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FIBRA

Exploration Strategy Plan

Report Nr 6.2

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Fostering the implementation of fibre-reinforced asphalt mixtures by ensuring its safe, optimized, and cost-efficient use

Report Nr 6.2 – Exploitation Strategy Plan

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Executive summary

The aim of this exploitation plan is to ease and foster the exploitation and implementation of the project results by the most important stakeholders. The FIBRA project aim was to increase asphalt pavement durability through safe and cost-efficient implementation of fibre-reinforced asphalt mixtures. To do so technical barriers needed to be overcome and practical experience gained. The broader impact of the project is the knowledge about the usability of fibre in asphalt and impact on the asphalt performance. This knowledge can aid decision makers in selecting the optimal materials suited to their performance needs, environmental impact, and cost. Furthermore, the experience gained through both laboratory and field testing gives clear method for developing other new asphalt materials and how these might behave in the field.

The project team first selected fibres for further use in the project. The fibres selected are Polyacrylonitrile and the blend of aramid/polyolefin fibres. After selecting the fibres these went through thorough laboratory testing before upscaling and field application. The results show the most suitable areas for the use of fibres in asphalt. Colder regions, with high share of studded tires are not suitable for fibre reinforcement while the use of fibre in PA is promising.

The project shows that the main markets for fibre reinforced asphalt mixture (FRAM) are within noise reducing asphalt. Fibre reinforced open graded noise reducing stone skeleton mixtures, such as PA, and noise reducing SMA are asphalt types used for this purpose today. Replacing these with the new FRAM would be a sound choice. The environmental and cost analysis furthermore support this suitability, as the PA is most promising. The reason is that FRAM is recyclable and is expected to have longer lifetime.

The target audience for the project results are divided into four groups decision makers, scientific community, sectoral community, and the public. The most important groups are the first three, with the NRAs being vital.

The exploitation of the results depends heavily on how well the necessary information is communicated to decision makers. Communication with stakeholders has been upheld throughout the project with direct contact, flyers, webpage, conference participation and publication.

Revision history

Date	Name, Partner	Description
2021-06-28	Hrefna Run Vignisdottir, SINTEF AS	First draft
2021-09-08	Hrefna Run Vignisdottir, SINTEF AS	Final draft

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1 Introduction

The definition of research is to systematically investigate a subject to reveal new knowledge in the form of facts, theories, etc. (Dictionary.com). Most practical research does not only aim at academic impact (advancing or developing knowledge or methods) but to effect current use of materials, improve processes, decreasing environmental impact etc. According to the US National Science Foundation the impact of a research is the potential it must benefit society and achieve desired societal outcomes. To have impact in practical real life, there is a need for communicating the results to audience that can use the results by directly using the new material, evaluate other new materials, or develop other new materials.

The aim of this exploitation plan is to ease and foster the exploitation and implementation of the project results by the most important stakeholders. To do so, the exploitation plan will first go through **why** the project was of interest before moving on to **what** are the main exploitable results. From there, the stakeholders **(the who)** are presented and **how** and **where** each of them can exploit the results from the project.

As the exploitation of project results should be considered throughout a research and development projects (European Commission, 2020; Heydebreck et al., 2015). This has been done throughout FIBRA, first with the Communication & Dissemination plan and finishes now with an exploitation report. This document outlines the plan for the exploitation of the results reached in the project period of FIBRA. The exploitation plan describes the main findings and outputs of the FIBRA project, the most relevant stakeholders, and describes in what situation fibre could be beneficial to use.

The document will therefore first present the main exploitable results, and then present how these results have been exploited throughout the project with communication and dissemination activities. The main stakeholders and their need for information is described. The target markets are then defined along with the most important market barriers and constraints. Finally, a description of how the industrial partners and the RTD partners can exploit the project results after the project is finished. The document furthermore contains a SWOT analysis results and a business case to ease communication with the target audience in further communicating the results of the project.

The plan will work as a roadmap for the exploitation and implementation of the results beyond the project time. Therefore, the plan targeted exploitation of the project results by each group of experts within the consortium, depending on its particular field and interest.

2 Project idea (the why)

The objective of the FIBRA project was to overcome the technical barriers for the safe and cost-efficient implementation of fibre-reinforced asphalt mixtures (FRAM) by NRAs with which an increase in the asphalt pavements durability could be achieved.

Despite promising results achieved in previous research works and the availability of commercial fibres whose providers ensure a pavement life extension of at least a 50% and asphalt mixture life extension of around 200% (depending on the type of fibre and provider), the use of reinforced-asphalt mixtures is not as widespread as could be expected. This was principally due to the existence of gaps in the state of the knowledge that make National Road Administrations reluctant to their incorporation. FIBRA project aimed at reducing these knowledge gaps to promote utilization of fibre in asphalt by rising the TRL level of the technology from 5 to 7.

The achievement of this challenging project was possible thanks to a unique combination of research knowledge and industrial expertise at international level, where 5 research institutions and 2 industries from 6 different countries participated.

3 Main results (the what)

Project partners can exploit results themselves or facilitate exploitation by others for ex. by making results available under open licenses. The RTD partners have done this through publications during the project. The method, workability, and potential use of the asphalt with fibre are experiences the partners possess themselves and can benefit from if they chose to utilize fibre in their production of asphalt. This section will go over the main exploitable results from the FIBRA project.

3.1 FIBRE selection

The literature review in the beginning of the project focused on selection of fibre for the project. A multicriteria decision making methodology was applied to rank the fibres according to their performance on different criteria (rutting, fatigue life, toughness, and indirect tensile strength).

From there six fibres were selected from the literature review and further evaluated in terms of their technical, environmental, and economic performance. The six fibres selected were Polyacrylonitrile (PAN), aramid/polyolefin blend (Aram/Pol), polypropylene (PP), polyester (PET), nylon and steel fibres. These were then ranked in relation to their environmental impact.

However, the effect of the fibres on the durability of the asphalt was not quantitatively documented in literature, therefore the impact from production process was used in a cradle-to-gate life cycle assessment (LCA) using ReCiPe 1.08, ReCiPe 2016 and CML 2016.

As the effect of fibre on the service life of the asphalt is not known the cost-benefit analysis calculated the estimated minimum percentage of service life extension that needed to be achieved by each FRAM layer to obtain 10%, 20% or 30% cost-benefits.

Finally, the state of development for the six fibres was analysed with regards to laboratory testing, implementation of pilot sections, and commercial availability of FRAM. The consortium selected Polyacrylonitrile and the blend of aramid/polyolefin fibres to continue investigating.

The literature review and process of selecting fibres are communicated to the PEB through D2.1 - Literature Review on the Use of Fibres in Asphalt Mixture.

3.2 Laboratory Research

The laboratory evaluation of the mechanical properties of fibre reinforced asphalt mixtures and fibre reinforced asphalt mortar were carried out by TUBS, UNICAN and EMPA. The chemo-mechanical response and interaction between fibre and binders were conducted by EMPA. The optimal designing and full characterization of dense- and open-graded fibre reinforced asphalt mixtures for different layers were performed by UNICAN, TUBS and VT.

3.2.1 Mechanical response of fibre-reinforced asphalt mixtures and rheological properties of fibre-reinforced asphalt mortar

EMPA evaluated the suitable fibre type for FRAMs to be used in AC, while TUBS and UNICAN determined the optimal fibre to be used in PA in both mortar and mixture phases, respectively. Rely on the previous *Deliverable 2.1*, two commercially available fibres, polyolefin-aramid and polyacrylonitrile based fibres, were used for this purpose. For the dense FRAM, four different AC mixtures with/without fibres were prepared at EMPA. Then, water sensitivity, rutting resistance and fatigue resistance tests were performed according to the European standards. In the case of open-graded FRAM, eight different PA mixtures were produced at UNICAN. Next, interconnected air voids, permeability, particle loss in dry and wet conditions, and indirect tensile strength were conducted to evaluate the mechanical response. TUBS conducted the rheological properties of PA mortar, in total 18 materials were designed with different bitumen types, and then mixed with/without fibres under different aging conditions. For different experimental methods, Multiple Stress Creep and Recovery Test (MSCRT), Linear Amplitude Sweep (LAS), Accelerated Fatigue Test (AFT) and Bending Beam Rheometer (BBR), were used to assess the rheological behaviour of these PA mortars. It is worth to mention that the optimization of FRAMs (AC and PA) designs was not the goal of this stage, more information can be found in the following chapter and *Deliverable 4.1*.

Based on the testing results, the following conclusions can be drawn:

- For the FRAMs types AC: FRAM showed similar water sensitivity and a slightly worse fatigue properties compared with the reference asphalt mixture. FRAM prepared with polyacrylonitrile fibre shows better anti-rutting properties.
- For the FRAMs types PA: The use of fibre slightly reduced the air voids and permeability, while limited improvement was observed in the ravelling resistance. A notable increase was found in the indirect tensile strength (ITS) and fracture energy when polyolefin-aramid fibre was used to prepare the FRAM. However, no remarkable differences in ITS were found between reference mixtures and FRAM under wet conditions.
- For the porous asphalt-based fibre reinforced asphalt mortar: the binder types show a greater influence on the rheological properties compared to the fibre types. An overall better rheological performance was found when the polymer 40/100-65 binder and polyolefin-aramid fibre were used, this is especially true for the fatigue properties. Additional results indicate that the use of polyolefin-aramid fibre could significantly improve the fracture energy of PA asphalt mortar at intermediate temperatures.

Overall, the polyolefin-aramid fibre was suggested to prepare the PA mixture, while in the case of AC mixtures, polyacrylonitrile fibres was demonstrated to be a better option. Detailed information about the entire set of materials including mixture and mortar, experimental results and discussion can be found in *Deliverable 3.1*.

3.2.2 Chemo-mechanical understanding of FRAM and interaction between fibre and binders

Empa evaluated the thermal, chemical response of different fibres, together with the fibres distribution within the asphalt matrix and rheological behaviours of bituminous binders recovered from the FRAM.

The objective of this experimental study was to understand the physicochemical mechanisms leading to the superior response of FRAM. With this in mind, two synthetic fibres were selected in order to analyse their effect within a conventional dense asphalt mixture used in Switzerland. The mechanical performance of the experimental mixtures along with the thermal properties of the fibres were jointly evaluated. First, it was concluded that the fibre reinforced asphalt mixtures could perform similarly to the standard mixtures prepared with polymer modified binder. In addition, it was also confirmed by imaging analysis that the reinforcing effect was associated to the physical presence of the fibres within the asphalt matrix rather than chemical. After extraction and recovery of the bitumen from the different asphalt mixtures, no significant modification due to the addition of the fibres was observed. The possible melting of the polyolefin fibres did not affect the bitumen properties. The chemical composition of these fibres (mainly carbon) made it impossible to distinguish them within the asphalt matrix in the ESEM analysis.

Based on the chemical understanding of the fibre-asphalt interaction and the rheological characterization of fibre-modified asphalt binders, the dry process was finally decided as the optimized blending process. More information about the materials and experimental work can be found in *Deliverable 3.2* together with the analysis and discussion of results.

3.2.3 Optimal designing and full characterization of dense- and open-graded fibre-reinforced asphalt mixes for different layers

TU BS and UNICAN optimized the design of different FRAM for open and dense grade asphalt mixtures. In particular, different gradation curves were used to compose the mixtures for surface, binder and base layers in accordance with the national requirements. All the mixtures were experimentally investigated in laboratory to evaluate their mechanical response. In particular, for the surface layer mixture, the polyolefin-aramid fibres were employed, and five different PA mixtures with/without fibres were prepared for comparison purposes. Air voids, Cantabro test, ITS, and moisture sensitivity were taken into consideration. Concerning the AC mixtures, polyacrylonitrile fibres were taken into consideration. Different sets of AC mixtures with/without fibres were manufactured and studied in the distinct layers of the pavement structure. In addition, the potential recyclability of FRAMs was studied manufacturing artificially aged fibre-reinforced RAP. Finally, the feasibility of incorporating high percentage of RAP without the presence of rejuvenators in the surface (30%RAP) and binder layer (50%RAP) was investigated. Volumetric properties, ITS, moisture sensitivity, rutting, stiffness, fatigue resistance, thermal cracking, and fracture energy were the main tests considered for comparison purposes.

The following protocol was used to produce the mixture: for the mixes prepared with a conventional binder, the mixing temperature was 150°C while in the case of the mixture done with PMB, a blending temperature of 170°C was employed according to the recommendations of the supplier. In any case, the aggregate temperatures were 15°C greater than the mixing temperature according to the bitumen type. In the case of mixtures modified with fibres, the fibre addition was done by dry method. In other words, fibres were blended with the aggregates homogeneously mixing in the drum for 1 minute prior to the addition of the binder to the mix.

From the test results the following conclusion can be drawn:

- Regarding ITS and moisture sensitivity results, adding fibres increased the tensile strength especially in dry conditions, leading to worse moisture resistance in comparison to the PMB reference mixtures.
- the mixture manufactured with polyolefin-aramid mixture showed the highest ravelling resistance in dry conditions followed by the mixture manufactured with PMB. Regarding the particle loss in wet conditions, the increase of the binder content is needed to adequately cover the fibres and hence achieved an effective reinforcement of the mixture.
- The addition of fibres significantly improved the rutting and fatigue resistance in comparison with the reference mixtures, but in the case of binder layers mixtures was not enough to achieve the performance properties of the PMB mixtures.
- It is recommended to use high percentages of bitumen to ensure the proper coating of the fibres.
- Thermal cracking resistance and fracture energy are worse than the reference mixture with PMB. Therefore, the addition of fibres does not make the fibre reinforced mixtures more suitable for cold regions than PMB and they are still not suitable to be laid in cold regions due thermal cracking has not been improved enough.
- The performances of the mixtures containing RAP show similar trends to the mixtures composed with fresh materials, mitigating the differences with the PmB mixtures.

The final balance between the environmental and economic impact of the mixtures with fibres respect to the mixtures with PMB seems to be crucial to consider the real possibilities of this technology, due to its mechanical behaviour is between the raw and the modified bitumen in general terms. In *Deliverable 4.1* more information concerning the materials, experimental work, the discussion of results, and the most relevant conclusions can be found.

3.3 Upscaling and Field Testing

The production process of the asphalt mixes designed and evaluated at laboratory in FIBRA were upscaled to industrial scale by BAM in the Netherlands and VEIDEKKE in Norway. The upscaling of the PA mixture was carried out by BAM and the upscaling of the AC mixtures was done by VEIDEKKE.

3.3.1 Porous asphalt (PA)

BAM and the Dutch NRA: Rijkswaterstaat (RWS) have installed test sections in the A73 in the last week of August 2020. In these test sections, four variants of the same top layer of a double layer porous asphalt (2L-PA 8) are applied. The 2L-PA 8 is a mixture with a maximum grain size of 8mm that is widely used on the primary road network. This mixture is designed with 25mm thickness and design air voids of 23%. Relative to a traditional single layer PA 16, this mixture has a smaller grain size (8mm vs. 16mm) and slightly higher air voids (23 vs. 20.6%). Commonly an SBS polymer modified bitumen is used in 2L-PA 8.

The following FIBRA variants are applied in the test sections and the characteristics of the FIBRA mixture is shown in Table 1:

- FIBRA 1, reference, conventional top layer of the double layer porous asphalt (2L-PA 8) mixture with PMB (Styrelf 65/105-80 A AP) produced at temperature of 185ºC.
- FIBRA 2, reference, 2L-PA 8 with penetration grade bitumen (70/100) produced at a temperature of 165ºC. This mixture comprises 0.2% cellulose fibre to prevent binder drainage.
- FIBRA 3, 2L-PA 8 with penetration grade bitumen (70/100) and 0.15% polyacrylonitrile fibre (trademark Panacea) produced at a temperature of 165ºC.
- FIBRA 4, 2L-PA 8 with penetration grade bitumen (70/100) and 0.05% aramid fibre (trademark Twaron 1080) produced at a temperature of 165ºC.

Table 1. Laboratory characteristics of the four FIBRA mixtures.

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
	PMB	70/100	Panacea polyacrylonitrile	Twaron 1080 aramid
Gyrator cycles needed to reach air voids [-]	48	61	45	52
Air voids specimen	23.0%	22.8%	23.4%	23.5%
ITS dry [MPa]	0.72	0.61	0.572	0.578
ITS wet [MPa]	0.63	0.52	0.455	0.446
ITSR	88%	86%	80%	77%

The test sections are installed in the A73 in the south of the Netherlands, near the city of Roermond, and are located on the southbound road half directly after the Tunnel Swalmen. The test sections have 2 traffic lanes and 1 emergency lane and have a traffic intensity of about 50,000 vehicles per working day. The mixtures applied in the test sections are produced at the BAC batch asphalt plant in the city of Helmond, with a transport distance of 60 km to the jobsite. The following gives key parameters of production and installation. During the production process, the fibres (panacea, aramid) are fed into the mixer manually after the dosing of aggregates through the inspection opening of the mixer. The mixing time of the fibre reinforced mixture was slightly increased by 5 second to ensure proper dispersion of the fibres in the mixture. Compaction of all sections was carried out using the same equipment and following the same standard compaction procedure for all 2L-PA 8 mixtures. No difference between compaction behaviour was observed. The FIBRA mixtures are easier to handle by handwork than the reference mixture with PmB. The mixing method for each asphalt mix is presented in Table 2.

Table 2. Mixing procedure for the PA asphalt types.

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4
Temperature produced mixture [°C]	181.2	160.6	159.5	165.5
Mixing sequence	1. aggregates 2. filler 3. bitumen 4. mixing for 25 seconds	1. aggregates 2. cellulose fibre 3. filler 4. bitumen 5. mixing for 30 seconds	1. aggregates 2. panacea fibre+cellulose fibre 3. filler 4. bitumen 5. mixing for 30 seconds	1. aggregates 2. aramid fibre+cellulose fibre 3. filler 4. bitumen 5. mixing for 30 seconds
Temperature mixture after the paver [°C]	156.2	145.0	144.4	149.2
Total production amount [ton]	217	214	206	201
Total paved length test section A73 [m]	330	350	350	320

The four mixtures in the test section have been evaluated through both laboratory testing and field testing. A summary of the test results can be found in Table 3.

Table 3. Test results for the four asphalt mixtures applied to the test site.

	FIBRA 1	FIBRA 2	FIBRA 3	FIBRA 4	Requirement
DSR mortar response test, virgin material (e.g. |G*| @1e-5 Hz, -10C)	3.39 MPa	8.41 MPa	20.4 MPa	29.3 MPa	
DSR mortar response test, aged material (e.g. |G*| @1e-5 Hz, -10C)	18.8 MPa	69.4 MPa	89.3 MPa	79 MPa	
DSR mortar response test, Aging index @1e-5 hz, -10°C)	5.6	8.3	4.4	2.7	
Water drainability, Becker test	13.4 s	10.9 s	14.1 s	11.7 s	< 20 s
Longitudinal evenness, C5	0	0	0	0	< 2%
Skid resistance RAW 2015/72 70 km/hour, week 0			0.550	0.565	> 0.42
Skid resistance RAW 2015/72 70 km/hour, week 3	0.517	0.560	0.570	0.555	> 0.42
Noise measurement CPX, CPXP [dB(A)] right lane for light vehicles	91.3	91.6	91.4	91.3	
Visual inspection after 3 month	Good	Good	Good	Good	

The following observations can be summarized from the porous asphalt test sections,

- Porous asphalt can be reinforced using synthetic fibres (Polyacrylonitrile and aramid).
- The use of synthetic fibres in combination with a pen grade bitumen for 2L-PA 8 allowed to reduce the production temperature by approximately 20°C compared to that of the reference mixture produced with PMB. Given the difference in production temperature, no differences in laboratory production and compaction were observed. This implies

that differences in bitumen properties are compensated with the difference in production temperature.

- The mechanical strength of fibre reinforced PA is similar to that of PA produced with a pen grade bitumen. The water sensitivity of the fibre reinforced PA is slightly lower than that of the pen grade bitumen mixtures.
- For the production of the fibre reinforced PA the fibres were pre weighed and prepacked in melt bags and fed into the mixer manually. As a result, the production speed slightly decreased to 130 ton/hour compared to that of the automatic process of reference mixture of 150 ton/hour. Similar temperature homogeneity of all mixtures was be observed.
- The installation temperature of fibre reinforced porous asphalt is 20 °C lower than that of the PMB reference section. No difference is observed on the compaction process. No fibre clusters or other production or installation problems occurred.
- Laboratory results show that all FIBRA mixtures have very limited variation in composition both directly after production at the plant and just in advance of installation in the paver hopper.
- The DSR mortar response test show that the PMB mixture is the most flexible mixture before and after aging. The addition of fibre increases the complex modulus and decrease the phase angle of the mortar. The mixture with fibre reinforcement shows less aging susceptibility than that of the reference mixture without fibre and also the PMB mixture with limited increase of the complex modulus after ageing.
- The filed evaluation shows that all FIBRA sections have good performance. All FIBRA sections have identical water drainage performance, longitudinal evenness. The fibre reinforced PA sections have better skid resistance performance than that of the reference section with polymer during the first 3 weeks after opening to traffic. The wearing off the bitumen film is faster than that of the polymer modified section.
- The noise measurement by the use of a CPX method after 3 months of service indicate that all the sections have similar noise-reducing performance.
- The visual inspection results indicate that after 3 months of service trafficking the test sections are in good condition and that no damage is observed.
- The test long term performance of the FIBRA test sections will be monitored by BAM in close collaboration with Rijkswaterstaat. At this moment a year 2 and year 5 HD video inspection is planned. These test sections will also be part of the yearly monitoring program of Rijkswaterstaat of visual inspection and skid resistance.

3.3.2 Asphalt Concrete with fibres

VEIDEKKE, Norwegian national public road authorities (SVV), and Trøndelag Fylkeskommune (road owner) have installed test sections near Singsås (Fv 30) in June 2020. Three types of FIBRA AC11 mixtures were constructed with a thickness of 40 mm. The mix-design is done according to the requirements in the Norwegian guidelines for asphalt pavements. The characteristics of the asphalt concrete are shown in Table 4.

Table 4. Results of laboratory testing of AC mixtures

	AC 11, binder 70/100 (ref)	AC11, binder 70/100 with fibre Panacea	AC11, binder PMB
Marshall test			
Marshall stability (kN)	7.8	7.6	10.3
Marshall flow (mm)	3.2	3.1	3.2
Marshall quotient	2.4	2.5	3.2
Void content of marshall samples (mean)	3.9	3.9	3.1
Wheel tracking test			
WTSair	0.111	0.097	0.029
PRDair (mm)	3.3	2.9	1.4
RDair (%)	6.6	5.7	2.9

Results and experience from the production and installation shows that the following parameters affect the mixing of the asphalt components:

- Mixing sequence,
- Temperatures,
- Mixing times, etc)

3.4 Life Cycle Environmental Assessment

Life Cycle Assessment (cradle to gate) of 1 ton of asphalt mixture for the 4 mixtures designed and tested early in the project (June/July 2020). The objective was to assess the differences of using the different type of fibres considering the transportation distance and main composition. After the mix design and upscaling were completed, a new assessment was carried out to find the environmental benefits of the FIBRA asphalt pavements. A Life Cycle Assessment was conducted according to the ISO 14040:2006 and ISO 14044:2006 standards. The analysis uses a cradle-to-grave approach where material production, road construction, use, road maintenance and end-of-life.

The main results from the study show that if the same service life for both the reference and the FRAM is assumed, the life-cycle environmental impact increases slightly (less than 10%). However, the fibres are expected to increase the service life of the wearing course, and consequently, the life expectancy of the road pavement. This results in an increment of 2 years in the service life of the road pavement and by that the environmental benefits associated with this life extension outweigh the negative impacts generated by the fibre production and transportation. The environmental impacts are shown in Table 5 for PA mixes.

Table 5. Results of the cradle-to-gate analysis of the four PA mixure alternatives.

			FIBRA-PA1	**FIBRA- PA2**	**FIBRA- PA3**	**FIBRA- PA4**
			PMB	Reference	PAN fibre	Aramid fibre
CC_{total}	Climate change (total)	[kg $CO_{2\ eq.}$]	7,61E+01	6,61E+01	7,41E+01	7,36E+01
$CC_{biogenic}$	Climate change (biogenic)	[kg $CO_{2\ eq.}$]	7,53E-02	7,63E-02	8,50E-02	9,61E-02
CC_{fossil}	Climate change (fossil)	[kg $CO_{2\ eq.}$]	7,60E+01	6,60E+01	7,39E+01	7,35E+01
OD	Ozone depletion	[kg CFC-11 $_{eq.}$]	2,63E-13	8,78E-13	7,52E-13	8,08E-13
AE	Acidification	[Mole of H^+ eq.]	7,01E-01	6,26E-01	6,46E-01	6,41E-01
EUT_f	Eutrophication, freshwater	[kg $P_{eq.}$]	2,51E-03	8,31E-04	8,37E-04	8,51E-04
EUT_m	Eutrophication, marine	[kg $N_{eq.}$]	1,80E-01	1,68E-01	1,75E-01	1,72E-01
EUT_t	Eutrophication, terrestrial	[Mole of $N_{eq.}$]	1,97E+00	1,84E+00	1,92E+00	1,88E+00
POF-HH	Photochemical ozone formation, human health	[kg $NMVOC_{eq.}$]	5,16E-01	4,84E-01	5,05E-01	4,96E-01
$RU_{m\&m}$	Resource use, minerals and metals	[kg $Sb_{eq.}$]	4,97E-06	4,96E-06	5,66E-06	6,20E-06
$RU_{fossils}$	Resource use, fossils	[MJ]	3,32E+03	3,23E+03	3,39E+03	3,37E+03
WU	Water use	[m^3 world $_{eq.}$]	1,98E+01	4,15E+00	4,90E+00	4,12E+00
PM	Particulate matter	[Disease incidence]	9,77E-06	8,17E-06	8,25E-06	8,31E-06
IR-HH	Ionising radiation, human health	[kBq $U_{235\ eq.}$]	4,24E+00	4,34E+00	4,95E+00	4,66E+00
$ETOX_f$	Ecotoxicity, freshwater	[CTU_e]	3,55E+00	3,41E+00	4,30E+00	4,03E+00
CHHE	Human toxicity, cancer	[CTU_h]	1,62E-07	1,62E-07	2,00E-07	1,88E-07

NCHH	Human toxicity, non-cancer	[CTU_h]	1,33E-06	2,29E-06	2,21E-06	2,23E-06
LU	Land use	[Pt]	2,00E+02	2,33E+02	2,39E+02	2,59E+02

Concerning the Cradle-to-gate analysis, the highest environmental impact corresponds to the PA mix with PMB with a difference higher than 10% (only with the MKI). The Fibre-reinforced PA mixes although with a higher environmental impact than the reference, the variation is kept below 10%. When the analysis cover all life cycle stages (cradle-to-grave), the differences between the environmental impact among the four mixtures are low (less than 4%).

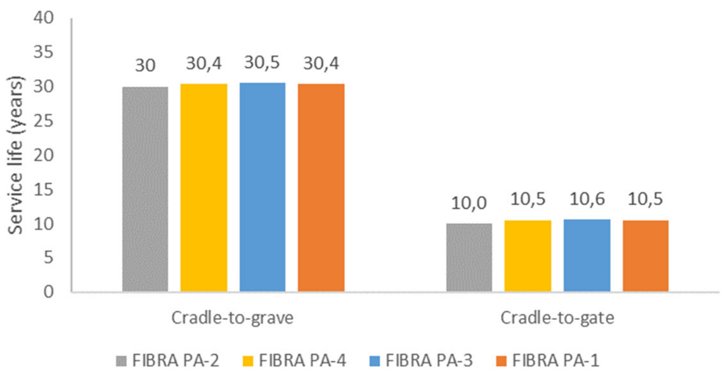

Figure 1. Minimum service life that need to reach FIBRA-PA1, -3 and -4 in order to match the environmental impact of FIBRA- PA2.

Translating this into service life is useful to see how the new asphalt mix compares to the reference one. Assuming 10 years of service life for the reference mixture FIBRA- PA2 and 30 years for the complete pavement, the other three mixtures/pavements need minimal increase in service life to match the environmental impact of the reference mix (Figure 1). Less than half a year is required but as the service life is still not confirmed this will be interesting to follow in other researches. Including possible benefits from recycling the new asphalt mix (Module D) did not drastically change the overall results, exept from increasing gap betwenn FIBRA PA-1 and the others.

Results for the evaluation of cradle-to-gate environmental impacts of the three alternative AC11 mixtures (Table 6) shows that the mixture FIBRA-AC1 with PMB presents similar results in 10 environmental impact indicators. The mixture however also shows the worst values in 9 of the other impact indicators. However, the FIBRA-AC3 reinforced with fibres, shows the worst environmental performance in 14 indicators.

Table 6. Results of the cradle-to-gate analysis of the three AC11 mixure alternatives.

			FIBRA-AC1	FIBRA-AC2	FIBRA-AC3
			PMB	Reference	PAN fibre
CC_{total}	Climate change (total)	[kg $CO_{2\ eq.}$]	5,92E+01	4,73E+01	5,54E+01
$CC_{biogenic}$	Climate change (biogenic)	[kg $CO_{2\ eq.}$]	5,85E-02	5,83E-02	6,75E-02
CC_{fossil}	Climate change (fossil)	[kg $CO_{2\ eq.}$]	5,91E+01	4,72E+01	5,53E+01
OD	Ozone depletion	[kg CFC-11 $_{eq.}$]	1,89E-13	1,89E-13	2,18E-13
AE	Acidification	[Mole of H^+ eq.]	2,57E-01	1,66E-01	1,90E-01
EUT_f	Eutrophication, freshwater	[kg P $_{eq.}$]	2,64E-03	8,39E-04	8,49E-04
EUT_m	Eutrophication, marine	[kg N $_{eq.}$]	6,10E-02	4,57E-02	5,44E-02
EUT_t	Eutrophication, terrestrial	[Mole of N $_{eq.}$]	6,61E-01	5,00E-01	5,87E-01
POF-HH	Photochemical ozone formation, human health	[kg NMVOC $_{eq.}$]	1,80E-01	1,38E-01	1,62E-01
$RU_{m\&m}$	Resource use, minerals and metals	[kg Sb $_{eq.}$]	3,29E+03	3,11E+03	3,28E+03
$RU_{fossils}$	Resource use, fossils	[MJ]	3,92E-06	3,87E-06	4,59E-06
WU	Water use	[m^3 world $_{eq.}$]	2,05E+01	3,83E+00	4,60E+00
PM	Particulate matter	[Disease incidence]	6,16E-06	4,28E-06	4,40E-06
IR-HH	Ionising radiation, human health	[kBq $U_{235\ eq.}$]	3,66E+00	3,66E+00	4,28E+00
$ETOX_f$	Ecotoxicity, freshwater	[CTU_e]	2,13E+00	2,10E+00	3,01E+00
CHHE	Human toxicity, cancer	[CTU_h]	9,46E-08	9,14E-08	1,33E-07
NCHH	Human toxicity, non-cancer	[CTU_h]	1,05E-06	1,03E-06	1,21E-06
LU	Land use	[Pt]	7,97E-02	7,91E-02	8,19E-02

Looking at the service life requirements for the new asphalt mixes and assuming 15 years of service life for the reference mixture FIBRA-AC2, the other two mixtures need to increase the minimum service life with around 1.5 and 2.5 years to match the environmental impact of the reference mix (Figure 2). The needed increase in the service life when using fibres in AC asphalt is higher than in the case of PA mixes.

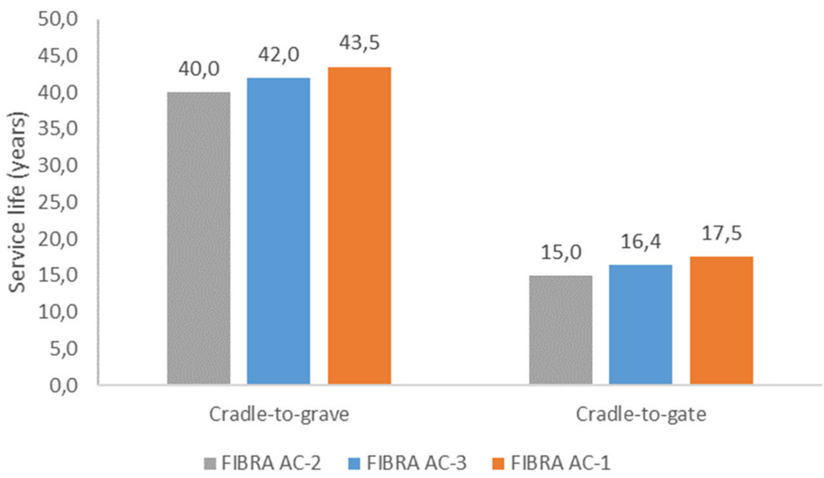

Figure 2. Minimum service life that need to reach FIBRA-AC1 and -3 in order to match the environmental impact of FIBRA-AC2.

Overall, the cradle-to-gate results can be used by the industrial partners when they present their asphalt options to decision makers. These results can be compared to other at-gate asphalt options to ease decision making based on environmental impacts of the asphalt products. Further can these results be used to compare environmental impacts of other new asphalt options emerging from the asphalt industry such as bio-asphalt or green asphalt. The result will therefore aid decision makers in choosing the asphalt type best suited to their needs.

3.5 Life Cycle Cost Assessment

The LCCA developed in this task will enable to calculate the economic feasibility of the FIBRA pavements by considering all the costs generated during the road life stages (material production, road construction, use, road maintenance and end-of-life). It is anticipated that any differences in the durability of the alternative materials, established by the software simulation and model scale performance will be essential in determining material replacement rates and overall life cycle costs.

The LCCA methodology is applied to two case studies. The first one corresponds to the pilot section built in the Netherlands. In this section, the type of mixture used was a 2-layer porous asphalt (2L-PA). The second one corresponds to the pilot section built in Norway, where asphalt concrete (AC) mixtures were implemented.

For the conditions analysed in the study, where the same service life is assumed, similar life cycle costs are obtained for all the alternatives evaluated in each case study (Figure 3). To consider FRAMs as an economically feasible alternative, a similar durability than the asphalt mixture with PmB needs to be achieved in case study nr1 and a slightly higher durability needs to be achieved (around 10%) than the asphalt mixture with PEN in case study n2 (Figure 4).

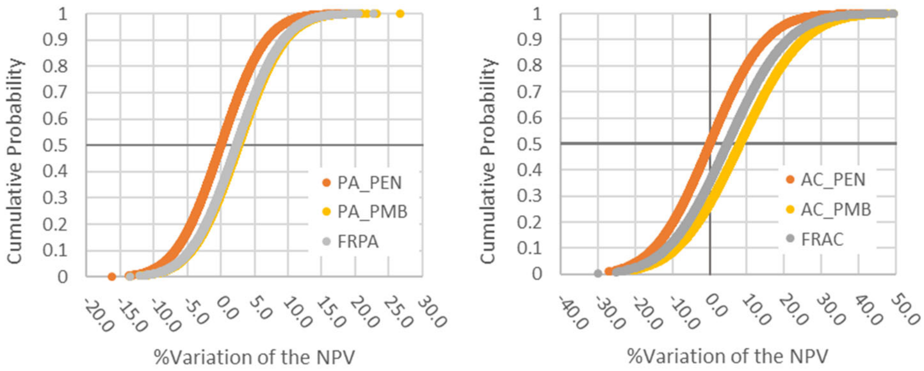

Figure 3: NPV differences (in %) between alterantives, PA mixes (left) and AC mixes (right).

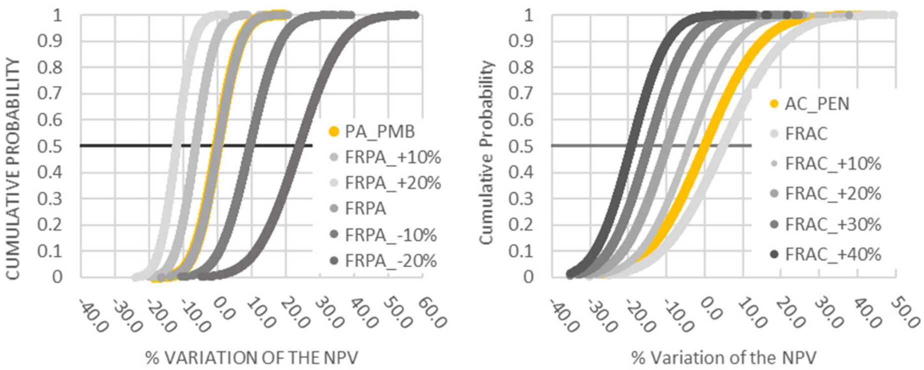

Figure 4: Sensitivity analysis of varying FRPA (left) and FRAC (right) service life.

4 Communication & dissemination during project

In the beginning of the project a communication and dissemination plan was developed. The objective of the plan was to ensure good practice and active communication from the project. Communication is important to successfully promote FIBRA during the project but also after the project is officially finished. To guide dissemination and communication efforts the plan identified groups of target audience, tools, and activities to communicate with those groups.

Various communication and dissemination channels have been used throughout the project (Table 7). These have been actively used by project members with attendance to conference, journal publication, sectoral newsletters, presence on ResearchGate and active communication with CEDR members.

Table 7 Communication and dissemination channels used during the FIBRA project.

Type of activity	Activities	Type of audience
Online	Website Partners' network channels ResearchGate Increased online presence	General public Due to covid-19 an increased emphasis is to be put on online presence, websites/RG
Events	Conferences Seminars Workshops Clustering activities Meetings	Decision makers Scientific community Sectorial community Online seminars important
Publications	Scientific publications Sectorial publications Deliverables	Decision makers Scientific community Sectorial community
Print	Leaflet Poster	Decision makers Scientific community Sectorial community

Communication with the scientific community has been an important for FIBRA as a research project. The results have been published in various scientific journals (5 peer-reviewed articles) as well as at conferences (see Table 8). In total FIBRA has been present at 4 conferences at European level, including the Transport Research Arena 2020 with technical and scientific papers.

During the project, an ongoing dialogue has been maintained with the main target group (e.g., the CEDR members). Furthermore, an active dissemination of the results in the scientific community through conference participation and local presentations. The main communication towards CEDR members is through the deliverables in the project (see Table 9).

Table 8 List of publications during the FIBRA project, both scientific publications and in sectoral news.

Type	Title	Authors	Arena	Published
Conference	An uncertainty-aware hybrid model applied to fiber selection in hot mix asphalt	Carlos J. Slebi-Acevedo, Daniel Castro-Fresno, Daniel A. Zuluaga-Astudillo, Pedro Lastra-Gonzalez, Pablo Pascual-Muñoz	TRB2020	?
Conference	Experimental investigation on the performance properties of fiber-reinforced asphalt mixture in the binder layer: a case study in Germany	Chiara Riccardi, Di Wang, Hamed Arabyar Mohammadi, Moises Bueno, Lily Poulikakos and Michael P. Wistuba	Materials 2020, Valencia, Spain	Mar-20
Conference	FIBRA - Fostering the implementation of fibre reinforced asphalt mixtures by ensuring its safe, optimized and cost-efficient use. Preliminary results.	Slevi-Acevedo, C.J; Lastra-González, P; Indacoechea-Vega, I; Castro-Fresno, D.	TRA2020	?
Conference	Investigation on the Effect of Fibers and Aging Conditions on the Fatigue and Low Temperature Properties of Porous Asphalt Mortar	Di Wang, Augusto Cannone Falchetto, Yun Su Kim, Chiara Riccardi, Goshtasp Cheraghian, Lily Poulikakos, Moises Bueno, Michael P. Wistuba	20th COTA International Conference of Transportation Professionals, July 2020, Xi´an, China	Jul-20
Journal	A multi-criteria decision-making analysis for the selection of fibres aimed at reinforcing asphalt concrete mixtures	Carlos J. Slebi-Acevedo, Pablo Pascual-Muñoz, Pedro Lastra-González & Daniel Castro-Fresno	International Journal of Pavement Engineering	26-Jul-19
Journal	An experimental laboratory study of fiber reinforced asphalt mortars with polyolefin-aramid and polyacrylonitrile fibers.	Carlos J. Slebi-Acevedoa, Pedro Lastra-Gonzáleza, Daniel Castro-Fresnoa and Moises Bueno	Construction and Building Materials	10-Jul-2020
Journal	Chemo-mechanical evaluation of asphalt mixtures reinforced with synthetic fibers	M. Bueno, L. Poulikakos	Frontiers in Built Environment, section Sustainable Design and Construction	9-Apr 2020
Journal	Laboratory assessment of porous asphalt mixtures reinforced with synthetic fibers	Carlos J. Slebi-Acevedo, Pedro Lastra-González, Irune Indacoechea-Vega, Daniel Castro-Fresno	Construction and Building Materials	11-Oct-19
Journal	Mechanical performance of fibers in hot mix asphalt: A review	Carlos J. Slebi-Acevedo, Pedro Lastra-González, Pablo Pascual-Muñoz, Daniel Castro-Fresno	Construction and Building Materials	23-Dec-18
Local presentation	CEDR FIBRA: Veilig en kosteneffectief toepassing van vezels in asfalt (E: Safe and cost-effective adaption of fiber in Asphalt)	Jian Qiu, Marinus Huurman, Daniel Castro-Fresno, Di Wang, Moises Bueno	CROW infrastructure day	24/06/2020
Local sectoral news	Tester om asfalt kan få lengre levetid med fiber	Joralf Aurstad (NPRA)	Utemiljø webpage (text: Bjørnhild Fjeld)	23/07/2020
Poster Conference	Experimental investigation on the effect of fibers on the mechanical properties of asphalt mortar at intermediate and high temperature	Yun Su Kim, Augusto Cannone Falchetto, Di Wang, Goshtasp Cheraghian, Lily Poulikakos, Moises Bueno, Johannes Büchner, Michael P. Wistuba	TRB2020	01-Jan-2020
Journal	Laboratory study on asphalt mixture modified by polyacronitrile fibres and reclaimed asphalt planings	Chiara Riccardi, Michael P. Wistuba, Di Wang	Journal of the Korean Asphalt Institute	Dec-20
Journal	Experimental investigation on fiber-reinforced asphalt mixtures with polyacrylonitrile fibers	Chiara Riccardi, Di Wang, Michael P. Wistuba	Construction and Building Materials	Under review

Table 9 Deliverables from the project represent the tangible knowledge generated.

Deliverable	Title	Authors	Date
D1.1	Quality Assurance Plan	Daniel Castro, University of Cantabria, Spain Irune Indacoechea, University of Cantabria, Spain Catalin Tirnauca, University of Cantabria, Spain	30.09.2018
D2.1	Literature Review on the Use of Fibers in Asphalt Mixture	Goshtasp Cheraghian, TU Braunschweig, Germany Augusto Cannone Falchetto, TU Braunschweig, Germany Daniel Castro Fresno, Universidad de Cantabria, Spain	30.01.2018
D 3.1	Mechanical response of fibre-reinforced mixtures (AC and PA) and rheological properties of fibre-reinforced PA mortar	Di Wang, TU Braunschweig, Germany Augusto Cannone Falchetto, TU Braunschweig, Germany Yun Su Kim, TU Braunschweig, Germany Goshtasp Cheraghian, TU Braunschweig, Germany Moises Bueno, Empa, Switzerland Lily Poulikakos, Empa, Switzerland Carlos Slebi-Acevedo, University of Cantabria, Spain Pedro Lastra-González, University of Cantabria, Spain Daniel Castro-Fresno, University of Cantabria, Spain	17.09.2019
D 3.2	Chemo-mechanical understanding of FRAM	Moisés Bueno, Empa, Switzerland Lily Poulikakos, Empa, Switzerland	17.09.2019
D 4.1	Practical instructions for the design and characterization of FRAM	Chiara Riccardi, Technische Universität Braunschweig, Germany Di Wang, Technische Universität Braunschweig, Germany Carlos Slebi-Acevedo, Universidad de Cantabria, Spain Pedro Lastra-González, Universidad de Cantabria, Spain Irune Indacoechea Vega, Universidad de Cantabria, Spain Daniel Castro-Fresno, Universidad de Cantabria, Spain	15.02.2021
D 4.2	Practical instruction for the structural design of pavements containing FRAM.	Pedro Lastra-González, Universidad de Cantabria, Spain Irune Indacoechea Vega, Universidad de Cantabria, Spain Daniel Castro-Fresno, Universidad de Cantabria, Spain Lily Poulikakos, EMPA, Switzerland	30.06.2021
D 5.1	Scaling up of the production process and implementation of test sections.	Rien Huurman, BAM, the Netherlands. Jian Qiu, BAM, the Netherlands. Bjorn Ove Lerfald, VEIDEKKE, Norway. Irune Indacoechea Vega, University of Cantabria, Spain Pedro Lastra González, University of Cantabria, Spain	15.02.2021
D 5.2	Assessment of the environmental impact of FIBRA pavements	Irune Indacoechea Vega, University of Cantabria, Spain Pedro Lastra González, University of Cantabria, Spain Rien Huurman, BAM, the Netherlands Jian Qiu, BAM, the Netherlands Bjorn Ove Lerfald, VEIDEKKE, Norway	15.02.2021
D 5.3	Life Cycle Cost Analysis of FIBRA pavements	Irune Indacoechea Vega, University of Cantabria, Spain	
D 6.1	Communication and Dissemination Plan	Sara Anastasio, SINTEF AS, Norway	30.09.2018
D 6.2	Exploitation plan	Hrefna Run Vignisdottir, SINTEF AS, Norway Irune Indacoechea Vega, University of Cantabria, Spain Pedro Lastra González, University of Cantabria, Spain Rien Huurman, BAM, the Netherlands Jian Qiu, BAM, the Netherlands Lily Poulikakos, Empa, Switzerland Chiara Riccardi, TTU Braunschweig, Germany Di Wang, Technische Universität Braunschweig, Germany Bjorn Ove Lerfald, VEIDEKKE, Norway	28.06.2021
D 6.3	Guidance for the implementation	Irune Indacoechea Vega, University of Cantabria, Spain	

The communication and dissemination plan has been revised as planned in the project. The main revisions included changes because of covid-19 restriction. Planned site visits, that was an important communication activity for the consortium members and CEDR members as well as for local actors had to be cancelled. However, the project team arranged an end-of-project online seminar and those who can, will visit their respective site later. This was arranged in August. In Norway, the team working on the test section will be invited to join, as well as the road owner (state road, Trøndelag Fylkeskommune) and Norwegian NRA.

5 Stakeholder analysis (the who)

Generally, an exploitation includes a process of convincing end-users of the benefits of adopting or using a certain product. In this case the end-user expects a certain standard of the asphalt road they drive on, but they do not have the ability to affect the asphalt type themselves. Therefore, this exploitation plan focuses on the main stakeholders identified e.g. the road owners, as well as the industry producing and supplying asphalt.

The main groups of stakeholders were identified early in the project and received targeted communication throughout. The identified groups (Figure 5) have not changed during the project. The communication message is heavily affected by the targeted stakeholder group. Each group has different needs for type of information and communication methods. Each stakeholder group is described shortly below and their main need for information and type of communication explained.

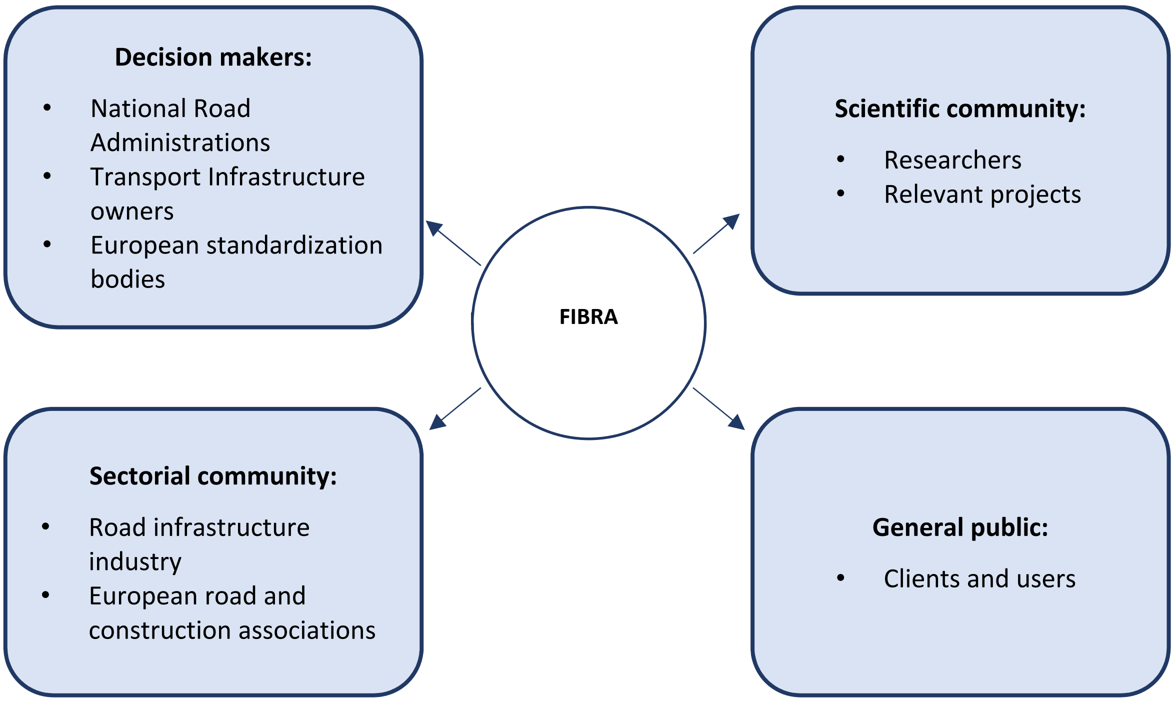

Figure 5 FIBRA target audience.

5.1 Decision makers

Decision makers are the main stakeholders for the FIBRA project as they could benefit from the results of the project. The decision makers are the ones that control where new asphalt is laid and the specifications of that asphalt. Knowledge about new asphalt types therefore needs to reach them to get any hold in the market.

Road owners (e.g. NRAs, municipalities) are the most important stakeholders for further exploitation of the results from the project. These stakeholders can choose to use FRAM in their projects to enhance the performance of the asphalt. Therefore, this group of decision makers need information about:

- Performance specifications, including environmental performance and life cycle cost.
- Documentation on pros and cons of the new FRAM material specific for their region.
- Technical information to fulfil regulatory and normative constraints in their region.
- FRAM suppliers in the market.
- General information (promotion) on the benefits and any downsides.

FRAM enhanced asphalt is considered to be best promoted through direct contact, sectoral news outlets and information leaflets. Road administrations and authorities can use product requirements or incentives in regulations or contracts to lead the direction of material use. For this purpose, they need information to compare material alternatives to each other, based on indicators such as performance, environmental impact, and cost.

5.2 Scientific Community

The scientific community needs numerical information about the laboratory results, testing, development, and performance of the asphalt mix. They need numerical information about the laboratory results, testing, development, and performance of the asphalt mix. For further research it can also be of interest to know about identified knowledge gaps and research questions. The following aspects of the project are of interest for the scientific community:

- Further research on fibre in asphalt.
- Knowledge on research of new materials or use of existing materials.
- Research method in the investigation of FRAM.
- Knowledge on for results f.ex. life cycle cost and life cycle environmental impact, mechanical aspects, and materials performance.
- Information on any research gaps and need that have become evident during the project.

5.3 Sectorial Community

The sectorial community includes the road and asphalt industry, industry organizations and other relevant organizations such as NOGs and news agencies. They will be evaluating the results of the project and can be an important channel for broadcasting the results and recommend products or action based on the results. For these purposes they are interested in the news value of the results and what the results means for the sector in terms of performance, environmental implications, cost, and such. The sectorial community can be a good channel to spread the results to decision makers and other relevant stakeholders.

The information needed this group has includes:

- The value of the results of the project for the sector, the community and environment.
- The main results that need to reach the market (news).
- Meaning of the results for the local sectoral community.

5.4 General Public

The general public, or the end-users are a diverse group with different need for information. The main information to the public is information on the main benefits of the use of new asphalt materials. Most of the general public have little interest in the technical details of asphalt materials but are more concerned with the societal consequences as well as road performance. They are interested in well-functioning road systems with little noise and little need for maintenance, and thereby have an indirect interest in the results through its consequences of road performance. Their main need for information is how the use of this new material will result in a better quality, less noise, and reduce down time.

6 Target Markets

The global asphalt market grew moderately during the period of 2015-2020 and is expected to grow around 3 – 5 % towards 2027 (imarc group, 2020; Wood, 2020). This growth is mainly due to increasing population, expanding road network, and increased urbanization. The need for cost-effective, durable, and sustainable road top-layer therefore increases.

The target markets for FRAM lie in the market for noise reducing asphalt. Today noise is recognised to affect human health in urban areas and the reduction of noise from traffic is becoming high on the agenda (Vignisdottir et al., 2019). Fibre reinforced open graded noise reducing stone skeleton mixtures, such as PA, and noise reducing SMA are asphalt types used for this purpose today. Replacing these with the new FRAM would be a sound choice. There are couple of reasons for this. First, there are many cases where the current option for surface layers is PMB. Replacing PMB with fibre reinforced pen bitumen is financially feasible because the option may be cost neutral with regards to the tested fibres in the FIBRA project.

Secondly, the expected benefits of the application of fibre will in these cases, where it replaces the application of PMB, be lowered production temperature, easier future recycling, reduced environmental cost indicator (MKI), reduced CO2-emissions, reduced emissions during installation and result in a product that is more durable.

In short, the application of fibre in noise reducing surface layers may result in a cost-effective solution for more durable roads.

7 Market barriers or constraints

As in all new designs and innovation projects there are both barriers and risks for exploitation of the results. For FIBRA the risks are mainly linked with service life of the asphalt mix, as the service life is unknown, and asphalt contractors often include guarantee time. This risk should be reflected in asphalt contracts until satisfactory experience is reached.

The target markets for the results from the FIBRA project are mainly European market but other markets, with similar road structure, can be assumed to benefit from the FIBRA results. The European asphalt market adheres to EN 13108 and EN 12697 European Standards for asphalt. These standards, along with national guidance for each country, are to ensure appropriate mixture compositions that results in desired performance level. The national guidance is region specific due to factors such as traffic speed, AADT, climate, winter maintenance practices etc.

In cold regions the use of studded tires is a controlling factor in the choice of asphalt type. The areas where studded tires are used have problems with rutting due to the asphalt type being too soft during winter months when studded tires are allowed. Then again, the harder type of asphalt increases noise from traffic, so the type of asphalt needs careful consideration. In Norway, the softer asphalt types are allowed on new roads with AADT ≤ 1000. The mixes tested in Norway all satisfy requirements for ITSR value over 80 %, and AC11 707100 + fibre and AC11 PMB satisfy requirements for AADT between 5001-10 000 while the reference mix satisfies requirements for AADT 1501-3000 vehicles. However, the requirements for wheel tracking test for resistance to permanent deformation were not satisfied for the reference mix, satisfied for AADT 5000-10 000 for the fibre mix with fibre while the PMB satisfied the requirements for AADT over 10 000 vehicles.

EPD for the new asphalt types as well as for the fibre types is important step to gain access to the market. From technology point of view, the market readiness level is high, as fibre production is already on industrial scale. However, the asphalt production plants would need adjustments for a more automatic process within the plant processes. In the FIBRA project the fibres were fed manually into the asphalt production system. Automation of the process would require some investments into a feeding system.

8 Future Exploitation

For the industrial partners, the exploitation plan analyses the business opportunities in the markets where they have a commercial presence and contact with the NRAs. BAM focus on opportunities for implementing fibre in asphalt in the Netherlands while VEIDEKKE address the potential use in Norway.

This section focuses on practical experience from the industrial partners. Both have tested the assigned fibres on a trial section. The section and description of the experience with asphalt production and laying is discussed. First the main characteristics of the asphalt types are shortly described based on the two test locations. Then an overview of the main benefits and drawbacks from the use of the fibre types in the asphalt mix are presented for each location.

The following section focuses on practical experience from the industrial partners BAM in the Netherlands and VEIDEKKE in Norway. Both have extended experience from asphalt production and development as well as from laying asphalt.

8.1 BAM – Netherland

In the Netherlands, the use of fibres in asphalt is not new. Especially the application of fibres in noise reducing stone skeleton surface layers such as porous asphalt or noise reducing SMA is promising. The strategical benefits of applying fibres in such surfacing layers requires further research such as FIBRA, but indications are as follows.

Lengthening of the service life

Extending the lifespan by using fibres in asphalt is very beneficial for the Dutch NRA, Rijkswaterstaat (RWS). This means that less maintenance is required. This provides advantages on several fronts, such as less consumption of raw materials, making roads more sustainable, fewer direct and indirect costs and higher safety for road users and road workers. The service life extension has to date not been demonstrated in full scale projects with certainty, which creates the need to examine more closely whether and how the reinforcement mechanism works and how you could test this.

Figure 6. Test section in the Netherlands A73, just after fiber asphalt application and during the work. Photo: Rien Huurman, BAM group.

The FIBRA test sections in the A73 will help to further strengthen the preliminary conclusion that fibres may lengthen the service life of open graded noise reducing surfacing layers.

Fibres to replace PmB

In the Netherlands, a relatively high percentage of PMB is used in the 2-layer PA5 or PA8, top layer of 2L-PA, to among other things limit bitumen drainage and improve the adhesion of bitumen and mineral aggregate, so contributing to a longer service life. One of the indications is that when PMB in 2L-PA may be replaced by standard bitumen (70/100) and fibres, this yields the same performance. In addition, there are signs that PMB mixtures are more difficult to recycle implying that the application of fibres is beneficial for future recycling. Combined the replacement of PmB by fibres and pen bitumen results in a more durable mixture with the same performance and price.

Sustainability

Sustainability is of great importance to RWS as it has set the goal to work fully circular and climate neutral by 2030. As mentioned earlier indications are that fibre reinforced mixtures are easier to recycle than similar mixtures with PMB, without problems. Also, the use of fibre allows for the production of asphalt (also PA and SMA) at a lowered temperature of 105°C so reducing energy usage and CO2-emissions during production by 35%, but also the emission of pollutants during installation (worker health). Finally, the Environmental Cost Indicator (MKI) of fibre reinforced open graded noise reducing asphalt is lower than that of its PMB bound equivalent.

Of course, the application of fibre needs to be at least cost-neutral compared to PMB bound equivalents. This has been proven by various projects so that the issues addressed above are decisive for the application of fibres in asphalt.

RWS has just started further research into the topics that were listed above. The results of the FIBRA project will be integrated into this research and especially the field performance of the FIBRA test sections in the A73 will be of great value to the research.

BAM strongly believes in the advantages of fibres over PMB, especially in relation to service life, production temperature and thus sustainability. Given the fact that all of these points are of great importance and that replacement of PMB by fibre reinforced bitumen is cost-neutral, BAM considers it a strategical advantage to help further explore the possibilities of fibre reinforced surface layers.

8.2 Veidekke – Norway

The following section focuses on practical experience from the industrial Partner VEIDEKKE in Norway. The test sections are located Singsås (Fv 30). Three types of FIBRA AC11 mixtures were constructed with a thickness of 40 mm.

Three types of asphalt were laid in Norway:

- AC 11, binder 70/100 (ref)
- AC 11, binder 70/100 with fibre

- AC 11, binder PMB.

The purpose of using fibre-reinforced asphalt in Norway will mainly be to improve the deformation properties. On roads with high traffic and a large proportion of heavy vehicles, polymer-modified binders are currently used.

Figure 7 Test section before the experimental asphalt was laid (left) and after the first test section was laid. Photo: Hrefna Run Vignisdottir, June 2020.

Results from the pilot section shows that the deformation property is improved by using fibre compared to the reference with 70/100 binder. However, the results show that the deformation properties are somewhat better for the asphalt mix with PmB. The other two parameters that were investigated, water sensitivity and wear from studded tire, show that asphalt mixture added fibre has approximately the same properties as the mixture with PmB. In Norway, we have a climate where temperatures vary widely throughout the year, with low temperatures during wintertime and high temperatures during summertime. In this study, the low-temperature effect of adding fibres has not been investigated and should be evaluated in further studies.

In the plant fibres were manually handled when added into the mixture. This requires extra resources and when using fibres in larger projects, adjustments had to be made so that the fibres can be added automatically. The costs for such an adjustment have not yet been investigated and will probably vary between asphalt plants. Without such an adjustment in the plant, the use of fibre today will only be relevant for small projects.

Furthermore, in Norway today many some contracts include weighting of CO_2 footprints when a contract is rewarded. This can be expected to become even more common in the years to come. It is therefore necessary to calculate the contribution of the new asphalt mixture to the overall $CO_{2eq.}$ footprint from the road project when fibre is used. For the Norwegian market it is also essential to have an EPD for this product.

8.3 Research, technology, and development partners

The exploitable results for the research, technology, and development partners (RTD) partners, UNICAN, EMPA, TUB, and SINTEF are versatile. The results might be a background for future collaborative research projects, further internal research to develop or to contribute to standardization work, or pure knowledge based. The exploitation also applies to educational purposes where the internal use of the results in teaching is beneficial to the universities in the consortium. Both the results and the methods used for testing and developing have great potential to be used in teaching.

The tangible results and output from the FIBRA project are knowledge based scientific publications. Therefore, the knowledge is the main exploitable result for the research institutes, as well as for the industrial partners. The knowledge produced in the project needs appropriated management and the IPR measures taken for the protection of knowledge and products generated is defined in the consortium agreement. The knowledge concerning the use of fibres in asphalt is documented throughout the project in form of publications and deliverable reports (Table 9). The scientific publications are owned exclusively by the authors and their organization while the deliverables are owned by the CEDR members, consortium members and their organization. It should be noted that the deliverables are publicly available as requested by CEDR.

The exploitability of the results is up to each of the partners, and it should be noted that the deliverables and information in these are owned by the CEDR members participating in the call. This implies that the information is possible free for use for the public as well as the CEDR members from the participating countries.

Furthermore, some of the publications are published during the project time on a open access base which makes the results available for anyone to read, learn from and use. The data behind the publications are however owned by the authors.

9 SWOT analysis

After going through the main results from the project the target audience and the type of information they need, as well as the target markets, it is possible to summarize the most important strengths, weaknesses, opportunities, and threats in a SWOT analysis. The analysis allows for identification of points for further development and support introduction to the correct target markets with regards to the product strengths and weaknesses.

Table 10 SWOT analysis of the FIBRA solutions

	HELPFUL To exploit the result	HARMFUL To exploit the result
INTERNAL ORIGIN (attributes of the technology)	**STRENGTHS** - FRAC improves ITS and rutting resistance of AC mixtures comparing to reference mixtures with PEN bitumen without negatively affecting other properties. - FRPA improves the ITS and particle loss resistance comparing to reference mixtures with PEN bitumen. - Better mechanical properties comparing to reference mixtures with PEN bitumen but still lower production temperatures (15-20ºC) than mixtures with PMB. - No special equipment or uncommon mix sequences are needed to produce FRAM. No initial investment is needed. - No modifications of the layer construction process (i.e. laying and compaction) are needed. - Recyclability is not affected by the addition of fibres.	**WEAKNESS** - FRAM's mechanical performance at aged condition has not been analysed. The evaluation of their long-term performance in real environments is a crucial step for the wider application of FRAM. - Further testing and verification is needed to ensure a cost-efficient use of the technology. - The initial cost of the asphalt mixes is increased due to the cost of the fibres.
EXTERNAL ORIGIN (attributes of the environment)	**OPPORTUNITIES** - PMB cannot be recycled. This makes FRAM a most suitable solution under the environmental point of view. - Asphalt mixtures with PMB need to be produced at higher temperatures, impacting negatively in their environmental impact. - New regulations and standards are shifting to more resource and cost-efficient materials and procedures. - Maintenance costs are the main matter of concern to all National Authorities. Solutions are sought to increase durability of road pavements. - Providers of fibres are very interested in road applications and new products can be developed (i.e. fibres from recycled materials).	**THREATS** - Other new technologies with also promising results concerning the increase of service life. - PMB obtain better results in several mechanical tests and it is well consolidated.

10 Business case

The role of a business case is to communicate shortly and directly to the target audience the main factors to facilitate decision making. The business case is therefore meant to be short, informative, and easy to understand to make the job of the decision maker possible.

The business case presented here is meant to ease communication with the target audience group *Decision makers* as the potential clients for products developed in the project. The case draws upon the experience from the lab and from laying the test sections in both the Netherland and Norway.

Through the FIBRA project it has been the experience that the use of fibre reinforced asphalt is a sound option when choosing asphalt types for roads, especially urban roads. First off, the extensive laboratory and field testing during the project has shown the main characteristics of the asphalt mixes and the results are well documented and openly available. To produce the new asphalt mixes there are none or limited investments required in the asphalt plants. The new material can furthermore be transported and installed using existing, normal road building equipment.

The main question remains, why should decision makers choose to increase their costs and use this material type over traditional asphalt used today, or the PMB? This is where the results from the environmental and cost assessment play a big role. The results imply that the costs of application of fibres in asphalt varies and is directly related to the product at hand in the specific project. Thus, there exists a direct and simple relation between the application of fibre and the price (costs) of asphalt, specifically in relation to the use of fibre.

In the Netherlands, the application of fibres in asphalt becomes cost neutral when PMB is replaced by pen bitumen with fibres. In Norway, the application of fibres in asphalt are an alternative in smaller projects where it is not appropriate to produce asphalt with PMB. This is mainly because of the use of studded tires in Norway where the PMB performs best but is of course affected by both environmental impacts and cost. This explains why a solid, well documented prove of field performance of fibre reinforced asphalt, in areas where PMB is commonly used, is so important for the business case and future application. The test sections will provide that information in the coming years.

As the emphasis on environmentally sound choices are especially strong in both the Netherlands and Norway, the environmental impacts are a factor that influence the material choice for the decision makers and could, especially in the Netherlands, increase their willingness to pay.

11 Final remarks

The broader impact of the project is the knowledge about the usability fibre in asphalt and impact on the asphalt performance. This knowledge can aid decision makers in selecting the optimal materials suited to their performance need. Furthermore, the experience gained through both laboratory and field testing gives clear method for developing and testing other new asphalt materials and how these might behave in the field.

Further monitoring of the test sections could bring valuable knowledge on the long-term behaviour towards traffic, weather, and for Norway, from the use of studded tires. The new asphalt type also shows promise towards effective noise reduction which is becoming more and more important in an urban environment.