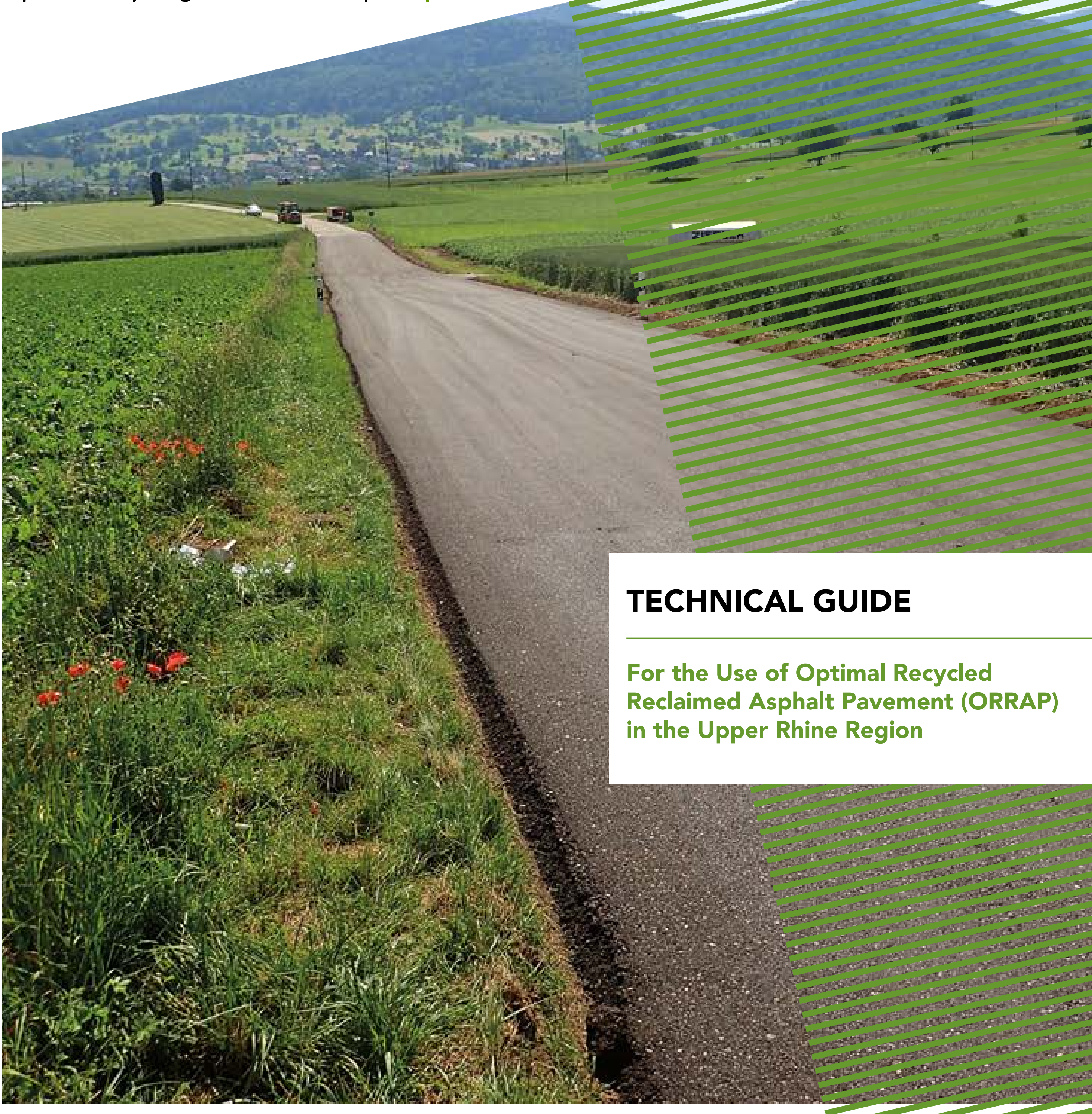
ORRAP

Optimal recycling of reclaimed asphalt pavement



TECHNICAL GUIDE

For the Use of Optimal Recycled Reclaimed Asphalt Pavement (ORRAP) in the Upper Rhine Region

Dépasser les frontières : projet après projet
Der Oberrhein wächst zusammen, mit jedem Projekt

Fonds européen de développement régional (FEDER)
Europäischer Fonds für regionale Entwicklung (EFRE)

Cover picture: **Figure 1/** ORRAP Switzerland. Source Cerema

INTERACTIVE

CONTENTS

1. CONTEXT

The construction, rehabilitation and maintenance of roads and streets involve the use of significant quantities of good quality natural resources, both aggregates and bitumen. Nowadays it is becoming more and more important to limit natural exploitation by promoting the use of recycled asphalt pavement (RAP) aggregates.

In addition, increasing budgetary constraints and rising environmental protection goals justify the use of more economical and energy-saving materials. Although the use of asphalt aggregates has been common practice for several decades, particularly when recycling hot bituminous mixes, there are currently real issues concerning the future of this resource once it has undergone several production cycles and the properties of the binder and the aggregates have irreversibly deteriorated.

At the same time, there are legal constraints limiting the use of recycling materials polluted by high concentrations of polycyclic aromatic hydrocarbons (PAHs) that cannot be reused in hot mix technology for environmental and health reasons.

Finally, the expectations of network managers on economic, environmental and sustainability aspects are increasing.

In order to meet the different objectives, a working group was set up as part of a European Interreg research project ORRAP (Optimal Recycling of Reclaimed Asphalt Pavement). The aim was to reuse 100% recycled asphalt pavement (RAP) aggregates at ambient temperature without adding bituminous binder or rejuvenators. This material is compacted with a certain water content and applied in flexible pavement structures for low or moderate traffic. As a result of this project, the ORRAP group developed and modified a method based on Swedish experiences[1, 2, 3].

This method will further be called «the ORRAP method». It accounts for various economic, environmental, technical and health aspects, as it allows for the saving of natural resources and using low quality (marginal) materials. Moreover, this 100% recycling technology does not only reduce the amount of RAP stockpiles, but represents an environmental friendly construction method resulting in CO_2 saving and the reduction of other emissions.

1 All annotations are compiled at the end of the document.

2. FIELD OF APPLICATION AND REGULATORY FRAMEWORK

The ORRAP method is a 100% asphalt pavement recycling method for low to moderate traffic roads (traffic class T3 – T5 in France, traffic class T1 – T3 in Switzerland, load class Bk 0.3 and Bk 1.0 in Germany, **see Table 1**). It is particularly suited for regional low volume roads.

The method further allows to reuse asphalt aggregates that are not suited for the use in hot asphalt mixtures in case of:

- a level of PAHs above the regulatory thresholds but within a limit allowing their reuse in cold mixtures **(see Table 2)**;
- a stock with RAP materials which do not fulfill the requirements for optimal use in a hot process (binder content, granulometric…);
- a material that has already undergone several cycles of recycling.

Table 1 / Suitable traffic load for the use of the ORRAP method, depending on the existing traffic class in France, Germany and Switzerland[4]

	ORRAP possible			Not recommended for ORRAP				
France: traffic class (average annual daily traffic of Heavy Good vehicles)	T5 (≤ 25)	T4 (25 - 50)	T3 (50 - 150)	T2 (150 - 300)	T1 (300 - 750)		T0 (750 - 2,000)	
Germany: load class Bk (Mio. equivalent 10 t axle load in 30 a)	Bk 0.3		Bk 1.0	Bk 1.8	Bk 3.2	Bk 10	Bk 32	Bk 100
Switzerland: traffic class (daily equivalent traffic load, 8,16 t axle load) [ESAL/d]	T1 (≤ 30)	T2 (30 - 100)	T3 (100 - 300)	T4 (300 - 1,000)	T5 (1,000-3,000)		T6 (3,000 - 10,000)	

As no harmonized regulations exist yet, the environmental and regulatory conditions for the use of the ORRAP method will depend on each country. While it is mandatory that asphalt aggregate stockpiles contain no asbestos, there are different regulatory thresholds for PAHs in each country **(see Table 2)**.

Table 2 / Authorized thresholds in road construction[5]

	Germany	Switzerland	France
Asbestos	NO		
PAHs	0 - 25 mg/kg*	0 - 500 mg/kg	
Hydrocarbons C10-C21	-		0 - 300 mg/kg
Lower quality asphalt aggregates	YES		
*Since 01.01.2018, materials with a PAH content > 25 mg/kg are no longer to be installed on German federal trunk roads. This regulation designed for federal highways is usually also applied to other road categories.			

3. ISSUES AND REGULATORY FRAMEWORK

3.1 /// TECHNICAL SPECIFICATIONS

Good mechanical performance was demonstrated in the laboratory in characteristic modulus tests[6, 7, 8] (repeated load triaxial tests), showing a material which in time reaches slightly higher values than an unbound material (UGM).

Its preferred use is as a base layer to be built on a new or an existing old pavement structure and covered by either a hot mix asphalt surface or a surface treatment (sealer).

3.2 /// ASSESSMENT OF SUSTAINABILITY AND HEALTH ASPECTS

3.2.1 // PURPOSE OF THE SUSTAINABILITY ASSESSMENT

In order to be able to make recommendations for the use of the ORRAP method, the sustainability of this method has to be taken into consideration. Table 3 lists factors which can influence the assessment results both positively and negatively. These factors also form the basis for general recommendations for the use of the ORRAP method. The recommendations made in this chapter are only valid if the country-specific thresholds mentioned in Chapter 2 as well as local and material-specific restrictions are observed. This chapter is based on a tri-national environmental and cost assessment, which includes French, German and Swiss standards, and an additional environmental and cost assessment for Swiss conditions. The results are consistent with both studies **(details in Annex 2)**, but the differences between the studies underline the influence of scenarios and calculations.

Table 3 / Possible conditional terms and their effects on the sustainability assessment

	Material, transport, construction site costs (economic)	Energy demand for material production, construction site, transports (economic and environmental)	Material consumption (environmental)	Time for additional traffic (traffic user)	Energy demand for additional traffic (environmental)	Human toxicity and ecotoxicity (PAH)
Layer thickness	X	X	X			X
Lifetime assumption	X	X	X	X	X	X
Need of an additional asphalt surface course	X	X	X	X	X	X
Distance between material production and mixing plant/construction site	X	X				
Additional distance of diversion				X	X	
Volume of diversionary traffic				X	X	
PAH limits in material and required handling						X

For the assessment of sustainability, different construction methods are compared from an environmental and economical point of view **(see Annex 2)**. In addition, the effects on traffic and the health of employees and the population must be considered when evaluating the method of construction.

The structures considered in Annex 2 reflect the limits of the expected use. Because a standardized ORRAP method does not exist yet, the following aspects are varied:

- lifetime;
- with or without an asphalt surface course on the top of the ORRAP course;
- replacement of a hot mix asphalt course or a layer of Unbound Granular Material (UGM).

The most important recommendations regarding the use of the ORRAP method are summarized below. The corresponding results of the environmental and economical assessment are documented in the Annex 2.

3.2.2 // ENVIRONMENTAL IMPACT

The primary energy demand and the consumption of natural resources have been compared. Greenhouse gas emissions are largely proportional to the primary energy demand. Although there are also other indicators concerning the environmental impact, these have not been applied within this study about the ORRAP method.

/ Primary energy demand and global warming potential (GWP)

The ORRAP method can lead to significant savings of the primary energy demand and GWP:

– this can be significantly reduced by the ORRAP method compared to hot mix structure (pavement with asphalt concrete hot mix), especially if no asphalt surface course is provided;
– it can be somewhat reduced by the ORRAP method compared to the UGM layer;
– it can be significantly reduced if the existing ORRAP layer is removed, reprocessed on site and reinstalled in comparison of moving it to a plant.

The primary energy demand and GWP for the diverted traffic are significant, but generally much lower than that needed for the construction measure. Primary energy demand and GWP are higher if long diversion routes and/or heavy diversion traffic are considered.

/ Use of natural resources

The ORRAP method can lower the demand for primary construction material:

– it is slightly lower with the ORRAP method compared to the hot mix structure, if no asphalt surface course is provided. If an asphalt surface course is necessary, the demand for primary construction material is nearly the same as a hot mix structure;
– it is significantly lower with the ORRAP method compared to the construction method with an UGM layer with primary natural aggregates.

The ORRAP method increases the use of reclaimed asphalt compared to an UGM layer, which can reduce stockpiles. The use of RAP is also higher with the ORRAP method than with a hot mix structure. However, this is only the case when the ORRAP layer is produced for the first time.

/ Environmental scarcity points

The environmental indicators were also aggregated with the environmental scarcity method, which is based on Swiss environmental policy. The results indicate a slightly better performance (12%) for the ORRAP method **(see Annex 2)**.

3.2.3 // ECONOMIC APPROACH

The ORRAP method can lead to significant construction cost savings under the following conditions (landfill costs are not considered):

– construction costs can be reduced by the ORRAP method compared to a hot mix structure, if no asphalt surface course is planned;
– compared to the construction method with an UGM course, the costs are approximately the same;
– the costs can be lowered if material transports can be reduced. This is possible if the existing ORRAP course is removed, reprocessed on site and reinstalled.

3.2.4 // IMPACT ON ROAD USERS

The ORRAP method and a hot mix structure require the same construction time and thus have the same impact on traffic. However, if the ORRAP course has a shorter lifetime, the additional renewal measures will lead to more time losses for road users. The longer the diversion route and/or the greater the volume of traffic to be diverted, the greater the time loss and other impacts on road users.

3.2.5 // HUMAN TOXICITY AND ECOTOXICITY

The human toxicity and ecotoxicity (environment) from PAH were calculated with the USEtox model. According to that method, exposure to fumes gives the highest and exposure to dust the second highest toxicity score. However, this effect could be explained by the fact that the data might not be truly representative. PAH exposure due to fumes was assumed proportional to the amount of hot processed RAP, which is part of the reference hot mix base layer but not the ORRAP layer. PAH exposure due to dust was further assumed proportional to the total amount of processed RAP, hot and cold. This amount is higher for the ORRAP method. Consequently, the PAH-exposure due to fumes is lower with the ORRAP method.

4. PRODUCTION, DEVELOPMENT AND IMPLEMENTATION

4.1 /// ORIGIN AND DEPOSITS

Most of the asphalt aggregates used in the Upper Rhine region are derived from Rhine siliceous-limestone alluvium. As a result, the intrinsic characteristics of the aggregates are considered to be more or less homogeneous and well controlled. The investigation carried out in the ORRAP project showed similar results for the values of density, resistance to fragmentation and wear between materials taken from stocks in Germany, Switzerland and France.

4.2 /// PRODUCTION PROCESS

Asphalt aggregates are produced by milling and by crushing and/or screening operations. During this process, it is of particular importance not to generate large chunks.

4.2.1 // MILLING

A good milling method (constant thickness, rotor drive speed, etc.) limits subsequent crushing and screening operations.

4.2.2 // CRUSHING AND/OR SCREENING

Recycled or reclaimed asphalt pavement (RAP) transported to crushing and screening plants often comes from a variety of sources. The condition of the material from diverse sources affects the production processes.

On a daily basis, asphalt plants receive reclaimed asphalt in four main forms:
- milled asphalt from road pavement;
- returns from the deconstruction of asphalt worksites in the form of slabs and crusts;
- unused surplus asphalt returns from worksites;
- unused surplus asphalt from the plant production.

The stock management of the RAP also determines what processing is necessary. In particular, the management of fresh unused asphalt returns must be carried out in order to avoid solid blocks being formed in storage.

When these precautions are not taken, pre-treatment with a breaker is required to reduce the block size to 500 mm before passing through the crushing plant.

Depending on the nature of the recovered materials (EN 13108-8), the preparation of Reclaimed Asphalt requires:
- crushing and screening for asphalt crusts and chunks, if necessary;

OR
- screening for coarse milling.

At the end of these operations, the product of the screening process is taken back to form a layered stockpile, by successively spreading it (in as homogeneous as possible) horizontal layers of RAP. This stock is taken, from bottom to top, for further use.

4.2.3 // STORAGE

All rules for the storage of natural aggregates apply to the storage of asphalt aggregates. However, to limit the occurrence of large chunks, it is advisable to avoid the circulation of machinery on stockpiles.

If a stockyard has several stocks of asphalt aggregates, these must be physically identified (a sign with the aggregate size).

In order to control the water content, it is recommended that RAP stockpiles should be covered or protected from rain after screening.

If the homogeneity of the stock is not considered to be sufficient, it can be improved by partial removal and mixing. For «large stocks», this allows better control of variations in binder content and grain size. In this case, it is necessary to characterize each sub-stock by its grain size and binder content, the other characteristics having already been identified in the initial stock.

4.3 /// SUBSTRATE PREPARATION

Before implementing the ORRAP method, a site visit and a survey of the condition of the support layer are recommended (see Controls part). It is important to undertake any necessary preparatory work. Depending on the state and the kind of materials of the existing pavement, it can be necessary to treat cracks and/or to apply a sealing layer (sealing coat on granular material, bonding coat or single-layer single-gravel coating).

In some cases milling or grinding of the existing pavement can be necessary to reduce its thickness and to achieve the surface roughness to insure good interlocking. In addition, a bond coat is recommended.

The ORRAP method on the Swiss and French sites was applied on stiff layer. Even though it has not been evaluated on this project, an application on an unbound layer could be done.

Figure 2 / ORRAP Switzerland & France - Substrate primer/single-layer coating
Source Cerema

4.4 /// APPLICATION

Before application, the presence and proper functioning of all the implementation equipment and the guidance methods of the application equipment shall be examined.

The application of the ORRAP materials can be carried out with a grader or paver.

Although the ORRAP layer can be applied at ambient temperature levels, the minimum temperature should not fall below 15°C. Overall, the application during warm season is preferable. It is recommended to not apply ORRAP materials during heavy rain.

Figure 3 / ORRAP Switzerland & France - Paving with paver/grader
Source Empa & Cerema

The recommended minimum thickness of the ORRAP method is not less than:
– 3 times U, with U being the largest dimension of the reclaimed asphalt aggregate;

OR

– 5 times D, with D being the largest dimension of the de-coated aggregate.

The maximum recommended thickness is 15 cm at one time. At the moment, it is not recommended to apply a total thickness of more than 25 cm (this thickness was not evaluated in the project and increases the risk of rutting).

During the application, a sufficient level of moisture must be maintained for the ORRAP materials (based on Modified Proctor Optimum test - MPO) in order to facilitate the compaction of the material. Typically, a water content W(MPO) + 2/- 1% can be adopted. In any case, it is important to have a sufficient compactness of the applied material (average density on site ≥ 97% of the density at the MPO).

The characterization of ORRAP materials shows a low sensitivity of the optimal density with the water content on the optimal density. Therefore, humidification in the plant is not necessary and on site watering can be applied. Thus, a specific device for watering the material must be used before and after spreading as well as before compaction. This can be done by using spray watering devices mounted on the paver or on a water tank.

Figure 4 / ORRAP Switzerland & France - Spray watering. Source Cerema

Compaction can be achieved by the use of pneumatic tire rollers and steel rollers that ensure material kneading, densification and a smooth and even surface appearance.

When using vibration on steel compactors, it is advisable to avoid the use of excessively heavy steel rollers in order to avoid cracking. Depending on the moisture level of the material, the vibration of the steel roller compactors can generate cracks that must be closed with the pneumatic compactor. If cracking persists after adding moisture to the material, it is advisable to stop the vibration and to increase the action of the tire rollers. In case of doubt, a test section should be made on the first 100 meters of the work site in order to adjust the level of compaction.

Figure 5 / ORRAP Switzerland - Vibration that can generate cracks. Source Cerema

The compaction of pavement edges (particularly outside urban areas) is more difficult than with hot mix and UGM. Therefore, it is recommended that the ORRAP layer should be applied over a greater width than the traffic lane in order to avoid having traffic on the edges (approximately 30 to 50 cm extra width). If necessary, stabilization of the shoulder with a conventional UGM may be considered before the implementation of the ORRAP layer.

Figure 6 / ORRAP Switzerland & France - Difficult compaction on pavement edges
Source Cerema

Generally, the required compacting effort (number of roller passes) is close to the use of unbound material (UGM) and approximately double the amount needed as for hot mix asphalt. Higher temperatures improve the compaction of the ORRAP material and help to reduce the number of passes.

Figure 7 / ORRAP Switzerland & France - Compaction. Source Cerema

After application of the ORRAP product, the section can only be left without surface layer for a few days with suitable traffic precautions (speed limit, user warning…).

The ORRAP method cannot be used as a surface layer because the asphalt aggregates do not meet the requirements of a surface layer (quality of aggregates, microtexture, macrotexture) and because of the risk of aggregate loss and raveling.

Therefore, the application of an asphalt concrete surface layer or a sealer the day after the application of the ORRAP materials is recommended.

In any case, it is recommended to monitor ORRAP sections during the first 3 months in order to evaluate rutting (linked to post-compaction of the material). If rutting appears, the sealer has to be covered with an asphalt concrete layer.

Figure 8 / ORRAP France - Surface dressing for finishing. Source Cerema

4.5 /// MATERIAL CHARACTERISTICS AND PRODUCT DATA SHEETS (PDS)

4.5.1 // COMPONENT: ASPHALT AGGREGATE

On the technical aspect, the use of asphalt aggregates in an ORRAP method implies the determination of certain characteristics and the provision of a product data sheet. The latter includes, at a minimum, the following elements:

- asphalt aggregate category U AE 0/D (EN 13108-8);
- sieve size curve of aggregates without binder (EN 12697-2), minimum and maximum values on the basis of one test / 2,000 tonnes - 3 analyses per stockpile minimum;
- RAP binder content (EN 12697-1), minimum and maximum values on the basis of one test / 2,000 tonnes - 3 analyses per stockpile minimum;
- determination of needle penetration (EN 1426) and ring & ball temperature (EN 1427), minimum and maximum values on the basis of one test / 2,000 tons - 2 analyses per stockpile minimum;
- determination of the Real Density of Mixtures (EN 12697-5) on the basis of 1 test per stock.

4.5.2 // PRODUCT: ORRAP METHOD

On the technical aspect, the use of asphalt aggregates in an ORRAP method implies the determination of certain characteristics and the provision of a product data sheet. The latter includes, at a minimum, the following elements:

- determination of the MPO (Proctor density) curve (EN 13286-2) and the optimum water content on the basis of 1 test per stockpile;
- determination of the immediate bearing index (EN 13287-47) on the basis of one test per stockpile.

The repeated load triaxial test[6, 7, 8] has to be performed to optimize the structure if a reduction of the thickness of the layer is wanted.

In case of doubt about the rutting behavior of the product at an early stage, a rutting test can be performed[9, 10]. This can be done with the standard test (EN 12697-22) or on a slab using MMLS3[11,].

5. QUALITY CONTROL

The company shall specify in its quality assurance plan, the means made available for carrying out the project and the control procedures that will be implemented for its acceptance.

5.1 /// SUBSTRATE PREPARATION

In case of doubt, the quality of the support must be checked mechanically beforehand (load-bearing acceptance).

5.2 /// CONTROLS ON SITE

Compaction checks should be done during application to ensure proper densification of the material used. In this case, a dual source gamma-densimeter is preferred (Cesium 137 - Americium 241/ Beryllium 9), as it also gives information on the water content of the product. Current measuring devices by electrical transmission cannot be used for this technique because of its high water content.

It is important to monitor the prevailing temperature during the application and eventually the temperature of materials during compaction.

The thickness of the layer can also be checked during the application with a depth gauge.

5.3 /// LABORATORY CONTROLS

It is recommended to take samples to determine the water content in a laboratory, if e.g. there is no compaction test made during application.

Furthermore, laboratory tests should be carried out to ensure the consistency of the elements between the product applied and the technical data sheet proposed beforehand, such as binder content and granulometry of the sampled materials. The results are compared with the data sheet provided.

5.4 /// CONTROLS AFTER APPLICATION

In case of rutting (checked visually), some tests have to be performed in order to quantify the rut depth. If the rut depth exceeds 10 mm (average) or 15 mm (maximum value) between 3 and 6 months, it is recommended to apply an asphalt concrete, possibly after a reprofiling by milling in case of already existing asphalt concrete.

Further tests are to be planned in order to check the stability of the material. In particular, deflection tests can be done at an "early stage" (after the application of the surface course) and after at least 3 months in order to compare the results and to evaluate the increase of the stability of materials.

At this moment, it is not possible to set any requirements for the longitudinal evenness but it is recommended to control this characteristic. A good evenness is difficult to achieve with the ORRAP layer with a sealer alone. If necessary, it can be improved with an asphalt concrete surface layer a few months later.

6. SUMMARY

Detailed results can be found in[12].

6.1 /// RECOMMENDATIONS

- The ORRAP method is only for base layers and is recommended for low traffic levels **(see Table 1)**. Its use for pavements on roads with higher traffic volumes is not recommended since it has not been evaluated;
- As compaction difficulties may occur (due to the negative effects associated with lower temperatures on both the compactability and the curing of the production as well as on the surface dressing used), the application of the ORRAP layer in the cold seasons is not recommended (high risk of failure);
- The preparation of the asphalt aggregate must make it possible to avoid chunks, which may complicate the application with the paver or contribute to defects appearing in the applied layer;
- The application is limited to 15 cm per layer; a total thickness less than 25 cm is recommended;
- To limit cracking, it is advisable to avoid the use of excessively heavy steel rollers;
- The ORRAP layer requires a high compaction effort, comparable to that with unbound material (UGM), but approximatively twice the amount as for hot mix asphalt;
- Since the compaction of pavement edges is difficult, it is recommended that the ORRAP layer should be applied over a greater width than the traffic lane in order to avoid having traffic on the edges (approximately 30 to 50 cm extra width). If necessary, stabilization of the shoulder may be considered;
- The ORRAP method has to be covered by a surface layer (sealer or asphalt concrete);
- A good evenness is difficult to achieve with the ORRAP layer with a sealer alone;
- The ORRAP method requires observation during the first months (potential rutting development).

6.2 /// COMPARISON WITH OTHER TECHNIQUES

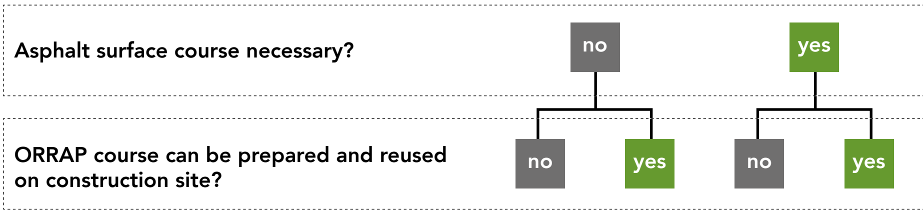
The summary table below presents the main differences between the ORRAP method and a traditional UGM made of natural aggregates on one hand, and an asphalt hot mix on the other hand.

Table 4 / Technical comparison of the ORRAP method with an UGM and a hot mix

	ORRAP compared to UGM	ORRAP compared to hot mix
Mechanical performance	= / + (early stage) / / (long term)	-
Ease of fabrication	= / + (UGM of quarry) / (UGM plant)	+ (no plant)
Ease of storage	- (formation of chunks)	+ (cold material)
Ease of implementation	- (difficulties of compaction)	- (difficulties of compaction)
Ease of characterization	- (binder content)	+ (less test requirements)
Recyclability	=	- (potential presence of PAH)
Behavior at an early stage	- / = (rutting risk)	- (rutting risk)
Long-term behavior	+	- (stiffness)

Key:
+: better
=: equal
-: worse

The primary energy demand and the global warming potential of the ORRAP method are often lower and the use of primary construction material can be reduced. These benefits depend on the kind of construction and the lifetime of the ORRAP method. A reduction of construction costs is possible, but does not constitute the main reason for using the ORRAP method **(see Figure 9, Figure 10)**.



	no / no	no / yes	yes / no	yes / yes
Assessment of primary energy demand*	+	++	+	++
Assessment of primary construction materials	+++	+++	+++	+++
Assessment of construction costs	+	++	+	++
Assessment of time required by users due to shorter blocking times of the route	0	0	0	0

*Primary energy demand directly attributable to the construction measure, without taking into account the additional fuel consumption due to diversion traffic resulting from the construction measures.

Figure 9 / Sustainability comparison of the ORRAP method with an UGM with natural aggregates

Asphalt surface course necessary?	no				yes			
Reduced lifetime of the ORRAP course compared to a conventional asphalt basecourse?	no		yes		no		yes	
ORRAP course can be prepared and reused on construction site?	yes	no	yes	no	yes	no	yes	no
Assessment of primary energy demand*	+++	+++	++	++	+	+	0	0
Assessment of primary construction materials	+++	+++	++	++	0	0	-	-
Assessment of construction costs	+++	+++	++	+	+	0	-	-
Assessment of time required by users due to shorter blocking times of the route	+++	+++	+	+	0	0	-	-

*Primary energy demand directly attributable to the construction measure, without taking into account the additional fuel consumption due to diversion traffic resulting from the construction measures.

Figure 10 / Sustainability comparison of the ORRAP method with a use of pavement with asphalt concrete hot mix

7. ACKNOWLEDGEMENTS

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ORRAP started in November 2016 and was scheduled to end in October 2019. Due to the requirements of the ongoing experimentation and the impacts of the covid-19 health crisis, its duration has been extended until December 2020.

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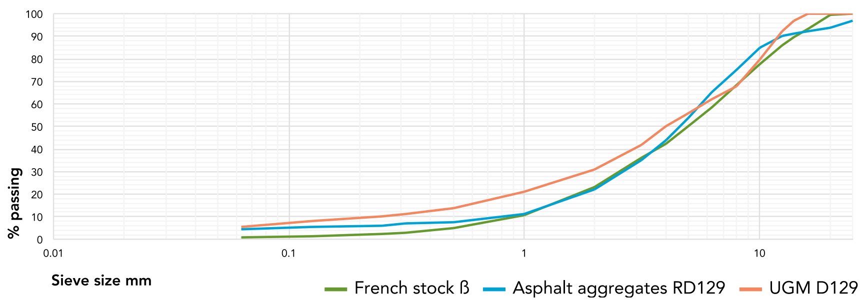
ANNEX 1. EXPERIMENTAL TEST SITES

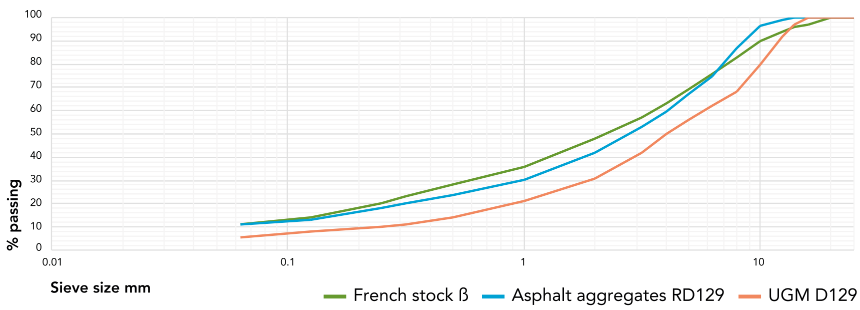
TRACKING TABLE – FRENCH IN SITU TEST SITE

Solutions	GNT 15 cm (basic solution)	ORRAP 12 cm	ORRAP 15 cm
Location	Sermersheim, Bas-Rhin (67), RD 129, France		
Number of trucks/days	70		
Section Length	200 m	200 m	200 m
Lane width	4.50 m		
Existing structure	60 to 100 mm SCAC on stabilized soil (6 cores)		
Rehabilitatiom	UGM 15 cm (reference)	ORRAP 12 cm	ORRAP 15 cm
Surface course	Surface dressing semi coarse aggregates MSG 6.3/10		
Additional work	5.5 m lane widening with UGM		
Amount of PAC of stockpile (16 PAC)	Not applicable	103 Mg/kg of M.S.	
Dry AVM at MPO	2.197 Mg/m³	1.956 Mg/m³	
Water content (Optimal Proctor)	7.2%	7.2%	
Dry AVM on site (gamma densimeter with retrodiffusion)	2.089 Mg/m³	1.883 Mg/m³	1.837 Mg/m³
Water content on site	7.0%	9.2%	

Asphalt aggregate (AA) distribution*



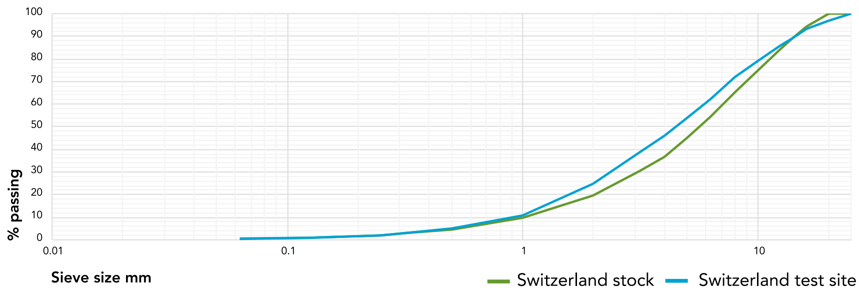
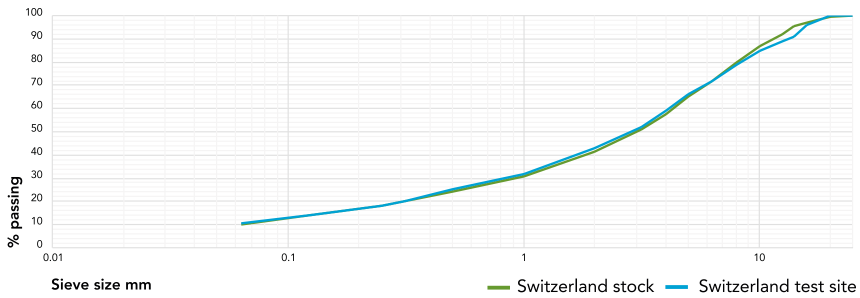
Aggregate (of AA) distribution*



Binder content	Not applicable	5.27%	
Characteristic modulus	222 MPA**	425 MPA	
Deflection value after construction	70 1/100e mm	81 1/100e mm	77 1/100e mm
Deflection value after 1 year	53 1/100e mm	70 1/100e mm	68 1/100e mm

*Stock Bêta: Asphalt aggregates studied in the laboratory in the framework of the ORRAP project.
**Determined on UGM reconstituted in the laboratory.

TRACKING TABLE – SWITZERLAND IN SITU TEST SITE

Solutions	**ORRAP 10 cm**
Location	Wahlen, Canton Basel-Landschaft, Suisse
Length of section	380 m
Lane width	5.5 m
Existing structure	200 mm of Asphalt Concrete 200 mm of SCAC
Milling	ORRAP 10 cm
Wearing course	4 cm Asphalt Concrete
Additonnal work	6 meter line widening with Asphalt Concrete
Asphalt aggregate (AA) distribution*	
Aggregate (of AA) distribution*	
Binder content	4.67%
Characteristic modulus	372 MPA

*Stock Bêta: Asphalt aggregates studied in the laboratory in the framework of the ORRAP project.

ANNEX 2. SUSTAINABILITY ASSESSMENT

For the sustainability assessment, the ORRAP method is considered as a substitute for either an asphalt base course or an unbound base course. The following construction methods are thus varied **(see Table 1)**:

- ORRAP method: ORRAP course on existing pavement without (OM1, OM2) or with asphalt surface course (OM3, OM4);
- hot mix structure (conventional method): asphalt base course on unbound layer and asphalt surface course, thickness of asphalt base course: 8 cm (CM1) or 11 cm (CM2);
- unbound Granular Material: unbound granular layer on existing pavement without (UGM1, UGM2) or with asphalt surface course (UGM3, UGM4).

Since no reliable statements on the lifetime of the ORRAP method are possible at present due to the lack of long-term results, the lifetime of the ORRAP course and, if necessary, the asphalt surface course is also varied. This variation of the lifetime is also made for the comparison with the construction method with unbound granular layer. The following lifetimes are assumed:

- worst case: 10 years for an ORRAP course, without (OM1) and with asphalt surface course (OM3) and an unbound granular layer without (UGM1) and with an asphalt surface course (UGM3);
- best case: 30 years for an ORRAP course, without (OM2) and with an asphalt surface course (OM4) and an unbound granular layer without (UGM2) and with an asphalt surface course (UGM4).
  A lifetime of 15 years is assumed for an asphalt surface course, as it can be assumed that damage to the ORRAP course or UGM layer will only occur later due to the longer lifetime of the layer concerned.

The partial life cycle is defined as 30 years, whereby the calculations take into account construction work in both year 0 and year 30.

Table 5 / Examined structures for assessment

	ORRAP method (OM)				Conventional method (CM)				Unbound Granular Material (UGM)			
	OM1	OM2	OM3	OM4	CM1		CM2		UGM1	UGM2	UGM3	UGM4
Layer thickness / Lifetime assumption in years		12 cm xx cm		4 cm 12 cm xx cm		4 cm 8 cm xx cm		4 cm 11 cm xx cm		12 cm xx cm		4 cm 12 cm xx cm
Asphalt surface course	-	-	10 a	15 a	15 a		15 a		-	-	10 a	15 a
ORRAP course	10 a	30 a	10 a	30 a	-		-		-	-	-	-
Asphalt base course	-		-	-	30 a		30 a		-	-	-	-
Unbound granular layer	-	-	-	-	-		-		10 a	30 a	10 a	30 a
Existing pavement												
Unbound layers												
Sealer												
Bitumen emulsion												

The system boundaries, as a basis for evaluating the various structures, comprise the following modules:

- raw material extraction;
- transports;
- mixture production;
- work on the construction site.

All results in the following figures are determined per m² of road surface, but values of typical lot sizes for maintenance measures are used as a basis for the calculation.

The calculation methodology and input variables are documented in detail in the research report of the ORRAP project.

/// ENVIRONMENTAL APPROACH

// PRIMARY ENERGY DEMAND

When determining the primary energy demand, 3 assessments are made.

Figure 11: comparison of the primary energy demand only for the maintenance measures with preparation of the ORRAP material in a mixing plant:

- the essential process for primary energy demand is the production of hot asphalt mix (see CM1 and CM2). For the OM3 and OM4 and UGM3 and UGM4 variants, asphalt mix is required for the surface course;
- the primary energy demand for the extraction of mineral aggregates and binder is very low for the ORRAP course (see OM1 and OM2). OM3 and OM4 require mineral aggregate and binder for the asphalt surface course, for which the primary energy demand is like CM1 and CM2;
- a primary energy saving of more than 75% can be achieved despite the reduced lifetime for OM1 (10 a) compared to CM1. With a longer lifetime (OM2), the primary energy demand can even be significantly reduced again;
- the reason for the primary energy difference of factor 3 between OM1 and OM3 is to be found in the asphalt surface course to be renewed every 10 years. The increased primary energy demand of, for example, UGM 1 compared to OM1 is due to the extraction of the raw materials.

Figure 12: comparison of the primary energy demand for the maintenance measures with processing of the ORRAP material in a mixing plant and an additional consideration of the primary energy demand of the diverted traffic (diversion length: 10 km, 2 days blocking for each base course or surface course renewal; 4 days blocking for base course and surface course renewal; 400 cars and 40 trucks per day):

- the additional primary energy demand must be taken into account in all construction methods; however, it is generally lower than the primary energy demand for the production or transport of materials;

– the primary energy demand can be particularly significant in the case of short renewal cycles and asphalt surfacing (see OM3 and UGM3). If no asphalt surface course is required and a lifetime of 30 years is achieved with the ORRAP method, its influence is significantly lower.

Figure 13: comparison of the primary energy demand for the maintenance measures and an additional consideration of the primary energy demand of the diverted traffic with the further assumption that the material for the ORRAP method only needs to be delivered to the construction site before the first installation. With each renewal, the existing ORRAP course is removed, reprocessed on site and reinstalled, thus avoiding material transport:

– this assumption gives ORRAP structures a higher advantage over hot mix structures in terms of primary energy demand because the transports are the main source of primary energy demand for the construction of the ORRAP course;
– the difference of primary energy for ORRAP structures compared with unbound granular layer increases due to the reduced ORRAP material transport.

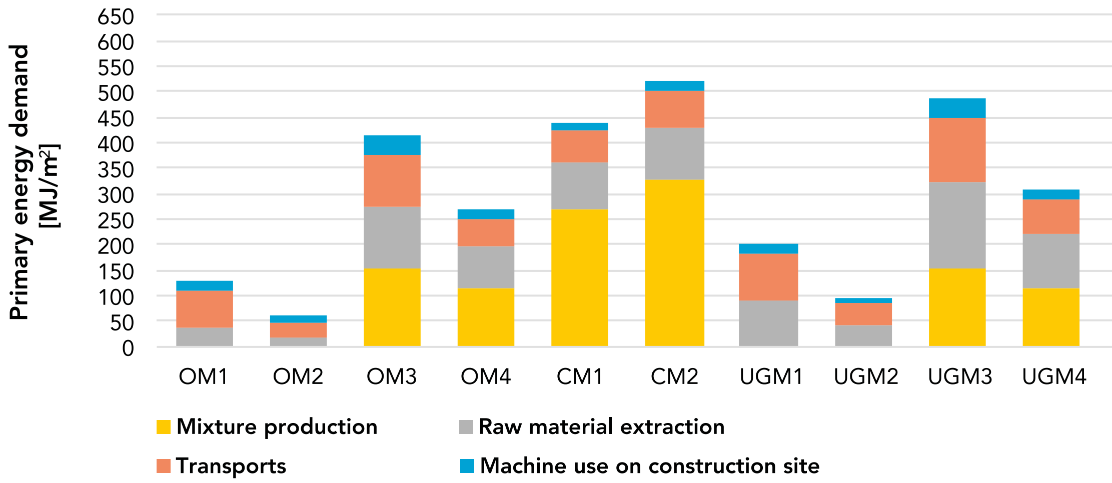


Figure 11 / Primary energy demand for the construction of the structures defined in Table 5

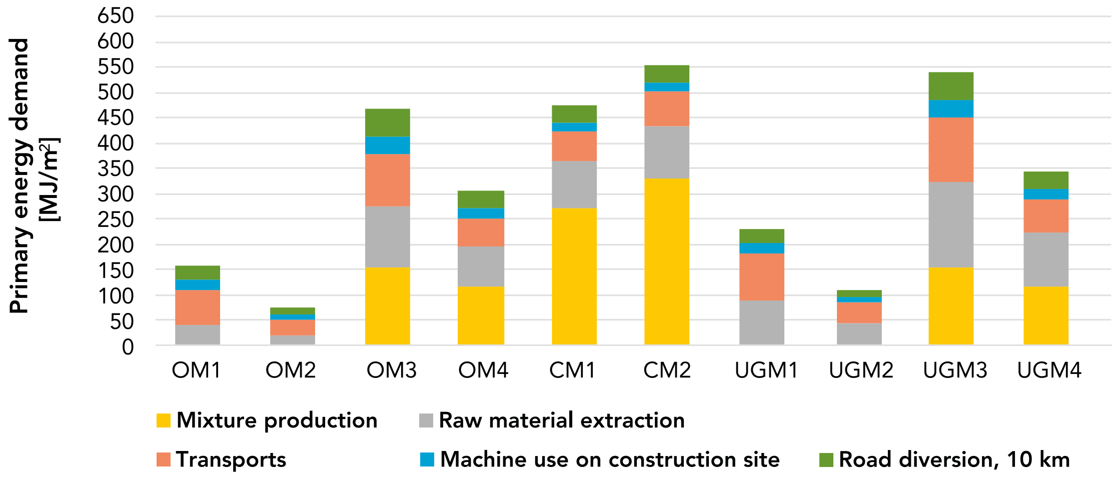


Figure 12 / Primary energy demand for the construction of the structures defined in Table 5 and the primary energy demand of the diversion traffic during the roadworks

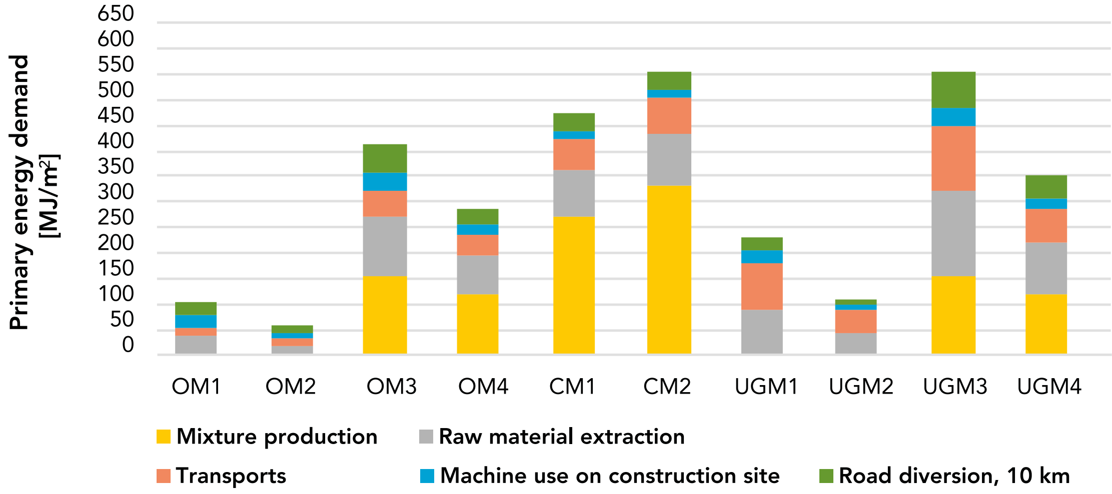


Figure 13 / Primary energy demand for the construction of the structures defined in Table 5 and the primary energy demand of the diverted traffic during the roadworks, without transport of the ORRAP material during the renewal measures

// USE OF NATURAL RESOURCES

Figure 14 shows for each scenario both the amount of materials installed and removed. A distinction is made between primary and secondary construction materials. Primary construction materials are usually natural resources that are used untreated apart from their extraction. In the present study, primary construction materials are understood to be bitumen and mineral rock first used. Secondary materials, on the other hand, are reused materials, in this study the recycled asphalt pavement (RAP) aggregates. The reuse of RAP saves natural resources and reduces the growth of stockpiles. Based on the assumption that primary construction materials are always used to construct the UGM layers, the following conclusions can be drawn:

– the decisive factor for a positive assessment is a low demand for primary construction materials. In this context, all ORRAP scenarios

are consistently positive, compared to the UGM scenarios.
OM1, OM2 and OM4 are also positive compared to CM1 and CM2 due to the lower demand for primary construction materials;

- due to the asphalt surface course in combination with the reduced lifetime, more primary construction materials are required for OM3 than for CM1 and CM2, and the advantage of the high secondary construction material demand of OM3 loses weight;
- the use of RAP is higher with the ORRAP method than with the reference hot mix structure. However, this only leads to a reduction of existing stockpiles of RAP when the ORRAP layer is produced for the first time, as the necessary material can be removed when the ORRAP layer is renewed. Since no recycling material is used for the UGM layer, the use of reclaimed asphalt in the ORRAP method is positive compared to the construction method with an UGM layer.

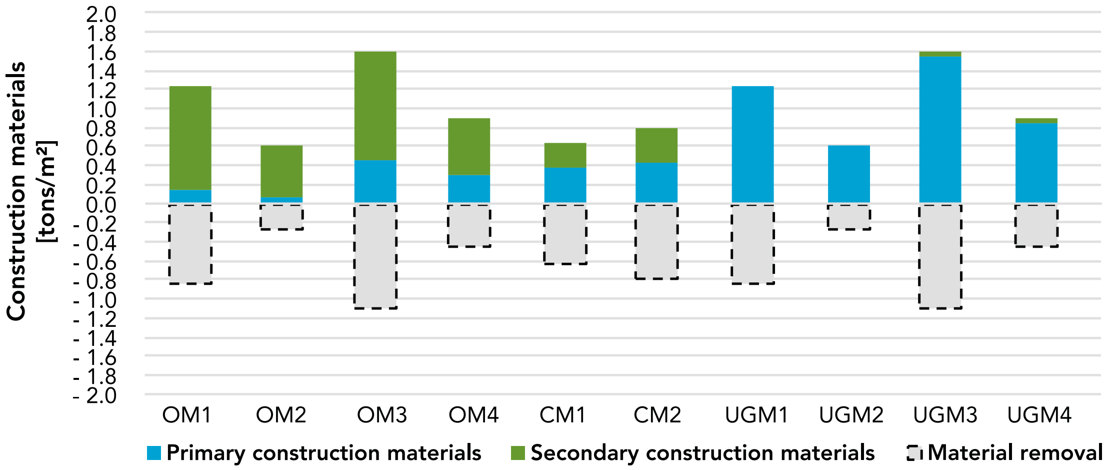


Figure 14 / Quantities of material to be paved and removed for the construction of the structures defined in Table 5

/// ECONOMIC APPROACH

The following figures compare the construction costs, calculated using the capital value method, over a period of 30 years, based on German unit prices. All future maintenance measure costs were adjusted to 2019 on the assumption of a discount rate of 3% per year. User costs and third-party costs attributable to the measures are not included. When determining the costs, 2 assessments are made:

Figure 15: comparison of the costs with preparation of the ORRAP material in a mixing plant:

- main costs are attributable to the construction materials. The additional material costs between e.g. OM1 and OM3 are to be allocated to the asphalt surface course;
- compared to the UGM structures, the ORRAP structures have only minor financial advantages;
- the lowest total costs can be achieved with OM2. This is partly due to the elimination of the asphalt surface course and partly to the long lifetime of 30 years. Compared to CM1 and CM2, significant cost savings can be achieved with OM2;

– the short lifetime of 10 years and the existence of an asphalt surface course lead to a significant cost increase for OM3 compared to CM1 and CM2.

Figure 16: comparison of the cost with the assumption that the material for the ORRAP method only needs to be delivered to the construction site before the first installation and can be reused on site when the ORRAP course is renewed, thus reducing the transports of material:

– the reduction of ORRAP material transports results in a reduction of costs, especially for OM1 and OM3. This is due to the frequent replacements resulting from the low lifetimes;
– the difference of costs for ORRAP structures compared with unbound granular layer increases due to the reduced ORRAP material transport, especially for OM1 und OM3.

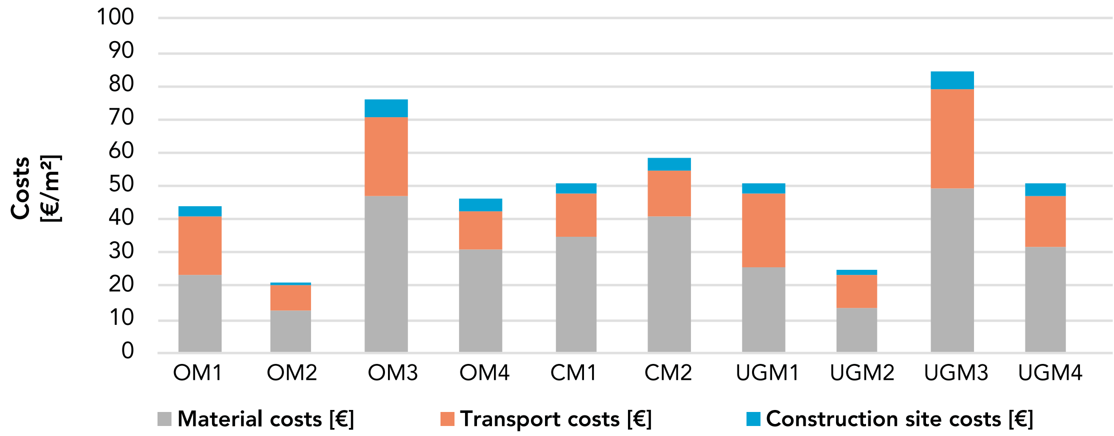


Figure 15 / Costs for the construction of the structures defined in Table 5; based on German unit prices

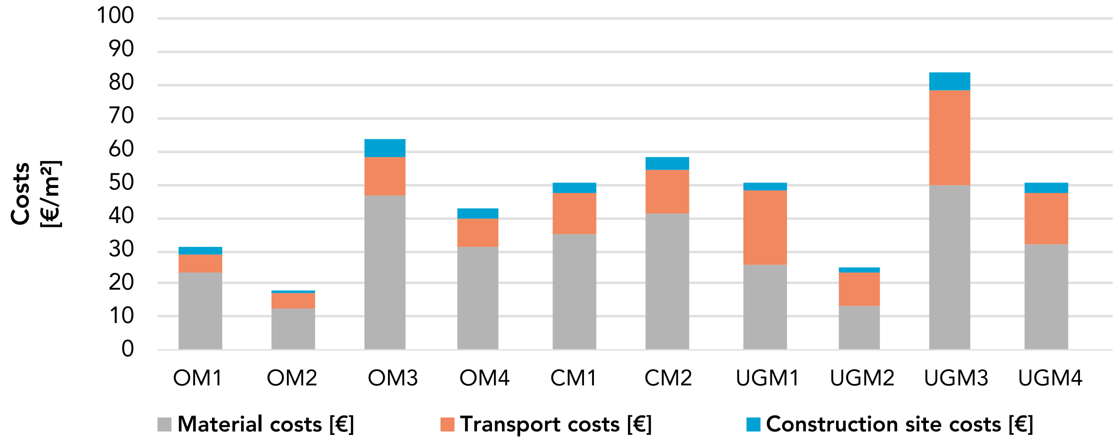


Figure 16 / Costs for the construction of the structures defined in Table 5, without transport of the ORRAP material during the renewal measures; based on German unit prices

// SWISS ENVIRONMENTAL ASSESSMENT

The Swiss study was based on:
- Swiss experience of road layer composition;
- Swiss inventory of national roads in Ecoinvent;
- the current plan for layers for the Swiss ORRAP test and reference route when the environmental assessment was done in the summer of 2018;
- energy data from the Swiss PLANET research project.

The Swiss ORRAP scenario is thus similar to the German OM4-CM1 scenario **(Table 6)**. The Swiss scenario, unlike the German scenario, reduces the thickness of the subbase layer, to take into account the added bearing capacity of the ORRAP layer.

Table 6 / Examined structures for Swiss assessment

	Switzerland		Germany	
	ORRAP	**Reference**	**OM4**	**CM1**
Layers considered (cm)	Surface course 4, ORRAP course 10, subbase 35	Surface course 4, base course 6, subbase 45	Surface course 4, ORRAP course 12, NO subbase considered	Surface course 4, base course 8, NO subbase considered
Life cycle (years)	SC 15, BC 40, SB 100	SC 15, BC 40, SB 100	SC 15, BC 30	SC 15, BC 30

The environmental influences were weighed using the aggregation method environmental scarcity which is based on Swiss environmental policy. In addition, greenhouse gas emissions were calculated as a comparison with Germany.

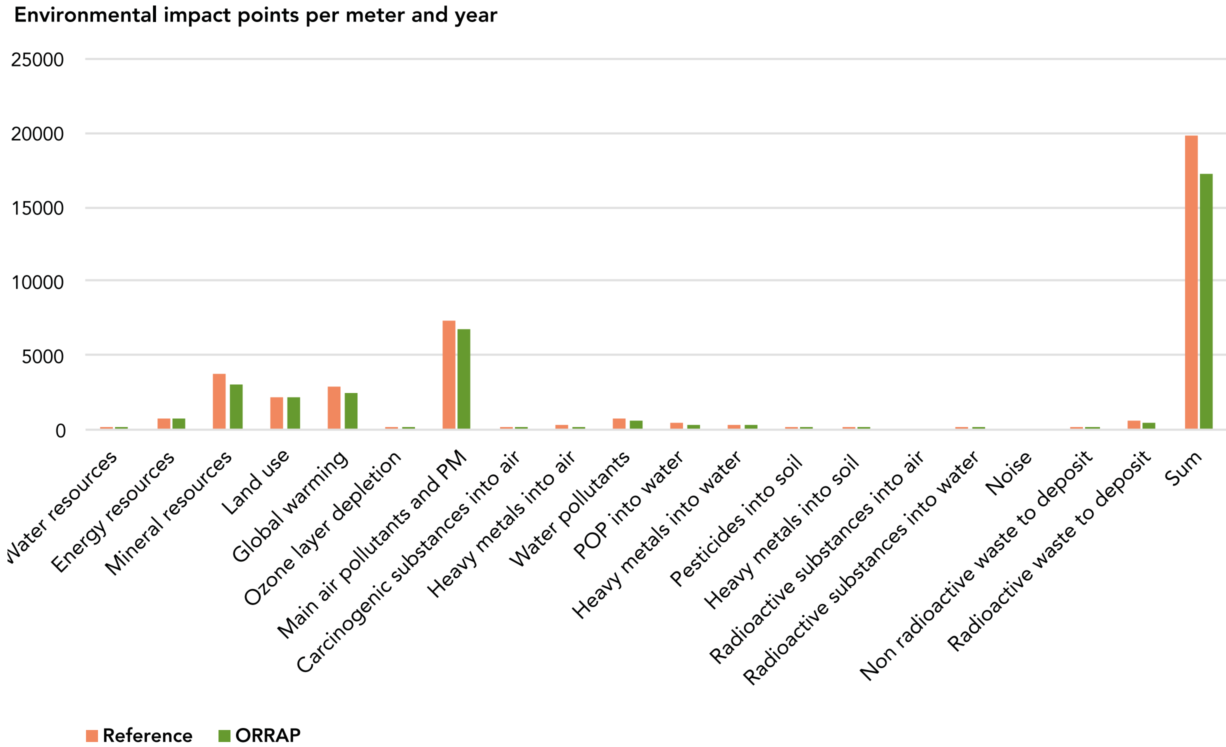


Figure 17 / Comparison of the Environmental Scarcity of ORRAP and a reference method

The environmental scarcity of ORRAP is 2500 points lower than the reference, i.e. about 12%. The global warming potential of ORRAP is 17% lower than the reference. This can be compared to the difference in primary energy between the German OM4 and CM2 which is about 45% (Figure 12).

The inventory and calculation can influence not only relative results between ORRAP and reference scenarios, but also absolute results. Absolute results of global warming potential for 3 cm surface course, 5 cm base course and 45 cm subbase show large differences between the results of FHNW and HsKa (factor 2.4). The difference between the results on the surface course from HsKa and the Swiss PLANET project is much smaller (factor 1.2).

// SWISS COST ASSESSMENT

The average cost for the layers in the ORRAP and the reference structure was provided by the Canton of Aargau. Under assumption of the above life cycle, the cost for the ORRAP setup is predicted to be slightly higher (up to 20%) due to the higher thickness and thus higher cost for the ORRAP base course compared to a regular base course. This cannot be compensated for by reducing the subbase thickness, since the subbase has a high lifetime and is less costly.

ANNEX 3. CONSULTATION

/// ELEMENTS FOR BUSINESS CONSULTATION

As a preamble, the use of the ORRAP product is subject to environmental and health acceptance. The use of such a product cannot be considered in case of presence of asbestos, too high concentration of PAHs or even hydrocarbons **(see Table 2)**.

/// ECONOMIC OPERATORS' CONSULTATION FILE (EOCF)

EOCF can favor the use of the ORRAP technique over a conventional UGM. In this case, it must apply the same technical and usage requirements as for an UGM.

The differences between the two products, mainly concerning the constituents and their characteristics, can be dealt with either specifically in the Special Technical Specification (STS) as a basic solution or in the consultation regulations with an authorized variant opening on the constituent materials of the UGM.

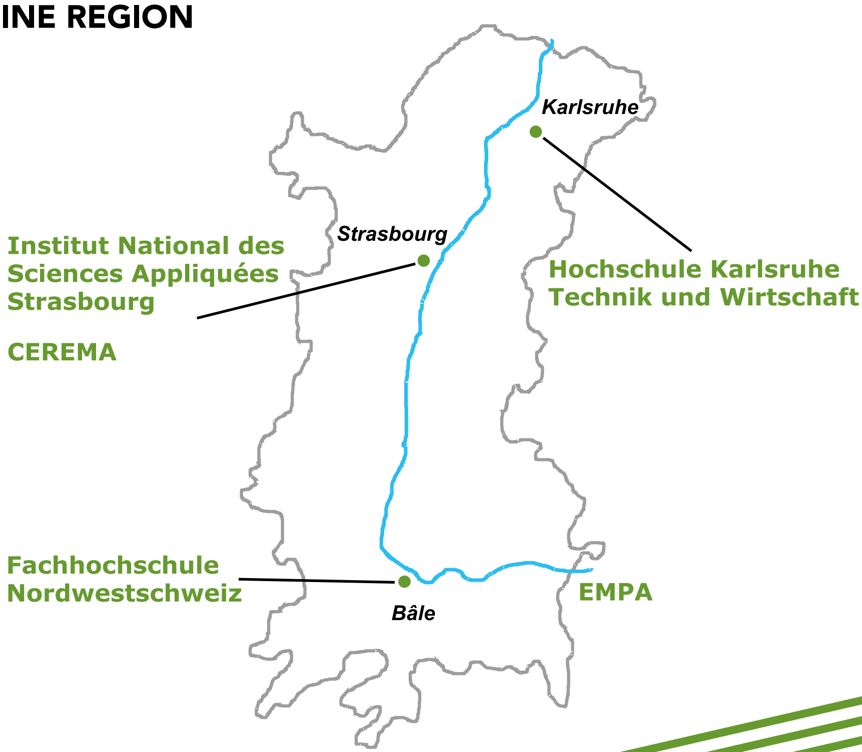
The choice of construction equipment is left to the company in charge of carrying out the work, according to its own equipment and know-how. In the context of this study, the two types of equipment (grader and paver) were assessed and did not show any difference or difficulty in their application to the task.

If necessary, the quality controls can be adapted according to the nature and the state of the construction site.

An adaptation of the Specific Administrative Clauses (SAC) may also be envisaged in order to settle possible disputes in the event of any defects observed.

It is advisable in the Estimated Detail (ED) and the Unit Price Schedule (UPS) to provide a specific price for the construction of the top/road surface made from an asphalt mix. This line, which is optional if the material on site does not change, makes it possible to dispense with any new prices in the event of a change.

THE UPPER RHINE REGION



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