Project Report

Life cycle analysis of representative French hot-mix asphalt concrete and asphalt pavement

Confidential document

January 2016 – Audited version by an independent third-party

Partners:

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Table of Contents

List of abbreviations

- LCA: Life Cycle Analysis
- AIMCC: French Construction Products Industry Association
- AC: Asphalt Concrete
- CPW: Construction and Public Works
- CML: Centre of Environmental Science University of Leiden – Netherlands
- EPD: Environmental Product Declaration
- EI: EcoInvent
- EME2: High-Modulus Asphalt 2
- FDES: Environmental and Health Product Declaration
- EF: emission factor
- HFO: Heavy fuel oil
- GB3: Gravel Bitumen 3
- NG: Natural gas
- LPG: Liquefied Petroleum Gas
- ISO: International Organisation for Standardisation
- FU: Functional Unit
- UNPG: National Union of Aggregate Producers
- USIRF: Union of French Road Industry Associations

1 Introduction

1.1 Context

The mission of the Union of French Road Industry Associations (USIRF) is to:

- Confederate and represent road builders,
- Spearhead initiatives to defend, promote and enhance the status of this profession among economic and political players,
- Serve as a vehicle for promoting road planning and building,
- Develop within a close-knit strategy by bringing together 20 regional trade unions.

Among its fields of action, USIRF is strongly committed to environmental sustainability and views the control of environmental impacts of road-building activities as a challenge and a powerful driver of innovation.

In this context, following the publication of experimental standard XP 01-010 and subsequently of standard NF P01-010, in 2006 and later in 2012-2014, USIRF conducted a Life Cycle Analysis (LCA) of one tonne of bituminous asphalt and one square meter of road pavement. Although Standard NF EN 15 804 focuses more specifically on construction products, it nevertheless represents the most appropriate frame of reference for public works projects. By applying it, USIRF was able to provide public works stakeholders with accurate and reliable information on the environmental performance of bituminous asphalt pavements.

Nevertheless, this work has resulted in developments in various areas, including:

- Upgrade of databases used to prepare FDES declarations (data of environmental performance of raw materials and methods used during the various stages of the product life cycle),
- Updates in standards and regulations representing the frame of reference for environmental assessment of construction products (Decree and Ordinance of 23 December 2013, standards NF EN 15804+A1 and XP P01-064 CN published in April 2014).

It is for these reasons that USIRF sought to update the LCA and FDES work carried out in the 2012 and 2014 period. It should be noted, however, that since production processes have evolved very little over the last years, it is considered that the activity data have not changed.

This study was performed by BIO by Deloitte, a consultancy firm with expertise in Life Cycle Analysis.

1.2 Objectives

Within this context, the objective of this study is to quantify the environmental impacts of representative French bituminous asphalt (mainland France) and of pavement based on it using the LCA method.

Consequently, two systems have been examined in this study:

- The "Asphalt Production System" from the extraction of raw materials to the output of the asphalt plant,
- The "Pavement Life Cycle System" from the extraction of raw materials to the end of life of the pavement.

In particular, the results of this study are intended to be used as basis for publication of a cradle-to-gate Environmental Product Declaration (EPD) and an Environmental and Health Product Declaration (FDES) relating to these two systems, respectively, prepared in compliance with the requirements of Standard NF EN 15804+A1 and its supplement XP P01-064/CN. Similarly to the FDES published in 2014, these new documents:

- Are collective declarations, i.e., they are representative for the products manufactured by members of the Union of French Road Industry Associations,
- Their objective is providing environmental data on bituminous asphalt to construction and public works stakeholders (project managers, contractors, etc.).

The major contemplated message of this cradle-to-gate EPD and FDES declaration is of the interprofessional B to B type, in particular targeting project owners and architects. In addition, the "Pavement Life Cycle" FDES will be published in the INIES construction products database (www.base-inies.fr).

This project report brings together all the data, assumptions and calculation methods used to compile the LCA on which the cradle-to-gate EPD and FDES declarations are based and presents the obtained results. In particular, it aims to support the third-party review process. It will be provided to the reviewer and any other stakeholders that may request it, in compliance with the confidentiality requirements specified in ISO 14025.

1.3 Study preparation context

This study is based on the same data as the LCA performed between 2012 and 2014 (activity data collected in 2012). This is justified by the fact that the production and application processes of bituminous asphalt have changed very little over the last four years.

In addition, the earlier study concerned two pavement scenarios defined by USIRF to assess the impact of potential variations in terms of road design and maintenance. These two scenarios related to types of pavement used on departmental and local roads, but were different in terms of the initial application structure and maintenance performed during their lifespan.

In contrast, this study examines a single typical pavement scenario. This is Scenario 2, as described in the previous study. This scenario is based on standard structure TC4 PF3 - 30 years listed in the October 1998 issue of the SETRA structures catalogue. According to USIRF, this scenario is more representative than the other scenario (Scenario 1), since it is prepared based on a standard initial structure from a catalogue used by public works contractors. Furthermore, only this Scenario 2 was the subject of a FDES in 2014. It was therefore decided to restart with the same scenario.

Finally, an additional EPD was prepared for hot-mix bituminous asphalt based on this study. Two types of hot-bituminous mixtures have been examined: asphalt concrete and gravel bitumen 3. In fact, asphalt concrete is used more often that gravel bitumen 3 for placement and maintenance of the wearing course. It was therefore decided to produce a single EPD for the production of asphalt concrete.

The following table sums up the various LCA studies prepared by USIRF since 2006.

Table 1 - Review of LCA Studies conducted by USIRF

LCA	Year(s)	External LCA expert	Studied System(s)	Compliance with standards	Published FDES	Other information
LCA of bituminous asphalts, Inventory analysis report of the transport, application, service life and end of life stages of hot-mix asphalts	2002 - 2006	Henri Lecouls	"Asphalt Production" and "Pavement Life Cycle" systems	Standard XP 01-010, later NF P 01-010	FDES project[1]	Collection of production data from manufacturing companies for the years 2001-2002 Covered indicators: total primary energy, climate change and air acidification
Life cycle analysis of average French hot-mix bituminous asphalt and bituminous asphalt pavement	2012 - 2014	BIO Intelligence Service	"Asphalt Production" and and "Pavement Life Cycle"	Standard NF P 01-010	"Pavement" system FDES	Collection of production data from manufacturing companies for the year 2011 Use of EI 2.2

[1] Unofficial, as the standard has temporarily excluded pavement materials. In contrast, the "Revue Générale des routes et aérodromes" (General Review of Roads and Airfields) no. 865 of March 2008 published an article and corrigendum in no. 872 on "Environmental characteristics of road materials - Life cycle analysis of bituminous mixtures: Inventory of the manufacturing, transport, application, service life and end of life of hot-mix asphalts. Toward an amendment of Standard P01-010 on Road Materials".

LCA	Year(s)	External LCA expert	Studied System(s)	Compliance with standards	Published FDES	Other information
Update of the life cycle analysis of average French hot-mix bituminous asphalt and bituminous asphalt pavement	2015	BIO by Deloitte	Identical to the previous study	Standard NF EN 15804+A1 and its supplement	Cradle-to-gate EPD for the “Asphalt Production” system and a FDES declaration for the “Pavement” system	Retrieval of activity data from the previous study. Use of EI v3.1

1.4 Compliance with standards

This study was carried out in compliance with the following international standards applicable to LCAs:

- NF EN ISO 14040 (October 2006): Environmental management – Life cycle assessment – Principles and framework,
- NF EN ISO 14044 (October 2006): Environmental management – Life cycle assessment – Requirements and guidelines, within the ISO 14040 life cycle assessment series,

In addition, given its objective, this study has also been prepared in compliance with the following FDES-related standards:

- NF EN 15804+A1 (April 2014): Contribution of construction work to sustainable development – Environmental Product Declarations – Rules governing the categories of construction products,
- XP P01-064/CN (April 2014): Contribution of construction work to sustainable development – Environmental Product Declarations – Rules governing the categories of construction products – National supplement to NF EN 15804+A1.

However, it should be noted that the complete rework of the Project Report of the previous study and restructuring it to meet the provisions of Chapter 8.2 of standard NF EN 15804+A1 is not contemplated as part of this update. Nonetheless, the requirements and recommendations of Standard NF EN 15804+A1 regarding the elements that must be integrated into the Project Report have been followed. References to the correlations between the data provided in this report and the structure of the Project Report defined in the standard are presented in Chapter 1.8.

Finally, we shall note that the FDES declarations published based on this study are compliant with Standard NF EN ISO 14025 (October 2006): Environmental labels and declarations – Type III environmental declarations – Principles and procedures.

1.5 Companies whose products are covered by FDES

As mentioned earlier, the EPD of asphalt production and the FDES of bituminous asphalt are both representative collective declarations of products and technologies used by USIRF members.

The companies whose products are covered by the FDES are road companies that are members of USIRF and/or one of the 20 Regional Professional Unions of the Road Industry (SPRIR)[2].

It should be recalled that the hot-mix bituminous mixtures modelled in this study are generic mixtures. Nevertheless, they reflect 90% of the national production of asphalt. They correspond to two “extreme” asphalt recipes that are primarily differentiated according to their respective bitumen content.

Likewise, the pavement modelled here is representative of the range of pavements used on worksites.

In this regard, these products are marketed among professionals (B-to-B). As such, determining a framework of validity for these products is not required by the regulations.

[2] See: http://www.usirf.com/usirf/organisation/organisation-20-sprir/

1.6 Steering Committee

This study was supervised by a steering committee coordinated by USIRF and consisting of representatives of different road industry companies, namely:

- François Verhée, USIRF;
- Christine Leroy, USIRF;
- Ismaïl Cavagnol, Mastic Asphalt Association, USIRF;
- Vincent Besse, COLAS;
- Carole Burgue-Mazars, Entreprise Malet;
- Clara Lorinquer, Eurovia;
- Ludovic Perisse, Eiffage Public Works ;

1.7 Critical Review

This LCA as well as the FDES declaration prepared based on it were subjected to third-party audit performed by two experts:

- François Witte, LCA Project Manager of Quantis,
- Sébastien Lasvaux, AFNOR-accredited FDES auditor, of CSTB (Scientific and Technical Centre for Building).

The Critical Review report is enclosed in Annex 8.10.

1.8 Table of correlations with Standard NF EN 15804

The following table clarifies the correlations between the various sections of this report and Section 8.2 of Standard NF EN 15804+A1, “Elements of the Project Report in Relation with the LCA”.

Table 2 - Correlation between the various sections of the report and elements of the Project Report to be integrated according to Standard NF EN 15804+A1

Elements of the Project Report	Corresponding report section
Entity that commissioned the LCA, in-house or external LCA practitioner	1.1 Context 1.4 Compliance with standards
Report date	Cover page
Statement that the study was performed in accordance with the requirements in this standard	Title 1.4 Compliance with standards 1.7 Critical Review
Study objectives	1.2 Objectives
Scope of the study	2.1 Studied products
Declared/functional unit, as well as: i) Definition, including the relevant technical specification(s); ii) Average data calculation rules, for example for cases where the functional unit is defined for: - a group of similar products produced by different suppliers.	2.2 Functional units studied 3.1 Data sources
System boundaries in accordance with the modular approach described in Figure 1, including: i) Omission of certain required life cycle stages, processes or data; ii) Quantification of inputs and outputs of energy and materials, taking into account the way in which factory-scale data are allocated to declared products; iii) Assumptions concerning electricity generation and other relevant baseline data;	2.3.1 System boundaries 2.3.2 Life cycle stages excluded from the systems 2.6 Principles of allocation among co-products 3.1.3 Environmental data and 8.7 Annex 7: Modelling the French electric power mix (kWh)
Cut-off criteria	2.4 Cut-off rules
Life cycle inventory: 1) Qualitative and quantitative description of the elementary processes necessary to model the life cycle stages of the declared unit, taking into consideration the provisions of EN ISO 14025 on data confidentiality; 2) Generic data sources or literature sources used to conduct the LCA; 3) Validation of data; 4) Allocation principles and procedures.	3 Sources and quality of data and 5 Life cycle inventory 5 Life cycle inventory 3.2 Data quality 2.6 Principles of allocation among co-products
Life Cycle Impact Assessment (LCIA): 1) LCIA procedures, calculations and study results; 2) Relationship between the LCIA results and the LCA results; 3) Reference to all the characterisation models, characterisation factors and used methods 4) Indication stating that the LCIA results are relative expressions and do not govern final impacts per category, exceeded thresholds, security margins or risks.	6 Life Cycle Impact Assessment (LCIA) 6.2 Calculation processes 6.1 Examined environmental impact indicators 6.3 Warning

Elements of the Project Report	Corresponding report section
Interpretation of the life cycle 1) Results;	6.4 Results for production of one tonne of asphalt and 6.5 Results for provision of 1 m² of pavement
2) Assumptions and limitations related to the interpretation of results, as declared in the EPD, in connection with the methodology and the data;	4 Comments regarding the study
3) The variance in relation to the average LCIA results should be described, if the declared generic data originate from several sources or concern a range of similar products;	6.6 Uncertainties and 6.7 Variance in relation to the average results
4) Assessment of the quality of data;	3.2 Data quality
5) Total transparency in terms of the choice of values, justifications and expert evaluations.	N/A

2 General Methodology and Scope of the Study

2.1 Studied products

2.1.1 Studied types of bituminous asphalt

Bituminous asphalt is a mixture of aggregates (gravel, sand, filler, etc.) and a bituminous binder (bitumen). It is the main road-building material used in France.

Bituminous asphalts can be classified according to their manufacturing process. Thus, we can distinguish:

- Hot mixes: This type of asphalt is produced in asphalt plants at temperatures between 130°C to 180°C, depending on the type of binder. This temperature allows mixing in dried aggregates.
- Warm mixes: The manufacturing process involves the use of techniques or additives that lower the drying and heating temperature of aggregates (as compared to hot mixes).
- Cold mixes: This method involves the use of bituminous emulsion, thereby eliminating the aggregate drying and heating steps.

Hot mix asphalt represents the largest part of asphalt production in mainland France. Warm mixes, however, represent an alternative that is expected to grow significantly in the coming years. Currently, the proportion of warm mixes is small (less than 5% of total production for the 8 asphalt plants). From the outset, warm mixes have a better environmental assessment than hot mixes (lower consumption of energy during production). Therefore, warm mixes have been assimilated to hot mixes. It should be noted that this assumption is more conservative compared to the studied system

This study focuses on hot mixes only, which will be referred to as "asphalt mixes". Asphalt mixes can further be classified according to their composition (proportion of binder, aggregate particle size, etc.). Depending on their composition, different types of bituminous mixes will have different technical characteristics and can be used in different road layers: sub-base course, base course and surface course.

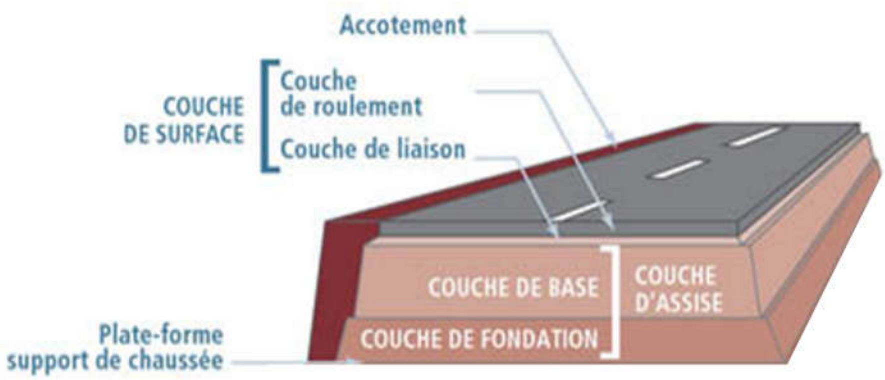


Figure 1 – Typical pavement cross-section (USIRF)

This study has examined two types of asphalt mixes having a different composition and which are used in different pavement layers:

- Asphalt Concrete (AC), which is used for the surface course, and,
- Gravel Bitumen (GB3), which is used for the base and sub-base courses.

These mixes were selected by USIRF and are representative of the types of asphalt used for road-building in mainland France.

2.1.2 Studied bituminous asphalt pavement

2.1.2.1 *Type of studied pavement*

There are many types of bituminous mix pavements and they can have very different structures.

The pavement in this study is a type of bituminous asphalt pavement used on departmental and local roads, which are the most representative roads of the French road network.

As indicated in the following tables, the running length of this network is estimated to consist of approximately 380,000 km of departmental roads and 666,000 km of local roads, accounting for approximately 98% of the length of the French road network. In terms of road traffic, this network of departmental and local roads accounts for 66% of travelled vehicle mileage.

Thus, the pavement examined in this study reflects the bituminous mix pavements used on roads making up the bulk of the French road network in terms of running length and which bear most of its traffic loads. Moreover, this road length also undergoes most of the maintenance work performed by public works companies.

These roads are suitable for average traffic (cumulated traffic of 3 to 6 million heavy-weight vehicles over 30 years).

Table 3 – Breakdown of types of roads used in France

Types of roads	Length of the road network		Source
	in km	**% of km**	
Motorways (toll roads and free roads)	11,465	0.9%	SOeS, Key figures on transport, 2014 Edition (2012 data)
National roads	9,784	1.1%	
Departmental roads	377,965	35.5%	
Local roads	666,343	62.5%	
Total	1,065,557	100%	

Table 4 – Breakdown according to traffic in France

Types of roads	Traffic in vehicle.km %	Source
Motorways (toll roads and free roads)	29.9%	SOeS, Key figures on transport, 2014 Edition (2012 data)
National roads	4.0%	
Departmental roads	66.1%	
Local roads		
Total	100%	

2.1.2.2 *General structure*

The bituminous asphalt pavement examined in this study consists of:

- One sub-base course and one base course, representing the road base,
- One surface course.

The various bituminous asphalt layers are bonded by a tack coat of bituminous emulsion, which is a mixture of bitumen and water.

The capping layer, which serves as road substrate, has not been included in the scope of this study. In fact, it is not included in the technical definition of road pavement, and is not an integral part of the pavement.

2.1.2.3 *Reference service life*

Defining the reference pavement lifespan is a debatable issue among public works experts and LCA practitioners.

Thus, the surface (or wearing) course undergoes regular maintenance over the entire road life, either by resurfacing or by removal and replacement.

In contrast, the road base layers (base course + sub-base course) are generally left in place. They are used as support for the successive surface layers. They are very seldom taken apart.

In order to better meet the requirements in Chapter 6.3.3 of Standard NF EN 15804+A1 (taking into account all the elements that contribute to pavement functionality), the selected principle in this study is a reference pavement lifespan of 100 years under conditions of regular maintenance of the surface course by resurfacing or replacement to ensure the pavement's functions over this reference lifespan.

In addition, for information purposes, the LCA results of the surface layer alone, i.e., pavement without road base layers (base course + sub-base course), are presented in Annex 8.8 to this report.

2.1.2.4 *Initial structure and maintenance*

As mentioned in Section 1.3, it has been decided to examine only the scenario based on a standard structure in the SETRA catalogue of structures of October 1998, ref. TC4 PF3 30 years (referred to as Scenario 2 in the previous study).

In the studied scenario, the initial structure was designed for a lifespan of 30 years (without maintenance). The considered maintenance stages during the service life can later preserve the pavement's functions over 100 years.

The initial structure and maintenance data for the studied pavement were calculated according to the French design method defined in Standard NF P 98 086 "Structural Design of Road Pavements - Application to New Pavements". The rate of damage was calculated by applying Miner's Rule model of cumulated damage. These scenarios are representative and current for most other existing practices in France.

The initial pavement structure is presented in Figure 2 below.

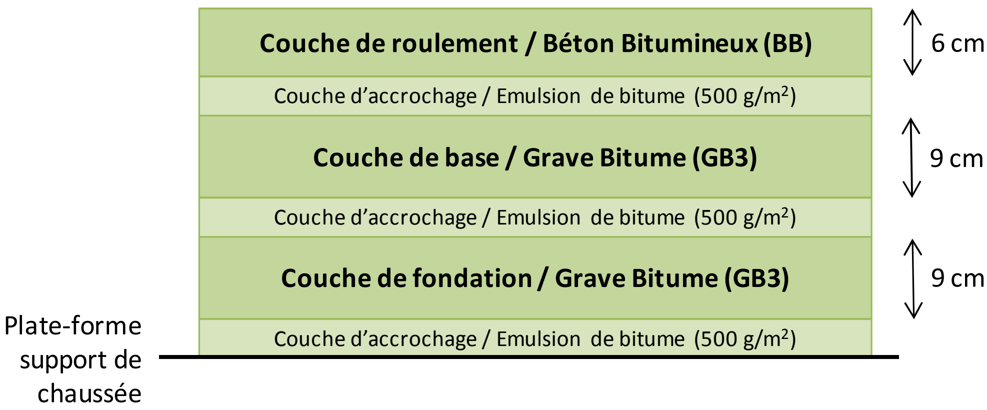


Figure 2 – Structure of the studied pavement

The masses of the materials used over the total life cycle of the pavement are presented in the following table. The densities of asphalt concrete (AC) and gravel bitumen (GB3) were assumed to be identical and equal to 2.35 t/m^3 (source: USIRF).

Table 5 – Masses of materials used in the selected Scenario

Materials		Details	Mass per m^2 (kg)
Initial application	**Wearing course**	Asphalt concrete (AC) (4.8% bitumen)	1.41E+02
	Base course	Gravel bitumen (GB3) (3.95% bitumen)	2.12E+02

Materials		Details	Mass per m² (kg)
	Sub-base course	Gravel bitumen (GB3) (3.95% bitumen)	2.12E+02
	Tack coats	Bitumen emulsion (60% bitumen)	1.50E+00
Maintenance during the service life	**Wearing course**	Asphalt concrete (AC) (4.8% bitumen)	6.82E+02
	Tack coats	Bitumen emulsion (60% bitumen)	4.00E+00
Total			1.25E+03

The calculated maintenance scenario for this type of pavement is presented in the following table.

It should be noted that high-modulus asphalt (EME2) is used instead of classic asphalt concrete (AC) for maintenance at 26 years. This use represents an economic optimisation, since EME 2 is asphalt with higher structuring performance. However, since its composition (in particular the bitumen content) is very close to that of asphalt concrete (AC), it has been assimilated to asphalt concrete.

Table 6 - Maintenance scenario (corrective and preventive treatment) of the pavement studied in the selected scenario

Age	Maintenance
13 years	Addition: 2.5 cm asphalt concrete (AC) + 1 tack coat
26 years	Planing: 8.5 cm Addition: 8 cm high-modulus asphalt (EME2) +2.5 cm asphalt concrete (AC) + 2 tack coats
39 years	Planing: 2.5 cm Addition: 2.5 cm asphalt concrete (AC) + 1 tack coat
52 years	Planing: 2.5 cm Addition: 6 cm asphalt concrete (AC) + 1 tack coat
65 years	Addition: 2.5 cm asphalt concrete (AC) + 1 tack coat
78 years	Planing: 2.5 cm Addition: 2.5 cm asphalt concrete (AC) + 1 tack coat
91 years	Planing: 2.5 cm Addition: 2.5 cm asphalt concrete (AC) + 1 tack coat
100 years	End of life

2.2 Functional units studied

The Functional Unit (FU) of an environmental assessment is the common reference unit of all the material and energy flows. This reference unit enables evaluating a system according to the service it performs. In this study, the selected functional unit for the pavement life cycle part is:

“Provision of 1 m² of pavement over 100 years”

For the asphalt production part, instead of “functional unit”, we refer to “declared unit” in accordance with Chapter 6.3.2 of NF EN 15804+A1. Accordingly, for this system, the declared unit is:

“Producing 1 tonne of representative French hot-mix asphalt”

2.3 Studied systems

2.3.1 System boundaries

As previously indicated, two systems are examined in this study:

- The "Asphalt Production System" from the extraction of raw materials to the output of the asphalt plant,
- The "Pavement Life Cycle System" from the extraction of raw materials to the end of life of the pavement.

These systems are presented in the following figures. More detailed diagrams of input and output flows are provided in Section 5.1.

It is important to note that the first system (the "Asphalt Production System") represents the production stage of the second system ("Pavement Life Cycle System").

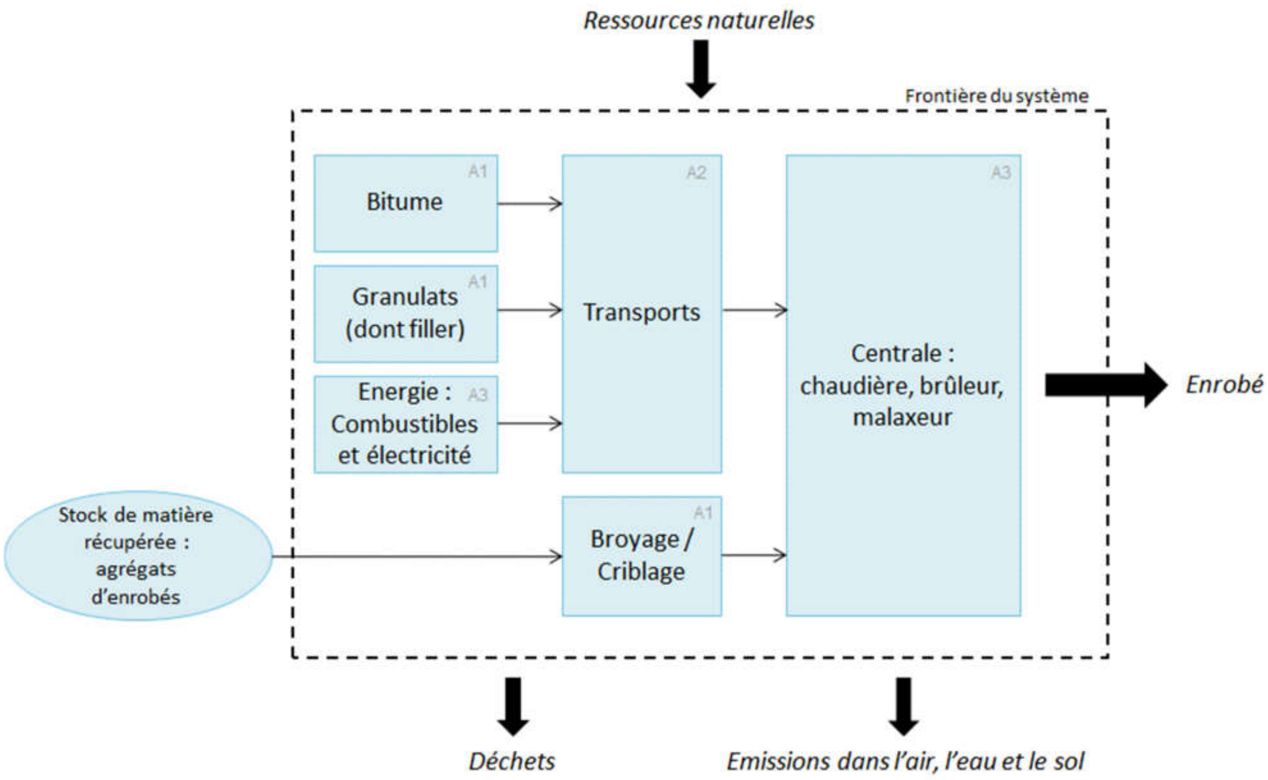


Figure 3 – Studied asphalt production system

For the Pavement Life Cycle system, the system boundaries are presented according to the modular structure of Standard NF EN 15804+A1.

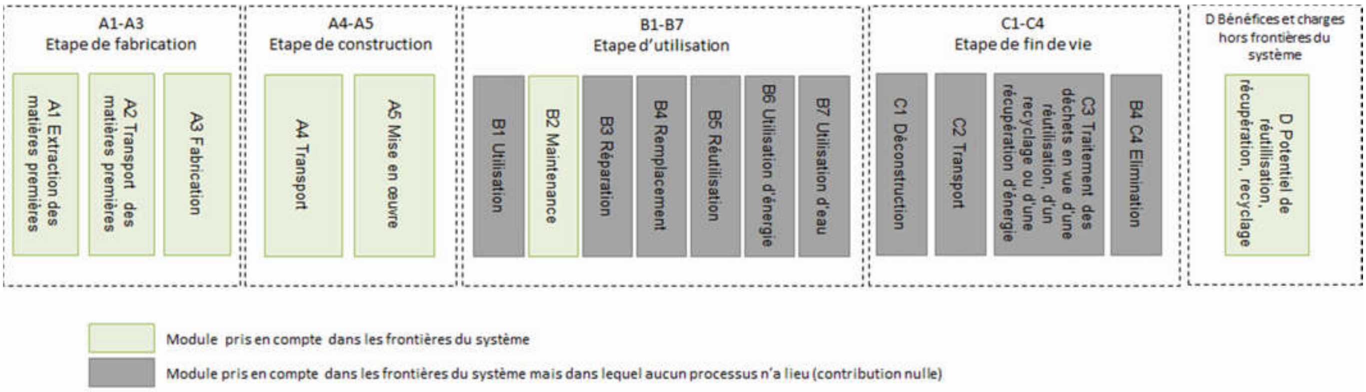


Figure 4 – Boundaries of the studied pavement life cycle system

Pavement maintenance during its serviceable life was included in Module B2 – Maintenance. Thus, in accordance with Section 6.3.4.4.2 of Standard NF EN 15804+A1, it is considered that this maintenance involves a "combination of planned technical and associated administrative actions during the service life of a construction product or its parts [...] to recover an acceptable state that ensures its required functional and technical performance".

The following table sets out in detail the different stages of the pavement's life cycle. It is important to note that the service life stage, which covers the various maintenance stages of the road over its lifespan, also includes production, transport and application stages of resurfacing and replacements. Furthermore, the end-of-life stages of the asphalt (1st life cycle) and of subsequent asphalt mixes until cycle n-1 have been factored in.

Table 7 – Breakdown of the life cycle stages

Stage (module)	Details
Production (A1-A3)	Extraction and processing of the raw materials used in the production of pavement bituminous mixes (A1): - Extraction and processing of the raw materials used in the production of the various types of asphalt mix (A1) - Processing of secondary materials (crushing of recycled asphalt aggregate) used in bituminous mixes (A1) Transportation of raw materials to bituminous mix production sites (A2) Production of the different types of asphalt (A3): - Energy consumption, - Water consumption, - Consumption of complementary products (consumables), - Emissions to air and water, - Transport and disposal of waste, infrastructures, - Production and transport of the bitumen emulsion used in the other pavement layers (tack coats).
Transport to the worksite (A4)	Conveyance of the materials used for the initial pavement structure to the construction site: - Emission of bitumen fumes during truck loading, - Transport by truck.
Application (A5)	Application of the materials used for the initial pavement structure: - Use of construction equipment, - Emission of bitumen fumes during application
Service life (B1-B7)	Maintenance phase relating to the upkeep of the wearing course (B2): - Production, transport and application of utilised materials, - Use of construction equipment for planing (removal).
End of life (C1-C4)	Road remaining in place after the lifespan taken into consideration (100 years): - Production of recycled waste (materials left on the ground that can serve as support for a new road) (C3)
Benefits and burdens beyond system boundaries (D)	Benefits of asphalt planings recycling: - Crushing asphalt planings for reuse as asphalt aggregate - Avoided production of "virgin" components of bituminous asphalt Benefits related to the recycling of the materials left in place at end of life: - Avoided production, transport and application of the road base courses.

It should also be noted that both the production and end-of-life stages of the asphalt plant and the production and end-of-life stages of all the construction machines used during the pavement's life cycle have been accounted for in the study.

2.3.2 Life cycle stages excluded from the systems

None of the pavement life cycle stages and flows were excluded from the studied systems. However, some stages have no contribution to the environmental impacts, since no processes take place during these stages:

- Utilisation stages other than replacement (B1, B3 to B7);
- Deconstruction stages (C1-C4) (except for the production of recycled waste).

Thus, this study assumes that the road base courses will remain in place beyond the 100-year period taken into consideration. Consequently, the environmental impacts of the end-of-life stage are nil. Only the material remaining in place at the end of the various maintenance stages has been included in calculations within the flow "Components intended for reuse".

It should be noted that after its end of life, part of the roadway will be reused. For the materials remaining in place at end of life, no impacts related to recycling or recovery processes are being considered.

In addition, the road planing (module B2) generates asphalt planings intended for recycling.

Regarding these asphalt planings, the planing operations are included in the period of serviceable life and are unrelated to the fate of the planings. The regulations concerning the end of waste status of these materials are still being developed by professional groups and public authorities as of the preparation of this study. Nevertheless, we have adopted a prospective scenario position where the case of asphalt planings is being handled from a legislation standpoint. In fact, this scenario reflects current practice, but it has been qualified as "prospective" as a precautionary step with regard to the regulations under development. In accordance with the CEREMA guideline "Acceptability of Deconstruction Materials for Road Construction" (under publication), such materials must undergo compliance tests to demonstrate that they do not contain any hazardous substances, such as asbestos or tar. As these substances have not been used in road construction for several decades, we consider that the tests were conclusive and that the planings can be reused, in accordance with Chapter 6.4.3.3 of Standard NF EN 15804+A1. Since the mass of the tested materials is low, we will also consider that the transport involved in this procedure is negligible. In order to be reused, the planings must still undergo grinding and screening operations.

In accordance with standard NF EN 15804+A1, no environmental benefits or impacts related to the recycling of these two types of waste and occurring beyond the "end-of-waste" status are taken into account within the system boundaries. These two types of recycling are factored in both as benefits and burdens beyond the system boundaries (D), considering that:

- The base and sub-base courses remain in place at the end of the road life and will replace the "virgin" road base courses (base course, tack coat, sub-base course and finally, another tack coat),
- The asphalt planings produced during planing will serve as substitutes for bitumen and aggregate.

Module D is calculated based on the net flows (output secondary materials minus input secondary materials).

We note that additional waste generated during the pavement's life cycle will be reused at a later stage, such as construction equipment, tyres and metal scrap. However, the amounts of additional recycled waste account for less than 1% compared to the quantities of recycled planings and materials left in place at end of life (refer to the calculation data in Table 58, page 50). This is why we estimate that the benefits and burdens involved in such recycling have a negligible contribution to the environmental impacts of the studied system.

Finally, it should be noted that earthwork and building the capping layer serving as road subgrade were not included in this study, since they are not an integral part of the pavement. The road use phase and specifically, the fuel consumption of vehicles travelling on it, was not included in the scope of this study. Similarly, components such as barriers, milestones or painting, were also not included in the study.

2.4 Cut-off rules

In order to simplify inventory activities, Standard NF EN 15804 allows a cut-off threshold of 99% of the mass of the input flows, provided that substances that are very toxic, toxic, harmful or hazardous to the environment and are intentionally introduced into the manufacturing of the assessed products should be taken into consideration.

Within this study, the cut-off threshold was observed, in accordance with Chapter 6.3.5 of Standard NF EN 15804+A1.

In fact, on the one hand, according to USIRF, no substances that are very toxic, toxic, harmful or hazardous to the environment are used in bituminous asphalt manufacturing.

On the other hand, from the collected data, only the consumptions of additional filler[3], colourants and additives were ignored. Although they are indeed part of the composition of asphalt, these represent less than 0.1% of the mass of the materials used to produce one tonne of asphalt. This is true for 7 out of 8 surveyed plants (the 8th did not have any available data, per ref. Annex 2: Data collected from the asphalt plants).

Finally, in accordance with Chapter 6.3.5 of Standard XP P01-064/CN, the following flows have been omitted from the system:

- Lighting, heating and cleaning of production sites,
- Administrative department,
- Employee transport,
- Long-term emissions (beyond the 100 years, primarily concerning emissions related to waste burial processes).

In connection with long-term emissions, it should be noted that bitumen and asphalt are considered to be inert waste. As defined by European Directive 1999/31/CE of 26/04/1999, inert waste is “waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn, or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to cause environmental pollution or harm to human health”.

2.5 Rules for assessing recycling

In accordance with the requirements in Standard NF EN 15804, the stocks method is the method used in this study to quantify the flows of materials intended for recycling, or the recovery or reuse of energy.

In this study, only the recycling of materials was considered (energy recovery was not considered). The relevant material flows for the recycling of materials are:

- Scrap tyres and metal, inert aggregate, as well as the infrastructures at end of life, during production (module A3);
- Construction equipment at end of life, used during pavement application (module A5);
- All the above items, during the service life of the pavement (module B2);
- Planings produced by planing maintenance work during the service life (module B2);
- Materials remaining in place at the end of life of pavement (module C3).

With regard to the planings, the grinding and crushing of the utilised planings are outside the system boundaries (module D).

In module D, the benefits of recycling are expressed as follows:

- For products that use the recycled material (namely the recovered material removed from stock), this implies obtaining an impact-free material where only the impact of the recycling process is taken into calculation.

[3] It should be noted that fillers are naturally present in aggregate in small amounts and therefore are not systematically added to the composition of asphalts.

- For products recycled at end of life (namely that are sent to the stock of recovered materials), this is expressed by the absence of disposals and impacts associated with such disposals.

The following diagram shows a general overview of the stocks method.

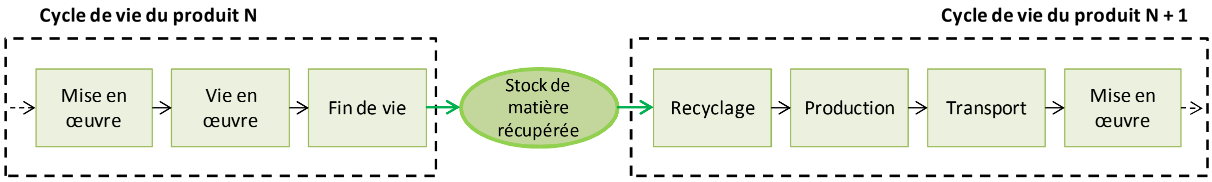


Figure 5 – Illustration of the stocks method for assessing recycling

Several recycling issues have been discussed in this study. The application of the stocks method in each of these cases has been detailed in annex 8.5.

2.6 Principles of allocation among co-products

Most of the plants participating in data collection produce both hot mixes and warm mixes.

However, during the reference data collection period (2010 or 2011, depending on the plants), the proportion of warm-mix asphalt was very small (less than 5% of total production for the 8 plants). Accordingly, warm-mix asphalt was assimilated to hot-mix asphalt. In practice, there was no allocation between the coproducts. Furthermore, since the warm mixes require lower heating conditions than hot mixes, it may be assumed that the impacts of warm mixes are also lower. Therefore, this assimilation is conservative in relation to the studied system.

We wish to recall that the allocation rules used in the Eurobitume study Life Cycle Inventory of Bitumen for the various stages of bitumen production were:

- Extraction and transport: allocation by mass,
- Refining: economic allocation.

The relevant assumptions and justifications have been listed in the report "*Life Cycle Inventory of Bitumen*"[4] published by Eurobitume in 2011, which underwent critical review in accordance with standards ISO 14040 and 14044.

[4] This study can be accessed at: http://www.eurobitume.eu/homepage/focus/eurobitume-life-cycle-inventory-bitumen

3 Sources and quality of data

3.1 Data sources

The data used in the study may be classified into three categories:

- Baseline asphalt production data,
- Baseline pavement life cycle data,
- Environmental data (Life Cycle Inventories) used to determine the life cycle inventory of the asphalt and pavement baseline data.

The data sources used for each category are described below.

3.1.1 Basic asphalt production data:

In mainland France there are approximately 500 asphalt plants producing around 32 million tonnes of hot-mix asphalt per year[5]. The base asphalt production data used in this study were compiled from different data sources indicated in the following table.

It should be noted that energy consumption data were collected from several plants belonging to the Colas, Eiffage and Eurovia companies, respectively, and the output of which represents approximately 77% of French production.

The emissions to air data are based on measurements made on site at 73 plants. We can estimate that these 73 plants account for about 15% of French production. However, taking into account the uniform types of the asphalt and the uniform manufacturing processes used in France, USIRF considers these plants as being representative for the currently-operated stationary plants in France

Finally, on other aspects, for which consolidated data of such a large number of plants were not available, the utilised data were based on a survey of 8 plants carried out as part of the previous LCA study of 2012-2014. These 8 plants, located all over France, have an annual production of 1 Mt of asphalt, accounting for approximately 3% of French production. However, taking into account the uniform types of the asphalt used in France and the uniform manufacturing processes, USIRF considers these 8 plants as being representative for the currently-operated stationary plants in France.

Regarding the representativeness of these data, it should be noted that the quality of the LCI data is variable. The efforts of USIRF to characterise the emissions of air pollutants related to the road industry have allowed us to improve the quality of these data in relation to the generic data in the Ecoinvent database.

Table 8 - Sources of base asphalt production data

Type of data	Data source
Consumption of raw materials (representative composition of bituminous asphalt)	Estimate of the USIRF Steering Committee + survey of 8 asphalt plants regarding the breakdown of aggregate types
Conveyance of raw materials	Survey of 8 asphalt plants
Water consumption	Survey of 8 asphalt plants
Consumption of consumables	Survey of 8 asphalt plants
Conveyance of consumables	BIO assumption
Proportional breakdown of asphalt	Consolidated data of all the asphalt plants belonging to three major French road industry

[5] 2013 data taken from the Environmental Assessment of USIRF published in May 2014, and available at http://www.usirf.com/wp-content/uploads/BILAN_ENVIRONNEMENTAL_2013_v06052014.pdf

Type of data	Data source
plants according to the type of fuel used at the burner-dryer **+ Consumption of energy at the burner/dryer**	companies Source details: The data were based on inputs from all the asphalt plants of Colas, Eiffage and Eurovia companies, which produce about 27 Mt of asphalt per year out of a total amount of 35 Mt per year produced in France, accounting for approximately 77% of French production (2011 data).
Other energy consumptions	Survey of 8 asphalt plants
Emissions to air	USIRF database concerning plant emissions + Survey of 8 asphalt plants + Ecoinvent database 3.1 Source details: The USIRF database includes atmospheric emission data of burners at about 150 plants out of the 500 existing plants in mainland France. These data were obtained from measurements carried out under regulatory reporting requirements or voluntary campaigns. In this study, only datasets collected after 2009 and which contained all the necessary data to be accounted for were used. Subsequently, these datasets were completed with emission data provided within the 8-plant survey. Thus, on the whole, the used air emission data were obtained from 73 plants. It can be estimated that these 73 plants account for approximately 15% of French production. Finally, we used the Ecoinvent database to fill in emission data in certain flows for which no data were available. Ecoinvent is an internationally-recognized life cycle inventory database of environmental data (consumption and waste) covering several thousand processes.
Emissions to water	Survey of 8 asphalt plants
Waste production	Survey of 8 asphalt plants
Infrastructures	SEVE system developed by USIRF + earlier USIRF LCA studies of bituminous mix pavements Source details: The SEVE system is an eco-comparator tool developed by USIRF between 2010 and 2011. It compares different technical solutions prepared in response to public works tenders from the environmental standpoint. This tool underwent a critical review in 2011 and subsequently in 2014. The earlier LCAs of bituminous asphalt pavements correspond to the following studies: - Environmental characteristics of road materials, LCA of bituminous asphalts, Inventory analysis report of the transport, application, service life and end of life stages of hot-mix asphalts, USIRF, 2006. - Life Cycle Analysis of average French hot-mix bituminous asphalt and bituminous asphalt pavement, USIRF, 2014.

- **Details of data obtained from the survey of 8 asphalt plants**

The asphalt plants were selected based on their annual production of asphalt, the type of used fuel (natural gas or heavy fuel oil) and the type of plant (continuous or discontinuous operation). In fact, in the LCA conducted by USIRF in 2006, these three parameters had been identified as the main influencing factors of the environmental performance of the plants. Accordingly, these parameters have resulted in a selection of a group of 2^3 = 8 plants, which were selected by the companies participating in the Steering Committee of the 2014 LCA. As the same data were retrieved for this study, this consideration has not changed.

These 8 plants are located all over France and have an annual production of 1Mt of asphalt, accounting for approximately 3% of French production.

The distribution of these plants according to the above-listed parameters is presented in the following table.

Table 9 – Distribution of the 8 selected plants according to different parameters[6]

Parameter	Details	No. of plants

[6] For practical reasons, one plant operating on LPG was selected for data collection in 2012. However, since this type of fuel is used by a very small minority of asphalt plants in France, the energy consumption of this plant was not included in the consolidated collected data.

Parameter	Details	No. of plants
Burner fuel	HFO	3
	GN	4
	LPG[5]	1
Operating regime	Continuous	3
	Discontinuous	5
Annual production	< 80,000 t/year	3
	Between 80,000 and 150,000 t/year	3
	> 150,000 t/year	2

Once the plants were selected in consultation with USIRF, the data were collected by means of a questionnaire sent to the Operations Manager of each plant. These questionnaires, a blank copy of which is enclosed in Annex 8.1, were used to collect the following types of data:

- Plant characteristics (primarily related to the above-listed parameters),
- Type and quantity of consumed raw materials,
- Type and quantity of consumed energies,
- Consumption of water and other consumables,
- Type and quantity of emissions to air,
- Type and quantity of emissions to water,
- Type and quantity of generated waste.

The collected data were subsequently weighted according to the respective outputs of the various plants to determine the data to be used in the study.

The entire array of data collected from the asphalt plants is presented in Annex 8.2.

3.1.2 Baseline data of the pavement life cycle

The different sources used for compiling the baseline data of the pavement life cycle are set out in the following table.

Table 10 – Sources of baseline data related to the life cycle of pavements

Type of data	Data source
Pavement lifespan	Estimate of the USIRF Steering Committee
Initial structure and maintenance of pavements during their lifespan	Calculation performed by the USIRF Steering Committee according to the French design method defined in standard NF P 98 086
Transport distance between asphalt plants and work sites	Estimate of the USIRF Steering Committee
Emissions of bitumen fumes during transport and application	Calculation performed by BIO using the CIMAROUT database Source details: The CIMAROUT database was created in 2011. It is a documentary database of toxicological and epidemiological studies published in international scientific journals. In addition, it also contains a database of over one hundred employee exposure assessment studies carried out on-site with the participation of the National Institute of Occupational Safety Research (INRS), the Inter-regional Chemical Laboratories of Pensions and Occupational Risks Fund (CARSAT), other occupational medicine bodies and the relevant companies.
Use of construction equipment for pavement application (including the construction equipment infrastructure)	USIRF SEVE system Source details: The SEVE system is an eco-comparator tool developed by USIRF between 2010 and 2011. It compares different technical solutions prepared in response to public works tenders from the environmental standpoint. This tool underwent a critical review in 2011

Type of data	Data source
	and in 2014.
End of life of pavement	Assumption of the USIRF Steering Committee

3.1.3 Environmental data

The different sources used for life cycle inventory data are specified in the following table.

Table 11 – Sources of the environmental data related to the life cycle of pavements

Type of data	Data source
Bitumen production inventory	EUROBITUME: Life Cycle Inventory of Bitumen Production, 2011
Aggregate production inventory	UNPG: Environmental information module - Aggregates from hard/soft rock, 2011
Other life cycle inventories (materials, energy, transport, etc.)	Ecoinvent 3.1 database Source details: The Ecoinvent database is an internationally-recognized life cycle inventory database of environmental data (consumption and waste) covering several thousand processes.

3.2 Data quality

3.2.1 Temporal representativeness

The energy consumption data for asphalt production are 2011 data. The data collected in the 8-plant survey are representative of 2010 for one asphalt plant and of 2011 for 7 plants.

USIRF has estimated that the production processes and technologies for asphalt manufacturing and application have not changed significantly over past four to five years. Thus, the collected plant data are still representative of the current state. In accordance with Section 6.3.7 “Data quality requirements” of Standard NF EN 15804, these data are much more recent than 5 years old. The supplementary data are also from recent sources that are less than 5 years old (data of emissions to air were taken from the 2009-2012 USIRF database, the CIMAROUT database was established in 2011, while the SEVE system was validated in 2011 and in 2014).

Pavement data used in the studied scenarios were calculated according to methods that are still in current use, according to USIRF. Moreover, the additional reported data were collected from recent sources.

Finally, the used environmental data are also recent (the bitumen and aggregate inventories were compiled in 2011 and the Ecoinvent 3.1 database was updated in 2014).

3.2.2 Technological representativeness

The utilised data are representative of the technologies used by French road industry professionals.

Depending on the type of data, the baseline data used for asphalt production were obtained from a variable number of plants accounting for a share of 3 to 77% of French production (see Section 3.1). Also, taking into account the uniform types of the asphalt used in France and the uniform manufacturing processes, USIRF considers that the reported data are still representative of the technology of stationary plants operated in France in 2015.

The types of pavement studied in this LCA are representative of bituminous asphalt pavements used in departmental and local roads, which are the most representative French roads in terms of running length and traffic (98% of the French road network and 66% of vehicle mileage, refer to Section 2.1.2.1). It should be pointed out, however, that there are many types of bituminous mix pavement that may have very different structures and consequently very different environmental impacts. In particular, it should be noted that the scope of this study does not cover the types of pavement used for heavy-traffic motorways or national roads.

3.2.3 Geographical representativeness

The baseline data used for the asphalt mix and the studied pavement scenarios are representative for the state of the industry in mainland France.

The environmental data are based on aggregate inventories that are representative of the aggregates manufactured and sold in France. This is also true for the utilised electricity inventory, which is representative of the French electric power mix (refer to Annex 8.7). The bitumen inventory is representative of the production of bitumen used in Europe. Finally, the inventory data in the Ecoinvent database are generally representative of European processes.

3.2.4 Completeness

For all the pavement life cycle stages (therefore including asphalt production), all flow inventories were compiled and accounted for either directly based on USIRF data, or from the Ecoinvent database. Accordingly, the level of data completeness is considered to be good.

3.2.5 Consistency

All used life cycle inventory data were extracted from the Ecoinvent 3.1 database or were published by the National Union of Aggregate Producers (UNPG) and Eurobitume, also relying on data from the Ecoinvent database. Consequently, data consistency is considered to be good.

3.2.6 Reproducibility

The reproducibility of LCA's results is ensured by a high level of transparency in retrieving the data sources of the study.

3.2.7 Accuracy

The data used in the production stage are site data with a high level of reliability and accuracy based, among others, on official reports such as the site's annual declaration of pollutant emissions.

The data used for the other life cycle stages are based on the expertise of Steering Committee members and their rich experience in road construction and road maintenance.

The accuracy level of the data is therefore considered to be good.

4 Comments regarding the study

The main limitations and comments in connection with this LCA are summarised below:

- **Type of studied pavement**

There are many types of bituminous asphalt pavement that may have different structures and consequently different environmental impacts. It should be recalled that the types of pavement included in this study are bituminous asphalt pavements used in departmental and local roads, which are the most representative French roads in terms of running length and traffic (see Section 2.1.2.1). The scope of this study does not cover the types of pavement used for heavy-traffic motorways or national roads.

- **Lifespan of the types of pavement being studied**

The definition of pavement lifespan is a debatable issue among public works experts and LCA practitioners. In fact, the surface (or wearing) course undergoes maintenance over the entire pavement life, either by resurfacing or by removal and replacement. In contrast, the road base layers (base course + sub-base course) are generally left in place. They are used as support for the successive surface layers. These layers are very seldom deconstructed. Accordingly, the selected principle in this study is to assume by default a pavement lifespan of 100 years, taking into account the necessary maintenance work to ensure its functions over this lifespan. This approach "amortises" the impact of the lower road layers, which can be used for several successive wearing courses.

- **Temporal and technological representativeness of data**

As previously indicated, particularly in Section 3.2, no new data collection was performed for this study. The data collected for the previous FDES declaration were reused while updating the model (to achieve compliance with the new standards and to update the environmental data). There remains, therefore, a certain uncertainty concerning potential technological developments during the period covered by the study, particularly for the utilisation and end-of-life phases. According to USIRF's assessment, however, the utilised technologies and methods have not significantly evolved over past four years. Thus, the collected data are still representative of the current situation. We note, however, that in accordance with Standard NF EN 15804+A1, activity data will have to be updated from 2016.

- **Studied environmental impact indicators**

The indicators examined in this study are the indicators of Standard NF EN 15804+A1 and its supplement XP P01-064/CN. They are scientifically and technically recognised and provide a multi-criteria insight into the environmental aspects of construction and public works. It should be mentioned, however, that these indicators do not cover the entire range of environmental aspects that may be affected by transport infrastructures (including bituminous asphalt pavements), such as land use, soil sealing, noise, ecosystem fragmentation, etc.

5 Life cycle inventory

This chapter describes the underlying assumptions and data used in compiling the life cycle inventory of the two examined systems. The data are presented according to the modular structure of Standard NF EN 15804.

First, in Section 5.2 to Section 5.4, we will present the data related to the production of one tonne of asphalt, distinguishing between the following two types of asphalt:

- Asphalt Concrete (AC), which is used for the road's wearing course, and
- Gravel Bitumen (GB3), which is used for the base and sub-base road courses.

As indicated in Chapter 3, the data are derived from different sources, and primarily from a survey conducted among 8 asphalt plants. The entire array of data collected from the asphalt plants is presented in Annex 8.2.

From Section 5.4.8 to the end of Chapter 5, we present life cycle data of bituminous asphalt pavement. The data for the other life cycle stages (transport, application, service life and end of life) were obtained from different sources (USIRF Steering Committee, CIMAROUT database, SEVE system, etc.).

As previously stated, this study has examined a single scenario, as against two in the previous study (referred to as "scenario 2" in the 2014 study). Accordingly, the following tables present data for the single examined scenario.

5.1 Flow block diagrams

The following figure presents all the input and output flows within the life cycle of the “Asphalt Production” system.

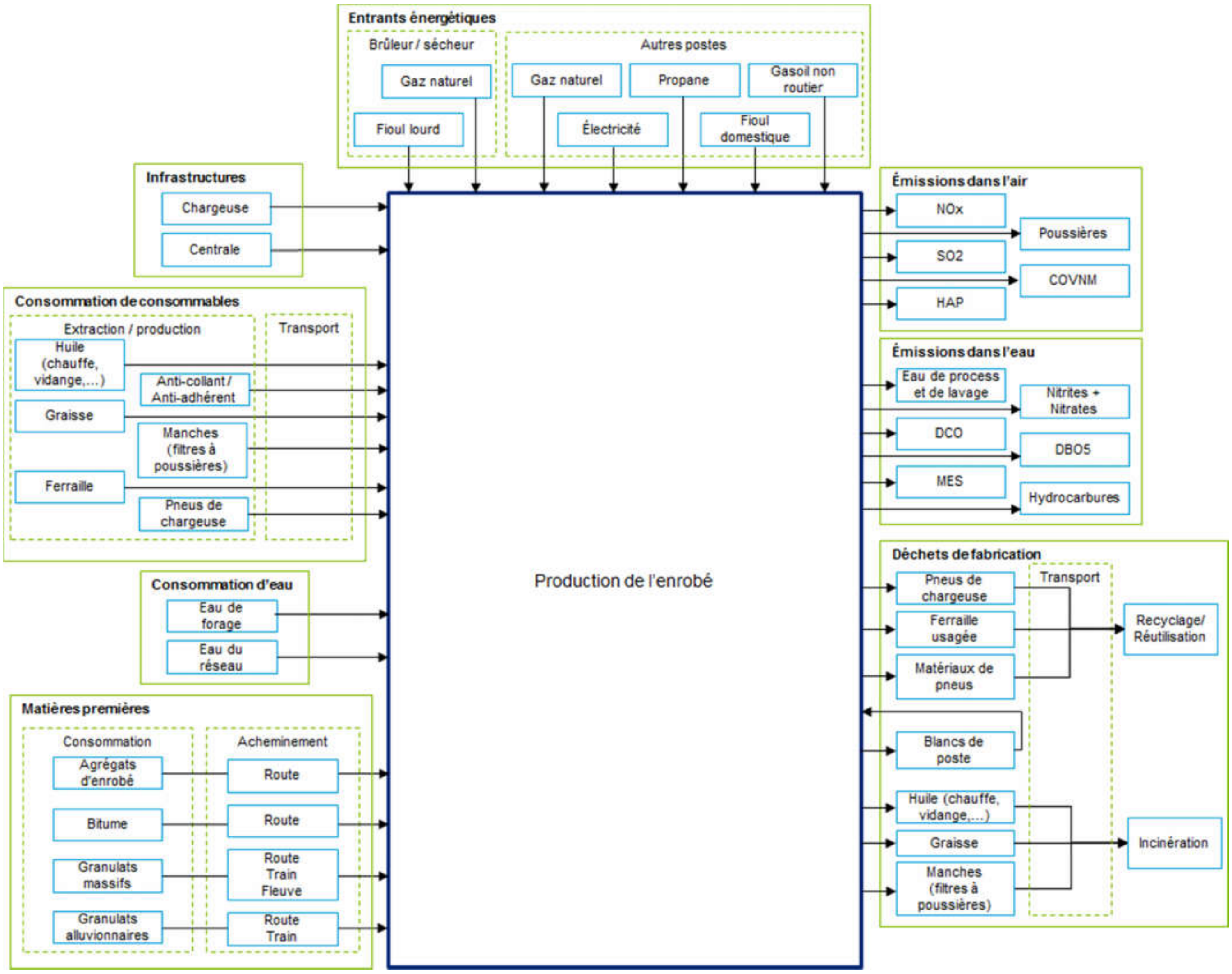


Figure 6 - Block diagram of input and output flows in the “Asphalt Production” system

This figure shows all the input and output flows of the life cycle of the second studied system, i.e., the "Pavement Life Cycle" system. It should be noted that the first system ("Asphalt Production" system) represents the production stage of the second system ("Pavement Life Cycle" system).

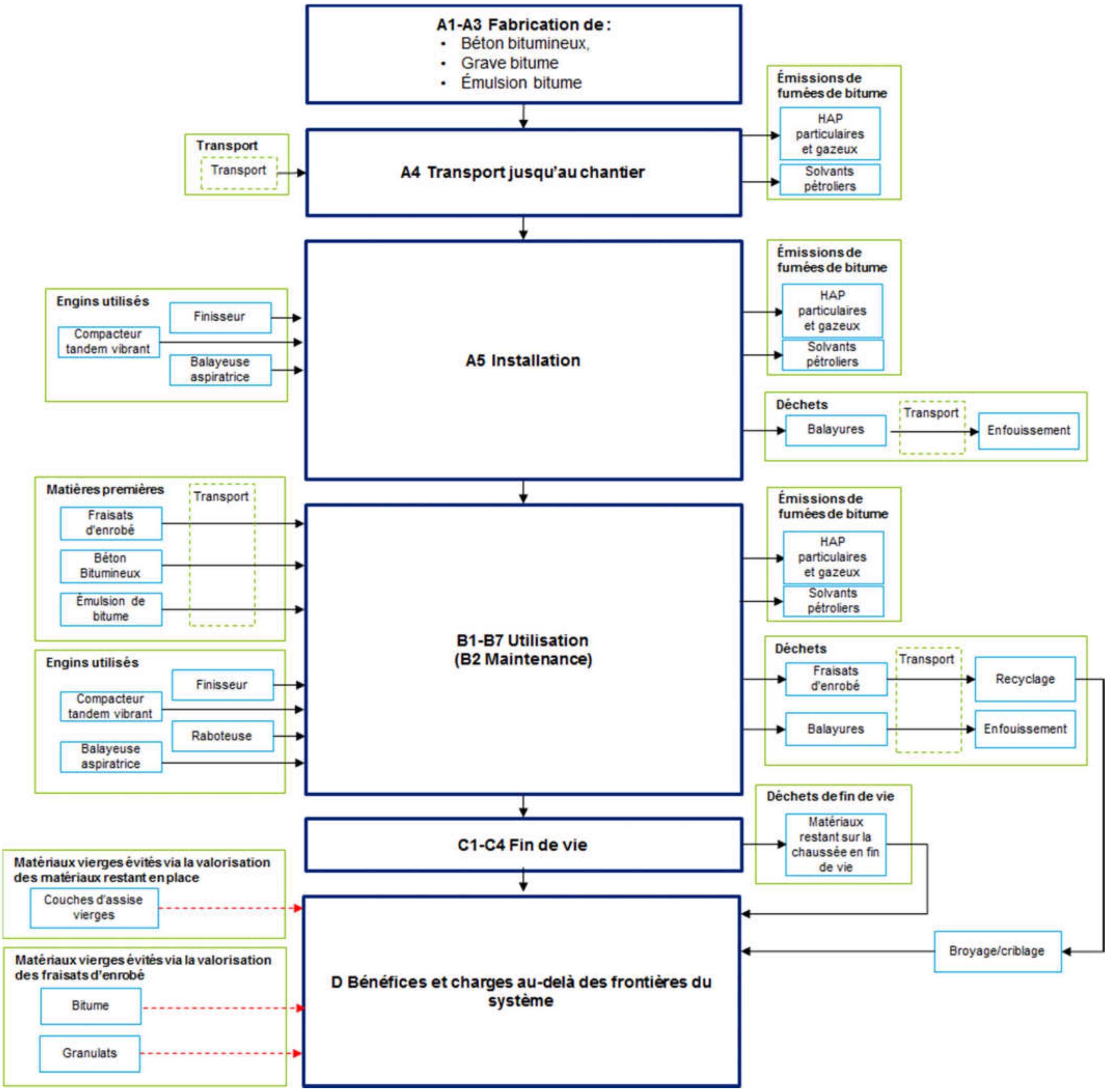


Figure 7 - Block diagram of input and output flows the "Pavement Life Cycle" system

5.2 Consumption of raw materials (A1)

5.2.1 Baseline data

The representative composition of the asphalt concrete (AC) and gravel bitumen (GB3) mixes was provided by the USIRF Steering Committee. These data are presented below.

Table 12 – Asphalt composition data

Raw material	Unit	Values for 1 t of asphalt concrete (AC)	Values for 1 t of gravel bitumen (GB3)	Source
Reclaimed asphalt	kg	9.50E+01	9.50E+01	USIRF Steering Committee
Bitumen	kg	4.80E+01	3.95E+01	
Aggregates (hard rock aggregate and alluvial aggregate)	kg	8.57E+02	8.66E+02	
TOTAL	kg	1.00E+03	1.00E+03	

In estimating the consumption of raw materials to produce one tonne of asphalt concrete (AC) and one tonne of gravel bitumen (GB3), we factored in a loss rate of 3% for aggregate (the aggregate loss at asphalt plant site - value supplied by the USIRF Steering Committee). Apart from this, no losses were taken into account for bitumen, which is stored in tanks.

Furthermore, the allocation of hard rock aggregate and alluvial aggregate was calculated based on data collected in the 8 asphalt plants survey. The allocation ratio is 76.4% of hard rock aggregate to 23.6% of alluvial aggregate.

The values obtained after applying the above loss rate and the allocation ratio are presented below:

Table 13 – Raw material consumption data

Raw material	Unit	Values for 1 t of asphalt concrete (AC)	Values for 1 t of gravel bitumen (GB3)	Source
Reclaimed asphalt	kg	9.50E+01	9.50E+01	USIRF Steering Committee + Survey of 8 asphalt plants
Bitumen	kg	4.80E+01	3.95E+01	
Hard rock aggregate	kg	6.74E+02	6.81E+02	
Alluvial aggregate	kg	2.09E+02	2.11E+02	
TOTAL	kg	1.03E+03	1.03E+03	

Additional fillers, colourants and additives indicated in the 8-plant survey collected data were ignored. These materials represent less than 0.2% of the asphalt mass.

Resource use flows were also accounted for. They are presented in Annex 8.6.

5.2.2 Environmental data

The environmental data used for producing the raw materials are presented in the table below.

Table 14 – Data used for raw materials modelling

	Environmental data
Reclaimed asphalt	Stocks method (see annex)
Bitumen	EUROBITUME: Life Cycle Inventory of Bitumen (with infrastructure) (2011)
Hard rock aggregate	UNPG: Environmental information module - Hard rock aggregates (2011)
Alluvial aggregate	UNPG: Environmental information module - Soft rock aggregate (2011)

5.3 Conveyance of raw materials (A2)

5.3.1 Baseline data

Data on the raw materials transport distances and means of transport were collected from the 8 asphalt plants survey. These data are presented in the following table.

Data	Conveyance method	Percent	Distance (km)	Source
Reclaimed asphalt	Road	100%	0.00E+00	Survey of 8 asphalt plants
Bitumen	Road	100%	2.34E+02	
Hard rock aggregate	Road	74.81%	4.90E+01	
	Train	18.77%	3.02E+02	
	River	6.41%	9.13E+01	
Alluvial aggregate	Road	97.97%	3.37E+00	
	Train	2.03%	1.10E+02	

We note that the supply distance for asphalt aggregate is nil. Since the aggregates are generally stored and recycled at the asphalt plants themselves, these transport distances are considered to be nil (see Section 8.5.1).

5.3.2 Environmental data

In contrast to the previous study, road transport was not modelled according to specifications document FD P 01-015. Instead, we used Ecoinvent inventories for transport by lorry in tonnes.kilometres. These are representative inventories of transport by standard EURO 4-type truck with a payload of 16 to 32 t expressed in tonnes.kilometre. They are calculated based on a representative loading rate and empty backhaul rate for Europe. Accordingly, they are not specifically adapted to the actual conditions of the studied transport, but enable estimating the flows related to this transport. Specifically, this LCI takes into consideration a gross weight rating of 15.79 t and a load of 5.79 t, according to data taken from the 2007 TREMOVE European project and the 2011 EcoTransIT eco-calculator. The total vehicle mileage over its life span (used to estimate the impact of infrastructures) has been estimated at 540,000 km.

The other Ecoinvent inventories for railway or river transport are also based on representative conditions of use at European scale.

Table 17 – Data used for raw materials conveyance modelling

Environmental data	
Road transport	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec
Rail transport	Transport, freight train {FR}| processing | Alloc Rec
River transport	Transport, freight, inland waterways, barge {RER}| processing | Alloc Rec

5.4 Production of asphalt (A3)

5.4.1 Water consumption

5.4.1.1 *Baseline data*

The net process and washing water consumption data were directly taken from the 8 plant data collection survey. They are presented below. Data on the consumption of energy for pumping the drilling water have been included in the overall energy consumption for operating the plant.

Table 15 – Process and washing water consumption data

Water type	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Network water	m^3	2.23E-03	Survey of 8 asphalt plants
Drilling water	m^3	9.53E-05	

5.4.1.2 *Environmental data*

The environmental data used for the water consumption are presented in the following table.

Table 16 – Data used for water consumption modelling

Environmental data	
Network water	Tap water {Europe without Switzerland}| market for | Alloc Rec
Drilling water	Flux "water, well, in ground"

5.4.2 Consumption of consumables

5.4.2.1 *Baseline data*

The data on consumption of consumables were directly retrieved from the 8 plant data collection survey. They are presented below.

Table 20 – Data on consumption of consumables

Raw material	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Oil (heating, discharge, etc.)	L	4.77E-03	Survey of 8 asphalt plants
Lubricating oil	kg	1.31E-04	
Loader tyres	kg	4.42E-03	
Scrap metal	kg	3.54E-02	
Non-stick / anti-adhesive material (rape oil methyl ester)	L	1.67E-03	
Sleeves (dust filters)	kg	7.82E-04	

To complete the above data, a distance of 100 km for the supply of consumables was used in calculations. This is an assumption made by BIO and considered acceptable given the small amounts of consumables per tonne of asphalt.

Resource use flows were also accounted for. These data are presented in Annex 8.6.

5.4.2.2 *Environmental data*

The environmental data used for the consumption of consumables are presented below.

Table 17 – Data used for modelling the consumption of consumables

Environmental data	
Oil (heating, discharge, etc.)	Lubricating oil {RER}| production | Alloc Rec
Lubricating oil	Lubricating oil {RER}| production | Alloc Rec
Loader tyres	Tyre LCI reconstructed by BIO IS (see below)
Scrap metal	Steel, low-alloyed {RER}| steel production, electric, low-alloyed | Alloc Rec
Non-stick / Anti-adhesive materials	LCI of "rape methyl ester, at regional storage", reconstructed by BIO (see below)
Sleeves (dust filters)	Nylon 6, at plant / RER

The utilised loader tyre data are presented in the following two tables.

Table 18 – Loader tyre data

Data	Unit	Value per tyre kg (430 kg per tyre)	Source
Rubber	kg	2.00E-01	Assumptions retrieved in the UNPG environmental data information module
Steel	kg	1.30E-01	
Brass	kg	1.00E-02	
Carbon black	kg	2.50E-01	
Resin	kg	1.30E-01	
Sulphur	kg	2.80E-01	

Resource use flows were also accounted for. They are presented in Annex 8.6.

Table 19 – Data used for loader tyre modelling

Environmental data	
Rubber	Synthetic rubber, at plant/RER
Steel	Steel, low-alloyed, at plant/RER
Brass	Brass, at plant/CH
Carbon black	Carbon black, at plant/GLO
Resin	Polyester resin, unsaturated, at plant/RER
Sulphur	Secondary sulphur, at refinery/RER

For anti-adhesives, the LCI "Rape methyl ester, at regional storage/CH" inventory from Ecoinvent 2.2. was used in the previous study. However, this inventory has not been transposed to Ecoinvent 3.1. The only remaining inventory is "Vegetable oil methyl ester {CH}| esterification of rape oil", but it lacks a manufacturing stage to be representative of the used anti-adhesives. Therefore, we reused the data of LCI "Rape methyl ester, at regional storage/CH" taken from Ecoinvent 2.2 based on the LCI of esterified rape methyl ester.

Table 20 - Data of the non-stick/anti-adhesive material based on rape methyl ester

Data	Unit	Values per kg oil	Source
Rape oil	kg	1.0005	Data of Ecoinvent 2.2 LCI "Rape methyl ester, at regional storage/CH"
Water	kg	6.89E-4	
Transport by rail	tkm	0.10005	
Transport by truck	tkm	0.15007	
Distribution infrastructure	Unit	2.62E-10	
Electricity	kWh	6.70E-3	
Domestic fuel oil combustion	MJ	6.21E-4	
Heat emissions to air	MJ	2.41E-2	
BOD5 emission to water	kg	3.50E-3	
DCO emission to water	kg	3.50E-3	
COD emission to water	kg	4.33E-4	
COT emission to water	kg	4.33E-4	
Emission of oil of biogenic origin to the ground	kg	5.00E-4	
Refinery waste	kg	1.68E-4	
Municipal waste	kg	6.27E-6	
Treatment of leached water	m3	7.50E-5	
Water treatment	m3	6.89E-7	

Table 21 – Data used for modelling non-stick/anti-adhesive materials

Environmental data	
Rape oil	Vegetable oil methyl ester {CH}| esterification of rape oil | Alloc Rec
Water	Tap water {CH}| market for | Alloc Rec
Transport by rail	Transport, freight train {CH}| market for | Alloc Rec
Transport by truck	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec
Distribution infrastructure	Infrastructure, for regional distribution of oil product {RER}| construction | Alloc Rec
Electricity	Electricity, low voltage {CH}| market for | Alloc Rec
Domestic fuel oil combustion	Heat, central or small-scale, other than natural gas {CH}| heat production, light fuel oil, at boiler 100kW, non-modulating | Alloc Rec
Heat emissions to air	Flux « Heat, waste » dans l'air
BOD5 emission to water	Flow: "Biological Oxygen Demand", to water
COD emission to water	Flow: "COD, Chemical Oxygen Demand", to water
COD emission to water	Flow: "DOC, Dissolved Organic Carbon", to water
COT emission to water	Flow: "TOC, Total Organic Carbon", to water
Emission of oil of biogenic origin to the ground	Flow: "Oils, biogenic", to the ground
Refinery waste	Refinery sludge {CH}| treatment of, hazardous waste incineration | Alloc Rec
Municipal waste	Municipal solid waste {CH}| treatment of, sanitary landfill | Alloc Rec
Treatment of leached water	Rainwater mineral oil storage {CH}| treatment of, in wastewater treatment plant, capacity 1.1E10l/year | Alloc Rec
Water treatment	Wastewater, average {CH}| treatment of, capacity 1.1E10l/year | Alloc Rec

5.4.3 Energy consumption

Energy consumption has been identified at the burner-dryer station and other stations (boiler for the binder storage tanks, general operations, construction equipment, etc.).

5.4.3.1 *Baseline data on energy consumption at the burner-dryer station*

According to USIRF, approximately 65% of French asphalt plants are equipped with a burner-dryer operating on natural gas and 35% of plants are equipped with a burner-dryer operating on heavy fuel oil. In addition, since the number of asphalt plants on French territory is very large (about 500 plants in mainland France), USIRF indicated that it may be assumed that about 65% of the quantities of asphalt manufactured in France are produced using a natural gas-operated burner and 35% using a heavy fuel-operated burner (assumption of a consistent production pattern of natural gas-operated and heavy fuel-operated plants).

The utilised data on energy consumptions at the burner-dryer are the consolidated data of all the asphalt plants of three major French road industry companies that produce approximately 27 Mt of asphalt per year out of a total annual production of 35 Mt, representing approximately 77% of French production (2011 data).

Table 22 – Source data for the energy consumption of burner-dryers operating on natural gas and heavy fuel oil

Company	Energy source	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3) (kWh)	Annual production (Mt)	Source
Company 1	Heavy fuel oil	6.70E+01	7	Consolidated data of all asphalt plants of three major companies accounting for 77% of the French asphalt production
	Natural gas	6.90E+01	7	
Company 2	Heavy fuel oil	6.10E+01	1.7	
	Natural gas	8.30E+01	4.7	
Company 3	All burner-dryer stations	6.80E+01	6.2	

The assumption used for Company 3, which had only global data without distinguishing between types of burners, was that this company produces 65% of its asphalt using natural gas burners and 35% using heavy fuel oil burners (national distribution). Furthermore, it was also assumed that all the burners of this company consume the same amount of energy per ton of output.

Based on these assumptions, the average consumptions of natural gas burners and heavy fuel oil burners were calculated by averaging the weighted consumptions according to outputs for the two types of burners of the three companies. On this basis, we have obtained the data shown in the following table.

Table 23 – Calculation of the average energy consumptions of burner-dryers operating with natural gas and heavy fuel oil

Company	Energy source	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3) (kWh)	Annual production (Mt)	Source
Company 1	Heavy fuel oil	6.70E+01	7	Consolidated data of all asphalt plants of three major companies accounting for 77% of the French asphalt production
	Natural gas	6.90E+01	7	
Company 2	Heavy fuel oil	6.10E+01	1.7	
	Natural gas	8.30E+01	4.7	
Company 3	Heavy fuel oil	6.80E+01	2.17	Assumptions and calculation
	Natural gas	6.80E+01	4.03	
Weighted average by type of burner for the three companies	**Heavy fuel oil**	**6.63E+01**	**10.9**	
	Natural gas	**7.29E+01**	**15.7**	

Finally, to calculate the energy consumptions at the burner for one representative tonne of asphalt made in France, we applied the French distribution pattern of natural gas-based burner-dryers (65%) and heavy fuel oil-based burner-dryers (35%) to the average consumptions of energy per type of burner presented in the above table. The final utilised data are presented below.

Table 24 – Calculation of energy consumptions at the burner-dryer stations for an average burner-dryer station in France

Station	Energy source	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Burner-dryer	Heavy fuel oil	kWh	2.32E+01	Steering Committee, calculation assumptions
	Natural gas	kWh	4.74E+01	

5.4.3.2 *Baseline data on energy consumption at other stations*

The other energy consumption data were directly retrieved from the 8 asphalt plants survey. The utilised data are presented below.

Table 25 – Data of energy consumption of other stations

Station	Energy source	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Boiler used as binder equipment	Electricity	kWh	6.55E-01	Survey of 8 asphalt plants
	Propane	kWh	1.58E+00	
	Natural gas	kWh	2.81E+00	
Plant operation	Electricity	kWh	3.51E+00	
Construction equipment	Non-road diesel	L	9.39E-02	
	Domestic fuel oil	t	9.31E-05	

5.4.3.3 *Environmental data*

The environmental data used for energy consumption are presented below.

Table 26 – Data used for energy consumption modelling

Environmental data	
Heavy fuel oil	Production: Adaptation of the flow “Heat, district or industrial, other than natural gas {Europe without Switzerland}| heat production, heavy fuel oil, at industrial furnace 1MW | Alloc Rec – Production” by eliminating all the flows related to emissions to air
	Combustion: See the Emissions to air section
Natural gas (burner-dryer)	Production: Adaptation of the flow “Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | Alloc Rec – Production” by eliminating all the flows related to emissions to air
	Combustion: See the Emissions to air section
Electricity	Electricity, medium voltage {FR}| market for | Alloc Rec (see Annex 8.7)
Propane	Propane, burned in building machine {GLO}| propane, burned in building machine | Alloc Rec
Natural gas (boiler)	Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | Alloc Rec
Non-road diesel	Diesel, burned in building machine {GLO}| processing | Alloc Rec
Domestic fuel oil	Light fuel oil, burned in building machine {GLO}| processing | Alloc Rec
	Combustion: Adaptation of the flow “Diesel, burned in building machine {GLO}| processing | Alloc Rec” to retain only the emissions to air

5.4.4 Emissions to air

Emissions to air have been noted at the burner-dryer station and other workstations (boiler for the binder tanks, general operations, construction equipment).

5.4.4.1 *Baseline data on emissions to air at the burner-dryer station*

The data used in this LCA were calculated based on the following sources:

- Data in the USIRF database,
- Specific data collected from the 8 surveyed asphalt plants (reports on air emissions).

The average was weighted according to the plant output.

The USIRF database was used only for data collected for the January 2009 report. Earlier data were not included in calculations, being considered too old. Furthermore, only data of plants that filled in both their production capacity and emission flows were taken into account. For these plants, the output was estimated to be 70% of the production capacity, as had been done in the previous LCA. This figure was estimated by USIRF as the ratio between the actual annual production of an asphalt plant and production at its maximum capacity.

In addition, for specific plants having different datasets in the USIRF database, only the average of the data was taken into account. Finally, for data of the "<x" type where x is the detection threshold, the selected value was x/2.

In addition, we used the Ecoinvent database to fill in data on types of emissions for which no measurements were available. In such cases, the emission data were reduced to one tonne of asphalt based on the representative consumption of fuel (natural gas or fuel oil) per tonne of asphalt. We should also note that the corresponding emission factors have increased slightly between Ecoinvent 2.2 and Ecoinvent 3.1. The representative fuel consumption data that were used (natural gas or fuel oil) were the representative French consumption values per type of burner listed in Table 23. The utilised inventories are presented in the following table.

Table 27 – Data used to fill in emission values at the burner-dryer station

Environmental data	
Heavy fuel oil	Heat, district or industrial, other than natural gas {Europe without Switzerland}| heat production, heavy fuel oil, at industrial furnace 1MW | Alloc Rec
Natural gas	Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at industrial furnace >100kW | Alloc Rec

The obtained emission data are presented in the following tables. The first table relates to burner-dryers using heavy fuel oil, the second to burner-dryers using natural gas. Finally, the last table shows the average emissions generated by a representative burner-dryer in France for one tonne of asphalt. This table factors in both types of fuel according to the national distribution of burners operating on natural gas (65%) and heavy fuel oil (35%).

The following example illustrates the calculations performed for the SO_2 flow.

$$\boldsymbol{SO2\ emissions\ (kg/t\ asphalt)} = SO2\ emissions\ of\ fuel\ oil\ burners\ (kg/t\ asphalt) \times share\ of\ fuel\ oil\ burners + SO2\ emissions\ of\ natural\ gas\ burners\ (kg/t\ asphalt) \times share\ natural\ gas\ burners$$

$$\boldsymbol{SO2\ emissions\ (kg/t\ asphalt)} = 2.67E-02 \times 35\% + 2.94E-03 \times 65\%$$

$$\boldsymbol{SO2\ emissions\ (kg/t\ asphalt)} = 1.13E-02\ kg/t\ asphalt$$

Table 28 – Data on emissions to air of burner-dryers operated with heavy fuel oil

Flow	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Dusts	kg	2.93E-03	USIRF database + Survey of 8 asphalt plants
CO	kg	1.47E-01	
SO_2	kg	2.67E-02	
NO_x	kg	3.97E-02	
NMVOC in C eq. C	kg	1.54E-02	
CH_4	kg	8.75E-04	
Total PAH	kg	2.20E-05	
Formic aldehyde (formaldehyde)	kg	1.86E-04	
Benzene	kg	1.16E-04	
Beryllium	kg	8.18E-07	
Chromium	kg	5.94E-06	
Arsenic	kg	1.31E-06	
Nickel	kg	5.75E-06	
Vanadium	kg	1.27E-05	
Manganese	kg	5.26E-06	
Cobalt	kg	4.12E-06	
Copper	kg	2.11E-06	
Zinc	kg	1.18E-05	
Tin	kg	1.32E-06	
Antimony	kg	9.95E-07	
Lead	kg	2.79E-06	
Cadmium	kg	4.45E-07	
Selenium	kg	4.32E-06	
Tellurium	kg	1.99E-06	
Thallium	kg	5.76E-07	
Mercury	kg	7.60E-07	
Acetaldehyde	kg	3.77E-05	Ecoinvent 3.1
Acetic acid	kg	1.51E-04	
Acetone	kg	3.77E-05	
Ammonia	kg	2.51E-06	
Benzo(a)pyrene	kg	7.03E-09	
Calcium	kg	2.76E-05	
Carbon dioxide, fossil	kg	1.98E+01	
Dinitrogen monoxide	kg	2.01E-04	
Ethanol	kg	7.54E-05	
Hydrocarbons, aliphatic, alkanes, unspecified	kg	1.51E-04	
Hydrocarbons, aliphatic, unsaturated	kg	7.54E-06	
Hydrocarbons, aromatic	kg	3.77E-05	
Hydrogen chloride	kg	3.62E-04	
Hydrogen fluoride	kg	1.21E-05	
Iron	kg	2.06E-04	
Methanol	kg	1.28E-04	
Molybdenum	kg	2.01E-06	
Propane	kg	7.54E-06	
Sodium	kg	1.88E-04	
Toluene	kg	7.54E-06	

Table 29 – Data on emissions to air of a burner-dryer operated with natural gas

Flow	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Dusts	kg	3.48E-03	USIRF database + Survey of 8 asphalt plants
CO	kg	5.05E-02	
SO_2	kg	2.94E-03	
NO_x	kg	7.83E-03	
NMVOC in C eq. C	kg	8.14E-03	
CH_4	kg	9.34E-03	
Total PAH	kg	3.78E-06	
Formic aldehyde (formaldehyde)	kg	2.46E-04	
Benzene	kg	9.19E-05	
Copper	kg	3.17E-06	
Lead	kg	1.63E-06	
Mercury	kg	8.29E-09	Ecoinvent 3.1
Acetaldehyde	kg	2.76E-07	
Acetic acid	kg	4.15E-05	
Benzo(a)pyrene	kg	2.76E-09	
Butane	kg	1.93E-04	
Carbon dioxide, fossil	kg	1.55E+01	
Dinitrogen monoxide	kg	2.76E-05	
Pentane	kg	3.32E-04	
Propane	kg	5.53E-05	
Propionic acid	kg	5.53E-06	
Toluene	kg	5.53E-05	

Table 30 – Data on emissions to air of a representative French burner-dryer

Flow	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Dusts	kg	3.29E-03	USIRF database + Survey of 8 asphalt plants
CO	kg	8.44E-02	
SO_2	kg	1.13E-02	
NO_x	kg	1.90E-02	
NMVOC in C eq. C	kg	1.07E-02	
CH_4	kg	6.38E-03	
Total PAH	kg	1.01E-05	
Formic aldehyde (formaldehyde)	kg	2.25E-04	
Benzene	kg	1.00E-04	
Beryllium	kg	2.86E-07	
Chromium	kg	2.08E-06	
Arsenic	kg	4.60E-07	
Nickel	kg	2.01E-06	
Vanadium	kg	4.43E-06	
Manganese	kg	1.84E-06	
Cobalt	kg	1.44E-06	
Copper	kg	7.38E-07	
Zinc	kg	4.14E-06	
Tin	kg	4.62E-07	
Antimony	kg	3.48E-07	
Lead	kg	2.03E-06	
Cadmium	kg	1.56E-07	
Selenium	kg	1.51E-06	
Tellurium	kg	6.95E-07	
Thallium	kg	2.02E-07	
Mercury	kg	2.71E-07	
Acetaldehyde	kg	1.34E-05	Ecoinvent 3.1
Acetic acid	kg	7.97E-05	
Acetone	kg	1.32E-05	
Ammonia	kg	8.79E-07	
Benzo(a)pyrene	kg	4.26E-09	
Butane	kg	1.26E-04	
Calcium	kg	1.57E-07	
Carbon dioxide, fossil	kg	1.70E+01	
Dinitrogen monoxide	kg	8.83E-05	
Ethanol	kg	2.64E-05	
Hydrocarbons, aliphatic, alkanes, unspecified	kg	5.27E-05	
Hydrocarbons, aliphatic, unsaturated	kg	2.64E-06	
Hydrocarbons, aromatic	kg	1.32E-05	
Hydrogen chloride	kg	1.27E-04	
Hydrogen fluoride	kg	4.22E-06	
Iron	kg	7.21E-05	
Methanol	kg	4.48E-05	
Molybdenum	kg	7.07E-06	
Pentane	kg	2.16E-04	
Propane	kg	3.86E-05	
Propionic acid	kg	3.59E-06	
Sodium	kg	6.59E-05	
Toluene	kg	3.86E-05	

5.4.4.2 *Baseline data on emissions to air related to the other stations*

The emissions to the air of other stations are generated by the energy consumption of these stations. They have been modelled based on the LCA in the Ecoinvent 3.1 database set out in Table Table 26.

5.4.5 Emissions to water

Emissions to water are related to two types of water discharges:

- Process and washing water discharges,
- Rainwater discharges.

5.4.5.1 *Baseline data on process and washing water discharges*

The quantities of process and washing water discharges are considered to be equal to the consumption of process and washing water.

Table 31 – Data of process and washing water discharges

Data	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Process and washing water (network + drilling)	m^3	2.32E-03	Survey of 8 asphalt plants

5.4.5.2 *Baseline data on rainwater discharges*

The emissions to water attributable to rainwater discharges have been calculated based on the data collected from the 8 plants.

Rainwater discharges were estimated based on the average rainfall in France (867 mm/year according to the World Bank), the surface areas of the asphalt plants and by assuming an impermeable surface of 20% of sites (source: USIRF Steering Committee).

The plant reports of emissions to water, which provided the concentrations of pollutants in water, were subsequently used to calculate the annual emissions of the plants, and subsequently the emissions per ton of asphalt for each plant.

These values were then weighted according to the output of each plant to determine the emissions to water for one representative tonne of asphalt.

Table 32 – Emissions to water from rainwater runoffs at plant sites

Flow	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Nitrites + Nitrates	kg N	3.57E-06	Survey of 8 asphalt plants
DCO	kg O_2	8.26E-04	
DBO5	kg O_2	4.84E-05	
MES	kg	7.49E-04	
Hydrocarbon index	kg	5.82E-06	

5.4.5.3 *Environmental data*

The emissions related to process and washing water discharges have been modelled using the data presented in the table below.

Table 35 – Data used for modelling emissions to water related to process and washing water discharges

Environmental data	
Process and washing water routed to wastewater treatment plant	Wastewater, average {CH}| treatment of, capacity 5E9l/year | Alloc Rec
Emissions of nitrites and nitrates to the water	Flow: “Nitrate”, to water

Environmental data	
COD emission to water	Flow: “COD, Chemical Oxygen Demand”, to water
BOD5 emission to water	Flow: “Biological Oxygen Demand”, to water
Suspended solids emissions	Flow: “Suspended solids, unspecified”, to water
Hydrocarbon emission to water	Flow: “Hydrocarbons, unspecified”, to water

5.4.6 Waste production

5.4.6.1 *Baseline data*

The plants' waste includes the waste of consumables and inert aggregates. The utilised data were obtained from the 8 plant data collection survey and are presented below.

The production of waste related to consumables was considered to be equal to the consumption of consumables of the plants.

The inert aggregates (waste produced at the start and end of production) are used at asphalt plant sites as a source of asphalt aggregates. This type of waste is therefore recycled in-house.

Table 33 – Data on waste generation

Type	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Oil (heating, discharge, etc.), incinerated	L	4.77E-03	Survey of 8 asphalt plants
Incinerated lubricants	kg	1.31E-04	
Recycled loader tyres	kg	4.42E-03	
Recycled metal scrap	kg	3.54E-02	
Incinerated sleeves (dust filters)	kg	7.82E-04	
In-house recycled inert aggregate	kg	9.88E+00	
Waste transport distance	km	3.00E+01	BIO assumption

Output flows have also been factored in. They are presented in Annex 8.6.

5.4.6.2 *Environmental data*

The environmental data used for modelling waste treatment flows are presented below.

Table 34 – Data used for waste modelling

Environmental data	
Oil (heating, discharge, etc.)	Waste mineral oil {CH}| treatment of, hazardous waste incineration | Alloc Rec
Lubricating oil	Waste mineral oil {CH}| treatment of, hazardous waste incineration | Alloc Rec
Loader tyres	Recycling (UNPG assumption) --> Stocks method (see annex)
Scrap metal	Recycling (UNPG assumption) --> Stocks method (see annex)
Tyre and metal scrap materials intended for recycling	Flow: “Materials intended for recycling”
Sleeves (dust filters)	Waste plastic, mixture {CH}| treatment of, municipal incineration | Alloc Rec
Inert aggregate waste	Recycling --> Stocks method (see annex)
Road transport at end of life	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

With regard to waste routed to incineration, we consider this waste to be discharged to a household waste incinerator and not to a plant operated with secondary fuels (refer to Note 4 of Chapter 7.2.5 of Standard NF EN 15804+A1). Therefore, we assume that no energy is transmitted to the outside.

5.4.7 Infrastructures

5.4.7.1 *Baseline data*

This part comprises asphalt plant infrastructure data and data of loaders used for asphalt production.

Loader data were obtained from the SEVE system (loader mass and lifespan data were retrieved from the database "Wheeled Loader, 20 to 25 t"). Loader amortisation was calculated by assessing the total asphalt production over the loader's lifespan. This was supplemented by the following assumptions/data:

- Tyres were not taken into account, as they were included in the section on consumables (5.4.2).
- The maintenance coefficient (as defined in the SEVE[7] system) was considered to be nil, since the steel used for loader maintenance was included in the section on consumables (5.4.2).
- The fuel was not taken into account, being included the section on energy consumption (5.4.3).
- The loader's steel structure at end of life was assumed as being 100% recycled (assumption made in the UNPG information modules). Consequently, according to the stocks method, it does not have any end-of-life environmental impact. Only one 30-km transport was included in the calculation.

The utilised data are presented in the following table.

Table 35 – Calculation of the amortised loader mass

Data	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Loader mass	t	2.20E+01	USIRF - SEVE system
Loader lifespan	h	1.20E+04	
Average output of one plant	t of asphalt/h	1.51E+02	Data collection
Loader mass per tonne of asphalt	**t/t of asphalt**	**1.22E-05**	**Calculation**

Data on plant infrastructures were retrieved from the earlier USIRF LCA. For consistency reasons, data of the respective plant's output was also retrieved from this earlier LCA.

Similarly to the loader, the plant's steel structure has been considered to be 100% recycled at end of life. Consequently, according to the stocks method, it does not have any end-of-life environmental impact. Only one 30-km transport was included in the calculation. Output flows and resource use flows are also accounted for. These data are presented in Annex 8.6.

The utilised data are presented in the table below.

[7] The maintenance coefficient is defined in the SEVE system as the coefficient to apply to the mass of a machine to estimate its maintenance cost (on the average 1 for conventional equipment and 2 for equipment that uses a large number of wear parts).

Table 36 – Calculation of the amortised plant mass

Data	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Plant mass	t	3.00E+02	Earlier USIRF LCA study
Plant lifespan	Year	2.00E+01	
Plant output	t of asphalt/year	1.00E+05	
Plant mass per tonne of asphalt	**t/t of asphalt**	**1.50E-04**	**Calculation**

5.4.7.2 *Environmental data*

In accordance with the assumptions made in the SEVE system and the earlier USIRF LCA study, the loader and the plant are considered to be entirely made of steel. The environmental data pertaining to the production and end of life of the materials making up the infrastructures are presented in the following table. It should be noted that the preparation of materials, which generally is a lower-impact step compared to the production of materials, has been ignored.

Table 37 – Data used for infrastructure modelling

Environmental data	
Loader output	Steel, low-alloyed, at plant / RER
Plant output	Steel, low-alloyed, at plant / RER
Loader end of life	Flow: "Materials intended for recycling"
Plant end of life	Flow: "Materials intended for recycling"
Transport	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

5.4.8 Consolidated data on the production of one tonne of asphalt

This section describes the underlying assumptions and data used in compiling the life cycle inventory for the production of one square metre of pavement over one year. In a way, it represents the link between the two studied systems: production of one tonne of asphalt on the one hand and the pavement life cycle on the other hand.

5.4.8.1 *Baseline data*

The quantities of materials required for the various pavement layers were calculated based on the pavement structures provided by the USIRF Steering Committee (see Figure 2). This structure is reviewed in the following table.

Table 38 – Source data for the pavement materials

Layer	Unit	Values for 1 m² of pavement	Source
Wearing course - Asphalt concrete	cm	6.00E+00	USIRF Steering Committee
Tack coat - Bitumen emulsion	g/m^2	5.00E+02	
Base course - Gravel bitumen	cm	9.00E+00	
Tack coat - Bitumen emulsion	g/m^2	5.00E+02	
Sub-base course - Gravel bitumen	cm	9.00E+00	
Tack coat - Bitumen emulsion	g/m^2	5.00E+02	

Since the respective compositions of asphalt concrete and gravel bitumen are different, their densities are not strictly identical (difference of 1 to 2%). Nevertheless, this difference was considered by the USIRF Steering

Committee to be negligible. The densities of asphalt concrete (AC) and gravel bitumen (GB3) were therefore assumed to be identical and equal to 2.35 t/m^3.

Moreover, in agreement with the study Steering Committee, the rate of loss was considered to be nil.

The data obtained based on these calculations are presented in the following table.

Table 39 – Data concerning the production of the various pavement materials

Layer	Unit	Values for 1 m² of pavement	Source
Wearing course - Asphalt concrete	t/m²	1.41E-01	Calculation
Tack coat - Bitumen emulsion	t/m²	5.00E-04	
Base course - Gravel bitumen	t/m²	2.12E-01	
Tack coat - Bitumen emulsion	t/m²	5.00E-04	
Sub-base course - Gravel bitumen	t/m²	2.12E-01	
Tack coat - Bitumen emulsion	t/m²	5.00E-04	
Total mass	**t/m²**	**5.66E-01**	

The data used for the production of asphalt concrete (AC) and gravel bitumen (GB3) are presented in the previous sections. Tack coat data are presented below.

Table 40 – Data of consumption of raw materials for production of tack coats

Raw material	Unit	Values for 1 t of tack coat	Source
Bitumen	kg	6.00E+02	USIRF Steering Committee
Water	kg	4.00E+02	

A simplifying assumption was made for the transport stages of tack coats by assuming that the bitumen emulsion was produced at the plants and was subsequently transported to the work site from the plants. Accordingly, the transport distance of the bitumen used in the bitumen emulsion was considered identical with that of the bitumen used in AC or GB3, namely 234 km. This assumption has no implication on the results of the LCA. In fact, since the mass of the tack coats is very small compared to the mass of the asphalt layers, the environmental impact of the transport of bitumen emulsion is very small compared to the impacts of asphalt transport.

5.4.8.2 *Environmental data*

The environmental data used for the production of asphalt concrete (AC) and gravel bitumen (GB3) are presented in the previous sections. Tack coat data are presented below.

Table 41 – Data used for tack coat modelling

	Environmental data
Bitumen	EUROBITUME: Life Cycle Inventory of Bitumen (with infrastructure) (2011)
Water	Tap water, at user / RER

5.5 Transport of materials to the work site (A4)

The sources of impact to be considered for this stage are the transport of asphalt to the work site and bitumen fume emissions during truck loading. These fumes are produced by hot vapours released by bitumen, which condense on cooling. The fine droplets thus formed produce a cloud called “bitumen fumes”. Later, during transport, since the trucks are covered, the bitumen fumes are considered nil.

5.5.1 Baseline data

A transport distance of 30 km was selected by the Steering Committee as an average distance between the asphalt plant and the work site. In fact, when the distance between a work site and the stationary plants is too large (about >60 km), mobile plants are used. Still, it may be noted that this distance parameter has no significant influence on the overall impacts of the pavement (less than 5% of impacts over the entire pavement life cycle, refer to Section 6.5.5).

Bitumen fume data were assessed based on the fume composition and concentration data provided in the CIMAROUT database. The full modelling is presented in detail in Annex 8.3.2 to this document.

The utilised data for the transport stage are presented in the following table. As indicated in the above paragraph, we made the simplifying assumption that the bitumen emulsion follows the same logistic route as the asphalt and is conveyed over the same distance (30 km).

Table 42 – Data on the transport of materials from the asphalt plant to the work site

Data	Unit	Values for 1 m² of pavement	Source
Transport distance (plant - work site)	km	3.00E+01	USIRF Steering Committee
Total mass to be transported	t	5.66E-01	Calculation

Table 43 – Data on the bitumen fume emissions during the transport of materials from the asphalt plant to the work site

Data	Unit	Values for 1 m² of pavement	Source
Fluoranthene	kg	1.82E-12	Calculation
Pyrene	kg	1.22E-12	Calculation
Benzo(a)anthracene	kg	5.78E-14	Calculation
Chrysene	kg	2.65E-13	Calculation
Benzo(b)fluoranthene	kg	1.42E-13	Calculation
Benzo(j)fluoranthene	kg	5.29E-14	Calculation
Benzo(k)fluoranthene	kg	6.02E-14	Calculation
Benzo(a)pyrene	kg	8.42E-14	Calculation
Benzo(e)pyrene	kg	2.02E-13	Calculation
Dibenzo(a,h)fluoranthene	kg	3.37E-14	Calculation
Benzo(ghi)perylene	kg	1.08E-13	Calculation
Indeno(1,2,3-cd)pyrene	kg	4.33E-14	Calculation
Naphthalene	kg	2.25E-07	Calculation
Acenaphthene	kg	4.78E-08	Calculation
Fluorene	kg	2.64E-08	Calculation
Phenanthrene	kg	4.72E-08	Calculation
Anthracene	kg	2.20E-09	Calculation
Fluoranthene	kg	2.94E-09	Calculation
Pyrene	kg	1.78E-09	Calculation
Benzene	kg	4.21E-09	Calculation
Cyclopentane	kg	4.81E-09	Calculation
n-Hexane	kg	1.20E-08	Calculation
Toluene	kg	3.37E-08	Calculation
Styrene	kg	2.41E-09	Calculation
Xylenes	kg	8.88E-07	Calculation
Ethylbenzene	kg	8.45E-07	Calculation
Formaldehyde	kg	2.41E-09	Calculation

5.5.2 Environmental data

The used transport modelling data are presented in the following table.

Table 44 – Data used for modelling the transport of materials from the asphalt plant to the work site

Environmental data	
Transport of materials (plant - work site)	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

The bitumen fumes were directly included in the inventory within the flows indicated in the following table. Some flows are not listed in the Ecoinvent database and were modelled based on approximated flows (for example, the cyclopentane was modelled according to a flow: “Hydrocarbons, unspecified”, to air. This does not impair the modelling, provided that such approximated flows contribute only to aggregated flow categories (Unspecified hydrocarbons, PAH, unspecified VOC) of the air pollution indicator with conversion factors equal to 1.

Table 45 – Data used for modelling bitumen fume emissions during the transport of materials from the asphalt plant to the work site

Substance	Associated flow
Fluoranthene	Flow: “Fluoranthene”, to air
Pyrene	Flow: “Pyrene”, to air
Benzo(a)anthracene	Flow: “Benzo(a)anthracene”, to air
Chrysene	Flow: “Chrysene”, to air
Benzo(b)fluoranthene	Flow: “Benzo(b)fluoranthene”, to air
Benzo(j)fluoranthene	Flow: “PAH, polycyclic aromatic hydrocarbons”, to air
Benzo(k)fluoranthene	Flow: “Benzo(k)fluoranthene”, to air
Benzo(a)pyrene	Flow: “Benzo(a)pyrene”, to air
Benzo(e)pyrene	Flow: “PAH, polycyclic aromatic hydrocarbons”, to air
Dibenzo(a,h)fluoranthene	Flow: “PAH, polycyclic aromatic hydrocarbons”, to air
Benzo(ghi)perylene	Flow: “Benzo(g,h,i)perylene”, to air
Indeno(1,2,3-cd)pyrene	Flow: “Indeno(1,2,3-cd)pyrene”, to air
Naphthalene	Flow: “Naphtalene”, to air
Acenaphthene	Flow: “Acenaphtene”, to air
Fluorene	Flow: “Fluorene”, to air
Phenanthrene	Flow: “Phenanthrene”, to air
Anthracene	Flow: “Anthracene”, to air
Fluoranthene	Flow: “Fluoranthene”, to air
Pyrene	Flow: “Pyrene”, to air
Benzene	Flow: “Benzene”, to air
Cyclopentane	Flow: “Hydrocarbons, unspecified”, to air
n-Hexane	Flow: “Hexane”, to air
Toluene	Flow: “Toluene”, to air
Styrene	Flow: “Toluene”, to air
Xylenes	Flow: “Xylene”, to air
Ethylbenzene	Flow: “Benzene, ethyl-”, to air
Formaldehyde	Flow: “Formaldehyde”, to air

5.6 Pavement laying (A5)

The sources of environmental impact to be taken into account for the laying stage are the construction machines used for applying the various types of materials and the bitumen fumes generated by asphalt heating during laying.

5.6.1 Baseline data

The data on construction equipment were retrieved from the SEVE system (Asphalt laying plant, medium production rate machine, 700 t/d) from the previous USIRF LCA study and from the USIRF Steering Committee. The construction equipment used for asphalt laying consists of one finisher and one roller. In addition, a vacuum sweeper pass is required before applying the materials.

The utilised source data are presented in the following table.

Table 46 – Source data related to pavement-laying machinery

Data	Unit	Values	Source
Finisher production rate (15 to 20t)	t/day	7.00E+02	USIRF - SEVE system
Production rate of a V1 tandem vibratory roller	t/day	3.50E+02	
Sweeper production rate (without prior planing)	m²/day	2.00E+03	USIRF Steering Committee
Production of sweepings (without planing)	L/m²	2.00E+00	Earlier USIRF LCA study

The data of asphalt-laying equipment was then expressed in terms of machine days required to lay one square metre of pavement. For the sweepings, since the source data were already expressed in square meters, no further calculation was necessary. The volume of sweepings was converted into mass based on the assumption of a density of 1 kg/L (source: earlier USIRF LCA study). The results of these calculations are shown below. Additionally, we have also assumed a distance of 30 km for transport of the sweepings from the work site to the landfill burial site (source: BIO assumption).

Table 47 – Data on asphalt-laying machines

Data	Unit	Values for 1 m² of pavement	Source
Finisher (15 to 20t)	Day	8.08E-04	Calculation
V1 tandem vibratory roller	Day	1.62E-03	
Suction sweeper	Day	5.00E-04	
Production of sweepings (without planing)	kg	2.00E+00	

Resource use flows for the steel contained in this equipment were also accounted for. They are presented in Annex 8.6.

Finally, data on the composition and concentration of bitumen fumes were supplied by the USIRF Steering Committee. The modelling performed to account for these fumes is set out in Annex 8.3. The results of these calculations are presented in the following table.

Table 48 – Data on bitumen fume emissions during asphalt laying

Data	Unit	Values for 1 m² of pavement	Source
Fluoranthene	kg	4.28E-08	Calculation
Pyrene	kg	2.87E-08	
Benzo(a)anthracene	kg	1.36E-09	
Chrysene	kg	6.22E-09	
Benzo(b)fluoranthene	kg	3.34E-09	
Benzo(j)fluoranthene	kg	1.24E-09	
Benzo(k)fluoranthene	kg	1.41E-09	
Benzo(a)pyrene	kg	1.98E-09	
Benzo(e)pyrene	kg	4.75E-09	
Dibenzo(a,h)fluoranthene	kg	7.92E-10	
Benzo(ghi)perylene	kg	2.54E-09	
Indeno(1,2,3-cd)pyrene	kg	1.02E-09	
Naphthalene	kg	5.30E-03	
Acenaphthene	kg	1.12E-03	
Fluorene	kg	6.20E-04	
Phenanthrene	kg	1.11E-03	
Anthracene	kg	5.17E-05	
Fluoranthene	kg	6.91E-05	
Pyrene	kg	4.18E-05	
Benzene	kg	9.90E-05	
Cyclopentane	kg	1.13E-04	
n-Hexane	kg	2.83E-04	
Toluene	kg	7.92E-04	
Styrene	kg	5.66E-05	
Xylenes	kg	2.09E-02	
Ethylbenzene	kg	1.98E-02	
Formaldehyde	kg	5.66E-05	

5.6.2 Environmental data

The environmental data related to asphalt-laying machines are presented below and are detailed in Annex 8.4. The sweepings are assumed to be buried as inert waste.

Table 49 – Data used for modelling asphalt laying activities

Environmental data	
Finisher (15 to 20t)	Finisher (15 to 20t) (see annex)
V1 tandem vibratory roller	V1 tandem vibratory roller (see annex)
Suction sweeper	Suction sweeper (see annex)
Buried sweepings	Inert waste {CH}| treatment of, sanitary landfill | Alloc Rec
Transport of sweepings	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

Similarly with the bitumen fumes released during truck loading, the bitumen fumes released during asphalt laying have also been directly included into the inventory (see Table 45).

5.7 Pavement service life (B1-B7)

The lifespan of the pavement comprises several maintenance stages. In line with the principle of modularity of Standard NF EN 15804, we can classify them within Maintenance module B2.

5.7.1 Baseline data

The baseline data for the service life stage were retrieved from the maintenance scenarios defined by the USIRF Steering Committee (Table 6 and Table 7). For asphalt production, transport and laying during the service life, we reused the source data presented in the previous sections after adjusting them according to the quantities required for road maintenance.

The data used for production and transport are presented in the following tables.

Table 50 – Data related to asphalt production during the service life

Data	Unit	Values for 1 m² of pavement	Source
Asphalt Concrete	t/m²	6.82E-01	Calculation
Bitumen emulsion	t/m²	4.00E-03	

Table 51 – Data related to transport during the service life

Data	Unit	Values for 1 m² of pavement	Source
Mass to be transported	t	6.86E-01	Calculation
Transport distance	km	3.00E+01	

Table 52 – Data related to bitumen fume emissions during the transport of materials from plant to the construction site during the service life

Data	Unit	Values for 1 m² of pavement	Source
Fluoranthene	kg	2.21E-12	Calculation
Pyrene	kg	1.48E-12	
Benzo(a)anthracene	kg	7.00E-14	
Chrysene	kg	3.21E-13	
Benzo(b)fluoranthene	kg	1.72E-13	
Benzo(j)fluoranthene	kg	6.42E-14	
Benzo(k)fluoranthene	kg	7.29E-14	
Benzo(a)pyrene	kg	1.02E-13	
Benzo(e)pyrene	kg	2.45E-13	
Dibenzo(a,h)fluoranthene	kg	4.08E-14	
Benzo(ghi)perylene	kg	1.31E-13	
Indeno(1,2,3-cd)pyrene	kg	5.25E-14	
Naphthalene	kg	2.73E-07	
Acenaphthene	kg	5.79E-08	
Fluorene	kg	3.20E-08	
Phenanthrene	kg	5.72E-08	
Anthracene	kg	2.67E-09	
Fluoranthene	kg	3.56E-09	
Pyrene	kg	2.16E-09	
Benzene	kg	5.10E-09	

Data	Unit	Values for 1 m² of pavement	Source
Cyclopentane	kg	5.83E-09	
n-Hexane	kg	1.46E-08	
Toluene	kg	408E-08	
Styrene	kg	2.92E-09	
Xylenes	kg	1.08E-06	
Ethylbenzene	kg	1.02E-06	
Formaldehyde	kg	2.92E-09	

As indicated in Section 5.4.8, we have made the simplifying assumption that the bitumen emulsion follows the same logistic route as the asphalt and is conveyed over the same distance (30 km).

In addition to the finisher and roller used for asphalt laying, pavement maintenance also requires periodic planing as well as sweeping before each application of asphalt. The source data for this equipment were provided by the USIRF Steering Committee and are presented below.

Table 53 – Source data related to asphalt-laying equipment during the service life

Data	Unit	Values for 1 m² of pavement	Source
Number of planing operations	Number	5.00E+00	SEVE system + USIRF Steering Committee
Planer production rate	t/day	7.00E+02	
Number of sweeper passes (without planing)	Number	2.00E+00	
Production rate of the sweeper (without planing)	m²/day	2.00E+00	
Production of sweepings (without planing)	L/m²	2.00E+00	
Number of sweeper passes (including planing)	Number	5.00E+00	
Production rate of the sweeper (including planing)	m²/day	2.00E+03	
Production of sweepings (including planing)	L/m²	8.00E+00	

All the construction equipment data were subsequently calculated per square meter of pavement.

Table 54 – Data related to asphalt-laying equipment during the service life

Data	Unit	Values for 1 m² of pavement	Source
Finisher (15 to 20t)	Day	9.79E-04	Calculation
V1 tandem vibratory roller	Day	1.96E-03	
Planer, 2m to 2.2m	Day	6.21E-04	
Asphalt planings	kg	4.35E+02	
Suction sweeper	Day	3.50E-03	
Sweepings	kg	4.40E+01	

To complement these data, we have assumed a distance of 30 km for the transport of planing and the sweeping waste from the work site to the landfill burial site (source: BIO IS assumption). Output flows have also been factored in. They are presented in Annex 8.6.

Finally, the data on bitumen fume emissions in the course of the various asphalt-laying phases during the service life state are presented below.

Table 55 – Data on bitumen fume emissions in the course of asphalt-laying during the service life stage

Data	Unit	Values for 1 m² of pavement	Source
Fluoranthene	kg	5.18E-08	Calculation
Pyrene	kg	3.48E-08	
Benzo(a)anthracene	kg	1.65E-09	
Chrysene	kg	7.54E-09	
Benzo(b)fluoranthene	kg	4.04E-09	
Benzo(j)fluoranthene	kg	1.51E-09	
Benzo(k)fluoranthene	kg	1.71E-09	
Benzo(a)pyrene	kg	2.40E-09	
Benzo(e)pyrene	kg	5.76E-09	
Dibenzo(a,h)fluoranthene	kg	9.60E-10	
Benzo(ghi)perylene	kg	3.08E-09	
Indeno(1,2,3-cd)pyrene	kg	1.23E-09	
Naphthalene	kg	6.42E-03	
Acenaphthene	kg	1.36E-03	
Fluorene	kg	7.52E-04	
Phenanthrene	kg	1.34E-03	
Anthracene	kg	6.27E-05	
Fluoranthene	kg	8.38E-05	
Pyrene	kg	5.07E-05	
Benzene	kg	1.20E-04	
Cyclopentane	kg	1.37E-04	
n-Hexane	kg	3.43E-04	
Toluene	kg	9.60E-04	
Styrene	kg	6.86E-05	
Xylenes	kg	2.53E-02	
Ethylbenzene	kg	2.41E-02	
Formaldehyde	kg	6.86E-05	

It should be noted that no emissions to the water were taken into account during the service life. In fact, studies carried out on asphalt aggregates in preparation of the guide "Environmental Acceptability of Alternative Materials in Road Construction - Deconstruction Materials from Building and Public Works" and a USIRF study on new types of asphalt have shown that the release levels are extremely low. Specifically, the USIRF study states that “the amounts of pollutants released in bituminous asphalt leachate are […] extremely small”. The concentrations of all the studied elements in solution are almost systematically below quantification limits”.

5.7.2 Environmental data

In addition to the environmental data presented in the foregoing paragraphs, we used the following data.

Table 56 – Data used for modelling the service life

Environmental data	
Planer, 2m to 2.2m	Planer, 2m to 2.2m (see annex)
Asphalt planings	Recycling - Stocks method (see annex)
Transport of planing waste	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec
Suction sweeper	Suction sweeper (see annex)
Sweepings	Inert waste {CH}| treatment of, sanitary landfill | Alloc Rec
Transport of sweepings	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

5.8 End of life of the pavement (C1-C4)

This study assumes that the pavement will remain in place beyond the 100-year period taken into consideration and can be reused as support for a future roadway.

Accordingly, no deconstruction phases were taken into calculation at the end-of-life stage.

The quantity of pavement remaining in place is calculated as follows:

- 566 kg are applied during the initial pavement laying (A3).
- Over the entire service life, the various additions and planings of asphalt produce an additional 10.5 cm of asphalt. Assuming that asphalt density is 2,350 kg/m^3 (source: USIRF), this corresponds to approximately 245 kg of materials left in place at end of life.

Table 57 – Data related to the end-of-life stage

Data	Unit	Values for 1 m² of pavement	Source
Mass of road materials remaining in place at end of life	t	8.11E-01	Calculation

Only the output flows were taken into consideration. These data are presented in Annex 8.6.

5.9 Benefits and burdens beyond system boundaries (D)

5.9.1 Introduction

Accounting for the benefits (and burdens) occurring beyond the system boundaries is a normative development that allows factoring in environmental benefits related to recovery of energy or materials (recycling) of reusable flows at end of life.

In accordance with Standard NF EN 15804+A1, these benefits and burdens are calculated:

- Based on the net flows of output secondary materials (secondary output materials minus input secondary materials),
- By taking into account the impacts related to recycling or recovery processes beyond system boundaries (beyond the “end-of-waste” status) up to the point of functional equivalence where the material replaces the primary production and by subtracting the impacts resulting from the replaced production of material.

The relevant flows are:

- For the output flows of secondary materials:
  - Asphalt planings resulting from planing during the pavement’s service life;
  - The road mass remaining in place after the pavement’s end of life.

- For the input flows of secondary materials:
  - Use of asphalt aggregate in the production of the asphalt mix used in the pavement.
- Regarding the recycling or recovery processes:
  - With regard to the asphalt planings, the planing operations are included in the service life stage and are unrelated to the fate of the planings. The regulations concerning the end of waste status of these materials are still being developed by professional groups and public authorities as of the preparation of this study. Nevertheless, we have adopted a prospective scenario position where the case of asphalt planings is being handled. In accordance with the CEREMA guideline "Acceptability of Deconstruction Materials for Road Construction" (under publication), such materials must undergo compliance tests to demonstrate that they do not contain any hazardous substances, such as asbestos or tar. As these substances have not been used in road construction for several decades, we consider that the tests are conclusive and the planings can be reused. Since the mass of the tested materials is low, we will also consider that the transport involved in this procedure is negligible. In order to be reused, planings must undergo crushing and screening, estimated to be identical with the processing of asphalt aggregate (see Section 8.5.1).
  - For the materials remaining in place at end of life, no impacts related to recycling or recovery processes are being considered.
- In coordination with USIRF members, it was agreed that the avoided impacts related to production of replaced material correspond to:
  - For planings: the production of bitumen and aggregate in the bituminous mix recipe;
  - For the mass of materials remaining in place at end of life: the production, transport and application of road base courses.

It should be noted that other waste generated during the pavement's life cycle is also recycled (tyres, scrap metal, infrastructures, steel from construction equipment at end of life). The following table presents the results of the indicators in the flows: "Components intended for reuse" and "Materials intended for recycling" during the pavement's life cycle (modules A1-A3 to C1-C4).

Table 58 - Flows of material reused or recycled during the pavement's life cycle

Stage	Materials	Type of reuse	Values for 1 m² of pavement (in kg)
A1-A3 Manufacture	Tyres Scrap metal Loader Plant	Materials intended for recycling	1.14E-01
A5 Placement	Construction equipment	Materials intended for recycling	6.73E-02
B2 Maintenance	Construction equipment Materials intended for recycling in modules A1-A3 Materials intended for recycling in modules A5	Materials intended for recycling	3.47E-01
	Asphalt planings	Materials intended for recycling	**4.35E+02**
C3 Waste treatment	**Materials remaining in place at pavement end of life**	**Components intended for reuse**	**8.11E+02**

As shown in the previous table, the masses of such recycled materials represent less than 0.05% of the total quantities of recycled waste. Accordingly, they have been ignored, taking into account only the recycling of planings and materials remaining in place at end of life for modelling module D.

The case of planings and materials remaining in place at end of life is discussed separately in the next two sections.

5.9.2 Asphalt planings

- **Input and output flows of secondary materials**

The following table sums up output and input flows of secondary materials in the system at the different stages of the life cycle.

Table 59 - Output and input flows of secondary materials (for 1 m² of pavement)

Type of flows	Stage	Material	Value (kg/m²)
Input flows: use of secondary materials	Production stage A1-A3	Asphalt aggregate	5.21E+01
	Service life stage – maintenance B2	Asphalt aggregate	6.29E+01
Output flows: materials intended for recycling and reuse	Service life stage – maintenance B2	Asphalt planings replacing bituminous asphalt	4.35E+02

The following table presents the balance of the net output flows for asphalt planings.

Table 60 - Calculation of the net output flows

Type of secondary material	Flow	Value
Asphalt planings that replace bituminous asphalt	Net output flow = Output flow - input flow (kg/m²)	3.20E+02

- **Composition of replaced materials**

The following table presents the composition of the replaced materials. It is estimated that the crushed asphalt planings inputted into production processes replace the respective components of material, considering virgin materials only. Thus, we estimate that recycling avoids the production of “virgin” constituent materials of “virgin” bituminous mix (without the asphalt aggregate content).

Since the study targets two types of asphalt mix, we consider the composition of the “virgin” replaced asphalt as having the average composition of bitumen and aggregate of asphalt concrete and gravel bitumen. This approximation is acceptable, considering the relatively similar composition of the two types of studied asphalt (within about 1%).

Table 61 - Composition of replaced materials by recycling end-of-life pavement materials

Type of secondary material	Replacement	Replaced material	Value (%)
Recycled asphalt planings	Replacement of “virgin” constituent materials of bituminous asphalt	Bitumen (%)	4.70%
		Hard rock aggregate (%)	72.6%
		Alluvial aggregate (%)	22.6%

- **Calculation of benefits and burdens beyond system boundaries**

For a secondary material flow in a recycling route, the formula to calculate the benefits and burdens beyond system boundaries is as follows:

$$\mathbf{I_D = M_{output} \times (I_{PR(i+1)} - I_{PV(i+1)}) - M_{input} \times (I_{PR(i)} - I_{PV(i)})}$$

Where:

- I_D: Module D inventory
- M_{output}: mass of secondary material leaving studied system i to enter the next system i+1
- M_{input}: mass of secondary material entering studied system i
- $I_{PR(i+1)}$: Inventory of the recycling processes resulting in the production of the ready-to-use secondary material used in the next system i+1
- $I_{PV(i+1)}$: Inventory of the production of virgin material replaced in system i+1
- $I_{PR(i)}$: Inventory of the recycling processes resulting in the production of the ready-to-use secondary material used in studied system i
- $I_{PV(i)}$: Inventory of the production of virgin material replaced in studied system i

The terms used for each of the two types of recycling are explained in the following table:

Table 62 - Explanation of the terms used for each type of pavement recycling

Type of processing	M_{output}	M_{input}	$I_{PR(i+1)}$	$I_{PV(i+1)}$	$I_{PR(i)}$	$I_{PV(i)}$
Use of asphalt planings to replace bituminous asphalt	Output flow of asphalt planings	Input flow of asphalt aggregate	Inventory of crushing and screening operations of planings	Inventory of the production of virgin component materials of asphalt	Inventory of the crushing and screening operations of asphalt aggregate	Inventory of the production of virgin component materials of asphalt

As previously indicated, the recycling of planings is part of asphalt aggregate processing operations. Thus, the formula of this type of recycling for module D becomes:

$$I_{D\ \text{asphalt planings}} = (M_{\text{output recycled planings}} - M_{\text{input recycled planings}}) \times (ICV_{\text{grinding/crushing}} - LCI_{\text{production of asphalt virgin materials}})$$

5.9.3 Materials remaining in place at pavement end of life

As mentioned in the introduction to Section 5.9.1, the materials remaining in place at end of life replace the production, transport and application of the road base courses produced during the A1-A3 stage.

The recommendations of the standard concerning the “materials”-based approach in calculating the benefits of module D have been adapted according to the specific characteristics of the studied system. Thus, the materials that remain in place at end of life preclude the production, transport and application of “virgin” road base courses. Therefore, we have selected a “functional” approach. The following table presents the assumptions made in this approach.

Table 63 - Description of the processing stages and replaced stages by recycling the materials remaining in place at pavement end of life

Reused secondary materials		Replaced materials	
Stage	Description/details	**Stage**	Description/details
Removal from end-of-waste status	No impact related to recycling or recovery processes was considered.	**Production of replaced materials**	Production of the gravel bitumen of the road base courses Production of the tack coat between the capping layer and the sub-base course Production of the tack coat between the sub-base course and the base course.

Reused secondary materials		Replaced materials	
Processing operations before reuse by the next system	None. The materials are directly reusable.	**Transport of replaced materials**	Transport of the road base courses and tack coats by truck Bitumen fume emissions
		Application of the replacement materials	Bitumen fume emissions Use of machinery (sweeper, paver, V1 tandem vibratory roller) Transport of sweepings to the treatment site and their treatment;

However, the data pertaining to modules A4 and A5 in Sections 5.5 and 5.6 are provided for all pavement and including not only the road base courses, but also the wearing course and a third tack coat.

It has been decided to approximate the impacts related to replacement in stages A4 and A5 according to the mass ratio of the road base courses. These represent 75% of the mass of applied materials for 1 m² of pavement. Given the lack of specific data on the distribution of process impacts between the road base courses and the wearing course (particularly regarding bitumen fume emissions), this simplifying approach has been considered acceptable.

- **Calculation of benefits and burdens beyond system boundaries**

Thus, the formula of this type of recycling for module D is:

$$I_{D\ \text{Materials left in place}} =$$

$$-\ LCI_{\text{production of "virgin" road base courses}} - LCI_{\text{transport of "virgin" road base courses}} - LCI_{\text{application of "virgin" road base courses}}$$

With the LCIs described below:

Table 64 - LCI of virgin materials replaced by materials left in place at pavement end of life

LCA	Item	Unit	Value for 1 m² of pavement
$\mathbf{LCI}_{\text{production of "virgin" road base courses}}$	Sub-base course – Gravel bitumen	kg	2.12E+02
	Base course – Gravel bitumen	kg	2.12E+02
	Tack coat – Bitumen emulsion	kg	1.00E+00
$\mathbf{LCI}_{\text{transport of "virgin" road base courses}}$	Module A4 Transport of 1m² of pavement to the worksite	-	75%
$\mathbf{LCI}_{\text{application of "virgin" road base courses}}$	Module A5 Placement of 1m² of pavement	-	75%

6 Life Cycle Impact Assessment (LCIA)

6.1 Examined environmental impact indicators

The environmental parameters examined in this study are those specified in Standard NF EN 15804+A1 and its supplement XP P01-064/CN. The parameters are presented in the following tables. They are grouped according to different categories:

- Parameters characterising environmental impacts,
- Parameters characterising the use of resources,
- Parameters characterising categories of waste,
- Parameters characterising output flows.

The characterisation factors are those presented in Annex C of Standard NF EN 15804+A1 and in annexes C, J and K of the XP P01-064/CN supplement.

Table 65- Parameters characterising environmental impacts

Impact category	Parameter	Unit	LCIA model
Global warming	Global warming potential, GWP	kg CO_2 equiv.	Global Warming Potential for a 100-year time horizon as in IPCC: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)].
Depletion of the ozone layer	Destruction potential of the stratospheric ozone layer, ODP	kg CFC equiv.	Ozone Depletion Potentials for Steady-state as in WMO (World Meteorological Organisation): Scientific assessment of ozone depletion. Global Ozone Research and Monitoring Project Reports. 2003.
Acidification des sols et de l'eau	Potentiel d'acidification des sols et de l'eau, AP	kg SO_2 equiv.	Acidification Potentials for average Europe total as in Huijbregts, M., 1999b: Life cycle impact assessment of acidifying and eutrophying air pollutants. Calculation of equivalency factors with RAINS-LCA. Interfaculty Department of Environmental Science, Faculty of Environmental Science, University of Amsterdam, The Netherlands.
Eutrophication	Eutrophication potential, EP	kg $(PO_4)^{3-}$ equiv.	Heijungs, R., J. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin, H.P. de Goede, 1992: Environmental Life Cycle.
Photochemical ozone formation	Tropospheric ozone formation potential, POCP	kg ethene equiv.	Jenkin, M.E. & G.D. Hayman, 1999: Photochemical ozone creation potentials for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters. Atmospheric Environment 33: 1775-1293. Derwent, R.G., M.E. Jenkin, S.M. Saunders & M.J. Pilling, 1998. Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism. Atmospheric Environment, 32. p 2429-2441.
Depletion of abiotic resources - elements	Abiotic depletion potential (ADP-elements) for non-fossil resources	kg Sb equiv.	Abiotic Resource Depletion Potentials for Ultimate ultimate reserves as in Oers, L.F.C.M., van & Koning, A., de & Guinée, J.B. & Huppes, G., 2002. Abiotic resource depletion in LCA: improving characterisation factors for abiotic depletion as recommended in the new Dutch LCA Handbook. Delft: Ministry of Transport, Public Works and Water Management. + XP P01-064/CN:2014:04 supplement, Annex C
Depletion of abiotic resources - fossil fuels	Abiotic depletion potential (ADP-elements) for fossil resources	MJ, net calorific value	
Water pollution	Water pollution	m^3 of polluted water	Method of fictitious volume of polluted water or air, based on the thresholds of Articles 27 and 32 of the Ordinance of 2 February 1998 XP P01-064/CN:2014:04 supplement, Annexes C and J
Air pollution	Air pollution	m^3 of polluted air	

Table 66- Parameters characterising the use of resources

Parameter	Unit
Use of renewable primary energy, excluding renewable primary energy resources used as raw materials	MJ, NCV
Use of renewable primary energy resources as raw materials	MJ, NCV
Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, NCV
Use of non-renewable primary energy, excluding non-renewable primary energy resources used as raw materials	MJ, NCV
Use of non-renewable primary energy resources used as raw materials	MJ, NCV
Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ, NCV
Use of secondary materials	kg
Use of renewable secondary fuels	MJ, NCV
Use of non-renewable secondary fuels	MJ, NCV
Net use of fresh water	m^3

Table 67 - Parameters characterising the categories of waste

Parameter	Unit
Hazardous waste disposed of	kg
Non-hazardous waste disposed of	kg
Radioactive waste disposed of	kg

Table 68 - Parameters characterising the output flows.

Parameter	Unit
Components intended for reuse	kg
Materials intended for recycling	kg
Materials intended for energy recovery	kg
Energy delivered externally	MJ, NCV

6.2 Calculation processes

The data were retrieved from the Excel file used for the previous study. The calculations were the performed in the Simapro 8.04 software. Long-term emissions (beyond the 100 years) were excluded from calculations.

6.3 Warning

The results are relative expressions only and do not predict the final impacts per category, exceeded thresholds, safety margins or risks.

6.4 Results for production of one tonne of asphalt

6.4.1 Production of one tonne of asphalt concrete (AC)

The following table and chart present the environmental impacts of the production of one tonne of asphalt concrete.

Indicators with zero environmental impact values are not represented in the respective charts.

Table69 - Environmental impacts of the production of 1 tonne of asphalt concrete

	Indicateur	Unité	Amont		Centrale						Total
			A1 - BB - Consommation de matières premières	A2 - BB - Acheminement des matières premières	A3 - Consommation d'eau	A3 - Consommation de consommables	A3 - Consommation d'énergie et émissions dans l'air	A3 - Emissions dans l'eau	A3 - Production de déchets	A3 - Infrastructures	
Impacts environnementaux	**Réchauffement climatique**	**kg CO_2 eq**	1,46E+01	7,54E+00	8,81E-04	4,07E-02	2,31E+01	9,19E-04	1,39E-02	4,38E-01	**4,57E+01**
	Appauvrissement de la couche d'ozone	**kg CFC-11 eq**	1,02E-06	1,52E-06	8,96E-11	8,82E-09	4,05E-06	9,56E-11	6,87E-11	3,08E-08	**6,62E-06**
	Acidification des sols et de l'eau	**kg SO_2 eq**	1,28E-01	3,33E-02	4,44E-06	2,36E-04	5,88E-02	8,37E-06	2,32E-06	3,95E-03	**2,24E-01**
	Eutrophisation	**kg PO_4^{---} eq**	1,78E-02	5,36E-03	4,64E-07	6,72E-05	5,86E-03	4,78E-05	5,68E-07	7,36E-04	**2,99E-02**
	Formation d'ozone photochimique	**kg C_2H_4 eq**	7,78E-03	1,47E-03	2,90E-07	1,41E-05	5,44E-03	3,48E-07	8,87E-08	2,51E-04	**1,50E-02**
	Épuisement ressources (éléments)	**kg Sb eq**	1,46E-05	2,37E-05	2,49E-09	4,05E-07	3,29E-06	5,34E-09	1,18E-09	1,26E-05	**5,46E-05**
	Épuisement ressources (fossiles)	**MJ**	2,22E+03	1,12E+02	1,33E-02	9,60E-01	3,71E+02	9,52E-03	5,54E-03	6,15E+00	**2,71E+03**
	Pollution de l'eau	**m^3**	9,52E+00	2,71E+00	3,02E-04	9,92E-02	5,61E+00	3,87E-02	3,98E-04	3,03E-01	**1,83E+01**
	Pollution de l'air	**m^3**	2,82E+03	1,14E+03	1,46E-01	8,39E+00	1,26E+03	2,17E-01	6,53E-02	1,56E+02	**5,39E+03**
Utilisation des ressources	**Energie procédé renouvelable**	**MJ**	2,49E+00	3,57E+00	1,19E-03	1,05E-01	4,27E+00	1,31E-03	1,31E-04	5,38E-01	**1,10E+01**
	Energie matière renouvelable	**MJ**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie primaire totale renouvelable	**MJ**	2,49E+00	3,57E+00	1,19E-03	1,05E-01	4,27E+00	1,31E-03	1,31E-04	5,38E-01	**1,10E+01**
	Energie procédé non renouvelable	**MJ**	3,21E+02	1,48E+02	1,75E-02	1,06E+00	4,19E+02	1,38E-02	5,71E-03	6,97E+00	**8,96E+02**
	Energie matière non renouvelable	**MJ**	1,93E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,93E+03**
	Energie primaire totale non-renouvelable	**MJ**	2,25E+03	1,48E+02	1,75E-02	1,06E+00	4,19E+02	1,38E-02	5,71E-03	6,97E+00	**2,83E+03**
	Utilisation de matière secondaire	**kg**	9,50E+01	0,00E+00	0,00E+00	1,33E-02	0,00E+00	0,00E+00	0,00E+00	6,00E-02	**9,51E+01**
	Energie secondaire renouvelable	**MJ**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie secondaire non renouvelable	**MJ**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Utilisation nette d'eau douce	**m^3**	1,21E-01	3,94E-02	2,34E-03	8,92E-04	4,59E-02	-2,07E-03	5,78E-06	5,72E-03	**2,13E-01**
Production de déchets	**Déchets dangereux éliminés**	**kg**	3,68E-01	1,16E-01	9,02E-05	4,88E-03	1,00E-01	1,61E-04	1,28E-04	5,32E-02	**6,43E-01**
	Déchets non dangereux éliminés	**kg**	2,09E+00	5,75E+00	4,60E-04	1,19E-02	1,01E+00	1,45E-03	2,91E-04	4,24E-01	**9,29E+00**
	Déchets radioactifs éliminés	**kg**	7,70E-04	1,20E-03	7,85E-08	5,25E-06	1,92E-03	8,53E-08	2,88E-08	2,01E-05	**3,92E-03**
Flux sortants	**Composants pour réutilisation**	**kg**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Matériaux pour recyclage	**kg**	1,50E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,98E-02	1,62E-01	**2,02E-01**
	Matériaux pour récupération d'énergie	**kg**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie fournie ext - Electricité	**MJ**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie fournie ext - Vapeur	**MJ**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie fournie ext - Gaz	**MJ**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**

NOTE: The resulting impact on “A3 – Emissions to water” of the indicator “Net use of fresh water” is negative. This sub-stage corresponds to process and washing water discharges (outputs). The water consumption (input) is included in “A3 – Water consumption”. The mass balance between the water input and output is well balanced (2.32E-03 m^3 of water per tonne of asphalt).

In addition, if we add up the values of these sub-stages for the “Net use of fresh water” indicator, the result is positive. This means that on the whole, the system extracts water into the environment, rather than the opposite.

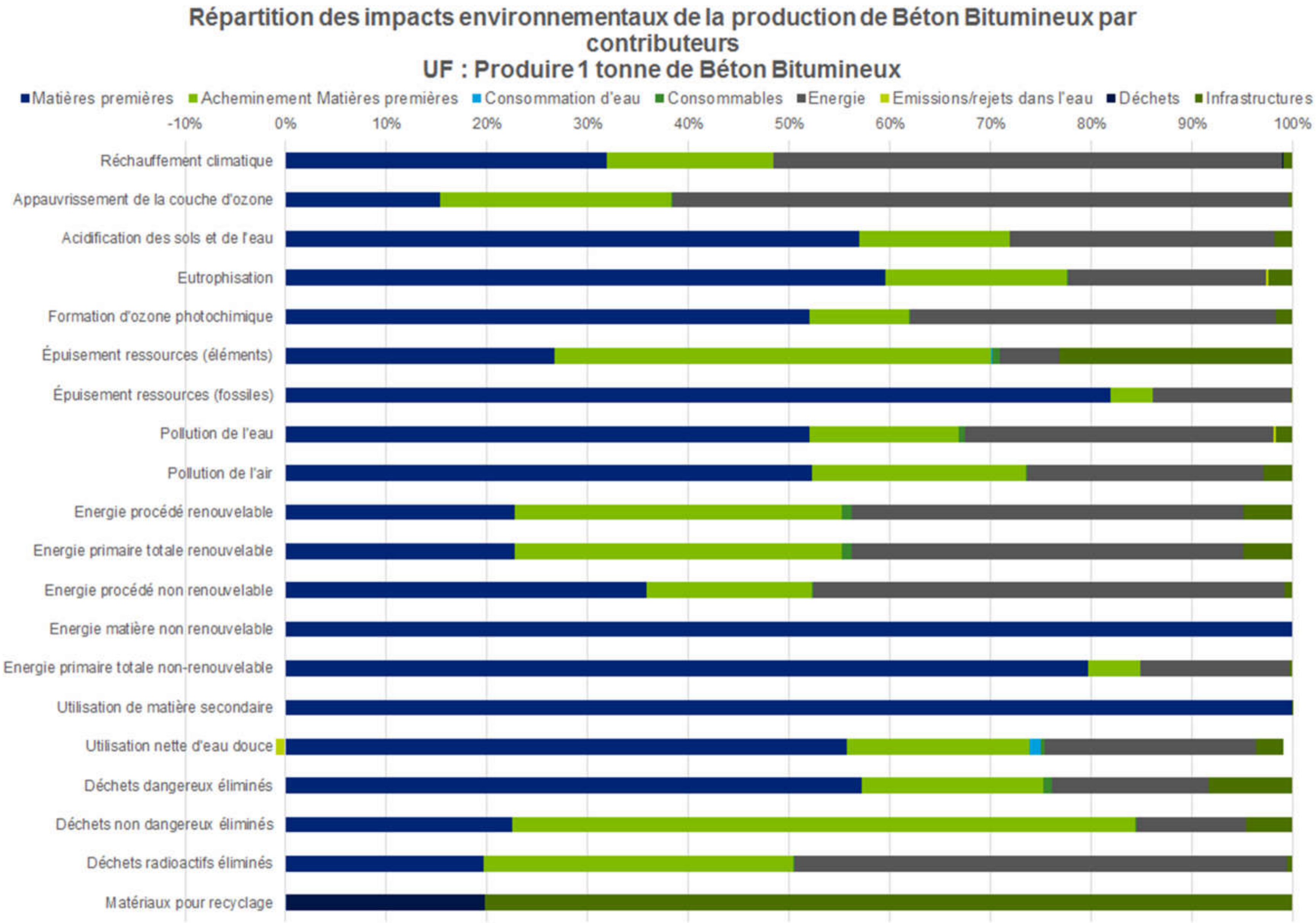


Figure 8 – Distribution of the environmental impacts of the production of 1 tonne of asphalt concrete, by contributors

We note that:

- The extraction and conveyance of raw materials and energy are the main sources of impact for all indicators, except for materials intended for recycling;
- The impact of consumable items, water consumption, emissions/discharges to water, waste and infrastructures are negligible for all indicators (except for the depletion of resources in the last case).

The major contributors are highlighted in the following charts.

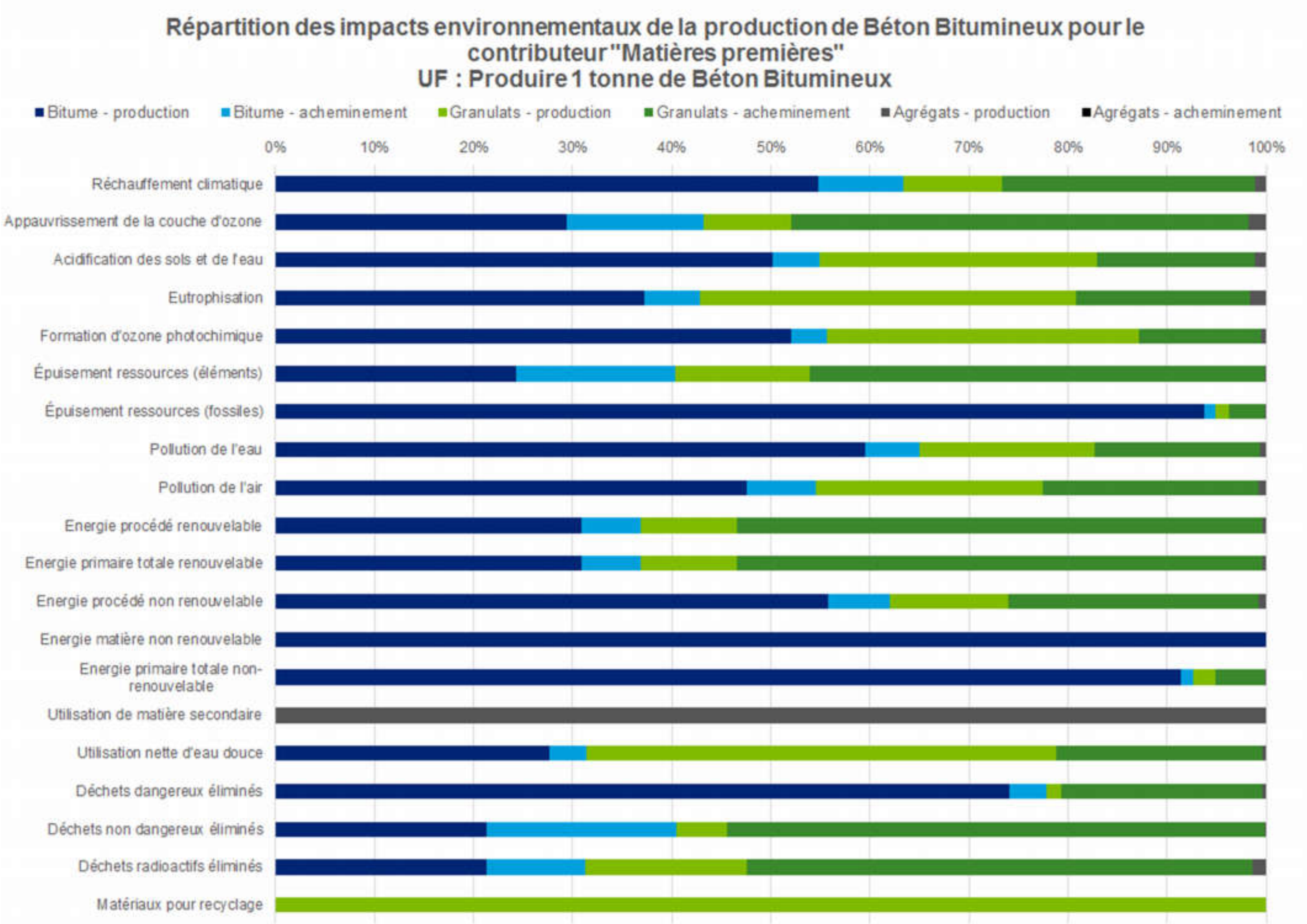


Figure 9 - Distribution of environmental impacts of the production of 1 tonne of asphalt concrete for the “Raw Materials” contributor

Based on the above chart, we note that:

- Bitumen production is a prime contributor for most potential impacts on the environment and for the resource depletion indicators. In particular, this contribution is related to environmental impacts inherent to the production of bitumen (253 kg CO_2 eq. per produced tonne, for example)
- The production and transport of aggregate are a second factor of potential impact on the environment. This contribution is primarily explained by the high proportion of aggregate used for one tonne of asphalt concrete (891 kg/tonne of asphalt). The unit-based environmental impacts per tonne of aggregate are relatively low compared to bitumen (for example, only 2.57 kg of CO_2 eq. per tonne for hard rock aggregate, according to UNPG data). The significant contribution of aggregate transport is primarily explained by the heavy weight of these materials.
- On all considered environmental indicators, the share of the production of asphalt aggregate is quite insignificant. This is mainly due to the fact that this secondary material is accounted for according to the stocks method. The impact of the “Transport” item for aggregate is nil, since, as recalled above, no transport is taken into account for recycling these materials.

Among the energy consumption indicators in particular, a distinction can be made between primary energy of materials (energy contained in the used materials) and primary energy of processes (energy resources used in processes):

- According to Table69 , the primary energy of materials is 100% of non-renewable origin. As shown in the previous figure, this is attributable to the production of bitumen, which is a heavy petroleum fraction (an energy resource at the source), used as raw material.
- Process energy is used for the production and transport of all the raw materials (screening and crushing of aggregate and asphalt aggregate, petroleum extraction and refining to produce bitumen, etc.). Again, the process-based energy is mostly of non-renewable origin.

The total primary energy comprises 70% of material-embodied energy. Still, the material-embodied energy contained in bitumen is not lost after being used in the asphalt mix. Thus, while process energy dissipates through use, the energy embodied in bitumen can in fact be reused by recycling the asphalt aggregate

The distribution of impacts for the "Energy" item is provided in the figure below.

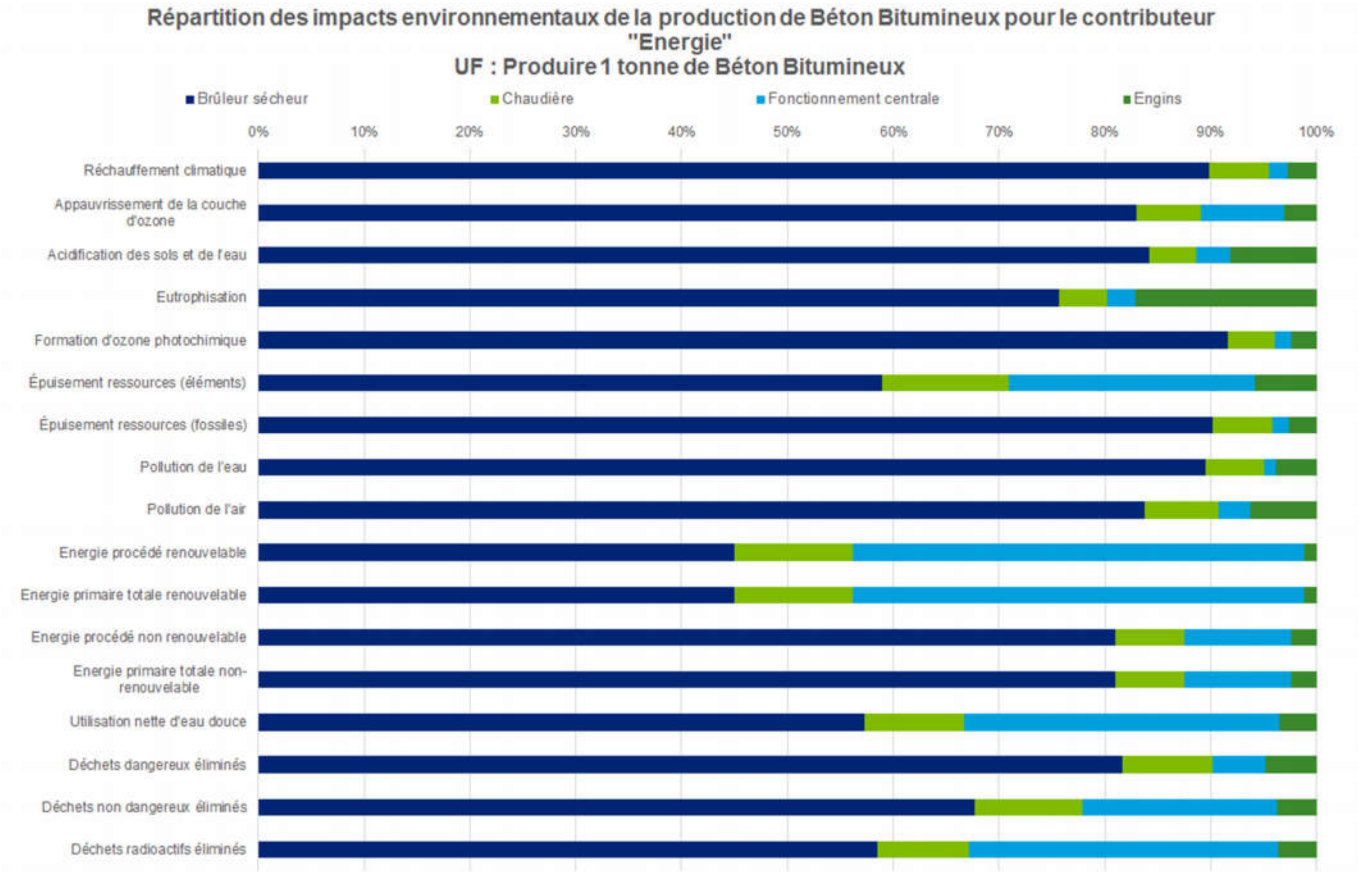


Figure 10 - Distribution of environmental impacts of the production of 1 tonne of asphalt concrete for the "Energy" contributor

As shown in the above figure, the burner-dryer has a prevailing impact for most indicators. This is explained by the consumption of energy at the burner-dryer compared to the other stations (2.32E+01 kWh heavy fuel oil and 4.74E+01 kWh natural gas per tonne of asphalt mix, respectively, as against, for example, 3.51E+00 kWh electricity per tonne of asphalt mix for operating the plant).

Individually, the impacts of the boiler and the construction equipment are lower by 10% than the impacts of the "Energy" item for all the environmental impacts.

In contrast, the contribution of electricity consumption is significant for several indicators, such as renewable process energy, net use of fresh water and the production of radioactive waste. This is due to the average French electricity mix (significant nuclear and hydroelectric power generation).

6.4.2 Production of one tonne of gravel bitumen (GB3)

Similarly to asphalt concrete, the results for gravel bitumen are presented below in table and chart format.

Table 70 - Environmental impacts of the production of 1 tonne of gravel bitumen

	Indicateur	Unité	Amont		Centrale						Total
			A1 - GB3 - Consommation de matières premières	A2 - GB3 - Acheminement des matières premières	A3 - Consommation d'eau	A3 - Consommation de consommables	A3 - Consommation d'énergie et émissions dans l'air	A3 - Emissions dans l'eau	A3 - Production de déchets	A3 - Infrastructures	
Impacts environnementaux	Réchauffement climatique	kg CO_2 eq	1,25E+01	7,26E+00	8,81E-04	4,07E-02	2,31E+01	9,19E-04	1,39E-02	4,38E-01	**4,33E+01**
	Appauvrissement de la couche d'ozone	kg CFC-11 eq	8,86E-07	1,47E-06	8,96E-11	8,82E-09	4,05E-06	9,56E-11	6,87E-11	3,08E-08	**6,44E-06**
	Acidification des sols et de l'eau	kg SO_2 eq	1,14E-01	3,22E-02	4,44E-06	2,36E-04	5,88E-02	8,37E-06	2,32E-06	3,95E-03	**2,09E-01**
	Eutrophisation	kg PO_4^{3-} eq	1,64E-02	5,17E-03	4,64E-07	6,72E-05	5,86E-03	4,78E-05	5,68E-07	7,36E-04	**2,82E-02**
	Formation d'ozone photochimique	kg C_2H_4 eq	6,96E-03	1,43E-03	2,90E-07	1,41E-05	5,44E-03	3,48E-07	8,87E-08	2,51E-04	**1,41E-02**
	Épuisement ressources (éléments)	kg Sb eq	1,30E-05	2,28E-05	2,49E-09	4,05E-07	3,29E-06	5,34E-09	1,18E-09	1,26E-05	**5,21E-05**
	Épuisement ressources (fossiles)	MJ	1,84E+03	1,08E+02	1,33E-02	9,60E-01	3,71E+02	9,52E-03	5,54E-03	6,15E+00	**2,32E+03**
	Pollution de l'eau	m^3	8,25E+00	2,61E+00	3,02E-04	9,92E-02	5,61E+00	3,87E-02	3,98E-04	3,03E-01	**1,69E+01**
	Pollution de l'air	m^3	2,49E+03	1,10E+03	1,46E-01	8,39E+00	1,26E+03	2,17E-01	6,53E-02	1,56E+02	**5,02E+03**
Utilisation des ressources	Energie procédé renouvelable	MJ	2,17E+00	3,54E+00	1,19E-03	1,05E-01	4,27E+00	1,31E-03	1,31E-04	5,38E-01	**1,06E+01**
	Energie matière renouvelable	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie primaire totale renouvelable	MJ	2,17E+00	3,54E+00	1,19E-03	1,05E-01	4,27E+00	1,31E-03	1,31E-04	5,38E-01	**1,06E+01**
	Energie procédé non renouvelable	MJ	2,75E+02	1,44E+02	1,75E-02	1,06E+00	4,19E+02	1,38E-02	5,71E-03	6,97E+00	**8,46E+02**
	Energie matière non renouvelable	MJ	1,59E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,59E+03**
	Energie primaire totale non-renouvelable	MJ	1,86E+03	1,44E+02	1,75E-02	1,06E+00	4,19E+02	1,38E-02	5,71E-03	6,97E+00	**2,43E+03**
	Utilisation de matière secondaire	kg	9,50E+01	0,00E+00	0,00E+00	1,33E-02	0,00E+00	0,00E+00	0,00E+00	6,00E-02	**9,51E+01**
	Energie secondaire renouvelable	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie secondaire non renouvelable	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Utilisation nette d'eau douce	m^3	1,14E-01	3,86E-02	2,34E-03	8,92E-04	4,59E-02	-2,07E-03	5,78E-06	5,72E-03	**2,06E-01**
Production de déchets	Déchets dangereux éliminés	kg	3,04E-01	1,14E-01	9,02E-05	4,88E-03	1,00E-01	1,61E-04	1,28E-04	5,32E-02	**5,77E-01**
	Déchets non dangereux éliminés	kg	1,80E+00	5,53E+00	4,60E-04	1,19E-02	1,01E+00	1,45E-03	2,91E-04	4,24E-01	**8,77E+00**
	Déchets radioactifs éliminés	kg	6,99E-04	1,18E-03	7,85E-08	5,25E-06	1,92E-03	8,53E-08	2,88E-08	2,01E-05	**3,83E-03**
Flux sortants	Composants pour réutilisation	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Matériaux pour recyclage	kg	1,51E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,98E-02	1,62E-01	**2,02E-01**
	Matériaux pour récupération d'énergie	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie fournie ext - Electricité	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie fournie ext - Vapeur	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**
	Energie fournie ext - Gaz	MJ	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**

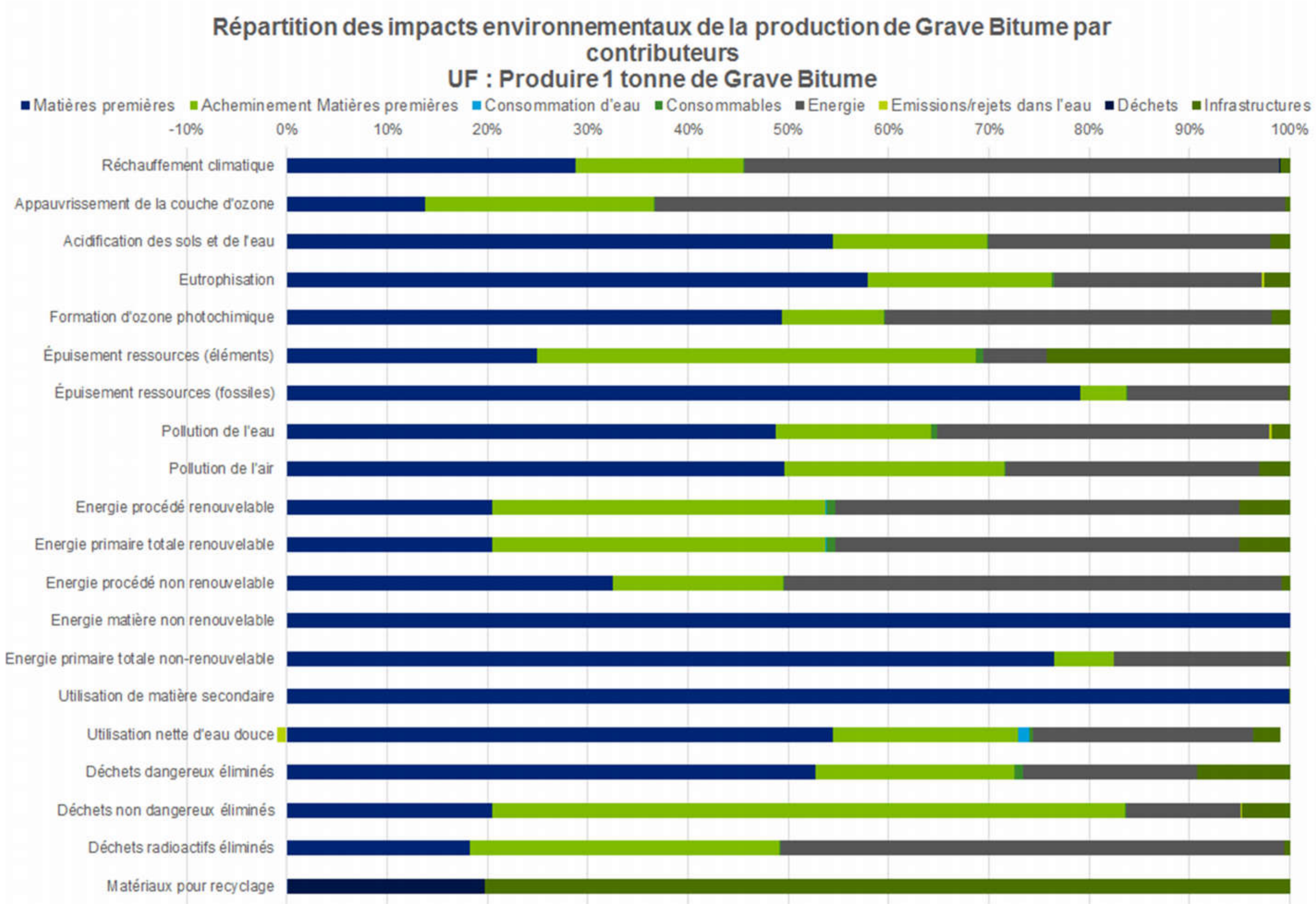


Figure 11 – Distribution of the environmental impacts of the production of 1 tonne of gravel bitumen, by contributors

Overall, the environmental profile of gravel bitumen is similar to that of asphalt concrete in terms of impact distribution. This is logical, given that the only activity data differentiating these two mix types are their bitumen and aggregate compositions.

However, in absolute figures, the impacts of the production of gravel bitumen are lower than the production of asphalt concrete. This is explained by the lower proportion of bitumen in the composition of gravel bitumen and by the fact that the unit-based impacts of bitumen are higher than the unit-based impacts of aggregate.

6.4.3 Results for the production of one tonne of asphalt concrete (AC) according to the tables in Standard NF EN 15804+A1 and its supplement

The results for production of one tonne of asphalt concrete are presented below, according to the required tables of Standard NF EN 15804+A1 and its supplement XP P01-064/CN. In accordance with the recommendations of the AFNOR programme, the stages of asphalt production are broken down into modules A1, A2 and A3. These tables are included in the cradle-to-gate EPD attached to this report.

6.4.3.1 *Environmental Impacts*

Table 71 - Environmental impacts of the production of 1 tonne of asphalt concrete
FU: "Producing 1 tonne of representative French hot-mix asphalt"

Impacts environnementaux	Étape de production				Étape de mise en œuvre			Étape de vie en œuvre								Étape de fin de vie					D Bénéfices et charges au-delà des frontières du système
	A1 Extraction	A2 Acheminement	A3 Fabrication	**Total A1-A3 Production**	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	
Réchauffement climatique kg CO2 eq/UF	1,46E+01	7,54E+00	2,36E+01	**4,57E+01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Appauvrissement de la couche d'ozone kg CFC 11 eq/UF	1,02E-06	1,52E-06	4,09E-06	**6,62E-06**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Acidification des sols et de l'eau kg SO2 eq/UF	1,28E-01	3,33E-02	6,30E-02	**2,24E-01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Eutrophisation kg $(PO_4)^{3-}$ eq/UF	1,78E-02	5,36E-03	6,66E-03	**2,98E-02**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Formation d'ozone photochimique kg Ethene eq/UF	7,78E-03	1,47E-03	5,71E-03	**1,50E-02**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Épuisement des ressources abiotiques (éléments) kg Sb eq/UF	1,46E-05	2,37E-05	1,63E-05	**5,46E-05**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Épuisement des ressources abiotiques (fossiles) MJ/UF	2,22E+03	1,12E+02	3,78E+02	**2,71E+03**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Pollution de l'eau m3/UF	9,52E+00	2,71E+00	6,02E+00	**1,82E+01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Pollution de l'air m3/UF	2,82E+03	1,14E+03	1,43E+03	**5,39E+03**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00

6.4.3.2 *Use of resources*

Table 72 - Use of resources for the production of 1 tonne of asphalt concrete
FU: "Producing 1 tonne of representative French hot-mix asphalt"

Utilisation des ressources	Etape de production				Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie					
	A1 Extraction	A2 Acheminement	A3 Fabrication	**Total A1-A3 Production**	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	D Bénéfices et charges au-delà des frontières du système
Utilisation de l'énergie primaire renouvelable, à l'exclusion des ressources d'énergie primaire renouvelables utilisées comme matières premières MJ/UF	2,49E+00	3,57E+00	4,91E+00	**1,10E+01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation des ressources d'énergie primaire renouvelables en tant que matières premières MJ/UF	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation totale des ressources d'énergie primaire renouvelables (énergie primaire et ressources d'énergie primaire utilisées comme matières premières) MJ/UF	2,49E+00	3,57E+00	4,91E+00	**1,10E+01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation de l'énergie primaire non renouvelable, à l'exclusion des ressources d'énergie primaire non renouvelables utilisées comme matières premières MJ/UF	3,21E+02	1,48E+02	4,27E+02	**8,96E+02**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation des ressources d'énergie primaire non renouvelables en tant que matières premières MJ/UF	1,93E+03	0,00E+00	0,00E+00	**1,93E+03**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation totale des ressources d'énergie primaire non renouvelables (énergie primaire et ressources d'énergie primaire utilisées comme matières premières) MJ/UF	2,25E+03	1,48E+02	4,27E+02	**2,83E+03**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation de matière secondaire kg/UF	9,50E+01	0,00E+00	7,33E-02	**9,51E+01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation de combustibles secondaires renouvelables MJ/UF	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation de combustibles secondaires non renouvelables MJ/UF	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Utilisation nette d'eau douce m3/UF	1,21E-01	3,94E-02	5,48E-02	**2,16E-01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00

6.4.3.3 *Categories of waste*

Table 73 - Waste generated by the production of 1 tonne of asphalt concrete
FU: "Producing 1 tonne of representative French hot-mix asphalt"

Catégorie de déchets	Étape de production				Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie					D Bénéfices et charges au-delà des frontières du système
	A1 Extraction	A2 Acheminement	A3 Fabrication	**Total A1-A3 Production**	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	
Déchets dangereux éliminés kg/UF	3,68E-01	1,16E-01	1,59E-01	**6,42E-01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Déchets non dangereux éliminés kg/UF	2,09E+00	5,75E+00	1,45E+00	**9,28E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Déchets radioactifs éliminés kg/UF	7,70E-04	1,20E-03	1,95E-03	**3,92E-03**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00

6.4.3.4 *Output flows*

Tableau 74 - Output flows of the production of 1 tonne of asphalt concrete
FU: "Producing 1 tonne of representative French hot-mix asphalt"

Flux sortants	Étape de production				Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie					
	A1 Extraction	A2 Acheminement	A3 Fabrication	**Total A1-A3 Production**	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	D Bénéfices et charges au-delà des frontières du système
Composants destinés à la réutilisation kg /UF	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Matériaux destinés au recyclage kg/UF	1,50E-04	0,00E+00	2,02E-01	**2,02E-01**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Matériaux destinés à la récupération d'énergie kg/UF	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – Electricité	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – vapeur	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – Gaz de process	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00

6.5 Results for provision of 1 m² of pavement

The following tables set out the results of the Life Cycle Impact Assessment. The results are first presented in the tables required in Standard NF EN 15804+A1 and its supplement P01 064/CN, before being presented in graphic format for easier reading. These tables are included in the FDES attached to this report.

6.5.1 Environmental Impacts

Table 75 - Environmental impacts for 1 m² of hot bituminous mix pavement

FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Impacts environnementaux	Étape de fabrication	Étape de mise en œuvre			Étape de vie en œuvre								Étape de fin de vie					Total cycle de vie de vie	D Bénéfices et charges au-delà des frontières du système
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**		
Réchauffement climatique kg CO2 eq/UF	**2,51E+01**	2,86E+00	1,25E+00	**4,11E+00**	0,00E+00	4,29E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**4,29E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**7,21E+01**	-2,54E+01
Appauvrissement de la couche d'ozone kg CFC 11 eq/UF	**3,68E-06**	5,24E-07	2,48E-07	**7,72E-07**	0,00E+00	6,65E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**6,65E-06**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**1,11E-05**	-3,48E-06
Acidification des sols et de l'eau kg SO2 eq/UF	**1,22E-01**	1,16E-02	9,16E-03	**2,08E-02**	0,00E+00	2,19E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**2,19E-01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**3,62E-01**	-1,40E-01
Eutrophisation kg $(PO_4)^{3-}$ eq/UF	**1,64E-02**	1,97E-03	1,90E-03	**3,87E-03**	0,00E+00	3,27E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**3,27E-02**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**5,29E-02**	-1,94E-02
Formation d'ozone photochimique kg Ethene eq/UF	**8,18E-03**	4,98E-04	1,55E-02	**1,60E-02**	0,00E+00	3,11E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**3,11E-02**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**5,53E-02**	-2,04E-02
Épuisement des ressources abiotiques (éléments) kg Sb eq/UF	**3,01E-05**	9,30E-06	5,09E-07	**9,81E-06**	0,00E+00	5,96E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**5,96E-05**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**9,94E-05**	-3,41E-05
Épuisement des ressources abiotiques (fossiles) MJ/UF	**1,41E+03**	4,35E+01	1,98E+01	**6,34E+01**	0,00E+00	2,13E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**2,13E+03**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**3,60E+03**	-1,74E+03
Pollution de l'eau m3/UF	**9,90E+00**	1,01E+00	4,85E-01	**1,49E+00**	0,00E+00	1,69E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,69E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**2,83E+01**	-1,12E+01
Pollution de l'air m3/UF	**2,93E+03**	4,17E+02	8,77E+03	**9,18E+03**	0,00E+00	1,47E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,47E+04**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**2,68E+04**	-9,84E+03

6.5.2 Use of resources

Table 76 - Use of resources for 1 m² of hot bituminous mix pavement

FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Utilisation des ressources	Etape de fabrication	Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie						
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie**	D Bénéfices et charges au-delà des frontières du système
Utilisation de l'énergie primaire renouvelable, à l'exclusion des ressources d'énergie primaire renouvelables utilisées comme matières premières MJ/UF	6,09E+00	5,44E-01	1,45E-01	6,89E-01	0,00E+00	9,51E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,51E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,63E+01	-5,75E+00
Utilisation des ressources d'énergie primaire renouvelables en tant que matières premières MJ/UF	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Utilisation totale des ressources d'énergie primaire renouvelables (énergie primaire et ressources d'énergie primaire utilisées comme matières premières) MJ/UF	6,09E+00	5,44E-01	1,45E-01	6,89E-01	0,00E+00	9,51E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,51E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,63E+01	-5,75E+00
Utilisation de l'énergie primaire non renouvelable, à l'exclusion des ressources d'énergie primaire non renouvelables utilisées comme matières premières MJ/UF	4,91E+02	4,43E+01	2,02E+01	6,44E+01	0,00E+00	8,00E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,00E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,36E+03	-4,99E+02
Utilisation des ressources d'énergie primaire non renouvelables en tant que matières premières MJ/UF	9,82E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,41E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,41E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,39E+03	-1,30E+03
Utilisation totale des ressources d'énergie primaire non renouvelables (énergie primaire et ressources d'énergie primaire utilisées comme matières premières) MJ/UF	1,47E+03	4,43E+01	2,02E+01	6,44E+01	0,00E+00	2,21E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,21E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,75E+03	-1,80E+03
Utilisation de matière secondaire kg/UF	5,37E+01	0,00E+00	2,49E-02	2,49E-02	0,00E+00	6,49E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,49E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,19E+02	2,80E+02
Utilisation de combustibles secondaires renouvelables MJ/UF	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Utilisation de combustibles secondaires non renouvelables MJ/UF	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Utilisation nette d'eau douce m3/UF	1,19E-01	9,10E-03	4,73E-03	1,38E-02	0,00E+00	1,96E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,96E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,28E-01	-1,37E-01

6.5.3 Categories of waste

Table 77 - Production of waste for 1 m² of hot bituminous mix pavement
FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Catégorie de déchets	Etape de fabrication	Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie					Total cycle de vie	D Bénéfices et charges au-delà des frontières du système
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie**	
Déchets dangereux éliminés kg/UF	**3,42E-01**	2,73E-02	1,77E-02	**4,50E-02**	0,00E+00	5,84E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**5,84E-01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**9,71E-01**	-3,92E-01
Déchets non dangereux éliminés kg/UF	**5,09E+00**	2,27E+00	2,10E+00	**4,37E+00**	0,00E+00	5,57E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**5,57E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**6,51E+01**	-7,64E+00
Déchets radioactifs éliminés kg/UF	**2,19E-03**	2,97E-04	1,40E-04	**4,38E-04**	0,00E+00	3,89E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**3,89E-03**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**6,51E-03**	-2,11E-03

6.5.4 Output flows

Table 78 - Output flows for 1 m² of hot bituminous mix pavement
FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Flux sortants	Etape de fabrication	Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie						
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie de vie**	D Bénéfices et charges au-delà des frontières du système
Composants destinés à la réutilisation kg /UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	8,11E+02	0,00E+00	**8,11E+02**	**8,11E+02**	0,00E+00
Matériaux destinés au recyclage kg/UF	**1,14E-01**	0,00E+00	6,73E-02	**6,73E-02**	0,00E+00	4,35E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**4,35E+02**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**4,36E+02**	-1,36E-01
Matériaux destinés à la récupération d'énergie kg/UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – Electricité	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – vapeur	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – Gaz de process	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00

6.5.5 Interpretation

The interpretation of the pavement life cycle is provided below. However, the benefits and burdens beyond the system boundaries are handled separately.

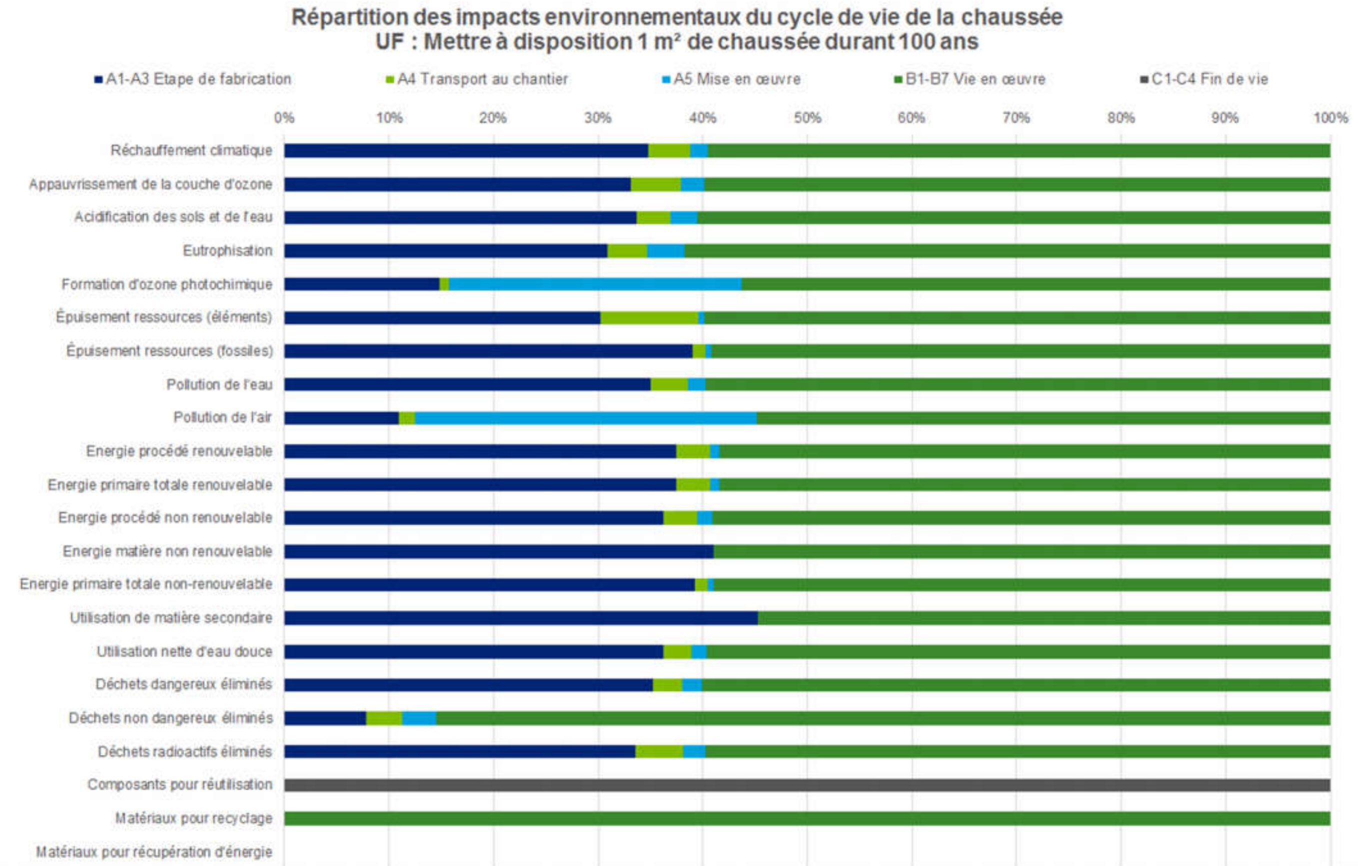


Figure 12 - Distribution of the environmental impacts for provision of hot bituminous mix pavement over a 100-year period – not including the benefits and burdens beyond system boundaries

We can make the following observations:

- On almost all the indicators, the service life (B2) has the highest contribution to environmental impacts. The manufacturing stage (A1-A3) of the various pavement layers is also a significant contributor to environmental impacts on most examined indicators. This is explained by the quantities of asphalt mix used at each stage. Thus, 565 kg/m² of asphalt mix are produced during the manufacturing stage compared to 682 kg/m² that are produced, transported and applied during the service life of the pavement.
- We note that the placement stage (A5) has a significant contribution to impacts related to air pollution and photochemical ozone creation indicators. This is due to bitumen fume emissions that occur during this phase. For other indicators, the contribution of this phase to impacts has little significance.
- In addition, the waste intended for recycling of materials is generated during the service life (B2) and end of life (C1-C4) stages. It consists of asphalt planings produced during pavement planing and the materials left in place after the 100-year pavement lifespan, which are recovered beyond system boundaries. The non-hazardous waste disposed of is primarily generated during the service life and predominantly consists of sweepings during planing operations.
- We note that hazardous waste and radioactive waste are disposed of during the product's life cycle. These are indirect impacts on the pavement's life cycle. The radioactive waste is primarily attributable to the consumption of electricity (the French electricity mix has a large nuclear power component). The hazardous waste is attributable to the bitumen production, at the refining stage.
- Significant amounts of input secondary materials are consumed during the application phases (A5) and the service life (B2). For the most part, they relate to asphalt aggregate incorporated into bituminous mix recipes. However, the impact values are slightly different from the values presented in Table 59,

considering that steel (of partially recycled origin) is also consumed during the production and service life of asphalt mixes (construction equipment, infrastructures, tyres and scrap metal).

- Finally, the stage of transport to worksite (A4) has a non-significant contribution to environmental impacts (less than 10% of impacts over the entire life cycle).

6.5.6 Results including the benefits and burdens beyond system boundaries

The above figure presents the impacts of the pavement life cycle (pavement LC, where LC means "life cycle"), including the avoided impacts in module D. To facilitate reading, the following chart includes only environmental impact indicators. The other results are presented in Annex 8.9.

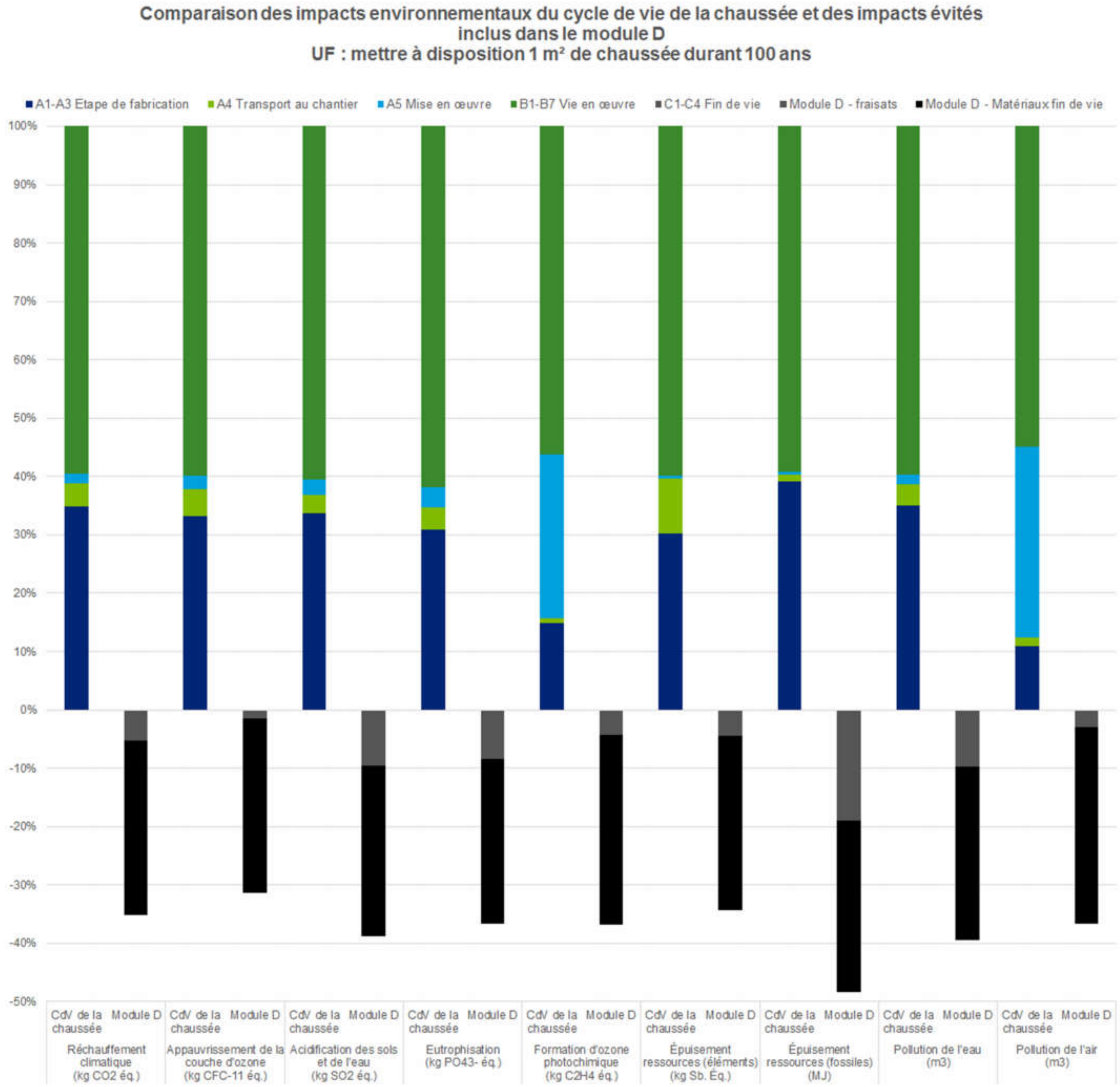


Figure 13 - Distribution of the environmental impacts for provision of hot bituminous mix pavement over a 100-year period – including benefits and burdens beyond system boundaries

Based on these results, we can make the following observations:

- Recycling asphalt planings avoids approximately 10% of the environmental impacts for most indicators. For some indicators, however, this proportion is higher. In particular, it reaches 19% on depletion of element resources, and 25% on non-renewable material-embodied energy. This is explained by the avoidance of bitumen production, which is correlated with a lower consumption of non-renewable natural resources and material-embodied energy. In a specific case related to the use of secondary material, this value increases to 270% for a recovered net output flow of 320 kg of used aggregate per m² of pavement.

- The recovery of materials left in place at end of life of the pavement represents for most indicators about 30% of impacts over the entire pavement life cycle. According to Figure 12 (see previous section), the production, transport and application contribute approximately 40% of impacts over the entire pavement life cycle. Considering that the road base courses represent 75.0% of the pavement mass, this value of 30% of avoided impacts is reasonable. We note that for the use of secondary materials, module D accounts for an increase of 320 kg/m² of used secondary material. This corresponds to the net output flow of recycled planings.
- Overall, in absolute value, the benefits beyond system boundaries represent approximately 40% of the total impacts of the pavement life cycle. Inclusion of benefits pertaining to module D is therefore equivalent with the impacts of production, transport and initial application of pavement on most environmental indicators.

These results confirm the relevance of the current practices of road industry professionals, particularly by leaving materials in place at end of life. Indeed, through these results, we can consider that destroying the entire road pavement at end of life would theoretically imply generating about 30% additional impacts.

6.6 Uncertainties

The scope of this report covers asphalt coatings produced at several production sites belonging to different companies. Nevertheless, there is high representativeness of the collected baseline data and limited uncertainty relating to the baseline data used to evaluate the environmental impacts of these products.

Still, the uncertainties of the results of this study, primarily related to the following aspects:

- Uncertainties related to general assumptions (service life scenario over 50 or 100 years, etc.),
- Uncertainties pertaining to the used environmental data (information modules, Ecoinvent inventories, etc.).

The overall quantification of the uncertainty would require identifying the specific uncertainties related to the various aspects listed above and propagating these uncertainties through the various calculation stages up to the environmental assessment of the studied products.

However, for the main raw materials (aggregates and bitumen), uncertainty data are not available. In addition, the other specific uncertainties are difficult to estimate. For this reason, it is not possible to calculate the overall uncertainty for the studied environmental parameters.

6.7 Variance in relation to the average results

To assess the variance of results in relation to the average baseline data requires taking the minimum and maximum collected data for each parameter and noting the difference between the results published in the FDES and the results with “extreme” baseline data values

In particular, the interpretation provided earlier has highlighted the main parameters affecting the environmental impacts of pavement, namely the production of bitumen and the use of the burner-dryer. Yet, the quantity of bitumen in asphalt mix recipes is a fixed amount provided by the Steering Committee. In contrast, the energy consumption data at the burner-dryer were derived from average data provided by three different companies for all their respective sites.

A simple evaluation of the variance of results has been performed below using only the “Carbon dioxide, fossil” flow emitted to air during combustion. As can be recalled, it is considered that 65% of burner-dryers operate on natural gas as against 35% on heavy fuel oil (source: USIRF). The values described in the following table are taken from Table 22, Section 5.4.3.1 page 30.

Table 79 - Average, minimum and maximum consumption values of burner-dryers

Parameter	Unit	Value Burner-dryers - HFO	Value Burner-dryers - GN	Weighted value
Minimal energy consumption	kWh/t of asphalt mix	6.10E+01	6.80E+01	6.56E+01
Average energy consumption	kWh/t of asphalt mix	6.63E+01	7.29E+01	7.06E+01
Maximal energy consumption	kWh/t of asphalt mix	6.80E+01	8.30E+01	7.78E+01

The value of the flow “Carbon dioxide, fossil” in MJ released in the air during combustion was taken from the Ecoinvent 3.1 LCIs used for modelling burner-dryer activities. Conversion into Kg CO_2 / t of asphalt was performed using the values in the previous table.

Table 80 – Calculation of average, minimum and maximum CO2 emission values of burner-dryers

Parameter	Unit	Value Burner-dryers - HFO	Value Burner-dryers - GN	Weighted value
Emission factor (EF) of fossil CO_2	Kg CO_2 / MJ	8.30E-02	5.90E-02	Not applicable
Minimal EF of fossil CO_2	Kg CO_2 / t of asphalt mix	1.82E+01	1.45E+01	**1.58E+01**
Average EF of fossil CO_2	Kg CO_2 / t of asphalt mix	1.98E+01	1.55E+01	**1.70E+01**
Maximal EF of fossil CO_2	Kg CO_2 / t of asphalt mix	2.03E+01	1.76E+01	**1.86E+01**

According to these values, the variability of the CO_2 flow emitted into the air during combustion is between -7% and 9% relative to the average, but only for the item “Energy consumption during production”. The overall variability of the results for the entire system for this parameter is therefore correspondingly lower.

Besides, the method of range of variance of results is related to the framework of validity. It does not concern products marketed on a “business to customer” basis (B to C). Therefore, it is not compulsory for bituminous mix pavements. Moreover, the methodology related to this framework of validity will only be clearly established by the 2017 horizon.

In light of these considerations, we did not examine in further detail the variance of results in this study relative to the averages of results.

6.8 Comparison of results with the previous study

Taking into account multiple reasons, including:

- Update of standards and related methodological aspects;
- Update of databases;
- Update of indicators;

It has been decided together with USIRF not to perform a comparison of results with the previous study. Only an analysis based on a consistent assessment framework could be relevant to quantify developments related to changes in the industry practices.

Nevertheless, when considering the 2014 Environmental Assessment of USIRF[8], we note, among others, that the GHG emissions of burners per tonne of produced asphalt mix have declined over the last six years. Thus, we can therefore assume that this study does not underestimate the environmental impacts of bituminous mixtures and is conservative regarding potential developments in this industry.

[8] See: http://www.usirf.com/wp-content/uploads/BILAN-ENVIRONNEMENTAL-2014.pdf

7 Conclusion

This study has enabled USIRF to provide updated results for bituminous mix pavements. USIRF and its partners have thus obtained objective and reliable data for reporting on the overall environmental performance of construction projects using hot-mix asphalt. These new results should be considered the most representative environmental information on bituminous mixtures and bituminous asphalt pavements used on the French market.

Several improvements have been made in this study, including:

- Update of environmental data by upgrading from the Ecoinvent database version 2.2 to Ecoinvent version 3.1;
- Achieving compliance with the new standards in force, NF EN 15804+A1 and XP P01-064/CN, in preparing FDES declarations for the French market;
- Accounting for the environmental benefits generated by the industry's efforts to reuse asphalt planings and the road base courses left in place at end of life;
- Introducing a new verification procedure by a Critical Review panel, thereby improving the robustness and reliability of the model and reinforcing the assumptions made within this study.

The FDES and cradle-to-gate EPD associated with this study are valid for the next five years from their publication. The following improvement areas should be considered in a future update:

- Collection of new activity data related to asphalt production and laying;
- Promoting the update of the LCI of bitumen production by Eurobitume in compliance with European Standard 15804;
- Promoting the update of the environmental information modules for the production of hard and soft rock aggregate by the UNPG, in compliance with Standard NF EN 15804 (work underway as of the preparation of this study).

Finally, the results of the study can be used by USIRF and its partners to further improve the environmental performance of industry activities within an eco-design approach. The following avenues for improvement may be considered:

- Improving asphalt mix manufacturing and laying processes, particularly in terms of energy consumption in connection with high application temperatures;
- Continuing the waste recovery efforts within the road building technologies, particularly in light of the environmental relevance of current practices demonstrated in this study;
- Launching research work to reduce bitumen fume emissions during transport and application, based on awareness of the significant impact of these emissions on several air pollution indicators.

8 Annexes

8.1 Annex 1: Data collection survey intended for the asphalt plants

USIRF
Routes de France

Analyse de cycle des enrobés à chaud et tièdes 2011

QUESTIONNAIRE RELATIF A L'INVENTAIRE DE LA FABRICATION

NOM DE LA CENTRALE : ....
NOM DE LA PERSONNE AYANT RENSEIGNE LE DOCUMENT : ....
DONNEES DE L'ANNEE : 2011
ANNEE DE COLLECTE : 2012

PRESENTATION

L'USIRF a réalisé en 2002 une première enquête auprès de 16 centrales en vue de disposer d'informations permettant d'établir l'inventaire de la fabrication des enrobés à chaud. Cet inventaire a ensuite été complété par celui de l'application afin de réaliser l'Analyse de cycle de vie (ACV) de l'enrobé à chaud (1).

Compte tenu de l'évolution depuis 2002 des techniques, des matériels et de la réglementation, la commission Développement Durable de l'USIRF a décidé d'actualiser cette première étude. Pour faire cette actualisation, des données doivent être recueillies. Pour l'inventaire de la fabrication, une nouvelle enquête est faite auprès de centrales représentatives du parc français. C'est l'objet du présent questionnaire.

QU'EST-CE QUE L'INVENTAIRE D'UNE PRODUCTION ?

L'inventaire d'une production est un bilan complet des échanges de matières et d'énergie aux frontières d'une unité de production, ici une centrale d'enrobage.
Ce bilan permet de recenser les impacts sur l'environnement générés par cette production.

Dans le présent cas, c'est la production d'enrobés qui a étudiée.

QUELLES DONNEES RECENSER ?

Les données concernant les entrées et sorties dues à la fabrication d'un enrobé peuvent être :
- soit relevées
- soit mesurées,
- soit calculées
- soit estimées par imputation au produit d'une partie des données globales de l'usine.

(1) Article de la revue générale des Routes et Aérodromes présentant les résultats de cette Analyse de cycle de vie joint

Pour faire cet inventaire, vous pouvez nous aider en nous fournissant des renseignements chiffrés et représentatifs d'une année de production, 2011 en l'occurrence, sur :

- les matières consommées sur le site (origines, quantités utilisées,…), lors des différentes phases de la fabrication de l'enrobé.
- la consommation d'énergie, détaillée par mode d'énergie utilisé (énergie électrique, gaz, fuel….).
- la consommation d'eau (différentes origines, quantité consommée).
- le transport en amont du poste des matériaux, des emballages et des suremballages en précisant le détail des palettisations, le mode de transport (moyen et tonnage), les distances parcourues.
- les émissions atmosphériques telles que les poussières, SO2, NOx, HC, CO, CO2 et les effluents tels que les matières en suspension, la DBO, la DCO, les hydrocarbures, huiles, solvants ainsi que les déchets solides (nature, tonnages et destination), rapportés à une année de production.

Les données transmises resteront confidentielles. Elles ne seront utilisées que par l'USIRF et présentées sous forme anonyme et compilée rendant impossible l'identification de la source et toute comparaison spécifique à l'une des entités parties prenantes.

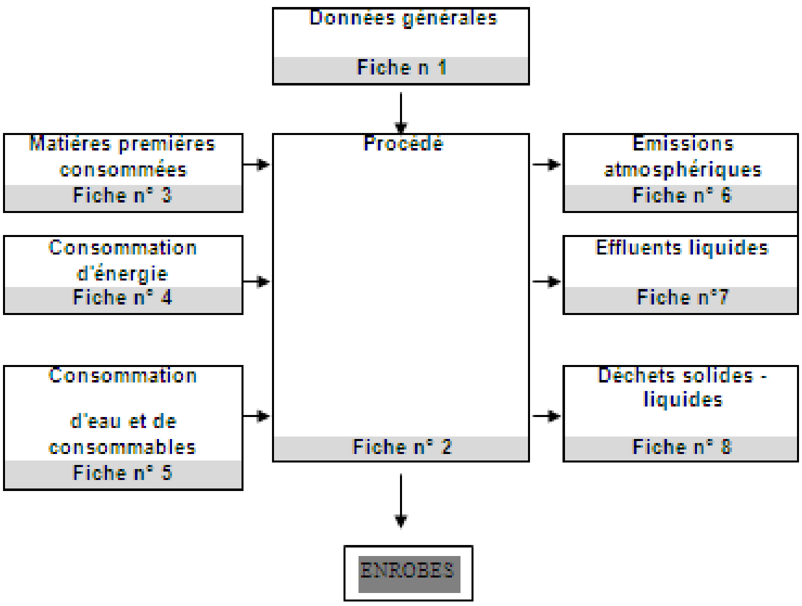
Contact USIRF : François VERHEE 01 44 13 32 94 / 06 09 17 99 72

LE RECUEIL DES DONNES

Pour bien renseigner les données, nous vous remercions de toujours indiquer les unités.

Le schéma ci-dessous présente l'articulation des différentes fiches du questionnaire à remplir.

ARTICULATION DES DIFFERENTES FICHES DU QUESTIONNAIRE



Fiche n° 1 DONNÉES GÉNÉRALES

Nom de la société

Centrale
Marque et dénomination du poste
Caractéristiques
- Type (Continu ou Discontinu)
- Débit nominal à 3% humidité

Installation
- surface du site
- surface imperméabilisée (sol + bâtiments)
- surface recouverte en enrobé

Production d'enrobés année 2011 (tonnes)
- production totale d'enrobés
  - dont production d'enrobés tièdes
- consommation totale d'agrégats d'enrobés introduits dans la production d'enrobés
- pour information
  - production 2010
  - production 2009

L'USIRF s'engage à ce que les données indiquées sur ces fiches soient exploitées de façon anonyme.

Fiche n° 2 DESCRIPTION DU PROCEDE

Principaux types d'équipements et de procédés de la centrale

- Couverture des stocks (oui/non et surface):
  - sable
  - agrégats d'enrobés

- Stockage bitume
  - nombre de cuves
  - capacité de chacune d'elles
  - type de chauffage

- Brûleur sécheur
  - type
  - puissance
  - combustible(s)

- Chaudière pour liant
  - type
  - puissance
  - combustible

- Stockage produits finis
  - nombre trémies
  - volume de chacune d'elles
  - chauffage casque éventuel

- Prétraitement des eaux pluviales
  - Décanteur/déshuileur : oui/non

- Engins
  - Chargeur 1
    - Marque et type
  - Chargeur 2
    - Marque et type
  - Autre engin
    - Marque et type
  - ...

Fiche n° 3

INVENTAIRE DES MATIERES PREMIERES CONSOMMEES

Rappel: Production d'enrobés de l'année 2011 :

					TRANSPORT ROUTE		TRANSPORT RAIL		TRANSPORT FLUVIAL	
nom courant	dénomination	quantité	unité	conditionnement	tonnage	départ / distance	tonnage	départ	tonnage	départ
Exemple : bitume	XYZ	800	tonnes	vrac	600	Le Havre				
Massif - carrière 1 - carrière 2 - carrière 3 - ... **Alluvionnaire** - carrière 1 - carrière 2 - carrière 3 - ... **Filler** **Bitume** - raffinerie 1 - raffinerie 2 - ... **Colorants** **Additifs**										

Union des Syndicats de l'Industrie Routière Française
9, rue de Berri 75008 PARIS

Fiche n°4 CONSOMMATION D'ENERGIE

Consommation pour l'année 2011

Pour les sites ne pouvant répartir les consommations entre les différentes utilisations

Source d'énergie	Consommation totale		
Fioul lourd*			
Gaz naturel			
Electricité			
Gasoil non routier			
FOD			
Propane			

* Pour le fioul lourd, préciser le % de soufre

Fiche n° 5 CONSOMMATIONS D'EAU ET DE CONSOMMABLES

Consommations de l'année 2011

Eau

TOTAL	Origine de l'eau consommée (1)	Quantité consommée	unité

(1) eau de pluie, puits de rivière, du réseau urbain

Consommables (facultatif)

Poste de consommation	Nom et nature du consommable (2)	Quantité consommée	unité
Ex : chaudière	Huile de chauffe	1000 KG	
– huile de chauffe – pneus – huiles autres – graisses – ferraille – anti-collant/anti-adhérent pour enrobés (EMHV) – filtres à poussières (fines)			

(2) nature : du solvant, détergents, produits de traitement de l'eau, etc…

Fiche n°6 EMISSIONS ATMOSPHERIQUES 2011

Joindre à ce questionnaire le rapport des émissions à la cheminée et le rapport de réglage du brûleur (complété éventuellement par la notice constructeur).

Fiche n°7 EFFLUENTS LIQUIDES

Joindre à ce questionnaire le rapport des rejets des eaux du site.

Fiche n°8 DECHETS SOLIDES - LIQUIDES

Joindre à ce questionnaire les Bordereaux de Suivi des Déchets Industriels (BDSI) pour la période du 01/01/2011 au 31/06/2012 et compléter le tableau ci-dessous.

			Valorisé en interne (2)	Sous-traité à l'extérieur		
Nature du déchet (1)	Origine du déchet	Volume ou poids total pour l'usine	Destination	Opérateur	adresse	téléphone
Exemple : huile de chauffe	chaudière	500 litres	récupération			
– huile de vidange – huile de chauffe – huile claire – solvants usés – ferraille – bois – retours de fabrication – ... Pour information (1) – blancs de poste	engins chaudière					

(1) ne sont pas de vrais déchets au sens de la législation
(2) par exemple récupération, recyclage, incinération, décharge.

8.2 Annex 2: Data collected from the asphalt plants

The following tables show the data collected from the 8 asphalt plants surveyed during this study. It is important to note that the data concerning the emissions to air and to water presented below have been reprocessed based on the emission reports supplied by the plants. Details of the calculations applied for these data are presented in the body of the report.

In addition, it should be noted that during the reference data collection period (2010 or 2011 depending on the plants), the proportion of warm-mix asphalt was very small (less than 5% of total production for the 8 plants). Accordingly, warm-mix asphalt was assimilated to the hot-mix asphalt and there was no allocation between these different types of asphalt. The data per tonne of hot-mix asphalt were calculated based on the overall plant data divided by the total production of the plants (hot-mix asphalt and warm-mix asphalt).

	N° de la centrale Année de référence	1 2011	2 2011	3 2010	4 2010/2011	5 2011	6 2011	7 2011	8 2011
Fiche 1 - Données générales									
Caractéristiques	Type	Discontinu	Discontinu	Discontinu	Continu	Continu	Discontinu	Discontinue	Continu
	Débit (t/h)	320	160	100	140	240	320	260	180
Installation	Surface du site (m^2)	15000	40000		15000	18000	36700	9713	45200
	Surface imperméabilisée	3000	8000		3000	3600	7340	1943	9040
Production d'enrobés	Production totale d'enrobés (t)	269810	97600	45200	119849	75596	237543	147798	56450
	dont enrobés tièdes (t)	16116	4300	0	5000	0	8544	12116	85
Fiche 2 - Description du procédé									
Brûleur sécheur	Combustible	GN	FOL	FOL	GN	FOL	GN	GN	GPL
Chaudière	Combustible	Electrique	Propane	Electrique	GN	Electrique	GN	Electrique	GPL
Engins (chargeuse)	Nombre	2	2	1	1	1	1	1	1

	N° de la centrale	1	2	3	4	5	6	7	8
	Année de référence	2011	2011	2010	2010/2011	2011	2011	2011	2011
Fiche 3 - Inventaire des matières premières consommées									
Granulats massifs	**Carrière 1 / Quantité totale (t)**	**118339**	**40300**	**8200**	**110049**	**0**	**210998**	**0**	**26800**
	Carrière 1 / Route (km)	93	650	141	20	0	0	0	53
	Carrière 1 / Route / Quantité (t)	100979	300	8200	110049	0	210998	0	26800
	Carrière 1 / Train (km)	0	650	0	0	0	0	0	0
	Carrière 1 / Train / Quantité (t)	0	40000	0	0	0	0	0	0
	Carrière 1 / Fluvial (km)	120	0	0	0	0	0	0	0
	Carrière 1 / Fluvial / Quantité (t)	17361	0	0	0	0	0	0	0
	Carrière 2 / Quantité totale (t)	**124126**	**55000**	**27188**	**0**	**0**	**3608**	**0**	**21700**
	Carrière 2 / Route (km)	135	200	0,5	0	0	30	0	267
	Carrière 2 / Route / Quantité (t)	43411	5000	27188	0	0	3608	0	21700
	Carrière 2 / Train (km)	125	200	0	0	0	0	0	0
	Carrière 2 / Train / Quantité (t)	50184	50000	0	0	0	0	0	0
	Carrière 2 / Fluvial (km)	75	0	0	0	0	0	0	0
	Carrière 2 / Fluvial / Quantité (t)	30531	0	0	0	0	0	0	0
	Carrière 3 / Quantité totale (t)	**428**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Carrière 3 / Route (km)	596	0	0	0	0	0	0	0
	Carrière 3 / Route / Quantité (t)	428	0	0	0	0	0	0	0
	Carrière 3 / Train (km)	0	0	0	0	0	0	0	0
	Carrière 3 / Train / Quantité (t)	0	0	0	0	0	0	0	0
	Carrière 3 / Fluvial (km)	0	0	0	0	0	0	0	0
	Carrière 3 / Fluvial / Quantité (t)	0	0	0	0	0	0	0	0
Granulats alluvionaires	**Carrière 1 / Quantité totale (t)**	**4683**	**0**	**0**	**0**	**65780**	**1410**	**159060**	**0**
	Carrière 1 / Route (km)	0	0	0	0	10	75	0	0
	Carrière 1 / Train (km)	110	0	0	0	0	0	0	0
	Carrière 1 / Fluvial (km)	0	0	0	0	0	0	0	0
Filler	**Quantité (t)**	**0**	**0**	**0**	**0**	**0**	**83**	**262**	**0**
	Distance route (km)	0	0	0	0	0	190	530	0
Bitume	**Raffinerie 1 / Quantité (t)**	**7150**	**4000**	**25**	**4381**	**3684**	**11845**	**8398**	**1610**
	Raffinerie 1 / Distance route (km)	274	173	661	64	150	180	232	470
	Raffinerie 2 / Quantité (t)	**230**	**2000**	**921**	**747**	**0**	**0**	**39**	**330**
	Raffinerie 2 / Distance route (km)	244	870	600	397	0	0	580	560
	Raffinerie 3 / Quantité (t)	**25**	**0**	**673**	**0**	**0**	**0**	**16**	**610**
	Raffinerie 3 / Distance route (km)	244	0	450	0	0	0	580	700
	Raffinerie 4 / Quantité (t)	**5875**	**0**	**750**	**0**	**0**	**0**	**0**	**0**
	Raffinerie 4 / Distance route (km)	76	0	135	0	0	0	0	0
Colorants	Nom	Oxyde de fer	Oxyde de fer	0	0		Oxyde de fer	Oxyde de fer	0
	Quantité (t)	**66**	**10**	**0**	**0**		**74**	**16**	**0**
	Distance route (km)	331	160	0	0		110	1300	0
Additifs	Nom	DOP CWM	CWM	0					DOPE
	Quantité (t)	**3,0**	**17,2**	**0,0**	**4,8**		**3,4**	**3,0**	**0,2**
	Distance route (km)	1077		0	150			2000	
Agrégats d'enrobé	**Quantité (t)**	**30284**	**3900**	**0**	**12961**	**8475**	**20829**	**10870**	**7190**
	Distance route (km)	0	0	0	0			3	0

	N° de la centrale Année de référence	1 2011	2 2011	3 2010	4 2010/2011	5 2011	6 2011	7 2011	8 2011
Fiche 4 - Consommations d'énergies									
Brûleur sécheur	FOL (kWh)	-	570	263	-	351	-	-	
	GN (kWh)	18767025	-	-	8105000	-	17465501	11425681	
Chaudière pour parc à liant	Electricité (kWh)	222560	-	53794	-	94001	-	280127	
	Propane (kWh)	-	1571940	-	-	-	-	-	
	GN (kWh)	-	-	-	1064985	-	1727357	-	
Fonctionnement de la centrale	Electricité (kWh)	850068	467000	215176,8	317286,64	376003,2	818811	443308	
Engins	GnR (L)	0	0	9382	16912	15016	34430	12323	10563
	FOD (t)	38,2	36,0	0,0	0,0	0,0	0,0	0,0	23,6
Fiche 5 - Consommation d'eau et de consommables									
Eau de process et de lavage	Réseau - Quantité (m3)	514	550	380	31	549	0	207	108
	Forage - Quantité (m3)	0	0	0	0	0	100	0	0
Huile & Graisse	Huile (chauffe, vidange,...) (L)	600	408	624	909				
	Graisses (kg)	30	40	0	0				
Pneus de chargeuse	Nombre	1	1	2	2			1	
Ferraille	Toles de blindage (t)	3	10						
Anti-collant / Anti-adhérent	Nom	BIO 3100							
	Quantité (L)	1000	10				0		
Filtres à poussières	Manche de filtre (kg)	100	40				333		
Fiche 6 - Emissions dans l'air									
Emissions au brûleur sécheur (calculées à partir des rapports d'émissions)	Poussières (kg/an)	92	21	3	155	4	297	2287	21
	SOx (oxydes de soufre en kg SO2eq/an)	891	4201	4003	6258	139	9	29	1
	NOx (oxydes d'azote en kg NO2eq/an)	1311	4383	3164	1032	2093	1555	1118	287
	NO (kg/an)		2613						
	CO (kg/an)	4611		1937	1306	2090	6342	950	336
	COV totaux (en kg Ceq/an)	2767	97	258	1757	74	5135	374	1156
	CH4 (en kg CH4eq/an)	1456			181		3968		
	COVNM (en kg Ceq/an)	1553	93	194	1621		1755	368	1149
	Benzène (kg/an)		4,8						
	HAP (kg/an)		0,03						

	N° de la centrale Année de référence	1 2011	2 2011	3 2010	4 2010/2011	5 2011	6 2011	7 2011	8 2011
Fiche 7 - Emissions dans l'eau									
Rejets d'eau de process et de lavage	Quantité (m3)	514	550	380	31	549	100	207	108
Emissions liées aux rejets d'eau pluviale (sortie du séparateur hydrocarbures) (calculées à partir des rapports d'émissions)	Nitrites + Nitrates (N) (kg/an)	1,0							
	DCO (kg O2/an)	153,5			26,0		95,5		290,0
	DBO5 (kg O2/an)	13,0			7,8		9,5		
	MES (kg/an)	221,1			44,2	259,1	12,7		31,4
	indice hydrocarbure (kg/an)	0,8			1,1	0,2	0,3		2,0
	Phosphore total (P) (kg/an)	0,2							
Fiche 8 - Déchets									
Huile & Graisse	Huile (chauffe, vidange,...) (L)	600	408	624	909				
	Graisses (kg)	30	40	0	0				
Pneus de chargeuse	Nombre	1	1	2	2			1	
Ferraille	Toles de blindage (t)	3	10						
Filtres à poussières	Manche de filtre (kg)	100	40				333		0
Retours de fabrication	Quantité (t)	10000	2000	0					
Blancs de poste	Quantité (t)	1000	3000	540	720				

8.3 Annex 3: Calculation of bitumen fume emissions

8.3.1 General data

Bitumen fumes are released during truck loading and during asphalt laying. The impacts of these fume emissions were estimated based on data provided by the USIRF Steering Committee. These data were retrieved from the CIMAROUT[9] database and represent the concentrations of the various compounds found in bitumen fumes. They were obtained by means of measurements behind the finisher during asphalt placement. The utilised data are presented in the following table.

Table 81 – Source data used for bitumen fume modelling

Family of compounds	Compound	Value	Unit
Particulate PAHs	Fluoranthene	7.56	ng/m^3 of air
	Pyrene	5.08	ng/m^3 of air
	Benzo(a)anthracene	0.24	ng/m^3 of air
	Chrysene	1.10	ng/m^3 of air
	Benzo(b)fluoranthene	0.59	ng/m^3 of air
	Benzo(j)fluoranthene	0.22	ng/m^3 of air
	Benzo(k)fluoranthene	0.25	ng/m^3 of air
	Benzo(a)pyrene	0.35	ng/m^3 of air
	Benzo(e)pyrene	0.84	ng/m^3 of air
	Dibenzo(a,h)fluoranthene	0.14	ng/m^3 of air
	Benzo(ghi)perylene	0.45	ng/m^3 of air
	Indeno(1,2,3-cd)pyrene	0.18	ng/m^3 of air
Gaseous PAHs	Naphthalene	936.62	ng/m^3 of air
	Acenaphthene	198.51	ng/m^3 of air
	Fluorene	109.67	ng/m^3 of air
	Phenanthrene	196.15	ng/m^3 of air
	Anthracene	9.14	ng/m^3 of air
	Fluoranthene	12.22	ng/m^3 of air
	Pyrene	7.4	ng/m^3 of air
Petroleum-based solvents	Benzene	17.5	ng/m^3 of air
	Cyclopentane	0.02	ng/m^3 of air
	n-Hexane	0.05	ng/m^3 of air
	Toluene	0.14	ng/m^3 of air
	Styrene	0.01	ng/m^3 of air
	Xylenes	3.69	ng/m^3 of air
	Ethylbenzene	3.51	ng/m^3 of air
Other chemical agents	Formaldehyde	0.01	ng/m^3 of air

[9] The CIMAROUT database was created in 2011. It is a documentary database of toxicological and epidemiological studies published in international scientific journals. In addition, it also contains a database of over one hundred employee exposure assessment studies carried out on-site with the participation of the National Institute of Occupational Safety Research (INRS), the Inter-regional Chemical Laboratories of Pensions and Occupational Risks Fund (CARSAT), other occupational medicine bodies and the relevant companies.

8.3.2 Bitumen fumes released during truck loading

8.3.2.1 *Assumptions and constants*

As previously indicated, the fume modelling source data were obtained from measurements performed behind the finisher during the placement stage. These are therefore not the emissions discharged during truck loading. However, given the scarcity of available data on these bitumen fumes, it has been assumed that the composition of bitumen fumes during asphalt placement is identical to the composition observed during truck loading.

To determine the emissions of the various compounds found in bitumen fumes during truck loading, we used an approach similar to the one described in the 2004 study. The main assumption of this approach is that the volume of air displaced in the truck tanker (containing the bitumen fumes) is equal to the volume of the corresponding quantity of bitumen.

Assuming an asphalt density of 2.35 t/m^3, the volume of displaced air per tonne of asphalt is:

$$Vdisplaced = \frac{1}{\rho asphalt} = 0{,}425\ \text{m}^3$$

Using the concentrations set out in the previous table and the volume of displaced air, we can estimate the emissions of the various compounds present in bitumen fumes.

A calculation example is presented below. The final data are presented in the body of the report.

- Concentration of fluoranthene in bitumen fumes: 7.56 ng/m^3 of air
- Volume of air displaced at truck loading: 0.425 m^3/t asphalt
- Emissions of fluoranthene during truck loading:
- 0.425 m^3 x 7.56 ng/m^3 = 3.22E-12 kg/t of asphalt

8.3.3 Bitumen fumes during asphalt application

The above concentration data were also used for the placement stage.

The volume of air affected by bitumen fumes was determined according to an approach similar to the one described in the earlier USIRF study. This approach is presented below.

8.3.3.1 *Concerned air volume*

The assumptions and baseline data used for calculations are presented below.

Table 82 - Assumptions and constants in calculating the bitumen fume emissions at asphalt laying

Variable	Symbol	Value	Unit
Average wind velocity	$V_{avg.}$	20	*km.h^{-1}*
		20,000	*m.h^{-1}*
Vertical work site section exposed to the wind	*S*	50	*m²*
Quantity of asphalt placed per hour	*Q*	100	*t. h^{-1}*

In one hour, the volume of air containing bitumen fumes is:

$$V = S\ \times v\ \times 1h =\ 10^6\ \text{m}^3$$

Assuming that the amount of asphalt mix applied in one hour is 100 t (value calculated based on the SEVE[10] database), the volume of air containing bitumen fumes per tonne of applied asphalt will be: 10^6/100 = 10^4 m^3.

---

[10] The USIRF's SEVE system relates to an asphalt-laying site with a capacity of 700 t/day working 7 hours per day.

Based on the concentration data provided in Table 67, it is therefore possible to estimate the emissions of the various bitumen fume compounds for one tonne of applied asphalt (and consequently also for 1 m² of pavement). The final data thus calculated are presented in the body of the report. A calculation example is presented below:

- Concentration of fluoranthene in bitumen fumes: 7.56 ng/m^3 of air
- Volume of air containing bitumen fumes per tonne of asphalt: 10^4 m^3
- Fluoranthene emissions during asphalt application: $7.56 \times 10^{-12} \times 10^4 = 7.56 * 10^{-8}$ kg/t of asphalt

8.4 Annex 4: Modelling the construction equipment

Construction equipment data are expressed as days of use of the respective machine.

8.4.1 Finisher (15 to 20 t)

8.4.1.1 *Baseline data*

The source data used for modelling finisher impacts were extracted from the SEVE comparator tool developed by USIRF and are presented in the following table.

Table 83 – Finisher source data

Data	Unit	Values	Source
Consumption - Operation	L/day	1.46E+02	USIRF - SEVE system
Fuel consumption - Transfer	L/day	5.00E+00	
Average number of operating hours	h/day	7.00E+00	
Machine lifespan	h	1.00E+04	
Machine mass	t	1.70E+01	
Maintenance coefficient	-	2.00E+00	
Fuel	-	DFO	

The next step was to calculate the mass of the machine as "mass per day" (thereby factoring in the amortisation of the finisher) by applying the following formula:

$$Machine\ mass(t/day) = \frac{Machine\ mass(t) \times Duration\ of\ \ use(h/j)}{Service\ Life\ (h)}$$

The maintenance coefficient[11] was then applied to the machine mass calculated according to the above formula to account for the maintenance needs of the machine under study. In practice, in the case of the finisher, this means calculating three times the mass of the machine (in t/d), (once to account for the production of the machine and twice for its maintenance).

Finally, for the end of life stage of machines, we have used the assumption of the SEVE system. We have assumed that the machines are refurbished and resold on the second-hand market. The mass of the machines as well as the mass corresponding to the maintenance needs, have been accounted for within the flow "Production of recycled waste, Recovered materials: Steel".

8.4.1.2 *Environmental data*

The finisher data used for modelling are presented in the following table.

Table 84 – Data used for finisher modelling

Environmental data	
Consumption - Operation	Diesel, burned in building machine {GLO}| processing | Alloc Rec
Fuel consumption - Transfer	Production: Diesel {Europe without Switzerland}| market for | Alloc Rec
	Combustion: Inventory adaptation: Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec
Machine production / Maintenance	Steel, low-alloyed {RER}| steel production, electric, low-alloyed | Alloc Rec

[11] The maintenance coefficient is defined as the coefficient to apply to the initial mass of material to estimate the maintenance cost (on the average 1 for conventional equipment and 2 for equipment that uses a large number of wear parts).

8.4.2 V1 tandem vibratory roller

The selected approach for modelling the compactor was strictly identical with the approach used for the finisher.

8.4.3 Baseline data

Table 85 – Compactor source data

Data	Unit	Values	Source
Consumption - Operation	L/day	6.40E+01	USIRF - SEVE system
Fuel consumption - Transfer	L/day	5.00E+00	
Average number of operating hours	h/day	7.00E+00	
Machine lifespan	h	8.00E+03	
Machine mass	t	8.00E+00	
Maintenance coefficient	-	1.00E+00	
Fuel	-	DFO	

8.4.3.1 *Environmental data*

The environmental data for the compactor are identical with the finisher data.

8.4.4 Planer (2m to 2.2m)

The selected approach for modelling the planer was strictly identical with the approach used for the finisher.

8.4.4.1 *Baseline data*

Table 86 – Planer source data

Data	Unit	Values	Source
Consumption - Operation	L/day	3.85E+02	USIRF - SEVE system
Fuel consumption - Transfer	L/day	5.00E+00	
Average number of operating hours	h/day	5.00E+00	
Machine lifespan	h	8.00E+03	
Machine mass	t	3.10E+01	
Maintenance coefficient	-	2.00E+00	
Fuel	-	DFO	

8.4.4.2 *Environmental data*

The environmental data for the planer are identical with the finisher data.

8.4.5 Suction sweeper

The selected approach for modelling the sweeper was strictly identical with the approach used for the finisher.

8.4.5.1 *Baseline data*

Table 87 – Suction sweeper source data

Data	Unit	Values	Source
Consumption - Operation	L/day	2.34E+02	USIRF - SEVE system
Fuel consumption - Transfer	L/day	5.00E+00	
Average number of operating hours	h/day	7.00E+00	
Machine lifespan	h	8.00E+03	
Machine mass	t	1.20E+01	
Maintenance coefficient	-	1.00E+00	
Fuel	-	Diesel fuel	

8.4.5.2 *Environmental data*

The environmental data for the planer are identical with the finisher data.

8.5 Annex 5: Application of the stocks method

8.5.1 Application to asphalt aggregates used in the production of asphalt

8.5.1.1 *Overview*

Asphalt aggregates are defined[12] as asphalt originating from:

- Milling/planing of the asphalt layer,
- Crushing of extracted asphalt pavement plates,
- Pieces of asphalts plates,
- Asphalt waste or asphalt production surplus.

In accordance with the stocks method, asphalt aggregates used in the production of asphalt represent recoverable material from stock, free of environmental impact. In fact, it is considered that they directly acquire end-of-waste status, in accordance with the CEREMA guideline "Acceptability of Deconstruction Materials for Road Construction" (under publication). Nevertheless, in order to recycle this waste, the impacts of the aggregate recycling process, namely the grinding and screening stages required to obtain usable aggregate, should be taken into account (see the following diagram). In addition, the stages of aggregate transport from the stock storage site to the recycling site and from the recycling site to the work site should also be accounted for. However, since these aggregates are generally stored and recycled at the asphalt plants themselves, these transport distances are considered to be nil.

The following diagram illustrates the application of the stocks method to asphalt aggregates.

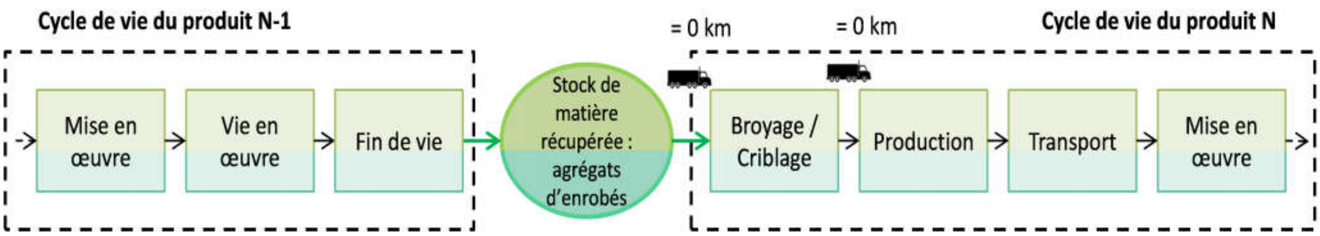


Figure 14 – Illustration of the stocks method applied to asphalt aggregates

8.5.1.2 *Baseline data*

The data used for asphalt aggregate grinding and screening are energy consumption data retrieved from the UNPG environmental data information module "Production of recycled aggregate". These data are presented below.

Table 80 – Data on asphalt aggregate production

Energy source	Unit	Values for 1 t of asphalt aggregate	Source
Fuel oil + Diesel	g/t of asphalt aggregate	6.43E+02	UNPG: Environmental information module on the production of recycled aggregate
Electricity	kWh/t of asphalt aggregate	1.85E-01	

[12] Standard NF EN 13 108-8 Bituminous mixtures - Material specifications - Part 8: Asphalt aggregates

8.5.1.3 *Environmental data*

Table 88 – Data used for modelling the energy consumed for the production of asphalt aggregate

Environmental data	
Fuel oil + Diesel	Diesel, burned in building machine {GLO}| processing | Alloc Rec
Electricity	Electricity, medium voltage {FR}| market for | Alloc Rec

Resource use flows were also accounted for. They are presented in Annex 8.6.

8.5.2 Application to planing waste

8.5.2.1 *Overview*

Planing waste is considered to be 100 % recycled. It consists of asphalt aggregates routed to the recoverable stock.

Therefore, application of the stocks method to the planing waste means taking into calculation only the transport of such waste from the road-building site to the stock. This transport distance has been assumed to be 30 km. This value corresponds to the distance between the road-building site and the asphalt plant (which accommodates the stock of recovered material).

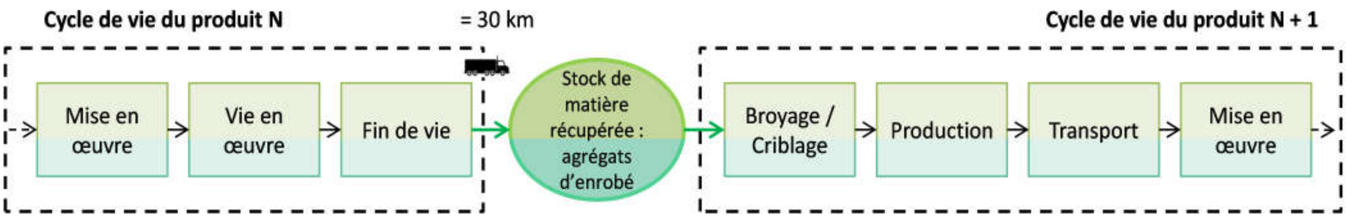


Figure 15 – Illustration of the stocks method applied to planing waste

For this waste, the environmental benefits related to their later recovery is accounted for within module D.

8.5.2.2 *Baseline data*

The planing waste is produced during the service life and end of life stages of the pavement. The masses of waste materials produced during each of these stages are presented in the body of the report. As previously noted, the transport distance is assumed to be 30 km.

Output flows have also been factored in. They are presented in Annex 8.6.

8.5.2.3 *Environmental data*

Table 89 – Data used for modelling the transport to the planing waste stock

Environmental data	
Transport	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

8.5.3 Application to loader tyre data

8.5.3.1 *Overview*

This study considers loader tyres to be 100% recycled when reaching end of life (source: Environmental information module for aggregate production, UNPG 2011). Consequently, all the used tyres are routed to the recovered material stock. It is considered that they acquire end-of-waste status directly on arrival to the recycling site. Therefore, there is no environmental impact to calculate for their end of life other than their transport.

8.5.3.2 *Baseline data*

The data used for modelling the end of life of tyres are presented in the following table.

Table 90 – Data related to the transport to loader tyres to the recovered material stock

Data	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Mass sent to the recycled stock	t	4.42E-06	Data collection
Transport distance	km	3.00E+01	BIO assumption

8.5.3.3 *Environmental data*

The modelling based on these data is presented in the following table.

Table 84 – Data used for modelling the transport of loader tyres to the recovered material stock

Environmental data	
Transport	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

Output flows have also been factored in. They are presented in Annex 8.6.

8.5.4 Application to inert aggregate waste

The inert aggregates (waste produced at the start and end of production) are used at asphalt plant sites as a source of asphalt aggregates. This type of waste is therefore recycled in-house. There is no transport to include in calculations.

Accordingly, in accordance with the stocks method, there are no environmental impacts to take into account for the end of life of inert aggregate waste.

8.5.5 Application to scrap metal

8.5.5.1 *Overview*

This study assumes that metal scrap (corresponding to the wear parts of production equipment) is 100% recycled and is sent to the recovered materials stock (source: Environmental information module for aggregate production, UNPG 2011). It acquires end-of-waste status directly on arrival to the recycling site. Therefore, there is no environmental impact to include in calculations other than its transport to the sock of recovered material.

8.5.5.2 *Baseline data*

The data used for modelling this stage are presented in the following table.

Table 91 – Data related to the transport to the stock of scrap metal

Data	Unit	Values for 1 t of asphalt concrete (AC) or 1 t of gravel bitumen (GB3)	Source
Mass sent to the recycled stock	t	3.54E-05	Data collection
Transport distance	km	3.00E+01	BIO assumption

Output flows have also been factored in. They are presented in Annex 8.6.

8.5.5.3 *Environmental data*

Table 92 – Data used for modelling the transport to the stock of scrap metal

Environmental data	
Transport	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec

8.6 Annex 6: Output flows and resource use flows

Standard NF EN 15804+A1 and its supplement XP P01-064/CN introduces several non-traditional LCA indicators, such as renewable or non-renewable process energy, use of secondary material, flows of materials intended for recycling or reuse, etc. Some of these flows had already been accounted for in the FDES in compliance with Standard NF P01-010, while others are newly introduced.

The purpose of this annex is to present these inventory flows throughout the pavement's life cycle, together with the underlying modelling assumptions. In the modelling performed in Simapro, these flows were directly added to the respective inventories.

Table 93 - Studied output flows and resource use flows in the pavement life cycle

Flow	Application(s)	Value	Unit	Source and/or comment	Modelling
Material-embodied energy of bitumen	Bitumen contained in asphalt mixes and bitumen emulsions (raw materials)	40.2	MJ/kg bitumen	IEA Energy considered as 100% non-renewable.	Use of non-renewable primary energy resources as raw materials
Use of asphalt aggregate as a secondary material	Aggregate (raw materials)	1	kg/kg of asphalt	-	Use of secondary materials
Materials derived from the production of hard rock aggregate and intended for recycling	Soft rock aggregate (raw materials)	1.34E-04	Kg/kg of aggregate	UNPG: Environmental information module - Hard rock aggregates, 2011	Materials intended for recycling
Materials derived from the production of soft rock aggregate and intended for recycling	Soft rock aggregate (raw materials)	2.84E-04	Kg/kg of aggregate	UNPG: Environmental information module - Soft rock aggregate, 2011	Materials intended for recycling
Use of steel as a secondary material	Scrap metal and tyres (consumables), loader and asphalt plant (infrastructures), construction equipment (asphalt application and service life	3.70E-01	kg/kg of steel	Steel produced in the electric furnace, Althaus H.-J. et al. (2007) Life Cycle Inventories of Metals. Final report ecoinvent data v2.0, No 10. EMPA Düberdorf, Swiss Centre for Life Cycle Inventories	Use of secondary materials
Recycling of steel at end of life	Scrap metal and tyres (consumables), loader and asphalt plant (infrastructures), construction equipment (asphalt application and service life	1	kg/kg of steel	Applies during A3 for scrap metal and infrastructures, during A5 and B2 to construction equipment	Materials intended for recycling
Recycling of tyres at end of life	Tyres (Consumables)	1	Kg/kg of tyres	-	Materials intended for recycling
Asphalt planings produced during planing	Asphalt planings (Service life)	1	Kg/kg of planings	-	Materials intended for recycling
Base course left in place at end of life	End of life of pavement (C3)	1	Kg/kg of pavement	-	Materials intended for reuse

8.7 Annex 7: Modelling the French electric power mix (kWh)

The French electric power mix was modelled based on Ecoinvent 3.1 data, which in turn uses the International Energy Agency figures for 2008.

It should be noted that the inventory includes national production and a share of imports from neighbouring countries. The considered production mix was taken from the LCI "Electricity, high voltage {FR}| market for | Alloc Rec, U".

Table 94 - French electric power mix based on Ecoinvent 3.1

Source	Share of the electric power mix (%)	Corresponding LCI
Coal	4.06%	Electricity, high voltage {FR}| electricity production, hard coal | Alloc Rec
Hydroelectric power (pumped storage)	0.868%	Electricity, high voltage {FR}| electricity production, hydro, pumped storage | Alloc Rec
Hydroelectric power (reservoir, alpine region)	1.61%	Electricity, high voltage {FR}| electricity production, hydro, reservoir, alpine region | Alloc Rec
Hydroelectric power (run-of-river)	8.47%	Electricity, high voltage {FR}| electricity production, hydro, run-of-river | Alloc Rec
Natural gas	3.81%	Electricity, high voltage {FR}| electricity production, natural gas, at conventional power plant | Alloc Rec
Nuclear	75.9%	Electricity, high voltage {FR}| electricity production, nuclear, pressure water reactor | Alloc Rec
Fuel oil	1.01%	Electricity, high voltage {FR}| electricity production, oil | Alloc Rec
Wind (< 1 MW)	0.0881%	Electricity, high voltage {FR}| electricity production, wind, <1MW turbine, onshore | Alloc Rec
Wind (1-3 MW)	0.991%	Electricity, high voltage {FR}| electricity production, wind, 1-3MW turbine, onshore | Alloc Rec
Wind (> 3 MW)	0.0220%	Electricity, high voltage {FR}| electricity production, wind, >3MW turbine, onshore | Alloc Rec
Biogas	0.119%	Electricity, high voltage {FR}| heat and power co-generation, biogas, gas engine | Alloc Rec
Biomass	0.251%	Electricity, high voltage {FR}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Alloc Rec
Blast furnace gas	0.511%	Electricity, high voltage {FR}| treatment of blast furnace gas, in power plant | Alloc Rec
Coal gas	0.163%	Electricity, high voltage {FR}| treatment of coal gas, in power plant | Alloc Rec
Import from Belgium	0.397%	Electricity, high voltage {FR}| import from BE | Alloc Rec
Import from Switzerland	0.734%	Electricity, high voltage {FR}| import from CH | Alloc Rec
Import from Germany	0.232%	Electricity, high voltage {FR}| import from DE | Alloc Rec
Import from Spain	0.323%	Electricity, high voltage {FR}| import from ES | Alloc Rec
Import from Great Britain	0.181%	Electricity, high voltage {FR}| import from GB | Alloc Rec
Import from Italy	0.222%	Electricity, high voltage {FR}| import from IT | Alloc Rec

It should be noted that the French power mix data for electricity production (not including imports/exports) were provided by RTE for 2012[13]. It is described in the following table.

[13] RTE (2013), Electricity production in France and peak time management. Accessible at http://www.developpement-durable.gouv.fr/IMG/pdf/15_-_La_production_d_electricite_en_France_et_l_effacement.pdf

Table 95 - French electricity production mix for 2012

Source	Output (TWh)	Share of the electric power mix (%)
Nuclear	404.9	74.8%
Coal	18.1	3.3%
Fuel oil	6.6	1.2%
Gas	23.2	4.3%
Hydraulic energy	63.8	11.8%
Wind energy	14.9	2.8%
Photovoltaic	4	0.7%
Other renewable energy	5.9	1.1%

We have noted that the differences between the two energy mixes were small and that the nuclear and hydro-electric power prevailed, accounting for over 86% the national electricity production. This is why it has been considered acceptable for this study to keep the electric power mix proposed by the Ecoinvent database.

The losses in the network, the infrastructures and the emissions related to the different power distribution systems for different voltages have been accounted for based on the methodology proposed by Ecoinvent[14] and a Paul Scherrer Institute[15] publication. The LCI used for modelling this study is the medium voltage electricity LCI: “Electricity, medium voltage {FR}| market for | Alloc Rec”.

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[14] Frischknecht R., Sachbilanzen von Energiesystemen. Final report n°6, Swish center for LCI, PSI

[15] Life Cycle Inventories of Electricity Mixes and Grid, Itten R. Frischknecht R., Sucki M. on behalf of the Paul Scherrer Institute (PSI), Ulster, July 2012.

8.8 Annex 8: Results for "Provision of 1 m² of pavement" not including the road base courses

Table 96 - Environmental impacts for 1 m² of hot bituminous mix pavement, not including the road base courses

FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Impacts environnementaux	Étape de fabrication	Étape de mise en œuvre			Étape de vie en œuvre								Étape de fin de vie						
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie de vie**	D Bénéfices et charges au-delà des frontières du système
Réchauffement climatique kg CO2 eq/UF	**6,53E+00**	7,14E-01	3,13E-01	**1,03E+00**	0,00E+00	0,00E+00	4,29E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**4,29E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**5,04E+01**	-3,74E+00
Appauvrissement de la couche d'ozone kg CFC 11 eq/UF	**9,40E-07**	1,31E-07	6,19E-08	**1,93E-07**	0,00E+00	0,00E+00	6,65E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**6,65E-06**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**7,79E-06**	-1,60E-07
Acidification des sols et de l'eau kg SO2 eq/UF	**3,21E-02**	2,90E-03	2,29E-03	**5,19E-03**	0,00E+00	0,00E+00	2,19E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**2,19E-01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**2,56E-01**	-3,47E-02
Eutrophisation kg $(PO_4)^{3-}$ eq/UF	**4,27E-03**	4,93E-04	4,75E-04	**9,68E-04**	0,00E+00	0,00E+00	3,27E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**3,27E-02**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**3,79E-02**	-4,43E-03
Formation d'ozone photochimique kg Ethene eq/UF	**2,14E-03**	1,24E-04	3,87E-03	**3,99E-03**	0,00E+00	0,00E+00	3,11E-02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**3,11E-02**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**3,72E-02**	-2,35E-03
Épuisement des ressources abiotiques (éléments) kg Sb eq/UF	**7,80E-06**	2,32E-06	1,27E-07	**2,45E-06**	0,00E+00	0,00E+00	5,96E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**5,96E-05**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**6,98E-05**	-4,42E-06
Épuisement des ressources abiotiques (fossiles) MJ/UF	**3,96E+02**	1,09E+01	4,96E+00	**1,58E+01**	0,00E+00	0,00E+00	2,13E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**2,13E+03**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**2,54E+03**	-6,85E+02
Pollution de l'eau m3/UF	**2,63E+00**	2,52E-01	1,21E-01	**3,73E-01**	0,00E+00	0,00E+00	1,69E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,69E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**1,99E+01**	-2,77E+00
Pollution de l'air m3/UF	**7,73E+02**	1,04E+02	2,19E+03	**2,30E+03**	0,00E+00	0,00E+00	1,47E+04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,47E+04**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**1,78E+04**	-7,98E+02

Table 97 - Use of resources for 1 m² of hot bituminous mix pavement, not including the road base courses

FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Utilisation des ressources	Etape de fabrication	Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie						
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie de vie**	D Bénéfices et charges au-delà des frontières du système
Utilisation de l'énergie primaire renouvelable, à l'exclusion des ressources d'énergie primaire renouvelables utilisées comme matières premières MJ/UF	**1,56E+00**	1,36E-01	3,63E-02	**1,72E-01**	0,00E+00	0,00E+00	9,51E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**9,51E+00**	0,00E+00	1,05E-01	0,00E+00	5,57E-01	**6,61E-01**	**1,19E+01**	0,00E+00
Utilisation des ressources d'énergie primaire renouvelables en tant que matières premières MJ/UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Utilisation totale des ressources d'énergie primaire renouvelables (énergie primaire et ressources d'énergie primaire utilisées comme matières premières) MJ/UF	**1,56E+00**	1,36E-01	3,63E-02	**1,72E-01**	0,00E+00	0,00E+00	9,51E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**9,51E+00**	0,00E+00	1,05E-01	0,00E+00	5,57E-01	**6,61E-01**	**1,19E+01**	0,00E+00
Utilisation de l'énergie primaire non renouvelable, à l'exclusion des ressources d'énergie primaire non renouvelables utilisées comme matières premières MJ/UF	**1,28E+02**	1,11E+01	5,04E+00	**1,61E+01**	0,00E+00	0,00E+00	8,00E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**8,00E+02**	0,00E+00	8,52E+00	0,00E+00	2,18E+01	**3,04E+01**	**9,75E+02**	0,00E+00
Utilisation des ressources d'énergie primaire non renouvelables en tant que matières premières MJ/UF	**2,84E+02**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	1,41E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,41E+03**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**1,70E+03**	0,00E+00
Utilisation totale des ressources d'énergie primaire non renouvelables (énergie primaire et ressources d'énergie primaire utilisées comme matières premières) MJ/UF	**4,12E+02**	1,11E+01	5,04E+00	**1,61E+01**	0,00E+00	0,00E+00	2,21E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**2,21E+03**	0,00E+00	8,52E+00	0,00E+00	2,18E+01	**3,04E+01**	**2,67E+03**	0,00E+00
Utilisation de matière secondaire kg/UF	**1,34E+01**	0,00E+00	6,22E-03	**6,22E-03**	0,00E+00	0,00E+00	6,49E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**6,49E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**7,83E+01**	0,00E+00
Utilisation de combustibles secondaires renouvelables MJ/UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Utilisation de combustibles secondaires non renouvelables MJ/UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Utilisation nette d'eau douce m3/UF	**3,06E-02**	2,28E-03	1,18E-03	**3,46E-03**	0,00E+00	0,00E+00	1,96E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**1,96E-01**	0,00E+00	1,75E-03	0,00E+00	2,37E-02	**2,54E-02**	**2,55E-01**	0,00E+00

Table 98 - Production of waste for 1 m² of hot bituminous mix pavement, not including the road base courses
FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Catégorie de déchets	Etape de fabrication	Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie					Total cycle de vie	D Bénéfices et charges au-delà des frontières du système
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie**	
Déchets dangereux éliminés kg/UF	**9,30E-02**	6,84E-03	4,42E-03	**1,13E-02**	0,00E+00	0,00E+00	5,84E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**5,84E-01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**6,88E-01**	0,00E+00
Déchets non dangereux éliminés kg/UF	**1,33E+00**	5,68E-01	5,24E-01	**1,09E+00**	0,00E+00	0,00E+00	5,57E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**5,57E+01**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**5,81E+01**	0,00E+00
Déchets radioactifs éliminés kg/UF	**5,57E-04**	7,43E-05	3,51E-05	**1,09E-04**	0,00E+00	0,00E+00	3,89E-03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**3,89E-03**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**4,55E-03**	0,00E+00

Table 99 - Output flows for 1 m² of hot bituminous mix pavement, not including the road base courses
FU: Providing an area of 1m² of hot bituminous mix pavement representative of the French market, based on a reference lifespan of 100 years

Flux sortants	Etape de fabrication	Etape de mise en œuvre			Etape de vie en œuvre								Etape de fin de vie					Total cycle de vie	D Bénéfices et charges au-delà des frontières du système
	Total A1-A3 Production	A4 Transport	A5 Installation	**Total mise en œuvre**	B1 Usage	B2 Maintenance	B3 Réparation	B4 Remplacement	B5 Réhabilitation	B6 Utilisation de l'énergie	B7 Utilisation de l'eau	**Total vie en œuvre**	C1 Déconstruction/ démolition	C2 Transport	C3 Traitement des déchets	C4 Décharge	**Total fin de vie**	**Total cycle de vie**	
Composants destinés à la réutilisation kg /UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Matériaux destinés au recyclage kg/UF	**2,85E-02**	0,00E+00	1,68E-02	**1,68E-02**	0,00E+00	0,00E+00	4,35E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**4,35E+02**	0,00E+00	0,00E+00	-5,17E-05	0,00E+00	**-5,17E-05**	**4,35E+02**	0,00E+00
Matériaux destinés à la récupération d'énergie kg/UF	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – Electricité	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – vapeur	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00
Energie fournie à l'extérieur (par vecteur énergétique) MJ/UF – Gaz de process	**0,00E+00**	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	0,00E+00	0,00E+00	0,00E+00	0,00E+00	**0,00E+00**	**0,00E+00**	0,00E+00

8.9 Annex 9: Share of impacts avoided due to benefits and burdens beyond system boundaries for all the indicators.

As a complement to Section 6.5.6, the following table presents avoided impacts by recovery of asphalt planings and materials left in place at end of life, for all the indicators required by Standard NF EN 15804+A1 and its supplement.

Table 100 – Share of avoided impacts through pavement waste recycling for all the considered indicators

	Indicateur	Bénéfices liés à la valorisation des fraisats d'enrobé	Bénéfices liés à la valorisation des matériaux restant en place lors de la fin de vie de la chaussée
Impacts environnementaux	Réchauffement climatique (kg CO2 éq.)	-5%	-30%
	Appauvrissement de la couche d'ozone (kg CFC-11 éq.)	-1%	-30%
	Acidification des sols et de l'eau (kg SO2 éq.)	-10%	-29%
	Eutrophisation (kg PO_4^{3-} éq.)	-8%	-28%
	Formation d'ozone photochimique (kg C2H4 éq.)	-4%	-33%
	Épuisement ressources (éléments) (kg Sb. Éq.)	-4%	-30%
	Épuisement ressources (fossiles) (MJ)	-19%	-29%
	Pollution de l'eau (m3)	-10%	-30%
	Pollution de l'air (m3)	-3%	-34%
Utilisation des ressources	Energie procédé renouvelable (MJ)	-4%	-31%
	Energie matière renouvelable (MJ)	0%	0%
	Energie primaire totale renouvelable (MJ)	-4%	-31%
	Energie procédé non renouvelable (MJ)	-7%	-30%
	Energie matière non renouvelable (MJ)	-25%	-29%
	Energie primaire totale non-renouvelable (MJ)	-18%	-30%
	Utilisation de matière secondaire (MJ)	270%	-34%
	Energie secondaire renouvelable (MJ)	0%	0%
	Energie secondaire non renouvelable (MJ)	0%	0%
	Utilisation nette d'eau douce (m3)	-12%	-30%
Production de déchets	Déchets dangereux éliminés (kg)	-11%	-29%
	Déchets non dangereux éliminés (kg)	-1%	-11%
	Déchets radioactifs éliminés (kg)	-2%	-30%
Flux sortants	Composants pour réutilisation (kg)	0%	0%
	Matériaux pour recyclage(kg)	0%	0%
	Matériaux pour récupération d'énergie (kg)	0%	0%
	Energie fournie ext - Electricité (MJ)	0%	0%
	Energie fournie ext - Vapeur (MJ)	0%	0%
	Energie fournie ext - Gaz (MJ)	0%	0%

8.10 Annex 10: Review comments

Revue critique de l'étude « Analyse de cycle de vie de l'enrobé bitumineux à chaud représentatif français et d'une chaussée en enrobé bitumineux » et des DEP sortie d'usine et FDES associées

Note finale de revue critique

Préparée pour : USIRF

Préparée par :

Quantis	CSTB le futur en construction
François Witte Chef de projets ACV	Sébastien Lasvaux, Vérificateur FDES habilité AFNOR

7 janvier 2016

Quantis est un cabinet de conseil en analyse du cycle de vie (ACV) spécialisé dans l'accompagnement d'entreprises afin de mesurer, comprendre et gérer les impacts environnementaux de leurs produits, services et activités. Quantis est une entreprise internationale qui compte des bureaux aux États-Unis, en Allemagne, en Suisse et en France et qui emploie près de 70 personnes, parmi lesquelles on retrouve des experts mondialement reconnus en analyse du cycle de vie.

Quantis offre des services de pointe dans les secteurs suivants : empreintes environnementales (indicateurs multiples incluant le carbone et l'eau), éco-conception, chaine d'approvisionnement durable et communications environnementales. Quantis fournit également un logiciel novateur en ACV, Quantis SUITE 2.0, qui permet aux organisations d'évaluer, analyser et gérer leur empreinte environnementale avec facilité. Forte de ses relations étroites avec la communauté scientifique et ses collaborations stratégiques de recherche, Quantis a fait ses preuves quant à l'application de ses connaissances et son expertise pour accompagner ses clients à traduire des résultats issus de l'ACV en décisions et plans d'action. Pour plus de renseignements, visitez www.quantis-intl.com.

Ce rapport a été préparé par le bureau français de Quantis. Toute question relative à ce rapport doit être adressée à Quantis France.

Quantis France

42, boulevard de Sébastopol

75003 Paris

France

Tel: +33 9 63 23 04 67

info@quantis-intl.com

www.quantis-intl.com

Table des matières

1.1. Constitution du comité de revue critique

Le comité de revue critique est constitué de :

- François Witte, Quantis : expert ACV
- Sébastien Lasvaux, CSTB : expert ACV, vérificateur FDES habilité par le programme de vérification AFNOR FDES-INIES

1.2. Portée de l'avis de revue critique

L'avis de revue critique porte sur les éléments suivants :

- le rapport de projet final post revue critique « *Analyse de cycle de vie de l'enrobé bitumineux à chaud représentatif français et d'une chaussée en enrobé bitumineux* »
- la déclaration environnementale produit (DEP) sortie d'usine :
  - « *Production d'enrobé bitumineux à chaud représentatif du marché français* », établi selon la norme NF EN 15804+A1 et son complément national XP P01-064/CN, communiquée dans sa version finale en date du 7 janvier 2016.
- Et la FDES:
  - « *Chaussée en enrobé bitumineux à chaud représentative du marché français* », établi selon la norme NF EN 15804+A1 et son complément national XP P01-064/CN, communiquée dans sa version finale en date du 7 janvier 2016.

1.3. Déroulement de la revue critique

Les travaux de la revue critique ont été réalisés selon les étapes suivantes :

- Analyse des documents provisoires : du 12/11/2015 au 11/12/2015 donnant lieu aux commentaires présentés dans la section 2.
- Réunion d'échange sur les commentaires les documents provisoires : 11/12/2015
- Analyse des documents finaux et rédaction de la note finale de revue critique : 7/01/2016

1.4. Contexte de réalisation de l'ACV, de la DEP sortie d'usine et de la FDES

L'ACV et la FDES associées constitue une mise à jour de la précédente ACV[1] et FDES publiée en Avril 2014, afin de la rendre conforme à la norme NF EN 15804+A1 et à son complément national XP P 01-064/CN ainsi que pour tenir compte des dernières mises à jour de la base de données d'Inventaire de Cycle de Vie utilisée. En complément, une fiche DEP sortie d'usine conforme à la norme NF EN 15804+A1 et à son complément national XP P 01-064/CN a également été réalisée.
Les modifications apportées à l'ACV et à la FDES par rapport à cette précédente version sont donc les suivantes :

[1] Analyse de Cycle de Vie de l'enrobé bitumineux à chaud moyen français et d'une chaussée en enrobé bitumineux, Avril 2014

- Intégration des nouvelles exigences de la norme NF EN 15804+A1 et du complément national XP P 01-064/CN, à savoir principalement :
  - La décomposition du cycle de vie selon les nouvelles étapes définies par la norme ;
  - L'évaluation des bénéfices environnementaux au-delà des frontières du système (module D)
  - L'évaluation des nouveaux indicateurs d'impact et de flux
- Mise à jour des données d'arrière-plan, issues de la base de données ecoinvent :
  - Passage de la version 2.2 à la version 3.1 d'ecoinvent
- Mise à jour de la modélisation du transport par camion, qui tient désormais compte de l'ensemble du cycle de vie des véhicules, et non plus uniquement des émissions directes en phase d'usage.

La précédente ACV a fait l'objet d'une revue critique et d'une vérification (pour le volet FDES) attestant de sa conformité à la norme NF P 01-010 et à l'ISO 14040 et 14044.
L'objectif principal de cette mise à jour étant la mise en conformité avec la norme NF EN 15804+A1 et à son complément national XP P01-064/CN, aucune mise à jour des données d'activité n'a été réalisée.
Si la présente revue critique couvre bien l'ensemble du rapport, la DEP sortie d'usine et la FDES, les travaux ont prioritairement porté sur les modifications par rapport à l'étude précédente et sur la nouvelle DEP sortie d'usine.

1.5. Points d'attention pour le lecteur

En préambule de la conclusion des travaux de revue critique, nous soulignons ici quelques points discutés au cours de la revue critique.

Remarques générales

Le comité de revue critique tient à souligner les points suivants :

- Le rapport de projet présente un très bon niveau de complétude et de transparence
- Un effort important a été déployé pour la constitution de l'inventaire de cycle de vie, notamment sur la comptabilisation des émissions directes.

Périmètre

Les travaux de terrassement ainsi que la constitution de la couche de forme qui sert de plateforme à la chaussée ne sont pas inclus dans le périmètre de l'étude. Ce point a fait déjà l'objet de discussions lors de la précédente version de l'ACV. La définition technique des chaussées ne considérant pas les couches de forme et de terrassement comme parties intégrantes de la chaussée, l'exclusion du périmètre a été considérée acceptable. Le comité de revue recommande de réaliser lors de futures études, une analyse de sensibilité sur l'inclusion de ces activités, afin d'identifier l'ordre de grandeur de leurs contributions aux impacts de la chaussée.

Évolution des résultats par rapport à l'ACV précédente

Du fait de l'utilisation d'une version plus à jour de la base de données ecoinvent, l'inventaire de cycle de vie et les résultats par indicateur ont évolué par rapport à la version précédente.

Sur l'indicateur de Changement Climatique par exemple, une augmentation d'environ 15% est observée ; celle-ci étant uniquement due à la mise à jour d'ecoinvent.

Validité temporelle
La représentativité temporelle des données est proche de l'âge maximal exigé par la norme NF EN 15804+A1 (5 ans). Lors de la prochaine mise à jour de l'ACV, une fois la période de validité expirée pour la DEP sortie d'usine et pour la FDES, il sera nécessaire de mettre à jour les données collectées ou de justifier le fait que les données sont toujours représentatives.

1.6. Conclusion

À l'issu des travaux de revue critique, à la lumière des différents échanges ayant eu lieu et compte tenu des modifications prises en compte dans le rapport final, le Comité de Revue Critique considère que :

Concernant l'étude « *Analyse de cycle de vie de l'enrobé bitumineux à chaud représentatif français et d'une chaussée en enrobé bitumineux* », la DEP sortie d'usine « *Production d'enrobé bitumineux à chaud représentatif du marché français* » et la FDES « *Chaussée en enrobé bitumineux à chaud représentative du marché français* »,

- Les méthodes :
  - sont cohérentes avec les normes ISO 14040, ISO 14044, ainsi que la norme NF EN 15804+A1 et le complément national XP P 01-064/CN,
  - sont valables d'un point de vue scientifique et technique.
- Les données utilisées sont appropriées et raisonnables par rapport aux objectifs de l'étude.
- Les interprétations reflètent globalement les principales limites identifiées et les objectifs de l'étude.
- Le rapport d'étude est transparent et cohérent.

Le Comité de Revue Critique considère que l'étude telle que présentée dans le rapport final « *Analyse de cycle de vie de l'enrobé bitumineux à chaud représentatif français et d'une chaussée en enrobé bitumineux* » la DEP sortie d'usine « *Production d'enrobé bitumineux à chaud représentatif du marché français », et la FDES* « *Chaussée en enrobé bitumineux à chaud représentative du marché français* » en date du 7 janvier 2016 est conforme aux exigences des normes ISO 14040 et 14044, ainsi que de la norme NF EN 15804+A1 et de son complément national XP P 01-064/CN.

François Witte

Sébastien Lasvaux

Le présent rapport de revue critique est délivré à l'USIRF. Le comité de revue critique ne peut être tenu pour responsable de l'usage de son travail par aucun autre tiers. Les conclusions du comité de revue critique couvrent le rapport d'ACV final (annexes 1 à 10 comprises) « Analyse de cycle de vie de l'enrobé bitumineux à chaud représentatif français et d'une chaussée en enrobé bitumineux », ainsi que la DEP sortie d'usine « Production d'enrobé bitumineux à chaud représentatif du marché français », et la FDES(« Chaussée en enrobé bitumineux à chaud représentative du marché français » réalisés par BIO by Deloitte. Ces conclusions ne couvrent aucun autre rapport, extrait ou publication qui pourraient *éventuellement être produits. Les conclusions du comité de revue critique ont été données en fonction de l'état de l'art et des informations reçues au cours du projet. Les conclusions de ce comité de revue critique auraient pu être différentes dans un autre contexte.*

2. Commentaires détaillés

Pour chaque document (rapport ACV et FDES), chacun des commentaires est décrit par :

- Le numéro du commentaire : nécessaire aux échanges ultérieurs entre le comité de revue critique et le commanditaire/réalisateur de l'étude
- Le numéro de la page
- Le paragraphe ou numéro de tableau ou numéro de figure ;
- Le type de commentaire :

  Ge : Commentaire général

  Te : Commentaire Technique

  Ed : Commentaire éditorial

- Le niveau de commentaire : le nombre de croix est croissant avec l'importance du commentaire

+	**Peu important**
++	**Assez important**
+++	**Très important**

- Le libellé détaillé du commentaire
- La réponse
- L'avis final

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
Iteration 1 - Submitted to USIRF on 04/12/2015									
Project Report	1	Entire document / 1.4		Gen.		FW	Comment that does not require a change: The document structure is not directly in line with the structure presented in 8.2 of 15804-A1; (this difference is mentioned in 1.4).	No response necessary.	OK
Project Report	2	1.1 and 1.3	1	Ed.	+	FW	Mention is made of the 2006-2012 study, the 2012-2014 LCA and the 2012-2014 FDES. The names of these documents should be explicitly cited. Clearly define the interrelationships between the different documents, as well as the scope of update after each iteration: updates related to activity data (new data collection), to databases and to standards.	A table summing up the history of the three LCA studies conducted by USIRF since 2006 has been added in Section 1.3	OK
Project Report	3	1.3	2	Ed.	+	FW	Define the cited catalogue item (or insert a reference to the relevant paragraph) to clearly indicate that this is a recognized professional database.	The following sentence was added in Section 1.3: "This scenario is based on standard structure TC4 PF3 - 30 years listed in the October 1998 SETRA structures catalogue." This clarification was also inserted in the FDES.	OK
Project Report	4	1.4	2	Ed.	+	FW	The reference to Standard 14025 does not seem necessary, since it is intended for setting up Type III declaration programmes.	The AFNOR programme requires that conformance with this standard should be stated in the FDES. The section has been adapted as follows: "Finally, we shall note that the FDES declarations published based on this study are compliant with standard NF EN ISO 14025 (October 2006): Environmental labels and declarations – Type III environmental declarations – Principles and procedures."	OK
Project Report	5	1.5	3	Te	++	FW	List the relevant products for each company to make the rules of utilisation more explicit.	According to the professional knowledge of USIRF, this is not feasible. The generic types of asphalt mix that were modelled in this study represent 90% of national production. The environmental values of products manufactured by various companies are similar, because the bitumen content is similar. The differences between one type of asphalt and another primarily consist in the types of used aggregate. In reality, the actual pavement types are specific for each site. Again, the modelled pavement is an average pavement. Since these are products marketed on a B to B basis, for these products the framework of validity will not become compulsory.	OK

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
								These issues are clarified in Section 1.5 of the report.	
Project Report	6	1.8	4	Ed.	+	FW	BIO has not been cited as an external LCA consultant for the preparation of this study	The participation of BIO was indicated in Section 1.1.	OK
Project Report	7	2.1.1	6	Te	++	FW	Include quantified data (market shares, trends) to justify the decision not to take into account warm mixes. (Place here the value indicated in 2.6)	The justification presented in Chapter 2.6 has been added in Section 2.1.1.	OK
Project Report	8	2.1.2.2 , 2.3.1 and 2.3.2	7, 11, 12	Te	+++	FW	Describe more precisely the composition of the capping layer and its structure. Generally, additional justification should be provided for excluding these activities: - Is the case of entirely new roads (i.e., without a pre-existing capping layer) a common occurrence? This could serve to further justify its exclusion. - According to 5.9.3 (Table 63), no processing is required for the direct use of the materials left in place as road base It has been proposed to include the capping layer within the system scope, as a recycled material: Based on the stocks method, the above-mentioned capping layer would be a system input (module A1) and output at end of life (module C3).	The technical definition of pavement does not consider the capping layers and the earthwork as being an integral part of the pavement. Likewise, we could take another example of the wall surrounding a window and which by definition is not a part of the LCA of the respective window. These capping and earthwork layers are therefore excluded from the perimeter of the study. In addition, we have no technical data on the mass values of capping layers required to support a road (this is highly dependent on the type of soil). The following sentence was changed in Section 2.1.2.2: "The capping layer, which serves as road subgrade for pavement laying, has not been included in the scope of this study. It is not included in the technical definition of the road pavement, as in fact, it is not an integral part of the road."	OK
Project Report	9	2.1.2.4	8	Te	+	FW	Clarify that the life span of 30 years should be understood as being "without maintenance", if this is the case. Considering that the first maintenance activities are performed after 13 years, this indeed seems to be the case.	The statement "without maintenance" has be added to the relevant sentence in Section 2.3.1	OK
Project Report	10	2.3.1	11	Te	++	FW	Maintenance belongs to B2 Maintenance, insofar that in involves planned activities. Refer to 6.3.4.4.2 of the standard and A4 of the CN supplement	This change has been implemented throughout the report by including this maintenance activity into module B2.	OK
Project Report	11	2.3.2	12	Ed.	++	FW	In this paragraph, the arguments related to maintenance activities should be clearly separated from deconstruction activities.	The separation has been made in the relevant section. The arguments related to planings appear after those concerning the materials left in place at end of life.	OK

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
Project Report	12	2.3.2	12	Ed.	+	FW	For the other recycled waste, it should be stated: "in accordance with the cut-off rule"	These amounts of recycled waste are indeed accounted for under the indicator "Materials intended for recycling" (although they represent a tiny share of the recycled amounts over the entire life cycle compared to asphalt planings - see the table in Section 5.9.1). In contrast, the environmental benefits related to recovery of this waste beyond system boundaries have been left out. Therefore, we have not changed this sentence.	OK
Project Report	13	2.4	13	Te	++	FW	"Long-term emissions (beyond the 100 years primarily concerning emissions related to waste burial processes." If the essential part of the pavement is left in place from the outset for a much longer period of time, the exclusion should be further justified by clarifying, if this is indeed the case, that there are no direct emissions related to the presence of the pavement.	The standard requires that long-term emissions should not be taken into account. This is true irrespective of the buried material and the considered burial period. Furthermore, bitumen and asphalt are considered to be inert waste (per Directive 1999/31/CE of 26/04/1999): "inert waste is waste that does not undergo any significant physical, chemical or biological transformations." Inert waste will not dissolve, burn, or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to cause environmental pollution or harm to human health". ... " This has been added to Section 2.4.	OK. For information, the standard states that "if relevant, a longer period should be used"
Project Report	14	3.2.1	18	Te	+	FW	<u>Comment that does not require a change:</u> Temporal representativeness is close to the limit. (Point that requires attention)	No. As indicated several times in the report (sections 3.2.1. and 3.2.2, section 4), the manufacturing processes have evolved very little. Moreover, aside from warm mixes, which a priori have better environmental assessment than hot mixes (per Comment 7) and the declining trend in the overall emissions (per USIRF Environmental Assessment), the study remains conservative.	OK These elements could be used as arguments for not performing a complete update of collected data during a future study update. The comment was intended to emphasize that at the next update, it will be necessary to provide such arguments to justify the deviation from the requirements in the standard (max. 5 years for specific data). See Comment 39
Project Report	15	5.7	45	Te	++	FW	Inconsistent with Figure 4, which shows B3 for the service life. We recommend changing to B2.	Typo has been corrected. This change has been implemented throughout the report by including this	OK

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
								maintenance activity into module B2.	
Project Report	16	5.7.1	47	Te	+	FW / SL	Lack of emissions to water: Orders of magnitude could be provided in support of this assumption. How about if we took into account long-term emissions? Can a significant impact be considered? The standard stipulates that a time period beyond 100 years should be adopted, if relevant.	No, this is not the case. Bituminous mixtures are inert (see reply to Comment 13).	OK, satisfactory reply
Project Report	17	Tables 57 and 58	48	Te	++	FW	How was the quantity of remaining pavement material calculated? Is this the total pavement mass per FU (1250 kg/FU) minus materials intended for recycling (436 kg/FU)? The result of this calculation is 814 kg/FU (as against 811 kg/FU for these tables). Is the difference attributable to rounded-off amounts only? Specify the method of calculation of the quantity of pavement material left in place.	The calculation of remaining materials at end of life is explained in Section 5.8.	OK
Project Report	18	5.9.3	51	Te	++	FW	Table 63: For the replaced materials, the production of gravel bitumen for the road base and the production for the sub-base course are provided; however, only the production for the road base should be indicated (since it includes the sub-base course and the base course). Specify the tack coats involved: the coat between the capping layer and the sub-base course and the one between the sub-base course and the base course. For the transport of replaced materials: "of the road base" + specify that this relates to the two previously-described tack coats.	The table has been remade to correct the typo related to road base courses and to specify which tack coats are replaced.	OK
Project Report	19	5.9.2	50	Te	+	FW	Table 59 states that the service life stage belongs to B4: it should be replaced with B2	This change has been implemented throughout the report by including this maintenance activity into module B2.	OK
Project Report	20	5.9.2	50	Te	++	FW	Table 59 indicates an input flow of secondary materials of 5.21E+1 for production (A1-A3), whereas Table 72 indicates 5.37E+1. What is the reason for this difference? Likewise for the service life stage (6.29E+1 in Table 59, 6.49E+1 in Table 72). Table 60 should also be functionally reviewed (calculation of net flows)	The difference is due to the other flows of secondary materials specified in Annex 6 (recycled steel). A clarification to this effect was added in Section 6.5.5.	OK
Project Report	21	6.7	70	Ed.	+	FW / SL	Variance in relation to the average results: Section 8.2 of the standard: "3) The variance in relation to the average	In Section 6.7 of the report, we added a calculation of the variance of burner-dryers for the CO2 emitted during	OK, satisfactory reply

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
							LCIA results should be described, if the declared generic data originate from several sources or concern a range of similar products; We propose indicating here the variance in the consumption of burner-dryers. Concluding the second paragraph: Since the input parameters have low variability, we can reasonably conclude that variance has a limited impact on results.	combustion. Results have shown that the range of variability of the results is between -7% et 9%. When related to the asphalt production system or pavement life cycle, this variance is therefore correspondingly lower.	
Project Report	22	Figure 7	23	Ed.	+	FW	In the B1-B7 unit, indicate “B2-Maintenance”	This change has been implemented throughout the report by including this maintenance activity into module B2.	OK
Project Report	23		3	Ed.	+	SL	Replace the name of Pierre Ravel by Sébastien Lasvaux (leave the rest of the sentence unchanged)	The change was implemented.	OK, satisfactory reply
Project Report	24		1	Ed.	+	SL	page 1 “this is why 'USIRF, etc.” -> add that the data have not changed	The following sentence was added in Section 1.1: “It should be noted, however, that the production processes have changed very little over the last years, so it is therefore considered that the activity data have not changed.” In any case, this point is clarified again in Section 1.3 on the next page.	OK, satisfactory reply
Project Report	25		9	Te	+	SL	For the 26-year maintenance. the justification for the use of EME2 instead of AC is missing. The reason is not obvious (technical reason? SETRA recommendation? SETRA recommendation?)	As discussed with USIRF, the following sentence was added in the relevant paragraph in Section 2.1.2.4: “This use represents an economic optimisation, since EME 2 is an asphalt with higher structuring performance.”	OK, satisfactory reply
Project Report	26		11	Te	+	SL	2nd section, page 11, service life stage, specify that the asphalt's end of life stages (1st life cycle) and of the subsequent asphalts until cycle n-1 have been factored in	The following sentence was added in the relevant paragraph: “Furthermore, the end of life stages of the asphalt (1st life cycle) and of the subsequent asphalts until cycle n-1 have been factored in.”	OK, satisfactory reply
Project Report	27		11	Ed.	+	SL	Replace the service life or supplement it with the “B2-Maintenance module” to property reflect the terminology used in NF EN 15804+A1	This change has been implemented throughout the report by including this maintenance activity into module B2.	OK, satisfactory reply
Project Report	28		12	Ed.	+	SL	Section 2.3.2. First indent, replace “replacement” with “module B2 - Maintenance” for reasons of consistency with your choices of entered modules	This change has been implemented throughout the report by including this maintenance activity into module B2.	OK, satisfactory reply
Project Report	29		12	Te	+	SL	Specify that the results of stage C3 is not nil, since there is recycled waste	There certainly is no impact, but this does not mean that there are no recycled materials.	OK, satisfactory reply

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
Project Report	30		12	Te	++	SL	Reservation concerning the prospective scenario of FDES documents. If new arguments in support of your choices have become available since carrying out the study, you should add them. However, the scenario must correspond to the practice of 2015. Otherwise, the calculations should be redone based on a contemporary scenario.	The relevant paragraph in Section 2.3.2 has been changed: "Nevertheless, we have adopted a prospective scenario position where the case of asphalt planings is being handled from the legislative standpoint. In fact, this scenario reflects current practice, but we are qualifying it as "prospective" out of precaution with regard to the regulations under development.	OK, satisfactory reply
Project Report	31		13	Te	+	SL	Omitted flows have changed from 0.2% to 0.1% between the report of 2012 and 2014. Does it mean that some flows were added to the LCA?	This is related to the index update (calculations); the scope of the flows is equivalent.	OK, satisfactory reply
Project Report	32	2.6	14	Te	++	SL	Explain the choices of simplification of coproduct allocation rules. Warm mixes currently represent only 5%, however, this figure may increase. Likewise, to justify the allocation of 100% of impacts to hot mixes you should specify that given the lower heating conditions required by warm mixes, the impacts are assumed to be lower. This would then justify your simplifying assumption.	The following sentences were added in Section 2.6: "Furthermore, since the warm mixes require lower heating conditions than hot mixes, it may be assumed that the impacts of warm mixes are also lower. Therefore, this assimilation is conservative in relation to the studied system."	OK, satisfactory reply
Project Report	33	2.6	14	Te	+	SL	Specify that the Eurobitume study underwent a critical review according to the selected reference system (at least ISO 14040-44).	Statement has been added	OK, satisfactory reply
Project Report	34	3.1.1	15	Ed.	+	SL	For consistency reasons, specify the number of plants accounting for 77% of French production.	This figure is not available. We added that this is a group of plants belonging to Colas, Eiffage, or Eurovia.	OK, satisfactory reply
Project Report	35	3.1.1	15	Ed.		SL	Correct the typo in "data of 8 sites collected during the previous LCA in 2014" (I seem to recall 2012)	Typo corrected. The study was performed between 2012 and 2014. The table added in Section 1.3 clarifies this point as well.	OK, satisfactory reply
Project Report	36	3.1.1	15	Ed.	+	SL	More generally, on representativeness, great effort has been made to collect energy consumption data (77% of sites) which is OK. Can you provide/clarify the variability of energy consumption (min. / max / avg. / mean) corresponding to the 27 Mt of asphalt mix?	These are confidential data that the concerned companies (Colas, Eiffage and Eurovia) are not willing to communicate.	OK, satisfactory reply
Project Report	36	3.1.1	15	Ed.	+	SL	At first sight, when reading that the emissions to air and the other data rely on 3% or 15% of French production, which is considered sufficiently representative, it seems paradoxical to place this side by side with 77% of national production data collected for energy consumption.	Indeed, reliability is not the same; this depends on the type of data. However, we should take advantage of USIRF efforts to improve the quality of data on emissions to air compared to the generic data in Ecoinvent. In this respect, a paragraph has been added to Section 3.1.1 before the	OK, satisfactory reply

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
							I suggest clarifying that the quality of the LCI data is variable (very high for energy consumption and lower for other flows). Discuss	table.	
Project Report	37	3.1.1	15	Ed.	+	SL	Should the number (and the list) of flows of emissions to air measured by USIRF be specified? Add a reference to "reporting required by regulations" (source: limit of ICPE emission limit or equivalent?) ? This allows better understanding which flow values were directly taken from Ecoinvent	The distinction is made in the tables in Section 5.4.4 regarding the emissions to air related to burner-dryers. The data on bitumen fume emissions during transport and application of materials are calculated using the CIMAROUT database, as indicated in Section 3.1.1. The header of Table 45 in Section 5.5.2 has also been changed, clarifying that the left-hand column relates to the emitted substance and the right-hand column to the modelled environmental flow.	OK, satisfactory reply
Project Report	38	3.2.3	19	Ed.	+	SL	Eliminate the repeated word "representative" at the end of the paragraph	Typo corrected.	OK, satisfactory reply
Project Report	39	4	20	Ed. / Te	+	SL	Representativeness: simply state that in accordance with Standard NF EN 15804, the data must be updated from 2016 (data collection dating from 2010 as a minimum)	The following sentence was added in Section 4: "We note, however, that in accordance with Standard NF EN 15804+A1, the activity data will have to be updated from 2016". Still, we should note that this does not call into question the 5-year period of validity of FDES declarations from publication.	OK, satisfactory reply
Project Report	40	5.5.2	42	Te	+	SL	"The flows are not listed in the databases" - what flows are you referring to?	We are referring to flows that are not listed in Ecoinvent, such as the cyclopentane flow, which was modelled based on the "hydrocarbons, unspecified" flow. The clarification was made in the corresponding paragraph in Section 5.5.2	OK, satisfactory reply
Project Report	41	Part 6		Te	+	SL	It would be useful to present a comparison of interpretable indicators (primary energy, CO2) between this 2014 version and the 2012 version. Indeed, the Ecoinvent database 3.1 can affect the variations in results. It seems useful to specify here the deviation related to upstream data.	See the reply to the next comment.	OK, satisfactory reply
Project Report	42			Te	+	FW / SL	Point for discussion: Possibility to integrate updates in terms of results between the previous and the current FDES. In Climate Change, we have noticed an increase of about 15% just by using the updated Ecoinvent. It could be useful to emphasize this point in the accompanying	For multiple reasons, including the update of standards and related methodological aspects, and update of databases and indicators, it has been decided together with USIRF not to make this analysis too cumbersome. Only an analysis based on a consistent assessment	OK, satisfactory reply

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
							report	framework could be relevant to quantify developments related to changes in the industry practices. A section to this effect has been added to the report at the end of Chapter 6.	
FDES “Production of hot bituminous mix representative of the French market” and FDES “Hot bituminous mix pavement representative of the French market”	43	1	1	Ed.	+	FW / SL	Manufacturer addresses have not been provided	The table included in the FDES mentions only companies belonging to several road industry unions. The table did not mention hundreds of SMEs that are also members of a road industry union. In order not to “offend” these companies and simplify the FDES, we have eliminated the table. Only the sentence.	OK, satisfactory reply
FDES “Hot bituminous mix pavement representative of the French market”	44	3.3	5	Te	+	FW	Service life should be included in B2 rather than B3	This change has been implemented throughout the FDES by including this type of maintenance into module B2.	OK, satisfactory reply
FDES “Hot bituminous mix pavement representative of the French market”	45	3	4	Te	++	FW	Describe the capping layer and specify that it is not part of the studied system	The following sentence was added in the product description: “Earthwork and building of the capping layer serving as road subgrade were not included in this study, since they are not an integral part of the pavement.”	OK, satisfactory reply
FDES “Hot bituminous mix pavement representative of the French market”	46	5	11	Ed.	+	FW	A reminder of the functional unit should be inserted before presenting the tables of results	A reminder of the functional unit was inserted before the tables of results.	OK, satisfactory reply

Document	No.	Chapter	Page	Type	Level	Author	Comment	Response	Final assessment
FDES “Production of hot bituminous mix representative of the French market” and FDES “Hot bituminous mix pavement representative of the French market”	47	Entire document		Gen.	+++	FW / SL	Report the changes in the accompanying report following the FDES Critical Review	The changes were propagated in both deliverables.	OK, satisfactory reply
Iteration 2 - Submitted to USIRF on 24/12/2015									
FDES “Production of hot bituminous mix representative of the French market” and FDES “Hot bituminous mix pavement representative of the French market”	48	6.2		Ed. / Te	++	SL	In section 6.2. Product characteristics contributing to the sanitary quality of water. Not applicable. Bituminous asphalt leaching tests were carried out and the obtained results were below regulatory emission thresholds or even below detection limits (see the article “WATER AND BITUMEN: NO PROBLEM!” published in Bitume.info No. 26 of September 2011). Please make reference to an official test report rather than a an abstract of a professional journal.	The reference to the study performed by the École Supérieure d'Ingénieurs des Travaux de la Construction (ESITC) of Cachan on behalf of USIRF in 2011 has been added.	OK, satisfactory reply