



PROJECT FINAL REPORT

Grant Agreement number: 603862

Project acronym: APSE

Project title: Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment

Funding Scheme: Collaborative project. ENV.2013.6.3-2

Period covered: from 01/01/2014 to 30/11/2017

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1. Final publishable summary report

1.1. Executive summary

Currently, the world is facing a serious threat of global warming, and as a result, more stringent environmental specifications are being introduced. In particular, the environmental impact of the hot asphalt mix industry is not negligible. Each kilometer of road covers a considerable amount of land and consumes a large amount of materials and energy during its construction.

In order to reduce the impact of road construction on the environment, the transport sector is moving towards the adoption of more sustainable concepts into the construction of roads infrastructures. However, at present, potential measures with sound sustainability credentials are not widely implemented, regulated and harmonized and a wholesale shift to use of these concepts has yet to occur.

To encourage the uptake of sustainable practices, a concept of a sustainable road pavement has been explored in the Asphalt Pavements for a Sustainable Environment (APSE) project under the Seventh European Research and Innovation Programme (FP7). The concept pavement utilises some well-established recycled components alongside some more novel bio-based products. Crude-derived bitumen and polymers are partially replaced in the surface course with a by-product of second generation ethanol production. Elevated levels of asphalt recycling in the structural layers are facilitated through the use of bio-based flux oil. Construction and demolition waste is used in the subbase, utilising the residual pozzolanic properties to reduce overall resource use.

The first part of the project was devoted to the validation of the materials and technologies at laboratory scale. APSE materials have then been taken to proof of concept through prototypes in UK and implementation road trials (Poland and Spain). Testing in the TRL's Pavement Testing Facility gave the opportunity to investigate primarily the structural properties of a full-scale road pavement and some of the surface characteristics during early-life. Based on the results of the accelerated testing, APSE materials should perform well in other European countries making like-for-like substitutions with conventional materials, as long as mixture designs are adapted to match local constituents and climatic conditions.

Demonstration road stretches are located in Poland and Spain, which allow to check the influence of weather conditions and locally available materials on the eco-pavement performance. 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 APSE sustainable pavement concept is suitable for industry and asset managers.

The environmental and economic profile of the APSE technologies was also investigated. The study involved the synergy of the life cycle analysis (LCA) and economic modelling, where the results of the LCA were used as an input data for the economic model to quantify the life cycle costs of the innovative pavement. The results showed that the use of these novel materials in pavement design is both an environmentally and cost effective solution as there are significant costs savings throughout the life time of the road, comparing to the conventional pavement alternative.

1.2. Project context and objectives

Project context and solution adopted

The construction of a new road has a number of implications for the environment. Materials commonly used are petroleum derived and extracted from quarries, therefore energy consumption and emissions associated are considerable. It is estimated that more than 90 percent of the 5.2 million km of European paved roads and highways are surfaced with asphalt. This massive use of asphalt in the EU road has correspondingly large environmental consequences.

Of the total environmental impacts of a road, a significant proportion derives from bitumen production, with crude oil extraction accounting for the major energy consumption and CO₂ emissions. 85 percent of all bitumen produced world-wide is used in asphalt pavements, where the 10 percent is used for roofing, and the remaining 5 percent is used in other ways².

Aside from bitumen, aggregates are the other main component in roads. Around 30.000 tonnes of aggregates are needed for construction of 1km of a national scale road, and it could be considered that depending on the type of extractive site and rock hardness the CO₂ emissions associated to aggregates production are in a range between 30 and 40 kg equivalent CO₂³. If it is considered that the European road network (EU27) is over five and a half million kilometers long according to Eurobitume, it is easy to guess that million tons of aggregates are needed each year to build and maintain European roads.

One of the potential measures to minimise the impact on the environment is the use of materials with greener profile. Current best practices for road products and infrastructures, such as the widely implemented CE Marking established by the EU Construction Product Regulation No. 305/2011, take into consideration a set of technical requirements for their established uses and in terms of environmental impact it is remarked that all construction materials should not have an exceedingly high impact over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition are focused on sustainability. In this line, APSE materials pay special attention to the green profile of the asphalt mixtures during their whole life cycle.

APSE project's concept is the design of an eco-innovative asphalt pavement to maximise environmental gains within the current constraints of asphalt and blending plant technology, therefore avoiding the need for major capital expenditure. This pavement concept uses recycled aggregates from construction and demolition waste, higher than typical reclaimed asphalt pavement, alongside more novel green binders, all integrated appropriately into optimal and eco-innovative designs of asphalt pavements.

The performance of the solution adopted in APSE road structure has been evaluated in the laboratory, through accelerated testing, and in the field.

² Asphalt Institute and Eurobitume (2008)

³ How to achieve aggregates resource efficiency in local communities”, SARM A project, www.sarmaproject.eu

Project Objectives

The main objective is to establish a new concept of asphalt pavement structures with ecologically oriented attributes, significantly reducing the asphalt pavement carbon footprint while achieving a level of long term performance comparable or greater than that of conventional pavement structures.

This goal is achieved by focusing on the two main components of asphalt mixture: bitumen and aggregates. In relation to bitumen, two types of greener binders are addressed; the first investigates bio-fluxing bitumen, which enables part of the petro-chemical binder to be replaced with bio-based products (vegetable oils); the second uses lignin, also bio-derived, to replace the crude-oil derived polymer in modified bitumen. In relation to aggregates, two different approaches are also explored: the use of high rates of reclaimed asphalt pavement (RAP) in new hot asphalt mixtures, thanks to the addition of bio-fluxing agents which will allow working at lower temperatures, and the use of construction and demolition waste (C&DW).

In order to demonstrate the environmental performance and cost-effectiveness of the APSE developments, the following activities were planned within the project:

1. *Design and up-scaling of the innovative components for the design of asphalt mixture and integration in the asphalt production plant.*

The feasibility of production of the APSE materials in quantities enough for the construction of the full-scale roads was investigated. Attention was paid not only the scaling up of the innovative materials ensuring they comply with the properties defined at laboratory scale, but also their integration into the asphalt plant for the production of asphalt mixtures with green profile.

2. *Construction, testing and characterization of the prototypes by means of accelerated loading testing.*

As part of the research activities of the project, prototypes were constructed and characterized by the accelerated load testing in order to determine the relative life of eco-innovative and conventional materials at each level, prior the construction of the real road trials.

3. *Construction and monitoring of two full-scale trial pavements.*

APSE materials have been validated in two trial roads subjected to different weather conditions and using local materials. Tests sections were built in Poland and Spain and are being monitored in the final part of the project. 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

4. *Life Cycle Analysis (LCA), an economic feasibility study and a complete market analysis to demonstrate the environmental and economic benefits of the solution proposed.*

Innovative technologies and materials developed in the project were analysed from the environmental and economic perspectives, where the life cycle analysis, economic feasibility and market analysis are distinguished.

The individual scientific and technical objectives that together will contribute to achieving the overarching aim of the project are described as follows:

Concerning the validation of the technical performance of the concept:

1. To demonstrate a green modified bitumen made of revalorised waste products (by-product of the bioethanol production)
2. To validate a new concept of bio-flux agent allowing the increase of the rate of reclaimed asphalt (RAP) in the design of new hot asphalt mixtures.
3. To establish a selective process for the separation of C&D waste, increasing the level of quality of the recycled aggregates.
4. To provide a systematic approach for eco-innovative asphalt pavements design.
5. To produce several eco-innovative designs of asphalt pavements prototypes by combining the proposed technologies.
6. To validate the eco-innovative asphalt pavement designs through accelerated loading testing at pilot scale.
7. To select the most suitable eco-innovative designs considering the demo cases (Madrid & Warsaw) specific requirements.

Concerning the demonstration of new solutions on real applications:

8. To scale up the production of the innovative solutions from lab scale to real industrial scale.
9. To validate the performance of the proposed eco-innovative asphalt pavement by means of the two real demo sites.

Concerning the economic and environmental performance of the new solutions developed:

10. To demonstrate the environmental value of the proposed practices, processes and products by means of life cycle analysis assessment (LCA)
11. To analyse the economic impact of the developed technology through a costing analysis.

Concerning the dissemination and exploitation:

12. Making better use of the results assuring that are taken-up by different stakeholders (civil engineers and construction workers, policy makers, technological providers...) to ensure follow-up.
13. Showing how European collaboration has achieved more than would have otherwise been possible developing advanced products contributing to European competitiveness and solving societal challenges.
14. To develop an exploitation plan for preparing market take-up of the critical results using business-oriented commercialisations plans which include dedicated business models & plans for each of the critical project results.

1.3. Description of the main S&T results/foregrounds

The development of the APSE project has been based on seven work packages:

1. Project Management
2. Analysis and selection of the green solutions for the asphalts manufacturings
3. Integrated “eco-construction” design of asphalt pavements
4. Up-scaling of the green asphalt pavements production
5. Demonstration and validation of the eco-pavement in real applications
6. Analysis of the environmental and economic impact of the innovative pavement.
7. Dissemination and Exploitation Plan.

The scientific development of different solutions to establish a new concept of asphalt pavement structures with ecologically oriented attributes has been researched and demonstrated within the technical tasks of WP2, WP3, WP4, WP5 and WP6. The main scientific and technical results of the APSE project are presented in the following work-package sections.

1.3.1. Analysis and selection of the green solutions for the asphalts manufacturings (WP2)

The main objectives of the Work Package 2 were to:

- Design an innovative green bitumen made of revalorised waste product.
- Validate at laboratory scale a new concept of bio-fluxing agent for pavements allowing increasing the rate of reclaimed asphalt introduced in the design.
- Establish a high performance selective process for the separation of C&D waste.
- Study the influence of the use of recycled aggregates in combination with the bio-based binders.

WP2 started in M1 and was successfully completed on schedule in M21. The tasks focussed on designing, characterising and validating at laboratory scale novel materials and technologies to integrate greener material, waste and recycled materials into the production cycle of asphalt mixtures. National certification schemes for both the technical issues as well as the environmental aspects of the application of recycled aggregates were also considered.

Task 2.1. Binders and RAP requirements

The purpose of this task was to identify and examine the successful approaches to asphalt recycling that specifically address the technical issues associated with including reclaimed asphalt pavement (RAP) into new asphalt mixtures. In particular, this study investigated the use of greener binders and increased RAP in new asphalt mixtures, the requirements that regulate these factors, and the long-term performances of these sustainable designs in comparison with conventional asphalt mixtures.

Task 2.1 was concluded in Month 6 of the project, with Deliverable 2.1, entitled State-of-the-art-review of reclaimed asphalt and fresh binder compatibility in the context of asphalt mixture design. This task undertook literature review and surveys to understand the current state of asphalt recycling across Europe, and the processes and procedures involved.

The aim of utilising more recycled materials together with the use of bio-binders (rejuvenators) and bio-polymers was also reviewed, not only as a replacement for asphalt binder, but also as a means of incorporating a higher percentage of RAP into new pavements. As a result, a ‘position’ for the APSE project to assume in terms of pre-existing levels of recycling and levels of technology could be established for the remainder of the project. The research also highlighted some of the issues surrounding the compatibility of fresh binder and that which pre-exists as a component of reclaimed asphalt.

The findings from this report show that in order to achieve higher RAP proportions in new asphalt mixtures, a mixing plant with the technical capabilities (parallel drums) to heat the RAP materials separately is recommended for producing the asphalt mixtures.

Whilst some nations are technologically advanced with regards to asphalt recycling, others remain at a very low base point. Application of the novel materials in this project should take this into account and consider which level of recycling technology should be focussed on – perhaps most appropriate level would be the ‘lowest common denominator’, in order to achieve the maximum gains.

There are numerous rejuvenators available for use in asphalt recycling which may allow increased RAP content in new asphalt mixtures. However, the performance of such additives are questionable, as are the economics, and further study of potential rejuvenators, as well as the technical processes associated with their incorporation, is required.

The potential use of bio-binders as an alternative, or as a supplement, to conventional binders, and the processes used to accommodate these recycled binders, or to achieve a large proportion of RAP, needs to be reviewed in more detail in order to meet industry standards (EN 13108).

As a result of the survey, it was concluded that there is no a standardised procedure to accommodate RAP in new asphalt mixtures along Europe; each country has different national procedures to utilise RAP in new asphalt mixtures.

Task 2.2. Bio-binders design and application

The main goal of this task was to design and validate at laboratory scale modified bitumen which fulfils the properties required by standards in EN14023:2010, substituting a proportion of the bitumen and polymer with lignin, a by-product from 2G bioethanol production.

In second generation bioethanol production, agricultural waste products such as wheat straw, corn stover, and sugarcane bagasse are utilised to produce bioethanol. Since the feedstocks are typically lignocellulosic biomasses containing a significant amount of lignin (20-30%), utilisation of this fraction is usually required to reach a profitable process. Currently, this is often done by pressing lignin into pellets for burning in power plants or for producing heat for the process itself.

Lignin varies in purity depending on the process conditions and feedstock used in the process. Hydrolysis lignin generally contains a residue of carbohydrates, since they are not fully hydrolysed by the enzymes in the reaction time available, but also due to the presence of lignin carbohydrate complexes in the material. These impurities, along with mineral impurities can constitute over 30% of the mass in standard hydrolysis lignin.

The composition of the different untreated lignin samples (hydrolytic lignin) was compared to organosolv lignin, which is a pure lignin product from ethanol extraction from wood. The optimal lignin for this research was the non-treated one, wherein the real content of lignin is 52 to 54% approximately.

The next step of the study was the production of the polymer modified bitumen with lignin, by blending SBS polymer and lignin with bitumen. The influence of different types of polymer, bitumen grades, lignin particular size and concentration and processing conditions was studied on the fundamental properties of the bitumen blends, according to the European standards:

- Determination of needle penetration (EN 1426)
- Determination of the softening point - Ring and Ball method (EN 1427)
- Determination of the tensile properties of modified bitumen by the force ductility method (EN 13589 and EN 13703)
- Determination of the elastic recovery of modified bitumen (EN 13398).
- Determination of storage stability of modified bitumen (EN 13399)

Results from the tests show that 70/100 penetration grade bitumen is recommended as base bitumen (although 50/70 may also be used). The maximum content of lignin to be added in the bituminous matrix is limited by the values of storage stability that should comply with normative. Processing conditions are other factor to look at. Mixing time, stirring rate and temperature are the three main parameters that should be well controlled.

The optimum formulation allows a significant reduction of the main ingredients, polymer and bitumen, by the addition of lignin. SBS content can be reduced up to a 15% and bitumen content up to 9%. Aside from the environmental point of view, the replacement of petroleum derived materials by renewable sources had a positive impact on the cost of the final product.

Aside from the study on binders, the asphalt mixtures produced using the APSE lignin polymer modified bitumen (lignin-PMB) were also investigated in the last part of the research and properties compared with those elicited by reference asphalt mixtures prepared with commercial PMB.

According to the asphalt mixtures developed and the characterization results, the addition of lignin to the bitumen has no negative impact on the performance of the resulting asphalt mixtures. Results are within the specifications and are comparable to those using conventional bitumen.

Task 2.3. Reclaimed asphalt pavement integration method design.

The objective of this task was to propose a method of application to increase limitation to the RAP content for the preparation of new asphalt mixtures, effectively working with bio-fluxing agents, using conventional techniques.

Work presented in this project is a proof of concept for commercial application of the previously developed bio-fluxing agents in order to allow higher RAP content in asphalt mixtures. The bio-flux agent, technology patented by WUT, partially behaves as asphalt rejuvenator, fluidizing the bitumen (asphalt binder) and making it possible for the bitumen to recover its original consistency.

Flux additive is a plant based product with partially unsaturated bonds with siccativ addition. Bio-fluxes offer considerable savings in terms of energy and VOCs emission. Also, these clean and ecological agents make the technology with higher RAP content suitable to be applied.

For the development of this task, three stages research plan were accomplished:

- Stage I: bio-agent production and testing; special laboratory device was built in WUT (chemical reactor),
- Stage II: bio-flux production and testing: bio-agent + virgin binder,
- Stage III: HMA with RAP and bio-flux production and testing.

Based on the existing experience of WUT, two types of bio-agent recipe were further investigated. Both types of bio-agents (version A and version B) were then mixed with binder (50/70) in the amount of 10% of bio-agent (by weight to the weight of binder) in order to produce bio-fluxed binder. Samples were then stored in thin layers in open containers subjected for the contact with air at room temperature (22-25°C). Temporary (at 0, 1, 3, 7 and 14 days) were tested for softening point (R&B method, EN 1427:2007) and viscosity (at 60 using Brookfield apparatus, EN 13302:2010).

Both bio-agents (Version A and Version B) placed similar impact on the binder. Due to this reason, for the further analysis and for the full scale application, the technologically less complicated method was selected. Version A (reaction in 20°C instead of 90°C) was further utilised.

Different concentrations of bio-flux were then tested. Based on the Ring & Ball results, bio-agent amount in the range of 2,5 - 5,0% (as referred to virgin binder by weight) was selected for the third stage of the research. Higher than 5% amount of bio-agent may cause the technology economically questionable; in addition, such amount would cause over flux and such modified binder would have to be applied for the surface treatment work rather than for the typical asphalt mixture production.

Taking into account road type and mixture category for the trial section construction (local road), Hot Mix Asphalt (HMA) with 30% RAP addition was further tested. It has to be stated, that however higher RAP content should work well based on the rheological point of view, proper blend design with typically available aggregates source would be problematic.

Asphalt mixtures were fabricated with the three types of binder (35/50, 50/70 and 70/100) and three levels of bio-agent amount (0%, 2,5% and 5%).

In general, it was assumed that bio-agent content should be on such level, that bitumen with bio-agent will change the properties by one class as referred to the base binder (35/50, 50/70, 70/100) according to EN binder classification system (35/50 -> 50/70, 50/70 -> 70/100). This was determined in the function of Dynamic Shear Rheometer (DSR) test in the wide temperature range (0°-100°C) based on the complex modulus G^* and phase angle δ .

To determine the stiffness, the 4-PB test was used according to PN-EN 12697-26, appendix B. Based on the obtained 4PB results it can be concluded that asphalt mixture with bio-agent added demonstrates better fatigue resistance properties than the one without. Also the Thermal Stress Restrained Specimen Test (TSRST) was conducted. Based on these results asphalt mixtures with bio-agent added demonstrate better low-temperature properties than the ones without.

The production of the HMA modified with the bio-fluxed binder can be conducted in a traditional HMA plant. Depending on the plant specific configuration, flux agent can be added either directly to the bitumen (asphalt binder) tank or through the installation dedicated mainly for the adhesive agent addition (alternatively).

Based on the State-of-the-art review it was found that in most cases 20% is the RAP limit for those plants which are not equipped with the dedicated infrastructure, such e.g. double barrel system for RAP heating (so called black drum). APSE proposed technology allows increasing of this limit by 10% (to 30% RAP addition). With special infrastructure, over-the-limit addition is also possible; however due to the previously mentioned problems related to the proper blend design will start to be crucial.

Task 2.4. Methods for the selection of recycled C&D aggregates for road construction

The objective of this task was to search for advanced C&DW processing concepts and methods using high grade sorting technologies already available on the market or at prototype level. In addition, a certification scheme (quality protocol) based on practical applications was established.

C&DW material composition and characterization according to EN 933-11 shows that, in order to obtain high grade recycled aggregates applicable in building and civil products applications, there is a need to sort out a number of contaminant components such as calorific fractions, gypsum and the non-concrete stony fraction.

In the actual market there is no complete advanced recycling concept available from input of raw (stony) C&DW to the dispatch of pure high-grade recycled concrete aggregates. Therefore an advanced processing concept was developed under the name “Stone Recycling”. This concept is a flexible solution to rather complex questions on how to obtain pure aggregates from raw C&DW. The Stone Recycling concept is conceived in two major parts, which can be operated separately, or in one line depending on the required outcome and product quality. In order to obtain high-grade recycled aggregates the complete processing concept is needed.

The processing concept consists of very well-known processing steps in the C&DW recycling industry such as primary crushing and sieving, wind shifting and the sorting out of ferric and non-ferric parts. Next to those the Stone Recycling processing concept is built around the purification of the material in terms of sorting out unwanted components such as gypsum by using Near-Infrared

(NIR) technology and the separation of the non-concrete fraction from the concrete fraction using colour-sorting equipment.

Finally the pure concrete aggregates resulting from the processing concept are brought to the right size fraction by crushing and sieving. These resultant high-grade recycled aggregates are applicable in both the bound and unbound applications for road construction.

Asphalt mixtures with different levels of recycled aggregates were designed and characterized. Findings from this research showed that asphalt mixtures up to 25% of recycled aggregates could be added without compromising the final properties of the asphalt mixture. Higher percentages affects to the water sensitivity.

C&DW can also be used as total replacement of granular material if property sieved ($C\&DW \leq 20$ mm). In cement-stabilised layers, the use of C&DW not only performs well as a granular material, but also allows a reduction in the cement content. California Bearing Ratio (CBR) increases from 9,8 to 17,0 if 1% cement is added to C&DW as the granular material.

The second objective of this task was to propose a certification scheme for recycled aggregates based on practical applications. The purpose of the Quality Protocol is to provide an uniform control process for producers from which they can reasonably state and demonstrate that their product has been fully recovered and is no longer a waste. It also provides purchasers with a quality-managed product to common aggregate standards increasing confidence in performance.

The described certification scheme was established as a voluntary certification scheme with the aim to increase the use of RCA and to give the user confidence in the product. The general quality protocol for the production of high grade secondary building aggregates under EN 13242 focuses primarily on the acceptance of the incoming materials through very severe acceptance criteria. Non-conforming incoming materials should by all means be avoided and rejected. If contaminant components remain in the aggregates throughout the manufacturing process the secondary building aggregates will never have the necessary confidence to the market.

Process control, as well as sampling and testing, should be carried out in a very professional way in order, again, to gain confidence over the complete manufacturing process. Finally, all of these measures have to be assessed by continuous surveillance by a notified body. The results of the evaluation should result in high level product certification issued to the manufacturer.

1.3.2. Integrated “eco-construction” design of asphalt pavements (WP3)

The main objectives of the Work Package 3 were to:

- Understand the requirements that eco-innovative asphalt pavement must comply with to be put on the market in Europe.
- Design the pavements prototypes for the real application selected.
- Evaluate the performance of the proposed eco-innovative asphalt pavement through accelerated loading testing at pilot scale.

WP3 started in M1 and lasted 36 months. The final goal of WP3 was to design and characterise asphalt pavements prototypes taking into account the materials investigated in WP2.

Task 3.1. Requirements/ standards to be complied with at EU level

The task reviewed the standards and national requirements for pavement materials in ten countries, including European and some other key countries around the world. In addition to the requirements for the materials, there are also requirements for the design of the materials into the pavement structure with thickness which are not harmonised across Europe and so are reviewed on country by country basis, noting the similarities and differences. It also highlights any concerns that the eco-innovative materials used in APSE will need to overcome. A number of design protocols were proposed as part of the task to assist with the materials selection and pavement design process.

The aim of this deliverable was to ensure that pavements designed and tested during the project meet the required standards so that widespread adoption is not hindered once the project is completed.

Following this review of a selection of European, national and international standards, the following conclusions were made:

- The increasing emphasis on performance-related rather than recipe-based requirements should allow more opportunity for innovative component materials to be used, but concerns about the long-term performance of mixtures with such components does restrict their acceptance.
- Aggregates are defined as ‘granular material used in construction’ that may be natural, manufactured or recycled and, as such, are not restricted in the European system. However, the chemical susceptibility of some potential aggregates, such as some slags, means that there need to be requirements to ensure their durability.
- The binder in asphalt has to be bituminous (i.e. contain some bitumen) so that any mixture with a non-bituminous binder could not be classified as asphalt. However, an innovative binder that contain bitumen could be used in asphalt.
- Additives are increasingly accepted as necessary for high-performance mixtures but there are generally no standards against which they can be assessed. Therefore, the European standards require such constituent materials to be validated by “demonstrable history of satisfactory use in asphalt”. However, there may be a difficulty in getting that demonstrable history if they cannot be used until they already have it.
- Innovative constituent materials will generally need the support of the highway authorities before they can be proven as demonstrating a history of satisfactory use in asphalt.

Task 3.2. Design of the pavement prototypes for the real application selected

This task described how pavement designs were simulated using the Alizé LCPC software, using properties of the novel materials determined from the laboratory in WP2. Analytical software programs determine the failure of the structure based on multilayer elastic models.

The simulations provided an indication of the performance of the materials, in terms of the pavement lifetime that they might theoretically achieve, measured in terms of the number of standard axles that they could potentially withstand.

Two typical asphalt pavements sections, flexible and semi-rigid, were selected in both Spanish and Polish scenario from the pre-defined sections in the respective catalogues according to the expected traffic intensity that should withstand the trial section in Spain and Poland, respectively.

Overall, the simulations indicated no concerns for the intended use of the novel materials within the project, and the standards that they would be required to meet at the road sites in Poland and Spain during WP5. The report also indicated how the pavements might need to be adapted to be used on highly trafficked roads in future scenarios beyond the scope of the current project.

Task 3.3. Testing and characterisation of the prototypes

The primary aim of this task was to provide a clear indication of how the APSE materials might perform in situ in the pavement sections of actual highways, in particular those that will be constructed later in the project, in Spain and Poland. In so doing, WP3 provided a key linkage between laboratory scale tests undertaken in WP2 and field-scale trials undertaken in WP5.

An accelerated testing trial was undertaken to elicit the properties of the APSE trial materials compared to their conventional alternatives. The primary investigation took place in TRL’s pavement test facility (PTF) between July and November 2016, during which time four pavement sections were constructed and subjected to loading in excess of 0.5M standard axles. The pavement sections were monitored throughout trafficking, with the primary aim being to determine the structural properties of the pavement sections under loading. This was achieved through the measurement of strain under loading and measurement of rut depth at regular intervals; thereby considering the two principal mechanisms by which road pavements fail structurally: through rutting and cracking. Visual inspections of the surface were also undertaken at regular intervals to record any incidence of surface disintegration. The four pavement sections contained APSE and conventional materials in the combinations shown in Figure 1 so that the specific performance of the materials used in different courses could be determined.

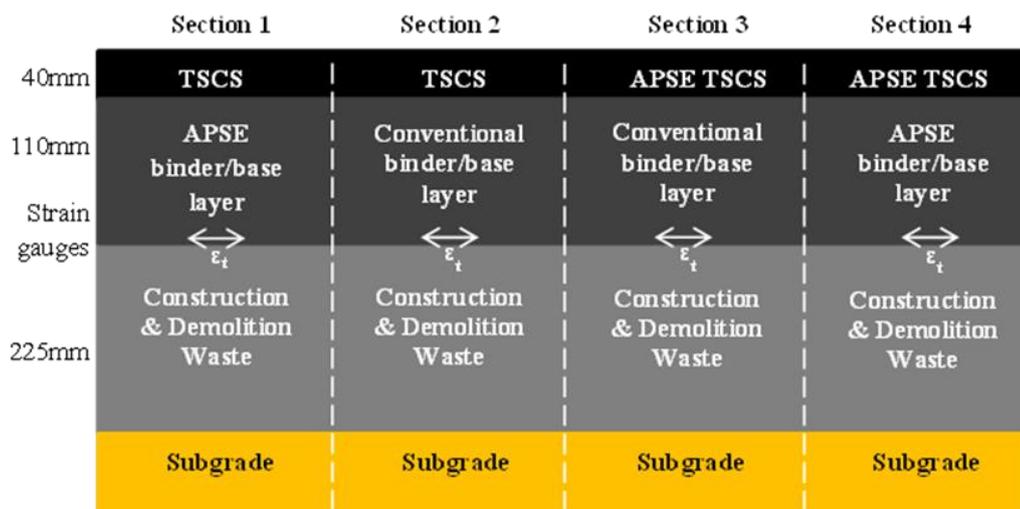


Figure 1. The four pavement sections subjected to accelerated testing

All four pavement sections were constructed with a construction & demolition (C&D) waste subbase. A separate, preliminary trafficking investigation was carried out in April 2016 to determine the suitability of the recycled aggregates from the same stockpile for this purpose. This preliminary trial

followed a standard procedure in the UK’s Specification for Highway Works (SHW) that is designed specifically to test the suitability of granular materials for use as subbase, comparing them to a control limestone. The trafficking trial and laboratory testing indicated that the recycled aggregates were suitable for use as unbound subbase, and hence could be used in the main PTF trial without having control sections of limestone subbase.

All of the materials used in the construction of the trial pavements (above the subgrade) were provided by CEMEX. The bituminous materials were manufactured at CEMEX’s Wickwar Plant and the recycled aggregates sourced from a long-established nearby supplier. The bituminous materials that were used are presented in Table 1.

Table 1. Bituminous materials used in the trial

Course	Material type
APSE base-binder	Asphalt concrete 20 mm dense; 40/60 straight-run bitumen; bio-flux; RAP
Conventional base-binder	Asphalt concrete 20 mm dense; 40/60 straight-run bitumen
APSE surface	Asphalt concrete 10 mm close-graded; lignin polymer modified binder
Conventional surface	Asphalt concrete 10 mm close-graded; 40/60 straight-run bitumen

The APSE-PTF trials measured various aspects of pavement response (structural rutting, asphalt strain response, and pavement deflections) under repeated trafficking at various wheel loadings using one type of tyre configuration. All of the experiments were performed at ambient temperatures, using highly controlled loading configurations and well-established techniques in the case of the pavement response measurements.

In terms of structural pavement performance, the rutting results after 151,018 passes (0.54 msa) showed that little or no structural deformation had occurred in any of the four trial sections. In addition, there were no visible signs of cracking or deterioration in the surfacing throughout the testing. The asphalt strain measurements, recorded at ambient temperatures, increased at first during the early stages of testing before stabilising and gradually decreasing by the end of testing. Any significant changes in strain were associated with changes in asphalt temperature. Finally, FWD survey results (under 40 kN load) showed that the pavement deflections, which are an indication of the relative pavement stiffness, did not radically change throughout the testing. Any slight changes in deflection were associated with variations in temperature.

In addition, a range of laboratory tests were conducted on material samples taken from the paver prior to compaction and on cored samples taken from the pavement sections after trafficking was completed. The compositional analysis of the bulk material samples showed that all mixtures were within specification. Tests on the cores post-trafficking revealed comparable air void contents for the APSE and conventional base-binder mixtures. This infers that the lower-temperature mixing of the APSE material and/or presence of RAP did not make the APSE materials less workable, most probably due to the presence of the bio-flux. ITSM values determined on the cores suggested that all trial sections, apart from one section containing an APSE base-binder course mixture, saw an

increase in average stiffness modulus after PTF trafficking. The APSE base-binder materials were generally not as stiff as the conventional materials, though this did not translate into inferior performance during trafficking. The final laboratory test determined moisture sensitivity on the core samples. Adequate moisture sensitivity was observed for all mixtures, though the APSE mixtures seemed to be marginally more susceptible to water ingress than their conventional alternatives.

Overall, the PTF trafficking trials demonstrated that the recycled materials used in this trial can perform satisfactorily in road pavements.

1.3.3. Up-scaling of the green asphalt pavements production (WP4)

The main objectives of the Work Package 4 were to:

- Design the manufacturing process for the pilot plant.
- Scale up the production of the green binder and the bio-based fluxing agents to an industrial level and their integration in the asphalt production plant.
- Develop a process quality risk assessment plan.

WP4 started in M10 and lasted 36 months. The main objective of WP4 was to guarantee the correct up-scaling of the APSE technologies from laboratory to industrial scale while developing a process quality and risk assessment plan.

Task 4.1. Design of the manufacturing process: pilots plant layout

The aim of this task was to demonstrate the feasibility of the production of the green components developed in WP2 at industrial scale, without affecting their final properties defined from previous studies at laboratory scale. In particular, two green technologies were considered to be scaled-up: lignin polymer modified bitumen and bio-fluxing agent.

To do so, the layouts of the pilot plants before the implementation of the process at real scale were drafted, considering both technical and functional requirements and costs.

This task ended with the design of the two pilot plants, based on product and equipment's requirements, operational conditions and methods.

In addition, a plant-performance analysis was carried out in order to develop an accurate understanding of plant operations, including:

- Operating instructions;
- Maintenance requirements
- Troubleshooting

Task 4.2. Up-scaling of the process; manufacturing of the green raw materials and integration in the asphalt production plants.

Task 4.2 reported not only the scaling up of the innovative materials ensuring their compliance with the properties defined at laboratory scale, but also their integration into the asphalt plant for the production of asphalt mixtures with green profile.

In this task the feasibility of production of the APSE materials in quantities enough for the construction of the trial roads later in the project was evaluated in detail. Particular attention was given to the scaling up of the bio-agent and lignin polymer modified binder, as the use of the other ingredients of the APSE project - reclaimed asphalt and construction and demolition waste as secondary aggregates - is some-how more known and people from the construction sector is more experienced.

Some recommendations for improving the confidence on the use of asphalt mixtures with high content of recycled aggregates were also provided at the completion of this task. The use of RAP and C&DW is only possible by correctly treating the material.

As a case study, main materials of the APSE project were produced in sufficient quantities and integrated in Wickar Asphalt Plant (CEMEX, UK) for the construction of pavement testing facility in TRL.

Based on the findings, a proposal of the integration of the eco-friendly materials taking into account asphalt plant configurations were drafted, prior to trial road sections were built. In addition, different configurations for the integration of these novel products in the asphalt plant were included, followed by a brief discussion on the advantages and difficulties of each method.

– Production of the lignin polymer modified bitumen

The production of lignin polymer modified bitumen at industrial scale can be carried out in bitumen modification plants. They can be mobile or fixed plants. Mobile plants are usually proprietary of construction companies for the production of their own modified bitumen. Non-mobile or fixed plants are the ones from oil companies which are on charge of the supply of bitumen for the construction of works.

In July 2016 a mobile plant property of ACCIONA (see Figure 2) was used for the production of 2 tonnes of lignin polymer modified bitumen to be supplied to CEMEX for the preparation of the asphalt mixtures for the pilot trial in TRL's facilities. Previous to the bitumen production the modifications defined in the previous task (T4.1) were implemented.



Figure 2. General view of the bitumen modification plant

For the production of PMB, bitumen, polymer and lignin were continuously loaded and dosed into a small pre-mixer tank for a continuous production of lignin-PMB with a single pass through the mill. Operating conditions as well as lignin and polymer dosage were determined and optimized during the validation phase of the industrial modification bitumen plant.

Once bitumen was produced a sample of the lignin-PMB was taken for quality control. Bitumen was characterized in the laboratory to validate that the produced bitumen fulfills the properties required by standards for a PMB 45/80-60.

By using this procedure, a challenge was to supply the lignin-modified binder to CEMEX in UK once pre-blended in Spain to be ready to use (by re-heating in place) in specially adapted tanks before incorporation into the trial mixtures.

To overcome this limitation a tank unit was designed with a self-heating system and stirring to facilitate the heating of the bitumen in place and also the connections needed to pump the bitumen from the tank directly to the asphalt plant. Lignin polymer modified bitumen produced in Spain was then discharged into the tailored made tank for the transport to UK.



Figure 3. Tank feeding in Spain (left) and tank placed in UK (right)

– Production of the bio-fluxing agent

The concept of bio-fluxing agents is based on the use of new vegetable origin binders where synthetic and petro-chemical products are replaced with plant-based products. This material is made from vegetable oils but requires some chemical processing to be potentially used as asphalt modifier as described in Task 2.3.

The material was produced starting from WUT recipe, developers of the technology, and slightly modified afterwards due to the outcomes of the industrial processing. The reaction was based on rapeseed oil methyl esters (RME) through oxidation. Once the route of synthesis was optimised, a sample was sent to WUT for the validation and approval.

The bio-fluxing material ended in two separated ingredients to be mixed on site. Following this recipe, 4,2 tonnes of bio-fluxing agent were produced in an experimental scale on a pilot plant and delivered to the places where the demo roads will be built (Poland and Spain). All the material produced was accompanied by a certificate of analysis and compared with the requirements which bio-fluxing must comply with defined by WUT.



Figure 4. Reactor 2000 dm3: upper part (left), lower part (right)

Aside for the production of the material and in order to assist WP5, the best method of addition of the bio-fluxing agent in the asphalt plant was selected. It is recommended to add the material to the bitumen storage tanks, so that during the plant operation and HMA production, virgin binder and bio-agent is added at the same time and only one binder, bioflux, is mixed with aggregates and RAP. Using this option will simplify whole technical process, although can be sometimes a little logistical challenging due to the need to use whole tank of bioflux (low concentrated).

Task 4.3. Process quality and risk assessment plan

The aim of this task has been twofold, 1) To check the products comply with the required properties (process quality) and 2) to identify the risks involved within the production cycle of asphalt mixtures (risk assessment plan).

- Quality control strategy

A quality control plan was drafted to include the production of the innovative materials under quality control criteria. In the quality plan all the factors involved in the production cycle of hot asphalt mixtures (HMA) were reviewed, from the constituents materials to the delivery of the mixtures and a measure of validation of such products were provided.

The final goal was to declare that the performance of asphalt mixtures, including new products, falls under the scope of the Construction Products Regulation (CPR), and thus has CE marking before can be put on the market. Therefore, it was necessary to apply a system of evaluation used under the CPR, specifically System 2+ “Factory production control (fpc) certification with continuous surveillance by a notified production control certification body”. More precisely, the focused on one of the five tasks involved with 2+ system: point 2 “Implantation of a factory production control”, following the standard EN 13108-21, *Materials Specifications – Part 21: Factory Production Control*.

It was assumed that the asphalt production plant belongs to a company that already has implemented a quality system ISO 9001 where general procedures for the treatment of non-conformities, staff training, control of documents and records, management of purchasing, internal audits, etc. already exist.

The development of a Quality Plan for HMA production control included the following general content:

- a. Organizational structure respect to compliance and quality. The authority and specific responsibilities in relation to the HMA Quality Plan were detailed.
- b. Control of documents. Documentation was checked according to the General Procedure "Control of documentation", which the company has been already implemented according to ISO 9001.
- c. Processes control. Procedures for control of the constituent materials and the product supplied were described.
- d. Requirements relating to the handling and storage of products.
- e. Calibration and maintenance of production and measurement equipment of the plant.
 - Risk assessment plan

A risk assessment plan was drafted to identify and evaluate the risks associated within the production process of the APSE materials in terms of both natural environment and health & safety of workers.

The risk assessment was performed following the methodology described in standard ISO 31000, which refers to the process for the risk management. It is an iterative process and can be applied to specific projects and activities.

Social, cultural and heritage risks were not considered in this task since APSE materials are incorporated in an asphalt plant which are generally installed or constructed far from any inhabited place or any considered place of archaeological or historical interest.

The methodology followed for the environmental risk assessment refers to norm UNE 15008, “Analysis and environmental risk assessment”. This methodology is identical to the standard ISO 31000, with the difference that standard UNE 150008 is specifically focused on the analysis of environmental risks. Taking into account this methodology the following steps were considered:

1. Study of the plant:

The general operation procedure of an asphalt plant was studied for analyzing in detail how new products can be incorporated into the asphalt production plant. Information from previous tasks (Task 4.1 and 4.2) were taken as a base line.

2. Identification of hazards and preventive measures:

An analysis of the hazardous substances handled at the plant was conducted, including the new materials from APSE. Based on international bibliography, environmental risks in relation to facilities and equipment have been identified too. The most significant ones are derived from loss of hazardous liquids materials from pipes, tanks, etc. and their magnitude will critically depend on the spilled amount, of possible sources of ignition and of containment mechanisms to avoid that substance reaches the soil or the drainage networks, etc.

After hazard identification, preventive and mitigation measures were proposed for each of the main equipment or system of the asphalt plant: bitumen tank, thermal insulation and cladding, heating system and pipeline system.

3. Lists of possible accidental relevant scenarios:

Hazardous events which have reasonable likelihood and a significant environmental impact severity were gathered in an extensive list. Each of them includes its causes, possible consequences and the proposed prevention and mitigation control measures.

4. Criteria to analyze and estimate the risk of the identified accidents by using the equation established in UNE 150008, where risk is likelihood x consequences.
5. Evaluation of the risk. The degree of risk was established by considering its constituent components of likelihood and consequence in the matrix shown in table below.

The second part of the study included the health and safety risk assessment, according to standard ISO 31000. The methodology used is very similar to the environmental risk assessment. The first step was the definition of the existing jobs related to the asphalt plant.

- Operating personnel of the plant
- Maintenance personnel
- Front end loader driver

Secondly, main health & safety hazards scenarios were identified in relation to plant processes, materials and loads handling (APSE new materials included), use of tools and machinery, etc. Possible risks were defined in each scenario and several preventive measures proposed, including personal protective equipment.

Conclusions from the study indicated that, taking into account the preventive measures applied to all scenarios studied had an acceptable risk.

1.3.4. Demonstration and validation of the eco-pavement in real applications (WP5)

The main objectives of the Work Package 5 were to:

- Select the demo sites in two locations (one in Poland and one in Spain to check the eco-pavement performance under different climate conditions.
- Coordinate the logistics and administrative work needed for a successful implementation.
- Monitor the eco-pavement performance and assess the results

WP5 started in M1 and run until the end of the project (M47). This WP was focused on the implementation of designed pavement solutions in two full scale roads so as on the validation and demonstration of their satisfactory performance. Test sections are located in Poland and Spain in order to evaluate the influence of weather conditions and locally available materials on the eco-pavement performance.

Task 5.1. Selection of the demo sites and analysis of the demo requirements

This task comprised the selection of the location in which both trial sections were built. The selection was made taking into account APSE materials requirements, asphalt pavement design outputs from Task 3.2. and, last but not least, national normative of pavement design in Spain and Poland respectively.

Comunidad de Madrid, regional Road Authority of the Madrid region, was responsible for the selection and construction of the trial section in Madrid, via a tendering process. GRANAR, a company which activity is mainly focused on road construction, was responsible for the trial section in Poland.

The definition of the technical requirements for the selection of the trial section was based on specific catalogues for pavement design that already exist in Spain and Poland. These catalogues include pre-defined pavement sections which are based on decades of successful experiences of pavement construction with proven and validated results both at service and laboratory levels. Most catalogues are defined based on similar criteria: availability materials, traffic loads and subgrade layer.

In the particular scenario of this project, pavement structures used in Spain and Poland are presented in Table 2 alongside a UK structure that was effectively ‘scaled-down’ for the purpose of the accelerated testing in the PTF. Given that the Spanish structure is similar to that of the UK and the Polish structure is for a lower-specification road, and subject to less traffic, it might be asserted that the APSE materials should perform equally well in these situations as has been observed in the pavement testing facility (PTF).

Table 2. Indicative pavement structures from Spain, Poland and the UK

Course	Spain	Poland	UK
Surface course	30 mm	40 mm	40 mm
Binder course	80 mm	50 mm	60 mm
Base	190 mm	70 mm	230 mm
Subbase	250 mm	200 mm	225 mm
Total	550 mm	360 mm	555 mm

As a result of this task, and based on the requirements defined in the project for the implementation of the APSE developments, two demo sites were selected. The test section in Poland was built in Chmielna Street, Makówka, in east-central Poland. In Spain the test section is part of a construction project in Tres Cantos, Madrid, where the main objective is to improve traffic density around the area, especially at rush hours. It is a road rehabilitation project in the junction of the M-607 road with M-606 road.

Task 5.2. Coordination and supervision of the green pavements implementation

The objective of this task was to coordinate the logistics and administrative work needed for a successful implementation of the innovative materials developed in APSE project in two local roads in two different locations, Poland and Spain.

This task represents the “real” proof of concept of the main goal of the project, in which the APSE materials were upscaled to plant mixed materials for the construction of the test road sections. Some key stipulations on the task were needed, in order to achieve the required outcomes:

- a. The APSE constituent materials were produced using full-scale production processes and supplied to the worksite, except for lignin polymer modified bitumen that some problems were experienced.
- b. The asphalt materials laid in the test roads were manufactured in a pre-existing asphalt plant and paver laid.
- c. Local specifications for roads works (Spanish and Polish respectively) were followed.

In practice two types of materials were tested in both sections:

1. Recycled aggregates from C&DW as total replacement of virgin aggregates in the subbase.
2. 30% RAP as partial substitution of the aggregate using conventional plants, with no technical capabilities (parallel drums) available to heat the RAP material separately for base and binder course

In this scenario, the application of higher RAP content than usual (>20%), might cause that the virgin aggregates should be preheated to very high temperatures. This might result into a significant decrease of the mechanical characteristics of the mixtures produced. The APSE project has overcome this technological barrier, where the incorporation of 30% of RAP was facilitated thanks to the use of bio-fluxing agent, which allows mixing at regular temperatures and thus avoiding the “super-heating” of virgin aggregates.

Unfortunately, lignin polymer modified bitumen could not be tested in Poland due to not receiving special APSE-developed lignin polymer modified bitumen in timely manner allowing for their use in the road construction. Due to this reason, both sections were only different in terms of the asphalt binder and base layers (30% RAP and bioflux used in APSE experimental section while only 20% RAP in standard section) and subbase (C&D waste in APSE experimental section substituting aggregate in standard section).

In Spain, due to climatic conditions (really low temperatures) the surface course with the lignin polymer modified bitumen could not be placed on time. However, as soon as the weather improves the surface course will be laid to fully validate the APSE concept structure and conclusions will be reported to the EU Commission as well as the project partners.

Prior construction, materials used in the field operations were validated at laboratory scale according to local specifications for road works. Results from the tests indicate that all mixtures meet the minimum values required by normative.

The Polish trial road was built by Granar during the summer in Makówka, in south east of Warsaw, with favourable weather conditions. Pictures from the construction phase are shown in the following figures.



Sub-base construction – virgin aggregates (left) and recycled aggregates form C&DW (right)



Paving and compaction process

Figure 5. Implementation of the APSE materials in Chmielna Street, Makówka

Field demonstration was an attempt to show and to verify that in practice a small-to-medium size construction company, thanks to the APSE technology with bioflux addition, can go much higher than usual with RAP, for up to 30% RAP without the costly re-designing of the whole asphalt mixture. Such verification is one of the most important proofs allowing for the commercialization of the project results.

APSE demo section was built in the regional road of Madrid M-607 as part of a construction project in the municipality of Tres Cantos, 20 km to the north of Madrid. The works were closely followed up by Comunidad de Madrid, owners of the road, and ACCIONA providing technical support.

The following pictures document the paving process:



Delivery



Paving



Compaction



Paved road

Figure 6. Implementation of the APSE materials in M-607 road, Tres Cantos, Madrid

Conclusions of the construction phase showed that APSE materials can be produced in traditional HMA-plant (not equipped with double barrel system). The incorporation of high RAP content was possible thanks to the integration of plant-derived fluxes (bio-flux).

Based on the findings, the trials demonstrated that the recycled materials and bio-binders used in the trials can perform satisfactorily in road pavements provided they are constructed to specification and laid by experienced site operatives.

Task 5.3. Monitoring and assessment of the results

The objective of this task was to provide an interpretation of how APSE materials perform *in situ* in the pavements sections subjected to regular traffic. Innovative materials were implemented in two local roads, in Poland and Spain and compared with their conventional alternatives. A detailed description of the construction phase and pavement structures as well as materials used in the trials road is presented in task 5.2.

The monitoring activities were based on non-destructive techniques (FWD testing) as well as invasive (cores samples). In addition visual inspections were made to check for cracking or any other signs of visual distress.

Polish trial road was constructed in July 2017. Monitoring started right after the construction was accomplished. Visual inspection was performed prior the road was opened to traffic and during its pavement life every month until the end date of the project (July, September and November). In

terms of the surfacing course, both the control and APSE surface layers held up well to the short time of trafficking with no visible signs of cracking or deterioration.

In addition and to verify quality of the construction, pavement layer thickness was also determined from cored samples taken from the pavement sections after trial was completed. Results shown that thickness of the paved asphalt layers remained on the satisfactory level, surface layer is slightly thinner in both sections while binder layer is thicker, resulting on the whole asphalt structure to be on the exactly desired thickness value.

First measurements of deflections using a Falling Weight Deflectometer (FWD) were conducted in September 2017 to determine stiffness modulus of structural layers based on the deflection tests conducted on the road. FWD equipment used in the study has a capability to maximum 120 kN load simulating pressure from the heavy truck vehicle traveling with the speed of 35-40 km/h. In particular, the FWD analysis were conducted under 50 kN load and a temperature of 18°C. In this research a loading plate with diameter of 300 mm with central geophone and with eight geophones placed in the distance of 200 mm, 300 mm, 450 mm, 600 mm, 900 mm, 1200 mm, 1500 mm, and 1800 mm from the center of the load plate was used.

Results separated for both tested sections (standard and APSE experimental) shown that deflections remained on a similar level for both types of sections and for both sides of the road (left and right).

Based on the pavement deflection curve developed with FWD and structural characteristics, stiffness modulus can also be calculated for road structural layers. Calculations were conducted with ELMOD6 software. Values of elastic modulus are within the range of typical results for similar asphalt structures in a good shape.

Unfortunately, monitoring activities in the Madrid trial to evaluated the structural performance of the road have not been able to be started due to the delays in the construction of the road (unfavourable weather conditions). However, a monitoring campaign is already planned. In relation to the pavement structural behavior, the pavement stiffness using the FWD will be studied. From the functional point of view, the following road surface properties are planned to be measured: macrotexture with SCRIM and Skid resistance.

Routine testing for quality control on the samples collected from the trials in Spain prior to laying have been conducted. Based on the results, all asphalt mixtures implemented complied with the minimum values required by normative for base and binder courses. Overall, APSE mixtures offer better performance than their reference samples, being less vulnerable to water ingress and more resistant to permanent deformation. This finding was already expected given the results from the laboratory validation of the mixtures in the Task 5.2.

Based on the conducted FWD tests and visual condition monitoring for the Polish trial it can be concluded that APSE technology behaves at the similar quality level as their standard-technology alternative. This short term (less than half year) monitoring assures that the APSE structure is suitable for the Polish climate and traffic conditions (stiffness modulus on the typical level for such road, no rutting, cracking, delamination's, etc.). However, to fully support this finding, a long term monitoring would be appreciated.

Partners involved in this task are planning to continue the monitoring tests once the project is ended with the objective to compare the influence of weather conditions in both locations, as well as the accuracy of the estimations provided by the Accelerated Loading Test and virtual simulations will be checked. Results of this monitoring will be disseminated in the scientifically and industry-oriented publications.

Outcomes from this WP, together with the results of WP4, proved the technical feasibility of the APSE project, in which providing technologies that facilitate asphalt recycling, use of waste and novel greener binders, all integrated appropriately into optimal and eco-innovative designs of asphalt pavements, and thereby increasing their commercial viability, can be adopted for widespread application in the right situations.

1.3.5. Analysis of the environmental and economic impact of the innovative pavement. (WP6)

The main objectives of the Work Package 6 were to:

- Quantitatively assess the sustainability of the novel technologies at economic and environmental level.
- Define key environmental/economic performance indicators for helping with the interpretation of the results of the LCA and LCC.

WP6 started in M1 and last 42 months. The main objective of this WP was to assess the sustainability of the novel technologies developed at economic and environmental level compared with the traditional ones.

Task 6.1. Life cycle assessment (LCA)

The goal was to conduct a comparative LCA in order to identify parameters that have a significant impact on the APSE pavements environmental performance. The scope of analysis was Cradle-to-Grave (60 Yrs) and Cradle-to-Site and the functional unit was 1m² of Single Lane Highway.

A full life cycle assessment, in accordance with ISO 14040 and 14044 (2006), and sensitivity analysis was conducted for conventional and APSE pavement designs. The comparative model was developed using GaBi (2017) software, alongside bespoke excel models. It used the most current life cycle inventory data available, harmonized for EU-27 member states. The study found that the APSE pavement offers a potential cradle-to-grave saving of 7.9kgCO₂eq/m² (across a 60 year design life) and a cradle-to-site saving of 8.8kgCO₂eq/m², both relative to the impact of a typical pavement constructed across Europe. The study examined a range of moisture contents, plant fuel types, efficiencies and consumptions, the effects of superheating aggregates, material quantities and sources, asphalt discharge temperatures, transport distances & efficiencies, end-of-life sequences, and so on. For further context, the LCA results were normalised for the European situation, in person equivalents.

Based on the findings, the results, both in terms of cradle-to-grave and cradle-to-site system boundaries, overwhelmingly indicated that recycling RAP and C&DW in the bound and unbound courses, alongside substituting a proportion of bitumen for lignin, and lastly using a bio-flux to

accommodate higher proportions of rejuvenated RAP, is environmentally advantageous across all mid-point impact categories. The environmental benefits associated with the additional processes of recycling, producing novel materials and their transportation, far outweigh the negative impacts they generate.

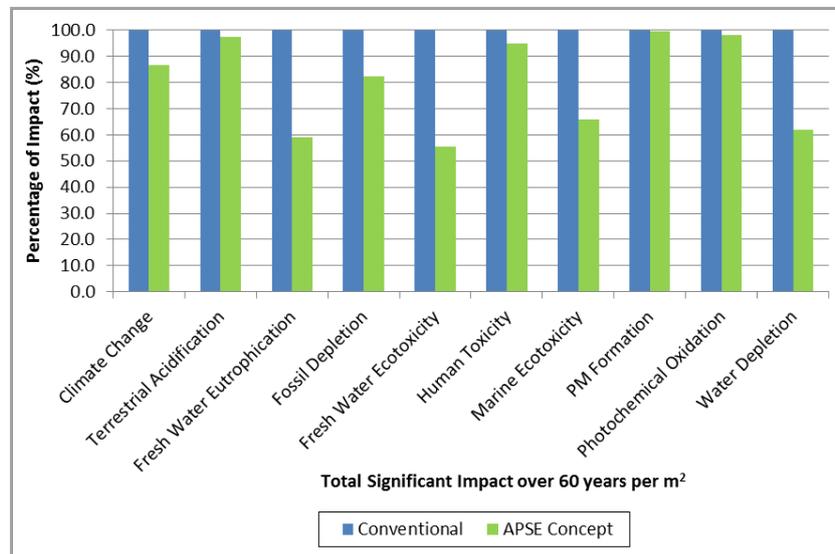


Figure 7. LCA results: APSE concept vs conventional

Additional benefits could be further realised through a number of measures, namely: incorporating a higher percentage of lignin in the surface course binder; substituting high specification aggregates in the surface course for RAP, through surface-to-surface course asphalt recycling; increasing the proportion of RAP in the binder and base courses; and most importantly minimising the impacts associated with transporting resources through the adoption of smaller measures such as the use of alternative, low carbon fuels, improved vehicle aerodynamics, and reduced transport distances.

Task 6.2. Economic feasibility and market analysis

This task was divided into two subtasks: 6.2.a) Economic feasibility/LCC and 6.2.b) Market analysis.

- Task 6.2a Economic feasibility

The feasibility of different pavement designs was assessed both from an environmental and economic perspectives. While the environmental performance of APSE pavement was analysed through a Life Cycle Analysis, the economic feasibility of innovative pavement materials was assessed applying a Life Cycle Costing approach, following the methodology of the ISO 15686-5 standard.

The economic feasibility of APSE pavement was estimated comparing the flexible and semi-rigid innovative pavement with the conventional pavement alternatives in three European countries: the UK, Spain and Poland. In total the model examined 12 pavement scenarios. The cost-effectiveness of APSE pavement was analysed from the life cycle perspective, where construction, rehabilitation and end-of life phases were considered.

The costs-effectiveness of flexible APSE pavement in construction stage was estimated to be the following: in Spain it is 26%, whereas in Poland it is 32% and in the UK it is 22%. The costs-effectiveness of semi-rigid APSE pavement is estimated to be 31% in Spain, 29% in Poland and 22% in the UK (Figure 8).

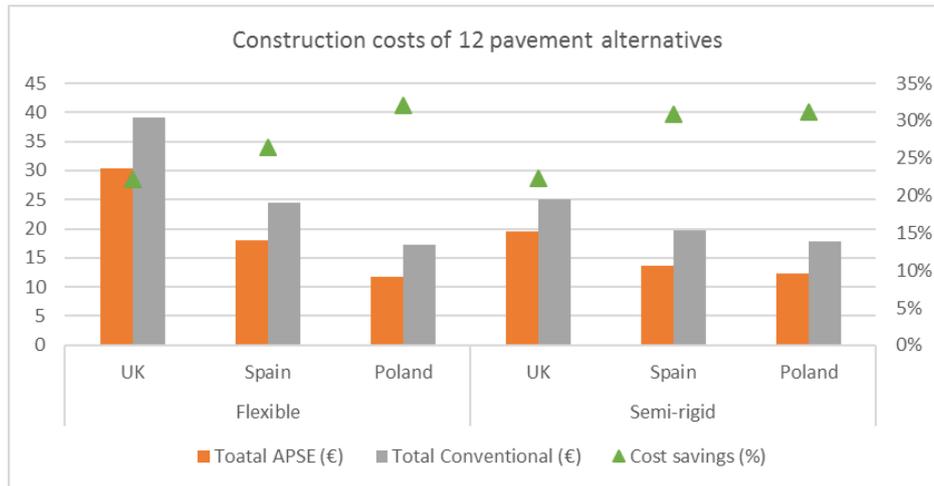


Figure 8. Construction costs of 12 pavement alternatives

In terms of rehabilitation costs, the rehabilitation of APSE pavement at the 30th year is 16% less costly than of conventional pavement in Spain, 13% in the UK and 11% in Poland.

The environmental impacts of pavement alternatives were also captured within the Life Cycle Assessment (Task 6.1), which allowed to estimate the environmental benefits of APSE pavement. By allocating unit costs on the environmental externalities, the environmental costs of conventional pavement and APSE pavement were compared within the whole life cycle of the pavement. Results of the analysis indicated that APSE pavement brings 27% savings in the environmental costs (Figure 10).

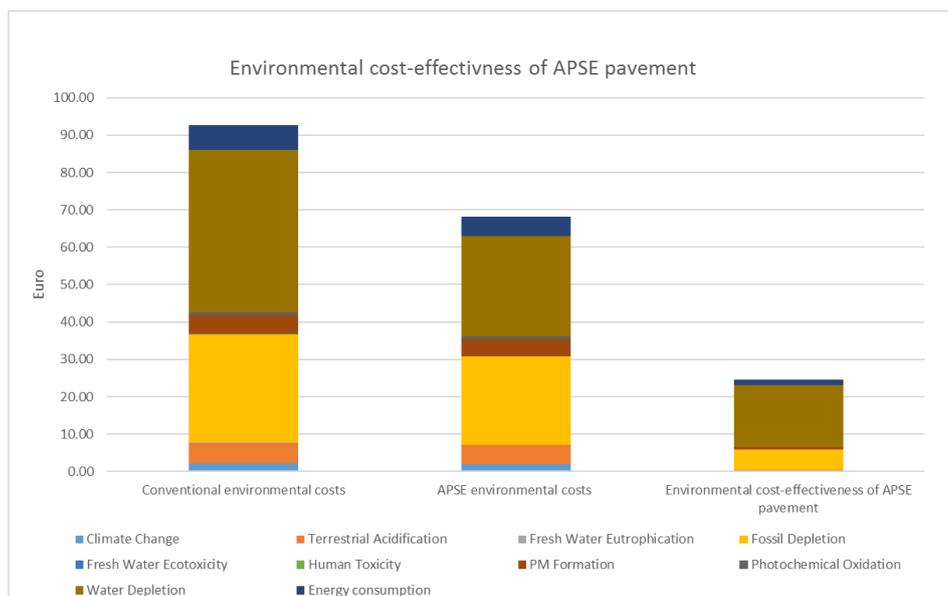


Figure 9 Environmental cost-effectiveness of APSE pavement

Following the Life Cycle Costing Analysis (LCCA) methodology, the net present costs of conventional and APSE pavement throughout the 60 years of life time were estimated. Figure 10 below illustrates the LCCA results, based on the UK mixtures for flexible pavement. In line with the LCA, the maintenance occurs every 15 years, where surface layer is replaced with a new one. At year 30 maintenance includes both the surface and binder layers replacement. Once the environmental externalities were internalised, the cost-effectiveness of APSE pavement increased from X to 32% within the construction phase. In case the net present value of the total costs over 60 years of pavements life is considered, the cost-effectiveness is estimated to be 29%, as maintenance and end-of-life costs are discounted at 4% level.

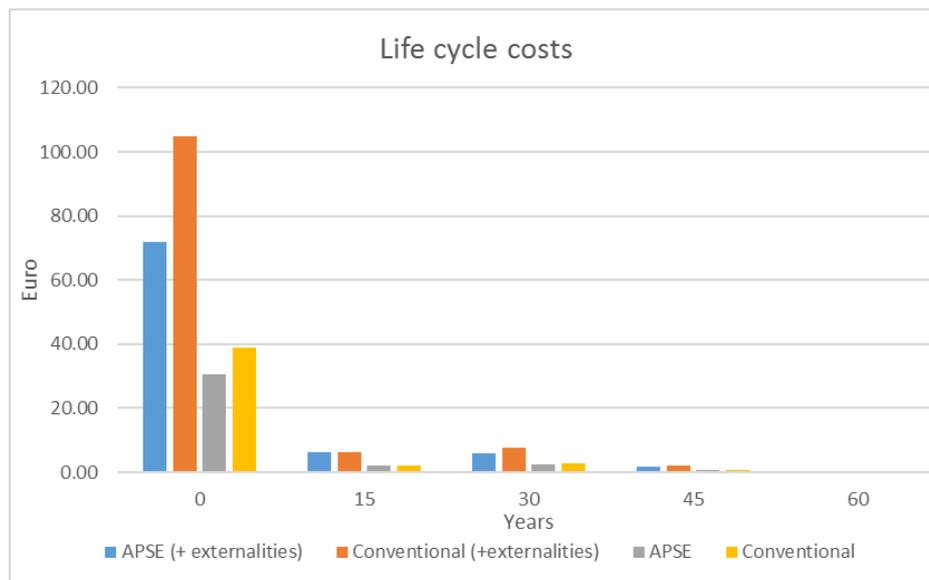


Figure 10 Life cycle costs (NPV)

A sensitivity analysis was also conducted to examine the impact of the market price of bitumen, market price of bio-flux and a discount rate.

According to the estimated results, increase in oil prices will make the crude-oil derived bitumen more expensive, whereas the bio-modified bitumen will become more favourable alternative for construction and rehabilitation purposes. At the same time, even in case of a market price decrease, the APSE solution will remain a cheaper alternative to the conventional one.

The 50% decrease in price of bio-flux slightly increases the cost-effectiveness of binder and base layers, increasing the cost-effectiveness of the pavement as a whole to 28% in Spain, 33% in Poland and 23% in the UK.

The choice of the discount rate has no impact on the construction costs, however with discount rate increase the total net present values of conventional and APSE pavements decrease, while the cost-effectiveness APSE pavement slightly increases.

- Task 6.2 b) Market analysis

The potential market for the APSE exploitable results can be viewed from different angles. Firstly, we can regard the entire APSE green road pavement concept consisting of all layers from base layer, binder and surface layer. However, given the different lifecycles of the different layers, we

could also regard the market potential for individual APSE components, e.g. lignin polymer modified bitumen, RAP + bio flux and CD&W subbase. Each of the APSE components would require very different market entrance strategies.

Another important dimension is the geographical scope. If we take the consumption of bitumen as a indicator for the overall demand for road construction globally, the European market constitutes around 10% of the global market, while the large growth potential comes from Asian countries.

The market analysis showed that the largest potential overall is in Asia, Middle East and Africa. In terms of ‘low-hanging fruits’, the immediate or mid-term opportunity lies in the lignin polymer modified bitumen, which with a substitution potential of bitumen and polymer represents a market value in EU28 alone of at least 300MEUR.

As far as RAP + bio-flux and CD&W are concerned for green solutions related to the binder layer and base layer the individual solutions are less interesting as these are not unique to the market, only as part of the overall APSE concept these green solutions add value to the overall green profile of the asphalt concept.

The timing of the APSE road construction concept is optimal as there are strong ‘green’ drivers supported by a number of EU directives, e.g. pressure to lower carbon footprint in both construction and maintenance, higher use of RAP, resource efficiency and lower energy use. In the longer also shortage of bitumen or price fluctuations would spark the demand for substitutes such as lignin.

The market analysis revealed that the addressable market for the APSE road pavement concept could be in the order of 8BEUR for the European market and in the order of 100BEURO globally in 2020. While the road construction market in Europe has matured at a level of about 8 BEURO per year, largest growth rates are seen in Asian countries and Africa. The largest individual market in Europe is resurfacing as maintenance of the existing road network is relatively high compared to investments in new road infrastructure, at least in western Europe.

Task 6.3. Eco-innovation metrics

Within the scope of Task 6.3 a framework for eco-innovation metrics was established, that quantified the key environmental and economic performance indicators of APSE project. The results were in line with the estimates of Life Cycle Analysis and Life Cycle Costing Analysis.

The developed eco-innovative metrics captured both the absolute impacts of APSE innovations as well as relative impacts, comparing a 1 m² of APSE road pavement with conventional pavement.

The following tables below represent results of the Task 6.3 - the developed eco-innovative metrics and quantified impacts.

Table 3. Eco-innovative indicators measuring improved environmental performance

Theme/ Objective	Eco-innovative indicators		Units per 1m ² of pavement	Absolute Impact per 1m ²	Relative Impact of APSE per 1m ²
Environmental performance/ Reduced environmental externalities	Air	Human Toxicity	kg 1,4-Db eq	1.34kg	14% reduction
		PM Formation	kg PM ₁₀ eq	2.08kg	0.4% reduction
		Photochemical oxidation	kg NMVOC	0.19kg	2% reduction
		Terrestrial Acidification	kg SO ₂ eq	0.18kg	3% reduction
	Water	Fresh Water Ecotoxicity	kg 1,4-Db eq	0.29kg	44% reduction
		Fresh Water Eutrophication	kg P eq	0.003kg	41% reduction
		Marine Ecotoxicity	kg 1,4-Db eq	0.03kg	34% reduction
GHG emissions	Global warming	kg CO ₂ eq	48.65kg	14% reduction	

Table 4. Eco-innovative indicators measuring resource efficiency

Theme/ Objective	Eco-innovative indicators		Units per 1m ² of pavement	Absolute Impact per 1m ²	Relative Impact of APSE per 1 m ²
Resource efficiency	Reduced consumption of non- renewable resources	Aggregates	kg	503 kg (ES) 283 kg (PL) 556 kg (UK)	59% less natural aggregates (ES) 65% (PL) 57% (UK)
		Bitumen	kg	22 kg (ES) 13kg (PL) 27kg (UK)	32% reduction (ES) 27% (PL) 29%(UK)
		SBS polymer	kg	0.1kg(ES) 0.2kg(PL) 0.1(UK)	25% less use of oil derived polymer (ES) 22% (PL) 21% (UK)
		Cement	kg	5 kg (ES) 18 kg (UK)	72% reduction in use of cement (ES) 29% (UK)
	Fossil	Oil eq	kg	74.28kg	18% reduction
	Water	Water consumption	m ³	38.5m ³	38% change to baseline
	Energy	Energy consumption	MJ	124 MJ	21% change to baseline
Improved circularity	Waste management	Use of recycled materials	kg	655 kg (ES) 456 kg (PL) 700 kg (UK)	56% of total materials (ES) 61% of total materials (PL) 53% of total materials (UK)

Table 5. Eco-innovative indicators measuring economic performance

Theme/ Objective	Eco-innovative indicators		Units 1m2 per of pavement	Absolute Impact per 1m2	Relative Impact of APSE per 1m2
Improved economic efficiency	Cost savings	Cost savings due to use of innovations	Euro/m2 (flexible pavement)	22€/m2 (ES) 16€/m2 (PL) 36€/m2 (GB)	24% reduction in costs (ES) 27% (PL) 20% (UK)
			Euro/m2 (semi-rigid pavement)	17€/m2 (ES) 17€/m2 (PL) 25€/m2 (GB)	27% reduction in costs; 24% (PL) 20%(UK)
	Environmental cost savings	Cost savings due to reduced externalities	Euro/m2 (flexible pavement)	68€/m2	27% reduction in environmental costs
	Patents	Number of patents developed	Quantity		NA
	Market opportunities	Entry into the new markets sectors		Application in roofing industry	NA

The results of Task 6.3 indicated that the APSE technologies have a better environmental performance as well as imply more efficient use of non-renewable resources, reducing the consumption of natural aggregates and crude oil products. The APSE pavement contributes to the circular economy, as the by-products of 2nd generation bioethanol production, as well as increased share of reclaimed asphalt pavement thanks to the bio-fluxing agent and construction and demolition waste are used in its production technologies. The recycled materials constitute around 60% of 1m² pavement’s total weight. The APSE concept has proved to be cost-effective, allowing for cost savings between 20%-27%, comparing to the conventional pavement. Moreover, the pavement is environmentally cost-effective, resulting in 27% cost savings due to avoided environmental externalities.

1.4. Potential impact and main dissemination activities

1.4.1. Potential impact

Transport infrastructure and roads in particular, with more than 5.000.000km⁴ in EU28, have a positive impact on economic growth, wealth and jobs creation, enhance trade due to geographical accessibility and mobility of people. However, each kilometer of road built consumes a large amount of materials and energy, not only during construction, but also due to maintenance and rehabilitation works. Hence, employing for more eco-friendly practices in road sector will increase the long-term sustainability of the construction of roads.

The APSE project has successfully demonstrated how the environmental profile and cost effectiveness of asphalt roads can be significantly improved as a consequence of the outcomes of the project:

Environmental impact

The following technologies to produce asphalt mixtures implemented and validated in the APSE project reduce the environmental impact of road pavement (as validated by an LCA assessment):

- WASTE RECYCLING. The reuse of waste and secondary aggregates reduce the environmental impact of road construction due to 1) the reduction of virgin bitumen content and increase the use of RAP content for new asphalt mixtures, 2) reduction in the use of natural aggregates in more than 50% in the whole asphalt pavement structure and 3) a substantial reduction in the amount of waste that is sent to landfill (in particular C&DW)
- BIO-BINDERS. The use of bio-binders (bio-flux and lignin polymer modified bitumen) as bitumen substitution reduces the need of using raw materials (resource efficiency) apart from reducing CO₂ emissions derived from bitumen production. Moreover, the use of bio-fluxing agents reduces the VOCs emissions associated to asphalt mixtures production and hence their negative health impact on workers.
- SUBSTITUTION OF OIL PRODUCTS. The use of lignin polymer modified bitumen to replace partially the bitumen and crude-derived polymer has been proved to reduce up to 10% de bitumen content and 15% of the polymer.

Economic feasibility and environmental costs

The APSE pavement concept results in up to 32% cost reduction in road construction expressed in market values of the materials. While considering the entire life cycle from raw materials to end-of-life. The life cycle assessment (LCA) was used to calculate the life cycle costs by assigned unit costs to the environmental externalities. The LCC or the environmental cost assessment showed that the APSE pavement brings 27% savings in the environmental costs, compared to the conventional pavement within the 60 years of its life cycle.

⁴ Report “Unity in diversity” DG-TREN Statistical pocket book 2007 and Eurostat. 2010.

Market impact

Most of the results of the project are technically mature for a full market deployment or at least has been proven at prototype level.

- Scarcity of bitumen, as crude oil production has become more efficient and leaves less and less bitumen as a residual. CO₂ footprint of bitumen is high, a 10% addition of lignin would improve the CO₂ performance and also:
 - Stabilise and lower the price of bitumen, due to the reduced dependency on crude oil production
 - Lower the price of bitumen as the cost of lignin would be cheaper than the cost of polymer and bitumen itself when commercially sold.

Two of the main strengths of this technology when compared with competing products that make this product attractive over the state of the art are: 1) Low priced lignin, compared to organosolv lignin and 2) natural hydrophobicity of Inbicon lignin makes it advantageous over eg Kraft.

The customers for this product are bitumen formulators and off-takers, bitumen blending companies, producers of asphalt pavements (ie. construction companies), National Road Authorities (NRAs), roofing felt and similar products

- Recycling of asphalt is picking up as it is cost effective for asphalt paving companies since reduces the need of virgin asphalt binder and also the demand on aggregates sources. The recycling rates vary a lot among countries mainly due to age of asphalt plants.

Part of the APSE concept is by using bio-flux to be able to increase the use of RAP in Hot Mix Asphalt with standard plant equipment (no extra RAP heating system). The APSE bioflux enter the market in a good timing as alternatives are being tested. Price and performance (in terms of rejuvenator efficiency) will determine the market uptake.

- Construction and demolition waste (C&DW) is one of the heaviest and most voluminous waste streams generated in the EU. The European Waste Framework Directive (2008/98/EC) will encourage all State Members to reduce landfilling to promote energy and resources efficiency and all the applications on civil work will have a huge market because it is the most intensive in terms of volume.

In the APSE project the use of recycled aggregates from C&DW has been proven as good alternative to granular material used as subbases. The trafficking trial in the PTF demonstrated that the C&D recycled aggregate can perform satisfactorily as unbound subbase. In fact, it performed slightly better than a control section of sub-base made with limestone.



The business case

The key selling points of the APSE pavement concept are:

- The APSE concept is cost-effective compared to traditional means of road construction, allowing for savings in the construction phase of up to 27%
- The APSE profile has a distinct green profile compared to traditional asphalt and reduces the environmental costs with 29%
- Recycled aggregates and C&DW replaces the use of virgin aggregates in the base layer and reduce the need for landfilling of C&DW at the same time.
- A 30% use of RAP, the double amount of current practice, without the use of additional pre-heating equipment.
- Lignin modified bitumen reduces the use of bitumen, although the environmental net effect is minimal, it still represents a bold green substitution and a reduced fossil fuel dependence.

Social Impact

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

Contribution to European Policy

The use of APSE 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 contribute to achieve the Europe 2020 target of greenhouse gas emissions reduction by 20% compared to 1990 levels by 2020.

APSE project is also in many ways aligned to the 6th Environmental Action Programme (2002-2012) and the EU Strategy, in which ensuring the sustainable management of resources and waste is one of the four priority areas. Also, it supports the main actions of the EU related to sustainable development: The Roadmap to a Resource Efficient Europe, Eco-innovation Action Plan (EcoAP) and the Sustainable Consumption and Production and Sustainable Industrial Policy (SCP/SIP) Action Plan.

APSE prioritises the reuse of RAP and valorization of materials that are being landfilled (C&DW). This approach meets the requirements of the Landfill Directive 1993/31/EC and guaranteed 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 economical impossible, disposal.

Discussion and perspectives

In the following the main perspectives and discussion point in relation to the results of APSE environmental costs analysis in the light of recent developments in the market and further perspectives related to likely future development trends are collected.

<p><i>Substituting virgin aggregates with C&DW makes very good sense – and has already been picked up by the market.</i></p>	<p>Using C&DW instead of virgin aggregates in the sub-base reduces environmental costs by 16,44€ per m² of road. Because of this obvious economic advantage, the use of C&DW has become common practices through-out the construction industry over the last few years.</p> <p>The potential of using recycled aggregates or C&DW also in the binder and base layer would further reduce the environmental impact in the order of 3-4€ per m²⁵</p>
<p><i>The use of RAP also makes good economic and environmental sense.</i></p>	<p>With the use of APSE bio-flux, higher RAP content can be incorporated into new asphalt mixtures using traditional techniques. This project has demonstrated that 30% RAP can be added without compromising the final properties of the asphalt mixtures.</p> <p>The increased use of RAP from 0% to 30% returns a high environmental cost saving equal to 8,12€ per m² of road.</p>
<p><i>However, common practice of using RAP has changed in recent years from zero to 15%-20%, but net effect of APSE is still significant.</i></p>	<p>In the last few years, the use of RAP in common road pavement practice has reached an average of around 15%-20% across European countries, which is regarded as a technical limitation for road pavements, unless specific devices for pre-heating the RAP are available, e.g. Parallel drum.</p> <p>The net effect of APSE bio-flux, therefore, should be seen in this perspective, rather than a comparison with 30% to zero, the actual effect is a comparison with 30% to 15%-20%.</p>
<p><i>Availability of RAP across EU28 might be a limitation in years to come.</i></p>	<p>RAP is valuable secondary raw material. Besides the technical limitation of RAP substitution without additional heating devices, another limitation hinders a 100% RAP use, namely the availability of RAP. As seen in the literature⁶, most of the available RAP is already used in new road pavements and only a small amount seems to end up in landfills with large variations across EU28.</p>
<p><i>The effect of APSE bio-flux compared to conventional flux</i></p>	<p>The use of conventional flux, which is flammable, leads to the evaporation of volatile organic compounds(VOCs) in the atmosphere, a potential danger for the people involved and a risk for the environment. Bio-flux agents have a very high flash point (>250°C), thus reducing flammability, an equivalent rise in binder cohesion compared to oil-based fluxed binders. The use of fluxing agents will also allow working at lower temperatures than the conventional bitumen, due to the lower viscosity of the binder. Therefore, bio-fluxes offer considerable savings in terms of energy and GHG and VOCs emissions. Also, these clean and ecological agents make the technology with higher RAP content suitable to be applied. Although, other organic fluxes has recently been introduced to the market, their detailed influence on the asphalt pavement construction and durability has not been proofed and validated to the same extent as is the case with APSE bio-flux.</p>

⁵ This is an estimate as this scenario has not been calculated in the Life Cycle Assessment.

⁶ Asphalt in figures 2016. EAPA.

<p><i>Lignin and bitumen.</i></p>	<p>Although substituting very costly bitumen with cheap lignin at first sounds very interesting both from an environmental (CO2 reduction) and economic point of view, it turned out that due to transport costs and the relatively modest rate of substitution, the green effect of lignin is almost zero. However, the image effect of using lignin and potential higher prices and scarcity of bitumen could turn out to be of a high strategic importance and a driver for promoting lignin.</p>																																										
<p><i>Business perspective Environmental costs versus material costs</i></p>	<p><i>In the economic assessment, we have distinguished between two types of costs: the costs of the material (which is equal to the market prices) and the environmental costs (also referred to as externalities), costs that is not internalized in the market prices.</i></p> <p>In a business perspective, e.g. in a tender situation, both types of costs are important, the material costs would represent the hard financial costs and the environmental costs will be part of the green profile of the offering, if required in the tender documentation as part of green public procurement.</p> <p>The table below gives an idea of the size of the environmental costs savings and the material costs savings respectively for the different scenarios.</p> <p>Table: Comparison of the cost structure between original APSE and conventional (in grey) and comparison of New APSE with old APSE and new Conventional (Costs per 1m2 of road pavement in EUR).</p> <table border="1" data-bbox="352 913 1441 1447"> <thead> <tr> <th></th> <th>Material costs m2</th> <th>Material costs savings (%)</th> <th>Environmental costs m2</th> <th>Environmental costs savings (%)</th> <th>Total costs m2</th> <th>Total cost savings (%)</th> </tr> </thead> <tbody> <tr> <td>Conventional <i>(no C&DW, no RAP)</i></td> <td>44.77 €</td> <td></td> <td>92.76 €</td> <td></td> <td>137.53 €</td> <td></td> </tr> <tr> <td>APSE <i>(100%C&DW in subbase, 30%RAP)</i></td> <td>35.64 €</td> <td>-9,13 € (-20%)</td> <td>68.14 €</td> <td>-24,62 € (-27%)</td> <td>103.78 €</td> <td>-33.75€ (-25%)</td> </tr> <tr> <td>New Conventional <i>(100C&DW in subbase, 20%RAP)</i></td> <td>37.17 €</td> <td></td> <td>70.74 €</td> <td></td> <td>107.91 €</td> <td></td> </tr> <tr> <td>APSE <i>(100%C&DW in subbase, 30%RAP)</i></td> <td>35.64 €</td> <td>-1.53€ (-4%)</td> <td>68.14 €</td> <td>-2,6€ (-4%)</td> <td>103.78 €</td> <td>-4.13€ (-4%)</td> </tr> <tr> <td>New APSE <i>(100%C&DW in subbase, 25%C&DW in asphalt layers, 30%RAP)</i></td> <td>35.09 €</td> <td>-2.08€ (-6%)</td> <td>64.74 €</td> <td>-6€ (-8%)</td> <td>99.83 €</td> <td>-8.08€ (-7%)</td> </tr> </tbody> </table> <p>The table shows that the APSE original solution is 25% cheaper than the conventional asphalt without any C&DW or RAP if both material and environmental costs are considered and 20% cheaper if only material costs savings are considered.</p> <p>Considering recent development in the uptake of recycled materials into mainstream road pavement practices, the additional effect of APSE still offers a cost advantage of 4% in reduction in material costs and environmental costs. If we consider the New APSE with 25% C&DW also in the asphalt layers compared to the new Conventional scenarios, the costs advantage is 7%. Percentages greater than 25% may compromise the properties of the resulting mixtures according to the findings in WP2 (Task 1.4).</p> <p>Since competition is high in the road pavement markets, a cost advantage of 7% is substantial. Likewise, the communication value of the APSE green profile should not be under evaluated and will become relevant when/if Green Public Procurement takes off.</p>		Material costs m2	Material costs savings (%)	Environmental costs m2	Environmental costs savings (%)	Total costs m2	Total cost savings (%)	Conventional <i>(no C&DW, no RAP)</i>	44.77 €		92.76 €		137.53 €		APSE <i>(100%C&DW in subbase, 30%RAP)</i>	35.64 €	-9,13 € (-20%)	68.14 €	-24,62 € (-27%)	103.78 €	-33.75€ (-25%)	New Conventional <i>(100C&DW in subbase, 20%RAP)</i>	37.17 €		70.74 €		107.91 €		APSE <i>(100%C&DW in subbase, 30%RAP)</i>	35.64 €	-1.53€ (-4%)	68.14 €	-2,6€ (-4%)	103.78 €	-4.13€ (-4%)	New APSE <i>(100%C&DW in subbase, 25%C&DW in asphalt layers, 30%RAP)</i>	35.09 €	-2.08€ (-6%)	64.74 €	-6€ (-8%)	99.83 €	-8.08€ (-7%)
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Footnote: the calculation of the environmental costs for the two new scenarios (New APSE and New Conventional) are estimates only as this was not included in the LCA

1.4.2. Dissemination activities

Dissemination is a significant issue of APSE project due to its importance to maximise the impact of the project.

Specific target audience (those stakeholders with potential interest in the project’s solutions adoption) were identified during the first stage of the APSE project:

- Policy makers (at National and Regional Road Authorities).
- Road owners and operators (National and Regional Road Authorities), city administrations (such as Municipality of Madrid), construction and civil engineering operators
- Road Associations and Federations.
- European Construction Association and Federations (like e.g. European Construction Forum and FIEC (European Construction Industry Federation)).
- Asphalt Pavement Associations such as EAPA (European Asphalt Pavement Association).
- Engineering Associations such as EFCA (European Federation of Engineering Consultancy Associations)
- Civil engineers Associations such as ECCE (European Council of Civil Engineers) and European Civil Engineering Education and Training Association. (EUCEET Association).
- European Technology Platforms related to the field like the ECTP (REFINE) and ERTRAC (European Road Transport Research Advisory Council).
- Europe Road research centres (like VTI from Sweden).
- General public and policy shapers: the APSE team will take the appropriate measures to engage the public, civil society and the media in the project which will promote the European Commission’s technical objectives in supporting the project and its financial support for the activities.

These target audiences were addressed through different communication channels, defined at the beginning of the project. The dissemination channels were selected to reach out a wide variety of audiences and comprised:

- **A dedicated website**

A website (www.apseproject.eu) was set-up by WUT at the very beginning of the project. APSE website presents the objectives, partners, results, public deliverables and news of the project. The website also features a section dedicated to private area where partners can upload deliverables, report, etc., and links to major websites and portals related to the topic of the project. News and events sections as well as the rest of the content have been continuously updated and managed by the Dissemination WP leader throughout the lifetime of the project.



Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment



This project has received funding from the EUROPEAN UNION'S SEVENTH FRAMEWORK PROGRAMME for research, technological development and demonstration under grant agreement No 602882.

• Newsletters

E-newsletters were published on the website every 6 months, to describe the project progress. They were sent to a dedicated mailing list obtained mainly from the partner's existing contacts and those generated during the project.



- **Brochures and roll up**

A first version of the brochure was designed and printed at the beginning of the project describing general information (content, main objectives, contact information). Second version was produced at the final part of the project summarising the main achievements of the project. Copies were distributed to the APSE partners and also attendants too different events, workshop and other conferences.

A Roll-up was also produced and shipped to each partner.

- **Publication on social media channels**

Project's news was regularly updated at the APSE social media channels Facebook, Twitter, and Youtube.

- **Press releases**

Press releases were produced to communicate key milestones, deliverables and findings during the lifetime of the Project. From the 49 dissemination activities registered more than 20 are press releases (publications in local newspapers, magazines).

- **Scientific publications and patents**

The research carried out by APSE was largely disseminated through 6 scientific publications, most of them published in high impact journals. The full list of which is included in the relevant section further below.

In addition the patent WO2017088892 “Bitumen compositions comprising lining” has been drafted by Inbicon and was internationally published in June 2017.

- **Workshops and webinars**

2 workshop and 1 webinar were organized throughout the project to present the project innovations to external stakeholders and engage with potential users.

- The first workshop was organised on 30 June 2017 in Jachranka, near Warsaw (Poland), as part of the XXXVI Technical Spring Seminar organised by the Polish Asphalt Pavement Association (Polskie Stowarzyszenie Wykonawców Nawierzchni Asfaltowych, PSWNA). During this seminar, one session, Session III: Sustainable Road Structure, was designated for the APSE project. The XXXVI Seminar brought over 150 participants.
- An online open access webinar, consisting of 5 different courses (1- Introduction, 2- Sub-base course, 3-Binder course, 4- Wearing course, 5- LCC and market prospects) was organised and hosted on the WUT Youtube channel. The online webinar is still accessible through <https://www.youtube.com/playlist?list=PLXisDUuvHeELPLDprTg56lcvl6QPwEtfM>.
- The second workshop was the APSE final conference on “Promoting Circular Economy for a Greener Road Construction”. This event was organised by Comunidad of Madrid, in collaboration with ACCIONA, back to back with the final project meeting held in Madrid on 21-22 November 2017. The workshop welcomed 52 participants from the construction

industry, infrastructure owners, National Road Authorities, policy makers as well as research and academia. The agenda and the presentations are available through <https://apseproject.eu/5768>.



- **Presentations and participation at congresses, workshops, symposia conferences, exhibition fairs**

APSE partners have participated in various events where information about project was disseminated. Particularly noteworthy is the participation in Industrial Technologies 2014, 6th Eurasphalt & Eurobitume Congress 2016, TRA 2016.

- **Policy brief**

A policy brief was prepared presenting the findings and recommendations of the APSE project to a non-specialised audience.

- **Audio-visual material**

A promotional project video was produced by WUT, and is accessible through <https://apseproject.eu/5729>. The video is hosted on the WUT Youtube channel, where up to date it has been viewed more than 275 times.

1.4.3. Exploitation of results

Within the APSE project a number of exploitable results have been achieved and the list is described below:

1. Bitumen grade lignin.
2. Polymer+lignin modified binder.
3. Bio-flux additive.

All of these three products can be market-delivered as different products within a single business. Evidently, all results aim at being delivered in the asphalt industry and will positively impact both on the business of the partners involved and on the related policies at European and Regional level. A summary of the KERs are shown below in Table 6.

Table 6. Summary of the exploitable results of the APSE project

			Main Contributor/s	Key Associated deliverable/s	Partners interested	TRL
KEY EXPLOITABLE RESULTS (KER)	KER 1	Bitumen grade lignin	Dong Energy	D2.2	Dong Energy, Acciona	9
	KER 2	Polymer+ lignin modified binder	Acciona, Azvi	D2.2, D4.2	Dong Energy, Acciona, Azvi, Cemex, Temecal, Granar, CWare	8
	KER 3	Bio-flux additive	WUT	D2.3, D4.2	Acciona, WUT, Cemex, Temecal, Granar,	7

As it can be seen from Table 6, it is clear that there are some results with an interesting commercial potential. It is important to highlight that all of KERs resulting from APSE project have a high TRL. For KER 1, TRL 9 means that the result is technically mature for a full market deployment, such as those encountered in operational test and evaluation. In the case of KER 2, TRL 8 means that technology has been proven to work in its final form and under expected conditions. Finally, KER 3 has the lower TRL (TRL 7) due to its still-prototype form but nonetheless very close to be available for its use in a controlled operational environment.

1.5. Website and contact details

The APSE website can be found at the following link: <https://apseproject.eu/>

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

Participant	Contact Person	Email
ACCIONA Construcción	Raquel Casado Barrasa	raquel.casado.barrasa@acciona.com
AZVI	Domingo Perez Mira	dperez@grupoazvi.com
Controlware	Birgitte Holt Andersen	bgaha@appliedeconomics.dk
Brijsse minerals & recycling	Yvan Brijsse	yvan.brijsse@b-mr.be
Cemex UK	Martin Ashfield	martin.ashfieldm@cemex.com
GRANAR	Artur Klimaszewski	artur.klimaszewski@granar.com.pl
TRL limited	Peter Jones	pjones@trl.co.uk
Comunidad de Madrid	José Antonio Plaza	jantonio.plaza@madrid.org
Politechnika Warszawska	Karol Kowalski	k.kowalski@il.pw.edu.pl
Temecal Caldereros	Luis Santacruz	temecal@temecal.com
Dong Energy Thermal Power	Duy Michael Le	DUYLE@dongenergy.dk

2. Use and dissemination of foreground

2.1. Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

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 ⁷ (if available)	Is/Will open access ⁸ provided to this publication?
1	Towards understanding polymerization process in bitumen bio-fluxes.	Jan Król, Łukasz Niczke, Karol Kowalski	Materials	Vol. 10 /Issue 9	MDPI	Switzerland	2017	10588	10.3390/ma10091058	Yes

⁷ 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).

⁸ 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.



2	Thermal and Fatigue Evaluation of Asphalt Mixtures Containing RAP Treated with a Bio-Agent.	Kowalski K. J., Król J. B., Bańkowski W., Radziszewski P., Sarnowski M.,	Applied Sciences	Vol. 7 /Issue 3	MDPI	Switzerland	2017	216	10.3390/app7030216	Yes
3	Eco-friendly materials for a new concept of asphalt pavement.	Kowalski K. J., Król J. B., Radziszewski P., Casado R., Blanco V., Pérez D., Viñas V. M., Brijse Y., Frosch M., Lee D. M., Wayman M.	Transportation Research Procedia	Vol. 14	Elsevier	Netherlands	2016	3582-3591	10.1016/j.trpro.2016.05.426	Yes
4	Effect of bitumen fluxing using a bio-origin additive.	Król J. B., Kowalski K. J., Niczke Ł., Radziszewski P.	Construction and Building Materials	Vol. 114	Elsevier	United Kingdom	2016	194-203	10.1016/j.conbuildmat.2016.03.086	No
5	Trwałe i ekologiczne nawierzchnie drogowe ze zużytych materiałów budowlanych/Durable and ecological road pavements from recycled materials.	Kowalski K.J., Radziszewski P., Król J., Piłat J., and Sarnowski M.	Ochrona środowiska i estetyka w budownictwie komunikacyjnym	zeszyt nr 2	wydawnictwo Ekkom	Kazimierz Dolny , Poland	2014	17-27		No
6	New concept of sustainable road structure with RAP binder course using bio-agent.	Kowalski K. J., Król J. B., Radziszewski P., Piłat J., Sarnowski M.	Proceedings of 6th Eurasphalt & Eurobitume Congress 2016			Prague, Czech Republic,	2016			No
7	Właściwości mieszanek mineralno-asfaltowych ze	Król J., Włodarski P.,	Drogownictwo	vol. LXIX, no. 11	SITK	Warsaw, Poland	2014	373-379		No



zwiększoną ilością granulatu asfaltowego/Properties of asphalt mix with increased contents of recovered asphalt	Jackowski Ł.								
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TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities ⁹	Main leader	Title	Date/Period	Place	Type of audience ¹⁰	Size of audience	Countries addressed
1	Press releases	Comunidad de Madrid	“Se investiga con nuevos asfaltos hechos con aceites vegetales y residuos de construcción” http://www.madrid.org/cs/Satellite?c=CM_Actualidad_FA&cid=1354277194696&language=es&pagename=ComunidadMadrid%2FEstructura	28/10/2013	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
2	Press releases	ACCIONA, Comunidad de Madrid	“Acciona y la Comunidad de Madrid investigan producir asfalto a partir de	28/10/2013	Madrid, Spain	Scientific Community (higher education,	-	Spain

⁹ 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.

¹⁰ 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).

			aceites y residuos” http://www.economista.es/mercados-cotizaciones/noticias/5263406/10/13/Economia-Empresas-Acciona-y-la-Comunidad-de-Madrid-investigan-producir-asfalto-a-partir-de-aceites-y-residuos.html			Research), Industry, Civil Society, Policy makers		
3	Press releases	Comunidad de Madrid / ACCIONA	“En busca de un asfalto realizado con aceites vegetales y residuos de la construcción” http://www.cronicanorte.es/en-busca-de-un-asfalto-realizado-con-aceites-vegetales-y-residuos-de-la-construccion/50944	29/10/2013	Alcobendas, Madrid. Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
4	Press releases	ACCIONA	“Nuevos afaltos con aceites vegetales” . 20 minutos newspaper (p.4). Año XIV. Número 3131 https://www.20minutos.es/edicion_impresa/ver/madrid/2013/10/29/	29/10/2013	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
5	TV Clip	ACCIONA	Description of the project in Telemadrid news http://www.telemadrid.es/noticias/sociedad/noticia/pavimentos-hechos-con-residuos-en-alcobendas	06/11/2013	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	-	Spain
6	Press releases	Comunidad de Madrid /ACCIONA	“La Comunidad de Madrid y Acciona impulsan un proyecto europeo para la investigación de nuevos asfaltos” http://www.europapress.es/madrid/noticia-comunidad-madrid-acciona-impulsan-proyecto-europeo-investigacion-nuevos-asfaltos-20131028152539.html	28/12/2013	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
7	Press releases	ACCIONA	“Asfaltos un 10% más duraderos gracias al empleo de residuos” La Razón newspaper (p.15)	03/11/2013	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	> 150.000	Spain

8	Website	WUT	Website creation	2014	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	> 3500	Worldwide
9	Press releases	ACCIONA	“Investigan nuevos asfaltos a partir de residuos vegetales y de construcción” https://www.residuosprofesional.com/investigan-nuevos-asfaltos-partir-de-residuos-vegetales-y-de-construccion/	13/02/2014	Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	-	Spain
10	Flyers	WUT	Creation of flyers (v1)	October 2014	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	> 1500	Worldwide
11	Flyer	WUT	Pocket size APSE brochure	October 2014	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	> 1000	Worldwide
12	Newsletters	WUT	APSE newsletters - released every 6 months	June 2014- November 2017	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	>200	Worldwide
13	Oral presentation to a wider public	WUT	III Winter Workshop of WUT and TPA: “Trwale i ekologiczne nawierzchnie drogowe ze zużytych materiałów budowlanych” / “Durable and ecological road pavements from recycled materials”	18/02/2014	Maslow, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	15	Poland
14	Oral presentation to a wider public	WUT	International Conference Environment Protection: “Trwale i ekologiczne nawierzchnie drogowe ze zużytych materiałów budowlanych” /	April 2014	Kazimierz nad Wisłą, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	80	Poland



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			“Durable and ecological road pavements from recycled materials”					
15	Media briefings	ACCIONA	Actualidad económica (magazine), o. 25 APSE received a prize as one of the best ideas of the year, under the category sustainability	01/04/2014	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	25.000	Spain
16	Poster	ACCIONA	Industrial Technologies Posters ad brochures	9-11/04/2014	Athens, Greece	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	EU
17	Press releases	ACCIONA	“Las carreteras de Madrid, 'laboratorio' de asfaltos más baratos y ecológicos” http://www.eleconomista.es/ecomotor/motor/noticias/5753819/05/14/Las-carreteras-de-Madrid-un-laboratorio-de-asfaltos-mas-baratos-y-ecologicos.html	05/05/2014	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
18	Press releases	ACCIONA	La revista 'Actualidad Económica' premia las 100 Mejores Ideas del año http://www.europapress.es/epsocial/rsc/noticia-rsc-revista-actualidad-economica-premia-100-mejores-ideas-ano-20140617191922.html	17/06/2014	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	-	Spain
19	Press releases	ACCIONA	El Mundo newspaper (p. 4): “Acciona planea carreteras más eficientes usando aceite y plástico” http://www.elmundo.es/economia/2014/12/22/549475b3e2704eb2688b4571.html	22/12/2014	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	> 150.000	Spain
20	Oral presentation to a wider public	WUT	XXXII Seminarium Techniczne Polskiego Stowarzyszenia Wykonawców Nawierzchni Asfaltowych, korzyści nawierzchni asfaltowych / XXXII Seminnar of Polish Asphalt Pavement Association, Asphalt Advantages. Innowacyjna nawierzchnia drogowa - zrównoważony rozwój / Innovative road	23-25./03/2015	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	150	Poland



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			pavement - sustainable development					
21	Exhibitions	Comunidad de Madrid	25 th World Road Congress	2-6/11/2015	Seoul, Korea	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	2700	Worldwide
22	Poster	Comunidad de Madrid	11 ^o Foro Plataforma Tecnológica Española de Construcción (PTEC): La innovación en el mantenimiento y adaptación de las infraestructuras del transporte. 11 ^o Spanish Construction Technological Platform Forum: Innovation in the maintenance and adaptation of transport infrastructures	06/04.2016	Barcelona, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	100	Spain
23	Poster	WUT	Eco-friendly materials for a new concept of asphalt pavement	18-21/04/2016	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	150	Worldwide
24	Oral presentation to a wider public	WUT	New concept of sustainable road structure with RAP binder course using bio-agent	02/06/2016	Prague. Czech Republic	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	550	Worldwide
25	Oral presentation to a scientific event	AZVI	12 ^o Foro Plataforma Tecnológica Española de Construcción (PTEC): Nuevos procesos constructivos de obra civil incorporando materiales reciclados en infraestructuras ferroviarias, carreteras y hormigones. 12 ^o PTEC Forum: New construction processes of civil works incorporating recycled materials in railway infrastructures, roads and concretes	15/11/2016	Seville, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	500	Spain
26	Articles published in the popular press	WUT	Journal Nawierzchnie Asfaltowe, nr 2-3 (46-47), 2016 ISSN: 1734-1434 published a note about APSE project progress	2016	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	-	Poland
27	Press releases	Comunidad de Madrid	“Dos millones y medio para mejorar el	7/12/2016	Madrid, Spain	Scientific Community	-	Spain



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			enlace de la M-607 con la M-616” https://www.madridiario.es/439405/enlace-de-la-m-607-con-la-m-616			(higher education, Research), Industry, Civil Society, Policy makers.		
28	Press releases	AZVI / ACCIONA/ Com. Madrid	APSE project publishes the e-newsletter http://www.plataformaptec.es/ver-noticia.php?id=3854	09/03/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	-	Spain
29	Organisation of workshops	WUT (ACCIONA/CWare/TRL)	XXXVI Seminarium Techniczne PSWNA Session III: Sustainable Road Structure, Zrównoważona konstrukcja nawierzchni drogowej	30/03/2017	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	150	Poland
30	Press releases	AZVI / ACCIONA/ Com. Madrid	“APSE project news” http://www.plataformaptec.es/ver-noticia.php?id=4241	27/09/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	-	Spain
31	Flyers	WUT	Creation of flyers (v2)	October 2017	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	-	Worldwide
32	Websites/Applications	WUT	APSE Webinar	October 2017	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	> 4500	Worldwide
33	Videos	WUT	APSE movie	October 2017	Warsaw, Poland	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	> 5500	Worldwide
34	Oral presentation to a scientific event	ACCIONA	Valladolid Circular Weekend	02/11/2017	Valladolid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	500	Spain
35	Presentations	WUT	Seminarium Sekcji Drogowej Rady Naukowej Instytutu Badawczego Dróg i	07/11/2017	Warsaw, Poland	Scientific Community (higher education,	30	Poland



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			Mostów „Recykling nawierzchni asfaltowych”/ Seminar of Road Section of Roads and Bridges Research Institute: “Zrównoważona konstrukcja nawierzchni drogowej – projekt APSE” / “Sustainable road structure - project APSE”			Research), Industry, Civil Society, Policy makers.		
36	Poster	ACCIONA	Innovacarretera 2017- Summary description about the APSE project http://www.ptcarretera.es/wp-content/uploads/2017/10/PTC_INNOVACARRETERA2017_ProgramaA5_Online.pdf	07/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers.	> 250	Spain
37	Press release	ACCIONA	Jornadas sobre Economía Circular. Evento final proyecto APSE (PTEC) http://www.plataformaptec.es/ver-noticia.php?id=4358	08/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
38	Press release	ACCIONA	APSE: Conference and final event (PTC) http://www.ptcarretera.es/apse-conference-and-final-event/	10/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
39	Press release	ACCIONA	“ACCIONA Construction organizes workshop on circular economy in the construction sector” http://www.acciona-construccion.com/pressroom/news/2017/november/acciona-construction-organizes-workshop-circular-economy-construction-sector/	11/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
40	Press release	ACCIONA	Jornada sobre Economía Circular en Madrid: “Uso de materiales más sostenibles para un nuevo concepto de construcción de pavimentos asfálticos” http://www.ecoconstruccion.net/noticias/jornada-sobre-economia-circular-en-madrid-uso-de-materiales-mas-sostenibles-para-	14/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain



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			un-n-l3Lfl					
41	Press releases	Comunidad de Madrid	<p>“Jornadas sobre Economía Circular. Evento final proyecto APSE”</p> <p>http://www.madrid.org/cs/Satellite?c=CM_Actualidad_FA&cid=1354680160200&destacado=si&idConsejeria=1109266187248&idListConjs=1109265444710&language=es&pagename=ComunidadMadrid%2FEstructura&sm=1109265843997</p>	14/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
42	Press releases	ACCIONA	<p>Jornada de Presentación de resultados del Proyecto Europeo APSE sobre Economía Circular</p> <p>https://www.construible.es/2017/11/15/jornada-presentacion-resultados-proyecto-europeo-apse-economia-circular</p>	15/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
43	Press releases	ACCIONA	<p>ACCIONA Construcción organiza una jornada sobre economía circular en el sector de la construcción</p> <p>http://www.plataformaptec.es/ver-noticia.php?id=4362</p>	16/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
44	Press releases	ACCIONA	<p>Workshop "Promoting Circular Economy for a Greener Road Construction"</p> <p>https://mailchi.mp/4cce5a87f3f7/workshop-promoting-circular-economy-for-a-greener-road-construction?e=794e9aaf14</p>	17/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	-	Spain
45	Organisation of Workshops	Comunidad de Madrid, ACCIONA	<p>Final workshop APSE project: “Promoting Circular Economy for a Greener Road Construction”</p>	22/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers	52	Spain
46	Presentations	TRL	TRL Seminar on LCA results	28/11/2017	Crowthorne, UK	Scientific community (higher education, Research)	15	UK
47	Press releases	ACCIONA	<p>Life Equinox en el evento final del proyecto APSE</p> <p>http://life-equinox.eu/life-equinox-en-el-</p>	29/11/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil	-	Spain



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			evento-final-del-proyecto-apse/			Society,		
48	Interviews	ACCIONA	Cadena Ser (radio). Programa Hora 25 http://play.cadenaser.com/audio/cadenaser_hora25_20171211_220000_230000/	11/12/2017	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	-	Spain
49	TV Clip	ACCIONA	TV 24 horas. Programa Europa 2017 http://www.rtve.es/alacarta/videos/europa/europa-2018-26-01-18/4439613/	26/01/2018	Madrid, Spain	Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias	-	Spain
50	Abstract	ACCIONA, WUT	Abstract accepted for the 7 th international conference on Bituminous mixtures and pavements: Field evaluation of a sustainable road structure concept	31/01/2018	Thessaloniki, Greece	Scientific Community (higher education, Research), Industry, Civil Society.	-	Worldwide



2.2. Section B (Confidential)

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the template B1 provided hereafter.

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights ¹¹ :	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patents	No	-	WO2017088892	Bitumen compositions comprising lignin	Inbicon

¹¹ A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Type of Exploitable Foreground ¹²	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application ¹³	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Bitumen grade lignin from 2 nd generation bioethanol production, certified for blending with bitumen or polymer modified bitumen for asphalt pavements.	YES	-	Bitumen grade lignin	F42.1.1 – Construction of roads and motorways C20.5.9 - Manufacture of other chemical products n.e.c.	2018	Patent	DONG Energy, ACCIONA, AZVI
Commercial exploitation of R&D results	Lignin polymer modified bitumen with performance comparable or greater to than that of conventional polymer modified bitumen and which fulfills the properties required by standards in EN14023:2010, substituting a proportion of the bitumen and polymer with lignin.	YES	-	Polymer+lignin modified binder	F42.1.1 – Construction of roads and motorways	2018	License	DONG Energy, ACCIONA, AZVI, CEMEX, TEMECAL, GRANAR, TRL,CWare, Comunidad Madrid
Commercial exploitation of R&D results	Bio-flux additive that partially behaves as asphalt rejuvenator, fluidizing the bitumen and making it possible for the bitumen to recover its original consistency. Produced by a chemical conversion of vegetable oils, specifically rapeseed oil.. It allows the use of high reclaimed asphalt (RA) content thanks to the reduction of the mixing temperature due to the low viscosity of the binder.	YES	-	Bio-flux additive	F42.1.1 – Construction of roads and motorways C20.5.9 - Manufacture of other chemical products n.e.c.	2018	Other	WUT, ACCIONA, CEMEX, GRANAR, TRL, Comunidad de Madrid

¹⁹ A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

¹³ A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

In addition to the table B2, in the following pages further information about the exploitable foregrounds is provided:

Bitumen grade lignin

- Its purpose

Lignin with the required quality to be used as replacement of crude-oil derived polymer in modified bitumen. The lignin is a by-product of the 2nd generation bioethanol processing, using wheat straw as raw material.

- How the foreground might be exploited and IPR exploitable taken or intended

A patent (WO2017088892) has been drafted by INBICON, third party of DONG Energy, in which specifications that lignin should be complied with to be blended with bitumen are described in detail.

The IPR of these results is owned mainly to DONG Energy and it is shared with ACCIONA and AZVI.

- Further research, if any

The product is mature enough to be produced in a full scale, provided that there is security supply of lignin. The future demand for 2G bio ethanol will first and foremost be driven by the implementation of the renewables directive, EU Directive 2009/28/EC, and the EU Directive 2015/1513 on 9 September, nicknamed the 'ILUC amendment'. This directive defines sustainability and the conditions under which biomass for transport fuel may be produced in order to reach the target of 10% renewables in all the transport fuels by 2020 and 25% in 2030.

- Potential expected impact (quantify when possible)

- *Benefits that will bring to customers:*

- ✓ Reduction in price.
- ✓ Replaces an oil based compound (bitumen) with a bio-based compounds (lignin), preserving the desired properties of bitumen.
- ✓ Reduced carbon foot print.

- *Market size*

The market size of this results is 125 M€ (assuming a 5% share of the Europe bitumen market of 250 €/ton).

In addition, a rough estimation indicates that lignin eventually will substitute polymer and bitumen by a rate of 10%. Considering that bitumen is approximately 3.5-7% of the total amount of asphalt, the total market potential of lignin is between 963ktones to 2.063Mtones.

Polymer + lignin modified binder

- Its purpose

A modified bitumen with lignin, as partial replacement of bitumen and polymer, has been developed that fulfils the requirements of the standard applied for EU bitumen. The designed bitumen has a green profile and offers comparable or greater properties than a polymer modified bitumen (PMB).

- How the foreground might be exploited and IPR exploitable taken or intended

A patent application was evaluated. However, conclusions from a patentability report indicated that it was not recommended to continue with the patent, since novelty of such an invention would be seriously prejudiced by previous publications. Other routes of exploitation are being evaluated as licensing.

The IPR of this result is shared between three main actors, ACCIONA, AZVI and DONG Energy; however other beneficiaries are also involved and interested in the technology.

- Further research, if any

Storage stability of the developed bitumen should be further explored.

- Potential expected impact (quantify when possible).

- *Benefits that will bring to customers:*

- ✓ Better environmental performing analysis
- ✓ Reduced cost
- ✓ Reduced carbon foot print.

- *Market size*

Approx. 60 M€ (assuming a 5% share of the EU polymer modified bitumen market of 450 €/ton).

Bio-flux additive

- Its purpose

The concept of bio-fluxing agents is based on the use of new vegetable origin binders where synthetic and petro-chemical products are replaced with plant-based products.

The main ingredient of the APSE bio-flux is rapeseed oil, which is plentifully available, actually is the third in production of vegetable oils.

Bio-fluxing agents allow the integration of higher percentage of reclaimed asphalt for the preparation of new asphalt mixtures using conventional techniques and without



compromising their technical properties. This is possible thanks to a reduction in viscosity that allows working at lower temperatures than conventional bitumen.

- How the foreground might be exploited and IPR exploitable taken or intended

Under valid Polish patent PL214138B1 (working in the Polish market only). Other routes of exploitation will be sought in the European market.

- Further research, if any

The production of the bio-flux additive has been optimized at industrial scale; however depending on the plant configuration some parts of the process would need to be re-designed or included minor adaptations.

- Potential expected impact (quantify when possible).

- *Benefits that will bring to customers:*

- ✓ Higher RAP content in HMA with a standard plant equipment (no extra RAP heating system)
- ✓ Reduced carbon foot print.

- *Market size: 5 M€*

The main ingredient of the APSE bio-flux is rapeseed oil, which is plentifully available, actually is the third in production of vegetable oils.

3. Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when Grant Agreement number is entered.)*

Grant Agreement Number:	603862
Title of Project:	Use of eco-friendly materials for a new concept of Asphalt Pavements for a Sustainable Environment
Name and Title of Coordinator:	Raquel Casado Barrasa

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

<input type="checkbox"/> Were those animals transgenic farm animals?	No	
<input type="checkbox"/> Were those animals cloned farm animals?	No	
<input type="checkbox"/> Were those animals non-human primates?	No	
RESEARCH INVOLVING DEVELOPING COUNTRIES		
<input type="checkbox"/> Did the project involve the use of local resources (genetic, animal, plant etc)?	No	
<input type="checkbox"/> Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No	
DUAL USE		
<input type="checkbox"/> Research having direct military use	No	
<input type="checkbox"/> 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	2	9
Experienced researchers (i.e. PhD holders)	6	11
PhD Students	0	2
Other	13	33
4. How many additional researchers (in companies and universities) were recruited specifically for this project?		
Of which, indicate the number of men:	0	
D Gender Aspects		
5. Did you carry out specific Gender Equality Actions under the project?	X ○ Yes ○ No	
6. Which of the following actions did you carry out and how effective were they?		
	Not at all effective	Very effective
<input type="checkbox"/> Design and implement an equal opportunity policy	○ ○ X ○ ○	
<input type="checkbox"/> Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○	
<input type="checkbox"/> Organise conferences and workshops on gender	○ ○ ○ ○ ○	
<input type="checkbox"/> Actions to improve work-life balance	○ ○ ○ ○ ○	
<input type="radio"/> Other: <input type="text"/>		
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?		
<input type="radio"/> Yes- please specify <input type="text"/>		
<input checked="" type="radio"/> 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)? <input checked="" type="radio"/> Yes- please specify <input type="radio"/> No	University students from WUT were eventually trained in laboratory
9.	Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)? <input checked="" type="radio"/> Yes- please specify <input type="radio"/> No	An e-learning course was developed based on practical examples of APSE.
F Interdisciplinarity		
10.	Which disciplines (see list below) are involved in your project? <input checked="" type="radio"/> Main discipline ¹⁴ : Civil engineering and Chemical Science: 1.3, 2.1, 2.3 <input type="radio"/> Associated discipline ¹⁴ :	
		<input type="radio"/> Associated discipline ¹⁴ :
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)	<input type="radio"/> Yes <input checked="" type="radio"/> No
11b	If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)? <input checked="" type="radio"/> No <input type="radio"/> Yes- in determining what research should be performed <input type="radio"/> Yes - in implementing the research <input type="radio"/> 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)?	<input type="radio"/> Yes <input checked="" type="radio"/> No
12.	Did you engage with government / public bodies or policy makers (including international organisations) <input checked="" type="radio"/> No <input type="radio"/> Yes- in framing the research agenda <input type="radio"/> Yes - in implementing the research agenda <input type="radio"/> 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? <input type="radio"/> Yes – as a primary objective (please indicate areas below- multiple answers possible) <input checked="" type="radio"/> Yes – as a secondary objective (please indicate areas below - multiple answer possible) <input type="radio"/> No	

¹⁴ Insert number from list below (Frascati Manual).

13b If Yes, in which fields?		
Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs	Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid	Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport
		X
13c If Yes, at which level?		
<input type="radio"/> Local / regional levels <input type="radio"/> National level <input checked="" type="radio"/> European level <input type="radio"/> International level		
H Use and dissemination		
14. How many Articles were published/accepted for publication in peer-reviewed journals?	6	
To how many of these is open access¹⁵ provided?	3	
How many of these are published in open access journals?	2	
How many of these are published in open repositories?	1	
To how many of these is open access not provided?	3	
Please check all applicable reasons for not providing open access:		
<input type="checkbox"/> publisher's licensing agreement would not permit publishing in a repository <input type="checkbox"/> no suitable repository available <input type="checkbox"/> no suitable open access journal available <input checked="" type="checkbox"/> no funds available to publish in an open access journal <input type="checkbox"/> lack of time and resources <input type="checkbox"/> lack of information on open access <input type="checkbox"/> other ¹⁶ :		
15. How many new patent applications ('priority filings') have been made? <i>("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).</i>	1	
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

¹⁵ Open Access is defined as free of charge access for anyone via Internet.

¹⁶ For instance: classification for security project.

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]