PROJECT FINAL REPORT

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1. FINAL PUBLISHABLE SUMMARY REPORT

1.1. Executive summary

Nowadays, traditional road materials, procedures and techniques need to increase performance but unexpected problems have a negative impact reducing its lifetime. Challenges such as extreme weather conditions due to climate change, or the significant increase of traffic flow in new freight corridors contribute to the deterioration of the road network. Consequently, pavement performance and resilience must be considered when designing and maintaining roads to avoid increase of upgrade works, reduction of the network availability and, as well, a need for additional and costly investment.

Under these aforementioned conditions, the concept of DURABROADS project arose, aiming at developing pavements adapted to new challenges and achieving an efficient, smarter and safer mobility, optimizing at the same time road pavement mechanical performance as well as minimizing the negative impact on the environment.

With this in mind, 8 work packages (6 of them technical) were carried out in order to develop innovative, cost-effective, eco-friendly, durable and resilient pavements based on innovative nanotechnology, enabling the achievement of the following main results:

- Development of a multi-criteria decision making model for the adoption by road authorities of the best surface materials and maintenance technologies.
- Assessment of the main constraints and gaps in road-related materials and procedures to achieve more cost-efficient, durable, resilient and greener roads.
- Development of a carbon black modified binder which fulfil the requirement of the standards applied for EU bitumen and behave better to ageing resistance than PMB.
- Greener and durable WMA improved with nanotechnology replacing between 65% to 97% of natural aggregates by RAP and slags.
- Evaluation of the comparative performance of road asphalt pavements incorporating DB asphalt mixes vs. conventional asphalt mixes covering different climate conditions and traffic loads.
- Definition of guidelines for the application of the DURABROADS solutions as well as introducing DURABROADS concepts within GPP processes.

A widespread dissemination of these results were possible by their promotion through 11 specialised publications (6 of them peer-reviewed), 9 articles published in the popular press, 15 international conferences and seminars, periodic newsletters, press releases and social media communications and other communication materials including an e-learning training course.

The DURABROADS project will contribute to the climate change adaptation policy of the EU as well as to the Green Economy by reducing the carbon footprint within the road sector and by creating markets for environmentally friendly products. Project context and objectives

1.2.Project context and objectives

Problems targeted

Road transport infrastructure has a great impact on economy and society in Europe and globally, since it underpins economic growth through the creation of jobs and the mobility of people and goods. However, each kilometre of road requires a large amount of materials and energy not only in its construction but also during its maintenance and rehabilitation. Hence, searching for more cost-effective, durable and eco-friendly practices and materials will lead to a tremendous impact.

Cost-effectiveness and durability of roads

The EU 27 comprises more than 5.000.000 km of paved roads and it should be noted that close to 10% of the investment structural funds in the EU for 2007-2013 period are allocated to road maintenance and rehabilitation works, as a result of the lack of long term durability of pavements

Negative effects of extreme weather conditions due to climate change, the significant increase of traffic flow in certain motorways due to the opening of freight corridors and the technical limitation of current materials and procedures are starting to have a great influence on the reduction of the asphalt pavements lifetime not only in Europe but also globally.

The continuous increase of freight traffic on an already aged road network is imposing a heavy burden on road structures leading to increasingly frequent maintenance and rehabilitation interventions. Thus, as traffic demand increases and funding becomes more limited, efficient design of more durable materials and pavement sections is of major importance.

The consequences of climate change can already be seen in Europe and worldwide and these impacts are predicted to intensify in the coming decades. Temperatures are rising, rainfall patterns are shifting, glaciers are melting, sea levels are getting higher and extreme weather resulting in hazards such as floods and droughts is becoming more common. According to the ERTRAC Research and Innovation Roadmap[2]"The road transport system is vulnerable to extreme climate events, and this vulnerability will increase in future as utilization rates go up and extreme weather events become more frequent and severe".

Intensive use of natural resources

Aggregates are the main natural resource consumed during road construction. The OECD stated that typically 10.000 m^3 of aggregates are needed for each kilometre of two-lane road constructed[3]. If it is considered that the European road network (EU27) is over five and half million kilometres long according to Eurobitume, it is easy to guess that millions tons of aggregates are needed each year to build and maintain European roads.

The use of fossil fuels is also an example of major natural resource consumption, required at every stage of road building, use, maintenance and replacement. According to the Spanish Association of Asphalt Mixtures Manufacturers (ASEFMA)[4], when working at the standard temperature of 180ºC

[2] ERTRAC (2011) Research and Innovation Roadmaps.
[3] OECD (1997), Recycling strategies for road Works
[4] ASEFMA (2005) "Mezclas semicalientes con Aspha-Min. Ecología en acción"

the consumption of fuel is 7.9 kg fuel/ton aggregate. That means approximately 158 tons of fuel consumed per km of two-lane road constructed.

These figures highlight the unsustainability of the road sector and the need of resource-efficient solutions.

DURABROADS Concept

The concept of DURABROADS project lies in the development of innovative, cost-effective and more durable designs of pavements based on new and eco-friendly nanotechnology-enhanced asphalt materials together with the optimization of road construction and rehabilitation procedures to build and rehabilitate long-life, safer and greener road infrastructures more adapted to climate change and the high freight corridor traffic loads.

DURABROADS Objectives

The overall objective is to provide a sustainable growth through the development and demonstration of cost-effective, eco-friendly, durable and resilient pavements based on innovative nanotechnology enhanced asphalts, and, through the optimization of procedures to build and rehabilitate long-life, safer and greener roads.

The **main scientific and technological objectives** are described below:

1. **Evaluation of current practices constraints and identification of best practices for the construction, maintenance and rehabilitation of the road asset.**

This objective involves the analysis of constraints concerning current road materials and procedures to withstand new road challenges (climate change impacts and the high vehicle load of freight corridors) in order to identify affordable, safer and environment-friendly practices for the management of the road asset. For analysing the existing constraints, the identification of the medium and long-term impacts of climate change and the increase of freight corridors traffic volume on the European network were performed.

2. **The development of advanced carbon-nanomaterial and carbon/polymer composite modified binders.**

The development of innovative bitumen modified with carbon nanomaterial is one of the main objectives of the project. The developed material is expected to present better physical and mechanical properties than conventional ones, such as increased durability and improved resilience to high temperatures.

3. **The development of advanced and high durable warm mix asphalts using the previously obtained binders and maximising the use of by-products and reclaimed asphalt pavement.**

DURABROADS aimed to develop advanced, cost-effective, eco-friendly and more durable Warm Asphalt Mixes for the construction of new pavement sections. These materials include the use of wastes (recycled asphalt pavement and by-products) and additives to reduce manufacturing temperature (WMA). On the other hand, DURABROADS asphalt materials will take advantage of

the improved properties enabled by the modified binders so that the mechanical properties are improved.

4. **Developing optimized and long-life pavement sections more resilient to climate change and freight corridors, using previously obtained binder and asphalt mixes.**

Cost-effective infrastructures are possible if their durability is enhanced. The optimization of road pavement sections in terms of the materials and thickness used in each layer is the key to ensure a good performance during the designed service life and a sustainable use of resources.

As explained before, the effect of current and future climate and traffic prospects will have a significant influence in the mechanical performance of the road, so this influence should be considered and implemented in the design phase. Thus, in this project, the effect of current and future climate and traffic prospects in the road pavement deterioration is assessed, including the evaluation of the improvements achieved by the new developed materials.

5. **Demonstration of the environmental benefits and economic feasibility of DURABROADS solutions.**

The new materials and techniques developed during the project needed to be validated from an environmental and economic point of view. For this reason, a Life Cycle Assessment and a Life Cycle Costing Analysis were carried out to establish the environmental characteristics of the new solutions developed compared with traditional ones and to report on the DURABROADS new material's economic competitiveness in the market, which highlight the benefits that they would bring to the costumers.

6. **Demonstration of DURABROADS most promising pavement sections by the implementation in a real case scenario.**

Changes in the material's quantities and equipment used when upscaling the production and compaction of asphalt mixes in a real roadwork can affect their behaviour. Therefore, to ensure the technical performance and economic feasibility of the new Warm Asphalt Mixes manufactured using the DURABROADS bitumen, the whole process (production, implementation and deployment of the new pavement sections developed) was shown in a realistic environment by the construction of a stretch in a real road in Spain.

7. **Definition of the criteria to include DURABROADS solutions into Green Public Procurement Procedures.**

The actual practices of green procurement procedures were evaluated and analysed in order to define the technical specifications and requirements to include DURABROADS solutions into the tender documents for the widely use of these eco-friendly mixes in the construction of roads and infrastructures.

8. **Identification of the next steps to be followed for the future standardization of the new materials developed.**

The identification of the next steps to be followed for the future standardization of the new materials developed is key to promote the fast and wide EU application of the new materials.

1.3.Main scientific and technical results

In order to achieve the objectives, the project was broken down into 8 work packages, 6 of them were technical while the other two related to the project management and dissemination of results. The list of work packages is presented below, and the structure of the project and the flow of information between the different work packages are shown in Figure 1.

- WP1: Project management.
- WP2: Evaluation and optimization of road-related materials and procedures
- WP3: Investigation and development of more suitable carbon nanomaterials for the modification of bituminous binders.
- WP4: Development of graphite-modified WMA including the use of industrial by-products and RAP.
- WP5: Development of optimized road pavements more resilient to climate change and freight corridors.
- WP6: Demonstration and validation.
- WP7: Guidelines and pre-standardization.
- WP8: Communication, dissemination and exploitation of the project results.

The project started with the evaluation in WP2 of current constraints in road-related materials and procedures to face new road challenges such as the increase of traffic and environmental loads. After this, a methodology was proposed to develop optimization criteria for the definition and selection of best practices.

Then, an intensive research was carried out in WP3, in which different nanomaterials and mixing processes were studied in order to produce an advanced carbon-nanomaterial modified binder. This bitumen was used in WP4 for the development of asphalt mixes. Thus, eco-friendly asphalt mixes incorporating the new bitumen were designed maximising the amount of recycled asphalt pavement and the amount of natural aggregates replaced by industrial by-products.

The Warm Mix Asphalts (WMA) developed in WP4 were used in WP5 for the design of long-life and more resilient pavement sections, taking into account the constraints identified in WP2. The influence of current and future climate and traffic loads on the mechanical performance of the road pavement was analysed to quantify the problem and eventually evaluate the improvements provided by the new developed materials.

The solutions proposed in the project were technical, economic and environmentally validated in WP5 and WP6 by performing an LCA and LCC analysis and by carrying out the upscaling of the production processes of the new bitumen and asphalt mixes and by implementing them in a pilot road in Spain.

Finally, and with the objective of fostering the wide acceptance and application of the proposed solutions, a number of criteria were analysed and proposed in WP7 to facilitate the inclusion of the DURABROADS environmental concepts into public procurement. In this line, the next steps to be followed for a future potential standardization of the developed materials have also been identified.

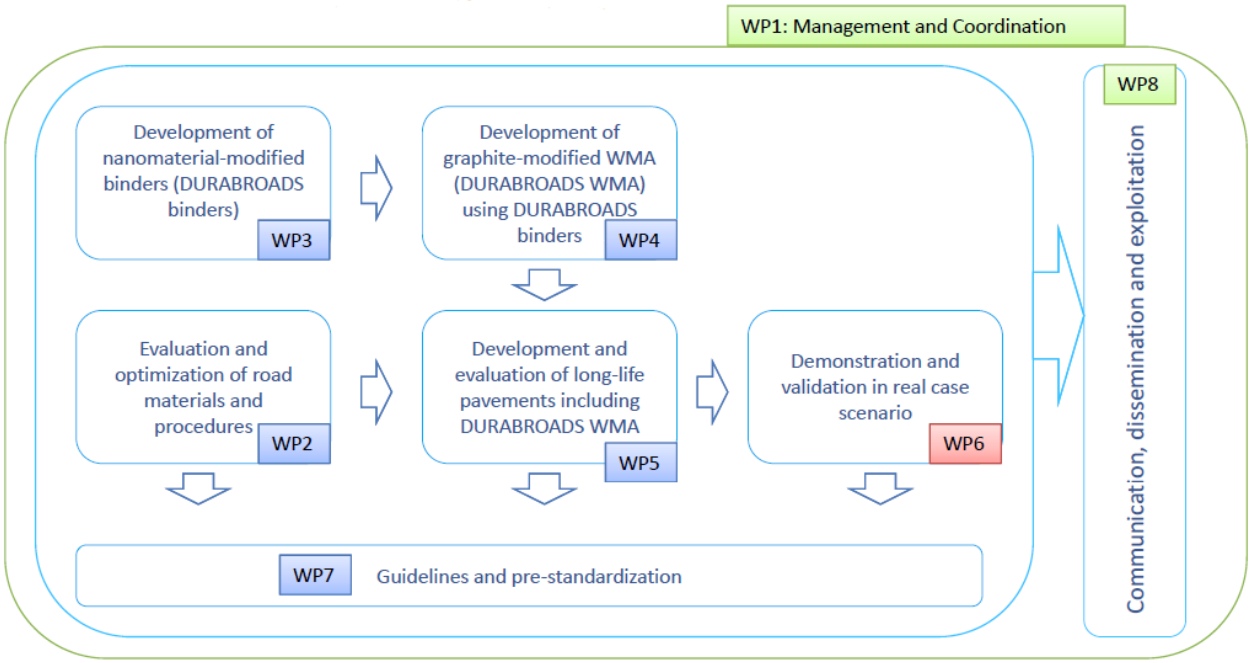


Figure 1. DURABROADS's flow chart

Following, a description of the main activities carried out in each work package and the main results obtained is presented:

1.3.1. Evaluation and optimization of road-related materials and procedures (Work Package 2)

Main Objective

The main objective of this work package was identifying and evaluating existing constraints concerning current road materials and construction, maintenance and rehabilitation procedures and techniques to withstand current road challenges (climate change and high vehicle load of freight corridors) in order to provide to highway managers with more affordable, safer and environment-friendly practices for road asset management purposes.

Work Done

For its achievement, WP2 was divided into three tasks:

Task 2.1: Quantification of the medium and long-term impacts of climate change and the implementation of freight corridors on the European road network.

For the identification of the harmful effects of increasing traffic and environmental loads on the European network, the list of actual pavement structural types on most heavily trafficked European routes were identified, and the ones which are in line with the main project ambitions were selected. Due to their different climatic and traffic features, four European regions (Northern, Western, Southern and Central Europe) were identified, and analysed separately. Then the climate change elements critical to roads were identified reviewing the region-specific pavement deterioration forms they accelerate. Next, the traffic loads on European highway freight corridors were evaluated

considering also their accelerated pavement deterioration forms. The synergistic effect of extreme climatic and mechanical loads was also scrutinised assessing the influence of vehicle load to pavement surface at extreme low and high temperature, as well as on wet pavement surface. Considering extreme traffic and climatic load combinations on European heavily-trafficked (TEN-T) roads, a comprehensive methodology – as a first phase of optimisation – was suggested for the characterisation of road-related materials, pavement design methods and rehabilitation procedures using the principles of lifetime engineering.

Results and conclusions drawn in this task were included in deliverable D2.2 "Quantification of the medium and long-term influence of climate change and of the implementation of freight corridors on European Road Network.

In addition, it should be noted that the information here collected and analysed were used in task 2.2 and 2.3 for the development of the optimization methodology.

Task 2.2: Definition of optimization criteria on durability, safety, cost-effectiveness, environment-friendliness and socio-economic factors using lifetime engineering concepts.

In this task, a multi-criteria methodology was developed aimed at assisting road managers with the selection of alternatives when considering the following two specific problems:

- Selection of asphalt surfacing materials.
- Selection of maintenance techniques.

The proposed decision-making model is based on the combination of the Analytical Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This methodology takes its inputs from knowledge acquired from literature pursuits and the opinions provided by a panel of experts in road management.

The methodology followed in this task is comprehensively described in deliverable D2.3 "Proposal of construction, maintenance and rehabilitation procedures more affordable, resilient and sustainable for the management of the road asset". Main actions carried out are outlined below:

Identification and definition of the optimization criteria to be considered for the selection of the alternatives.

To ensure meeting the principles of sustainability, several criteria were selected according to the concept of lifetime engineering. Lifetime engineering is based on using technical performance parameters such that roads are capable of fulfilling economic, environmental and social requirements throughout their whole life cycle (Sarja, 2010). These are conflicting aspects, in that the satisfaction of some of them might result in a dissatisfaction of some others. This fact justifies the need for a holistic approach based on multi-criteria decision-making theory to properly analyse them.

The following critical technical, economic, environmental and social criteria for both study cases were selected and agreed among WP2 partners.

Table 1. Decision-making tree for the selection of wearing courses

$R_{\#}$	Requirements	$C_{\#}$	Criteria	$I_{\#}$	Indicators
R_1	Economic	$C_{1.1}$	Costs	$I_{1.1.1}$	Initial Investment
				$I_{1.1.2}$	Life Cycle Cost
R_2	Environmental	$C_{2.1}$	Resources Efficiency	$I_{2.1.1}$	Aggregates Usage
				$I_{2.1.2}$	Bitumen Usage
		$C_{2.2}$	Consumptions	$I_{2.2.1}$	Energy Consumption
		$C_{2.3}$	Emissions	$I_{2.3.1}$	CO_2 emissions
R_3	Social	$C_{3.1}$	Comfort	$I_{3.1.1}$	Ride Quality
				$I_{3.1.2}$	Noise
		$C_{3.2}$	Safety	$I_{3.2.1}$	Skid Resistance
				$I_{3.2.2}$	Spray or Hydroplaning
R_4	Technical	$C_{4.1}$	Mechanical resistance	$I_{4.1.1}$	Disintegration resistance
				$I_{4.1.2}$	Deformation resistance

Table 2. Decision-making tree for the selection of road rehabilitation techniques

$R_{\#}$	Requirements	$C_{\#}$	Criteria	$I_{\#}$	Indicators
R_1	Economic	$C_{1.1}$	Costs	$I_{1.1.1}$	Initial Investment
				$I_{1.1.2}$	Life Cycle Cost
		$C_{1.2}$	Flexibility	$I_{1.2.1}$	Sensitivity to Weather
R_2	Environmental	$C_{2.1}$	Resources Efficiency	$I_{2.1.1}$	Aggregates Usage
				$I_{2.1.2}$	Bitumen Usage
		$C_{2.2}$	Consumptions	$I_{2.2.1}$	Energy Consumption
		$C_{2.3}$	Emissions	$I_{2.3.1}$	CO_2 emissions
R_3	Social	$C_{3.1}$	Comfort	$I_{3.1.1}$	Delays & Congestions
		$C_{3.2}$	Safety	$I_{3.2.1}$	Risk for Labours
R_4	Technical	$C_{4.1}$	Mechanical resistance	$I_{4.1.1}$	Disintegration resistance
				$I_{4.1.2}$	Deformation resistance

Preparation of questionnaires and collection and analysis of results.

A well-prepared questionnaire was needed for both properly characterizing the decision-making problem and capturing the knowledge provided by the experts. Therefore, two types of questionnaires were created to gather the information required.

- Questionnaire number 1: its objective was to get road stakeholders judgement with respect to the weights of the elements shown above.

- Questionnaire number 2: the objective was to get the comparative performance of the alternatives for each criterion. This survey was mainly sent to road materials experts coming from research.

Weighting of criteria.

This phase aimed to process the questionnaires sent back by the experts with respect to the weights of the elements. To this end, first the completeness of the returned questionnaires was revised to confirm their validity. After that, the consistency of the pairwise comparisons contained in the remaining questionnaires was checked.

Task 2.3: Analysis of road material specifications, and road design, construction, maintenance and rehabilitation procedures and techniques.

This task was divided into 4 subtasks, which methodology, results and conclusions are collected in deliverables D2.1 and D2.3. Main actions carried out are outlined below:

Assessment of main constraints of road related procedures.

In order to identify main gaps in road materials and procedures a questionnaire was distributed among stakeholders of several countries and it was answered by stakeholders (industry, road administration, scientific and road platforms) of 17 European countries: BE, HR, CZ, EE, FR, DE, HU, IT, LT, LV, NO, PT, SK, SI, ES, RS and UK.

The information collected was:

- Main information about each TEN-T roads in the country (traffic lanes, maximum AADT, heavy axle unit…)
- Material information of the typical highly trafficked road in the country (bitumen types, aggregates…)
- Pavement design for highly trafficked roads in the country (design methodology, consideration of local climate)

Besides, literature survey and complementary data collection were carried out in order to complete the information given by the authorities.

After compiling the information provided by experts and analysing main road distress modes in each country, main current challenges and gaps in road-related procedures were identified for each European region and were collected in deliverable D2.1.

Assessment of road-related procedures and techniques.

As explained before, two recurrent decision-making situations were addressed according to the methodology proposed and developed in task 2.2: 1) the selection of asphalt surfacing and 2) the selection of maintenance/rehabilitation techniques.

The alternatives for both case studies were selected from the typical materials and techniques used in European countries (according to the information collected before):

- Typical wearing course types: Asphalt concrete (AC), Stone Matrix Asphalt (SMA), Porous asphalt (PA), Hot Rolled Asphalt (HRA) and Betón Bitumineux Très Mince (BBTM)

- The typical maintenance and rehabilitation technique are: Double chip seal (DCS), Microsurfacing (MS), Thin HMA overlay (THMA), HMA overlay (OV), Mill and overlay (MOV), Hot-in-place recycling (HIR), Cold-in-place recycling (CIR) and Full depth reclamation (FDR).

The aim of this step was to rank alternatives from the processing of their ratings with respect to each of the criteria defined in task 2.2.

Benchmarking of road-related procedures and techniques.

Following the multi-criteria methodology developed in this WP, the alternatives for the two problems addressed can be ranked. Results obtained are summarized next:

1) Multi-criteria optimization of asphalt surfacing materials: The final ranking of alternatives obtained is:

SMA>HRA>BBTM>AC>PA.

2) Multi-criteria optimization of maintenance and rehabilitation techniques: Although the differences between the alternatives are not as obvious as with asphalt surfacing options, a ranking can be established according to the most likely performances:

Preventive maintenance THMA>MS>DCS

Corrective/rehabilitation maintenance MOV>FDR>CIR>OV>HIR

Sensitivity analysis

In the context of the decision-making model proposed in this study, sensitivity analysis consists of determining how and how much specific changes in the weights of criteria and ratings of alternatives modify the results.

In this study, the sensitivity analysis was conducted to assess the effects of climate change and possible traffic evolution in the final ranking of alternatives provided by the TOPSIS method.

Five scenarios were proposed in order to evaluate the impact of both climate change and traffic loads in different European regions. Results for the selection of wearing courses reaffirm the supremacy of SMA, decreasing its superiority only when considering the long-term consideration of climate change in Southern countries.

Main scientific and technical results

- Identification and evaluation of the harmful effects of increasing traffic and environmental loads on the European network (Deliverable D2.2 and D2.3).
- Assessment of the main constraints and gaps in road-related materials and procedures to achieve more cost-efficient, durable, resilient and greener roads (Deliverable D2.1).
- A Multi-criteria optimization methodology has been developed for assisting road managers with the selection of alternatives in decision-making problems within the road pavement sector (included in D2.3). This methodology has been implemented for two specific cases:
    - Selection of optimal road surface material for its use in freight corridors.

- Selection of optimal road maintenance techniques according to the proposed criteria.

- Technical, economic, environmental and social criteria have been defined and weighted considering road pavement stakeholders judgement (included in D2.3).
- Most typical asphalt surfacing materials used in Europe have been assessed, compared and rated according to their technical, economic, environmental and social performance (included in D2.3).
- Most typical maintenance techniques used in Europe have been assessed, compared and rated according to their technical, economic, environmental and social performance (included in D2.3).
- 5 scientific peer-reviewed papers.

1.3.2. Investigation and development of more suitable carbon nanomaterials for the modification of binders (Work package 3)

Main Objective

The general objective of WP3 was the development and characterization of graphite-modified binder to be used in greener, cost-effective and more durable asphalt materials.

Work Done

The WP was divided into 4 tasks:

Task 3.1: Analysis and characterization of the most suitable carbon nanomaterials for binder modification. Size, quality and geometry.

During this task, the size, shape and quality of graphite nanoplatelets (GNPs) were investigated resulting from different synthesis methods and sources, in order to find out the most suitable oriented to the target application: high-performing additive for bitumen and polymeric matrices. The work carried out in this task as well as the results and conclusions are collected in deliverable D3.1.

The activities carried out in this task are:

Literature review concerning the compatibility and processability of carbon nanomaterials with polymers

Based on the information found during this review, exfoliated graphite nanoplates (xGNP) seemed to be suitable for blending with SBS in terms of compatibility and processability. Concerning the shape, they resembled other layered, sheet-like mineral materials like organophillic montmorillonite (OMMT), which had already been used as filler to raise properties like the softening point of PMB. Like montmorillonite, the layers of xGNP needed to be separated for improvement. From the economic point of view, xGNP were also much cheaper than carbon nanotubes (economic aspect).

Literature review concerning the compatibility and processability of carbon nanomaterials and bitumen

Carbon materials with a layered- or flake-like- shape structure seemed suitable for the modification of bitumen and PMB if the processability criteria and the starting materials properties are considered.

As exfoliated graphite nanoplatelets (GNP) and graphite flakes fulfilled these criteria, they seemed suitable for the improvement of the properties of bitumen and PMB. Besides, in comparison to other carbon nanomaterials like carbon nanotubes, their prices were modest (xGNP 61-64 €/kg, Graphite flakes: 90 €/kg).

Other possibly suitable carbon-nanomaterials were Expanded Graphite (EG) and Graphite Oxide (GO). EG and GO could be suitable, as their structure resembles a fraction of bitumen. However, the high price for commercially available GO (starting from 120 €/g) made it inappropriate with respect to the criterion of economic aspects.

Selection of the most suitable carbon nanomaterials for binder modification

In order to address the objectives of WP3, three different approaches were followed. On the one hand, the following carbon nanomaterials were selected from the literature review carried out:

- Exfoliated Graphite nanoplatelets:
- Graphite microflakes
- Expanded graphites (EG), produced from 2 Expandable graphites.
- Graphite oxide (GO), made from expanded graphite received from expandable graphite.

On the other hand, the use of graphene nanosheets was proposed to be used into the bitumen (so called bitumen "concentrates"). Previous know-how suggested that cost-effective graphene nanosheets could be obtained from natural graphite powder and effectively dispersed into the bitumen. Bitumen concentrates containing graphene nanosheets were prepared through different procedures.

Additionally, as part of the contingency plan, 2 other materials were also studied: carbon black (CB) and nitrogen-doped graphene.

Characterization of the selected carbon nanomaterial

For the characterization of carbon nanomaterials as starting materials, not only size, shape and quality (graphitic grade, polarity) have to be determined. As the blending of carbon nanomaterials and polymer, bitumen and PMB occurs by heating/melting of the matrix materials, it was also necessary to investigate the behaviour of the carbon nanomaterials at the processing temperatures (~150-160°C) and above. Thus, they were analysed using the following methods:

- Optical Microscopy,
- Single Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectroscopy (EDX),
- Differential Scanning Calorimetry (DSC),
- Thermogravimetric Analysis (TGA),
- X-ray Diffractometry (XRD).

The nanoparticles in the second approach mentioned above were generated directly (*in situ*) in bitumen because the impossibility of isolating the nanoparticles from the bitumen-nanoparticle

mixture. Thus, a characterisation of these particles using the enlisted analytical methods was not possible. These concentrates were characterised directly in task 3.3.

The analyses confirmed the platelet/flake-like structure of the materials, their graphite (crystal) structure and their thermal stability in the temperature range of 150-160°C (where bitumen blends were prepared). Taking into account results from literature, these carbon (nano) materials seemed suitable concerning size, shape, quality and compatibility to improve bitumen.

Task 3.2: Investigation of the bonding interaction between the most common polymers used in asphalt production and carbon nanomaterials.

This task looked for the development and evaluation of new composites made of carbon nanomaterials and polymeric matrices.

The "functionalization" of the carbon materials in WP3 was not only limited to a chemical functionalization (where additional chemical functional groups on the surface of the materials are generated), but also included the processing of the graphite materials with polymer.

Three approaches were considered:

Method 1. GNP-Polymer Compounding via Extrusion

For this study, the melt blending (extrusion) procedure was selected for the industrial scale, as it allows traditional mixing equipment like extruders of two-roll milling to be used.

Regarding the selection of the Polymer for GNP-Polymer compounding, the Styrene-Butadiene-Styrene (SBS) was selected because it was confirmed that the SBS can extremely improve the mechanical properties of bituminous mixtures such as ageing, permanent deformation, low temperature cracking and moisture damage resistance.

In the extrusion process, the polymer material is melted and moves towards a screw mechanism. The polymer is compounded with the graphite nanoparticles when the mixture is forced to advance through the extruder cavity and is pushed through the die. After exiting the die, the compound is cooled in a water-bath, solidifies and is cut obtaining the finished "Nano+Polymer" (NP) pellets, referred to as Blends "NP" (Blend of Nanomaterial with Polymer).

Firstly, composites with 2% of Nanomaterial (nanographite particles) and 3% of SBS polymer in the bitumen were considered, what required the preparation of blends of 40% nano in SBS polymer. However, this high percentage of "Nano" made unfeasible the preparation of the blend.

Secondly, the percentage of nanomaterial was reduced to achieve the production of new blends with 20% of nano in SBS polymer (Blend "NP-20"), but no compound was achieved after several trials.

Finally, by decreasing the amount of graphite Nanoplatelets (N) in extrusion compounding, the preparation of the following compounds was achieved:

- Blend "NP-10", 10% of graphite Nanoplatelets (N) in SBS polymer, and
- Blend "NP-6", 6% of graphite Nanoplatelets (N) in SBS polymer. This concentration was selected as suitable concentration to produce nanomaterial polymer blends via extrusion.

Due to the difficulty of carrying out the extrusion procedure of graphite xGnP nanoplatelets at higher concentration in SBS, this strategy was considered to be not suitable.

Method 2: Preparation of expanded graphite and synthesis of graphite-oxide (GO) from expanded graphite

For the production of expandable graphite, typically sulphuric or nitric acid are intercalated into the crystal layers of large natural graphite flakes. The intercalation leads also to an increase of the layer distance. On heating, the graphite layers suddenly expand, due to a sudden vaporisation of the intercalated substance. When the graphite flakes increase their volume several hundredfold in comparison to their original volume, expanded graphite is formed.

Like expandable graphite, graphite oxide (GO) is also typically made starting from natural flake graphite. Apart from flake graphite, also commercially expanded graphite is used. Besides nitric and sulphuric acid additional oxidants are employed. If the GO is exfoliated/delaminated afterwards into sheets (by ultrasonication), the then formed product consisting of a single layer is called graphene oxide, which can be purified by centrifugation. GO can be reduced to graphene in a further step. The so made graphene is usually called (chemically converted) graphene (CCG) or called reduced graphene oxide (rGO).

All synthesis procedures are deeply described in the deliverable D3.2 and more details of expanded graphite and graphite oxide are included in the deliverable D3.4.

Method 3. In-situ activated graphene concentrates

A new process developed by Norwegian Graphite AS allows the preparation of graphene nanosheets from natural graphite in a scalable manner at mild conditions. The resultant material is mixed/ activated into a graphene-in-bitumen concentrate. This concentrate (or pre-mix) can be diluted into more bitumen.

These materials were characterised by scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), Raman spectroscopy and X-ray photoelectron spectroscopy (XPS).

Preparation and characterisation of samples is described in the deliverable D3.2.

Task 3.3: Investigation of different compounds and mixing processes used for the production of bituminous binders.

The following scenarios were defined for the production of the different modified-bitumen (all production details about the preparation of the modified bitumen, characterisation and additional explanations are shown in the deliverable D3.3):

SCENARIO A "Based on powders in Bitumen":

Graphite nanoparticles in powder form are directly blended with bitumen (B) and/or polymer modified bitumen (PMB). Powder nanomaterial is added in such amounts that final comparatively low nanomaterial concentrations in bitumen are achieved.

Two different approaches were carried out in order to obtain firstly a concentrate of nanoparticles in different carriers. Depending on the matrix materials in those concentrates, we can distinguish:

SCENARIO B "Based on concentrates of nanomaterial in polymer and in bitumen":

The objective in this scenario was to study the dispersion process in a polymer matrix (SBS). In this medium the processing conditions are different to the ones achieved in direct bitumen dispersions. Process conditions were adjusted to promote the exfoliation of the nanomaterials. Those concentrates were also made to investigate the interaction of the powder nanomaterial with the polymer. This aspect is discussed in detail in the deliverable D3.2.

SCENARIO C "Based on concentrates of nanomaterial in bitumen":

There are dispersed graphene nanosheets in bitumen. The dispersions can be considered as concentrates of nanomaterial in bitumen. The difference from SCENARIO A is that, in this case, nanomaterial is generated *in situ* in a bituminous medium, and furthermore organically modified. Due to its *in situ* generation, this nanomaterial does not exist as isolated powder.

Scenarios B and C were designated to be diluted with bitumen. The aim of the use of already nano-scaled powder, on the one side, and the concentrates in polymer and bitumen, on the other side, was to find out which way of preparation leads to an optimized exfoliation and distribution of nanomaterial in bitumen and, finally, to improved properties. However, the mechanical and rheological results were not as successful as expected, which was the reason why another 2 scenarios (D and E) were defined:

SCENARIO D" Based on carbon black in bitumen":

Bitumen D I and II were selected as the most promising modified bitumens extracted from the research and development of modified bitumen from carbon black.

- Bitumen D I, with CB and low SBS content and which meets requirements for a polymer modified bitumen 45/80-60.
- Bitumen D II, with CB and high SBS content, which offers similar performance to Highly Modified Binders and fall into the category of PMB 45/80-75.

SCENARIO E "Based on nitrogen-doped graphene in bitumen":

- Bitumen E (N-Graphene/Bitumen-A) was selected as the most promising modified bitumen extracted from the search and development of modified bitumen from nitrogen-doped graphene and/or from graphite oxide.

In these cases, results showed that:

- Bitumen D I and Bitumen D II fulfil the requirement of the standards applied for Bitumens, and both offer a performance at least comparable or better than commercial bitumens (references PBM and conventional Bitumen).
- In terms of production costs Bitumen D I is less expensive than Bitumen D II.
- Bitumen E does not fulfil all the requirements of the standards, especially offers a penetration grade too low and values of the elastic recovery lower than expected for a PMB.

As general conclusion of the study, it can be said that for the scenarios A, B and C in some cases for individual properties of the bitumen blends a slight improvement of individual properties could be found, but these positive aspects were not strong enough for justifying commercial use. The scenario E showed some improvement of elastic recovery, but not strong enough to compensate the properties of a PMB. It seemed that a chemical modification of graphite – as it was tried here in the graphite oxide approach – could be a suitable way. However, the effort for this seemed to be currently too expensive for commercial use. These results were in contrast to some ones in literature publications: It seemed that, for example, improvements of the pen grade in these publications could be due more to an oxidation of bitumen during the blending, than to the addition of graphite particles. The results also showed that the improvement of a natural product with a complicated and varying composition like bitumen is still challenging.

Finally, the use of carbon black (Scenario D) as an alternative of graphite/graphene materials, gave the best results. From these blends, the DURABROADS BITUMEN, as “Bitumen I “named blend, was thus chosen for the use in the subsequent WPs.

Task 3.4: Analysis of the preliminary up-scaling of the selected bitumen.

Taking into account previous Task 3.3 and the results of the deliverable D3.3, this task focused on preliminary conclusions on modified asphalt upscaling process. For all graphite-based nanomaterials as fillers the same target exists: to exfoliate individual or few layers and to achieve and maintain their homogenous dispersion in the bitumen matrix (without oxidizing the bitumen or damaging also added polymers). To be precise, also for carbon black a homogenous dispersion in the bitumen matrix is needed and should be aimed for.

The steps on the way of preparing carbon-filler (graphite based and carbon black) modified bitumen mixtures to be evaluated concerning upscaling, and the criteria of cost-effectiveness and sustainability are:

- the preparation of the carbon (nano)particles using a mechanical or chemical approach,
- the preparation of a pre-dispersed/pre-mixed blend
- the preparation of carbon-(nano)particles-(polymer)-bitumen mixtures.

The upscaling was considered from the point of view of

- Process-development (kind of reaction, used chemicals, mechanisms)
- Chemical reaction engineering (development of reactors/machines).

Among the carbon (nano)materials, natural graphite, flake graphite, expandable graphite and carbon black are available in large quantities from industrial processes. Exfoliated Graphene Nanoplatelets xGnP® are already available in larger quantities, but, for its use in bitumen, the amounts could be still too small. Graphite oxide, is today available in small quantities and different qualities (oxidation grade) at rather high prices. The preparation conditions limit the upscaling.

The extrusion process for nanocarbon-polymer-composites is also available at large scale. The bitumen blending processes can require additional process development to achieve a homogenous dispersion of added materials.

Main scientific and technical results

- The research carried out in this WP is surely one of the most extensive studies concerning the modification and improvement of bitumen using graphite/graphene based (nano)particles that has been conducted, not only concerning the investigated species (graphite nanoplatelets and microflakes, expanded graphite, graphite oxide, N-doped graphene nanosheets), but also referring the processes to blend them with the bitumen or to generate them in-situ (Deliverable 3.3).
- A new process starting with natural graphite, has been used for the first time to obtain graphene-nanocarbon containing bitumen concentrates. The method of preparation is compatible with the use of SBS polymer.
- Pellets of 6% graphite-nanoplatelets/SBS composites have been successfully obtained.
- Two bitumen (bitumen DI and bitumen DII) have been developed that fulfil the requirement of the standards applied for EU bitumen. The selected bitumen offers comparable or greater properties than polymer modified bitumen (PMB). In particular, carbon black modified binders behave better to ageing resistance than PMB while meet minimum values required for their fundamental properties.
- Preliminary conclusions on modified asphalt upscaling (Deliverable 3.4).

1.3.3. Development of graphite-modified WMA including the use of industrial by-products and RAP (Work package 4)

Main Objective

The main goal of this WP was the development of three type of asphalt mixtures, an asphalt concrete (AC), a porous asphalt (PA) and a very thin layer asphalt concrete (BBTM) that incorporate the bitumen developed in WP3 (DB bitumen), and maximize the use of reclaimed asphalt pavement (RAP) and industrial by-products. Warm mix asphalt additives are also used to reduce the production temperature.

Work Done

The WP was divided into 3 tasks:

Task 4.1.: Selection of additives and characterization results of the industrial by-products and RAP material to be used in the Warm Mix Asphalts (WMA).

The main objective of this task was to provide an overview of the state-of-the art in the use of the green technologies for the asphalt industry; specifically the revision of five different technologies: RAP, WMA, RAP+WMA, slags and nanoparticle technology combinations.

As a result of this investigation the most promising materials and additives were selected for further study in Tasks 4.2 and 4.3.

From the study, it was concluded that the combination of nano-modified asphalt mixes with the rest of innovative approaches (WMA, RAP, steel slag aggregates) was beyond the state-of-the-art and would result in a challenge for the Project. The study is reported in D4.1.

TASKS 4.2 and 4.3 – Development of WMA (AC, PA and BBTM) incorporating the graphite-modified binders from WP3, by-products and RAP, either combined or separated.

To develop asphalt mixes with sound sustainability credentials by using the sustainable and greener materials selected in the previous task, a three stages work plan was followed, what enables to analyse the impact of the new bitumen and the effect of incorporating additives to reduce the production temperature.

- Initially, three mixtures (AC, PA and BBTM) were designed with the alternative aggregates (EAF slag and RAP) and a commercial polymer-modified bitumen (PMB). The objective was to maximize the amount of EAF slag and RAP and therefore to minimize the use of natural aggregates.
- Later, new three mixes (AC, PA and BBTM) with the same amount and type of alternative aggregates and PMB were produced at a lower temperature by incorporating a WMA additive.
- Finally, the nanomaterial-modified bitumen developed in WP3, DURABROADS (DB) bitumen, was used instead of the PMB but maintaining the previous WMA additive and alternative aggregates.

Phase I		**Phase II**		**Phase III**	
Bitumen	Aggregates	Bitumen	Aggregates	Bitumen	Aggregates
PMB	EAF slag + RAP + Limestone	PMB + Evotherm	EAF slag + RAP + Limestone	DB + Evotherm	EAF slag + RAP + Limestone

Table 3. Phases carried out to design the mixtures

Because the pilot road was going to be built in Spain, Spanish standards and regulations were considered for the design of the asphalt mixes. Characterization tests were carried out according to European Standards.

Different mechanical and dynamic tests were carried out to analyse the performance of each mixture:

1) Tests required by the Spanish normative (PG-3): voids test (EN 12697-8), water sensibility (EN 12697-12), wheel tracking test (EN 12697-22) and particle loss in PA mixes (EN 12697-17).
2) For a more accurate analysis of the mechanical performance of the asphalt mixes, the following dynamic tests were carried out: stiffness test (EN 12697-26), resistance to fatigue test (EN 12697-24) and the workability test (EN 12697 – 31).

Main results and conclusions obtained from the characterization of the mixes are:

- An AC asphalt mix with 35% of EAF slags and 30% of RAP by volume was designed using 3.20% of DURABROADS bitumen, which met all the requirements for conventional asphalt mixtures according to the Spanish specifications.
- The PA mix was manufactured with 77% of EAF slags and 20% of RAP by volume using 3.60% of DURABROADS bitumen, meaning 97% (v/v) of recycled content.

- This mix was designed using 52% of steel slags, 45% of RAP and 3.6% of DURABROADS bitumen, meaning 97% (v/v) of recycled content.
- All the mixes complied with Spanish specifications required for the highest traffic category and warmest climate areas.
- Values in stiffness are much higher than those for conventional mixes, being in the case of the AC mixture close to high modulus mixtures.
- The increase in stiffness affect negatively the fatigue resistance of the bituminous mixtures since the asphalt layer is less flexible. However, the result obtained is good.

Based on the research conducted, it can be concluded that the addition of slags, RAP, WMA additive and bitumen improved with nanotechnology, either separately or combined, accomplish the requirements of the Spanish standards for the highest trafficked roads. As the mixes with DB bitumen presented a lower fatigue resistance, the mixes would resist less cycles when subjected to a specific strain. However, their higher stiffness would make it difficult to reach that strain. Considering this, these mixes would be especially suitable for the wearing course since their higher stiffness would reduce the stress in the lower layers, increasing the fatigue resistance of the complete pavement and potentially increasing its durability.

Main scientific and technical results

- Development of three asphalt mixes (PA, AC and BBTM) with the following properties:
    - Incorporation of 20, 30 and 45% (by volume) of RAP respectively in a high performance asphalt mixture, and from 35% to almost 80% of slags. The PA and BBTM mixtures only have natural aggregate in the filler fraction.
    - Replacement of 65% to 97% of natural aggregates depending on the type of mixture.
    - Reduction of 20ºC in the production temperature.
    - Fulfil the requirements of the Spanish standards for the highest traffic categories and the warmest climate.
    - Increase the stiffness in comparison with conventional mixtures, decreasing the loads that have to bear the layers below.
    - Perform better in mixes with less percentage of voids.

1.3.4. Development of optimized road pavements more resilient to climate change and freight corridors (Works package 5)

Main Objective

The main goal of WP5 was the development of asphalt pavements more resilient to climate change and freight corridors and the quantification of the environmental and economic impacts of the new developments and designs in relation to the new products.

Work Done

The WP was divided into 3 tasks:

Task 5.1: Setting the needed parameters to feed the numerical simulation software for pavement design and renewal.

To carry out the optimized design of pavements, the FlexPave software was selected. The FlexPAVE software program, developed by the North Carolina State University (NCSU), is a pavement performance analysis tool that is based on the combination of time-scale separation and layered viscoelastic analysis. This analysis tool captures the effects of the viscoelasticity of the pavement material, the temperature (thermal stress and changes in the viscoelastic properties), and the moving nature of the traffic load. Details of this analysis framework can be found in Eslaminia et al. (2012)[5]. The use of this software (in development) was facilitated by the FHWA as part of the EU/US collaboration.

In order to predict asphalt performance, the tool includes models that can represent fatigue damage growth and permanent deformation. The simplified viscoelastic Continuum Damage (S-VECD)[6] model is a mechanistic approach that has been applied effectively to predict the performance of asphalt concrete mixtures during pre-localization stages under different modes of loading. The rutting performance is evaluated in this tool using a permanent deformation model called shift model[7].

In order to predict asphalt performance, the FlexPave software requires following a test protocol that is normally performed in a servo-hydraulically controlled testing machine called AMPT which is used extensively in the US. However, as this equipment was not available, the adaptation of the Universal testing machine (UTM) was carried out to perform the following tests:

- Linear viscoelastic properties of asphalt concrete are defined by using dynamic modulus test inputs, the master curve of the dynamic modulus or the Prony series. Dynamic modulus test are performed according to AASHTO T342-11.
- Direct tension cyclic fatigue tests according to AASHTO TP107-14 are conducted to determine the coefficients of the viscoelastic continuum damage model implemented in FlexPAVE.
- Finally, the Stress Sweep Rutting test (SSR) is used to calibrate the permanent deformation model implemented in FlexPAVE (shift model).

After the equipment was adjusted, the DB asphalt mixes developed in Tasks 4.2 and 4.3 were characterized according to the test protocols implemented before.

[5] Eslaminia, M., S. Thirunavukkarasu, M.N. Guddati, and Y.R. Kim, "Accelerated Pavement Performance Modeling Using Layered Viscoelastic Analysis." 7th International RILEM Conference on Cracking in Pavements, 20-22 June 2012, Delft, The Netherlands.

[6] Hou T, Underwood BS, Kim YR. (2010). Fatigue Performance Prediction of North Carolina Mixtures Using Simplified Viscoelastic Continuum Damage Model. Journal of the Association of Asphalt Paving Technologists, Vol. 79, pp. 35-80.

[7] Y. Choi, Y.R. Kim, Implementation and verification of a mechanistic permanent deformation model (shift model) to predict rut depths of asphalt pavement, J. Assoc. Asphalt Paving Technol. 83 (2014) 481–514.

Task 5.2: Optimized design of innovative, long-life and more resilient to climate change and freight corridors pavements.

As explained before, the Flexpave software was used for the design of the asphalt pavement. Several simulations and analyses were performed to cover different materials, pavement structures and the different climate and traffic in Europe, including the potential increase in temperature due to the climate change and the traffic evolution in each region.

In order to achieve the objective of this task, the work was divided into four sub-tasks:

Obtaining of Traffic Data inputs for the Flexpave software

For the simulation of the asphalt pavement deterioration during its lifetime, the Flexpave software needs traffic data inputs including the single axle load, the annual average daily truck traffic (AADTT) and the growth rate. Therefore, in this sub-task the collection and analysis of typical heavy traffic loads on one or more of the most heavily trafficked TEN-T sections in European road have been carried out.

To do so, an e-mail request was sent to road experts in almost all European countries (utilizing the research coordinators' network of FEHRL). Finally, information from 19 countries was collected. This information included the daily standard axle load repetition number of the most heavily trafficked TENT-T section of each country, the annual heavy traffic progression (growth) rate forecasted for the TEN-T road section and the period for this annual growth rate.

About the traffic growth (evolution) factors, the majority of the values presented for heavy axle load repetition numbers are "official" forecasted factors for the designated periods (typically for the coming 10-20 years).

In addition, following the practice selected and applied in the WP2 of DURABROADS project, four typical European regions (Northern, Central, Southern and Western Europe) were differentiated in the analysis. All regions were represented by 3-7 countries.

The information here collected is reported in the deliverable D5.1.

Obtaining of Climate Data inputs for the Flexpave software

For carrying out the simulation, the user must also provide the temperature profile of the asphalt pavement for analysis.

The Flexpave software allows the input of the temperature data in four different ways: from the EICM database, as an EICM text file, as an isothermal condition or input manually.

The isothermal condition and the manual input option were discarded because, to achieve the objective of this WP, it is necessary to include the effect of temperature in the prediction of the pavement performance.

On the other hand, the Flexpave software includes a complete database for all the states in the United States. For each state, major cities data are available. The temperature profile of the asphalt pavement for one year is stored for each city. Initially, it was tried to match the climate, in terms of hourly temperature, solar radiation and precipitation, of EU and US cities with the aim of using the

already available database. However, there was not possible to find such similarities between major cities in US and EU (Figure 2).

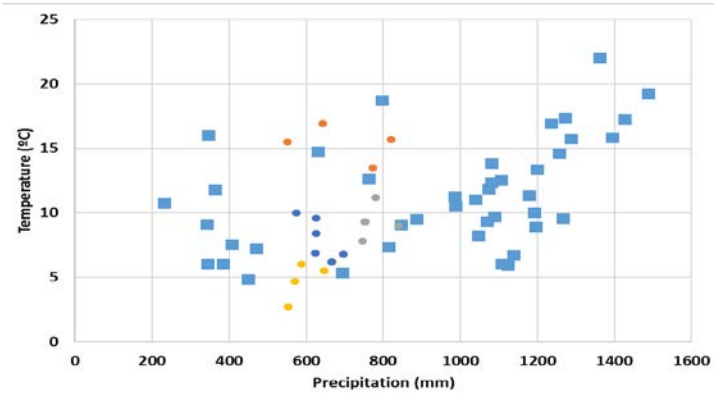


Figure 2: Temperature and precipitation data of US and EU.
□ US states, • EU countries

For this reason, it was necessary to create a new database for EU cities within the four regions that are being considered. To create the database, the following steps were carried out:

- Search and collection of temperature, wind and solar radiation (hourly data) for different EU cities (representative of each climatic region).
- With the hourly data of temperature, wind and solar radiation, the pavement temperature profile (hourly data) was calculated using an estimation model called TEMPS (Temperature Estimate Model for Pavement Structures) developed by the University of Nevada[8].
- The hourly temperature profile of the asphalt pavement was prepared to conform to the format required by the program. The vertical variation of temperature was defined by specifying the temperature at different nodes along the pavement depth.

Obtaining of Climate Data considering climate change potential effects

The simulation of the lifecycle deterioration of asphalt pavement with the Flexpave software will also take into account the impact of Climate Change, in order to assess the resilience of the road pavements to variations due to changing climate in the variables used by the TEMPS model.

Therefore, in addition to a stationary scenario in which climate variables are assumed to be constant over time, two Climate Change scenarios are being considered for the projection of temperature, wind speed and solar radiation: RCP4.5 and RCP8.5. The RCPs (Representative Concentration Pathways) were designed in 2005 as a response to the need for new emission scenarios to facilitate the evaluation of Climate Change impacts. These scenarios consider different increases in the concentration of equivalent CO_2 and evaluate their effects on climate variables.

Forecasted variations in climate variables are being collected from Regional Climate Models (RCMs), which have finer resolutions (10-50 km) than General Circulation Models (GCMs) and can incorporate relevant regional scale processes such as orographic lifting of air masses into their simulations. As in previous sub-tasks, this operation is being developed according to representative

[8] http://www.arc.unr.edu/software.html

areas of the four typical European regions identified in the WP2 of the DURABROADS project: Central, Northern, Southern and Western Europe.

The complete study is reported in the deliverable D5.1.

Performance analysis of pavements including DURABROADS asphalt mixes for different climate and traffic scenarios

This sub-task has also been divided in 4 different studies:

a) *Comparative assessment of the performance of DB asphalt mixes with conventional surface courses.*

Twelve road pavement structures were simulated to analyse the effect of asphalt layer properties on the road pavement performance during its lifetime, considering the temperature profile of Frankfurt. These twelve structures included six different wearing courses: four mixes with DB bitumen (AC, PA and BBTM mixes designed according to EU standards and a AC Superpave mixture designed according to US standards) and two control mixes with a PG64-22 bitumen (Superpave). Variations in the binder and base layer properties were also analysed.

According to the results, road asphalt pavement incorporating AC DB asphalt mixes in the surface course presented better mechanical performance in terms of fatigue and rutting comparing to road pavements that incorporate the control mixes. When comparing the three different DB asphalt mixes, road pavements incorporating DB-PA asphalt mixes had higher plastic deformation.

b) *Evaluation of the performance of DB asphalt mixes in different EU regions*

The impact of different climatic regions defined in WP2 (Northern Europe, Western Europe, Southern Europe and Central Europe) was analysed by simulating the road structure formed by the AC Superpave mixture with DB bitumen in four cities: Riga, Frankfurt, Madrid and Budapest. The results obtained in this study showed the importance of the climate on the pavement response, particularly on the rutting resistance. Thus, the high temperatures in Madrid increase the damage in the road for the same ESALs applied to the pavement system, drastically reducing the number of ESALs that the road can withstand before it needs to be rebuilt (89% reductions related to the coldest climate). The other three locations present lower pavement temperatures, and consequently the effect on the pavement performance is more limited.

c) *Analysis of the effect of climate change on the road pavement performance in different EU regions*

New simulations were carried out to analyse the expected increase in the pavement temperature profile due to the climate change in each EU region. In this case, results showed a shortening of between 1% and 25% and between 33% and 51% in the fatigue and rutting resistance respectively depending on the city analysed (Budapest, Riga or Frankfurt). In Madrid, the increase in temperatures does not practically change the fatigue damage, whereas the rutting increases significantly.

d) Road pavement optimization using FlexPave

Based on the previous analysis, the simulated road structure was found to be not suitable for the region of Madrid nor for Riga. In the first case, the high temperatures and heavy traffic of the TEN-T section considered required the use of a base and subgrade layers with higher bearing capacity. Therefore, new simulations were carried out using higher quality base and subgrade layers and analysing the effect of the type and thickness of the asphalt layers on the road performance. In the second case, the simulated road structure resulted to be oversized for the climate and the amount of heavy traffic in Riga. New simulations were carried out to match the size of the road layers to the requirements.

The complete study is reported in the deliverable D5.1.

Task 5.3: Evaluation of DURABROADS new products through LCA and LCCA tools and comparison with traditional materials

An environmental and economic feasibility study of the materials developed in the project, DB bitumen and DB asphalt mixes, has been carried out through a life cycle assessment and life cycle costing analysis. Within the scope of this study, the LCA has been done for the following:

- Cradle-to-Gate Assessment of 1kg of Bitumen
- Cradle-to-Gate Assessment of Initial Construction Process of Road Surface Layer
- Cradle to Grave Assessment of Total Road System

In the analysis, three pavement mixtures (AC, BBTM, and PA) were considered. The DB Bitumen was designed to be used with all three cases, following which the overall mixtures were also modified with different additives such as Evotherm, carbon black and SBS (Styrene Butadiene Styrene); and steel slag, basalt as aggregates. This analysis was carried out for six cases where the base case was the asphalt concrete road named AC Base. The other five pavement alternatives namely AC Alt, BBTM Base, BBTM Alt, PA Base and PA Alt were compared against the AC Base case to select the one that has the lowest environmental impacts and maximizes net savings. The functional unit that the study reports on is: “The impact assessment of a road cross- section of 7.4 m*1000 m (width*length) for a life cycle of 50 years”.

The LCC Model was calculated as the net present value over a 50 year period using a discount rate of 6% per year. The 50-year period has been selected to match the period used for the environmental impact assessment done in the LCA while the 6% discount rate was chosen, as it is a typical value used for a private sector construction project undertaken by a trusted investor. The total life cycle costs include the construction, maintenance and transportation costs.

When analysing only the production of 1kg of bitumen, a higher environmental impact of the DB bitumen is found due to the Carbon Black material used. However, when analysing the overall road system, AC Base has the highest environmental impact while the environmental damage caused by BBTM Alt is the lowest for the life cycle environmental assessment of the total road system (Figure 3). Similarly, based on the LCC analysis of the total road system across a life cycle of 50 years, the BBTM Alt has the lowest life cycle costs while AC Base the highest life cycle costs.

Overall, each DURABROADS Alternative case had lower environmental impacts and lower life cycle costs across the 50-year life cycle when compared to its base case.

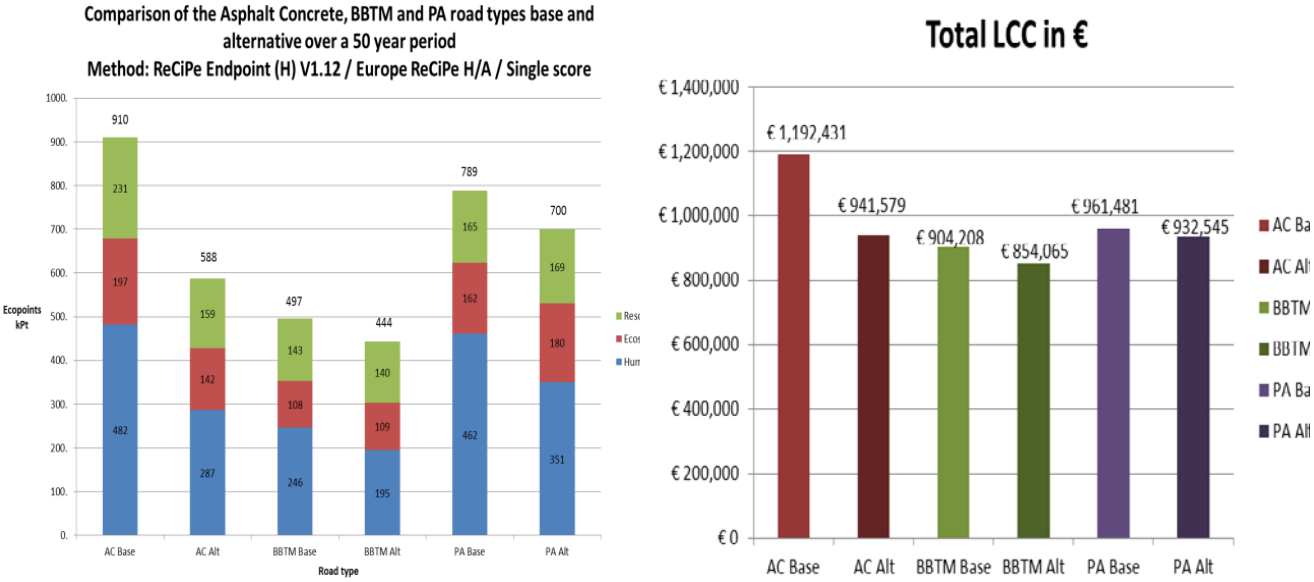


Figure 3. LCA by ReCiPe EndPoint (H) (left) and Net present value of costs incurred (right) of total road system in the AC, BBTM and PA Base vs Alt

Main scientific and technical results

- Creation of a database with the hourly temperature profile of asphalt pavements for 19 European cities. This database can be used in the FlexPave software in the same way as the database already available for US cities.
- Creation of two databases with the forecasted hourly temperatures profile considering the effect of climate change according to RCP4.5 and RCP 8.5 scenarios.
- Evaluation of the comparative performance of road asphalt pavements incorporating DB asphalt mixes vs. conventional asphalt mixes.
- Assessment of the effect of climate (based on the pavement temperature profile) and traffic loads on the European Road Network.
- Assessment of the increase in the pavement temperature profile due to climate change and the effect it may have on the road pavement performance, in terms of fatigue and rutting damage.
- Economic and environmental validation of the DURABROADS bitumen, DB asphalt mixtures and road pavements incorporating DB asphalt mixes in their surface course.

1.3.5. Demonstration and validation (Work package 6)

Main Objective

The main objective of WP6 was to demonstrate the technical and economic feasibility of the DURABROADS solution. With this aim in mind, two road stretches with alternative materials were built and compared with a reference section with a total length of approximately 250m.

Work Done

Both trial road stretches were produced with asphalt mixes incorporating the DB bitumen. For the production of this bitumen a mobile bitumen modification plant property of ACCIONA was used. Bitumen, SBS polymer and carbon black, together with the WMA additive were continuously loaded and dosed into a small pre-mixer tank for a continuous production of the innovative bitumen with a single pass through the mill. Once bitumen was produced, a sample of the produced modified bitumen was taken for quality control.

Aside from bitumen, aggregates were partially replaced by RAP in one section and in combination with slags in the other according to the WP4 findings:

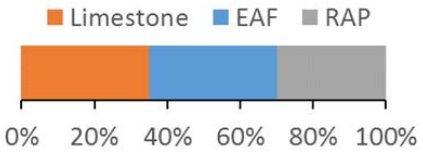
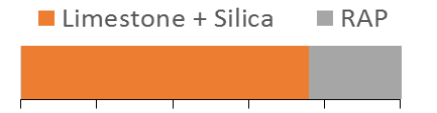
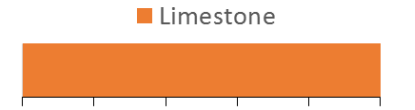
	Composition	
Asphalt mix type: AC16	Aggregates	Bitumen
DURABROADS Section 1		DURABROADS bitumen
DURABROADS Section 2		DURABROADS bitumen
Reference section		Conventional bitumen

Figure 4. Composition of the wearing course of each section

The effectiveness of the asphalt was evaluated through all the phases, from early laboratory assessment to plant production, handling, application and post-trial evaluation. A direct comparison was made versus the reference asphalt mixes.

This validation provided an opportunity to observe construction from start to finish and to record material property data, take samples, record observations through the construction, monitor early-life performance and provide some recommendations for future applications, demonstrating that the DURABROADS innovative solutions is suitable for industry and asset managers.

Some photos of the whole process are shown in the figure below:

Plant production	Application	Post-trial evaluation: Quality Control & Monitoring
	  	  

Figure 5. Photos of the production and implementation of the pilot road

Results from the quality control support the implementation of the technologies achieved at laboratory scale. Only small deviations in some properties of the asphalt mixtures from the expected values were noticed, mainly in terms of compaction level and thus low density.

According to the values for road surface properties no appreciable differences were observed between the DURABROADS mixtures and the reference section, so that the innovative asphalt mixes does not have any influence on the final road surface properties.

Main scientific and technical results

- Upscaling of the DB bitumen from the laboratory pilot plant to a real scale mobile bitumen modification plant.
- Upscaling of the DB asphalt mixes production process.
- Checking the economic feasibility of the production, implementation and deployment of the new mixtures
- Validation of the technical performance of the DB asphalt mixtures in a real scale road.

1.3.6. Guidelines and pre-standardization (Work package 7)

Main Objective

WP7 aimed for promoting the use of the DURABROADS products and techniques within the road infrastructure sector by the elaboration of Guidelines and pre-standardization activities.

Work Done

TASK 7.1– Development of guidelines considering best practices identified along the project and definition of the criteria for introducing DURABROADS environmental concepts within GPP processes

This task has been divided in two main sub-tasks.

Development of a guideline including all the best practices identified along the project

During this task, best practices identified along the project and detailed procedures for the production and utilization of the new materials was recollected in a guideline (deliverable D7.1) that will serve to encourage policy makers and end users to adopt the DURABROADS concept.

This document starts informing about the backgrounds of the DURABROADS project: 1) The most common deterioration forms in the EU roads and the effect traffic and climate change (together and separately) have on them; 2) The general approaches usually used to design roads and the current use of recycled resources in the different countries of the European Union. The guide continues describing the characteristics, technical requirements and applicability of the DURABROADS asphalt mixtures and also of the materials which form them (DURABROADS bitumen, EAF steel slags and RAP). As the FlexPave software was used for the design of road pavements, a brief explanation is made of the model in which the FlexPave is based, describing the required inputs and the obtained outputs. Then, the deliverable refers to the environmental and economic validation of the mixtures carried out by means of a life cycle and life cycle cost assessment, summarizing the scope and the main results. Finally, the text ends up describing some guidelines for the upscaling of the technology at a real scale road.

Guideline for introducing the environmental concepts of DB project in GPP

To support the decision of the public bodies of adopting the DURABROADS technologies, a guideline for introducing DURABROADS environmental concepts within GPP processes has been created (deliverable 7.2). This guideline and the criteria proposed on it are based on the GPP criteria document for Road design, construction and maintenance developed by the Commission's Joint Research Centre in Seville, Spain. .

For the elaboration of this guideline, the following activities have been carried out:

- Analysis of the legal framework and policy of GPP in Europe, including the last public procurement directives and the procurement process stages.
- The identification of the environmental aspects applicable to DB bitumen and DB asphalt mixes such as the use of secondary materials, energy efficiency and the increase of the technical performance.

- Critical evaluation of the EU GPP criteria proposed by the JRC that is applicable to DB materials.
- Final criteria proposal.

Task 7.2: Development of activities focused on the pre-standardization of DURABROADS products.

Once carbon black has been identified as the most convenient material for the modification of the bitumen, the next step was to test the new modified bitumen following current European Norms.

Although the DoW indicated initially that a pre-standardization route could be started for the new bitumen, it was not required since current standards covered materials used for the modification of the asphalt bitumen. Therefore, no preparation of additional CEN Workshop Agreement was necessary.

The new DURABROADS solution has been tested within the framework of all current regulations. For further information about the results, please check D7.3. Specifically the following standards have been used:

- UNE-EN 12591 – Bitumen and bituminous binders – Specifications for paving grade bitumen.
- UNE-EN 14023 – Bitumen and bituminous binders – Specification framework for polymer modified bitumen.

Main scientific and technical results

- Elaboration of guidelines for the application of the DURABROADS developments: DB bitumen, DB asphalt mixes, increase of the use of RAP and industrial by-products, new approaches in the design of road pavements and the evaluation of the effect of climate in road performance.
- Definition of a guideline for introducing DURABROADS concepts within GPP processes. Criteria to be directly used as part of the conventional procurement process have been proposed.
- Determination of the next steps for the future standardization of the DURABROADS materials: the development of the DURABROADS asphalt has been done according the current European Standards framework. Since ENs allow use of specific modification materials for the bitumen and asphalt, not further standardisation route has been necessary to open (i.e. CWA)

1.3.7. US/EU Twinning Programme

Main Objective

As established by the Transport Work Programme 2013, EU selected projects that addressed the assessment of the performance of WMA with high recycled materials should capitalize on the existing experience available in the United States. In the same way, projects led by the US Department of Transportation would collaborate with European researchers.

In 2014, two FP7 projects (DURABROADS and LCE4ROADS) were selected by the European Commission to initiate a collaboration with researchers from the US Federal Highway

Administration as part of a flagship initiative to establish the bases of a collaboration in the transportation infrastructure sector between the USA and the EC.

Work Done

In March 2014, representatives from the DURABROADS consortium and the European Commission travelled to Washington DC to meet counterparts of the Federal Highway Administration (FHWA). The objective of the meeting was the elaboration of the roadmap identifying bridges between the EU project DURABROADS and other similar US initiatives in the sector.

In September 2015, a second joint meeting was held in Madrid. In this meeting, the line work for the next two years was defined, crystallising in the following research activities and information exchange.

Table 4. US/EU twinning activities

ACTIONS TAKEN	RESPONSIBLE
Collaboration and participation on a multicriteria decision tool (MDP) developed in DB WP2	FHWA
Exchange of experimental results from different types of modified binders analogous to those used in DB WP3	FHWA
Exchange of information about the way the RAP is incorporated into the asphalt mixes at lab level. Elaboration of videos.	FHWA / DB
Exchange of information about the use of WMA additives and observed impacts on material properties	FHWA
Agreement on the use of Flexpave software for the simulation of pavements in WP5	DB / FHWA
Analysis of climate and traffic loads at EU and US level	DB / FHWA
Calibration of UC equipment for the development of US tests: training tests	DB
Exchange of training videos concerning US tests	FHWA
Calibration of UC equipment for the development of US tests: characterization of a dense mix with AMPT tests	FHWA
Calibration of UC equipment for the development of US tests: shipment of dense mix and delivery of results	FHWA
Calibration of UC equipment for the development of US tests: development of dynamic modulus, fatigue and SSR tests at the UC with dense mix	DB
Performance evaluation of the DB binder: tests done by the FHWA to different binders developed by ACCIONA	FHWA
Selection by ACCIONA of the DB binder according to own results (EU standards) and FHWA results (US standards)	DB
Shipment by the FHWA of two binders for EU characterization purposes.	FHWA
EU tests of the binders shipped by the FHWA	DB
Design of PA mixes with binders shipped by the FHWA and EU characterization tests of the asphalt mixes	DB
Performance evaluation of the DB asphalt mixes: development of tests according to US and UE standards	DB / FHWA

Main benefits and challenges

Several benefits were obtained from this collaboration:

- Partners cross-check each other.
- Ensure the robustness of new materials, test methods, equipment specifications and software.
- Advanced knowledge on materials and testing technologies.
- Selection of the DB binder considering its performance according to EU and US tests.
- Advanced knowledge on pavement performance models and tools.
- Performance evaluation of DB asphalt mixture.

However, there were also challenges to overtake:

- Planning problems and adaptation to new methods and standards.
- Very high workload of EU and US participants.
- Shipment of materials from the US to Spain and vice versa resulted not to be as easy as expected.
- Change of contact point at FHWA in 2016, making the communication more difficult during some time.

1.4. Potential impact and main dissemination activities

1.4.1. Impacts

As it was already mentioned "Transport infrastructure have a positive impact on economic growth, create wealth and jobs, and enhance trade, geographical accessibility and the mobility of people. However, each kilometre of road consumes a large amount of materials and energy not only in its construction but also during its maintenance and rehabilitation works". Hence, applying for more eco-friendly practices as those shown in the DURABROADS project will lead to a tremendous impact.

Therefore, many positive impacts on innovation, growth and sustainability in the asphalt sector are expected as a consequence of the results and outcomes of the project:

Greener road pavements

The following technologies implemented and validated in the DB asphalt mixtures contribute to the reduction of the environmental impact of road pavements:

- The reuse of waste and the recycling of industrial by-products contributes to reduce the environmental impact of the road due to 1) the reduction of virgin bitumen content by increasing the RAP rates in wearing courses, 2) the reduction of natural aggregated in 65 to 95% depending on the mixture and 3) decreasing the amount of waste that is sent to landfill (both RAP and EAF slags).

- Warm mix asphalt additives. DB asphalt mixes have been proven to be compatible with the use of warm mix asphalt additives. This allows that the production temperature remains to conventional levels in spite of using high performance viscous bitumen.
- Increase durability and resilience of road pavements. The properties found on the DB asphalt mixtures (especially in the AC mixture) have been observed to reduce both fatigue and rutting damage in the road pavement. On the one hand, due to their high resistance to plastic deformation and on the other hand, because the higher stiffness increases the bearing capacity of the surface layer and reduce the loads in the lower layers, increasing their fatigue life.

Cost-efficient pavements

The LCC assessment carried out in WP5 has proven the cost-efficiency of the technology when compared with traditional materials. The use of DB materials influences the following costs:

- Rehabilitation costs are reduced if the road structure increases its service life, including the costs related to traffic disruption.
- Cost associated with the purchase of natural aggregates will be reduced when being replaced by wastes and by-products.
- The cost associated to waste and by-products landfilling.

On the other hand, the multi-criteria methodology developed in WP2 may be applied to a wide range of decision-making situations within the road pavement sector. This kind of methodology will help road authorities to select the alternatives according to economic, environmental and social criteria.

Guidelines and recommendations for the application and adoption of cost-effective innovation in the road infrastructure.

The guideline for introducing DURABROADS environmental concepts within GPP processes is aimed to support the decision of the public bodies in adopting the technologies proposed in the project. The guideline and the criteria proposed on it are based on the GPP criteria document for Road design, construction and maintenance developed by the Commission's Joint Research Centre. To facilitate their inclusion, the criteria conform to the standard format of the procurement process and to its standard format.

Competitiveness of the European industry

The project collaboration mechanism has enable an active and reciprocal cooperation between SMEs, public research centres, universities and large companies. Main impact of DURABROADS has been that the SMEs have gain knowledge and experience for their future activities. The research with carbon nanomaterials and asphalts has created a new market niche and new research and innovation opportunities for both the nanotechnology and asphalt related companies within the project.

On the other hand, public procurement can shape production and consumption trends and a significant demand from public authorities for "greener" goods will create or widen markets for environmentally friendly products and services.

Contribution to European policy

The use of DURABROADS solutions would contribute to achieve the European environmental objectives. Hence, the project meets the premises established by Europe 2020 strategy in relation to sustainable growth by helping to:

- Build a more competitive low-carbon economy that makes efficient, sustainable use of resources.
- Protect the environment and reduce emissions
- Capitalise on Europe's leadership in developing new green technologies and production methods.

Thus, the project contributes to achieve the Europe 2020 target of reducing greenhouse gas emissions by 20% compared to 1990 levels by 2020. In 2011, the European Council with the communication "A roadmap for moving to a competitive low carbon economy in 2050" reconfirmed the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels. The reduction of GHG emissions along with the decrease of resource intensity of what we use and consume are benefits of the project also in accordance with the aim is of Europe 2020 flagship "Resource-efficient Europe" that intends to support the shift towards a resource-efficient, low-carbon economy.

In order to tackle the enormous challenge of the waste management, the Sixth Environment Action Programme of the European Union (2006-2012) identified waste prevention and management as one of its four top priorities. Furthermore, waste prevention and recycling is also one of the seven Thematic Strategies or key environmental issues to be tackled using a holistic approach.

DURABROADS prioritises the reuse of RAP and valorises materials that are being landfilled (EAF slags). This approach meets the requirement of the Landfill Directive 1999/31/EC and guarantees the principle of the Waste Framework directive 2008/98/EC on respecting the priority given to reuse, recycle, recovery and, just where the former versions are technically and economically impossible, disposal. This hierarchy is also mentioned within the Directive 2010/75/EU on industrial emissions.

Finally, the project outcomes also contributes to the objectives of the communication COM2008, 400 "public procurement of a better environment" in which the implementation of GPP by validating new procured works with a reduced environmental impact is fostered.

1.4.2. Dissemination activities and exploitation of the project results

Dissemination is a significant issue of DURABROADS project due to its importance to maximize the impact of the project. In order to communicate and promote the DURABROADS activities and results to industry and institutional stakeholders, the following channels were used.

Logo and corporate identity

A logo and corporate identity of DURABROADS were designed during the first three months of the project. Both elements appear in all the internal and external communication materials of the project.

Web site

A specific DURABROADS website was created with the objective to offer the visitor an easy to use and regularly updated tool to obtain detailed project information. The dedicated domain name is:

www.DURABROADS.eu . The website newsroom was regularly updated with DURABROADS main news and progress



Contact database

It was identified and classified the main target stakeholders, dissemination methods and channels to ensure a proper dissemination of the project generated knowledge, publication and results.

E-Newsletter

The e-newsletter was edited every 6 months to describe the on-going progress of the project. It was sent to a dedicated DURABROADS mailing list that was continuously 'populated' throughout the project based on member's existing contacts and those generated during the project.

Brochure

A brochure was designed and printed at the beginning of the project describing general information (content, objectives, methodology, etc.). It could also be converted into a poster to be used at relevant European and international events. Copies were distributed to the DURABROADS partners and also attendants to different events, workshops and other conferences.

Press releases

Press releases were produced to communicate key milestones, deliverables and findings during the lifetime of the Project.

Articles published in specialised media

Results achieved during the project were published in specialized media in order to obtain a good publicity of the project but also to ensure that the DURABOADS concepts are results set the base for future knowledge and researches.

Conference abstracts and participation to events

All the partners undertook regular monitoring activities of major conferences, seminars and forums taking place in Europe an US to present project results

Social media

Project's news were regularly mentioned at the ERF social media channels: Facebook and twitter

Workshops

Three workshops were organized in order to show latest developments to stakeholders.

1st Workshop: it was organized on June 15, 2015 and had a triple objective. First, the presentation of DURABROADS to external stakeholders, second, to unveil and analyse the results of WP2 and finally, to receive inputs from similar initiatives.

2nd Workshop: it was held on June 20, 2017 in Brussels (Belgium) with the objective of presenting the project's results to asphalt experts from Europe.

3rd Workshop: it was organized on 12 September 2017, in Madrid (Spain). This workshop focused on the EU/US twinning experience, benefits and results. The discussions dealt with the need for the exchange the knowledge at global level.

Final conference

DURABROADS final results were presented on 12 September in Madrid during the Conference "Enhancing Research and Innovation in Europe: the road sector experience" which was organized in cooperation with the European Commission Representation in Spain. The first panel offered an overview of various techniques and alternative materials which aim to reduce the consumption of natural resources, energy and CO_2 emissions, through the development of end-of-life and self-healing materials, biomass, and software to assess environmental performance. Subsequently, the DURABROADS panel focused on the development of more durable and resilient asphalt pavements to better deal with the impact of climate change and freight transport. Finally, the third panel showed how public authorities will play a key role in a successful market implementation of these innovations and therefore the transformation of the road sector to the socio-economic and environmental trends. The ppt presentations and photos of the event are publically accessible through the DURABROADS website.

Networking activities

One of the innovative elements of DURABROADS is the establishment of links with other US research projects to avoid overlapping and find synergies. During the development of the DURABROADS project, coordination and research actions were carried out with researchers of FHWA, what permitted a constructive approach.

Besides, a technical advocacy to the European Commission JRC Green Public Procurement Criteria for road construction in relation to techniques to optimise the environmental performance of the asphalt mixtures was carried out. The ppt presentations and photos of the event are publically accessible through the DURABROADS website.

Finally, networking with other transportation research project has been carried out by most partners during the organized and attended events. As an example, industrial partners of the ALTERPAVE project have attended DURABROADS events to be aware of the project results and exchange their research activities and results. This project is aiming at fostering circular economy within the road sector.

Exploitation strategy plan

To maximise the chances of the DURABROADS materials and techniques being implemented in the market, a comprehensive exploitation strategy plan was developed in order to establish the ownership of the results.

1.5. Website and contact details

The DURABROADS website can be found at the following link: www.DURABROADS.es

For further information, the contact details of the DURABROADS partners can be checked in the table below:

Table 5. Contact details

Participant	Contact person	Email
UNIVERSIDAD DE CANTABRIA	**Daniel Castro-Fresno**	**castrod@unican.es**
ACCIONA INFRAESTRUCTURAS S.A	Raquel Casado-Barrasa	raquel.casado.barrasa@acciona.com
FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	Raphael Adinall	raphael.addinall@ipa.fraunhofer.de
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BSRIA LIMITED	Ian Wallis	Ian.wallis@bsria.co.uk
INZENIERBUVE SIA	Ilze Paeglīte	ilzepaeglite@inbox.lv

2. USE AND DISSEMINATION OF FOREGROUND

2.1. Dissemination measures

A communication plan was developed to provide an overall framework for managing and coordinating the wide variety of communication activities. Within this plan the communication activities included in the templates A1 and A2 were carried out during the project lifetime.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[9] (if available)	Is/Will open access[10] provided to this publication?
1	Complex Optimization of Heavy Duty Asphalt Pavement Types in DURABROADS Project	Gáspár László	Transportation Research Procedia	Volume 14	Elsevier BV	Netherlands	2016	pp. 3519 - 3526		no
2	Aszfaltburkolat-típusok optimálása (Optimization of asphalt pavement types)	Gáspár László	Közlekedéstudományi Szemle	Volume 66, Issue 2	Közlekedéstudományi Szemle	Hungary	2016	pp. 16-30	ISSN 0023 4362	yes
3	Döntéstámogató modell nagy nehézforgalmú utak aszfalt kopórétegének kiválasztásához (Decision support model for selecting the optimal asphalt wearing course type on heavily-trafficked roads)	Gáspár László	Útügyi Lapok	Volume 4, Issue7	Útügyi Lapok	Hungary	2016		ISSN 2064-0919	yes

[9] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[10] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

4	Szakirodalmi szemle nagy nehézforgalmú utak „optimális” aszfalt kopóréteg-típusának kiválasztásához. (Literature review for the selection of "optimal" asphalt wearing course types for heavily trafficked roads)	Gáspár László	Útügyi Lapok	Volume 4, No. 8	Útügyi Lapok	Hungary	2016		ISSN 2064-0919	yes
5	Nagy nehézforgalmú utak „optimális” felújítási technológiájának kiválasztása (Selection of “optimal” pavement rehabilitation techniques on heavily trafficked roads)	Gáspár László	Útügyi Lapok	Volume 5, issue 1	Útügyi Lapok	Hungary	2017	pp.20-31	ISSN 2416-2175	yes
6	Esettanulmány nagy nehézforgalmú utak „optimális” aszfaltkopóréteg-típusának kiválasztásához (Case study for the selection of „optimum” asphalt wearing course types on heavily trafficked roads)	Bencze Zsolt	Útügyi Lapok	Volume 5	Útügyi Lapok	Hungary	2017	pp.79-87	ISSN 2416-2175	yes

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[11]	Main leader	Title	Date/Period	Place	Type of audience[12]	Size of audience	Countries addressed
1	*Corporate identity*	ERF	Logo creation	December 2013	-	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Media	-	Global
2	*Brochures*	ERF	Creation of brochures for its distribution in dissemination events	December 2013	-	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Media	-	Global
3	*Web*	ERF	Specific DURABORADS website creation and update	December 2013 – September 2017	-	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Global
4	*Newsletter*	ERF	Dedicated articles and mentions in the ERF newsletter	October 2013 – September 2017	-	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	EU
5	*Media*	ERF	Mentions at social media channel: Facebook and twitter	October 2013 - September 2017	-	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Media	-	Global
6	*Articles published in the popular press*	ERF	"La Durabilità verde: l´Europa punta su pavimentazioni eco-friednly e, insieme, ad alter prestazioni". Le Strade	01/06/2014	*Italy*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	Italy
7	*Press releases*	ACCIONA	"Técnicas de constucción y mantenimiento innovadoras y competitivas para carreteras más seguras, ecológicas y resistentes frente a cambios climáticos".	01/10/2013	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain

[11] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[12] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

8	*Articles published in the popular press*	NwG	"Vil lage bedre vei med nanoteknologi". Teknisk Ukeblad	01/10/2013	*Norway*	Scientific Community (higher education, Research), Industry, Policy makers	-	EU
9	*Press releases*	UC	"GITECO coordinará un proyecto financiado por la Comisión Europea".	07/10/2013	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain
10	*Oral presentation to a scientific event*	ERF	17th World Road Meeting.	10/11/2013	*Riyadh (Saudi Arabia)*	Scientific Community (higher education, Research), Industry, Policy makers	>50	Global
11	*Articles published in the popular press*	ERF	"The DURABROADS project targets safer mobility". World Highways	01/03/2014	*International*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	Global
12	*Press releases*	UC	"Reunión UE/EEUU para colaboración en proyectos de infraestructuras".	27-28/03/2014	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain
13	*Articles published in the popular press*	ACCIONA	"ACCIONA Infraestructuras, miembro de la PTEC, colaborará con la Administración Federal de Carreteras Americana". PTEC	01/04/2014	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	Spain
14	*Brochures*	ACCIONA	Industrial Technologies 2014	09/04/2014	*Athens (Greece)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
15	*Poster*	KTI	TRA 2014	14/04/2014	*Paris (France)*	Scientific Community (higher education, Research), Industry, Policy makers	*>100*	EU
16	*Brochures*	ERF	TRA 2014	14/04/2014	*Paris (France)*	Scientific Community (higher education, Research), Industry, Policy makers	*>100*	EU

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

17	*Oral presentation to a wider public*	ERF	Asphaltica	08/05/2014	*Verona (Italy)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*100*	Italy
18	*Brochures*	ERF	Asphaltica	08/05/2014	*Verona (Italy)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*100*	EU
19	*Oral presentation to a wider public*	ERF	VI Transport Congress	14/05/2014	*Moscow (Russia)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*150*	Global
20	*Oral presentation to a wider public*	ERF	ERF Annual Symposium	18/06/2014	*Brussels (Belgium)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*75*	EU
21	*Brochures*	ERF	ERF Annual Symposium	18/06/2014	*Brussels (Belgium)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
22	*Article published in a specialized media*	ERF	"Standardization in research and innovation projects. Success story: green construction". CEN-CENELEC	01/09/2014	*Belgium*	Scientific Community (higher education, Research), Industry, Policy makers	-	EU
23	*Exhibitions*	ERF	Standards: your innovation bridge	30/10/2014	*Brussels (Belgium)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias		EU
24	*Brochures*	ERF	Standards: your innovation bridge	30/10/2014	*Brussels (Belgium)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
25	*Brochures*	ERF	Pavement Preservation and Recycling Summit	23/02/2015	*Paris (France)*	Scientific Community (higher education, Research), Policy makers, Medias	-	Global

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

26	*Brochures*	ERF	Promoting Sustainable Infrastructure in EU Regions	03/03/2015	*Brussels (Belgium)*	Scientific Community (higher education, Research), Policy makers, Medias	-	EU
27	*Oral presentation to a scientific event*	ERF	Promoting Sustainable Infrastructure in EU Regions	03/03/2015	*Brussels (Belgium)*	Scientific Community (higher education, Research), Policy makers, Medias	*100*	EU
28	*Oral presentation to a scientific event*	ERF	Joining forces to tackle the road transport CO2 challenge	30/04/2015	*Brussels (Belgium)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*20*	EU
29	*Articles published in the popular press*	ERF	"Positioning Europe as a global decisive actor in innovation and sustainability: the role of road infrastructure". European Files, EU	01/05/2015	*EU*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
30	*Brochures*	ERF	Polish Road Congress	12/05/2015	*Warsaw (Poland)*	Scientific Community (higher education, Research), Policy makers, Medias	-	EU
31	*Oral presentation to a wider public*	ERF	Innovation in Road Construction	26/05/2015	*Sochi (Russia)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*275*	Global
32	*Brochures*	ERF	Innovation in Road Construction	26/05/2015	*Sochi (Russia)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias		Global
33	*Brochures*	ERF	Argus Bitumen Europe 2015	10-11/06/2015	*Istanbul (Turkey)*	Scientific Community (higher education, Research), Industry, Policy makers	-	Global
34	*Oral presentation to a wider public*	ACCIONA	"Asphalt mixtures improved by the use of nanotechnology" 6th International Conference Bituminous mixtures and pavements	10-12/06/2015	*Thessaloniki (Greece)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	>100	Global

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

35	*Workshop*	ERF	European Workshop dedicated to present project inputs to an EU-wide audience	15/06/2015	*Madrid (Spain)*	Scientific Community (higher education, Research), Industry, Policy makers		EU
36	*Press releases*	UC	"El equipo DURABROADS acoge la segunda reunión de colaboración en investigación entre la UE y EEUU".	16/09/2015	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain
37	*Oral presentation to a scientific event*	ERF	First Europe-Asia Road Congress organized exhibition	15-18/09/2015	*Istanbul (Turkey)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	*300*	Global
38	*Brochures*	ERF	First Europe-Asia Road Congress organized exhibition	15-18/09/2015	*Istanbul (Turkey)*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	Global
39	*Poster*	ERF	PIARC World Road Congress 2015	2-6/11/2015	*Seoul (South Korea)*	Scientific Community (higher education, Research), Industry, Policy makers	*4000*	Global
40	*Brochures*	ERF	PIARC World Road Congress 2015	2-6/11/2015	*Seoul (South Korea)*	Scientific Community (higher education, Research), Industry, Policy makers	-	Global
41	*Oral presentation to a wider public*	ERF	Development & Maintenance of Road surfaces in the Danube region	25/11/2015	*Bled (Slovenia)*	Policy makers	*100*	EU
42	*Brochures*	ERF	Development & Maintenance of Road surfaces in the Danube region	25/11/2015	*Bled (Slovenia)*	Policy makers		EU
43	*Twinning session*	UC	95th Edition of the Transport Research Board (TRB)	12/01/2016	*Washington (USA)*	Scientific Community (higher education, Research), Industry, Policy makers	*>100*	Global

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

44	*Press releases*	UC	"GITECO participa en la 95 edición del prestigioso Congreso Americano de Ingeniería del Transporte (TRB)".	12/01/2016	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain
45	*Article published in a specialized media*	BSRIA	DURABROADS – Innovate, cost-effective construction and maintenance for safer, greener and climate resilient road. (Delta T magazine edition called Soft Landings, bridging the performance gap, Pg-20,21). Article by Divya Deepankar.	01/04/2016	*UK*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
46	*Poster*	KTI	TRA 2016	18-21/04/2016	*Warsaw (Poland)*	Scientific Community (higher education, Research), Industry, Policy makers	*120*	EU
47	*Brochures*	KTI	TRA 2016	18-21/04/2016	*Warsaw (Poland)*	Scientific Community (higher education, Research), Industry, Policy makers	*120*	EU
48	*Poster*	ACCIONA	6th Euroasphalt and Eurobitumen Congress	1-3/6/2016	*Prague (Czech Republic)*	Scientific Community (higher education, Research), Industry	*1000*	EU
49	*Brochures*	ERF	6th Euroasphalt and Eurobitumen Congress	1-3/6/2016	*Prague (Czech Republic)*	Scientific Community (higher education, Research), Industry	-	EU
50	*Oral presentation to a scientific event*	KTI	International Civil Engineering Conference	16/06/2016	*Cluj (Romania)*	Scientific Community (higher education, Research), Industry	*40*	Global
51	*E-news*	BSRIA	"DURABROADS - Innovation for safer, greener roads"	01/07/2016	*UK*	Scientific Community (higher education, Research), Industry, Medias	-	Global
52	*Oral presentation to a scientific*	UC	European Road Infrastructure Congress	18-20/10/2016	*Leeds (UK)*	Scientific Community (higher education, Research), Industry, Policy makers	*>50*	EU

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

	event							
53	*Brochures*	UC	European Road Infrastructure Congress	18-20/10/2016	*Leeds (UK)*	Scientific Community (higher education, Research), Industry, Policy makers	*500*	EU
54	*E-learning training course*	BSRIA	E-learning course on 'Life Cycle Assessment with DURABROADS' where LCA principles are explained using DURABROADS examples. Available on: https://www.bsria.co.uk/information-membership/events/details/life-cycle-assessment-with-DURABROADS/	01/02/2017	*UK*	Scientific Community (higher education, Research), Industry	-	Global
55	*Articles published in the popular press*	IB	"Siltais asfaltbetons". Būvinženieris, N54	01/02/2017	*Latvia*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	Latvia
56	*Article published in a specialized media*	BSRIA	"DURABROADS- Base Case and Alternative Scenarios" (Delta T magazine edition called Facilities Management, pp.12-13). Article by Chris Thompson and Divya Deepankar	01/03/2017	*UK*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
57	*E-news*	BSRIA	”DURABROADS- Base Case and Alternative Scenarios	01/03/2017	*UK*	Scientific Community (higher education, Research), Industry, Medias	-	Global
58	*Oral presentation to a scientific event*	BSRIA	Life cycle assessment of base case and alternative scenarios' at SAM 11, 2017 Conference at NTNU. Published on: https://www.sovamat.org/sam-conferences/	15-16/05/2017	*Trondheim (Norway)*	Scientific Community (higher education, Research), Industry, Policy makers	*65*	EU

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
59	*Oral presentation to a scientific event*	KTI	XV. European Transport Congress and the. X. International Road Congress	7-9 June 2017	*Budapest (Hungary)*	Scientific Community (higher education, Research), Industry, Policy makers	*300*	EU
60	*Workshop*	ERF	European Workshop dedicated to present project inputs	20/06/2017	*Brussels (Belgium)*	Scientific Community (higher education, Research), Industry, Policy makers	*21*	EU
61	*E-news*	BSRIA	"DURABROADS - Life Cycle Costing Analysis of Road System"	30/06/2017	*UK*	Scientific Community (higher education, Research), Industry		Global
62	*E-news*	BSRIA	"BSRIA presents results on life cycle analysis of DURABROADS materials"	01/07/2017	*UK*	Scientific Community (higher education, Research), Industry		Global
63	*Press releases*	BSRIA	"BSRIA presents results on life cycle analysis of DURABROADS materials"	24/07/2017	*UK*	Scientific Community (higher education, Research), Industry		Global
64	*Newsletter*	UC	"Madrid acogerá el próximo seminario europeo de DURABROADS, en el que participa ASEFMA". ASEFMA	14/08/2017	*Spain*	Scientific Community (higher education, Research), Industry	-	Spain
65	*E-news*	ACCIONA	"Save the date: 12-September 2017. Enhancing Research and Innovation in Europe: the road sector experience" PTEC	27/08/2017	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	EU
66	*Article published in a specialized media*	BSRIA	Article on Life Cycle Costing Analysis of Road System in Delta T edition called Construction – A better way? Pp. 14-15	01/09/2017	*UK*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
67	*E-news*	BSRIA	Validating Economic and Environmental Feasibility of DURABROADS Asphalt Mixes'	01/09/2017	*UK*	Scientific Community (higher education, Research), Industry, Medias		Global

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

68	*Articles published in the popular press*	ERF	Article published in Le Strade describing the main inputs of the project	01/09/2017	*Italy*	Scientific Community (higher education, Research), Industry, Policy makers, Medias		Italy
69	*Newsletter*	TECNALIA	PESI Newsletter dedicated to the 3rd Workshop	01/09/2017	*Spain*	Scientific Community (higher education, Research), Industry, Media	-	Spain
70	*Press releases*	TECNALIA	Article (in English and in Spanish) dedicated to the 3rd Workshop. "Enhancing research and innovation in Europe: The road sector experience" "Jornada para impulsar la investigación e innovación den Europa: experiencia en el sector de carreteras"	01/09/2017	*Spain*	Scientific Community (higher education, Research), Industry, Media		EU
71	*Final conference*	ERF	Presentation of final results within a wider conference "Enhancing Research and Innovation in Europe: the road sector experience".	12/09/2017	*Madrid (Spain)*	Scientific Community (higher education, Research), Industry, Policy makers	*70*	EU
72	*Twinning session*	ERF	Specific Workshop to explain twinning activities between EU and US	12/09/2017	*Madrid (Spain)*	Scientific Community (higher education, Research), Industry, Policy makers	*70*	EU
73	*Press releases*	UC	"Enhancing research and innovation in Europe: the road sector experience (Final conference DURABROADS)".	12/09/2017	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain
74	*E-news*	ACCIONA	"Road infrastructure stakeholders recognize the need to adapt to latest innovation trends". PTEC	21/09/2017	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	EU
75	*E-news*	ACCIONA	"Finaliza el Proyecto DURABROADS". PTEC	04/10/2017	*Spain*	Scientific Community (higher education, Research), Industry, Policy makers	-	Spain

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
75	*Articles published in the popular press*	ERF	Article covering the final conference published in Le Strade	01/11/2017	*Italy*	Scientific Community (higher education, Research), Industry, Policy makers, Medias		Italy
76	*Article published in a specialized media*	BSRIA	Article on- Validating Economic and Environmental Feasibility of DURABROADS Asphalt mixes. To be published in Dec 2017 edition of Delta T magazine.	01/12/2017	*UK*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	EU
77	*Articles published in the popular press*	IB	Asfaltbetona seguma tipi Eiropā (Asphalt concrete types in Europe)".Būvinženieris, N59. To be published in Dec 2017.	01/12/2017	*Latvia*	Scientific Community (higher education, Research), Industry, Policy makers, Medias	-	Latvia
78	*Article*	UC	"Decision support model for the selection of asphalt wearing courses in highly-trafficked roads" (Under revision)	-	-	Scientific Community (higher education, Research)	-	Global

2.2.Exploitation plans of partners

3. REPORT ON SOCIETAL IMPLICATIONS

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	605404
Title of Project:	Cost-effective DURABle ROADS by green optimized construction and maintenance.
Name and Title of Coordinator:	Daniel Castro Fresno, Professor, University of Cantabria

B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No

• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	1	0
Work package leaders	5	14
Experienced researchers (i.e. PhD holders)	8	16
PhD Students	1	1
Other	7	21

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**8**
Of which, indicate the number of men:	6

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

● Yes
○ No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
■	Design and implement an equal opportunity policy	○	○	●	○	○
■	Set targets to achieve a gender balance in the workforce	○	○	●	○	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
■	Actions to improve work-life balance	○	○	○	●	○
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

● No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

● No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

● Yes- please specify: An e-learning course on Life Cycle Assessment was developed with the illustrative example of DURABROADS

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

● Main discipline[13]: Chemical science and Civil engineering: 1.3, 2.1, 2.3

○ Associated discipline: ○ Associated discipline[13]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ Yes
● No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

● No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

[13] Insert number from list below (Frascati Manual).

○ Yes, in communicating /disseminating / using the results of the project	

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ Yes ● No	

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ● Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ● Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
		Foreign and Security Policy		Space	
Education, Training, Youth		Fraud		Taxation	
Employment and Social Affairs		Humanitarian aid		Transport	X

13c If Yes, at which level?

- ○ Local / regional levels
- ● National level
- ● European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**5**
To how many of these is open access[14] provided?	**4**
How many of these are published in open access journals?	**0**
How many of these are published in open repositories?	**0**
To how many of these is open access not provided?	**1**
Please check all applicable reasons for not providing open access:	
■ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[15]: ……	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**0**
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**0**
	Registered design	**0**
	Other	**0**
17. How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	■	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

[14] Open Access is defined as free of charge access for anyone via Internet.
[15] For instance: classification for security project.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

● Yes ○ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ● No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

■	Press Release	■	Coverage in specialist press
❑	Media briefing	■	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
■	Brochures /posters / flyers	■	Website for the general public / internet
❑	DVD /Film /Multimedia	■	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

■	Language of the coordinator	■	English
■	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]