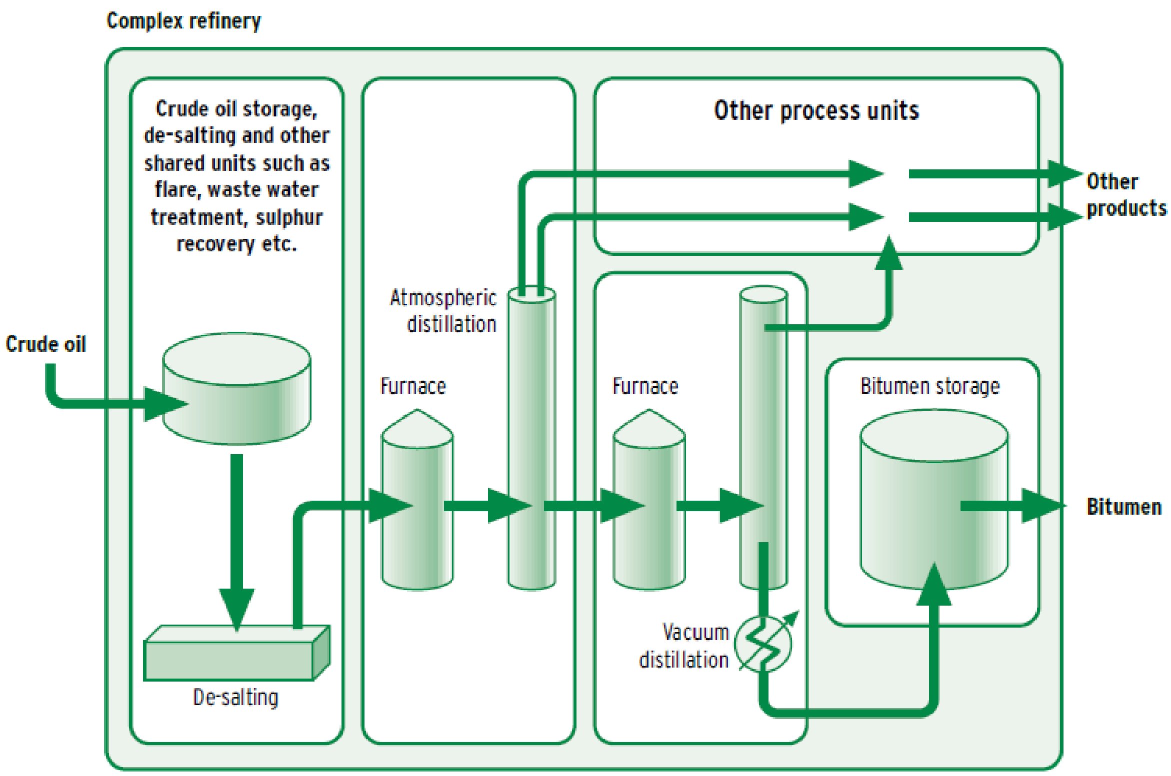

Figure 2: Straight-run distillation of bitumen within a complex refinery [1]

Assumption and limits of the study

In the analysis, the following assumptions and limits have been taken into account:

- since data come from real pavement experiences, some details about the local origin of materials were available. Anyway, such considerations have not been included in the analysis. In particular, the transportation phase has been kept out of the system boundaries in order to make a more reliable comparison between the different technologies;
- metal recycling has been evaluated by means of an economic allocation. In detail the market price ratio between the scrap and virgin metal has been used to estimate the open-loop recycling credits.

Life Cycle Inventory (LCI)

According to the ISO 14044 standard, the inventory analysis requires that the process is represented as a system and also provides a quantitative description of all flows of materials and energy across the system boundary. Data collection, reported in the following sections, has been then processed with the GaBi (version 6), LCA software to calculate the environmental impact results.

Rubber powder recycled from ELT

Starting from the LCA evaluation performed in the action 2.2, the rubber powder production from the ELT recycling has been updated with data provided by Ecopneus. In detail, Table 5 shows the material and energy data collected from plants in different regions in order to represent the Italian scenario. Afterwards, the average data have been processed with LCA software.

Granulation plant	INPUT		OUTPUT			
Location	Small ELTs (%)	Big ELTs (%)	Rubber powder (%)	Metal (%)	Textile (%)	Energy (kWh/t)
NORTH	54	46	68	21	11	230
CENTER	63	37	64	16	20	250
SOUTH	59	41	69	25	6	300
Average	59	41	67	21	12	260

Table 5: Material and energy for the ELTs pulverization process (source: Ecopneus)

In Table 6, data for the production of rubber powder starting from 1 ton of ELTs are summarized. Metals and textiles have been respectively considered as recycled and disposed in landfill.

Input	*Output*	*Amount*	*Unit*
End of Life Tyres		1000	kg
Electricity		936	MJ
Water		150	kg
Oil		0,011	kg
	Fine pulverized tyres (<0.7 mm)	672	kg
	Iron scrap	206	kg
	Textiles	122	kg

Table 6 - Amounts of inputs and outputs for the rubber powder production from ELTs

Aggregates

The bituminous conglomerates are generically blends of aggregates, bitumen. The types of aggregates used in road constructions are mainly sand, gravel and crushed stones and are extracted from mines.

In Table 7: Description of the aggregates (sand, gravel and crushed stones) productionTable 7, the production process of aggregates is explained, while Table 8 shows data collection referred to 1 ton of aggregates.

Process	***Material***
Extraction	tout venant
From the TOUT VENANT:	
Roughly screening	material > 80 mm material < 80 mm stones pre-screened (discard)
From MATERIAL with size < 80 mm:	
Sorting of natural materials	sand coarse sand material > 30 mm
From MATERIAL with size > 80 mm:	
First shredding and screening	material > 25 mm stone chipping 12-25 material < 12 mm
From MATERIAL with size > 25 mm and > 30 mm:	
Second shredding	Shredded
From SHREEDED and MATERIAL with size > 25 mm:	
Second screening	gravel 0-3 gravel 0-6 gravel 5-10 gravel 12-25

Table 7: Description of the aggregates (sand, gravel and crushed stones) production

Resources	***Quantity***	***Unit***
Electricity	5,291	kWh
Water	2,334	m^3
Diesel	0,314	l
Metal net	0,112	kg
Metal from hammers	0,060	kg
Lubricant oil	0,005	l
Rubber	0,0011	kg
Grease	0,0009	kg

Filter	0,0002	kg

Table 8: Resources consumption referred to 1 ton of aggregates

In particular, filters, used for the extraction phase, are made of: polyester fabric I (25%) and steel alloy ETH S (75%).

Bitumen

Bitumen is an oil based substance and is a crucial component in road constructions. More precisely, it is a semi-solid hydrocarbon product produced by removing the lighter fractions (such as liquid petroleum gas, petrol and diesel) from heavy crude oil during the refining process.
The Eurobitumen database provides already a datasets for this material, but, in the present work, such a dataset has been updated by Politecnico of Turin with data directly collected in the field. Table 9 shows the updated bitumen eco-profile (1 ton).

Raw materials		
Crude oil	1000	kg
Consumption of energy resources		
Natural gas	22,5	kg
Crude oil	50,5	kg
Coal	10,9	kg
Uranium	0,0003	kg
Consumption of non-energy resources		
Water	1239	l
Emissions to air		
CO_2	226167	g
SO_2	899	g
NO_x	1142	g
CO	1040	g
Ch_4	719	g
Hydrocarbon	52,4	g
NMVOC	404	g
Particulates	300	g
Emissions to water		
Chemical Oxygen Demand	675	g
Biological Oxygen Demand	511	g
Suspended solids	224	g
Hydrocarbon	150	g
Phosphrous compounds	77,4	g
Nitrogen compounds	23,7	g
Sulphur compounds	1801	g
Emissions to soil		
Hydrocarbon (oils)	155	g

Table 9: Input flows for the production of 1 ton of bitumen

Asphalt Rubber bitumen

As for the wet technology, the rubber powder is directly mixed with bitumen obtaining so the Asphalt Rubber (AR) bitumen. For such a step, it can be estimated a diesel consumption of about 18 l/ton.

Technologies of bituminous conglomerates

Starting from data coming from the real pavements, the transports have been considered (Table 10) even though they have not been included in the analysis indeed.

Technology	Aggregates	Bitumen	Rubber powder	AR Bitumen	Bituminous conglomerate
STD	Settimo Torinese (To)	Volpiano (To)	-	-	Settimo Torinese (To)
DRY	Settimo Torinese (To)	Volpiano (To)	San Maurizio Canavese (To)	-	Settimo Torinese (To)
WET (gap-graded)	Cavaglià (To)	Livorno (Li)	Terni (Tr)	Agliana (Pt)	Cuorgnè (To)
WET (open-graded)	Cavaglià (To)	Livorno (Li)	Terni (Tr)	Agliana (Pt)	Cuorgnè (To)

Table 10: Transports of materials

The material quantities have been calculated referring to the functional unit and are summarized in Table 11.

Technology	Thickness [cm]	Volume [m^3]	Aggregates [kg]	Rubber powder [kg]	Bitumen [kg]
STD	4	200	445455	0	25840
DRY	4	200	437107	4371	26049
WET (gap-graded)	3,3	165	333313	4750	20913
WET (open-graded)	3,9	195	366938	5838	25725

Table 11: Materials referred to 1 km of road

Besides, diesel consumptions of 462 l and 568 l have been calculated respectively for the gap-graded and open-graded wet technologies.

The bituminous conglomerates production process requires the energy and natural gas consumptions. Such data was collected by Politecnico of Turin through surveys and on-site visits at the Sintexcal plant in Turin and are summarized in Table 12.

Technology	Electricity [kWh]	Natural gas [m^3]
STD	2003	5090
DRY	1987	5049
WET (gap-graded)	1526	3877
WET (open-graded)	1694	4304

Table 12: Energy and natural gas consumptions referred to 1 km of road

Life Cycle Impact Assessment

Data, collected during the Inventory Analysis phase, have been processed with the LCA software to estimate the environmental impacts. To this end, several models that correlate the inventory data to the environmental impacts can be used.

Environmental impact categories

The results are referred to the environmental categories from the CML2001 method (update April 2013) and, in addition, to the total energy consumption:

- Global Warming Potential (GWP 100 years) [kg CO_2 eq.]
- Abiotic Depletion Potential (ADP elements) [kg Sb eq.]
- Abiotic Depletion Potential (ADP fossil) [MJ]
- Acidification Potential (AP) [kg SO_2 eq.]
- Eutrophication Potential (EP) [kg PO_4^{3-} eq.]
- Ozone Layer Depletion Potential (ODP) [kg R11 eq.]
- Photochemical Ozone Creation Potential (POCP) [kg C_2H_4 eq.]
- Primary Energy Demand from renewable and non-renewable resources (PED) [MJ]

Results

All the results for each technology and environmental impact are shown in Table 13.

	STD	DRY	WET (open-graded)	WET (gap-graded)
ADP elements [kg Sb eq.]	4,71E-02	4,64E-02	3,95E-02	3,56E-02
ADP fossil [MJ]	1,60E+06	1,61E+06	1,57E+06	1,30E+06
AP [kg SO_2 eq.]	1,37E+02	1,37E+02	1,33E+02	1,11E+02
EP [kg PO_4^{3-} eq.]	1,73E+01	1,92E+01	1,94E+01	1,60E+01
GWP [kg CO_2 eq.]	2,47E+04	2,66E+04	2,57E+04	2,17E+04
ODP [kg R11 eq.]	4,28E-06	-1,97E-06	-4,70E-06	-3,49E-06
POCP [kg C_2H_4 eq.]	2,21E+01	2,21E+01	2,14E+01	1,77E+01
PED [MJ]	1,77E+06	1,78E+06	1,73E+06	1,43E+06

Table 13: Overview of the environmental impact assessment for each solution

Life Cycle Interpretation

The result interpretation is one of the main phases of the LCA methodology and it allows to underline advantages and disadvantages from the solutions comparison.

Global Warming Potential (GWP)

The main environmental indicator GWP (Figure 3) shows results slightly higher, but comparable, for the dry (+7,56%) and open-graded wet (+4,11%) technologies in respect with the standard solutions. Instead, the gap-graded wet technology, which allows to reduce the thickness and so material quantity, shows an improvement of 12,41%. Comparing materials, bitumen is the main contribution affecting the GWP.

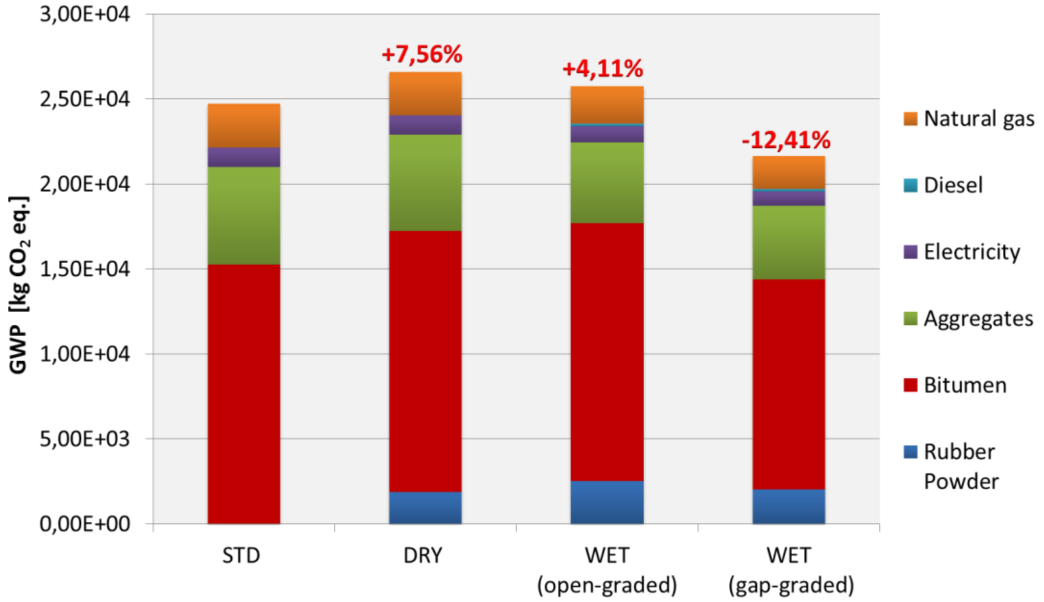

Figure 3: GWP impact for each solution compared to the standard one

Primary Energy Demand from renewable and non-renewable resources (PED)

Figure 4 shows the PED impact for each evaluated solution in comparison with the reference one. From the comparison, the wet technologies show improvements of 2,10% and 18,82% respectively for the open-graded and gap-graded solutions. The dry technology is comparable with the standard solution.

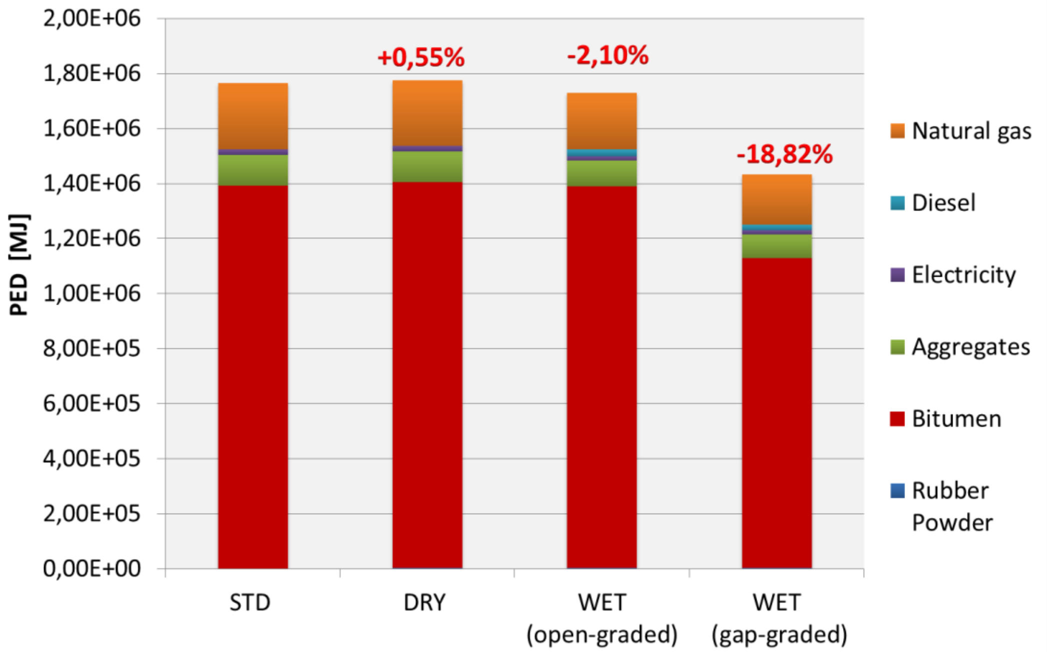

Figure 4: PED impact for each solution compared to the standard one

Ozone Depletion Potential (ODP)

Figure 5 shows high improvements for the solutions containing rubber powder recycled from ELTs. Such improvements are due to credits of steel recycling during the rubber powder production process.

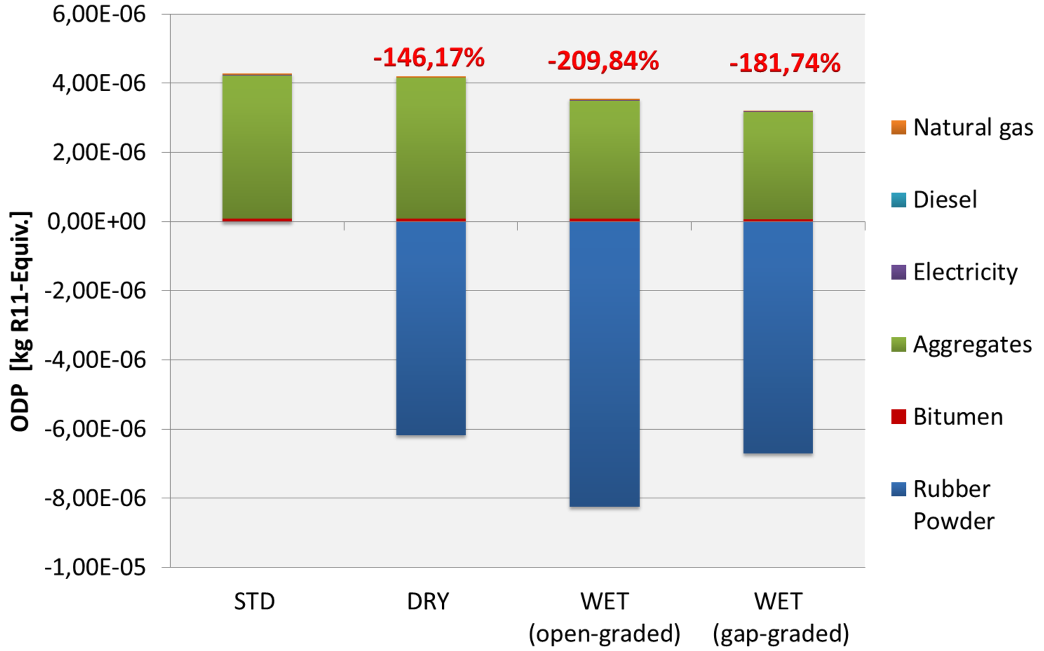

Figure 5: ODP impact for each solution compared to the standard one

Abiotic Depletion Potential elements (ADP-e)

The ADP element impact (Figure 6) improves at reducing the quantity of aggregate. The wet solutions, which use less aggregates, show an improvement of 16,13% and 24,41% respectively for the open-graded and gap-graded typologies. The dry solution is, instead, comparable with the standard one since that both are the same thickness (4 cm).

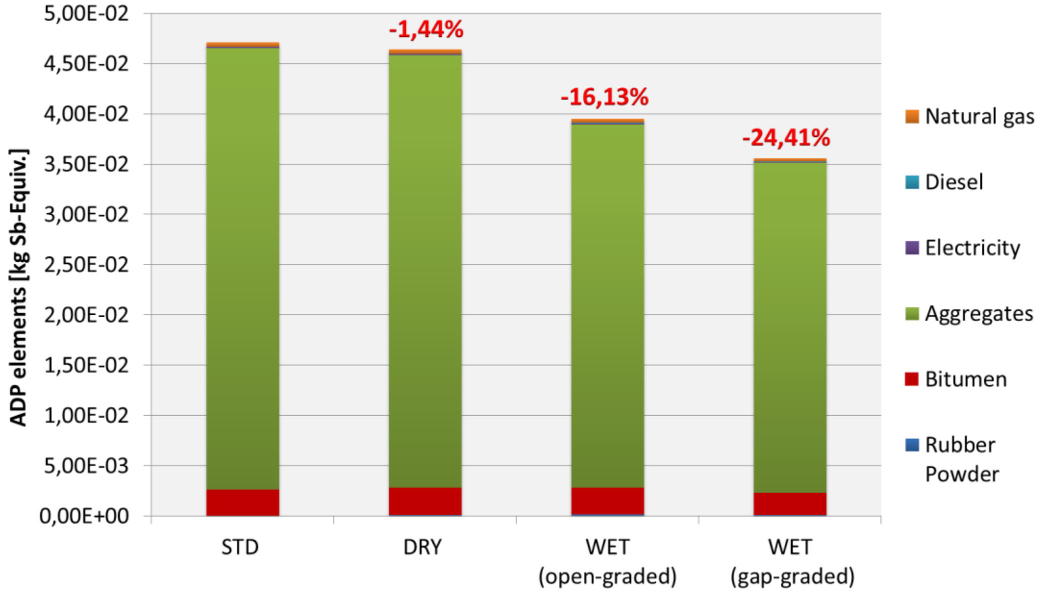

Figure 6: ADP-e impact for each solution compared to the standard one

Abiotic Depletion Potential – fossil (ADP-f)

The ADP fossil impact depends on the use of fossil resources and the production of bitumen is the main contribution affecting such an impact. Comparing the results (Figure 7), the gap-graded wet solution is the only one showing improvements (-18,92%) respect to the standard one because it is possible to use a lower thickness and so less bitumen. All other solutions, having similar thickness, are comparable to the standard solution.

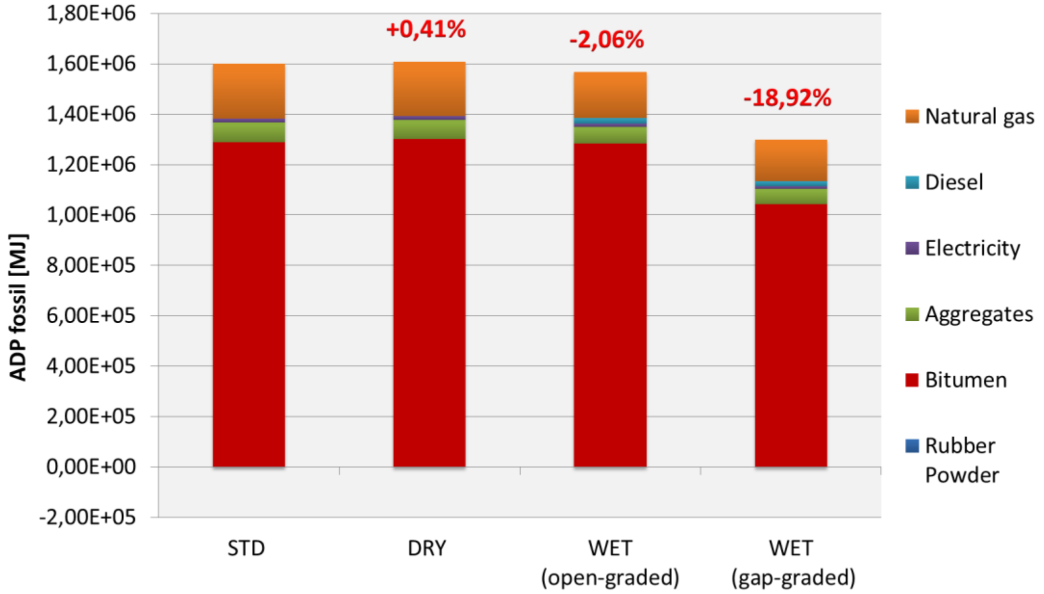

Figure 7: ADP-f impact for each solution compared to the standard one

Acidification Potential (AP)

The AP impact is affected by the bitumen production and so, as shown in Figure 8, the gap-graded wet solution, because can use less bitumen, is the only one showing improvements (-19,35%) in respect with the standard solution.

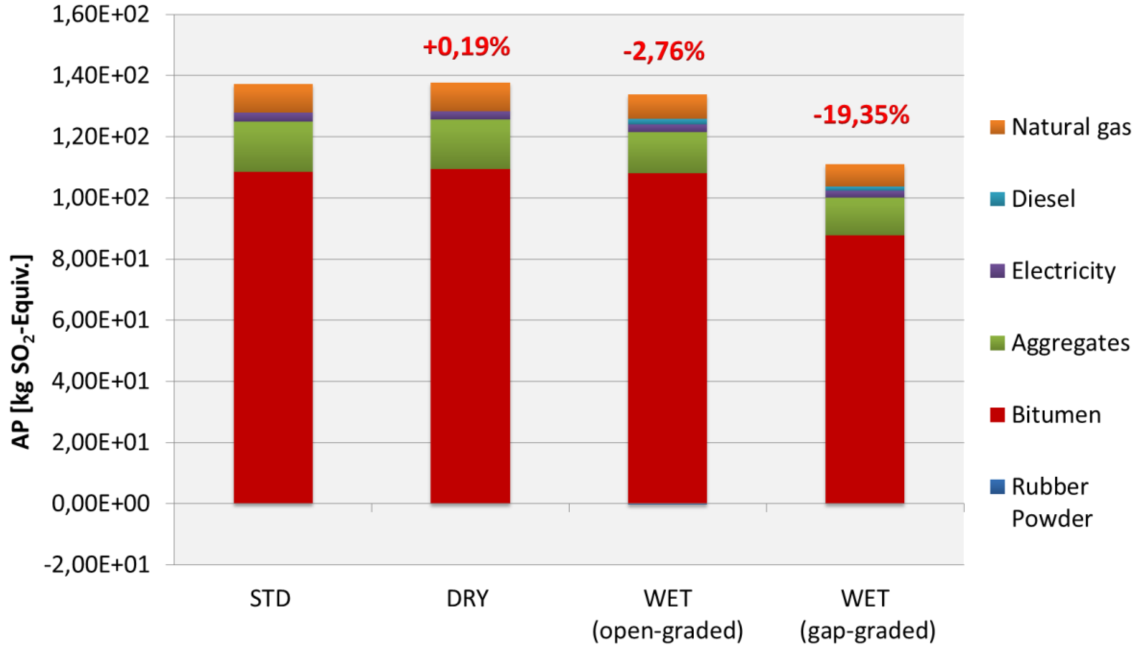

Figure 8: AP impact for each solution compared to the standard solution

Eutrophication Potential

Figure 9 shows an improvement of the EP impact only for the gap-graded wet solution (7,60%), while the other solutions are around 11% worse than the standard one.

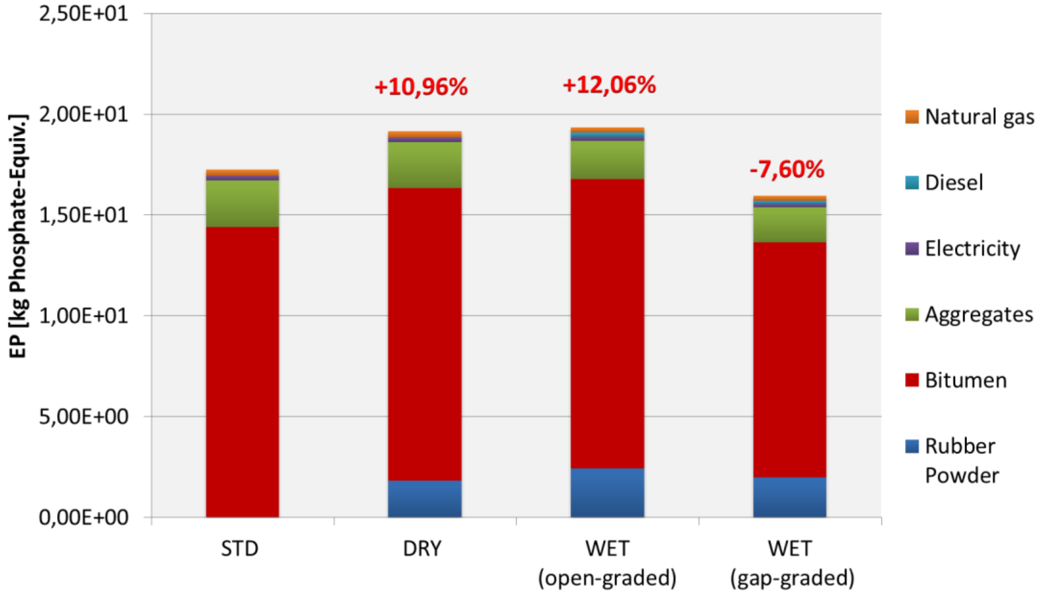

Figure 9: EP impact for each solution compared to the standard one

Photochemical Ozone Creation Potential (POCP)

The POCP impact is affected mainly by the bitumen contribution so, comparing the results (Figure 10), the gap-graded wet solution is the best one because can use less bitumen in respect with the other solutions, which are anyway comparable to the standard one.

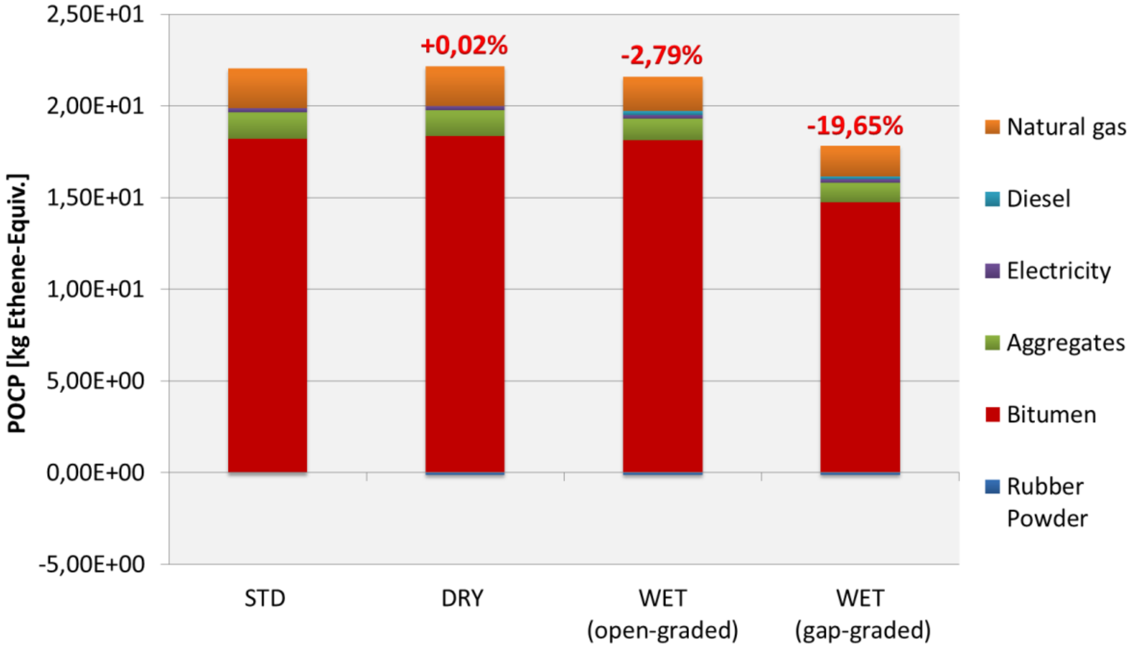

Figure 10: POCP impact for each solution compared to the standard one

Conclusions

The LCA study has shown the benefits of environmental solutions of the innovative bituminous conglomerates, containing rubber powder recycled from ELTs, in comparison with the standard one.

The dry solution results are comparable with the standard ones. In fact, such a solution is very similar to the standard materials in terms of percentage of bitumen, total quantity of conglomerate, thickness of the wearing course and so on.

Instead, the wet solution shows results better than those of the standard one because allows to reduce the thickness and so the total quantity of conglomerate needed to pave the wearing course.

In particular, the gap-graded mixture underlines remarkable benefits mainly due to the possibility of reducing the thickness, which is one of the main advantages of the AR conglomerates.

Anyway, this study dealt with the material production phase and further advantages could be possible including in the analysis also the use and maintenance phases. In fact, these kinds of bituminous conglomerates ensure, for example, a longer durability reducing so the ordinary maintenance operations.

REFERENCES

[1] LIFE CYCLE INVENTORY: BITUMEN, Eurobitume 2011 published by the European Bitumen Association

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