J R C   T E C H N I C A L   R E P O R T S

Revision of Green Public Procurement Criteria for Road construction

Preliminary report

Elena Garbarino (JRC-IPTS)
Rocio Rodriguez Quintero (JRC-IPTS)
Shane Donatello (JRC-IPTS)
Oliver Wolf (JRC-IPTS)

19th February 2014

European Commission

Joint Research Centre

Institute for Prospective Technological Studies

Contact information

Elena Garbarino, Rocio Rodriguez Quintero and Shane Donatello (JRC – IPTS)

Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)

E-mail: JRC-IPTS-ROADS@ec.europa.eu

http://ipts.jrc.ec.europa.eu

http://www.jrc.ec.europa.eu

http://susproc.jrc.ec.europa.eu/road/

Some sections of this document are adapted from a preliminary contribution sent by COWI A/S.

Contents

List of tables

List of figures

Terms

Albedo: The diffuse reflectivity or reflecting power of a road or other surface.

Ash: The residual solid material from the combustion process in either coal fired power stations or incineration facilities.

Asphalt: Asphalt is a mixture of aggregates, binder and filler, used for constructing and maintaining all kind of roads and other surface areas. Aggregates used for asphalt mixtures could be crushed rock, sand, gravel or slags. In order to bind the aggregates into a cohesive mixture a binder is used. Most commonly, bitumen is used as a binder.

Asphalt concrete: Composite material used for road surfaces. Consist of asphalt as a binder and mineral aggregates.

Bitumen: Binder used in the production of asphalt. It is a brown or black viscous residue from the vacuum distillation of crude petroleum. It consists of high molecular weight hydrocarbons and minor amounts of sulfur and nitrogen.

CE marking: A guarantee of conformity of the aggregate to all applicable provisions of the Construction Products Regulation.

Cement: A binder added together with water and granular materials to make cement bound mixtures/ concrete. Cements used in road construction are normally characterized as being hydraulic. Hydraulic cements (e.g., Portland cement) harden because of hydration.

Cold mix: This is an asphalt type where the asphalt is produced without heating the aggregate. This is possible due to the use of a specific bitumen emulsion which breaks either during compaction or during mixing. After breaking, the emulsion coats the aggregate and over time, increases its strengths. Cold mixes are particularly recommendable for lightly trafficked roads.

Construction and demolition waste: Material produced as a waste from the demolition of buildings or structures.

Cracking: Fracture in the pavement. Cracking can, e.g., be transverse or longitudinal or in grids (alligator cracking). In traditional flexible pavement design fatigue cracking occurs at the underside of the asphalt layer and develops with traffic, time and climate into a crack visible at the surface of the pavement.

Hot mix: Asphalt pavement - in its simplest form, the hot mix asphalt pavement is a proportioned combination of aggregate and asphalt that's been heated in a central mixing plant. It is then transported to a project and spread and compacted on a road surface before cooling.

Feedstock energy: The chemical energy embodied in a material when it is not used as fuel.

Frost blanket: A built-up covering of sacks, matting, or other suitable material placed over freshly finished concrete; such covering is moistened to supply water in the early hydration process, and tends to maintain a uniform temperature. Can also be used for other surfaces to reduce adverse effects caused by frost.

Mastic asphalt: Mastic asphalt is a pavement type which differs from asphalt concrete by having a higher bitumen content (binder), approx. 7-10% of the aggregate mix.

Membranes: Flexible continuous sheets of one or more synthetic material which are relatively impermeable. Membranes have to be site glued or welded to ensure waterproof function.

Natural aggregate: Aggregates produced from mineral resources; sand and gravel are natural aggregates resulting from rock erosion; crushed rock is extracted from quarries.

Public Private Partnership: A Public Private Partnership (PPP) is generally a medium to long-term relationship between the public and private sectors (including the voluntary and community sector), involving the sharing of risks and rewards and the utilisation of multi-sectoral skills, expertise and finance to deliver desired policy outcomes or projects that are in the public interest. There is a range of types including the introduction of private sector ownership into state-owned businesses, the Private Finance Initiative (PFI), and selling Government services into wider markets.

Recycled aggregates: Aggregate resulting from the processing of inorganic material previously used in construction.

Reflective cracking: Cracks that appear in a surface layer of a pavement but stem from an underlying layer. The term is often used in the case of rigid pavements with a bituminous surface layer. Joints and cracks from the concrete layer will generally (with traffic and time) appear in the top asphalt layer.

Residues: Materials, often classifiable as waste, remaining after a part is removed, disposed of, or used; remainder; rest; remnant.

Road network: All roads in a given area

Rutting: Distortion of pavement surface caused by consolidation of one or more of the pavement layers.

Secondary aggregates: Usually by-products of other industrial processes not previously used in construction that can be processed to produce secondary aggregates. Secondary Aggregates can be further sub-divided into manufactured and natural, depending on their source. Examples of manufactured secondary aggregates are pulverised fuel ash (PFA) and metallurgical slags. Natural secondary aggregates include china clay sand and slate aggregate.

Skid resistance: Resistance of the pavement surface to sliding of the vehicles. Skid resistance is an important safety factor in pavement design.

Stone mastic asphalt: Surface for heavily trafficked roads. It contains high course aggregates (70-80%) filled with a mastic of bitumen (6-7%)and filler (8-12%)to which fibres (0.3%) are added.

Sustainable construction: Sustainable Construction involves delivering buildings and structures that provide greater satisfaction; increasing well-being and value to customers and users; respecting and treating stakeholders more fairly; enhancing and better protecting the natural environment; minimising construction's impact on the consumption of energy and natural resources - as well as making the construction industry more profitable and more competitive.

Warm mix: A typical warm mix asphalt is produced at a temperature around 20 - 40 °C lower than an equivalent hot mix asphalt. Less energy is consumed during production of the asphalt. Furthermore, the temperature in the mix is lower during the paving operations, resulting in improved conditions for the workers.

Abbreviations and Acronyms

AADT	Annual Average Daily Traffic
C&DW	Construction and demolition Waste
CEDR	Conference of European Directors of Roads
CEN	Comité Européen de Normalisation
CO_2	Carbon dioxide
CPR	Construction Product Regulation
EEA	European Environmental Agency
EIA	Environmental Impact Assessment
EMAS	Eco-Management and Audit Scheme
EPD	Environmental Product Declaration
GHG	Green House Gases
GPP	Green Public Procurement
GWP	Global Warming Potential
IRI	International Roughness Index
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life cycle cost
LLCC	Least Life Cycle Cost
MEAT	Economically advantageous tender
MSWI	Municipal Solid Waste Incinerator
NO_x	Nitrogen oxides
OECD	Organisation for Economic Cooperation and Development
PPP	Public Private Partnership
RAP	Reclaimed Asphalt Pavement
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical substances
SEA	Strategic Environmental Assessment
SO_x	Sulphur dioxide
TEN-T	Trans-European Transport Network
UNECE	United Nations Economic Commission for Europe
WFD	Waste Framework Directive

0 INTRODUCTION

Public procurement constitutes approx. 19% of overall GDP in Europe but is managed by relatively few decision makers who are in the position to use procurement criteria – and thus consider the environmental performance of products and services. This situation offers the chance to gain significant environmental improvements in the public sector.

To ensure a higher share of green public procurement (GPP) in Europe, it is important to identify and develop GPP criteria for products and services with a high degree of leverage in procurement decision-making combined with a significant improvement potential for environmental performance.

The development of GPP criteria for road construction aims therefore at helping public authorities to supplement basic requirements and specifications with additional criteria either to ensure that road construction projects are procured and implemented in an environmentally-friendly way or to give credit to innovative technical solutions that fulfil even stricter and additional environmental demands for road construction.

The development of criteria for a greener public procurement requires in-depth information about the technical and environmental performance of the product in question – in this case road construction – as well as the procurement processes.

For this reason, the European Commission has developed a process which attempts to bring together both technical and procurement experts to develop a broad body of evidence which can be cross checked with real experience "in the field" and to develop in a consensus oriented manner, a proposal for criteria which promise to deliver the optimum environmental improvements.

This process comprises the following steps:

Task 1: Stakeholder survey, statistical and legal review, scope and definition proposal

Task 2: Market analysis

Task 3: Technical analysis

Based on tasks 1-3, the project team has prepared this preliminary report which is the basis for producing the Technical report including draft criteria proposals. Both reports comprise the working documents for the 1st Ad Hoc Working group meeting. The Technical report including draft criteria proposal will be revised in the light of the output of this meeting

The Internet page (http://susproc.jrc.ec.europa.eu/road/) with information related to the development of the GPP criteria is prepared by IPTS to allow stakeholders to retrieve information about the project. It is also possible to register at this Internet page to be involved in the consultation process.

1 SCOPE DEFINITION, LEGISLATION, EXISTING GPP CRITERIA, LABELS AND STANDARDS

1.1 Scope and definitions

1.1.1 Scope and definitions of the current/previous GPP criteria for Road construction and traffic signs

The current set of GPP criteria for road construction and traffic signs was released in 2010 (EC, 2010), and the definitions within it were as follows:

Road Construction is defined as "the preparation and building of a road using materials, including aggregate, bituminous binders and additives that are used for the sub-base, road-base and surfacing layers of the road"

Traffic signs have three elements: sign facings (containing the sign's message), substrates (the backing material onto which the facing is attached) and the fixing (the posts or frame onto which the sign is mounted).

The elements excluded from the scope are road marking materials such as paints and other items of road furniture such as pedestrian walkways, bollards, overhead gantries, central reservations, public street lighting and traffic signals. The latter ones are justified since there is a separate set of EU GPP criteria for Street Lighting and Traffic Signals (EC, 2012a).

Some comments received from the stakeholder consultation pointed that cement is not an additive but a hydraulic binder, thus, the definition should include a more precise definition of binder to include cement.

Further comments about the scope and definitions proposed in the questionnaire are available in Annex I.1 Tab A.1.1 Stakeholders feedback on scope and definition.

1.1.2 Definitions and classifications of road construction

The aim of this section is to gather the definitions of road and road construction from different standards and legal text, and also to take into account relevant feedback received during the stakeholder consultation.

An overview of the existing references related to road and road construction shows a lack of unified definition of those terms. Most sources present a series of classifications for different types of road.

The construction of some roads falls within the remit of EU Directive 2011/92/EU and following amendments on the assessment of effects of certain public and private projects on the environment. These roads include:

- Construction of motorways and express roads [1] (Annex I, referred to in article 4(2), 7(b))
- Construction of new roads of four or more lanes or realignment and/or widening of an existing road of two lanes or less so as to provide four or more lanes where such new road or realigned and/or widened section of road would be 10 km or more in a continuous length (Annex I), projects referred to in article 4(2), 7 (c)).
- Construction of roads, harbours and port installations, including fishing harbours (projects not included in Annex I) (Annex II, projects referred to in article 4(2), 10(e)).

The European Agreement on Main International Traffic Arteries of 15 November 1975 International roads (UN, 2008) that established the International E-Road Network includes the following classification of roads in order to identify which ones are covered by this agreement:

1. Motorways

"Motorway" means a road specially designed and built for motor traffic, which does not serve properties bordering on it, and which:

1 For the purposes of this Directive, 'express road' means a road which complies with the definition in the European Agreement on Main International Traffic Arteries of 15 November 1975

i. *Is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other by a dividing strip not intended for traffic or, exceptionally, by other means;*

ii. *Does not cross at level with any road, railway or tramway track, or footpath; and*

iii. *Is especially sign-posted as a motorway.*

2. Express roads

An express road is a road reserved for motor traffic accessible from interchanges or controlled junctions only and which:

i. *Prohibits stopping and parking on the running carriageway(s); and*

ii. *Does not cross at level with any railway or tramway track, or footpath.*

3. Ordinary roads

An ordinary road is one open to all categories of users and vehicles. It may have a single carriageway or separate carriageways.

From another perspective, OECD (OECD, 2013)) and EUROSTAT (Eurostat, 2009) use a similar definition of roads in their statistical reports.

"Line of communication (travelled way) using a stabilized base other than rails or air strips open to public traffic, primarily for the use of road motor vehicles running on their own wheels" (OECD, 2013)

"Line of communication (travelled way) open to public traffic, primarily for the use of road motor vehicles, using a stabilized base other than rails or air strips" (Eurostat, 2009)

Furthermore, EUROSTAT distinguishes between "paved road" and "unpaved road":

"Paved road: road surfaced with crushed stone (macadam) with hydrocarbon binder or bituminized agents, with concrete or cobblestone"

"Unpaved road: road with a stabilised base not surfaced with crushed stone, hydrocarbon binder or bituminized agents, concrete or cobblestone"

EUROSTAT also provides a classification of roads to develop its statistics figures:

Roads are categorised according to three internationally comparable types:

a) Motorway

b) Road inside a built-up area

c) Other road (outside built-up area).

Motorway / freeway

Road, specially designed and built for motor traffic, which does not serve properties bordering on it, and which:

a) *Is provided, except at special points or temporarily, with separate carriageways for traffic in two directions, separated from each other, either by a dividing strip not intended for traffic, or exceptionally by other means*

b) *Has no crossings at the same level with any road, railway or tramway track, or footpath*

c) *Is especially sign-posted as a motorway and is reserved for specific categories of road motor vehicles.*

Express road

Road specially built for motor traffic, which does not serve adjacent properties, and:

a) *Does not normally have separation of carriageways for the two directions of traffic*

b) *Is accessible only from interchanges or controlled junctions*

c) *Is specially sign-posted as an express road and reserved for specific categories of road motor vehicles*

d) *On which stopping and parking on the running carriageway are prohibited.*

Road inside a built-up area: urban road

Road within the boundaries of a built-up area, with entries and exits sign-posted as such.

Roads inside a built-up area often have a maximum speed limit of around 50 km/h.

Excluded are motorways, express roads and other roads of higher speed traversing the built-up area, if not signposted as built-up roads. Streets are included.

Road outside a built-up area

Road outside the boundaries of a built-up area, which is an area with entries and exits sign-posted as such.

The E-road system comprises 87,000 km (2004) of major European roads, many of which are part of international links. Another main network exists in Europe, the Trans European Transport Network (TEN-T), managed by the TEN-T Agency under the European Commission (CEDR, 2009). TEN-T includes roads, railways and waterways and comprises 90,000 km of major and international European roads. 70% of the two road networks are the same.

In Eurostat, aggregated data on the construction of roads and motorways are provided with reference to the NACE code 42.11 and they refer to the following activities:

- construction of motorways, streets, roads, other vehicular and pedestrian ways
    - surface work on streets, roads, highways, bridges or tunnels (asphalt paving of roads, road painting and other marking, installation of crash barriers, traffic signs and the like)
- construction of airfield runways

This classification excludes:

- installation of street lighting and electrical signals (included in NACE code 43.21)
- architectural and engineering activities (included in NACE code 71.1)
- project management for construction (included in NACE code 71.1)

The International Road Federation (see ERF, 2013) builds its statistics upon a slightly different classification:

Motorways: Kilometre length of roads, specifically designed and built for motor traffic, which does not serve properties bordering on it, and which:

a) is provided, except at special points or temporarily, with separate carriageways for the two directions of traffic, separated from each other, either by a dividing strip not intended for traffic, or exceptionally by other means;

b) does not cross at level with any road, railway or tramway track, or footpath;

c) is especially sign-posted as a motorway and is reserved for specific categories of road motor vehicles.

Highways, main or national roads: Kilometre length of A-level roads. A-level roads are roads outside urban areas that are not motorways but belong to the top-level road network. A-level roads are characterized by a comparatively high quality standard, either non divided roads with oncoming traffic or similar to motorways. In most countries, these roads are financed by the federal or national government.

Secondary or regional roads: Kilometre length of roads that are the main feeder routes into, and provide the main links among highways, main roads, or national roads.

Other roads - Urban: Length of roads within the boundaries of a built-up area, which is an area with entries and exits specially identified by signposts as such. Urban roads often have a maximum speed limit of around 50 km/h. Excluded are motorways and other roads of higher speed traversing the built-up area, if not sign-posted as built-up roads. Streets are included.

Other roads - Rural: Length of all remaining roads in a country not included in above mentioned categories.

Paved roads: Length of all roads that are surfaced with crushed stone (macadam) with hydrocarbon binder or bituminized agents, with concrete or with cobblestone.

There is a clear correspondence between EUROSTAT and IRF classifications, as shown in Table 1.1:

Table 1.1: Eurostat - IRF classification

Eurostat	**IRF**
Motorway / freeway	*Motorways*
Express road	*Highways, main or national roads*
Road outside a built-up area	*Secondary or regional roads*
	Other roads - Rural
Road inside a built-up area: urban road	*Other roads - Urban*

It is worth highlighting that other roads (rural and urban) are considered together within the statistics provided by the International Road Federation IRF and the European Road Federation ERF (ERF, 2013)

Another classification is applied by the UN in their statistics, which is covered by the Section 5 Construction and construction services, subclass 53211 - Highways (except elevated highways), streets and roads.

This subclass includes:

- highways (except elevated highways), streets, roads and other vehicular and pedestrian ways
- surfaced parking areas, driveways, pedestrian walkways and bicycle paths
- vehicular and pedestrian underpasses and overpasses
- safety installations for roads etc.

This subclass does not include:

- Elevated highways
- Highway tunnels

This classification is relevant since it is used by the Product Category Rule in the EPD® System (see Annex I.5) to define its scope.

1.1.3 Categorization of roads

The purpose of the categorization of roads is the identification of those parameters that characterize a road and that are critical in the activities of construction and maintenance. A second step would be the definition of ranges of those parameters, meaning the "categories", in such way that each category implies different technologies, materials, maintenance frequencies, etc., of the roads. The aim of the categorization is depicting different roads that can be considered representative samples and therefore useful in the forward chapter of technical analysis.

The parameters that are potentially relevant a priori are the following:

- Pavement layers
- Type of construction
- Climatic zones
- Loading conditions

1.1.3.1 Categorization according pavement layers

The construction of modern paved roads proceeds along a number of stages. Initially the top soil and the vegetation are removed from the area to be paved. The depth of excavation will depend on the condition of the ground, the sub-grade; more excavation with backfilling may be required, or the ground may require compacting. The strength of the soil is dependent on its composition of solid matter, water and air. If necessary, where the soil is weak, lime or cement can be used to stabilize the upper part of the sub-grade and reduce the maintenance requirements of the road during its lifetime (FHWA, 2006). Advanced materials can be brought in to provide extra strength if water tables are high, or subsoil is weak. Alternatively, if the road already exists but is to be resurfaced or reconstructed, then layers of the existing road will be removed. It is at this stage the drainage systems must be dug and installed.

Once construction begins, roads are built in layers. There are three main types of road construction (Sherwood P., 2001):

- Flexible pavement roads
- Rigid (concrete) pavements
- Composite pavements

Flexible pavement layer system

Flexible pavements reduce the level of stress being transmitted vertically from the surface down to the soil below the road as a vehicle passes. Flexible pavements are built using a number of layers built on top of each other. The actual number varies depending on local conditions and methods of description. The layers comprise compacted granular material such as crushed rock, gravel or sand that is bound together by bitumen based binders in some layers. The thickness of the layers depends on expected traffic volumes - more traffic means greater layer thickness is required.

In Figure 1.1 an example diagram of a road illustrates the roles of the various layers as described below:

1. The sub-grade: the upper surface of a roadbed upon which the pavement structure and shoulders are constructed. The purpose of the sub-grade is to provide a platform for construction of the pavement and to support the pavement without undue deflection that would impact the pavement's performance. For pavements constructed on-grade or in cuts, the sub-grade is the natural in-situ soil at the site. The upper layer of this natural soil may be compacted or stabilized to increase its strength, stiffness, and/or stability (FHWA, 2006).
2. The sub-base: This can be the first layer to be constructed and is placed directly onto the sub-grade. It is built from aggregates compacted together. The sub-base can be unbound or stabilized with one of various binders such as cement, lime or other chemical additives to achieve an acceptable level of stiffness and bearing capacity. The purpose of the layer is to assist the spread of weight from a vehicle over the sub-grade, and to allow drainage into the sub-grade. A sub-base course is not always needed or used.
3. The road-base: This is the main load bearing element of the flexible pavement structure. The materials may therefore vary depending on the expected volume of traffic. Materials are based on granular aggregates. The layer can be bound as well as unbound. If the road base is treated with e.g. cement the pavement becomes a composite system.
4. The base course: The main function of this layer is to provide support for the top layer of the road and to provide protection for the underlying layers of the road.
5. The surface course and binder course: The surface course constitutes the top layer of the pavement and should be able to withstand high traffic- and environment-induced stresses without exhibiting unsatisfactory cracking and rutting in order to provide an even profile for the comfort of the user and at the same time possessing a texture to ensure adequate skid resistance. Depending on local conditions, functional characteristics such as skid resistance, noise reduction and durability are often required for surface courses. In some cases, for example where spray from vehicle wheels in wet conditions could be hazardous (FHWA, 2009), rapid drainage of surface water is desired through a porous surface while in other cases the surface course should be impermeable in order to keep water out of the pavement structure.

The binder course is the layer between the surface course and the base course.

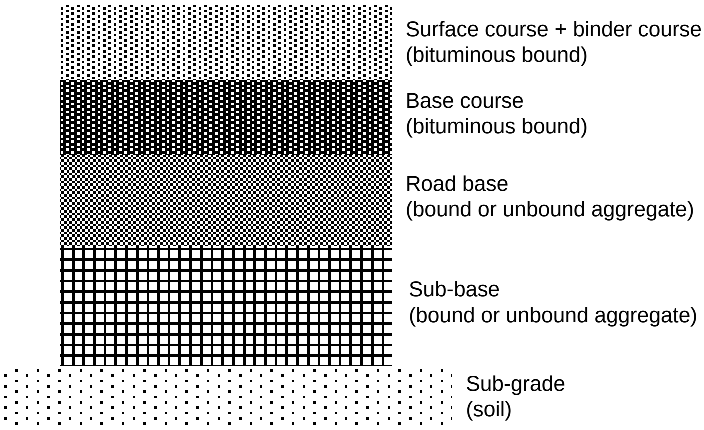


Figure 1.1: Diagram illustration the flexible pavement layer system

Depending on the local conditions, the bearing capacity of the sub-grade, the amount of expected traffic and available road building materials, the road-base may consist of two layers (a lower and an upper layer) and the same applies for the sub-base.

Rigid pavement layer system

Rigid pavements are so named due to the stiff nature of the pavement. It is possible to overcoat the rigid pavement with a bituminous layer that can be replaced when worn out which enhances the riding quality of the road and contributes to noise reduction. However, thin asphalt overlays over concrete structures tend to crack (reflective cracking) as a result of movement of the underlying concrete slabs (changes in moisture content or temperature of the subgrade can cause slab movement).

Rigid pavements are usually made of concrete, and typically consist of two or three layers above the sub-grade: the concrete slab and the sub-base, as shown in Figure 1.2. In addition, reinforcing materials, such as longitudinal steel bars (typically used in continuously reinforced concrete) and dowels (used to provide load transfer between slabs), can be used in the concrete slab to prevent thermal and load cracking. Likewise slip membranes may be used between the slab and sub-base to prevent moisture entering into the lower layer, facilitate movement of the concrete layer and thus accommodate thermal expansion and contraction.

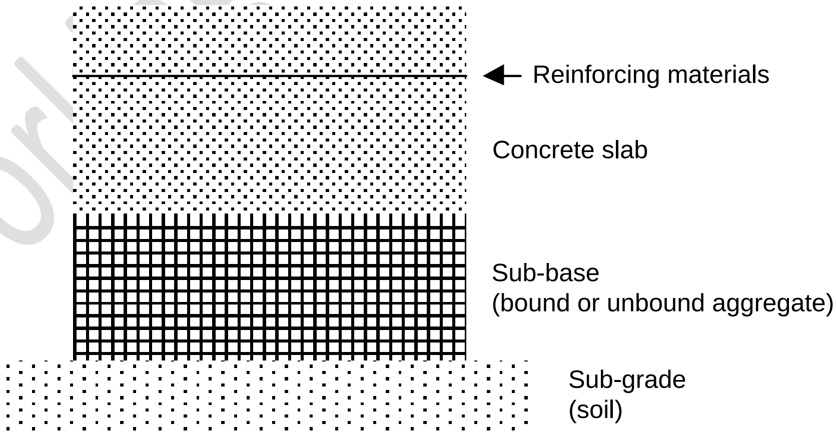


Figure 1.2: Rigid pavement layer system

In some cases rigid pavements are given a bituminous surface course (Figure 1.3) either when the road is constructed or later when a new pavement surface layer is needed. In both cases the flexible surface course can provide improved evenness, noise reduction or skid resistance. If the concrete surface is deteriorated but the concrete layer itself is structurally sound, a new thin bituminous surface course is often constructed.

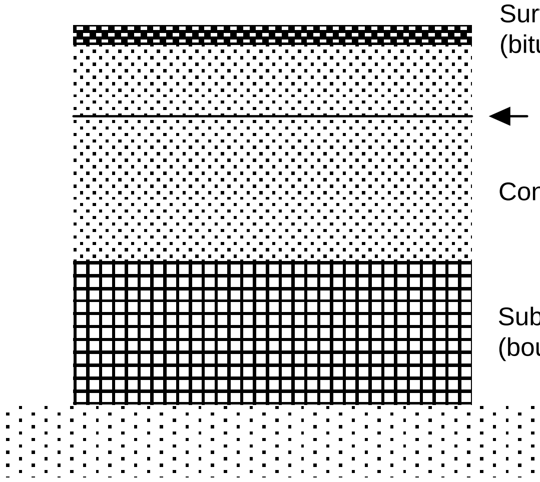


Figure 1.3: Rigid pavement layer system

Pavements with a composite layer

A composite pavement is a mixture between a flexible and a rigid pavement. The most common types of composite pavements are a flexible pavement with a cement-treated base course and a rigid pavement with a bituminous surface course. (Figure 1.4). A stakeholder has specified that in the case of composite pavement layer systems, a layer that prevents cracking can also be included between the base course (hydraulically bound) and the surface course; depending on the type of the base course, this layer can consist of a bituminous product, eventually completed by a reinforcing mesh (see Annex I.1). The cement increases the stiffness of the road.

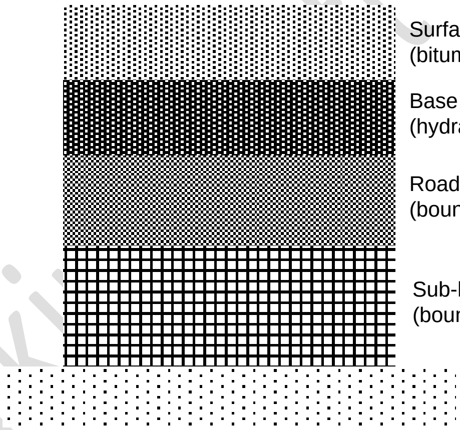


Figure 1.4: Composite pavement layer system

Material types used for the hydraulically bound base course can be found in EN 197-1:2011 and 13282-1:2013.

Inclusion of the drainage system

Drainage systems are often included in a pavement design (as shown in Figure 1.5). In questionnaire feedback, several stakeholders have underlined the importance of including the drainage system in the overall evaluation of pavement systems (see Annex I.1). The permeable base drainage layer is provided to remove infiltrated water quickly from the pavement structure. Suitable features, including edge drains and drain outlets, must be included in the pavement design for collecting and removing any accumulated water from the drainage layer. In order to function properly, the layer below the drainage layer must be constructed to grades necessary to promote positive subsurface drainage (i.e., no undulations and reasonable crown or cross slope). Filter materials (e.g., geotextiles) may also be required to prevent clogging of the drainage layer and collector system.

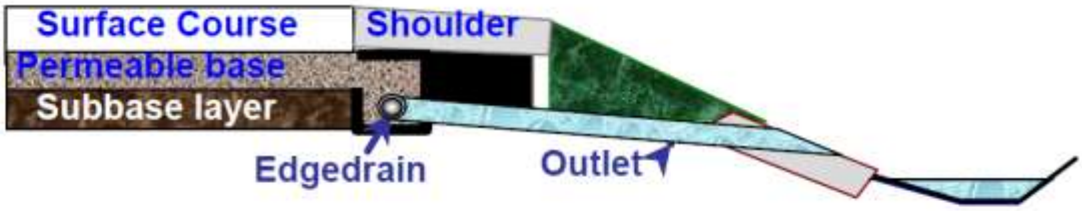


Figure 1.5: Pavement system with the drainage system (FHWA, 2006)

1.1.3.2 Categorization according to type of construction

Pavements can also be categorized based on type of construction (FHWA, 2006):

- *New construction*: The design and construction of a pavement on a previously unpaved alignment. All pavements start as new construction.
- *Rehabilitation*: The restoration or addition of structural capacity to a pavement. Overlays (either asphalt or concrete), crack and seat and full or partial depth reclamation are examples of rehabilitation construction.
- *Reconstruction*: The complete removal of an existing pavement and construction of a new pavement on the same alignment. Except for the demolition of the existing pavement (usually done in stages, *i.e.,* one lane at a time) and traffic control during construction, reconstruction is very similar to new construction in terms of design.

1.1.3.3 Categorization according to climatic zones

The different weather conditions that are characteristic of different climatic zone across Europe determine both road construction and maintenance activities. *Depending on the climate conditions, weather constraints can consist of very cold winter conditions and frequent freeze-thaw cycles, intense precipitation or large diurnal temperature fluctuations in hot arid areas. Weather constraints can be particularly important for maintenance operators. For example safety requirements can stipulate specific road pavement and asphalt design in case of frequent intense rainfalls and frequent freezing days (*EC JRC, 2012a*).*

Frost effects on road pavement represent the most important source of deterioration in regions experiencing cold winter conditions. Two main effects are deep or moderate frost depth and freeze-thaw cycles (FTC). The effects are also influenced by precipitation conditions.

In the case of regions exposed to extreme summer temperatures, it should be considered that the type of asphalt and asphalt binder required to sustain certain temperature conditions are dependent on the high temperatures and defined in current standards.

*JRC IPTS report (*EC JRC, 2012a*) presented the estimated damage costs associated with weather conditions in transport infrastructures, for seven zones characterized by broadly similar climate conditions (*Figure 1.6*), based on the WEATHER project. (Doll and Sieber, 2011)*

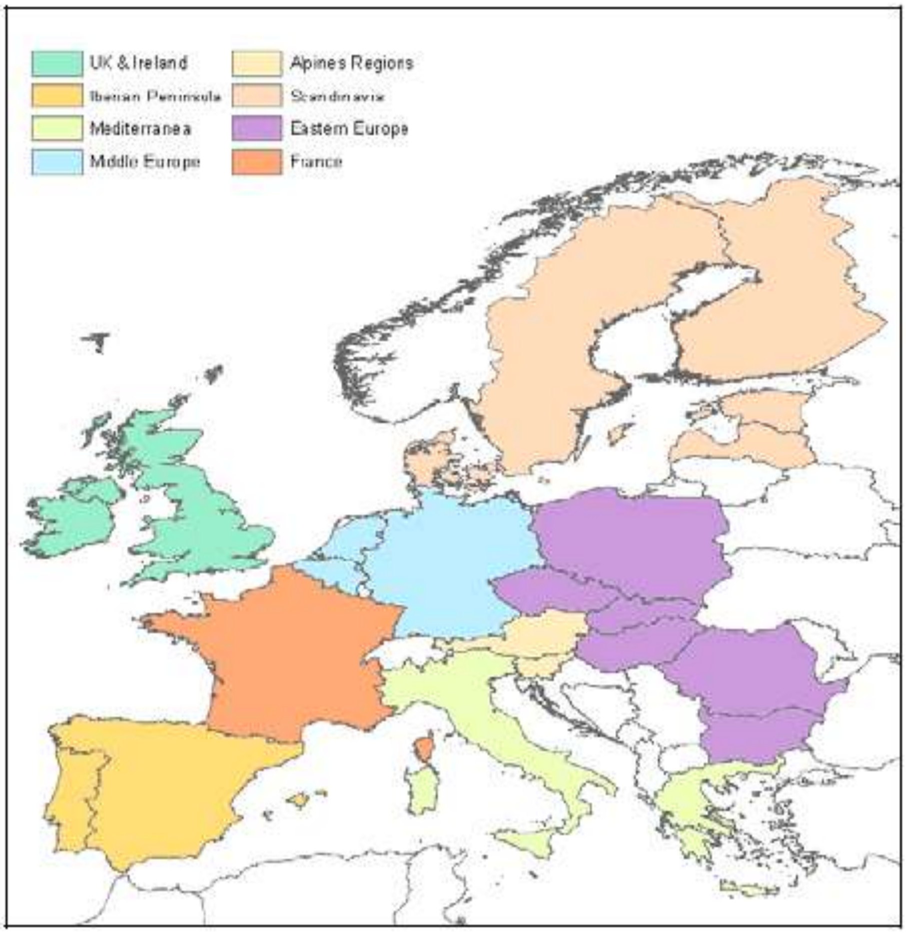


Figure 1.6: Climate zones in WEATHER project

The climate zones considered in the WEATHER project were the following:

- UK and Ireland
- Iberian Peninsula
- Mediterranean regions
- France
- Middle Europe
- Alpines regions
- Scandinavia
- Eastern Europe

1.1.3.4 Categorization according to traffic conditions

One of the main functions of a road is the load distribution, therefore the loading conditions expected to be borne by the road might comprise several parameters that determine both construction and maintenance activities. Many types of distress in asphalt pavements are load-related, such as fatigue cracking, patch deterioration, polished aggregate potholes, water bleeding, rutting and slippage cracking. Besides, one of the key parameters to define the bearing capacity of a road are the axle loads expected to occur on it.

Some examples of categorization are based on traffic conditions (flow, average speed, share of heavy goods vehicles). These are used in GPP criteria, statistics and projects related to road transport energy consumption.

Dutch criteria for the sustainable procurement of roads

The Ministry of Housing, Spatial Planning and the Environment in the Netherlands has developed criteria for the sustainable procurement of roads (NL Agency, VROM, 2010). They define roads as follows:

- Main road network (motorway, trunk road, urban motorway);
- Heavily-loaded road (urban motorway, provincial road);
- Moderately-loaded road (water board road (busy), city access road);
- Lightly-loaded road (water board road (quiet), neighborhood access road, service road, agricultural road);
- Road in residential district (residential area, car park, residential street);
- Road in accommodation area (shopping precinct, square);
- Cycle paths;
- Footpaths.

Italian Green Public Procurement (procurement of a local public authority)

The following categories are considered within the Specifications Special Contract Type (Universitá di Pisa et al., 2013) to set different requirements dependant on the traffic load of the road:

- PP: very heavy (> 3000 commercial vehicles per day)
- P : heavy (1100 - 3000 commercial vehicles per day)
- M : medium (450 - 1100 commercial vehicles per day)
- L : light (< 450 commercial vehicles per day)

A commercial vehicle is defined as those ones whose weight is ≥3 t.

CEDR (Conference of European Directors of roads)

CEDR defines different categories to build up its statistics about the TEN-T road network (CEDR, 2012), according average traffic flow, traffic density, proportion of heavy goods vehicles and heavy goods vehicle traffic flow.

Average traffic flow is expressed as Annual Average Daily Traffic (AADT), and the ranges used are:

- < 5000 vehicles
- 5000 – 20000 vehicles
- 20000 – 40000 vehicles
- 40000 – 80000 vehicles
- 80000 – 100000 vehicles
- > 100000 vehicles

Traffic density is expressed as Annual Average Daily Traffic per lane, and the ranges are the following:

- < 3000 vehicles
- 3000 – 6000 vehicles
- 6000 – 12000 vehicles
- 12000 – 18000 vehicles
- > 18000 vehicles

MIRAVEC

MIRAVEC is a project aimed at determining the most important road infrastructure characteristics which influence vehicle energy consumption.

The investigated effects are categorised into the following groups A to E (Haider et al, 2012):

A. Effects of pavement surface characteristics (rolling resistance, texture, longitudinal and transversal unevenness, cracking, rutting, other surface imperfections)

B. Effects of road design and layout (overall design standards, road trajectories, gradient and crossfall, lane provision)

C. Traffic properties and interaction with the traffic flow (e.g. free flowing traffic vs. stop-and-go, speed limits, and access restrictions)

D. Vehicle and tyre characteristics including the potential effect of technological changes in this area

E. Meteorological effects (e.g. temperature, wind, water, snow, ice)

The groups have been chosen because the effects in each of the groups share certain common characteristics.

Group C comprises several parameters, but just the following ones might be considered of interest for categorization of roads:

1. Traffic volume (AADT) and composition

The road traffic emission and fuel consumption tool HBEFA (Keller, 2010) distinguishes the following road categories for non-urban driving in descending order of expected traffic volume:

- Motorway
- Semi-motorway
- Trunk/Primary road
- Distributor/Secondary road
- Local/Collector road
- Access/residential road

The traffic composition, defined as the relative shares of the individual vehicles categories, also plays an important role, as the fuel consumption of different vehicles can differ considerably. The relative share of heavy goods vehicles (HGVs) is especially important due to their large impact on overall energy use. For the purposes of modelling traffic volume has to be subdivided into the individual traffic volumes of the vehicle categories. A distinction between passenger cars and HGVs is the minimum requirement, however, for improved accuracy more vehicle classes need to be used. HBEFA distinguishes the following vehicle categories:

- Passenger car
- Light duty vehicle (< 3.5 t, including e.g. minibuses, trucks, camper vans)
- Heavy duty vehicles (> 3.5 t), subdivided into
    - *Single truck*
    - *Truck with trailer*
    - *Articulated truck*
- Coach (tour coach, holiday coach)
- Bus (urban bus, public transport bus)
- Motorcycle

2. Traffic flow

The traffic flow describes the average travel profile of the vehicle collective on a specific road section. Free-flowing traffic is the situation where it is possible to travel at a constant speed without being forced to accelerate or brake. The opposite situation is stop-and-go traffic, where frequent idling, acceleration and deceleration phases dominate over phases with constant speed. Stop-and-go traffic results in a low average *speed and increased fuel consumption due to the idling, acceleration and deceleration phases. In HBEFA and Artemis project (Joumard et al, 2007) four "levels of service", corresponding to combinations of speed and traffic capacity, are distinguished:*

- *Free-flowing traffic (constant high speed)*
- *Heavy traffic (constrained but constant speed)*
- *Saturated traffic (heavy and unsteady traffic, variable speed, possible stops)*
- *Stop and go (congestion, low speed, frequent stops)*

3. Other parameters to categorize roads

MIRAVEC project studies other parameters in Group A and B that could potentially be used as categorization base:

A. pavement surface characteristics (rolling resistance, texture, longitudinal and transversal unevenness, cracking, rutting, other surface imperfections)

B. road design and layout (overall design standards, road trajectories, gradient and crossfall, lane provision)

<u>ARTEMIS</u>

The Artemis project "Assessment and reliability of transport emission models and inventory systems" proposes to combine the experience from different emission calculation models and ongoing research in order to arrive at a harmonised methodology for emission estimates at the national and international level. It addresses the Competitive and sustainable growth programme of the 5th framework programme of the European Commission, Key Action KA 2: Sustainable mobility and intermodality, Task 2.2: Infrastructures and their interfaces with transport means and systems, Sector 2.2.2: Environment, Sub-Task 2.2.2/2: Monitoring emissions from transport including particulates. The project develops a harmonised emission model for all transport modes, which aims to provide consistent emission estimates at the national, international and regional level (Joumard et al, 2007).

In order to identify Reference Test Patterns, Artemis project establishes a set of characteristics that should be defined for this purpose:

- *Area:*
  - *Urban*
  - *Rural*
- *Road Category and speed limit (*Figure 1.7*):*

	Main function	*Characteristics*	*Speed limit (km/h)*
Urban	National and regional network - Through-traffic	5a - Motorway	80 - 130
		5b – Non-motorway	70 - 100
	Agglomeration primary network - Primary distributor	4a - Motorway (ring, etc.)	60 - 110
		4b - Non-motorway	50 – 90
	Districts distributor	3 - Road	50 - 80
	Local distributor- Inner exchange, local traffic	2 - Road	50 – 60
	Access road - Local traffic.	1 - Road, side road, etc.	30 - 50
Rural	National and regional network - Through and distribution traffic	5 - Motorway	80 - 150
		4 - Trunk road	60 - 110
	Distributor	3 - Road	50 - 100
	Local distributor - Inner exchange, local traffic	2 - Road	50 - 80
	Access road - Local traffic	1 - Road, side road, etc.	30 - 50

Figure 1.7: Road category and speed limit in Artemis project

- *Gradient, sinuosity:*
    - *flat, non-sinuous;*
    - *hilly, sinuous;*
    - *mountainous, sinuous*
- *Traffic condition:*
    - *Free-flowing traffic (constant high speed)*
    - *Heavy traffic (constrained but constant speed)*
    - *Saturated traffic (heavy and unsteady traffic, variable speed, possible stops)*
    - *Stop and go (congestion, low speed, frequent stops)*

1.2 Legislation on public procurement

1.2.1 Directives on public procurement

The public procurement directives 2004/17/EC and 2004/18/EC set requirements for the manner in which certain public contracts above specified value thresholds must be awarded. The essential requirement is the use of a competitive procedure (tendering) with conditions and processes that are non-discriminatory, proportionate, transparent, verifiable and applied in a consistent manner. The directives allow the use of various tender procedures ranging from an open procedure through to competitive dialogue, which may be used in the case of particularly complex contracts. For the public sector, use of the negotiated procedure is only possible in exceptional circumstances, whereas in the utility sector the negotiated procedure may be used more freely.

The scope of the directives is limited to contracts above certain values because it is assumed to be particularly relevant in the context of economic activities between EU Member States. Concession agreements and other forms of public-private partnership are also not subject to the full application of the directives; however the general Treaty requirements and principles apply.

This broader application means in practice that the EU procurement rules must be considered for all types of public contracts for the realisation of road construction, whether they cover the design and construction only or also include operation and investment activities. Such contracts are thus subject to competitive procedures based on EU legal principles of equal treatment and transparency. The requirements relate to the advertising of contracts as well as the way in which competition is structured and the formulation of technical specifications, selection and award criteria. The directives explicitly allow environmental considerations to be included at different stages in the procedure and in this connection the directives explicitly refer to the requirements under EU environmental arrangements concerning environmental management and eco-labels. However, to ensure transparency and equal treatment, products that fulfil the requirements under the eco-label without having the label must also be accepted. The various options in this respect are further outlined in Annex I.2.

1.2.2 Communication on GPP

In 2008, the European Commission adopted a Communication on GPP (COM400, 2008), which, as part of the Sustainable Production and Consumption Action Plan, introduced a number of measures aimed at supporting GPP implementation across the EU. Its key features are:

EU GPP criteria

To assist contracting authorities in identifying and procuring greener products, services and works, environmental procurement criteria have been developed for 19 product and service groups, which can be directly inserted into tender documents. These GPP criteria are regularly reviewed and updated to take into account the latest scientific product data, new technologies, market developments and changes in legislation.

Helpdesk

The European Commission established a Helpdesk to disseminate information about GPP and to provide answers to stakeholders' enquiries. Contact details are available on the GPP website at: http://ec.europa.eu/environment/gpp/helpdesk.htm

Monitoring

The European Commission has commissioned several studies aimed at monitoring the implementation of GPP at all governmental levels. The most recent study was published in 2011, and the results can be found on the GPP website: http://ec.europa.eu/environment/gpp/studies_en.htm

Information

The GPP website is a central point for information on the practical and policy aspects of GPP implementation. It provides links to a wide range of resources related to environmental issues as well as local, national and international GPP information. This includes a News-Alert featuring the most recent news and events on GPP, a list of responses to Frequently Asked Questions (FAQs), a glossary of key terms and concepts, studies and training materials. All are available for download from the website:

http://ec.europa.eu/environment/gpp/index_en.htm

Legislative principles

GPP criteria must take into consideration the specific principles of EU environmental policies, namely the precautionary principle, the principle of preventive action, the principle of rectification at source, and the polluter pays principle.[2] These principles are not mere political declarations. They play an important role as guidance in cases where the detailed text of a piece of legislation does not provide the full answer. The precautionary principle would for example speak in favour of design and construction of infrastructure that can easily be upgraded e.g. roads with lower rolling resistance even in cases where the reduced environmental impacts are not entirely certain and thus might be difficult to justify from the point of normal planning and in the context of a local political context. On the other hand there can be practical and economic reasons for the use of traditional materials.

Similarly, rectification at source (the transport vehicles themselves) may lead to a situation where a procuring entity insists on strict emission requirements even when the required quality levels in force, in the environment surrounding the infrastructure, allow some slack.

Approaches for implementing sustainable public procurement (SPP) in both developed and developing countries developed by the Marrakech Task Force on Sustainable Public Procurement (MTF on SPP) is reported in Annex I.3.

1.2.3 National GPP criteria for road construction in EU Countries

1.2.3.1 The Dutch GPP criteria on roads

The Ministry of Housing, Spatial Planning and the Environment VROM has developed criteria for the Sustainable Public Procurement of Roads in 2010 (NL Agency, VROM, 2010). The criteria apply to new construction, reconstruction and also to management and maintenance of existing roads. Earthworks, and specifically embankments, are included within the criteria. Road markings and traffic signs are not included in the criteria because *there is little sustainability gain to be made here, particularly in relation to other aspect of the roads product group. Criteria for crash barriers will form part of this product group in due course.* It includes requirements for the following aspects:

- Minimum requirement: processing/removal of released substances (with reference to crushed rock, tar-containing asphalt, waste storage and management)
- Award criteria for sustainable roads

2 The principles are included in Art.191 of the EU Treaty but with the precise definition left to ECJ case law

- Sustainable materials usage: the lower the environmental impact, the higher the tender will be scored. Environmental impacts have to be calculated using an environmental life cycle analysis.
- Closed soil balance: the lower the quantity of soil transported offsite (which is suitable as a secondary building material), the higher the tender will be scored.
- The use of road infrastructure as energy source.

• Contract provisions

- Management and maintenance plan that should describe the means of management and maintenance, necessary to maintain the sustainable aspects of the road.

Two tools have been developed for encouraging sustainable procurement: the CO_2-Performanceladder [3] and Dubocalc[4].

The CO_2-Performanceladder enables the Public Authorities to assess the CO_2 emissions due to a project and use it as an award criterion for calls to tender. It is a CO_2 management tool used at organisational level, but also applied in the procurement of projects, as it is compatible with European regulations and the Public Procurement Directive.

Dubocalc is a LCA based tool based on sustainable materials and construction and energy efficient installations and it is related to the 7th basic requirement for construction works of the CPR, which regards the sustainable use of natural resources in the design and construction of a building.

1.2.3.2 The French voluntary commitment between USIRF and Ministry of Ecology

In March 2009, the French Ministry of Ecology and the French Road Contractors' Federation (USIRF) signed a voluntary commitment, aimed at improving savings in non-renewable materials; a reduction in energy consumption; the preservation of biodiversity and increased safety of local residents and road users, workers and maintenance staff who are exposed to traffic during construction sites. It was also design a software tool for all businesses to promote other environmental solutions among public contractors.

Finally, all the stakeholders involved in the operations of construction, maintenance and repair of roads, streets and other infrastructure mobility, decided to create an Institute to enable the development of a doctrine shared by all, to gather feedback and disseminate comprehensive documentation useful to everyone, whether regulatory, normative, technical or environmental: this is "IDRRIM", Institute of Roads, Streets and Infrastructures for Mobility.

The quantified indicators assessed every year since 2009 are:

- progression of warm mix asphalt,
- reduction emissions of greenhouse gases,
- Increased use of recycled materials to conserve natural resources, including aggregates and bitumen.

This agreement shows a similar approach to the one applied in GPP.

A specific LCA tool, the eco-comparator SEVE, has been developed by USIRF. The aim of these eco-systems comparators is to compare the environmental impact of contractors. According to stakeholder feedback, it is now used by 80 companies, including 66 entities by more than 2,160 users in favour of 3,280 projects studied. Its use implies direct and positive tenders: the owners can introduce objective indicators common to contractors and businesses.

1.2.3.3 The draft Italian GPP criteria on road construction and maintenance

The Italian Ministry of Environment are currently developing GPP criteria for Road construction and maintenance together with The Italian Authority for public procurement (CONSIP) and other stakeholders.

3 www.skao.nl

4 http://www.rijkswaterstaat.nl/zakelijk/duurzaam/duurzaam_inkopen/duurzaamheid_bij_contracten_en_aanbestedingen/dubocalc/index.aspx

According to stakeholder feedback, the criteria will refer to all public local roads and are in the final stage of development. Traffic signs and lighting systems are excluded from the scope.

It is proposed that the GPP criteria will include the following aspects:

- Use of natural resources:
    - use of non-renewable energy
    - use of recycled/secondary materials and by-products
    - reduction of the transportation distances
    - re-use of excavated soil
    - durability
- Natural ecosystems protection
    - Emissions decrease
    - Waste reduction and waste management
    - Avoiding use of hazardous substances
    - Water run off management
    - re-use of excavated soil
    - durability
- Human health
    - Temperature of workability of road materials
- Innovative engineering technologies

The Trento local administration established in 2010 (Provincia di Trento, 2011a - DGP 885/2010) new categories for GPP criteria development, including the category Materials for building and road construction; technique and environmental standard for recycled aggregates production and use (Provincia di Trento, 2011b - DGP 1333/2011). The aim is to promote GPP criteria development for this category.

1.2.3.4 CEEQUAL rating system

CEEQUAL, originally called the '**C**ivil **E**ngineering **E**nvironmental **Qual**ity Assessment and Awards Scheme' is the Assessment and Awards Scheme for improving sustainability in civil engineering, infrastructure, landscaping and public realm projects, based in the United Kingdom. It is promoted by the Institution of Civil Engineers (ICE) and several civil engineering organisations including CIRIA, CECA and ACE. It is aimed at improving the environmental and social performance in project specification, design and construction.

Through the development of Version 5 of the Methodology, original CEEQUAL has turned into the 'Sustainability Assessment and Awards for Civil Engineering, Infrastructure Landscaping and Public Realm Works'. Being evidence-based, it provides a sustainability rating system for project and contract teams (award thresholds: 25% pass, 40% good, 60% very good, > 75% excellent). The CEEQUAL Project Assessment process is applicable to all types of civil engineering, infrastructure, landscaping and public realm projects, including the infrastructure associated with building developments, whether the project is located in the UK & Ireland or anywhere else in the world. CEEQUAL for Term Contracts has been specifically created for the assessment of civil engineering and public realm works that are undertaken through contracts over a number of years and in a geographical or operational area. Additional information is provided in Annex I.4.

1.2.4 National GPP criteria for road construction in non EU Countries

1.2.4.1 Australian rating system

In Australia most state road authorities are requiring carbon/GHG emission calculations for their future road constructions (Lehtiranta et al, 2012).

Some of the states require other environmental data to assess several aspects e.g. the use of green materials, fuel consumption, GHG emission reduction initiatives.

The road authority in the state of Victoria, VicRoads, has developed a tool for assessing the sustainability aspects of road projects including sustainability rating system. The tool is named INVEST (Integrated VicRoads Environmental Sustainability Tool).

This system comprises 11 categories to be dealt with when a road is planned and constructed:

- Air quality (dust monitoring and mitigation)
- Behavioural change & capacity building
- Biodiversity (especially creation of additional habitat through revegetation and reuse of natural material removed during construction)
- Cultural heritage
- Community engagement
- Energy management (energy consumption, substitution of electrical energy sources, purchase of green power and carbon offsets)
- Noise management
- Resource management
- Urban design
- Water management

Based on the above mentioned aspects all selected road projects are awarded with credits and an overall sustainability score is provided for all bidders. These results serve as the basis for the ranking of all projects.

The assessment tool also includes a verification process where designated people undertake the assessment and verify compliance and documentation.

The following are examples of where VicRoads has already embedded environmental requirements in procurement.

- Continually improving Site Environmental management controls for managing environmental impacts on construction sites.
- The use of energy efficient luminaires (LED lighting) and voltage regulation devices (active reactors) within road construction.
- The ability to more easily incorporate and encourage the use of recycled materials within road construction. This includes warm mix asphalt, the inclusion of Reclaimed Asphalt Pavement, crushed concrete and bricks and the use of glass fines.

As a part of this sustainability and climate change action plan, VicRoads is also piloting the evaluation of 'sustainability attributes'. A relative assessment of value for money from the tender responses is made, and award points are given to the road construction contract based on this assessment. It does this by assessing costs, initiatives within the areas of pavement materials, non-pavement construction materials and sustainable technologies.

1.2.4.2 United States rating system

Greenroads™ attempts to measure performance of sustainable roadway design and construction. The performance metric was developed by a team headed by the University of Washington (UW) and CH2M HILL (Greenroads, 2011). The Greenroads™ program attempts to quantify the sustainable attributes of a roadway project and is a tool for the following:

- Defining project attributes that contribute to roadway sustainability
- Accounting for sustainability-related activities

- Communicating sustainable project attributes
- Managing and improving roadway sustainability
- Certifying projects

The Greenroads™ program has two major best practice categories, mandatory and voluntary.

Greenroads™ applies only to roadway design and construction. The mandatory best practices—Project Requirements—provide the minimum level of sustainable activities and each must be met as part of this metric. The voluntary practices—Voluntary Credits— are the optional attributes which show how the project has moved toward a truly sustainable endeavour.

For a roadway project to be evaluated, the project team overseeing the work will document how the Project Requirements have been met and which Voluntary Credits are being pursued. The Greenroads™ team verifies the application and the point totals and assigns the certification level. The levels include those shown in Figure 1.8.

Certification Level	Project Requirements	Voluntary Credits
Certified	All	32 – 42
Silver	All	43 – 53
Gold	All	54 – 63
Evergreen	All	64 and greater

Figure 1.8: Greenroads™ Certification Levels

Project Requirements

The Project Requirements are as follow:

- Environmental review process, which requires the project team to perform an environmental review of the project
- Life-cycle cost analysis performed according to the Federal Highway Administration's Life-Cycle Cost Analysis in Pavement Design
- Life-cycle inventory of final pavement design (reporting global warming potential and total energy only) using PaLATE v2.0 (LCA excel tool developed by the Consortium on Green Design and Manufacturing) or approved equal
- Quality control (QC) plan that lists responsibilities and qualifications of QC personnel and QC procedures during construction
- Noise mitigation plan needs to be established and implemented during construction
- Waste management plan needs to be established and implemented during construction
- Pollution prevention plan for storm water that meets EPA Construction General Permit or local requirements, whichever is more stringent
- Low-impact development hydrologic analysis must be considered for storm water management in the right-of-way
- Pavement management system to maintain and operate a pavement including evaluation and documentation of preservation actions
- Site maintenance plan for roadway maintenance, storm water system, vegetation, snow and ice, traffic control infrastructure, and cleaning
- Educational outreach to the community as part of the operation of the roadway

Voluntary Credits

The optional Voluntary Credits are the attributes which show how the project has moved beyond the minimum requirements (Greenroads, 2011). There are 37 voluntary practices which are scored from one to five points each for a total of 108 points. Custom credits are available per the approval of the Greenroads™ program for up to an additional ten points. The voluntary credits are grouped into the following categories:

- Environment and water (environmental management system, storm water, habitat, light pollution and vegetation)
- Access and equity (modal access, culture, aesthetics and safety)
- Construction activities (construction equipment, processes, quality etc.)
- Materials and resources (material extraction, processing and transport). In this topic, it is possible to include credit points for the conduction of a detailed LCA for the entire project. Furthermore there are credits for the use of recycled and/or regional material.
- Pavement technologies (pavement design, material use and function). The topic allows the user to include credit points for the pavement (life time, permeability etc.). No credits are provided for reduced rolling resistance.
- Custom credit

An example of the Greenroads rating system applied to the real case of the US 97: LAVA BUTTE project (Scarsella, 2010) is reported in Figure 1.9:

Credit Scorecard

Point Totals
A = Achieved by this project
P = Potientially achievable with low additional effort
M = Maximum achievable reguardless of additional

Certification Levels
C = Certified (All PR's Met + At Least 32 Points)
S = Silver (All PR's Met + At Least 43 Points)
G = Gold (All PR's Met + At Least 54 Points)
E = Evergreen (All PR's Met + At Least 64 Points)

Project Requirements (PR)		Possible	A	P	M
PR-1	Environmental Review Process	Req	X	X	X
PR-2	Lifecycle Cost Analysis	Req	X	X	X
PR-3	Lifecycle Inventory	Req		X	X
PR-4	Quality Control Plan	Req	X	X	X
PR-5	Noise Mitigation Plan	Req		X	X
PR-6	Waste Management Plan	Req		X	X
PR-7	Pollution Prevention Plan	Req	X	X	X
PR-8	Low-Impact Development	Req	X	X	X
PR-9	Pavement Management System	Req	X	X	X
PR-10	Site Maintenance Plan	Req	X	X	X
PR-11	Educational Outreach	Req	X	X	X
	Total	11	8	11	11

Environment & Water (EW)		Possible	A	P	M
EW-1	Environmental Management System	2			2
EW-2	Runoff Flow Control	1 - 3			3
EW-3	Runoff Quality	1 - 3			3
EW-4	Stormwater Cost Analysis	1		1	1
EW-5	Site Vegetation	1 - 3	3	3	3
EW-6	Habitat Restoration	3			
EW-7	Ecological Connectivity	1 - 3	3	3	3
EW-8	Light Pollution	3			3
	Total	21	6	7	18

Access & Equity (AE)		Possible	A	P	M
AE-1	Safety Audit	1 - 2			2
AE-2	Intelligent Transportation Systems	2 - 5	3	3	5
AE-3	Context Sensitive Solutions	5	5	5	5
AE-4	Traffic Emissions Reduction	5	5	5	5
AE-5	Pedestrian Access	1 - 2	1	1	2
AE-6	Bicycle Access	1 - 2	1	1	2
AE-7	Transit & HOV Access	1 - 5			
AE-8	Scenic Views	2	2	2	2
AE-9	Cultural Outreach	1 - 2		1	2
	Total	30	17	18	25

Construction Activities (CA)		Possible	A	P	M
CA-1	Quality Management System	2			2
CA-2	Environmental Training	1		1	1
CA-3	Site Recycling Plan	1		1	1
CA-4	Fossil Fuel Reduction	1 - 2			2
CA-5	Equipment Emission Reduction	1 - 2			2
CA-6	Paving Emission Reduction	1	1	1	1
CA-7	Water Use Tracking	2		2	2
CA-8	Contractor Warranty	3			3
	Total	14	1	5	14

Materials & Resources (MR)		Possible	A	P	M
MR-1	Lifecycle Assessment	2			2
MR-2	Pavement Reuse	4 5	4	4	5
MR-3	Earthwork Balance	1			
MR-4	Recycled Materials	1 - 5	2	5	5
MR-5	Regional Materials	1 - 5	4	5	5
MR-6	Energy Efficiency	5			
	Total	23	10	14	17

Pavement Technologies (PT)		Possible	A	P	M
PT-1	Long-Life Pavement	5	5	5	5
PT-2	Permeable Pavement	3			
PT-3	Warm Mix Asphalt	3		3	3
PT-4	Cool Pavement	5			5
PT-5	Quiet Pavement	2 - 3			
PT-6	Pavement Performance Tracking	1			1
	Total	20	5	8	14

Custom Credit (CC)		Possible	A	P	M
CC-1/2	Custom Credit Title	1 - 5	5	5	5
CC-3/4	Custom Credit Title	1 - 5	2	2	5
	Total	10	7	7	10

		A	P	M
All 11 PR Met?		No	Yes	Yes
Greenroads Total	108	46	59	98
Certification Level		-	G	E

Figure 1.9: Example of Greenroad rating system

1.3 Relevant European legislation

1.3.1 Mandatory legislation

1.3.1.1 Construction Products Regulation

The Construction Products Regulation, CPR 305/2011/EU that has repealed the Construction Product Directive CPD 89/106/EEC, is aimed at creating a single market for construction products, through the use of the CE marking. It defines the essential requirements of construction works (buildings, civil engineering works) which indirectly determines the requirements for construction products (in function of the works design and the climatic and geological conditions in the place where the construction works are situated).

Construction products must declare their performance for mechanical strength and stability, fire safety, health and environment effects, safety of use, sound nuisance and energy economy if EU or national regulatory requirements exist. When harmonised standards developed by CEN are not available, existing national standards apply. Standards related to road construction will be analysed in section 1.4.

With the introduction of the Construction Products Regulation (305/2011/EU), standardisation activities need to take into account environmental requirements if national requirements have created barriers to trade for products covered by harmonised European standards. This is due to the expansion of the basic safety requirements of the Regulation to cover sustainable use of natural resources, including recyclability, durability and emissions.

The regulation ensures the free movement of all construction products within Europe by introducing a common technical language consisting of harmonised European standards (hEN) and European Assessment Documents (EAD), in which manufacturers can state product performance on the European market (http://ec.europa.eu/enterprise/sectors/construction/declaration-of-performance/index_en.htm#h2-1). There are four main elements to the CPR:

- a system of harmonized technical specifications
- an agreed system of attestation of conformity for each product family
- a framework of notified bodies
- the CE marking of products

1.3.1.2 Strategic Environmental Assessment (SEA) Directive

The Strategic Environmental Assessment Directive 2001/42/EC aims at introducing the assessment of environmental impacts of strategic land use related plans and programs. Strategic Environmental Assessment is a preliminary process for reviewing and evaluating policies, plans and programs, as well as other draft proposals for large-scale projects and initiatives. Its aim is to determine potential environmental impacts and help include them in the decision-making process. It entails three main tasks: advocating sustainable development, determining environmental impacts and conducting the environmental assessment. Typically the SEA is performed for regional and local plans e.g. waste plans, traffic plans and urban planning.

It is mandatory to perform a SEA for plans and programmes which are:

- prepared for agriculture, forestry, fisheries, energy, industry, transport, waste/ water management, telecommunications, tourism, town & country planning or land use and which set the framework for future development of projects listed in the EIA Directive.
- or if the project is required to perform an assessment according to the Habitats Directive 92/43/EEC.

1.3.1.3 Environmental Impact Assessment Directive (EIA)

The Environmental Impact Assessment (EIA) Directive 2011/92/EU ensures that the environmental consequences of projects are identified and assessed before authorisation is given. The need for the development of an EIA is determined by the local or national authorities in the individual Member States. The EIA Directive outlines which project categories shall be made subject to an EIA, which procedure shall be followed and the content of the assessment (see section 1.1.2). New motorways and expressways must be assessed by an EIA. Other roads and expansion of existing roads must be screened for EIA requirement and then possibly assessed through a full EIA depending on the result of the EIA screening.

The EIA must cover the direct and indirect effects of a project on the following factors:

- Human beings, fauna and flora.
- Soil, water, air, climate and the landscape.
- Material assets and the cultural heritage.
- The interaction between the factors mentioned in the first, second and third indents.

The assessment has to consider whether any alternatives would have lesser impacts. The other important requirement of the directive is public consultation and information.

A distinction is made between categories of projects where assessment is mandatory and other categories where an assessment is only required if a significant environmental effect is highly likely or certain. Large roads that service areas with populations beyond a certain size are covered by the first category, whereas other roads are covered by the second category.

An EIA must be performed before a project can be approved. Thus the EIA becomes relevant at the earliest phases of the planning of a project. For projects where an EIA is not automatically mandatory, the competent national authorities must establish procedures for screening of projects to check for likely environmental effects that would require EIA.

It depends on the specific circumstances of the project to what extent EIA relevant activities are part of the planning and design phase. Such activities should in any case be made subject to separate procurement covering the design phase exclusively. To have EIA activities included as part of a tender for an entire road construction project would lay the procurement process open to criticism due to the obvious conflict of interest that the appointed operator would inevitably find itself in.

1.3.1.4 Waste framework directive

The Waste Framework Directive WFD 2008/98/EC sets the basic concepts and definitions related to waste management and lays down waste management principles such as the "polluter pays principle" and the "waste hierarchy". The key aspect is to prevent waste in all activities. The ways to administrate resources and thus reduce the consumption of natural resources and generation of waste can be seen in Figure 1.10:

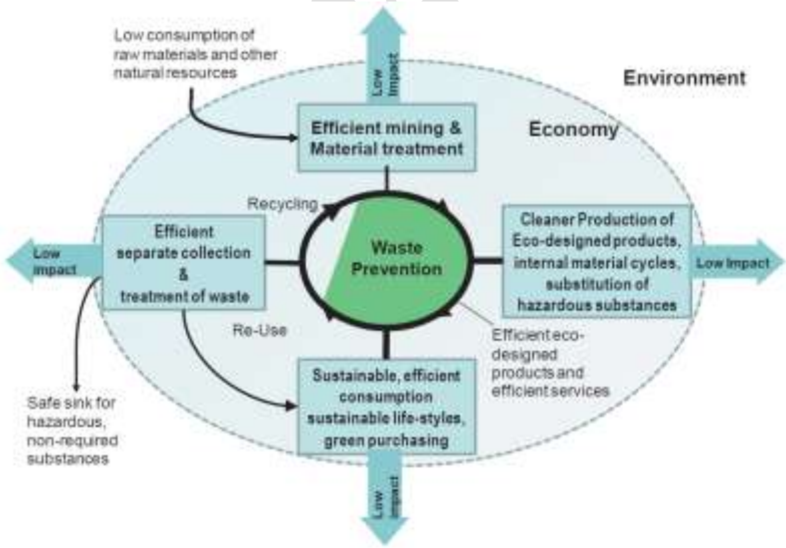


Figure 1.10: Scope of waste prevention (EEA, 2007)

According to art.4, the waste hierarchy shown in Figure 1.11 shall apply as a priority order in waste prevention and management legislation and policy.

Figure 1.11: The waste hierarchy[5]

The Directive provides clarification regarding the definition of waste and other concepts such as recycling and recovery. With regards to materials for road construction, article 2 excludes the following from the scope of the Directive (i.e. does not consider them as waste):

1….(b) land (in situ) including unexcavated contaminated soil and buildings permanently connected with land

(c) uncontaminated soil and other naturally occurring material excavated in the course of construction activities where it is certain that the material will be used for the purposes of construction in its natural state on the site from which it was excavated

2. Waste resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries covered by Directive 2006/21/EC

This information will be helpful in the development of GPP criteria related to earthworks and re-employment of excavated soil. Moreover, mineral waste from quarry excavation can be classified as non-waste.

According to art. 5 section 1, *a substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste … but as being a by-product only if the following conditions are met:*

(a) further use of the substance or object is certain;

(b) the substance or object can be used directly without any further processing other than normal industrial practice;

(c) the substance or object is produced as an integral part of a production process; and

(d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

According to art. 6 section 1, *certain specified waste shall cease to be waste when it has undergone a recovery, including recycling, operation and complies with specific criteria to be developed in accordance with the following conditions :*

(a) the substance is used for a specific purpose;

(b) a market or demand exists;

(c) the substance fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products; and

5 http://ec.europa.eu/environment/waste/framework/

(d) the use of the substance will not lead to overall adverse environmental or human health impacts

In this area, it is also helpful to mention the EC Communication of 21 February 2007 on the Interpretative Communication on waste and by-products

In order to move towards a European recycling society with a high level of resource efficiency, the WFD has designed the following target on re-use and recycling (art. 11.2): *(b) by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste* (C&DW) *excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.*

C&DW has been identified as a priority waste stream by the European Union because there is a high potential for recycling and re-use of this waste type. Furthermore, the technology for the separation and recovery of C&DW is well established, readily accessible and in general inexpensive. The potential is assessed to be large due to the existing level of recycling and re-use of C&DW which varies greatly (between less than 10% and over 90%) in the Member States. (EC, 2013b). This target is significant for road construction, since it is one of the main drivers for the employment of recycled aggregates derived from C&DW.

By 2014 the European Commission will be publishing a report examining this target and suggestions for the revision of the WFD.

1.3.1.5 Environmental liability

Directive 2004/35 on environmental liability is focused on environmental damages and provides for, in principle, strict liability for the polluter. The directive allows room for special national rules as regards, for example, cases where there was no fault or negligence on the polluter's/operator's part, and as to whether insurance should be compulsory. Depending on national solutions, the requirements of the directive could be reflected in contractual terms for the operator concerning strict liability for certain environmental damages and/or obligations to take up environmental damage insurance.

1.3.1.6 Other EU legislation and voluntary schemes

A number of other directives and regulations are or could be relevant to road construction including:

- The European Waste Catalogue – Directive 2000/532/EC
- The Landfill Directive (31/99/EC)
- Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries
- Directive 2002/49/EC relating to the assessment and management of environmental noise
- Directive 2005/88/EC of the European Parliament and of the Council of 14 December 2005, and Regulation (EC) No. 219/2009 of the European Parliament and of the Council of 11 March 200, amending the Directive 2000/14/EC on the noise emission in the environment by equipment for use outdoors
- The Water Framework Directive (Dir. 2000/60)
- The Industrial emissions Directive 2010/75
- The Seveso II Directive (Directive 96/82 on the control of major-accident hazards involving dangerous substances being replaced by the SEVESO III Directive 2012/18/EU to be transposed into national legislation by June 2015
- Environmental quality standards in the field of water policy ("The EQS Directive"), Directive 2008/105/EC (a daughter directive under the Water Framework Directive)
- Directive 2011/76/EU on the charging of heavy goods vehicles for the use of certain infrastructures
- Regulation 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemical substances (REACH), 1st of June 2007 (EU, 2006)

- Regulation 1272/2008 on classification, labelling and packaging (CLP regulation)

Besides from this existing, relevant legislation there is a proposal for the Soil Framework Directive (COM(2006) 232).

1.3.2 Voluntary environmental legislation, ecolabels and other schemes

Voluntary legislation

- EU Ecolabel Regulation 66/2010
- Eco-management and audit system (EMAS) Regulation 1221/2009

Additional information is included in Annex 1.5

Ecolabels

Information about national ecolabels can also be consulted. Additional information is included in Annex I.5

Type III labels, EPD

Additional information is included in Annex I.5

1.3.3 Stakeholder feedback on national legislation

From stakeholder consultation, comprehensive information about legislation that is relevant to road construction was provided, particularly how this applies in the countries relevant to each respondent. The information received covers different requirements that are split in two main areas:

- Legislative requirements.
- Relevant legislation banning the use of specific substances in materials for road construction.

The results of the survey in this field are gathered in Annex I.6.

1.4 Standards

Standards are an indispensable part of a road designer's daily work. The standards define the needed quality of materials, processes, quality assurance etc. The goal of the standards is thus to provide risk minimization for the Public Authorities by ensuring quality and safety.

The European standardization system has developed a strategy with strategic objectives for 2020 enabling the European standardization system to:

- deliver cost-effective, timely, efficient, flexible, market-relevant standards, standards solutions and related services;
- create standards that are used globally through our relationship with international and regional standardization bodies;
- use standardization to consolidate and strengthen the European Single Market;
- remove technical barriers to trade and supports economic growth and well-being;
- anticipate future market, social and environmental trends, and identifies emerging opportunities and innovative or convergent technologies that would benefit from early, coherent standardization;
- reflect the breadth of interests in standardization and the diversity of its stakeholders and engages with them in an inclusive and collaborative way to develop standards solutions that meet their particular needs;
- value and invest in awareness-building and education and European technical expertise to maintain and improve the high-quality of standards.

1.4.1 CEN Technical Committee related to road constriction

There are many CEN Technical Committees developing EN Standards that are relevant for the activity of road construction. The most important technical committees are listed in Annex I.7:

More information about the technical committees and standards can be found on the CEN website[6] and in Annex I.13 where the stakeholder feedback about national standards is also collected.

1.4.2 Relevant standards for materials in road construction in the EU

Road construction involves a number of different materials. The major materials can be listed as:

- Asphalt
- Cement
- Concrete (Cement concrete or asphalt concrete)
- Aggregates

All of these materials are well covered by harmonised EN standards and come under the Construction Products Regulation CPR, which came into force in July 2013. Two big issues with CPR are conformity assessment / constancy of performance and the requirement for a declaration of the potential release of dangerous substances to the environment.

Conformity assessment tasks and related responsibilities of the manufacturer are normally provided in Annex ZA of the relevant EN standard (may not yet appear in older standards). This is linked to verification and auditing systems which are very useful for GPP.

The declaration required for the potential release of dangerous substances to the environment is an area that is still evolving. Many construction materials that are known to contain dangerous substances do not yet have test methods agreed upon that would measure potential release of such substances against specified limits.

Relevance standards for materials in road construction in the EU are reported in Annex I Section I.8.

1.4.3 Relevant standards on sustainability of construction works

The technical committee under CEN TC 350 has been mandated to develop voluntary horizontal standardized methods for the assessment of the sustainability aspects of new and existing construction works and standards for the environmental product declaration of construction products. The European standardisation approach mandate is based on a lifecycle assessment methodology covering production (mandatory), construction, use (including maintenance) and end of life stages (all optional).

Relevance standards for materials in road construction in the EU are reported in Annex I Section I.9.

1.4.4 Relevant standards on construction products – Assessment of release of dangerous substances

The technical committee under CEN TC 351 was established in 2005 under the framework of the Construction Products Directive CPD. It deals with the emission of dangerous substances from construction products that may have harmful impacts on human health and the environment.

Relevance standards for materials in road construction in the EU are reported in Annex I.10.

6 http://www.cen.eu/cen/Sectors/TechnicalCommitteesWorkshops/CENTechnicalCommittees/Pages/default.aspx

1.4.5 Relevant standards related to noise management in road construction (and use) in the EU

Legislation and standards regarding noise is split into two distinct categories:

- Noise exposure in places of work (regarding workers and employers).
- Environmental noise (regarding the general public).

During the construction phase, significant noise will be generated by heavy machinery, compaction equipment and the movement of large quantities of raw materials. Noise exposure to workers is generally complied with thanks to the appropriate use of personal protective equipment and is covered by relevant Occupational Health and Safety legislation that is outside the scope of GPP. However, environmental noise levels expected to be generated during construction works should be detailed in the Environmental Impact Assessment (EIA) for the project. More details regarding EIA's are included in section 1.3.1.3 Environmental Impact Assessment Directive (EIA).

Relevance standards for materials in road construction in the EU are reported in Annex I.11.

1.4.6 Standards for drainage performance of roads

Road surfaces are generally impermeable and the sheer scale of road infrastructure means that during rainfall events, they have a significant impact on the natural flow of storm water. Adequate drainage of roads is required because they are not designed to perform their function, which is to permit the safe passage of traffic, while standing water remains on the road surface. Relevance standards for materials in road construction in the EU are reported in Annex I.12.

1.5 Scope and definition proposal

1.5.1 Definition of road

According to the common definitions used by OECD and EUROSTAT, it is proposed to define "road" in the same wording as EUROSTAT:

"Line of communication (travelled way) open to public traffic, primarily for the use of road motor vehicles, using a stabilized base other than rails or air strips" (Eurostat, 2009)

1.5.2 Definition of road construction and road maintenance

The previous GPP for Road construction and traffic signs defined "road construction" as "the preparation and building of a road using materials, including aggregate, bituminous binders and additives that are used for the sub-base, road-base and surfacing layers of the road". This definition is proposed to be retained in the framework of the current revision, but adding the comments receive from the consultation related to the cement:

Road construction: the preparation and building of a road using materials, including aggregate, bituminous and hydraulic binders and additives that are used for the sub-base, road-base and surfacing layers of the road.

Other additional definitions of maintenance are also proposed, based on the definitions provided by the Australian Asphalt Pavement Association (AAPA, 2010):

Routine maintenance is concerned with minor activities required to slow down or prevent deterioration of a road pavement. It tends to be preventive as well as corrective and includes such activities as:

- *crack-sealing*
- *pothole repair*
- *minor correction of surface texture deficiencies*
- *minor shape correction.*

Periodic maintenance primarily involves preservation of the asset using thin surfacing to restore texture or ride quality, protect the surface against entry of moisture, or prevent deterioration through ravelling and weathering.

Rehabilitation includes major work carried out to restore structural service levels. As such, the treatments are corrective in nature and include:

- *non-structural overlays*
- *structural asphalt overlays*
- *reconstruction or recycling of pavement materials, etc.*

1.5.3 Classification of roads

The sources analysed set different classifications of roads, but there is shared classification among Eurostat and IRF as shown in the Table 1.2:

Table 1.2: Classification of roads

Eurostat	**IRF**
Motorway / freeway	*Motorways*
Express road	*Highways, main or national roads*
Road outside a built-up area	*Secondary or regional roads*
	Other roads – Rural
Road inside a built-up area: urban road	*Other roads – Urban*

The market analysis carried out in Task 2 of the project showed that the main source of market data is IRF, which provides the figures for the main statistics published by the European Commission (EC 2013a). For that reason, it is proposed to use the IRF classification. It has to be underlined that in this statistics other roads (rural) and other roads (urban) are aggregated in one class called 'other roads'.

1.5.4 Categorization of roads

The main categorization parameters have been identified according to their influence in road construction and maintenance (materials, technologies, pavement lifetime, maintenance frequency and activities). The following ones have been evaluated as the most appropriate to set road categorizations:

- Pavement conditions
- Type of construction
- Climatic zones
- Traffic loading conditions
- Road gradient

The categorization according pavement conditions comprises the following categories:

- Flexible pavement roads (which can incorporate composite pavements)
- Rigid (concrete) pavements
- Composite pavements

The categorization according to the type of construction comprises the following categories:

- New construction
- Rehabilitation
- Reconstruction

The categorization according climatic zones comprises the following categories:

- Roads located in UK and Ireland
- Roads located in Iberian Peninsula
- Roads located in Mediterranean region
- Roads located in France
- Roads located in Middle Europe
- Roads located in Alpines regions
- Roads located in Scandinavia
- Roads located in Eastern Europe
- Roads located in France

The categorization according traffic loading conditions contains the evaluation of three parameters:

- Traffic density, expressed as Annual Average Daily Traffic per lane
- Traffic composition, specially the share of heavy goods vehicles
- Speed limit

The categorization according road gradients includes the following categories:

- Flat
- Hilly
- Mountainous

1.5.5 Scope

An initial proposal on scope and definition was discussed during the GPP Advisory Group meeting of March 2013. In this proposal it was recommended to include all phases of the road construction in the product scope:

- The raw materials phase
- The production phase (manufacturing of materials for the road, transport of materials to the construction site etc.)
- The road construction phase
- The use phase
- The maintenance and operation phase
- The end-of-life phase

Furthermore, in addition to the road itself, it is suggested to include earth mounds (noise barriers of soil and geosynthetics) in the product scope as they are an integrated part of the earth works during construction of a road, for a closed loop soil balance.

Also the drainage and run off systems must be included as it was also the case in the previous EU GPP for Road Construction and Traffic Signs.

A first questionnaire on scope and definitions and market data has been sent in March 2013, together with the scope proposal, to the stakeholders involved within the project. 23 feedbacks have been collected from different stakeholders (Member States representatives (13% of the total number of replies), Public Authorities and Environmental Agencies (22%), Research centres and Universities (17%) and Industry Association (48%)).

80% of the stakeholders agreed on the appropriateness of the approach. Moreover they have suggested to base the analysis on the procurement practise and to include a performance based approach within the process.

60% of the stakeholders have suggested including other aspects within the scope of the project. In detail, they have suggested to include:

- Design routes, alignment, dimension (height and depth), design speed and flows

- Transportation of the raw materials from the extraction/processing site to the construction site
- Recycling phase, since a part of the asphalt is reuse in maintenance activities
- Ground works and earthworks
- Obstruction of traffic during construction and maintenance works (considering also the use of hard shoulders)
- Drainage and water run off systems, considering also pollution control (particularly, accidents during the operation phase, as they can cause a major pollution of water courses) and climatic resilience (flood risk)
- Noise: noise reducing surfaces, the role of hard shoulders in noise reduction.
- In addition of earth mounds (noise barriers of soil), noise barriers (and fencing and vehicle restraints systems).

These suggestions have been taken into consideration in the Technical and Environmental analysis (see Chapter 3) and are included in the scope of the project. Based on the comments and a literature review, a final description of the road phases to be included in the product scope is:

- **Materials production including raw materials extraction**. This phase consists of the processes needed to manufacture construction materials and products and includes the entire upstream supply chain needed to produce each material (for examples extraction and production of aggregates, refining of crude oil for the production of bitumen). Transportation needed to move pavement materials to and from production facilities and to the project site are included in this phase. Transportation distances can vary widely based on project location. Off-site equipment used in the materials production is accounted for in this phase. This phase also includes the employment of by-products, recycled/secondary materials and recovered waste materials.
- **Construction**. This phase usually includes clearance of the construction site (removal of infrastructure and vegetation), earthworks including the possible construction of earth mounds, ground works including the stabilisation of the sub-grade, on-site equipment (as pavers, dozers, millers, etc.), construction of the pavement layers, construction and laying of the drainage and water run off systems, placement of road furniture. Analysis of congestion is included.
- **Use**. This phase includes the daily traffic on the road pavement and thus vehicle fuel consumption during the road service life. It has to be considered that a pavement and its properties are only responsible for a fraction of the vehicle fuel consumption, namely those associated with its structural characteristics and surface texture (influencing the rolling resistance).
- **Maintenance (and operation)**. This phase runs in parallel with the use phase, ending when the road is decommissioned. Some maintenance operations share the same materials, and hence impacts, with the construction phase. In detail, it typically includes repair (for example filling potholes in the surface), rehabilitation (resurfacing and sealing of entire sections of road surface), winter maintenance (de-icing, road salting/gritting) and substitution of lighting or road furniture elements. Analysis of congestion is included.
- **End-of-life (EoL).** In this phase it is possible to include EoL of pavements and EoL of the road itself.

Finally, it has to be specified that noise has been included in the project scope, considering noise reducing surface and noise abatement measures. Noise barriers are implicitly included inside the noise assessment, even though the focus will be on their operation and not on materials used for their production, particularly if they are done by steel or wood. There is a low significance of material use and potential environmental impacts from the production of noise barriers compared to all other impacts (Stripple, 2001; SUSCON, 2006; Loijos et al., 2013). Therefore, the production, also including recycled materials, of noise barriers doesn't appear one of the main hot-spots in a LCA perspective.

1.5.6 Exclusions

During the stakeholder's consultation, a set of exclusions was suggested within the questionnaire:

- Road markings

- Street lighting and traffic signals
- Traffic signs
- Information systems
- Foundations or lighting of traffic signs
- Other types of road furniture (pedestrian walkways, bollards, overhead gantries and central reservations)

Road markings are products quite similar to paints and varnishes and for this reason they will be included in the EU GPP criteria for paints and varnishes[7].

The reason for exclusion of **street lighting and traffic signals** is that these products are covered by separate EU GPP criteria (EC, 2012a).

It was recommended that **traffic signs** including foundations are excluded from the product scope because traffic signs are of minor importance to the total potential environmental impacts (Stripple, 2001; SUSCON, 2006; Loijos et al., 2013). See Chapter 3 Technical Environmental Analysis and Annex III Literature review). The conclusion is based on the results from the literature review where Stripple (2001) indicate approximate influence of the traffic signs below 1% of the phases raw materials extraction, construction, operation and maintenance. If the daily traffic is taken into account (including the fuel consumption of cars and trucks), the traffic signs only contribute to less than approx. 0,1% of the total potential environmental impacts during the full life cycle of a road. This exclusion was likewise settled within the Criteria for the Sustainable Public Procurement of Roads developed by the Dutch Ministry of Housing, Spatial Planning and the Environment in 2010 (NL Agency, VROM, 2010). Moreover, traffic signs are not taken into consideration in the GPP criteria for road construction actually under development by the Italian Environment Ministry[8].

Typically, **information systems** are energy efficient and therefore use relatively small amounts of energy compared to the energy consumption through the full life cycle of a road. Furthermore, information systems are of varying importance depending on the energy sources used for electricity production. It is thus recommended that information systems are excluded from this product scope - but it can be relevant to develop specific criteria for these products to ensure public green procurement for information systems. The final energy consumption used by the information systems is really low. For example, according to Stripple (2001), during 40 years of service life of a local road, the total energy consumption of lighting is approximately 5% of the total energy consumption during the road life cycle. Information system only use a small part of this energy consumption, therefore these systems don't appear on of the main hot-spots within the environmental analysis. Information systems have great relevance related to safety (http://ec.europa.eu/information_society/activities/esafety/doc/studies/energy/energy_eff_study_final.pdf).

Foundations and lighting of traffic signs are of minor importance to the total environmental impact. Lightning of traffic signs are energy effective and therefore use relatively small amounts of energy compared to the energy consumption through the full life cycle of a road (Stripple, 2001; Mroueh et al., 2001).

Other types of road furniture (pedestrian walkways, bollards, overhead gantries and central reservations) are based on the literature review typically of minor importance to the total potential environmental impacts (Stripple, 2001). Therefore it is recommended that these products are excluded from the EU GPP criteria for road construction.

The criteria will be developed for roads in general and thus apply for all typical roads in all EU Member States.

Overall, it is thus suggested to focus the project resources on what is clearly indicated to be the major source of environmental impacts not covered by other criteria: The life cycle of the road construction itself.

Further, given the diversity of roads, it is already challenging to develop usable and clear criteria for road construction. Adding further issues to the scope would add further complexity, possibly resulting in separate criteria for those additions within the GPP criteria to be developed (as was the case in the previous GPP criteria for road construction and traffic signs).

7 http://susproc.jrc.ec.europa.eu/paints/

8 Personal communication

As a result of the survey, the stakeholders showed their disagreement on the exclusion of:

- Traffic signals. These products (traffic signals and noise barriers) could be manufactured using recycled plastics, so it could be an opportunity to foster the plastic recycling.
- Road marking not painted (LED marking)
- Foundations for lightning and gantries, as they might be integrated into concrete barriers in the central reservation.
- Metallic safety fences, as they seem to be implicated in pollution due to their corrosion.
- Road furniture, since this category of products shows a very interesting ratio cost-benefit so the potential criteria on them could bring an environmental improvement with low efforts.

The comments received concerning these exclusions are collected in Annex I.1.

The first approach of the scope proposal is to exclude some elements that seem to be less relevant in relation to the main environmental issues involved in the road construction and maintenance. Notwithstanding, the output from the stakeholders survey shows a concern about these exclusions, and the consequent potential improvement that might be ruled out at this stage of the project. In order to achieve the broadest view of the sector, these elements are part of the technical analysis carried out in Task 3 (see chapter 3), and the results of this analysis, together with the stakeholders feedback, will constitute the ground for the discussion along the project.

2 MARKET ANALYSIS

2.1 Introduction

The aim of the market analysis is to update and/or collect key data which will enable the economic relevance of the product group at micro and macro level to be quantitatively assessed. The data will also provide information on the functioning of the market for the product group, facilitating the identification of relevant trends, drivers, innovation and initiatives, which could impact on the formulation of GPP criteria.

First of all, the general economic situation for Europe is presented to quantify and assess the state and trend of the market. Secondly, the road construction sector is analysed to provide a sound basis for assessing the size of this sector. This includes economic indicators and data on employment. Furthermore, the total road length in all Member States is provided to describe the current situation and provide a basis for assessing the consequences of any expected future growth in road construction. Finally, data regarding the production and availability of construction materials/products is provided as a basis for the assessment of the current market and of the potential for future improvements with respect to materials used for road construction.

The primary sources of information are Eurostat, the International Transport Forum, the Statistical Pocketbook 2013 for EU transport (EC, 2013a), contributions from European stakeholders and existing knowledge from other projects. In some cases the data is retrieved from the European Road Statistics from 2012 developed by the European Road Federation, who have summarized most of the relevant data regarding roads from various sources.

2.2 Economic indicators

In this chapter economic indicators are provided to describe recent development in Europe via key indicators, such as inflation, Gross Domestic Product (GDP) and unemployment rate.

2.2.1 General economic indicators for Europe

The economic situation in Europe will, to some extent, reflect the need for and investment in road construction. In an expanding economy with high inflation, reduced unemployment rate and increasing GDP, the construction sector will be boosted by demand for new housing and commercial/industrial parks and facilities. New road infrastructure is generally required with such developments. However, certain long-term investments in infrastructure and roads may be considerably decoupled from economic growth.

The link between road construction and economic growth is underlined by Siim Kallas, the vice-president of the European Commission: "*Road transport is a tool for reviving growth through the enhancement of competitiveness and the creation of jobs*" (EC, 2012b).

The economic indicators for the Member States are summarised in *Annex II, Tab. A.2.1*. In 2011 GDP was marginally positive (1.6% overall), but then shrank by 0.4% in 2012. Every single Member State showed either a negative change in GDP from 2011 to 2012 or a reduction in the rate of GDP growth.

Concerning the investment component of GDP (the Gross Fixed Capital Formation) the trend in 2013 is a negative one – implying that consolidated economic recovery consolidation after the financial crisis has not yet occurred. The inflation rate in Member States is positive, which is an indication of the European Central Banks success to control the prices and ensure growth is aligned with countries outside of Europe.

The average unemployment rate has reached 10.9% across Member States, and is especially significant in Spain (26.4%) and Greece (26.9%), whose economies have traditionally been very dependent on the jobs in the tourism and construction sectors.

In summary, the economy is unstable and has not yet shown a consolidated economic recovery. However, the economic situation in itself is not directly related to the need for new roads as economic stagnation could also trigger increased public investments in infrastructure/road construction in an attempt to stimulate growth.

2.2.2 General economic indicators in the transport sector

Roads facilitate a very important mode of transport in Europe. Some 45.9% of goods transport takes place by road (see Figure 2.1). Over 80% of the passenger transport within Europe occurs on roads, as shown in Figure 2.2.

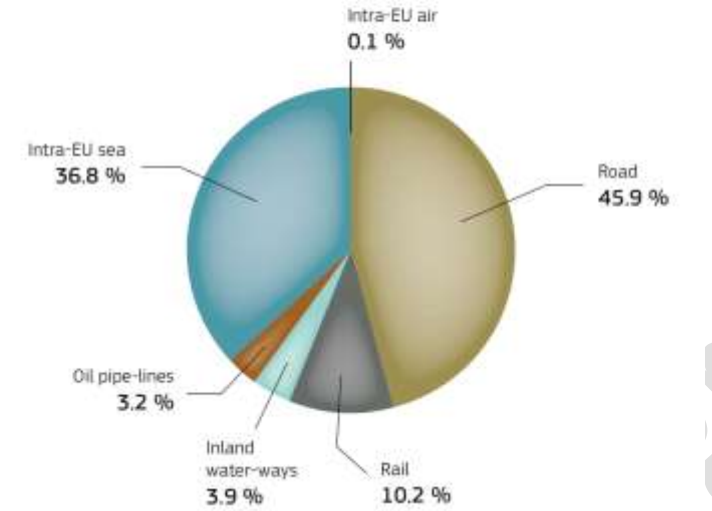


Figure 2.1: Model split intra-EU goods transport in 2010 (EC, 2012b)

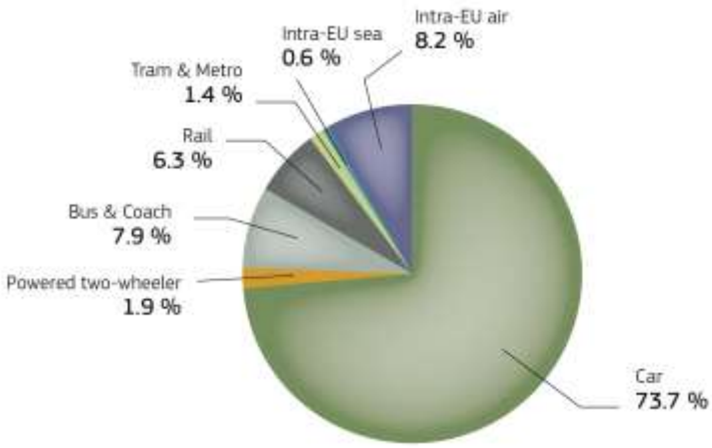


Figure 2.2: Modal split intra-EU passenger transport in 2010 (EC, 2012b)

These figures indicate the importance of road transportation in Europe. General turnover for road passenger transport and road freight transport is approximately 368 billion Euro in the EU-27 (data from 2009 from ERF; 2013), accounting for 32.4% of total turnover in the transport sector.

However, while growth in freight transport kilometres was reported as 5.3%, during the same period passenger transport kilometres were shown to drop by 1.0% (ERF; 2013).

The importance of the road transport sector is supported by employment data in Europe. In 2010, 2.93 million people were employed in road freight transportation and 1.93 million in road passenger transportation. This accounts for around 46.5% of all employment in the transport sector (EC, 2013a).

2.2.3 General economic indicators for the construction sector in Europe

The construction sector is split into two main categories: buildings and civil engineering work. Civil engineering works is then subdivided into several categories and defined as: "*construction not classified under buildings, for example railways, roads, bridges, highways, airport runways and dams*" (EC, 2013b). The data presented in Figure 2.3 shows that "*production for construction*" in Europe is at its lowest level during the last 10 years (data from Eurostat, 2012). Economic indicators in EU-28 for 2011 and 2012 are reported in *Annex II, Tab. II.1*.

The recession is affecting many Member States. Ten Member States experienced negative rates of change during 2008-2011. Three countries In particular (Denmark, Spain and Ireland) experienced an even longer period of downturn which lasted for 4 consecutive years. In contrast, seven Member States recorded an increase in construction output in 2010.

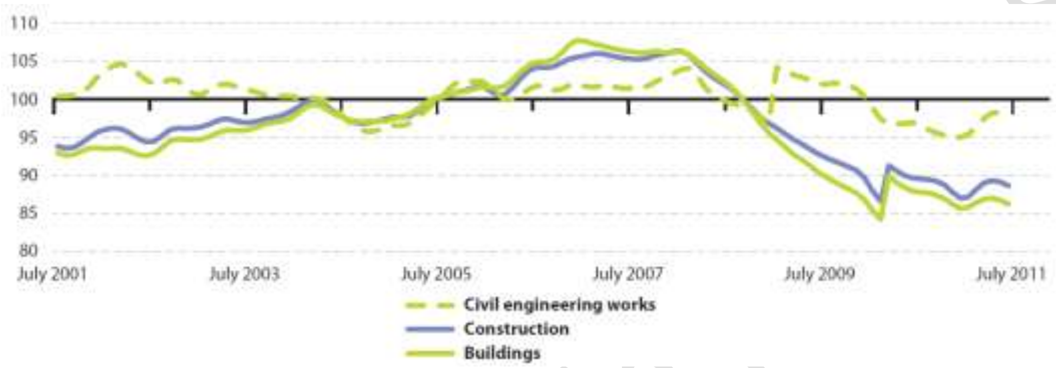


Figure 2.3: Index of production for construction, EU-27, 2001-11 (trend cycles, estimates) (Eurostat, 2012)

2005= index 100

Production value

The production value of the construction sector is a picture of the dominating activities occurring in Europe leading to employment and trade.

Production value for the construction sector in EU-28 for 2008, 2009, 2010, 2011 and the trend 2010-11 are reported in *Annex II, Tab. II.2*. In 2011, the production value for the construction sector in EU-28 was 1,555,007 Million Euro. The production value of the construction sector in Europe from 2010 to 2011 indicates that the overall value is decreasing slightly (-1.5%). By analysing the data from the previous years the tendency is that the degree of the recession is reduced significantly from 2008 to 2011 and thus indicates a stabilization of the market.

Nevertheless the data from individual Member States shows a very heterogeneous situation in national level markets. Changes in production value between 2010 and 2011 have ranged from -31.8% (Belgium) to +33.7% (Estonia).

Number of employees

The number of construction sector employees in Member States between 2008 to 2011 is reported in *Annex II, Tab. II.3*. The total number of employees in 2011 is about 10.2 million people. Overall the number of people employed in Europe decreased by 2.4% from 2010 to 2011. However, this overall figure masks the variation in trends between different member states which ranged from -19.0% (Spain) to +24.6% (Ireland).

2.2.4 General economic indicators for the road construction sector in Europe

Several publications (ERF and IRF, 2007; ERF, 2013) stress the significance of the road sector and consider it as being one of the most important in Europe.

The data in this section refer specifically to the road construction sector. If data for indirect activities, such as raw material production, construction-related investment revenues and activities prior to construction are considered, the importance of the sector increases significantly.

Number of enterprises in the road construction sector

In 2011, the number of enterprises in the EU-28 was 33,186. The trend in the number of enterprises in the road and motorways construction sector from 2008 to 2011 in EU-28 and in the Member States is presented in *Annex II, Tab. II.4*. The overall trend between 2010 and 2011 was a moderate increase (+5.7% in EU-27) in the number of enterprises. However, as with other indicators mentioned previously, this masks a large degree of variation in individual Member States.

Turnover or gross premium written

The turnover in the roads and motorways construction sector is significant and data from 2008 to 2011 in EU-28 are reported in *Annex II, Tab. II.5*. "*Gross premiums written*" shall comprise all amounts due during the financial year in respect of insurance contracts regardless of the fact that such amounts may relate in whole or in part to a later financial year, and shall include inter alia reinsurance premiums received from other insurance undertakings. The above amounts shall not include the amounts of taxes or charges levied with premiums.

In 2011 the turnover in EU-28 was 108,050 Millions Euro. The general trend in EU-27 turnover from 2008 to 2010 was negative (-10.9%) but then rose in 2010-11 (+5.5%). As with the data on the number of employees and enterprises in the road sector (*Annex II, Tab. II.3 and Tab. II.4*), the trends differ significantly for individual Member States, ranging from +34.5% in Poland to -28.3% in Slovenia.

Production value

Large quantities of many different materials are used for the construction of roads including bitumen, cement, asphalt, concrete, fuel and aggregates. In 2011 the production value for the road and motorway contruction sector in the EU-28 was 108,785 million Euro. Data on production value in EU-28 and in individual Member States from 2008 to 2011 are reported in *Annex II, Tab. II.6*. It can be seen that while in 2008-2011 the trend indicated a declining market for Europe in general, in 2010-11 it shows an improvement (+6.7%). Once again, the overall trends masked wide variation in individual Member States.

2.2.4.1 Gross investment in machinery and equipment

The gross investment in machinery and equipment for the roads and motorways construction sector in EU-28 and the Member States from 2008 to 2011 is reported in *Annex II, Tab. II.7* (some data for certain Member States was not published). For many countries the trend in gross investment in machinery and equipment has been clearly affected by the financial crisis. The situation for individual Member States again varies widely, from -65,8% (Slovakia) to +82.9% (Romania).

2.2.4.2 Number of employees

The number of employees is directly linked to the economic performance of the road construction sector. In EU-28 the numbers of employees working in the roads and motorway sector in 2011 was 635,900. Specific data for individual Member States regarding the number of employed people in the *roads and motorway construction sector* in EU-28 from 2008 to 2011 is provided in *Annex II, Tab. II.8*.

The data show an overall decline in the number of employees in road and motorway construction during the period 2008-2010. Between 2010 and 2011 however, the overall number remained stable. Again, there was no common trend amongst individual Member States – some experienced a positive trend, and others a negative one.

2.3 Market data on road construction

2.3.1 Total length of the road network in Europe

The total length of the road network in different Member States is reported in Table 2.1, according to data provided by EC (2013a) Pocketbook and the European Road Federation (ERF, 2013). According to the ERF (2013), the definition of road types indicated in Table 2.1 varies from country to country. Therefore data are not directly comparable between different Member States.

Nonetheless, an approximate comparison can be made between most countries. The total length of the EU road network is about 5.3 million km, of which around 1.3% are motorways. The category “other roads” accounts for the largest share of road network length.

Table 2.1. Length of total road network by category and country (EC (2013) Pocketbook and ERF, 2013)

Member State	Motorways	Main or national roads	Secondary or regional roads	Other roads	Total
	(km)	(km)	(km)	(km)	(km)
Belgium	1,763	12,760	1,349	138,000	153,872
Bulgaria	418	2,975	16,044	n.a.	n.a.
Czech Republic	729	6,198	48,791	74,919	130,637
Denmark	1,130	2,707	69,737		73,574
Germany	12,813	39,887	178,269	413,289**	644,258
Estonia	100	3,893	12,427	41,911	58,331
Ireland	663	4,780	11,631	78,958	96,032
Greece	1,103	10,189	30,864	75,600	117,756
Spain	14,021	11,621	139,833	501,053	666,519
France	11,163	9,768	377,986	642,256	1,041,173
Italy	6,661	19,375	154,513	312,100***	492,649
Cyprus	257	2,136	2,834	4,203	9,430
Latvia	n/a	1,653	5,327	58,668	65,648
Lithuania	309	6,358	14,591	50,680	71,938
Luxembourg	152	837	1,891	n/a	2,880
Hungary	1,273	6,802	23,303	166,142	197,520
Malta	n/a	184	665	1,379	2,228
The Netherlands	2,631	2,445	7,836	123,914	136,826
Austria	1,696	10,003	23,653	88,666	124,018
Poland	849	17,928	28,403	221,826	269,006
Portugal	2,705	5,976	4,431	63,900**	79,513
Romania	321	16,182	65,210		81,713
Slovenia	747	911	5,117	32,225	39,000
Slovakia	391	3,496	14,050	25,942	43,879
Finland	765	12,563	13,537	51,295	78,160
Sweden	1,891	13,462	83,131	122,378	220,862
United Kingdom	3,674	49,040	122,542	244,340	419,596

Data are mainly referred to 2009; **data referred to 2006; ***data referred to 2009

2.3.2 Data on production and trade of road construction materials and products

Numerous construction materials and products are used in the road construction sector. The analysis is focused those materials that are used in the largest quantities and/or have significant improvement potential in accordance to the feedbacks provided by stakeholders to the sent questionnaire. Possible GPP criteria related to such materials would therefore constitute relevant improvement potentials in road construction.

2.3.2.1 Aggregates

General data

Aggregates are an important constituent in road construction since they constitute the bulk volume of the road pavement structure. They are employed in unbound and bound mixtures in different road layers.

A necessary background is the definition of Sustainable Supply Mix (SSM) of aggregates: "*a procurement of aggregates from multiple sources, according to criteria of economic, environmental and social efficiency*" (Blengini *et al.*, 2012). SSM can therefore be regarded as a blend of natural aggregates, quarry by-products and recycled waste, which together maximise net benefits of aggregate supply. SSM goes beyond the need to ensure a secure supply of aggregates to the economy by adding the requirement that the selected blend must be produced and transported in an eco-efficient manner that minimises total negative impacts and maximises overall benefits to society (Blengini *et al.*, 2012). SSM therefore requires procurement from multiple sources, each of which must be selected based on a comparison of their environmental and socio-economic impacts and benefits. The promotion of recycling and the encouragement of SSM policies was one of the main challenges of the EU projects SARMa 'Sustainable Aggregates Resource Management' (*www.sarmaproject.eu)* and SNAP SEE (www.snapsee.eu/).

Aggregates are granular materials used in construction and, according to the source material, can be classified as:

- natural aggregates, produced from mineral sources; sand and gravel are natural aggregates resulting from rock erosion; crushed rock is extracted from quarries;
- recycled aggregates, produced from processing material previously used in construction;
- secondary aggregates, secondary materials arising from industrial processes (in the CPR 2011, this category is classified as 'manufactured aggregates').

However, in some cases, this classification could be seen as not fully comprehensive, for instance, it might be unclear in which category excavated soil and stones would fall, as well as recycled mining waste and, finally, quarry/mine co-products. In the SARMa project, the following four types of recycling were therefore considered as potential sources of unconventional aggregates:

- R1: recycling of by-products, waste and residues from extractive activities;
- R2: recycling of C&DW;
- R3: recycling of excavated soil and stones from civil works;
- R4: recycling of industrial waste (e.g. slag from ferrous metal production, bottom ash from Municipal Solid Waste (MSW) incineration, ash from coal combustion)

As it is shown in Table 2.2, in EU-28, approximately 2.8 billion tonnes of aggregates were produced in 2010, representing a value of 20 billion Euros (UEPG, 2012). Specific data for individual Member States and other relevant countries are reported in *Annex II Table II.9*.

Table 2.2. Production of different typologies of aggregates for 2010 in EU-27 Countries (UEPG, 2012)

Member State	Total number of producers	Total number of extraction sites	Sand gravel (Mt)	Crushed rock (Mt)	Marine aggregates (Mt)	Recycled aggregates (Mt)	Manufactured aggregates* (Mt)	Total Production (Mt)
EU-27	13,221	22,377	1,168	1,323	58	180	55	2,784

*secondary aggregates (e.g. pulverised fly ash PFA and slag)

Total aggregate production is dominated by sand and gravel (42%) and crushed rock (48%). Recycled and manufactured aggregates only account for 6% and 2% of total production respectively (Figure 2.4). However, it is expected that the contribution of unconventional aggregates to the SSM is likely to increase by a large extent in the future.

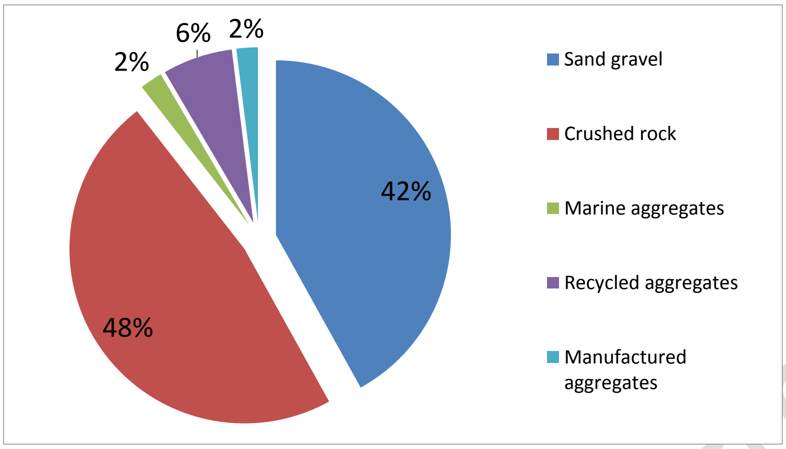


Figure 2.4. Origin of the aggregates in Europe (UEPG, 2012)

Aggregates are primarily produced by small and medium sized companies operating in about 22,400 sites across Europe. The number of employees is approximately 250,000 people including contractors.

The manner in which produced aggregates are used across the different construction sectors in Europe is shown in Figure 2.5. Around 20% of aggregates are used in roads, runways, railways and waterways. According to the UEPG, some 500-600Mt of aggregates are used in roads, runways, railways and waterways, accounting for around 20% of all produced aggregates in the EU (see Figure 2.5). Of this quantity, at least half is considered to be used in road construction and maintenance in the EU. The type of aggregates most commonly used in roads are of the crushed rock type.

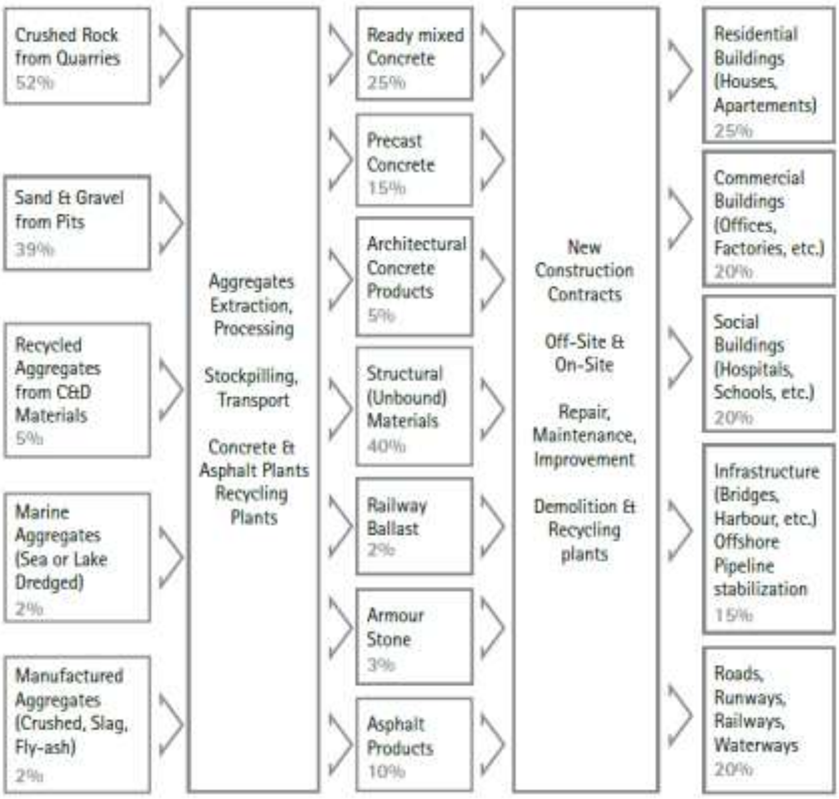


Figure 2.5. The use of aggregates in Europe (UEPG, 2012)

For a general idea of how much aggregate is used for road construction on a per km basis, the following figures can be considered:

- 20,000 t/km for a two-lane road (EC, 2010).
- 10,000 m³/km of two lane road (OECD, 1997) which equals approximately to 20,000 t/km.
- 30,000 t/km for a motorway (EC JRC, 2009).

Data from EU statistics

According to Eurostat the following data for aggregates are available for EU-28.

Construction sands

Construction sands consist of clayey sands; kaolinic sands, feldspathic sands (excluding silica sands and metal bearing sands) (PRODCOM 08.12.11.90).

In 2012 the produced quantity of construction sand in EU-28 was 380 Mt. Data on production, import and export of construction sands from 2009 to 2012 in the EU-28 are reported in *Annex II Tab. II.10.* The production of construction sand, quantities important and quantities exported all decreased between 2011 and 2012. It has not been possible to obtain data about the share of construction sand used for road construction in EU-28. Very little data at national level are available although in Denmark, approximately 55% of construction sand was used for road construction (Statistics Denmark, 2012;NCC Råstoffer, 2013).

Gravels and pebbles

According to Eurostat this group contains gravels and pebbles of a kind used for concrete aggregates for road metalling, for railway ballast or other ballast; shingle and flint (PRODCOM 08.12.12.10).

In 2012 the produced quantity of gravels and pebbles in the EU-28 was 472 Mt. Data on production, import and export from 2009 to 2012 in EU-28 are reported in *Annex II Tab. II.11.* During the period 2011-2012, the produced quantity amount was reduced by 50 Mt while exports decreased by 2 Mt and imports increased by 3 Mt..

It has not been possible to obtain data about the share of gravels and pebbles production used in road construction in the EU-28. At the national level however, Denmark state that approximately 55% of the gravels and pebbles production is used for road construction. (Statistics Denmark, 2012; NCC Råstoffer, 2013)

Crushed stone

Crushed stone includes all stones of a kind used for concrete aggregates, for road metalling, for railway ballast or other ballast (excluding gravel, pebbles, shingle or flint) (PRODCOM 08.12.12.30).

In 2012 the produced quantity of crushed stones in the EU-28 was 808 Mt. Data on production, import and export from 2009 to 2012 in EU-28 are reported in *Annex II Tab. II.12.* The produced quantity has declined significantly – though still maintaining the approximately same price per produced tonne of crushed stone. The export quantity and price per tons crushed stone has decreased from 2011 to 2012.

Crushed stone is mainly used for road construction as aggregate for asphalt and for unbound base layers. In addition to this, they are also used in paving blocks (Statistics Denmark, 2012). It has not been possible to obtain data about the share of crushed stones used for road construction in EU-28. At the national level, Denmark report that approximately 80% of crushed stone production is used for road construction (Statistics Denmark, 2012).

Pre-coated aggregates

Pre-coated aggregates can be used for several reasons specific for the individual projects (PRODCOM 23.99.13.20).

Pre-coated aggregates are typically crushed aggregates enveloped with bitumen or similar for improved adhesion to another pavement layer. The pre-coated aggregate is spread on top of an unbound base course as a thin surface layer or on top of asphalt pavements (new or old) as a sealant and friction course. The pre-coated aggregate is already accounted for in the production of sands, gravels and pebbles.

In 2012 the produced quantity of pre-coated aggregates in EU-28 was 21 Mt. Data on production, import and export from 2009 to 2012 in EU-28 are reported in *Annex II Tab II.13.* Produced, imported and exported quantities of pre-coated aggregate all dropped between 2011 and 2012.

Silica sands

The group "silica sands" consist of quartz sands and industrial sands (PRODCOM 08.12.11.50). Sand is used for several pavement layer types in roads.

In 2012 the produced quantity of silica sand in EU-28 was 71 Mt. Data on production, import and export from 2009 to 2012 in EU-28 are reported in *Annex II Tab. II.14.* While imported, exported and produced quantities rose significantly during the years from 2009 to 2011, during the period 2011-12 the total quantities involved decreased.

It has not been possible to obtain data about the share of silica sand production used for road construction in the EU-28. A reasonable estimate based on limited information would be that only 5% of the total amount of silica sands produced in Europe are used for road construction.

2.3.2.2 Bitumen

General data

Bitumen is distilled from crude oils and represents on average 3-4% of refinery production.

There are 115 oil refineries in Europe (EU 27) of which 74 produce bitumen. Of the 1,300+ types of crude oils that exist, only approximately 10% can be used to produce bitumen that meet the stringent engineering requirements of end users today.

The European bitumen industry (EU 27) produces approximately 20 Mt of bitumen each year. (Eurobitume, 2013a). Asphalt mixtures contain approximately 5% of bitumen Eurobitume (2011b). Modified bitumen, whose rheology is altered by the use of chemical admixtures, can account for 10-20% of bitumen markets according to EAPA (2012).

In the past years another type of binder, coal tar (often referred to simply as tar) was used in the paving industry. The tar is produced by the destructive distillation of coal, and consequently contains PAHs. It has been widely recognized that the PAH content in coal tar is far higher than the PAH content in bitumen (NAPA and EAPA, 2011). In Europe, by the early 1990s, the use of coal tar in road paving had been generally phased out.

Data from EU statistics

Natural bitumen and natural asphalt

Natural bitumen and natural asphalt includes asphaltites and asphaltic rocks (PRODCOM 08.99.10.00).

In 2012 the produced quantity of natural bitumen and natural asphalt in EU-28 was **1.9 Mt**. Data on production, import and export from 2009 to 2012 in EU-28 are reported in *Annex II Tab. II.15.* While the quantities involved in production, import and export increased between 2009 and 2010, the latest trend between 2011 and 2012 has been a decrease.

2.3.2.3 Asphalt and other bituminous mixtures

In the first part of this section, the data from Eurostat regarding production, import and export are presented. Furthermore, data from the European Asphalt Pavement Association (EAPA) has been received via the stakeholder questionnaire distributed in 2013 will also be presented. In the last part of the section, specific data are collected to describe specific aspects such as warm mix, reclaimed asphalt pavements.

General data

According to the EAPA (2012), **324 Mt** of hot mix asphalt (HMA) and warm mix asphalt (WMA) asphalt were produced in 2011. Production data of hot mix asphalt (HMA) and warm mix asphalt (WMA) in EU-27 from 2006 to 2011 are reported in *Annex II Tab. II.16.* The trend from 2006 to 2011 is represented in Figure 2.6.

In EU-27 from 2007 to 2010 the amount of used warm and hot mix asphalt declined to a low level of approx. 310 Mt in 2010. This trend also reflects the price of oil, which caused the decreased production of asphalt. In many Member States the economies are kick-started by the governments investing in public works of which an example is road construction and maintenance, in order to stimulate the public economy. This appears to be the case according to the rise between 2010 and 2011 in Figure 2.6.

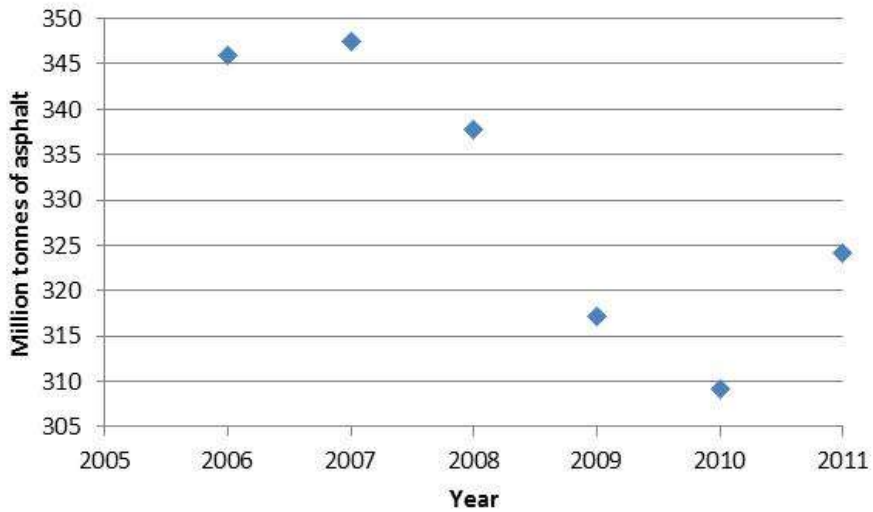


Figure 2.6: The trend in the use of warm and hot mix asphalt (EAPA, 2012)

Warm Mix Asphalt is defined as mixtures produced by using special techniques and/or additives to reduce the production temperature. The production temperature is between 100 and 150 degree Celsius. Two types of warm-mix asphalt are available, one using foaming of the bitumen and one using polymer additives. According to EAPA (2012) 3.0 Mt of warm mix asphalt were produced in 2011 in the EU. When extrapolated to include countries for which data are missing, this figure can be estimated to rise to **7.1 Mt**.

According to EAPA (2012), cold bituminous mixture production was **3.1 Mt** (evaluated on 17 Member States). The main applications are in France, UK and Spain. In terms of quantities produced, by far the most important type of asphalt is hot mix asphalt.

Bituminous mixtures (according to EU statistics)

Bituminous mixtures are all based on mixtures with natural and artificial aggregate and bitumen/natural asphalt as a binder (PRODCOM 23.99.13.10).

According to Eurostat, in 2012 the production of bituminous mixtures was 79 Mt, less than half the level in 2009. Production, import and export data for bituminous mixtures in EU-28 from 2009 to 2012 are reported in in Annex II, Tab. II.17

The exported and imported quantities are naturally quite low due to the rapid hardening properties of the material. Thus the bituminous mixtures must be laid quite quickly after production. This practically limits export and import to neighbouring countries. The trend in produced and exported quantities was negative from 2011 to 2012. But still the price per imported tonne is decreased from 2011 to 2012,.

According to the European Asphalt Pavement Association approx. 300 Mt of bituminous mixtures (including aggregates) are used for road construction in Europe per year. This indicates that the Eurostat PRODCOM group 23.99.13.10 statistics only represent a part of the total actual production of bituminous mixtures used in the EU.

Asphalt material used in Europe

According to the stakeholder feedback to the questionnaire distributed in 2013, in Europe the main pavement layer type is the flexible one. The UK Road Administration has reported that in the UK, 96% of pavements are flexible. The Danish Road Directorate has reported that that 100% of all pavements are flexible and in the Netherlands 97% of all pavements are flexible. It is uncertain if this simply refers to surface courses or to all types of courses involving binders.

There are three generic types of asphalt mixture that can be used: hot mix asphalt (HMA), warm mix asphalt (WMA) and cold mix asphalt (CMA). The dominant binder type is HMA, accounting for over 300 Mt each year in the EU since at least 2006. Annual production of WMA and CMA are around 3 Mt each, totally only 2% of total asphalt production combined (EAPA, 2012). Therefore trends in HMA are the most important to report. The split between use of HMA in different road courses is as follows:

- Surface courses account for an average **49%** of total annual HMA production (variable from 20 to 95% in the different MS) (elaborated from EAPA, 2012).
- Binder courses account for an average **21%** of total annual HMA production (variable from 0 to 58% in the different MS) (elaborated from EAPA, 2012).
- Base courses account for an average **30%** of total annual HMA production (variable from 4 to 70% in the different MS) (elaborated from EAPA, 2012).

A detailed look into the materials used for surface courses reveals that the percentage of different materials in the different Member States are:

- Surface courses with Asphalt Concrete EN 13108-1: an average of 40% of total HMA and WMA production in 2011 (variable from 8-76%) (based on data for 21 MS from EAPA, 2012).
- Surface courses with Stone Mastic Asphalt EN 13108-5: an average of 9% of total HMA and WMA production in 2011 (variable from 1-19%) (based on data for 19 MS from EAPA, 2012).
- Surface courses with Asphalt concrete for very thin layers EN 13108-2: an average of 3% of total HMA and WMA production in 2011 (variable from 0.04 to 8%) (based on data for 7 MS from EAPA, 2012).
- Surface courses with soft asphalt EN 13108-3: figures of 5% and 13.5% of total HMA and WMA production in 2011 are provided for Finland and Sweden (EAPA, 2012).
- Surface courses with hot rolled asphalt EN 13108-4: figures of 5% and 10% of total HMA and WMA production in 2011 are provided for Portugal and Romania (EAPA, 2012).
- Surface courses with mastic asphalt EN 13108-6: an average of 1% of total HMA and WMA production in 2011 (variable from 0.02-7%) (based on data for 12 MS from EAPA, 2012) (Mastic pavements result in mixing and placement taking place at 180°-250° C, higher than the temperature for typical asphalt pavements according to NAPA and EAPA, 2011).
- Surface courses with surface courses with porous asphalt EN 13108-7: an average of 2.4% of total HMA and WMA production in 2011 (variable from 0.2-9.2%) (based on data for 10 MS from EAPA, 2012).

The figures listed above are for the production in EU countries in 2011 (EAPA, 2012). These figures indicate that there is no clear, general preference of the material for the surface course of the road.-However, it seems that surface courses using asphalt concrete are preferred in several countries

Reclaimed asphalt pavement (RAP)

When focus is directed towards the degree of recycling, the approaches vary greatly from Member State to Member State. The production of RAP in different Member States is reported in *Annex II Table II.18*. A total production of 49 Mt is shown for 2012. The range of recycled materials is from approximately 4% of the available RAP in Poland to 100% in Hungary. Furthermore, the percentage of the new hot and warm mix production that contains RAP varies from 0.01% to 80%. The wide range expresses the fact that the Member States have very different approaches towards the use of recycled materials.

The latest data (EAPA (2013) reported show that 56 Mt of RAP is now available in Europe and that more than 85% of the available RAP is reused in Europe (EAPA, 2013).

These figures indicate that there is a significant potential to be exploited by increasing the share of recycled asphalt since asphalt is 100% recyclable (Eurobitume, 2013). Increased recyclability entails reduced extraction of virgin materials for road construction.

Structure of the asphalt sector

The asphalt sector is dominated by relatively few companies dedicated solely to the production of asphalt, totalling 690 in Europe (EAPA, 2012). A total of 2,141 companies are involved in both the production and actual laying of asphalt, while >7,952 companies in Europe are involved on in the laying of asphalt. The companies producing and laying the asphalt are generally small and medium sized enterprises (NAPA and EAPA, 2011).

2.3.2.4 Cement

General data

CEMBUREAU countries accounted for approximately 6% (220 Mt) of world production (3.6 billion tonnes) whilst the proportion of world production from the EU Member States fell to around 4.3% (CEMBUREAU, 2012). Compared to 2011, and according to the latest data available, 2012 cement production in the CEMBUREAU countries recorded a considerable decrease of -13% down to 228.4 Mt, a record low. Major European markets recorded sharply negative performances, most notably Spain (-39.5%) and Italy (-20.8%), whilst the drop was more moderate in Germany (-4.8%) and France (-7.3%). Decreases in cement production were also observed in Eastern European countries, such as the Czech Republic and Poland with drops of -10% and -16%, respectively. In the EU27, cement production fell by -20%, year-on-year, in 2012 i.e, from 195.5 to 156.3Mt. Data are represented in Figure 2.7.

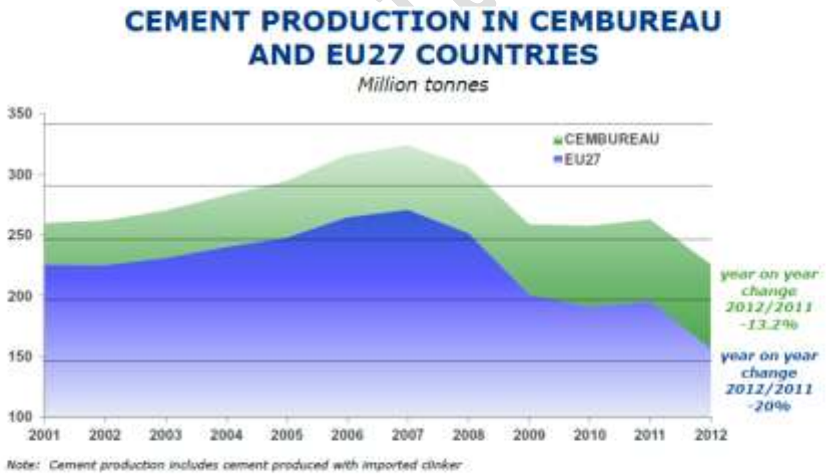


Figure 2.7: The trend in cement production in CEMBUREAU Countries and EU 27 (CEMBUREAU, 2012)

European roads are roughly 90% flexible (asphalt) and 10% rigid (concrete) according to 'The Asphalt Paving Industry (NAPA, EAPA, 2011). The stakeholders also confirm this fact in the questionnaires that only approx. 5% of the roads are rigid and 95% are flexible roads . It is uncertain to whether this information refers simply to surface courses or also to underlying binder and bound base courses.

In 2011 production of asphalt was approx. 324 Mt. It can be assumed that virtually the entire production of asphalt was dedicated to road construction and maintenance. If the 90% share of asphalt corresponded to all courses in road construction and maintenance, then the quantity of cement concrete used in the same sector can be assumed to be somewhere around 32-33 Mt. Comparing this data with the overall production for ready-mix concrete of around 550 Mt in the EU in 2012, we could say that road construction and maintenance accounts for around only 6% of total ready mix concrete demand in the EU. However, we must state that this percentage will depend on whether the 90%-10% split between asphalt and concrete only refers to surface courses or not.

Cement (according to EU Statistics)

The Eurostat statistics include several categories for cement. In this report focussed only on Portland cement and any other hydraulic cements used extensively on road construction.

Portland cement

As per EN 197-1, Portland cement is classified under 27 different categories and 5 different groups based on the precise composition of the cement and the degree of blending with supplementary cementitious materials such as slags, fly ash etc.). Cements are further classified according to strength development and sulfate resistance.

In 2012 the quantity of Portland cement produced was 146 Mt. Production, import and export data for Portland Cement (PRODCOM 23.51.12.10) in EU-28 from 2009 to 2012 are provided in *Annex II Table II.19*.

The produced volume of Portland cement has declined from 2011 to 2012. The exported quantity in 2012 is higher than the level in 2009. The import quantity has decreased from 2011 to 2012. The reason for the decline is primarily the financial crisis which has set a stop to many production activities – especially in the construction sector for buildings.

"Other" hydraulic cements

Hydraulic cements can be used for a variety of purposes, including road construction.

In 2012 the production value of "other" hydraulic cements was 30 Mt. Production, import and export data for other hydraulic cements (PRODCOM 23.51.12.90) in EU-28 from 2009 to 2012 are provided in *Annex II Table II.20*. The produced quantity has declined from 2011 to 2012 but in terms of produced value, thanks to increased prices, has actually risen slightly.

Due to lack of available data specifically regarding the use of other hydraulic cements in road construction, it is uncertain how important this sector is to the "other" hydraulic cement industry.

2.3.2.5 Concrete

Analagous to bitumen with asphalt, cement is rarely used alone, but instead constitutes the binder used in conjunction with aggregates, to produce concrete. Concrete is used in many different types of construction, including road construction.

Solid concrete components and products can either be produced under controlled conditionsin a factory (pre-cast concrete) or added in carefully controlled batches to trucks and mixed en-route to the construction site where it is poured into place (ready mixed concrete). The latter group is by far the most relevant to road construction.

Concrete (according to EU Statisatics)

Ready mixed concrete

Ready mixed concrete can be used for a variety of purposes such as building foundations, floors and structural columns poured into moulded formwork onsite. Road construction is just one of the many sectors that require the use of ready mixed concrete.

Due to lack of available data specifically regarding the use of ready mixed concrete in road construction it is assumed that 2% of the produced ready mixed concrete is used for the construction of roads. This assumption is based on the assumptions made for Portland cement which is described in the previous section. See if I can find out anything here

General production, import and export data for ready mixed concrete (PRODCOM 23.63.10.10) in the EU-28 from 2009 to 2012 are reported in *Annex II Table II.21.* The imported and exported quantity has declined from

2011 to 2012. As with bituminous mixtures, the exported and imported quantities are naturally quite low due to the rapid hardening. The ready mix concrete must thus be placed within several hours after dispatch. Considering that transport is by truck, this limits the export and import to neighbouring countries at EU's borders.

2.3.2.6 Lime

Data from the first questionnaire to stakeholder has resulted in responses – one of them being from the European Lime Association.

In 2008, 4 Mt of lime (dry material) were used in general across Europe. This figure has since been reduced by approximately 20% in the recent years due to the financial crisis.

Specifically for road construction, approx. 10-15% or 400,000-600,000 tonnes of hydrated lime were used in 2008. In line with general lime demand, it is also assumed that the consumption of lime for road construction is reduced by approximately 20%.

2.3.2.7 Waste-derived materials and industrial by-products

In 2011, the EC issued two Communications on 'A resource efficient Europe' and 'Roadmap to a Resource Efficient Europe'. the overall idea is to reconsider the whole life cycle of resource use, so as to make the European Union (EU) a 'circular economy' based on recycling and the use of waste as a resource (EC COM(2011) 21, *A resource- efficient Europe – Flagship initiative under the Europe 2020 Strategy*; COM(2011) 571, *Roadmap to a Resource Efficient Europe*). There is a strong connection with the Directive 2008/98/EC, the so- called (Waste Framework Directive), which revised the legal framework for waste based on the entire life cycle, from generation to disposal, with emphasis on waste prevention, re- use, recycling and recovery.

Member States in Europe have developed individual guidelines and regulation regarding the use of waste products in Europe (EC JRC, 2009). This fact prohibits a general listing of waste products used for road construction at the European level. Nevertheless, examples of used waste products and industrial by-products are:

- C&DW.
- Reclaimed asphalt pavement (described in paragraph 2.3.2.3).
- Ash (coal fly ash and coal bottom ash).
- Municipal solid waste inceneration MSWI bottom ash.
- Slag from iron and steel production (blast furnace slag and steel slag).
- Reclaimed rubber from tyres.

These materials can be used as:

- fill on-site for constitution of landscape hillocks and anti-noise embankments;
- sub-grade or sub-base and base courses of roadways with the addition of binders;
- wearing courses which can be regenerated in place, hot or cold;
- pavement which can be treated in place by mixture with binders;
- pavement which can be treated on the spot by crushing or screening before reemployment;
- fill with or without prior treatment.

The use of waste products (or industrial by-products) in road construction depends on numerous factors. The most important are (EC JRC, 2009):

- Taxes on natural aggregates.
- Taxes on landfilling.

- Availability of natural aggregates.
- Costs of natural aggregates.

According to the groups in Eurostat's statistics, slags and similar waste products have been grouped. This product group contains mixtures of slag and similar industrial waste products, whether or not incorporating pebbles, gravel, shingle and flint for construction use.

2.3.2.7.1 Construction and demolition waste (C&DW)

C&DW has been identified by the EC as a priority stream because of the large amounts that are generated and the high potential for re- use and recycling embodied in these materials. For this reason, the WFD requires MS to take any necessary measures to achieve a minimum target of 70% (by weight) of C&DW by 2020 for preparation for reuse, recycling and other material recovery, including backfilling operations using non-hazardous C&DW to substitute other materials. The above target excludes naturally occurring material, defined under code 17 05 04 as 'soil and stones' n the European Waste Catalogue.

Construction and demolition waste (C&DW) is a possible source of unconventional aggregates. According to EC JRC 2009, the mineral fraction of C&DW is seen as a potential material for producing recycled aggregates.

Depending on the generation of the waste, the following differentiation for C&DW could be established (Umweltbundesamt, 2008):

- construction waste: waste arising from the construction of buildings and/or civil infrastructure;
- demolition waste: waste arising from the total or partial demolition of buildings and/or civil infrastructure;
- road construction and maintenance waste: road construction material and associated materials arising from road maintenance activities;
- soil, rocks and vegetation: waste arising from land levelling, civil works and/or general foundations.

Data from Eurostat (Eurostat, 2013a) indicates that the total mineral C&DW in the EU-27 is **341 Mt per year**. However, according to BIOIS (BIOIS, EC, 2011) the total amount of C&DW generated in EU-27 is approx. **531 Mt per year**. Total C&DW production and recycling rates in the EU-27 and in the Member States are reported in *Annex II Table II.22* (BIOIS, EC, 2011).

- The ranges are assessed to be between 309 Mt per year (low estimate, referred to 2005) and 697 Mt per year (high estimate, referred to 2005).
- According to the recycling rate, it is important to note that in *Annex II Table II.22* recycling rates are intended as 'preparation for re- use, recycling and other forms of material recovery', as defined by the WFD. An average recycling rate for EU-27 of 46% is shown. Other sources provide an higher overall recycling rate across the EU-27 of 71% (ref) of all mineral waste is recycled..Although on average the EU-27 countries are doing well, there is a large discrepancy between the best performing countries such as the Netherlands (99%) and Denmark (94%) and many countries in Southern Europe (e.g. Spain: 14%, Portugal: 5% and Greece: 5%). Consequently, there is still significant potential for improvement, simply by other countries following examples of best practice already established in some European countries.
- A major source of uncertainty in reporting is inclusion/exclusion of excavated soil and stones. Analysis of the table shows that the quantities reported in national statistics include high amounts of excavated material, which is not included in the definition of C&DW for the purpose of the 70% target set by the WFD. This flow represents up to 80% (e.g. in France) of the total amount of construction, demolition and excavation waste.
- The inclusion of excavation waste would significantly increase the quantities involved, from 341-531 Mt to a total of 1,350-2,900 Mt of C&D and excavation waste per year.
- Based upon Eurostat (Eurostat 2012c), a total of 62 Mt of mineral waste is estimated to have been landfilled in 2010.

The importance of waste products is also reflected in stakeholder contributions to this project via the first questionnaire.

The average composition of C&DW reported in BIOIS, EC (2011) is reported in Table 2.3.

Table 2.3: Ranges of composition of C&DW for some MS (Netherlands, Flanders, Denmark, Czech Republic, Ireland, Germany, Spain) (BIOIS, EC, 2011)

Ranges	% - Min	% - Max	Million tonnes - Min	Million tonnes - max
Concrete and Masonry - total	40,0%	84,0%	184	387
Concrete	12,0%	40,0%	55	184
Masonry	8,0%	54,0%	37	249
Asphalt	4,0%	26,0%	18	120
Other mineral waste	2,0%	9,0%	9	41
Wood	2,0%	4,0%	9	18
Metal	0,2%	4,0%	1	18
Gypsum	0,2%	0,4%	1	2
Plastics	0,1%	2,0%	0	9
Miscellaneous	2,0%	36,0%	9	166

2.3.2.7.2 Coal combustion by-products

The inorganic impurities in coal remain as ashes or slag after combustion and are periodically removed from the system. The three main combustion by-products are coal fly ash, coal bottom ash and boiler slag. The production of these by-products was estimated to total 109 Mt in 2004 (Umweltesbundesamt, 2008). Specific data for member states in 2004 is included in Annex II Tab. II.23.

Of these, **coal fly ash** is invariably produced in the highest quantities (77 Mt in 2004). It is a fine powder that exits the furnace with the exhaust gases. The fineness of the ash owes to the fact that coal is pulverised prior to being fed to the furnace to improve burning efficiency. Not all coal fly ashes are equal. The physical and chemcial characteristics are largely dependant on the source coal used, any coal pre-treatment employed, the mode of operation of the power plant (e.g. running at base or peak load) and the nature of the ash separation technology employed (e.g. electrostatic precipitators with or without ammonia dosing or cyclones).

The use of coal fly ash in blended Portland cements (as per EN 197-1) represents the highest value reuse option that is widely used today. For use in such applications (cement and concrete) in Europe, fly ash must, as a minimum, comply with the specifications in EN 450. There is strong demand for good quality fly ash and many companies specialise in the benficiation of fly ash in order to improve its marketability. Lower quality fly ash can be used in lower value applications such as fine aggregate or filler in bound and unbound materials in road construction.

According to EC JRC 2009, approximately 33 % of the total fly ash produced in Europe is used as cement clinker raw material (low value), as a constituent in blended cements (high value) and as a fine aggregate or filler addition for the production of concrete (low value). Some 23% was employed in road construction and filling application (see Tab. 2.4).

On a global scale, coal fly ash production is estimated to be around 800-1000 Mt/yr with China (415 Mt) and India (200Mt) the main producers. Ash production is only moderately linked to coal power generation since ash contents in coal can vary from 3 - 40%. Reuse rates in different countries tend to lie in the range of 40-70%. Data reported for coal fly ash reuse in the EU-15 ocuntries in 2009 showed a 44% reuse rate. However, if other debatable types of reuse such as land restoration and land reclamation are considered, the reuse rate for 2009 rises to an impressive 93%. In many EU countries large stockpiles of coal fly ash that have accumulated over decades are available and thus this material could be important in future road construction materials, either as fill, fine aggregates or in blended cements.

Coal bottom ash is produced as a granular material and removed from the furnace bottom. It is much coarser than fly ash and is too heavy to be carried away by exhaust gas currents. A production of 11 Mt of bottom ash is reported in 2004 (*Annex II Tab. II.23*). The inherent properties of coal bottom ash make it useful as a lightweight aggregate. Despite this fact, the European Coal Combustion Products Association (ECOBA) reported that only 45% of coal bottom ash was reused in 2009. The case is similar in the US where the ACAA reported bottom ash reuse rates of 39%. Of the bottom ash reused in the EU, around 48% was used as fine aggregate in pre-cast concrete blocks, 33 % in road construction and about 14% in other cement and concrete applications (see Table 2.4). There is clearly potential for increasing the total quantities of coal bottom ash used in road construction.

Coal boiler slag is a glassy material produced in much smaller quantities (about 3 Mt) that is removed from the boiler area. ECOBA reported that 100% of this by-product was reused in the EU-15 ocuntries in 2009. It is a glassy material of which about 55% was used in road base while around 31% was used as blasting grit and smaller amounts as aggregates in concrete and grout.

Table 2.4: Reuse data for different types of coal combustion by-products in construction (based on EC JRC, 2009).

Applications	Fly ash	Bottom ash	Boiler slag
	(% of total reuse)	(% of total reuse)	(% of total reuse)
Road construction and filling application	23	33	47
Raw materials for clinker production	26		
Concrete addition	28	4	8
Cement		10	
As a costituent of blended cement (EN 197-1)	11		
Pre-cast concrete blocks	6	48	
Blasting grit			31
Grouting			6
Infill	3		
Others	3	5	8

2.3.2.7.3 Slag from iron and steel production

The Iron and Steel industries are intimately linked. Some 95-98% of all Iron production is used as a feedstock for steel production and most sites possess facilities for both processes. Slag from Iron production is termed blast furnace slag (BFS) and can either be:

- air cooled (non-reactive and crystalline phases) or
- rapidly quenched (reactive non-crystalline glassy phases).

The latter type is particularly useful as a supplementary cementitious material (high value) and is ground to produce ground granulated blast furnace slag (GGBFS). Demand for GGBFS from the Portland cement industry generally outstrips supply. In particular, Portland-GGBFS cement (i.e. CEM III according to EN 197-1) is useful in the pouring of large concrete slabs in road construction due to its low heat of hydration.

Air cooled BFS is also useful, but as lower value aggregates, that can be used for sub-base materials for roads with medium-level traffic. The USGS estimate global production of BFS (air-cooled and GGBFS combined) to be in the region of 270-320 Mt in 2012, (USGS, 2012). Whether GGBFS or air-cooled BFS is produced depends on the ancillary facilitates available at the plant. In the EU, EUROSLAG (2010) have stated that BFS production in Europe (evaluated on 13 Member States) in 2010 was 25.6 Mt. Approximately 66% of BFS was used directly in the cement industry while the remainder was employed as aggregates, especially in road construction (EUROSLAG, 2010).

Steel slag can be produced from either electric arc furnaces (EAF) or basic oxygen furnaces (BOF) and also include secondary slags too. The USGS estimate global production to be around 150-230 Mt in 2012. At the European level, EUROSLAG reported that 21.1 Mt of steel slag were produced in 2006 of which almost 100% was reused. The dominant reuse application was in road construction (55%).

Feedback from stakeholders in the questionnaire stated that currently around 44% of slag produced in Europe is used in road construction. The main uses of Iron and steel slags in the EU is summarised in Figure 2.8.

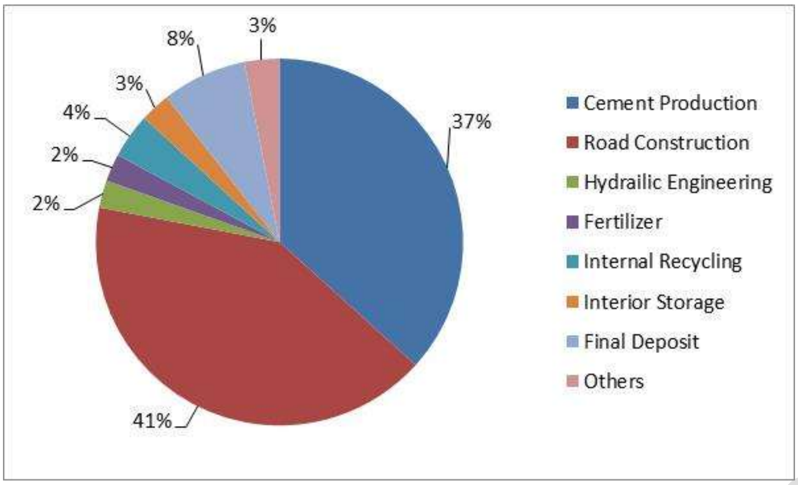


Figure 2.8: Utilisation of slags from the iron and steel industry. (EC JRC, 2009)

The reuse applcations shown in Figure 2.8 inmply that there is only a limited potetnial for increasing the quantities of slag used in road construction. Use in cement may indirectly already be reused in road construction via type III Portland cement. At most, slag utilisation in roads could increase by some 10%.

2.3.2.7.4 Municipal Solid Waste Incineration Bottom Ash

According to Birgisdóttir (2005), MSWI residues can be classified as:

- Bottom ash: is a product of the combustion process and consists of the non-combustible and un-combusted fractions of the waste. It is formed while the waste is transported on the moving grate through the combustion chamber. Bottom ash is the largest residue stream from the incineration process, typically 150-300 kg/t of waste incinerated and accounting for 85-95% of all the residues generated.
- Fly ash: is also a product of the combustion process and consists of relatively fine ash particles that are entrained in the flue gas from the boiler and recovered in electrostatic precipitators or fabric filters. Depending on the Air Pollution Control (APC) equipment used in the incineration plant, fly ash is either collected separately or mixed with other APC residues from gas scrubbing.
- APC residues: are reaction products from the neutralization of acidic components and desulfurisation of flue gas with lime and consist of the reaction product and any un-reacted lime. Spent powdered activated carbon particles will also end up in this waste stream if used in the APC process
- Other residues: “grate siftings” is material that has passed through the openings in the grate, either because of the small size of the material or because it melts. This fraction is usually collected and mixed with bottom ash. Boiler ash (approximately 5 kg/ton waste) consists mostly of larger ash particles that are removed from the flue gas in or immediately outside the boiler.

MSWI bottom ash produuction has been estimated at 20 Mt/year in Europe, as shown in Figure 2.9 (Muchova, 2010). The largest MSW bottom ash producers in the EU-24 are France and Germany. The Netherlands estimate that they produce 1 Mt per year. According to the Danish EPA (2005), in Denmark annual production of MSWI residues of approximately 0.73 Mt, with bottom ash constituting approximately 88% of this total amount (Birgisdóttir et al., 2007).

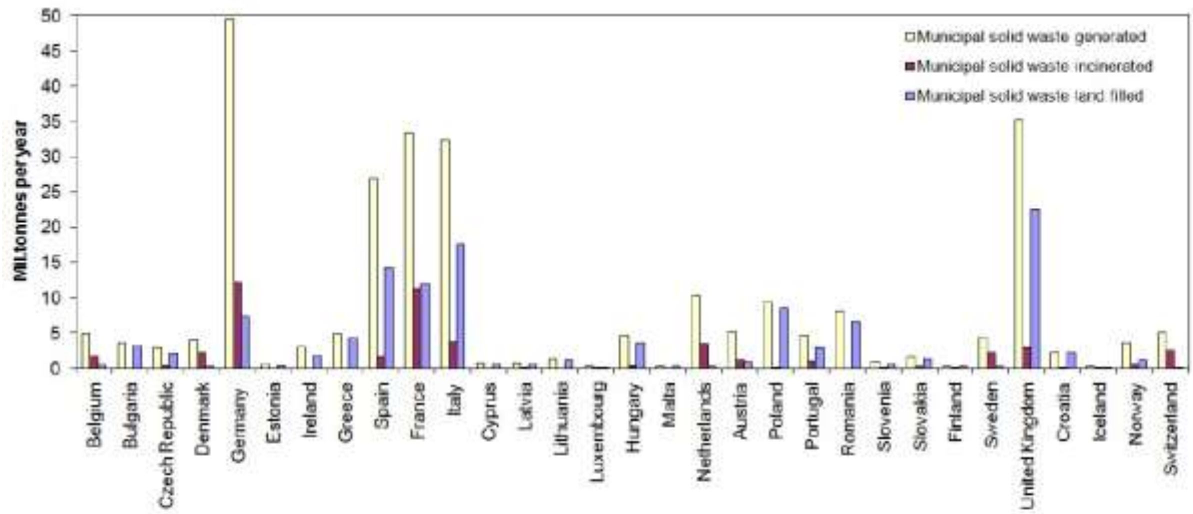


Figure 2.9: Amounts of municipal solid waste landfilled and incinerated in EU-24 IN 2005 (Muchova, 2010)

2.3.2.7.5 Reclaimed rubber

Reclaimed rubber can be used for a variety of purposes, including road construction. Many studies indicate lots of potential advantages, but also challenges, from using rubber in road surface courses. This research is still very much under development and may change significantly once the main challenges are overcome and confidence in long-term performance is gained (Sandberg et al., 2010).

Reclaimed rubber is used as an additive to asphalt products in many European Member States. The amount is relatively low due to other cheaper alternatives on the market according to information from the Danish Road Directorate (Olesen, 2013). It has not been possible to quantify the amount of reclaimed rubber used in roads.

Production, import and export data for reclaimed rubber (PRODCOM 22.19.10.00) in EU-28 from 2009 to 2012 are reported in *Annex II Tab. II.23*). This product group includes reclaimed rubber in primary forms or in plates, sheets or strips. The production in 2012 was 0.5 Mt. Although the quantities involved are small reative to other materials in road construction, reclaimed rubber is clearly a high value product, with a value in the range of 290-530 Euro per tonne and possibly much higher depending on the specific grade of reclaimed rubber.

The produced quantity has risen by around a factor of 6 between 2010 and 2011 – indicating a new market opportunity for the European producers of reclaimed rubber products.

2.4 Market segmentation of road construction

Public investment in transport infrastructure in the European Union fell from 1.5% of GDP in the 1980's to less than 1.0% in 2004, which constitutes an amount of roughly EUR 95 billion for the EU-15. When compared to the estimated amount of all the fiscal revenues of EUR 346 billion generated by the road sector in the EU-15 in 2004 the aggregated expenditure on road transport infrastructure in the EU today indeed looks very small. This translates into an annual shortfall of billions of Euros every year with road investment particularly hard hit.

According to the European Investment Bank (EIB), road construction loans to the EU-15 Member States are constantly declining to the advantage of railways. Between 2000 and 2003, EIB loans earmarked for building or modernising roads fell from EUR 2,582 to EUR 2,326 million, representing a decrease of 10%. In 2003, the rail sector received more loans from the EIB than the road sector even though rail represents only about 8% of freight transport (in tkm) and 9.5% of passenger transport (in billion pkm) in Europe. A report published by the French Senate in the year 2000 paints an alarming picture of the distribution of public investment in transport infrastructure.

Out of an estimated EUR 8 billion allocated by the government, 60% was earmarked to the loss-making rail sector, with perhaps 25% invested in road infrastructure development. During the same fiscal year, tax perceived on the road sector in France alone was estimated at EUR 50 billion against EUR 730 million for the rail sector. Conversely, not investing in road maintenance costs road authorities and users money. According to the PIARC report entitled "How road transport gets countries moving," for every EUR 1 not invested in preventive road maintenance, road users waste EUR 3 on extra transport costs and road authorities will spend EUR 4 on asset reconstruction costs.

Roads are important and very valuable assets to societies, providing users with the mobility they require and the EU member states with important tax incomes. A survey of current road maintenance expenditures conducted in recent several European Union countries (Denmark, France, Spain, Germany, Finland, Sweden, Belgium and Portugal) revealed that the budgets currently spent on road maintenance are grossly insufficient. In the analysed countries, the budgets actually available represented only around 76% of the required expenditure (ERF, 2006)

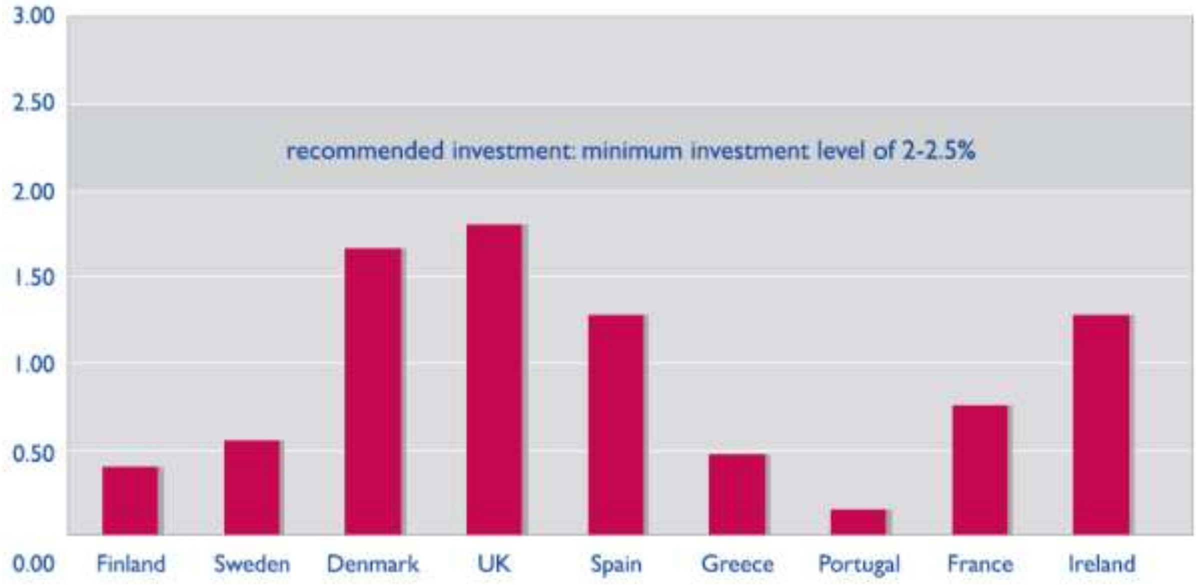


Figure 2.10: Investment in road maintenance (% of Total Road Network Value)

In this section a market segmentation is provided to provide a solid evidence and knowledge base for the development of GPP criteria for Road Construction.

2.4.1 Road types

The distribution of roads types in the single Member States varies significantly. A comparison between countries is complicated because different countries have different definitions for each road type. With regards to raods defined as motorways, the proportion compared to the total road network span varies from approx. 0.1% to more than 5% (ERF, 2013).

The distribution of roads by classification with individual Member States is also shown in Figure 2.11:

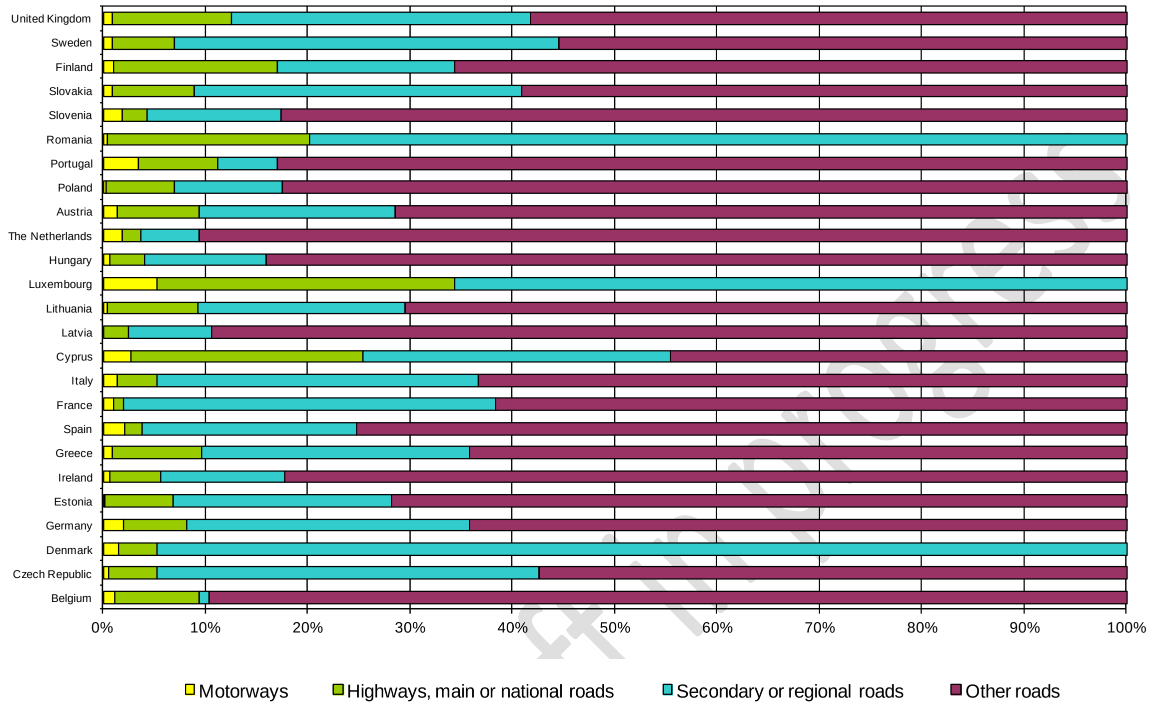


Figure 2.11: Distribution of roads types within the Member States of Europe (based on data in Table 2.1)

The road classifications from left to right are in descending order of width or traffic volume in general as per each Member State's definition. Figure 2.11 shows that no "other" roads were present in Romania, Luxembourg and Denmark. However, this is simply due to the definition system in these countries. In general, it is clear that the smaller "other"roads are by far the category that accounts for the longest length of road in each country.

2.4.2 Road pavement layer system

According to the stakeholders input from the first questionnaire, between flexible (asphalt) and rigid (concrete), flexible pavements were constructed (90%). Composite pavement layer systems were not mentioned by the stakeholders.

It is uncertain if the stakeholders simply referred to surface courses, or also binder and base courses when mentioning flexible (asphalt bound) and rigid (cement bound) materials.

2.4.3 Density of roads and motorways

With regards to the density of the total road network (km road per km² land area) densities range from approx. 0.1 to just above 7 km road/km² land area (see Figure 2.12). The highest densities were in Malta and Belgium (ERF, 2013).

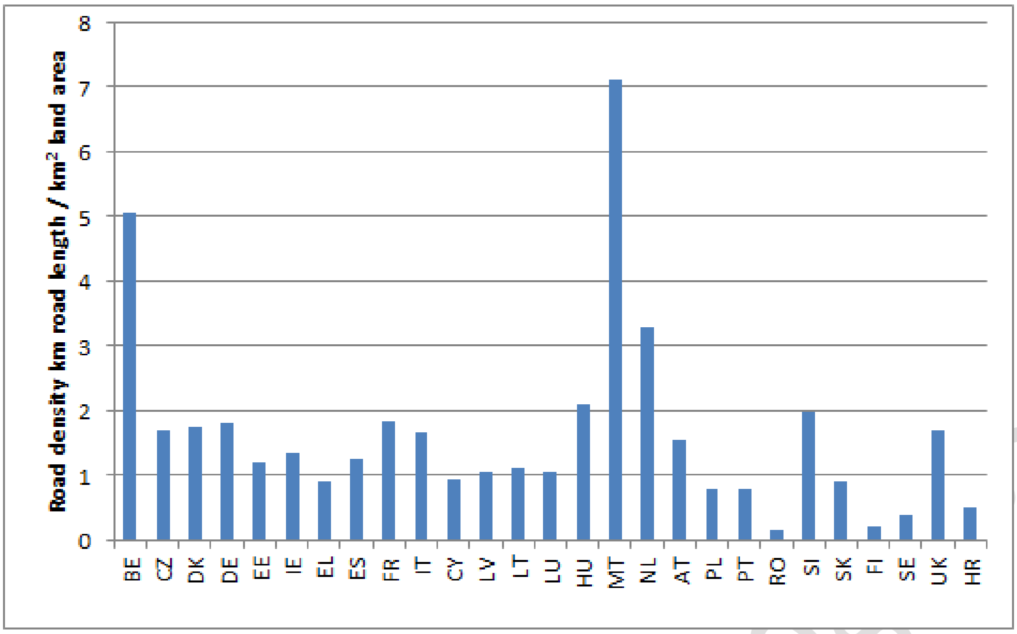


Figure 2.12: Density of the total road network in km road/km² land area (EC, 2013a)

The high road density in Malta is simply due to a lack of available land on the island and can be considered as a non-typical scenario. As a general rule, there is a correlation between road density and population density, as shown by the plot in Figure 2.13.

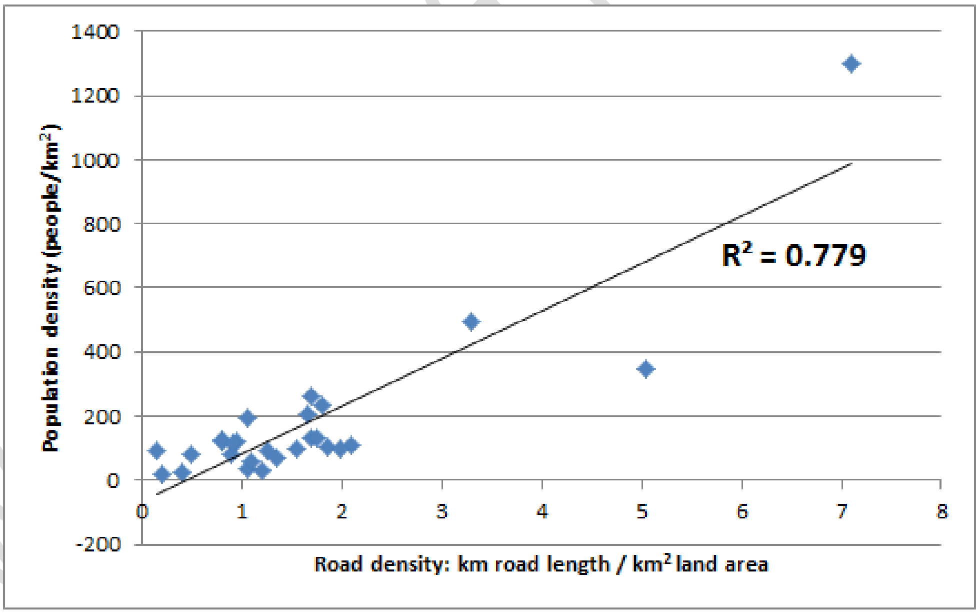


Figure 2.13: Correlation of road density and population density for EU Member states

A reasonable linear correlation coefficient of 0.779 was found between road density and population density. Other factors that are likely to be important include the maturity of the road network, the economic history of the country, the historical development of rail transport and the existence of any strategic trasnport routes between different countries and ports.

2.4.4 Climate zones

The impact of the climate zones on the choice of road type is described in Section 1.1.3.3.

A generalised attempt to break down road lengths into different region types in Europe is shown in Figure 2.14

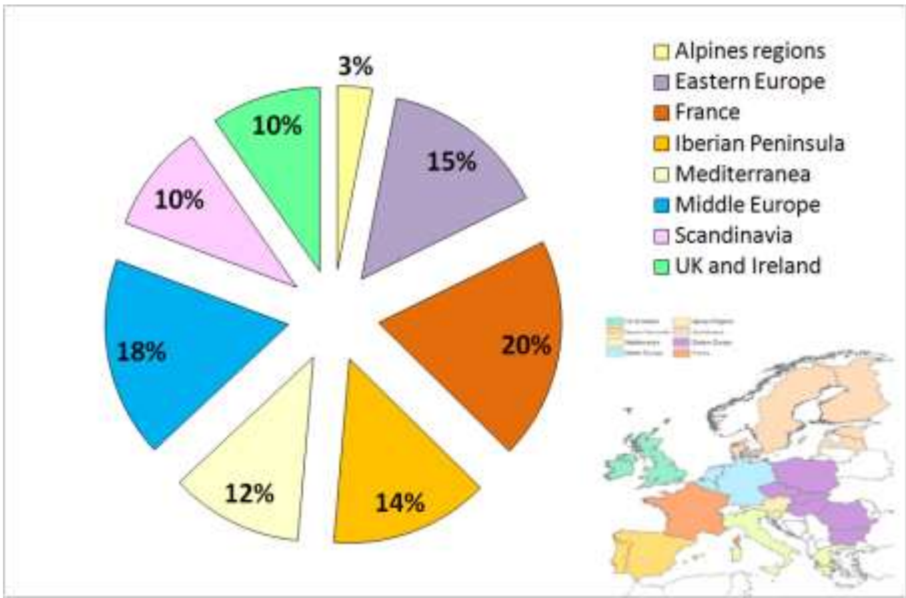


Figure 2.14: Road lengths in Europe split into different geografic regions

Although such a distribution is interesting, road construction needs to account for highly localised conditions such as rainfall, temperature, topology, etc., and the materials used need to meet any local standards required. Climate conditions can change dramatically even in local areas due to changes in land elevation.

The general consensus amongst stakeholders is that the materials used in road construction are similar throughout different climate zones in the Member States. However, their application, in terms of volumes and costs, may differ. One clear example of this is the widespread use of Asphalt in general across the EU but that Soft Asphalt (EN 13108-3) only tends to be used in the Nordic countries.

Based on the above mentioned evaluation it is concluded that no clear universal categorisation of roads can be made based on specific climatic zones or countries that could be applied to the development of GPP criteria for road construction.

2.5 Maintenance needs

The need for maintenance varies significantly depending on numerous aspects e.g. traffic volume/density, heat stress, type of road (rigid, composite or flexible), underground conditions, proximity to the coast, intense precipitation, share of heavy vehicles in traffic flow, frost depth, freeze-thaw cycles etc. (EC, JRC, 2012).

2.5.1 Statistical data

Data from the European Road Statistics (ERF, 2013) reveals that the relative expenditure on maintenance in 2009 can vary significantly between different countries (see Figure 2.15).

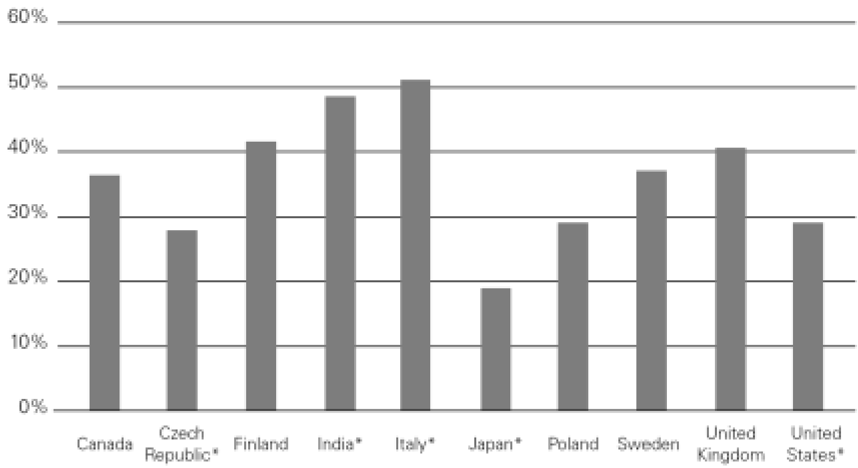


Figure 2.15: Road maintenance share of total road expenditure (ERF, 2013)

As it can be seen in the figure, the encompassed countries spend a sizeable share of the total road expenditure on road maintenance (approx. 10-50%).

The total expenditure in road maintenance for all Member States is also assessed to investigate the trend and is presented in Table 2.5. The data presented here is from the International Transport Federation, summarised in the European Road Statistics (ERF, 2013).

Table 2.5: Maintenance expenditure (Million EUR) in road infrastructure in selected countries (ERF, 2013)

	2005	2006	2007	2008	2009
Bulgaria	n/a*	108	215	203	69
Czech Republic	350	544	590	584	587
Denmark	763	701	728	712	866
Estonia	26	28	32	38	39
Ireland	53	54	50	55	45
France	2,189	2,235	2,294	2,184	2,207
Italy	12,549	13,452	9,764	10,756	n/a*
Latvia	80	129	213	227	135
Lithuania	122	125	161	125	134
Luxembourg	35	24	23	27	n/a
Hungary	283	1,255	1,367	444	453
Austria	443	495	486	n/a*	n/a*
Poland	1,265	1,670	1,515	2,007	2,340
Portugal	177	203	192	n/a*	n/a*
Romania	426	1,041	1,338	n/a*	n/a*
Slovenia	99	140	139	148	155
Slovakia	100	130	156	161	192
Finland	600	612	611	673	684
Sweden	788	810	836	858	n/a*
United Kingdom	5,953	6,155	6,272	5,425	4,944
TOTAL	26409*	29911	26982	26157	26021

*where data was not available n/a, no change from the data for previous or following year was assumed.

Confidence in the data from 2009 is not so good because data for Italy, the country with the highest road maintenace costs included in Table 2.5, was not available. Assuming no sudden changes from previous available data, the trend in road maintenance expenditure appears to be relatively stable across the countries listed in Table 2.5

Concluding remarks

The countries listed in Table 2.5 do not include some of the major European Member States such as Germany, Spain, Belgium and the Netherlands. The trends between 2005 and 2009 indicate a reasonably stable overall investment in road maintenance. However, since 2009, the effects of the economic crisis across Europe may have had a significant effect on maintenance budgets. This is discussed further in the forecast section (2.8.3).

Complications in compiling maintenance expenditure data arise due to the highly fragmented distribution of budgets and responsibilities between local authorities in each country in particular for "other"roads which accounts for the biggest share of road length in the EU (see Table 2.1).

2.6 Key manufacturers and procurements entities

Major impacts of road construction include earthworks, the production of the pavement materials, transport to site and laying of the materials on site.

2.6.1 Construction companies

The ten largest construction companies in Europe, based on sales, are: (Construction Europe, 2008)

1. Vinci (France)
2. ACS (Spain)
3. Bouyges' Construction Division (France)
4. Hochtief (Germany)
5. Eiffage (France)
6. Strabag (Austria)
7. Skanska (Sweden)
8. Saipem (Spain)
9. FCC (Spain)
10. Balfour Beatty (UK)

Of the ten companies, nine are involved with infrastructure projects, including road construction. Number 8 on the list, Saipem, is involved with energy. The nine companies all operate internationally, and some are not only involved in construction work but also in motorway concessions, quarries, etc. These companies both produce and lay pavement materials.

2.6.2 Earthworks

Equipment is key to earthworks. The material is either already present at the site or it is hauled in from, say, gravel pits in the vicinity of the construction site. The task for the contractor is often simply to move materials from one place to another within the construction site. Earthworks are often sub-contracted to companies specialised in earthworks. The trend in this sector goes towards larger national companies that can afford investment in modern (computer controlled) equipment usually applied at larger construction projects. Only rarely are earthwork projects carried out by foreign contractors.

2.6.3 Production of pavement materials

The production of sand and gravel is limited to geographical regions where they can be economically exploited and where permits are issued by relevant authorities. Due to the low bulk value of aggregates, the choice of location is dominated by where aggregate is in demand in order to minimise transport costs. In Denmark for example, it is difficult to obtain permission to extract natural resources and as a consequence there has been a concentration of companies in the sand and gravel producing sector to currently two primary players.

Bitumen for asphalt materials is produced at specialised oil refineries and in certain countries without refinery capacity, transport may be significant. Portland cement kilns are located according to suitable sites for raw materials, in particular limestone, which makes up 80% of raw material requirements. Where cement has to be transported long distances, the cement clinker may be transported due to its higher stability before being ground with gypsum and any other materials in a smaller plant located nearer the client. The higher bulk value of bitumen and cement has meant that production capacity has become concentrated between relatively few companies in Europe.

Key European bitumen manufacturers are (members of Eurobitume): API, BP, CEPSA, ENI, ExxonMobil, Galp Energia, Nynas, OMV, Q8, Repsol, Shell Bitumen and Total (Eurobitume, 2013b).

The European Cement Association, CEMBUREAU, has more members than Eurobitume. In many countries, however, there is only one company producing Portland cement.

Production of asphalt (bitumen plus aggregate) and concrete (cement plus aggregate) can take place in many places. The European Asphalt Pavement Association (EAPA) lists more than 4,000 stationary asphalt production plants in Europe owned by 690 companies (EAPA, 2011). Equivalent information is not available from the concrete paving industry, but it is likely that the picture is similar. Both asphalt and concrete should be laid within a limited time (a few hours) after production, necessitating the high number of geographically spread production sites.

2.6.4 Laying of pavement materials

In most cases, especially for asphalt pavements, the asphalt is laid by the same company that produced the material. But, there are no major technical constraints to prevent any contractor from buying and laying material produced from a different company. Most European national standards within the pavement sector take their starting point in common European standards thus easing cross-border trade. With concrete, most contractors that put concrete in place are completely independent of the cement manufacturer.

2.6.5 Conclusions on manufacturers

Today, European road construction is characterised by a large number of small or medium sized national road construction companies.

Only a limited number of very large companies exist that operate in several European countries. These large companies are invariably involved in very large construction projects, including road, bridge and tunnel construction and involving several technical disciplines (earthworks, bridges/tunnels, and pavements). These projects require major financial commitments. The large companies then take charge of the projects, tendering sub-contracts to smaller and more specialised/local contractors where necessary.

Earthworks and the laying of pavement material are prime examples of the type of work that is sub-contracted to smaller and local companies. They have a competitive advantage due to either the level of specialisation (i.e. in heavy equipment) or logistical advantages . The trend in these sectors is that companies are getting larger, retrieving markets shares from the smaller contractors.

2.7 Public Procurement volumes and expenditure

Most European road works are tendered by public authorities at the state, regional or municipal level. In some cases, new tendering schemes like Public Private Partnerships, Build Operate Transfer etc. are applied. This usually means that a consortium consisting of a number of private companies is hired to finance the construction and possibly the operation of one or more roads for a period of years. In some cases, the roads are turned over to the public after a certain period. In any case, the procurer is still the public road authority.

In case an investor would take over responsibility for financing the construction and operation of a road on behalf of a public body, then the investor would subsequently procure the construction and operation of the road. This method is not common in Europe today though.

The investments made in the European road infrastructure in the years 2007 to 2010 are listed in Table 2.6:

Table 2.6: Gross investment spending in road infrastructure in selected countries (ERF, 2013)

Millions of Euro	2007	2008	2009	2010
Albania	253	497	486	242
Bulgaria	134	169	101	281
Czech Republic	1,493	2,043	1,987	1,720
Denmark	1,029	936	714	937
Germany	n.a.	n.a.	n.a.	n.a.
Estonia	131	162	133	140
Ireland	1,425	1,319	1,173	841
Spain	7,770	8,099	8,692	6,858
France	12,489	12,623	12,648	11,942
Italy	13,664	13,051	5,641	n.a.
Cyprus	n.a.	n.a.	n.a.	n.a.
Latvia	241	265	135	140
Lithuania	312	437	448	422
Luxemburg	157	138	138	n.a.
Hungary	646	979	1,566	840
Austria	802	n.a.	n.a.	n.a.
Poland	3,443	4,508	5,340	6,510
Portugal	1,453	1366	951	1,511
Romania	2,806	3,891	3,105	2,850
Slovenia	666	694	406	221
Slovakia	520	567	662	342
Finland	802	973	922	890
Sweden	1,423	1,604	1,574	1,653
United Kingdom	6,341	6,137	6,610	6,555

Across Europe there is a drive for shifting towards Green Public Procurement (Directives 2004/17/EC and 2004/18/EC). Significant progress has been made in some of the more enviornmentally conscientious countries. For example, The Netherlands state that by 2010, 100% of public procurement should be "sustainable". The Dutch Rijkswaterstaat has decided that sustainability should complement price and quality as criteria in procurement of road construction projects. The sustainability criterion rates the durability of business operations of a bidder as well as the durability of the product offered. The use of the sustainability criterion has been applied in a case study with positive results.

2.8 Forecast

A forecast of future construction of new roads and maintenance of existing roads in Europe is difficult to make in light of the lack of concrete data on such a matter. Furthermore road construction projects can also be subject to political influences and changes to allocated budgets.

2.8.1 Construction of new roads

Due to the lack of data available, estimates for planned new road construction was one of the questions included in the stakeholder questionnaire. The responses received are summarised below:

- The Highways Agency in England report of approx. 190 lane km of road per year in average during the last 3 years.
- Regarding Turkey the Istanbul Technical University reported a an average of newly constructed roads of 1,250 km per year.

2.8.2 Waste materials/residues including waste derived materials in road construction

The use of waste materials are an important aspect of recent European legislation as depicted in the Waste Framework Directive (section 1.3.1.4) etc. The Directive aims to facilitate the increased use of recycled materials or industrial by-products and to distinguish between "waste" and "by-products" - this matter is of particular importance to the road construction sector.

At the European level, and as per the relevant summaries in section 1.3.1.4, there is considerable potential to increase the use of coal fly ash and bottom ash in road construction, although there is only a limited potential to increase the use of Iron and steel slags in road construction. The use of MSW bottom ash may increase although this will largely depend on attitudes of individual Member States and the local availability of such ash.

It is likely that recycled C&DW, reclaimed asphalt and secondary/manufactured aggregates will become increasingly important in sustainable road construction in the near future. In some countries, the use of reclaimed asphalt is already near the maximum possible, but in others a major improvement is possible.

2.8.3 Maintenance needs

Maintenance needs can cover various tasks that may or may not be covered under the same budget, depending on the responsible parties. Tasks can range from the maintenance and inspection of road drainage systems, filling of potholes to replacing entire sections of surface courses.

It is very difficult to obtain information on maintenance requirements. Hence the inclusion of this question in the questionnaire to stakeholders in March 2013. Responses were only with regards to motorways and highways (main or national raods) and appear to be specifically about the need for resurfacing:

- The Italian National Agency for New Technologies, Energy and Sustainable Economic Development stated that the maintenance of 1,341 km of road for 2012 (5.1% of total road length).
- The National Road Administration in England expressed a need for maintenance of 1,500 lane km/year (2.8% of total road length). This percentage may actually be higher since it is uncertain whether this figure only corresponds to highways in England or also in Scotland, Wales and Northern Ireland, whose road lengths are included in the total road length in Table 2.1.
- The Ministry of Infrastructure & Environment in the Netherlands is in charge of about 3,000 km motorway. They resurface approx. 10% of their roads every year.

Maintenance of roads is indeed a very variable cost among European road agencies. The agencies see road maintenance as a very important aspect, but it is often difficult at the political level to attract the funds that the agencies see as necessary for maintaining a satisfactory level of service for their users. Road maintenance is linked to level of service provided to the users of the roads, but there is often a significant time lag between lack of investment in road maintenance and a visible decrease in perceived level of service or safety. Here are four specific examples of trends for the years 2010 to 2013:

- Spain: Has seen a reduction of 38% on maintenance of roads since 2009 (Eurorap, 2013).
- Sweden: Funds for road maintenance are rising. Trafikverket has heavy focus on efficient administration, and savings should boost maintenance of roads (and railways). (Trafikverket, 2013)
- Denmark: The Danish Road Directorate has seen a historically high level of maintenance in the period because they were able to demonstrate a significant backlog in investments in maintenance of roads and bridges.
- UK: The Highways Agency is required to improve its efficiency and to steadily improve its performance. As a result, maintenance budgets are being reduced (Highways Agency, 2013).

Other studies have assessed the need for future maintenance due to climate changes (EC JRC, 2012a). On the one hand, milder winters are expected to result in reduced maintenance requirements but on the other hand heavier localised rainfall may result in the need for modifications to drainage systems.

2.8.4 Concluding remarks

Many countries in the EU have a "mature" road infrastructure, which requires relatively low levels of new road construction each year. In countries where road infrastructure is still being developed, for example Turkey, the scale of new road construction is huge by comparison (see section 2.8.1).

As with construction, there is no information available for maintenance aspects for local roads and only limited data for national roads (motorways and highways). Clearly maintenance needs will increase in line with any new construction. However, maintenance costs will also increase for any section of road as a function of its age and any previous history of under-investment. These factors are impossible to calculate and often even unknown by relevant local authorities.

Regardless, maintenance is a fundamental aspect in the sustainability of roads and well designed and constructed roads will generally require less maintenance in the long term. The decoupling of construction and maintenance responsibilities creates the risk of lower quality (and cheaper) construction, at the expense of increased maintenance costs and all the associated environmental impacts of traffic delays and the need for additional repair materials etc.

3 TECHNICAL AND ENVIRONMENTAL ANALYSIS

3.1 Life Cycle Assessment literature review

When the current EU GPP criteria for "road construction and traffic signs" were set (EC, 2010) several environmental studies had been analysed. From that analysis it resulted that the main environmental issues of relevance for road construction are related to the combustion of fossil fuels: the emission of CO_2 and NO_x, contributing to GHGs emissions and global warming, atmospheric pollution (ground level ozone creation and acidification) as well as nutrient enrichment. The materials used in the construction of the road have varying impacts. When bitumen is used, asphalt was found to have the largest contribution to the environmental impacts above, due to the inherent or feedstock energy of the bitumen. When cement concrete is used, cement binders and aggregates are responsible for the largest contribution on the environmental impacts. The use of natural aggregate and crushed rock is highlighted due to their consumption of non-renewable materials, quarrying impacts and transportation for road construction. During road maintenance, the study also found that road salting could pollute large amounts of groundwater/surface water in the area near the road. For traffic signs the greatest environmental gains can be achieved through eco-design by selecting materials that are durable and recyclable at their end of useful life.

The key environmental impacts identified for the definition of the current GPP criteria can be listed as:

- Extraction and consumption of raw materials.
- Energy required to process raw materials to form suitable products.
- Energy consumption by plant equipment and transport vehicles during the construction of the road.
- Pollution of air, land and water due to the use of fossil fuels to power machinery/transport vehicles.
- Generation of waste material, including hazardous wastes.
- Noise and visual impacts.

For the current revision of the EU GPP criteria, a new comprehensive review of available Life Cycle Assessment (LCA) studies for road infrastructure and pavements has been performed. LCA studies allow the identification of potential environmental impacts of road construction along all life cycle phases. This analysis in particular aims at identifying main environmental areas of concern and life cycle hot-spots for road construction and at estimating the environmental improvement potential of applicable measures. The goal of the GPP criteria for road construction is basically to define environmental criteria that could or should be included in an invitation to tender (ITT) for the construction (and the maintenance) of road infrastructure. This goal has been kept in mind during the review of the selected LCA papers.

A review of LCA studies covering road construction, including aspects such as construction materials and products supply chain (particularly of recycled/secondary materials and by-products) has been carried out. However, the analysis has also been extended to some aspects of the use phase, such as the vehicle-pavement interaction (rolling resistance). In order to establish a robust basis for the criteria revision process, the LCA studies have been screened by means of methodological and quality standards. Screening criteria consisted in the collection of the available literature and the further selection of studies through a set of criteria covering issues as methodology used, relevance of scope, environmental indicators considered and outcomes. Main results and outcomes were analysed carefully and common conclusions were drawn for this study.

3.1.1 Selection of the LCA studies

3.1.1.1 Description of the LCA studies

Many examples of studies dealing with the LCA of road construction or other issues related to the road sector are available in the literature. From a preliminary review of the literature, 43 documents are potentially related to LCA of road construction (listed in section 3.1.1.2). The information gathered includes:

- Papers and reports on the environmental performance of the transport sector in which road construction and maintenance is mentioned.

- Papers and reports on the environmental performance of the road life cycle, including raw materials extraction and materials production, construction, use, maintenance and end of life. Some of these papers refer only to the environmental performance of some phases, i.e. construction and/or maintenance phase.
- Papers and reports focused on specific lifecycle stages (e.g. employment of recycled materials and by-products in road construction, use of reclaimed asphalt pavement, end of life).

A brief analysis of Environmental Product Declarations (EPDs) and Product Category Rules (PCRs) available for road infrastructure and construction products (according to ISO 14025:2006), ISO 21930:2007 and EN 15804:2012 that provide core rules for PCR for Construction Products) was carried out. Only one PCR for roads, titled "UN *CPC 53211 Highways (except elevated highways), streets and roads. 2013:20 version 1.01*", was found (published on 21.11.2013 by the International EPD®system - see ENVIRONDEC, 2013. It is based on the requirements and guidelines given in the "PCR Basic Module, CPC Division 53 Land transport infrastructure (version 1.0 - October 2013). Available PCR´s for specific construction products have been compiled (*See* Annex III*. Table III.1).* The first EPD on road infrastructure has been published by Acciona (2013) on 14.01.2014 (Annex III*. Table III.2*).Moreover, examples of EPDs for construction products (asphalt, concrete, cement) have also been listed in Annex III*. Table III.2.*

3.1.1.2 Screening of LCA studies

The quality and the applicability of the above mentioned LCA studies to the revision of the GPP criteria for road construction have been analysed. A general methodology has been defined for the LCA screening in order to select the LCA studies and gather the information that would be used in the technical analysis. Three steps have been followed:

Step 1: Preliminary identification of key environmental issues: a set of key environmental indicators to focus on were identified based on preliminary screening of studies, the available PCR and other pieces of literature providing scientific evidence. Such identification is not based on a comprehensive assessment, but rather on key environmental issues perceived as relevant by the authors of the studies available in the literature.

Step 2: Screening of studies: Studies that do not satisfy minimal cut-off requirements (scope, impacts, and outcomes) were disregarded. A scoring system was used to evaluate the quality of the studies that passed the first level of screening. Studies have been ranked according to the screening rules.

Step 3: Findings related to the key environmental issues identified: outcomes from studies of satisfactory quality were described by road phases and by key environmental indicators.

3.1.1.2.1 Step 1: Preliminary identification of key environmental issues

In the first screening stage, a set of key environmental indicators of relevance to road construction have been identified based on the available PCR and the observation of relevant documents of reference.

The impact categories and characterisation factors recommended by the PCR on "UN CPC 53211 Highways (except elevated highways), streets and roads" (ENVIRONDEC, 2013) have been considered, as shown in Table 3.1. The PCR recommends using the IPCC method (2007) for the assessment of the impact on climate change and the CML2001 (reference) method for the characterization of other impact categories. The PCR also requires data on the use of resources (primary energy, non-renewable and renewable, MJ) as a flow indicator. This PCR requires also providing additional environmental information (see *Annex III Table III.3*)

Table 3.1: Impact categories according to the PCR on "UN CPC 53211 Highways (except elevated highways), streets and roads" (ENVIRONDEC, 2013)

Environmental impacts	Impact category	Characterisation
Emission of greenhouse gases	Global warming potential (kg CO_2e)	GWP100, CML 2001
Emission of acidifying gases	Acidification potential (kg SO_2e)	AP, CML 2001
Emissions of gases that contribute to the creation of ground level ozone	Photochemical oxidant creation Potential (kg C_2H_4e)	POCP (high NOx), CML 2001
Emission of substances to water contributing to oxygen depletion	Eutrophication potential (kg PO_43^{-e})	EP, CML 2001

With reference to the reviewed LCA studies, all of them include either energy consumption (mainly non-renewable energy consumption) or GHGs emissions, provided as metrics. Some 40% of studies provide a LCIA assessment, the majority according to the CML2001 (Institute of Environmental Sciences, University of Leiden, 2002) method and a few according to EDIP97 (Hauschild and Wenzel, 1997). As it is shown in Table 3.2, Global Warming is included in all the studies providing a LCIA. Around 50% of these studies consider also acidification, photochemical ozone formation and eutrophication. Human toxicity and eco-toxicities are relevant impact categories particularly when assessing the environmental impacts of the use of recycled/secondary materials employment in road construction.

Table 3.2: Impact categories analysed in the selected LCA studies

	% of the 8 studies on road infrastructure that provide a LCIA	% of the 3 studies on the supply chain that provide a LCIA	**Overall % inclusion in the studies on average**
Indicators			
Energy consumption (non-renewable and renewable)	100	100	**100**
Impact categories according to the (EC JRC, 2012b)			
Climate change	100	100	**100**
Acidification	50	100	**64**
Photochemical Ozone Formation	33	67	**42**
Eutrophication	33	67	**42**
Ozone depletion	33	0	**24**
Resources depletion (mineral – fossil)	25	0	**18**
Ionizing radiation	12.5	0	**9**
Human Toxicity	0	100	**27**
Eco-toxicity	0	100	**27**
Stored eco-toxicity	0	100	**27**

On the basis of the analysis done, it is considered that the key indicators and impacts category of reference for screening the LCA studies were:

1. **Energy consumption**
2. **Global warming**

Other impact categories to be considered were:

3. Acidification
4. Photochemical ozone formation
5. Eutrophication

3.1.1.2.2 Step2: Screening of studies

LCA studies have been screened in order to identify those that satisfy minimal requirements for quality and robustness and to select and rank the most relevant ones. The evaluation has concerned 43 studies and it has been performed in two steps.

1) In order to select the LCA studies to be evaluated, minimal cut-off requirements have been set for:

- Scope: functional unit properly defined and relevant for this revision, scope coherent with goal analysis, respect of ISO 14040 standard
- Impact assessment: satisfactory broadness or quality of the indicator(s) considered in the analysis.
- Outcomes (relevant and applicable).

Studies not passing these criteria have not been used to analyse the life cycle hot-spots of road construction. Nevertheless, the disregarded studies have been used for dealing with some issues relevant for the revision process (e.g. best available technologies, improvement potential and recycling).

2) The quality of the studies passing the first level of screening has been evaluated through a scoring system, according to the screening rules reported in Annex III *Table III.4*.

- Six parameters have been taken into account: scope, data, impact assessment, outcomes, robustness of the study and critical review.
- For each parameter a score from 1 to 5 has been assigned as described in the table provided in Annex III *Table III.4*.
- Quality of the studies has been considered satisfactory when the sum of the scores is higher than 15.

The Recommendations of the ILCD Handbook (EC JRC, 2011b) have been consulted in order to evaluate which assessment methods are more appropriate to quantify impacts for each of the environmental categories identified in paragraph 3.1.2.1. Impacts assessment methods are classified from A to E (see *Annex III. Table III.5).* The above mentioned classification has been applied to the impact categories of each paper, where available.

Each of the above mentioned studies has been analysed in order to check if cut-off requirements on scope, impact assessment and outcomes are matched (☑) or not (☒). The results of the assessment are reported in Table 3.3.

From the 43 studies found:

- 35 have been considered to satisfy the minimal cut-off criteria set,
- 8 have been considered to have limited application in the revision process.

Table 3.3: List of studies dealing with LCA of road construction

Category	References [red (disregarded study)]	Cut-off scope	Cut-off impacts	Cut-off outcomes	Reasons for exclusions
Transport	Treloar G. J., Love P. E. D. and Crawford R. H. (2004). Hybrid Life-Cycle Inventory for Road Construction and Use. Journal of Construction Engineering and Management © ASCE, pp. 43-49	☑	☑	☑	
	Chester M.V. (2008). Life-cycle Environmental Inventory of Passenger Transportation in the United States. Dissertations, Institute of Transportation Studies, University of California, Berkeley http://repositories.cdlib.org/its/ds/UCB-ITS-DS-2008-1	☑	☑	☑	
	Chester M. V. and Horvath A. (2009). Environmental assessment of passenger transportation should include infrastructure and supply chains.	☑	☑	☑	
	Mithraratne N. (2011) Lifetime liabilities of land transport using road and rail infrastructure. NZ Transport Agency research report 462. 100pp	☑	☑	☑	
	Hill N., Brannigan C., Wynn D., Milnes R., van Essen H., den Boer E., van Grinsven A., Ligthart T.and van Gijlswijk R. (2012). EU Transport GHG: Routes to 2050 II The role of GHG emissions from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions	☑	☑	☑	
Road infrastructure	Häkkinen T., Mäkele K. (1996). Environmental adaptation of concrete. Environmental impact of concrete and asphalt pavements. VTT Research notes 1752, 61 p. + app. 32 p.	☑	☑	☑	
	Mroueh U-M., Eskola P., Laine-Ylijoki J., Wellman K. (2000). Life cycle assessment of road construction. Finnish National Road Administration Finnra Reports 17/2000 http://alk.tiehallinto.fi/tppt/lca3.pdf	☑	☑	☑	
	Mroueh U-M., Eskola P., Laine-Ylijoki J. (2001). Life-cycle impacts of the use of industrial by-products in road and earth construction. Waste Management 21, pp. 271-277	☑	☑	☑	
	Stripple H. (2001). Life Cycle Assessment of Road. A Pilot Study for Inventory Analysis. Second Rev. Ed.. IVL	☑	☑	☑	
	Chappal M., Bilal J. (2003). The environmental road of the future. Life cycle analysis. Energy consumption and greenhouse gas emissions. Colas report	☑	☑	☑	
	Hoang, T., Jullien, A. & Ventura, A. (2005). A global methodology for sustainable road – Application to the environmental assessment of French highway, 10th DBMC International Conference of Building Materials and Components, Lyon, 17–20 April, 2005	☑	☑	☑	
	SUSCON National Technical University of Athens (2006). Life Cycle Assessment of Road Pavement. SUSCON LIFE05.	☑	☑	☑	
	Zhang H., Keoleian G.A. and Lepech M.D. (2008). An integrated life cycle assessment and life cycle analysis model for pavement overlay systems. Life-Cycle Civil Engineering, pp. 907-912	☑	☑	☑	
	Huang Y., Bird R., Heidrich O. (2009). Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. Journal of Cleaner Production 17, pp. 283–296	☑	☑	☑	
	Santero NJ, Horvath A. (2009) Global warming potential of pavements. Environ Res Letts;4:034011	☑	☑	☑	
	ECRPD (2010). Energy conservation in road pavement design, maintenance and utilisation, Intelligent Energy Europe, Feb 2010, www.roadtechnology.se/ecrpd.eu/	☑	☑	☑	
	Sayagh S., Ventura A., Hoanga T., Franc D. & Jullien A. (2010). Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures, Resources, Conservation and Recycling, 54, 348–358	☑	☑	☑	
	Milachowski C., Stengel T. and Gehlen C. (2011). Life cycle assessment for road construction and use. EAPA on-line publication	☑	☑	☑	
	Carlson A. (2011). Life cycle assessment of roads and pavements. Studies made in Europe. VTI rapport 736A	☑	☑	☑	
	Santero N.J., Masanet E., Horvath A. (2011). Life-cycle assessment of pavements. Part I: Critical review. Resources, Conservation and Recycling 55, pp. 801–809	☑	☑	☑	
	Santero N.J., Masanet E., Horvath A. (2011). Life-cycle assessment of pavements Part II: Filling the research gaps. Resources, Conservation and Recycling 55, pp. 810–818	☒	☒	☑	Second part of a study with recommendations
	Finnveden G., Brattebø H., Birgisdóttir H., Potting J. and Toller S. (2012). LICCER Life Cycle Considerations in EIA of Road Infrastructure. ENR2011 ENERGY – Sustainability and Energy Efficient Management of Roads	☒	☑	☒	On-going project. No final outcomes

	Yu B., Lu Q. (2012). Life cycle assessment of pavement: Methodology and case. Transportation Research Part D 17, pp. 380–388	☑	☑	☑	
	Giustozzi F., Crispino M., Flintsch G. (2012). Multi-attribute life cycle assessment of preventive maintenance treatments on road pavements for achieving environmental sustainability. Int. J Life Cycle Assess 17, pp.409–419	☒	☒	☑	
	Huang Y., Spray A., Parry T. (2012). Sensitivity analysis of methodological choices in road pavement LCA. Int. J Life Cycle Assess.	☒	☒	☑	Theoretical study
	Tatari O., Nazzal M., Kucukvar M. (2012). Comparative sustainability assessment of warm-mix asphalts: A thermodynamic based hybrid life cycle analysis. Resources, Conservation and Recycling 58, pp.18– 24	☒	☒	☑	Not an LCA study
	Wang T., Lee I-S., Kendall, Harvey, Lee E-B, Kim C. (2012). Life cycle energy consumption and GHG emission from pavement rehabilitation with different rolling resistance. Journal of Cleaner Production 33, 86-96	☑	☑	☑	
	Wang T., Lee I-S., Kendall, Harvey, Lee E-B, Kim C. (2012). UCPRC Life Cycle Assessment methodology and Initial Case Study on Energy Consumption and GHG Emissions for Pavement Research Preservation Treatment with Different Rolling Resistance. Research Report: UCPRC-RR-2012-02 at the Pavement Research Center at the University of California	☑	☑	☑	
	Wayman M., Parry T., Andersson-Sköld Y., Raaberg J., Bergman R., Enell A. and Huang Y. (2012). Life Cycle Assessment of reclaimed asphalt. Re-Road project. Deliverable 3.4	☑	☑	☑	
	Taylor P., Van Dam T., Fick G., Gress D., VanGeem M., Lorenz E. (2012). Sustainable Concrete Pavements: A Manual of Practice. Report of the NCPTC National Concrete Pavement Technology Center, Iowa State University Funded by the Federal Highway Administration	☒	☒	☑	Manual of practice. Not an LCA study
	Buyle M., Braet J. and Audenaert A. (2013). Life cycle assessment in the construction sector: A review. Renewable and Sustainable Energy Reviews 26 (2013), pp.379–388	☒	☒	☑	Theoretical study on construction sector
	Barandica. J.M., Fernández-Sánchez G., Berzosa A., Delgado J.A. and Acosta F.J. (2013). Applying life cycle thinking to reduce greenhouse gas emissions from road projects. Journal of Cleaner Production 57 (2013), pp.79-91	☑	☑	☑	
	Loijos A., Santero N., Ochsendorf J. (2013). Life cycle climate impacts of the US concrete pavement network. Resources, Conservation and Recycling 72, 76– 83	☑	☑	☑	
	Liljenström C. (2013). Life Cycle Assessment in Early Planning of Road Infrastructure. Application of The LICCER-model. Master of Science Thesis at KTH Royal Institute of Technology, Sweden	☑	☑	☑	
	PE EC DG-ENV (2013). Assessment of Scenarios and Options towards a Resource Efficient Europe. Topical Paper 4: Validation of technical improvement options for resource efficiency of buildings and infrastructure	☒	☒	☑	LCA study not yet available
Supply chain	Birgisdóttir H. (2005). Life cycle assessment model for road construction and use of residues from waste incineration. Ph.D. Thesis. DTU University	☑	☑	☑	
	Olsson S., Kärrman E. & Gustafsson J.P. (2006). Environmental systems analysis of the use of bottom ash from incineration of municipal waste for road construction, Resources, Conservation and Recycling 48,pp. 26–40	☑	☑	☑	
	Birgisdottir H., Bhander G., Hauschild M.Z., Christensen T.H. (2007). Life cycle assessment of disposal of residues from municipal solid waste incineration: Recycling of bottom ash in road construction or landfilling in Denmark evaluated in the ROAD-RES model. Waste Management 27, pp. S75-S84	☑	☑	☑	
	Carpenter A.C., Gardner K.H., Fopiano J., Benson C.H., Edil T.B. (2007). Life cycle based risk assessment of recycled materials in roadway construction. Waste Management 27, pp. 1458-1464	☑	☑	☑	
	Carpenter A.C., Gardner K.H.(2009). Use of Industrial By-Products in Urban Roadway Infrastructure Argument for Increased Industrial Ecology. Journal of Industrial Ecology, 13 n. 6, pp. 965-977	☑	☑	☑	
	Korre A. and Durucan S. (2009). Life Cycle Assessment of Aggregates. WRAP Report (EVA025)	☑	☑	☑	
	Blengini G.A. and Garbarino E. (2010) Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. Journal of Cleaner Production 18, 1021–1030	☑	☑	☑	
	Chowdhury R., Apul D., Fry T. (2010). A life cycle based environmental impacts assessment of construction materials used in road construction. Resources, Conservation and Recycling 54, pp. 250–255	☑	☑	☑	

3.1.1.2.3 Qualitative scoring and summary of the selected LCA studies

Quality of 35 LCA studies satisfying the presented quality cut-off criteria have been analysed comprehensively using the screening criteria presented in *Annex III Table III.4*. Five studies refer to the transport sector, 22 deal with the LCA of a road infrastructure while 8 deal with the LCA of the supply chain of construction materials, especially considering the employment of recycled/secondary materials and by-products.

The complete results of the LCA studies literature review are reported in *Annex III LCA literature review*. Studies obtaining an overall score above 15 have been considered to present a satisfactory level of quality and relevance to this study. Of those that passed, 20 LCA studies were about road infrastructure (see Table 3.4) and 7 LCA studies were focussed on the supply chain (see Table 3.5).

Table 3.4: Selected LCAs studies on road infrastructure

LCAs on road infrastructure
Loijos A., Santero N., Ochsendorf J. (2013). Life cycle climate impacts of the US concrete pavement network. Resources, Conservation and Recycling 72, 76–83
Santero NJ, Horvath A. (2009) Global warming potential of pavements. Environ Res Letts;4:034011
Santero N.J., Masanet E., Horvath A. (2011). Life-cycle assessment of pavements. Part I: Critical review. Resources, Conservation and Recycling 55, pp. 801–809
Wang T., Lee I-S., Kendall, Harvey, Lee E-B, Kim C. (2012). Life cycle energy consumption and GHG emission from pavement rehabilitation with different rolling resistance. Journal of Cleaner Production 33, 86-96
Wang T., Lee I-S., Kendall, Harvey, Lee E-B, Kim C. (2012). UCPRC Life Cycle Assessment methodology and Initial Case Study on Energy Consumption and GHG Emissions for Pavement Research Preservation Treatment with Different Rolling Resistance. Research Report: UCPRC-RR-2012-02 at the Pavement Research Center at the University of California
Barandica. J.M., Fernández-Sánchez G., Berzosa A., Delgado J.A. and Acosta F.J. (2013). Applying life cycle thinking to reduce greenhouse gas emissions from road projects. Journal of Cleaner Production 57 (2013), pp.79-91
Häkkinen T., Mäkele K. (1996). Environmental adaptation of concrete. Environmental impact of concrete and asphalt pavements. VTT Research notes 1752, 61 p. + app. 32 p.
Stripple H. (2001). Life Cycle Assessment of Road. A Pilot Study for Inventory Analysis. Second Rev. Ed.. IVL
Milachowski C., Stengel T. and Gehlen C. (2011). Life cycle assessment for road construction and use. EAPA on-line publication
Yu B., Lu Q. (2012). Life cycle assessment of pavement: Methodology and case. Transportation Research Part D 17, pp. 380–388
Sayagh S., Ventura A., Hoanga T., Franc D. & Jullien A. (2010). Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures, Resources, Conservation and Recycling, 54, 348–358
Wayman M., Parry T., Andersson-Sköld Y., Raaberg J., Bergman R., Enell A. and Huang Y. (2012). Life Cycle Assessment of reclaimed asphalt. Re-Road project. Deliverable 3.4
Carlson A. (2011). Life cycle assessment of roads and pavements. Studies made in Europe. VTI rapport 736A
Mroueh U-M., Eskola P., Laine-Ylijoki J. (2001). Life-cycle impacts of the use of industrial by-products in road and earth construction. Waste Management 21, pp. 271-277
Zhang H., Keoleian G.A. and Lepech M.D. (2008). An integrated life cycle assessment and life cycle analysis model for pavement overlay systems. Life-Cycle Civil Engineering, pp. 907-912
Mroueh U-M., Eskola P., Laine-Ylijoki J., Wellman K. (2000). Life cycle assessment of road construction. Finnish National Road Administration Finnra Reports 17/2000
Liljenström C. (2013). Life Cycle Assessment in Early Planning of Road Infrastructure. Application of The LICCER-model. Master of Science Thesis at KTH Royal Institute of Technology, Sweden
SUSCON National Technical University of Athens (2006). Life Cycle Assessment of Road Pavement. SUSCON LIFE05.
Huang Y., Bird R., Heidrich O. (2009). Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. Journal of Cleaner Production 17, pp. 283–296
ECRPD (2010). Energy conservation in road pavement design, maintenance and utilisation, Intelligent Energy Europe, Feb 2010

Table 3.5: Selected LCAs studies on the supply chain

LCAs on supply chain
Korre A. and Durucan S. (2009). Life Cycle Assessment of Aggregates. WRAP Report (EVA025)
Blengini G.A. and Garbarino E. (2010) Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. Journal of Cleaner Production 18, 1021–1030
Chowdhury R., Apul D., Fry T. (2010). A life cycle based environmental impacts assessment of construction materials used in road construction. Resources, Conservation and Recycling 54, pp. 250–255
Birgisdottir H., Bhander G., Hauschild M.Z., Christensen T.H. (2007). Life cycle assessment of disposal of residues from municipal solid waste incineration: Recycling of bottom ash in road construction or landfilling in Denmark evaluated in the ROAD-RES model. Waste Management 27, pp. S75-S84
Carpenter A.C., Gardner K.H.(2009). Use of Industrial By-Products in Urban Roadway Infrastructure Argument for Increased Industrial Ecology. Journal of Industrial Ecology, 13 n. 6, pp. 965-977
Olsson S., Kärrman E. & Gustafsson J.P. (2006). Environmental systems analysis of the use of bottom ash from incineration of municipal waste for road construction, Resources, Conservation and Recycling 48,pp. 26–40
Birgisdóttir H. (2005). Life cycle assessment model for road construction and use of residues from waste incineration. Ph.D. Thesis. DTU University

3.1.2 Life cycle phases

Many site-specific factors such as regional climate, local design practices, geological and geotechnical conditions, budget, service life, material availability, sensitivity of the local environment, daily traffic load, distribution between heavy vehicles and cars, rolling resistance and many other factors play a role in the choice of road type and in the design of the road construction.

Road constructions are thus a complex web of parameters which are tailored for each individual project. The complexity and diversity of road projects makes the assessment of potential environmental impacts challenging. The results of an LCA on road construction are related to the different design characteristics of the road project. A representative number of case studies have been assessed in an attempt to derive consistent conclusions.

A first outcome of the review of LCA studies is that the sources of the environmental impacts and their relative importance can vary greatly within a single phases of a roads life cycle. In general, a road life cycle can be divided into five phases, as shown in Figure 3.1:

1. **Materials production including raw materials extraction**. This phase consists of the processes needed to manufacture construction materials and products and includes the entire upstream supply chain needed to produce each material (for examples extraction and production of aggregates, refining of crude oil for the production of bitumen). Transportation needed to move pavement materials to and from production facilities and to the project site are included in this phase. Transportation distances can vary widely based on project location. Off-site equipment used in the materials production is accounted for in this phase. This phase also includes the employment of by-products, recycled/secondary materials and recovered waste materials.
2. **Construction**. This phase usually includes clearance of the construction site (removal of infrastructure and vegetation), earthworks including the possible construction of earth mounds, ground works including the stabilisation of the sub-grade, on-site equipment (as pavers, dozers, millers, etc.), construction of the pavement layers (see Section 1.1.3.1)), construction and laying of the drainage system, placement of road furniture (as traffic barriers, bollards, lighting systems, traffic lights, traffic signs etc.). An important consideration in the design of street furniture is how it affects road safety. This phase can also include other specific necessary activities during the entire period of the on-site construction works, such as remediation of polluted soil and ground water, protection of wildlife, winter precautions, etc..
3. **Use**. This phase includes the daily traffic on the road pavement and thus vehicle fuel consumption during the road service life. It has to be considered that a pavement and its properties are only responsible for a fraction of the vehicle fuel consumption, namely those associated with its structural characteristics and surface texture (influencing the rolling resistance). The majority of fuel consumption is attributable to stages of vehicle life cycle that are independent from the road infrastructure. Therefore only the impacts that are caused by the pavement itself can be allocated to the road infrastructure. The use phase is a very significant life cycle stage from an environmental point of view. The possibility of affecting the environmental impacts during the design stages is reflected in this section.

   During the feasibility and overall planning stage when road alignment is evaluated and chosen, the length of the road construction is the most important parameter reflected in the use of fuel for the vehicles using the road. Examples are alignments of road constructions from point A to point B. At the feasibility stage there may be several alternatives of varying lengths. The alignments and many other decisions are assessed in the EIA. At this stage the length of the road is the most important parameter in the life cycle of a road construction because the fuel consumption causes the largest potential environmental impacts. When the alignment of the road has been decided upon, the following stages (conceptual, preliminary and detailed design) of the road construction will ultimately influence fuel consumption too.

   Fuel consumption is affected by rolling resistance, weather conditions (wind, snow, rain etc.), weight of the vehicle, types of tyres, engine size and aerodynamic performance etc. As traffic in terms of vehicle types is not within the scope of this report, emphasis is placed on the aspects most relevant to GPP for road construction. These are primarily the rolling resistance of the road surface and the choice of materials and the construction methods.
4. **Maintenance (and operation)**. This phase runs in parallel with the use phase, ending when the road is decommissioned. Some maintenance operations share the same materials, and hence impacts, with the

construction phase. In detail, it typically includes repair (for example filling potholes in the surface), rehabilitation (resurfacing and sealing of entire sections of road surface), winter maintenance (de-icing, road salting/gritting) and substitution of lighting or road furniture elements.

5. **End-of-life (EoL).** In this phase it is possible to include EoL of pavements and EoL of the road itself. In EoL of pavements, recycling is handled through a materials feedback loop during maintenance (for example reclaimed asphalt pavements RAP). With reference to the EoL of entire road sections, it has to be considered that a road is not usually entirely demolished and removed. For example, if a new road with a different alignment substitutes an old road, this latter one is usually downgraded (change in classification) to a lower level of importance with reduced traffic volume. In this case new materials are used for refurbishment to expand the service of the road construction.

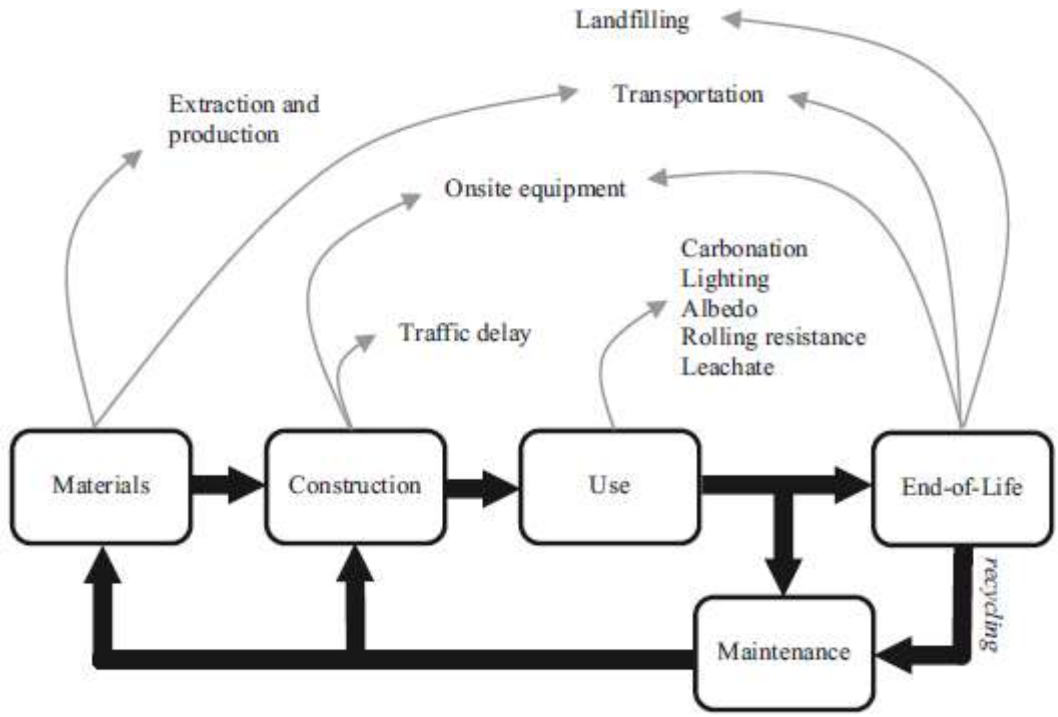


Figure 3.1: Phases and components of a road life cycle (according to Santero et al., 2011a)

A general conclusion from the LCA literature review is that each phase of the road life cycle includes various components, that each represent a unique interaction between the road and the wider environment. According to Santero and Horvath (2009) the impacts from road infrastructure extend far beyond the materials production, construction and maintenance phases (as a repeated sequence of operations), as it is usually evaluated. Other aspects should be also included, such as:

- Congestion: specifically traffic delays that occur when construction and maintenance activities change the normal flow of traffic (e.g., lane closures, detours). The impact from congestion can be measured as the difference between conditions under "normal" circumstances and those when construction/maintenance activities take place. Congestion varies widely based on location and time of day (e.g. traffic volume, capacity) and pavement design parameters (e.g. frequency of necessary maintenance operations).
- Vehicle-pavement interaction: the rolling resistance (related to the pavement structure and roughness) is one of the forces resisting vehicle movement. Both the pavement structure and the pavement roughness affect the rolling resistance, thus altering the fuel consumption, and thus GHG, of vehicles. Rolling resistance is linked to three main factors:
  - Roughness (evaluated by means of the International Roughness Index IRI),
  - Structure: macrotexture measured as mean profile depth (MPD) for asphalt pavements or mean texture depth (MTD) for concrete pavements.

- Deflection: describes the movement of the pavement surface due to traffic loading. Two aspects are associated with deflection and rolling resistance: the fact that traffic load creates a bowl in the pavement surface, which requires more fuel to pass and energy dissipation in an asphalt pavement. The relationship between pavement deflection and rolling resistance are still being researched.

- Concrete carbonation: a naturally occurring phenomenon that occurs in concrete pavements where a portion of the atmospheric CO_2 is sequestrated. The carbonation rate varies based on the permeability of concrete, relative humidity, temperature and exposure to the atmosphere.

- Pavement albedo: basically the solar reflectance capacity of a pavement. Solar reflectance values range from 0 (indicating a perfectly non-reflective material) to 1 (if material is totally reflective). Solar reflectance has the greatest importance in urban areas as it is known to contribute to the formation of urban heat islands (local areas of elevated temperature located in a region of cooler temperatures). According to Taylor et al. (2012), pavements with higher albedo reduce Global Warming by mitigating the urban heat island effect and by increasing the radiative forcing of the surface. It is also relevant to evaluate the effect of pavement albedo on the reduction of the need for lighting.

According to Santero et al. (2011a), the above-mentioned elements are rarely fully incorporated into a road LCA and their allocation rules are under discussion in the scientific literature. Nevertheless, several Authors have suggested that these omitted elements could have significant impacts on the overall road life cycle. For example, according to Santero and Horvath (2009), rolling resistance and congestion could be orders of magnitude more important than construction materials and equipment. Therefore, it is suggested to evaluate a road infrastructure by means of a more comprehensive approach, trying to account for all interactions between pavements and the environment. The scale of the project is also relevant in order to decide to what extent to include these aspects. For example with projects at macro level it would be advisable to include aspects as lighting, carbonation and other components; at micro level decision, such as the comparison of two construction products, the exclusion of these aspects could be justifiable (EC, 2010).

Moreover, the inclusion or exclusion of different life cycle phases of a road construction is still under discussion in the scientific literature. For example, the PCR on "UN CPC 53211 Highways (except elevated highways), streets and roads" (ENVIRONDEC, 2013) have excluded the use phase from the LCA of the road infrastructure (see the flowchart at Figure 3.2).

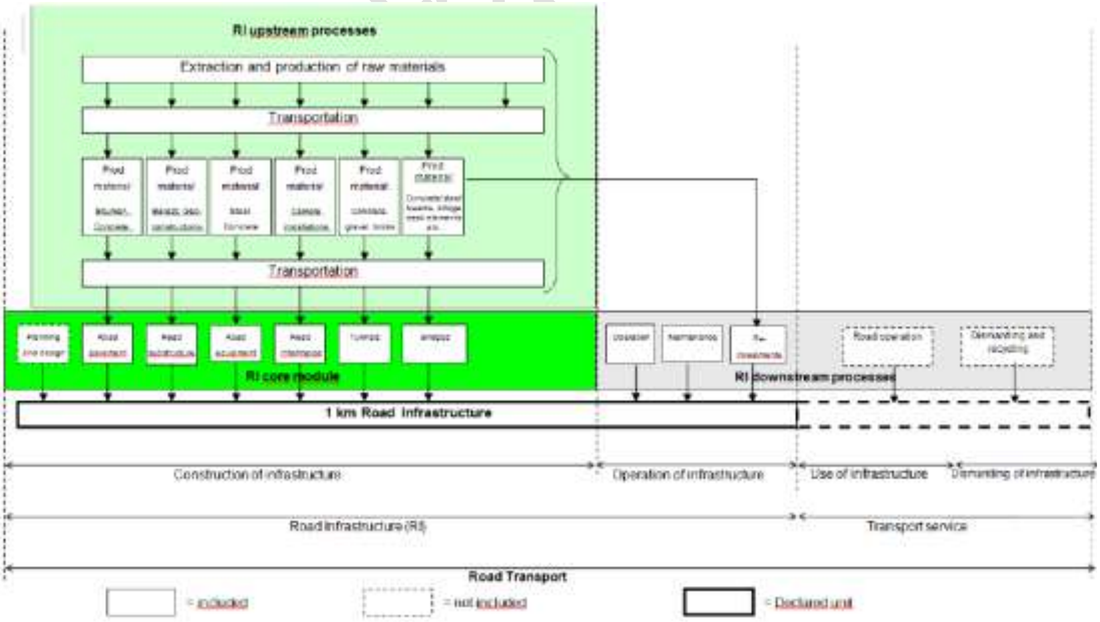


Figure 3.2: Flowchart of the product system for road infrastructure (ENVIRONDEC, 2013)

Via the LCA screening process, we have tried to analyse in a critical way all the life cycle phases of a road infrastructure, trying to identify the key environmental areas for the development of GPP criteria.

All of the life cycle phases for road construction have been considered important for the analysis and description of the technical/environmental aspects and the improvement potentials. Thus, these phases are also relevant to consider in relation to development of GPP criteria.

The GPP criteria should be developed with an approach to make it simple for the public authorities to obtain large environmental gains via the procurement process. Since environmental impacts occur in all phases, but can be influenced differently during the feasibility study, the conceptual design or the detailed design, it is desirable to focus GPP criteria on those specific aspects with the largest environmental benefits at the design and planning phases throughout the life cycle of a road construction. This approach will require some specific GPP criteria for the planning and design stages as well as some general criteria.

3.1.3 Assumptions in the selected LCA studies

3.1.3.1 Scope and method

As summarised in Table 3.6, the analysed LCA studies differ in scope and method, due to the fact that specific rules have not been yet developed for this sector. Three studies have provided a review of existing LCAs on roads and pavements (Carlson, 2011- European sub-project 3 in MIRIAM: "Life cycle assessment of roads and pavements – studies in Europe"; Santero et al., 2011a; Barandica et al., 2013) and the selection of literature in the current review has been inspired by them.

Several authors have investigated the need of expanding the current view of the LCA of road pavements to other aspects such as rolling resistance and congestion (Santero and Horvath, 2009; Loijos et al., 2013). A large number of papers assess the environmental impacts of asphalt and concrete road pavements (Häkkinen and Mäkelä, 1996, Stripple, 2001, SUSCON, 2006, ECRPD, 2010, Milachowski C. et al. 2011). Other authors have analysed the sustainability of pavement overlays and maintenance strategies (Zhang et al., 2008, Huang et al., 2009, Yu and Lu, 2012; Wang et al., 2012a; Wang et al., 2012b). Furthermore, papers analysing the sustainability of the supply chain of construction materials have also been considered, particularly for comparing the use of conventional materials, by-products and recycled and secondary materials (Mroueh et al., 2000, Mroueh et al., 2001; Birgisdóttir, 2005; Olsson et al., 2006; Birgisdóttir et al., 2007; Carpenter et al., 2007; Carpenter and Gardner, 2009; Korre and Durucan, 2009; Blengini and Garbarino, 2010; Chowdhury et al., 2010; Sayagh et al., 2010). Finally, one paper has evaluated the recycling of reclaimed asphalt pavement at the EoL stage (Wayman et al., 2012).

Table 3.6: Scope and methods of the selected LCA studies

References	Asphalt pavement	Concrete pavement	Alternative materials	Maintenance and rehabilitation strategies
Häkkinen and Mäkele, 1996	SMA	PCC		2-3 grindings for concrete
Mroueh et al., 2000	HMA		FA,CC, BFS	
Mroueh et al., 2001	HMA		FA, CC,BFS	
Stripple, 2001	HMA CMA	PCC		
SUSCON, 2006	HMA			
Zhang et al., 2008		PCC		3 overlay systems: PCC – HMA - ECC
Huang et al., 2009	HMA			Effects of speed of delivery of the roadworks
Santero and Horvath, 2009				
ECRPD, 2010	HMA + application of adhesion layer (tack coat)			- hot method recycling in asphalt plant - hot in place method of recycling
Sayagh et al., 2010			BFS	
Milachowski C. et al. 2011	MA – PA	PCC	Recycled materials for frost blanket	SMA – PA tc - EAC
Yu and Lu, 2012		PCC		3 overlay systems: PCC – HMA - CSOL
Wang et al., 2012a	HMA – RHMA	PCC - CSA		CAPM with HMA or RHMA CPR with PCC or CSA
Wang et al., 2012b	HMA – RHMA	PCC - CSA		CAPM with HMA or RHMA CPR with PCC or CSA
Wayman et al., 2012	SMA		RAP	
Loijos et al., 2013		PCC		
Supply chain				
Birgisdóttir, 2005			MSWI	
Olsson et al., 2006	HMA		MSWI	
Birgisdóttir et al., 2007			MSWI	
Carpenter and Gardner, 2009			FA, foundry slag, and sand	
Korre and Durucan, 2009			RA, CC, Rasphalt	
Blengini and Garbarino, 2010			RA	
Chowdhury et al., 2010			FA, BA	

Abbreviations:

FA fly ash BA bottom ash CC crushed concrete BSF blast furnace slag RAP reclaimed asphalt pavement MSWI municipal solid waste incineration bottom ash RA recycled aggregates Rasphalt	HMA hot mix asphalt SMA stone mastic asphalt MA mastic asphalt CMA cold mix asphalt PA porous asphalt RHMA Rubberized HMA	PCC Portland cement concrete CSOL crack, seat and overlay ECC engineered cementitious composite tC pavement with textured surface EAC exposed aggregate concrete surface layer CSA calcium sulpho-aluminate cement concrete	CAPM: Capital Preventive Maintenance asphalt overlay CPR: Concrete Pavement Restoration

3.1.3.2 Functional units

As can be seen in Table 3.7, the functional units used in the reviewed LCAs studies show a lot of variability. Usually a unit of 1 km per average service life is used. The papers related to the supply chain usually refer to a functional unit of 1 ton of material.

Table 3.7: Functional units in the reviewed LCAs studies

References	Functional unit	Location	Service life (year)	Width (m)	Traffic (AADT)
Häkkinen and Mäkele, 1996	1 km motorway	Finland (Tampere)	50	8.5	20,000
Mroueh et al., 2000	1 km motorway	Finland	50	12	7,000, 14% heavy
Mroueh et al., 2001	1 km motorway	Finland	50	12	7,000, 14% heavy
Stripple, 2001	1 km road	In Sweden	40	13	5,000
SUSCON, 2006	1 km urban road	Cyprus	50	12	
Zhang et al., 2008	10 km freeway Overlays: PCC - HMA - ECC	US	20-20-40		70,000, 8% heavy
Huang et al., 2009	2.6 km dual carriageway	UK	40	7 (**lane**)	different in the 2 carriageway 12,410 - 14,083 (**per lane**)
Santero and Horvath, 2009	1 lane-km	US	50	3.6 (**lane**)	
ECRPD, 2010	1 km motorway 1 km dual carriage 1 km wide single carriageway 1 km single carriageway	Czech Republic, France, Ireland, Portugal, Sweden		9.5 11.5 25.5 27.5	20,500, 41% heavy 18,500 30% heavy 15,500, 25% heavy 7,500, 12% heavy
Sayagh et al., 2010	1 km pavement		30	3.5	
Milachowski C. et al. 2011	1 km motorway	Germany	30	2 lane on each carriageway	52,000, 19% heavy
Carlson, 2011	functional unit of each reviewed paper	EU			
Santero et al., 2011a	functional unit of each reviewed paper	US			
Yu and Lu, 2012	1 km of overlay system PCC, HMA,CSOL	US , Florida	16-16-16	11.1	70,000, 8% heavy growth of 4% a year
Wang et al., 2012a	16.1 km of rural road, 2 lanes, flat, HMA/RHMA 8 km of rural road, 4 lanes, flat, HMA/RHMA 16.1 km rural road, 2 lanes, flat, PCC 8 km rural road, 2 lanes, flat PCC	US, California	5 5 10 10		34,000, 35% trucks 3,200, 15% trucks 86,000, 25% trucks 11,200, 29% trucks
Wang et al., 2012b	16.1 km of rural road, 2 lanes, flat, HMA/RHMA 8 km of rural road, 4 lanes, flat, HMA/RHMA 16.1 km rural road, 2 lanes, flat, PCC 8 km rural road, 2 lanes, flat PCC	US, California	5 5 10 10		34,000, 35% trucks 3,200, 15% trucks 86,000, 25% trucks 11,200, 29% trucks
Wayman et al., 2012	1 m^2 highway, 1 lane	EU	60		
Barandica et al. 2013	30.36 km highway, 4 lanes 9.7 km highway, 2-4 lanes 6.2 km highway 4 lanes 29.2 km conventional road, 2 lanes	Spain	50		
Loijos et al., 2013	1 km, 12 different traffic loadings Rural roads (interstate, arterial, collector, local) Urban roads (interstate, expressway, arterial, collector, local)	US	40 (rehabilitation at 20 and 30)		177-22,074 980-78,789 s
Liljenström, 2013					
Supply chain					
Birgisdóttir, 2005	4,400 t ash (1 km road)	Denmark	100	17.25	
Olsson et al., 2006	1 km road	Sweden			
Birgisdóttir et al., 2007	4,400 t ash (1 km road)	Denmark	100	17.25	
Carpenter and Gardner, 2009	1-tonne-km				
Korre and Durucan, 2009	1 t of material				
Blengini and Garbarino, 2010	1 t of material				
Chowdhury et al., 2010	1 km long section		20-100-infinity	2.5	
HMA hot mix asphalt PCC Portland cement concrete	CSOL crack, seat and overlay ECC engineered cementitious composite				

The following comments can be made regarding the contents of Table 3.7:

- Different types of road are evaluated, including motorways, highways and main national roads, secondary or regional roads or other roads (urban and rural). This is also reflected in the traffic level (AADT average annual daily traffic) and is considered in each study.
- The service life of the road infrastructure usually varies from 30 to 50 years.
- When maintenance operations are investigated, the service life of the pavement overlays varies in relationship to road type and materials. In the reviewed papers, a service life of asphalt overlays vary from 5 to 20 years and a service life of concrete overlays vary from 10 years to 20 years with reference to the different characteristics of the projects. Maintenance and rehabilitation strategies are related to the practices of relevant road directorates and public authorities and on local conditions.

3.1.3.3 System boundaries

The system boundaries analysed in the reviewed LCA studies are summarized in Table 3.8.

Table 3.8: System boundaries in the reviewed LCAs studies

References	Production (including raw materials extraction)		Construction				Use						Maintenance				End of life	
	Production	Transportation	Earthworks	Pavement	Road equipment (barriers, road markings, traffic signs)	Congestion	Traffic (general values)	Rolling resistance	Carbonation	Lighting	Albedo	Leaching	Repair	Rehabilitation	Road equipment (barriers, road markings, traffic signs)	Congestion	On site	Transportation
Häkkinen and Mäkele, 1996	•	•		•			•		•	•				•		•		
Mroueh et al., 2000	•	•	•	•			•							•				
Mroueh et al., 2001	•	•	•	•			•							•				
Stripple, 2001	•	•	•	•	•		•			•			•	•	•			
SUSCON, 2006	•	•	•	•	•								•	•	•		•	
Zhang et al., 2008	•	•		•				•						•		•	•	
Huang et al., 2009	•	•		•		•		•					•	•		•	•	
Santero and Horvath, 2009	•	•		•		•		•	•	•	•			•		•	•	
ECRPD, 2010	•			•										•				
Sayagh et al., 2010	•	•		•														
Milachowski C. et al. 2011	•	•		•				•						•				
Yu and Lu, 2012	•	•		•		•		•	•		•			•		•	•	•
Wang et al., 2012a	•	•		•				•					• °	• °				
Wang et al., 2012b	•	•		•				•					• °	• °				
Wayman et al., 2012	•	•		•										•			•	•
Barandica et al. 2013	•		•	•					•	•				•				
Loijos et al., 2013	•			•		•		•	•	•	•			•		•	•	
Liljenström, 2013	•		•	•	•		•			•			•	•			•	
Supply chain																		
Birgisdóttir, 2005	•	•		•								•		•				
Olsson et al., 2006	•	•										•						
Birgisdóttir et al., 2007	•	•	•	•								•		•				
Carpenter and Gardner, 2009	•	•																
Korre and Durucan, 2009	•	•															•	•
Blengini and Garbarino, 2010	•	•															•	•
Chowdhury et al., 2010	•	•																
	°	Excluded routine maintenance																

Raw material extraction / materials production processes are the only components taken into consideration in each paper. Material transportation is less studied; but is still included in several studies (21/25). The construction of the road pavement is accounted for in most of the studies. Six papers consider congestion (Häkkinen and Mäkelä, 1996; Zhang et al., 2008; Huang et al., 2009; Santero and Horvath, 2009; Yu and Lu, 2012 and Loijos et al., 2013).

The use phase is considered in 12 papers. 4 of which include fuel consumption and emissions from the traffic over the road pavement, but providing absolute values (Häkkinen and Mäkele, 1996; Mroueh et al., 2000; Mroueh et al., 2001; Stripple, 2001). These values reflect the total traffic rather than the interaction between the pavement surface and the vehicle. The other 8 papers consider rolling resistance during the use phase and some of these (Zhang et al., 2008; Huang et al., 2009; Santero and Horvath, 2009; Milachowski C. et al., 2011; Yu and Lu, 2012; Wang et al., 2012a; Wang et al., 2012b; Loijos et al., 2013). Some of the papers discuss other components such as albedo, carbonation and lighting (Häkkinen and Mäkele, 1996; Stripple, 2001; Santero and Horvath, 2009; Yu and Lu, 2012; Loijos et al., 2013).

Although included in more than two-thirds of LCA studies, pavement maintenance could be far more complicated than a series of simple procedures that are repetitively carried out over the service life. Maintenance has the potential to be a significant contributor to the overall environmental impact. Accurately forecasting future maintenance and restoration strategies is a challenging task, as it is investigated in 5 papers (Zhang et al., 2008, Huang et al., 2009, Yu and Lu, 2012; Wang et al., 2012a; Wang et al., 2012b).

3.1.3.4 Emissions inventory data and impact categories

Several reviewed studies were found to contain only life-cycle inventories (LCIs) of the emissions and do not provide a complete impact assessment LCIA (see Table 3.9).

Each of the reviewed papers contains energy consumption as a metric for the evaluation of the environmental impacts of a pavement. Nine studies added an inventory of various conventional air pollutants (e.g. SO_2, NO_X, CO, particulate matter), and another 10 added GHGs. Seven studies report environmental impacts not directly associated with energy consumption or air emissions, including nitrogen releases into water, hazardous waste generation, heavy metal releases, and other environmental indicators.

Other studies have considered impact categories, mainly according to CML2001 (Institute of Environmental Sciences, University of Leiden, 2002) (Table 3.10) and few according to EDIP97 (Table 3.11), as it has been discussed in paragraph 3.1.2.1. Global Warming is included in all these studies; about 50% of them consider also acidification, photochemical ozone formation and eutrophication.

Table 3.9: Emissions inventory in the reviewed LCAs studies

References	Energy consumption	Feedstock	GHG			NO_x	SO_2	CO	VOC	PM	HC	Other
			CO_2	CH_4	N_2O							
Häkkinen and Mäkele, 1996	•	•	•			•	•	•	•			Heavy metals, waste generation, water releases, dust, noise (land use)
Mroueh et al., 2000	•		•			•	•	•	•	•		Heavy metals (As, Cd, Cr, Cu, Mo, Ni, Se, Pb, Zn), waste generation, resource use, effluents to water bodies, leaching into land, Cl, SO_4-- land use, noise and dust
Mroueh et al., 2001	•		•			•	•	•	•	•		Heavy metals (As, Cd, Cr, Cu, Mo, Ni, Se, Pb, Zn), waste generation, resource use, effluents to water bodies, leaching into land, Cl, SO_4-- land use, noise and dust
Stripple, 2001	•	•	•			•	•					
Zhang et al., 2008	•	•	•	•	•							
Huang et al., 2009	•		•			•		•		•	•	Aggregates, bitumen, solid waste
ECRPD, 2010	•											
Yu and Lu, 2012	•	•	•	•	•	•	•	•	•	•		
Liljenström, 2013												
Supply chain												
Olsson et al., 2006	•		•	•	•	•	•	•	•	•	•	emission to water (COD, N-tot, Oil, Phenol, As, Cd, Cr, Cu, Ni, Pb and Zn), natural aggregates
Carpenter and Gardner, 2009	•		•	•	•	•	•	•		•		Hg, Pb, Hazardous Waste, human toxicity potential (HTP) cancer HTP non cancer (Horvath 2004)
Sayagh et al., 2010	•		•	•		•	•		•			NMGOC, HCl, HF, COD, metals

Human toxicity and eco-toxicity are relevant impact categories particularly when assessing the environmental impacts of the use of recycled/secondary materials or by-products in road construction, particularly where MSWI bottom ash is considered.

Table 3.10: Impact categories (CML2001) in the reviewed LCAs studies

	Energy consumption	LCIA according to CML2001 and GWP according to IPPC, 2007													Normalization	Weighting
		GWP 100 years	AP	POCP	EP	ODP	ADP	HTP	FAETP	MAETP	TETP	RAD	FSETP	Land-use		
SUSCON, 2006	•	•	•	•	•	•	•	•	•	•	•	•				• Env.. Score
Santero and Horvath, 2009	•	•														
Milachowski C. et al. 2011	•	•	•	•	•	•										
Wang et al., 2012a	•	•														
Wang et al., 2012b	•	•														
Wayman et al., 2012	•	•	•	•	•	•	•	•	•	•	•				•	
Barandica et al. 2013	•	•												•		
Loijos et al., 2013	•	•														
Supply chain																
Korre and Durucan, 2009	•															
Blengini and Garbarino, 2010	•															
Chowdhury et al., 2010	•	•	•					•	•		•		•			
Abreviations:																

GWP 100 years Global Warming Potential AP Acidification Potential POCP Photochem. Ozone Creation Potential EP Eutrophication Potential	ODP Ozone Layer Depletion Potential AP Abiotic Depletion HTP inf.Human Toxicity Potential MAETP Marine Aquatic Ecotoxicity Pot.	FAETP inf. Freshwater Aquatic Ecotoxicity Pot. TETP Terrestric Ecotoxicity Potential RAD Radioactive Radiation FSETP Aquatic sediment ecotoxicity potential

Table 3.11: Impact categories (EDIP97) in the reviewed LCAs studies

	Energy consumption	LCIA according to EDIP97											Normalization	Weighting
		GW	AF	POF	NE	HTa	HTw	HTs	ETw	ETs	SETw	SETs		
Supply chain														
Birgisdóttir, 2005	•	•	•	•	•	•	•	•	•	•	•	•		
Birgisdóttir et al., 2007	•	•	•	•	•	•	•	•	•	•	•	•		

GW Global Warming impact POF PhotoChemical Ozone Formation NE Nutrient enrichment AF Acidification	HTa Human toxicity air HTw Human toxicity water HTs Human toxicity soil	ETw Ecotoxicity water ETs Ecotoxicity soil SETw Stored ecotoxicity water SETs Stored ecotoxicity soil

3.1.3.5 Closing remarks on the assumptions

According to Carlson (2011) and Santero et al., (2011a), it is impossible to perform straightforward comparisons of the results in reviewed LCA studies due to the differences in approach, scope, functional units, analysis periods, system boundaries, regional differences, input data (LCIs).

A common result is the conclusion that all roads are unique and have their own specific conditions, which means that a flexible method is needed that can be adjusted to suit the road that you want to study. Some papers have compared the use of primary and recycled/secondary materials in road construction, others the construction and maintenance of asphalt and concrete pavements.

Differences have been highlighted also in the service life and functional unit considered, as it has been summarised in Table 3.7.

Some authors have used different databases regarding the input data needed and some have gathered primary information from manufacturers. Differing electricity mixes, production practices, pavement designs, available materials, local maintenance practices, and other region-specific elements will create different results depending on the location under study. Moreover, data refers often to a single EU Member State or to a non-EU Country (i.e. US) and therefore, due to the local validity of these data, it has to be carefully evaluated if they can be applied to the whole of the EU or only to particular Member States.

The extents to which studies were carried out differed somewhat. Some of them make an inventory where resource use and emissions are presented; others have gone further by presenting the resulting environmental impacts of such emissions and resource use (see Table 3.9, Table 3.10, Table 3.11).

With reference to the toxicity impact categories, from a GPP criteria perspective, it appears more important to consider how local potential impacts related to toxicity (leaching from construction materials) could be controlled and mitigated during a road use phase. The main area of improvement is the optimisation of the water run-off and drainage system, in order to design effective leaching control and water management. These topics will be addressed in a specific paragraph (see paragraph 3.5.4) in the section related to impacts not detected by means of a LCA.

Feedstock of bitumen

Environmental impacts of bitumen need to be allocated amongst a multitude of petroleum products, such as gasoline, diesel, and plastic. Two potential allocation solutions could be proposed: the first uses mass and the second the economic value of the product. According to Wayman et al. (2012), a combination of the two methods could be used: allocation by mass could be applied to crude oil refining and transport and economic allocation could be applied once crude oil reaches the refinery.

Moreover, as a hydrocarbon, bitumen has a certain amount of feedstock (or inherent) energy associated with it. By ISO 14040 standards, this chemical energy needs be included in any energy assessment. There is active debate amongst the pavement LCA research community regarding the appropriate accounting technique and several authors seems suggesting that bitumen's feedstock energy is fundamentally different from embodied energy and thus should be treated differently from that of consumed energy and thus they have to be reported separately (Santero, 2011a).

3.1.4 Identification of key environmental impacts and hot-spots for road construction

As mentioned in the previous paragraph, it is impossible to compare the results of the reviewed LCA studies due to their differences in approach, functional units, boundaries and LCIs. The more important results of several papers will be summarised in order to provide evidence of how the main environmental hot-spots of road construction could be identified for the development of the GPP criteria. Reading the following summary paragraphs, one should bear in mind that all results are related to a specific project and they cannot be generalised. The challenging exercise consists of trying to draw some general conclusions to be used as a basis for the development of the GPP criteria.

The results of the literature review are fully reported in *Annex III.2 LCA Literature review*.

3.1.4.1 Key environmental impacts in the use phase

3.1.4.1.1 General consideration

The main environmental impacts arising from daily traffic during the use phase of a road are illustrated in Figure 3.3. Emissions related to road construction, maintenance and EoL may range from just a few per cent to typically 10-15% of total road life cycle emissions (Hill et al., 2012).

According to the study by Santero and Horvath (2009), a large range of impacts are possible for all the components of the pavement life cycle. These authors stated that greenhouse gas emissions could range from negligibly small values to 60,000 t of CO_2e per lane-kilometre over a service life of 50 years. Moreover, in the review by Barandica et al., (2013), the range of variation of the emissions of CO_2e is also provided (see Table 3.12). Additional results from the current LCA literature review have also been included in Table 3.13. Both literature reviews show a huge variability in results.

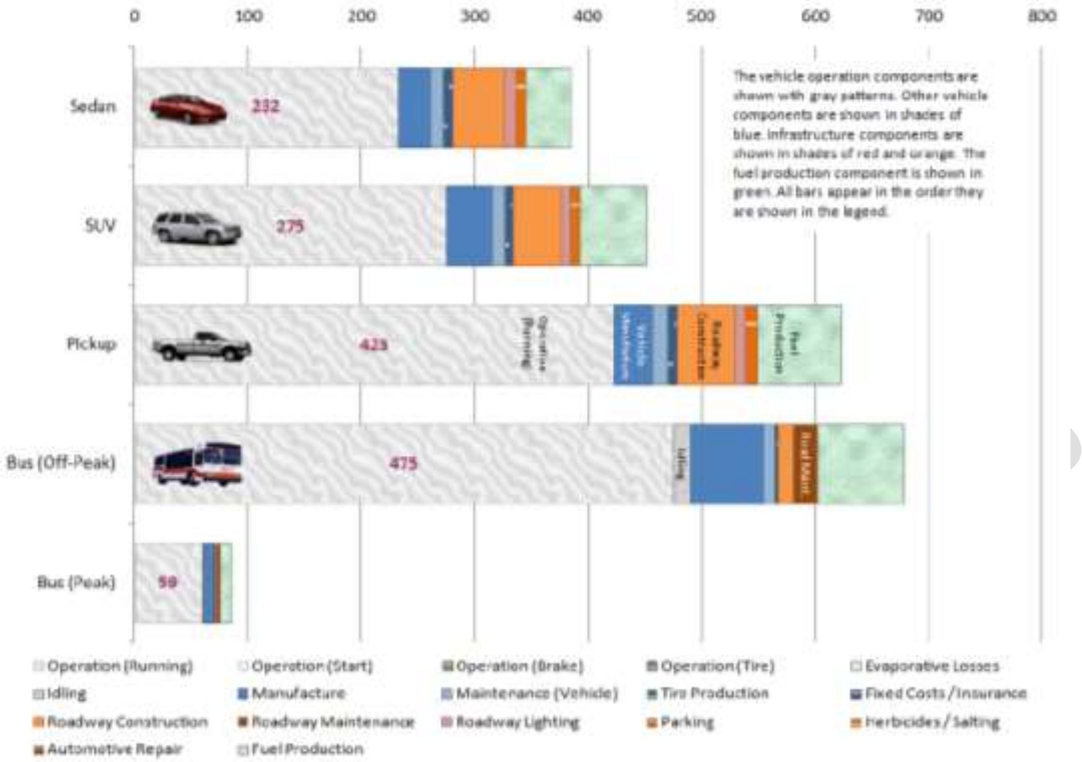


Figure 3.3: . Example of transport GHG Inventory (GHG emission in g CO2 e / person miles transported) (Chester, 2008)

Table 3.12: Results from the review of Barandica et al., 2013

Authors	Year	Life-cycle stages								Gas species					Other aspects			Results
		Material extraction and production		Transport	Construction		Maintenance		End of life	CO_2	CH_4	N_2O	Shown as CO_2e	Others	Lifespan (years)	Land use and land-use change	Concrete carbonation	tCO_2e/km
		Pavement	Others		Earthworks	Roadway	Preservation	Repair										
Mroueh	2000	•		•	•	•		•					•		50			297–300
Stripple	2001	•	•	•	•	•	•	•		•	•	•		•	40		•	2000–2500
Nisbet et al.	2000	•		•		•				•	•				40			n/d
Park	2003	•	•	•	•	•	•	•	•				•	•	20			8940
Treloar	2004	•				•	•						•		40			1632
Athena	2006	•		•		•		•		•	•	•	•		50			490–1266
Birgisdóttir et al.	2006	•	•	•	•	•	•	•					•	•	100			1755
SUSCON	2006	•		•	•	•	•	•					•	•	50			940
Garraín and Vidal	2008	•		•		•							•		40			1320–3760
Huang et al.	2009a	•		•		•	•	•					•	•	15			853–900
Huang et al.	2009b	•		•				•	•				•	•	–			284[a]
Chang et al.	2010												•		–			n/d
White et al.	2010	•		•		•							•		–			128–387
Weiland and Muench	2010	•		•		•		•					•	•	50			0.124–0.331[c]
Milachowski et al.	2011	•		•	•	•		•					•	•	30			2214–3093[b]
Loijos	2011	•		•		•	•	•	•				•		40		•	404–6500
Cass and Mukherjee	2011	•		•	•	•							•		–			1956–3436[b,c]
Huang et al.	2012	•		•	•	•		•					•		25			897–9626
Melanta et al.	2012	•		•	•	•							•		20	•		38 785
$CO_2NSTRUCT$	2011	•	•	•	•	•	•	•		•	•	•	•	•	50	•	•	8880–50 300

[a] Note that this study do not include the Construction stage. It is a rehabilitation project.
[b] Only counting road construction (1425–2821) and repair, traffic is not included in this value.
[c] A four lane road is assumed.

Table 3.13: Other results from our literature review

References	Functional unit	Service life	t CO_2e/km	Comments
Häkkinen and Mäkele, 1996	1 km motorway	50	560-940	construction and maintenance
Santero and Horvath, 2009	1 lane-km	50	Up to 60,000	
Milachowski et al., 2011	1 km motorway	30	230,905	including use phase
Yu and Lu, 2012	1 km of overlay system	16	636-1219	including use phase
Loijos et al., 2013	1 km, 12 different road categories	40	404-6670	

Ignoring potential effects of different road surfaces, absolute values of energy consumption and emissions during the use phase are up to 2 orders of magnitude higher than the other phases (i.e. materials production, construction, maintenance and EoL) (Häkkinen and Mäkele, 1996; Mroueh et al., 2000; Mroueh et al., 2001; Stripple, 2001; Huang et al., 2009; Milachowski C. et al., 2011) (see *Annex III Literature review*). It seems that 2 orders of magnitude is applicable to motorways (Häkkinen and Mäkele, 1996), while lower values are shown for local roads. For example, in the study of Stripple (2001), the use phase energy consumption from traffic is roughly evaluated in 229.2 TJ/km for 1 km of a local road over a service life of 40 years and results in a 1 order of magnitude increase in energy consumption compared to construction, maintenance and operation phases.

In other studies, the interaction between vehicle and pavement have been considered and allocated. For example, in the study by Milachowski C. et al. (2011), the evaluated impact categories (GWP, ODP, POCP, AP, EP) in the use phase are 1 order of magnitude higher than the construction and maintenance categories. The same results are presented in the study by Huang et al. (2009) with reference to energy consumption and CO_2 emissions.

3.1.4.1.2 Rolling resistance

According to the study by Santero and Horvath (2009) on pavement GWP, a large range of impacts are possible for all the components of the pavement life cycle.

Rolling resistance (associated to the pavement structure and roughness) has the highest-impact potential, while components, such as onsite equipment and carbonation, appear to be relatively small contributors to the overall impact, as shown in Figure 3.4. According to the results of this study, material types and volumes, their transportation, congestion (traffic delay), albedo and maintenance operations are important factors, even though they present a huge variability. The impact of an individual component varies in relationship to the project details (such as pavement location, structure) and to the traffic levels. Because of this variability and uncertainty, it is not possible to define which component has more impact than another overall.

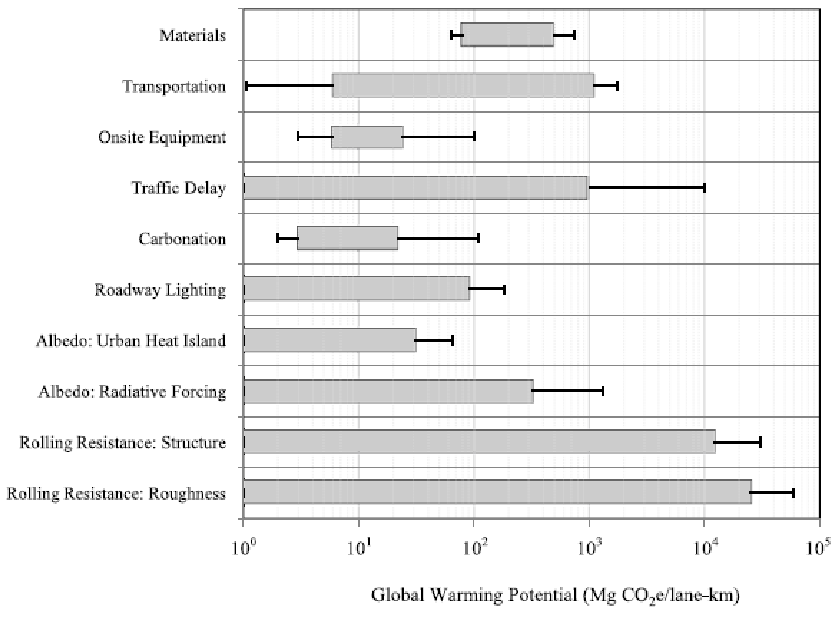


Figure 3.4: GWP impact ranges for components of the pavement life cycle (Santero and Horvath, 2009)

Note: Two ranges are provided: 1) variability of pavements: a probable range of values based on the best estimates (grey bars); 2) uncertainty: an extreme range of values based on outlying data and less likely scenarios (black lines)

3.1.4.1.3 Influence of the traffic flow and road categories

According to the LCA literature review, rolling resistance and congestion (traffic delay) are potentially the main components for high-traffic pavements (i.e. example motorways, highways, main national roads.), but their impacts diminish significantly for low traffic pavements (i.e. secondary and other roads). The categorization according traffic loading conditions, (i.e. traffic density and traffic composition), plays an important role in the results associated to rolling resistance.

For low-traffic roads, materials production and transportation have at least a comparable impact to that of rolling resistance (see Figure 3.5). The decrease in impact for rolling resistance would be even more pronounced if a very low- traffic road is considered. These results should be carefully taken into consideration in the development of the GPP criteria.

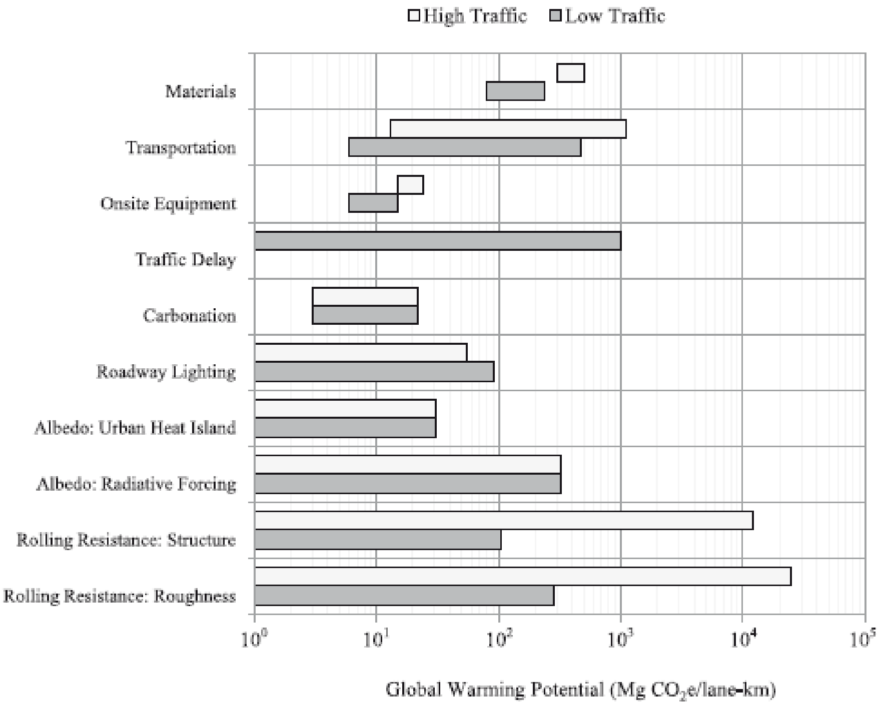


Figure 3.5: Comparison of GWP ranges for low and high-traffic pavements

Note: In this case, the low traffic scenario is modelled as 425 AADT, 8% heavy

3.1.4.1.4 Main results regarding the use phase from the reviewed studies

Rolling resistance associated with pavement structure and roughness appears to have the highest-impact potential. Häkkinen and Mäkele (1996) have evaluated that a reduction of vehicle fuel consumption of around 0.1-0.5% due to the concrete pavement properties would bring energy consumption savings of the same order of magnitude as those used for materials production and construction of a concrete pavement and savings in CO_2 emissions of 50% compared to those from materials production and construction of a concrete pavement.

Milachowski C. et al. (2011) have analysed 1 km of asphalt and concrete motorway over a service life of 30 years and they have considered different scenarios of decreases in fuel consumption due to road surface properties. They concluded that fuel consumption could be reduced by 5-20% when the road surface is optimized, i.e. with reduced unevenness (macro-texture) and increased stiffness. The authors provided examples of relationships between fuel consumption and impact categories, (see Table 3.14). The data in table show a directly proportion relationship between emissions and fuel savings of 0.5% or 2.0%, but emission savings were calculated to be much less when considering high fuel savings for heavy vehicles.

Table 3.14: Use phase scenarios for 1 km of motorways with a service life of 30 years presented in the study of Milachowski C. et al. (2011)

Scenario	**GWP**	**ODP**	**POCP**	**AP**	**EP**
	t CO_{2eq}	kg CFC_{11eq}	kg $C_2H_{4\text{-eq.}}$	kg $SO_{2\text{-eq.}}$	kg $PO_2^{\ 3-\text{-eq.}}$
Scenario A: Standard fuel consumption	230,905	29.84	167,980	1,066,521	202,078
Savings in the environmental impacts	(%)	(%)	(%)	(%)	(%)
Scenario B. 0.5% fuel savings	0.5	0.5	0.5	0.5	0.5
Scenario C: 2% fuel savings	2.0	2.0	2.0	2.0	2.0
Scenario D. 10% fuel savings for heavy goods vehicles	4.7	5.2	0.9	5.4	6.0

Wang et al., 2012a analysed energy consumption and GHGs emissions from pavement rehabilitation strategies. Furthermore, case studies are described in the study to evaluate the effect of rolling resistance on the life cycle performance of the selected pavement. Concrete and asphalt pavements are included in the study where the material production, construction, use (including rolling resistance) and maintenance phases of the road life cycle are addressed (see the functional unit in Table 3.7 and the literature review in Annex III.2).

It was concluded that traffic during the use phase dominates the life cycle impacts of a road construction with expected high traffic volume. The authors referred to studies indicating that a 10% reduction in the rolling resistance can lead to 1-2% improvement in fuel economy (Evans et al, 2009, Tiax et al, 2003 and Transportation Research Board, 2006). Furthermore, the paper identifies two main benefits of smooth pavements: reduced fuel consumption and slower rate of pavement deterioration. The latter also causes reduced materials consumption due to less need for maintenance and repair of the road surfaces.

The study also concluded that there a great potential for reduction of environmental impacts exists by reducing the roughness of the road surface to reduce rolling resistance on high-traffic roads (providing examples with 34,000, 86,000 and 11,200 AADT). For roads with less traffic volume the construction quality and the materials production become more important, due to the fact that the share of the potential environmental impacts from the use phase naturally becomes lower and because the total energy use from the traffic is lower due to reduced number of vehicles. No general rule can be given concerning the size of the potential environmental impacts caused in the use phase compared to the material and construction phases. Nevertheless an example is provided in the paper where a smaller road with 3,200 annual average daily traffic (AADT) is assessed. In this specific scenario, materials production and construction phase were calculated to be three times higher than the impacts during the use phase.

In Wang et al., 2012b, total energy use and GHG emissions from materials production, construction, use and maintenance are evaluated. The paper also evaluated the effects of changing road surface roughness and macro-texture on rolling resistance. Scenarios with low and high traffic volume are evaluated and the main results are listed below:

- It is concluded that for roads with high traffic volume, when the roughness and **macro-textures** were improved, the reduction in energy consumption and GHG emissions can be significantly larger than the emissions from materials production and construction. The reduced roughness contributed to the largest savings in energy consumption and GHG emissions.
- The authors include another parameter, i.e. the increase of **surface roughness**, and consequently of the rolling resistance, during the life cycle of the road. The relationship between roughness and surface texture is described to be as follows: the most important factor for the fuel consumption is the surface roughness. An increase in International Roughness Index (IRI) of 1 m/km will increase the fuel consumption of passenger cars by about 2%, independent of velocity. For heavy trucks, this increase is about 1% at normal highway speed (96 km/h) and about 2% at low speed (56 km/h). The third pavement factor to influence rolling resistance is **deflection**, but the authors excluded this factor from the study because relations between pavement deflection and rolling resistance are still being researched.
- For roads with low traffic volume the share of impacts from the use phase is reduced overall compared to the impacts from the material production and construction phases.

Loijos et al. (2013) have analysed the Global Warming Potential (GWP) of 1 km of concrete pavement for 12 different structures of the US roadway network (from interstate to local roads in rural and urban areas) over a service life of 40 years (functional units are summarised in Table 3.7). In this study, vehicle fuel consumption has been allocated to the pavement based on roughness increase over the life cycle. Thus, the pavement roughness at initial construction is taken as baseline parameter, and GHG emissions from fuel consumption are calculated based on the progressive increase from that initial roughness. This means that only the fraction of rolling resistance due to the increase of roughness, not its whole amount during the life cycle, is evaluated.

- The authors found that the majority of emissions occur during materials production and transportation (64%-80% on all roads) (see Figure 3.6). In particular, cement production has the largest GWP contribution on all roads: from 43% on urban interstates to 56% on rural local roads.
- The second largest contribution derives from fuel consumed due to the increase of the rolling resistance for high traffic roads (both rural and urban). For local roads (both rural and urban) EoL disposal was the

third largest contribution. In the analysed case studies, congestion (traffic delay) and construction activities were less important.

- A sensitivity analysis has shown that the results were most sensitive to traffic flow (varying the results by up to 60%), design parameters affecting cement emissions (i.e. shoulder width, lane width), aggregate transport distances and the pavement roughness value. From smaller to larger roads the results become more sensitive to rolling resistance. For smaller roads pavement design characteristics, carbonation, albedo and aggregates transportation are more important.

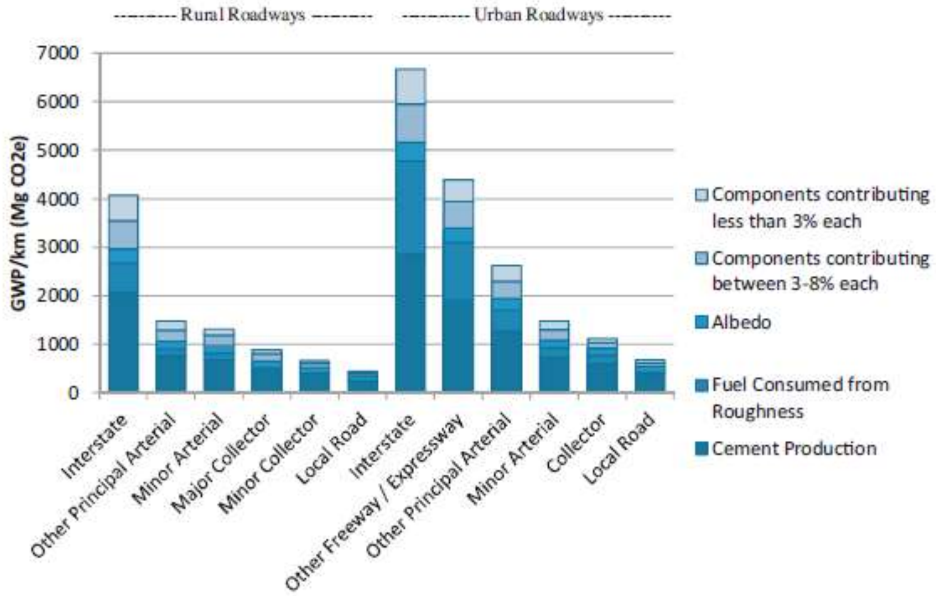


Figure 3.6: Life-cycle GWP per km of new concrete pavements for 12 roadway classifications (Loijos et al., 2013)

3.1.4.1.5 Hot-spots identified in the use phase

Depending on project-specific features and the traffic levels, the following conclusions can be drawn:

- Rolling resistance generally has the highest impact potential.
- Congestion (traffic delay) are more relevant for motorways and highways
- Materials production and transportation is the third most important aspect to be taken into consideration, but is more important in lower traffic volume roads.

With regards to rolling resistance, the main points from the literature are:

- According to Milachovski et al. (2010), savings in fuel consumption in the use phase of 0.5% and 2% could bring the same order of savings in global warming, ozone depletion, photochemical ozone potential, acidification and eutrophication.
- According to Wang et al., (2012a), a 10% reduction in rolling resistance could lead to 1-2% of improvement in fuel economy.
- Smooth pavements decrease rolling resistance and present a lower rate of pavement deterioration.
- A preliminary relationship between roughness and fuel consumption is provided by Wang et al. (2012b): increase in International Roughness Index (IRI) of 1 m/km will increase the fuel consumption of passenger cars by about 2% (not depending on the speed). For heavy trucks, this increase is about 1% at normal highway speed (100 km/h) and about 2% at low speed (50 km/h) (Wang et al., 2012b)

An important factor is the influence of traffic volume on the relative importance of the identified hot-spots:

- In high traffic roads, rolling resistance and congestion have the highest impacts on energy consumption and emissions.
- In low traffic roads: higher impacts on energy consumption and emissions come from materials production, transportation, albedo and carbonation rather than from rolling resistance and congestion. The relative importance of materials production and transportation increases with the decrease of the traffic volume. Therefore, materials production and transportation is extremely relevant for local roads (urban and rural).

3.1.4.2 Key environmental impacts during the construction phase - including materials production

In this section the main outcomes of the LCA literature review on materials production, construction and maintenance are presented, bearing in mind each of their unique aspects (see Table 3.6 on scope, Table 3.7 on functional units and Table 3.8 on boundaries).

3.1.4.2.1 General consideration

In general, excluding the use phase, the second largest impacts are in the construction phase (including materials production), while maintenance shows a lower impact (Häkkinen and Mäkele, 1996; Mroueh et al., 2000; Stripple, 2001; Milachowski et al., 2011; ECRPD, 2010). It has to be underlined that in these cases, maintenance is simply modelled as a sequence of routine (construction) activities. All the results of the literature review are reported *in Annex III.2*.

Some examples coming from the single studies are summarised as following:

- According to Mroueh et al. (2000), in their case studies, maintenance has less importance than construction (see Table 3.15).

Table 3.15: Average distribution of energy consumption and emissions in the construction and maintenance phases in the study of Mroueh et al. (2000)

		Construction	Maintenance
Energy consumption	(%)	81-89	11-19
CO_2	(%)	89-94	6-11
NO_X	(%)	95-96	4-5
SO_2	(%)	99	1
CO	(%)	97-98	2-3

- Milachowski et al. (2011) have also analysed the impacts of the construction and maintenance phases of 1 km of asphalt and concrete motorway over a service life of 30 years, excluding the use phase and have found that for all the evaluated impact categories, construction has higher impacts with the exception of eutrophication (EP) (see Table 3.16).

Table 3.16: Average distribution of impact categories in the construction and maintenance in the study of Milachowski et al. (2011)

1 km of motorway over a service life of 30 years	GWP	ODP	POCP	AP	EP
	(%)	(%)	(%)	(%)	(%)
Construction	75	59	61	61	35
Maintenance	25	41	39	39	65

- In the case studies evaluated within the ECRPD project (2010), energy consumption associated with the construction phase (including materials production) of asphalt motorways and dual carriageways is about 9700 GJ/km (+/- 3%) and in the case of asphalt single carriageway is about one third of the previous value (3200 GJ/km). These energy consumption values for the construction phase represent 82-87% (motorways/dual carriageways) and 78-84% (single carriageways) of total energy consumptions for construction and maintenance phases combined.
- Stripple (2001) included lighting energy in the operation phase in the case studies of 1 km of a local road (asphalt and concrete) over a service life of 40 years. In this case, the largest energy consumption and

CO_2 emissions are in the operation phase, while construction accounts for 35-44% of the impacts and maintenance only accounts for minor parts (see Table 3.17).

Table 3.17: Average distribution of energy consumption and CO2 emissions of construction and maintenance (including operation) in the study of Stripple (2001)

			Construction	Maintenance	Operation
Asphalt pavement	Energy consumption	%	35	13	52
	CO_2	%	85	10	5
Concrete pavement	Energy consumption	%	44	7	48
	CO_2	%	85	10	5

Similar results are shown in the recently published EPD 516 on a dual carriageway Spanish road (N-340) (Acciona, 2013) where construction processes had the highest contribution to the overall environmental performance (50-60%). Operation activities represent around 30-10% of total impacts and maintenance around 30%-15% (see Figure 3.7).

In this case study, materials production (upstream processes) and maintenance and operation (downstream processes) contribute 80-90% of the total environmental impacts while construction activities (core processess) contributed only 10-20% (see Figure 3.8).

The same general results have been identified in other studies too (Häkkinen and Mäkele (1996); Mroueh et al., 2000; Huang et al., 2009; Wang et al., 2012b).

For example, in the case study evaluated by Huang et al. (2009), materials production (asphalt and aggregates) represented an average 93% of total energy consumption, 90% of GHGs emissions and 70% of NOx and CO emissions. Transport of materials represents the second largest contributor, while the pavement laying has a lesser impact (Table 3.18).

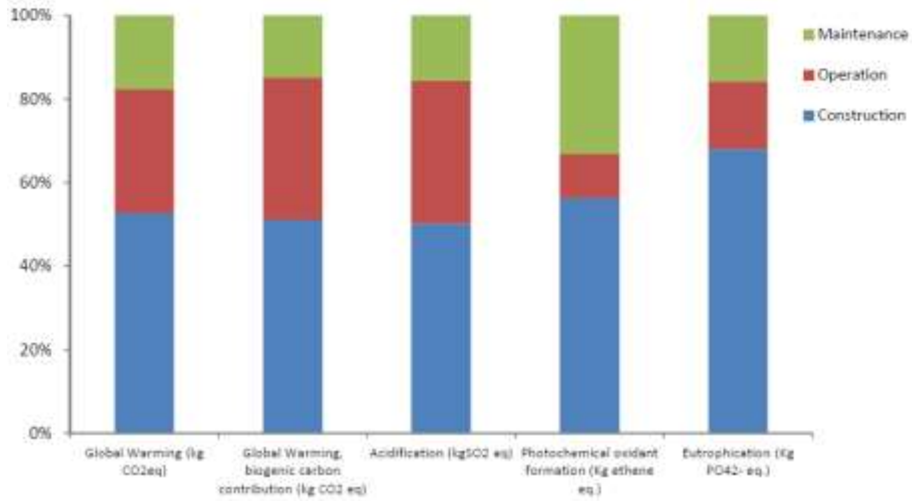


Figure 3.7: CML impact categories of 1km of N-340 road according to different life cycle stages (Acciona, 2013)

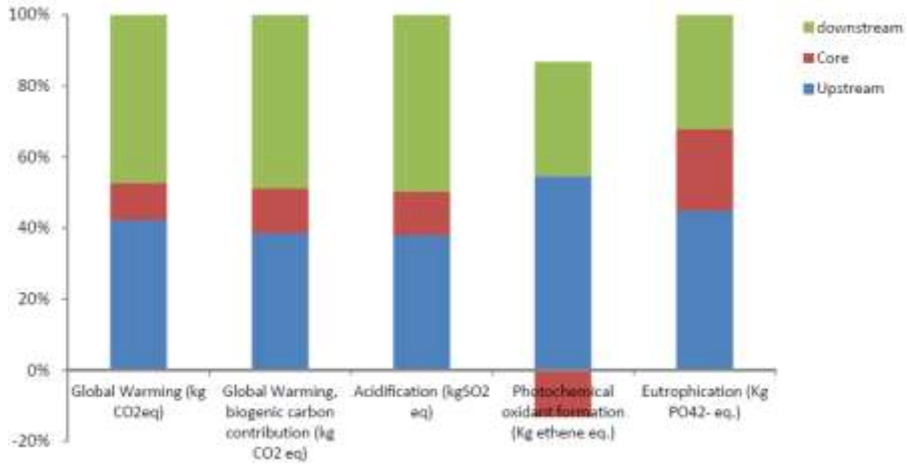


Figure 3.8: CML impact categories of 1km of N-340 road according to different modules (upstream, core and downstream (Acciona, 2013)

Table 3.18: Average distribution of energy consumption and emissions in the construction, maintenance and operation phases in the study by Huang et al. (2009)

Process		Energy (%)	CO2 (%)	CO (%)	NOx (%)	HC (%)	PM (%)
Production	Aggregates	7.7	7.5	27.5	10.4	4.7	10.5
	Bitumen	26.9	29.3	15.8	40.8	80.1	49.4
	Emulsion	0.2	0.0	0.0	0.0	0.0	0.1
	Asphalt	58.2	53.5	29.4	17.5	14.2	39.7
	Total	**93.1**	**90.4**	**72.7**	**68.8**	**99.0**	**99.7**
Transport	Aggregates	4.5	7.1	20.2	28.3	0.0	0.0
	Bitumen	0.9	1.0	2.6	1.1	0.4	0.1
	Emulsion	0.2	0.2	0.4	0.3	0.1	0.0
	Asphalt	0.9	1.1	2.5	1.0	0.4	0.1
	Total	**6.5**	**9.3**	**25.7**	**30.7**	**0.9**	**0.1**
Placement	Tack coat	0.1	0.1	0.5	0.2	0.0	0.1
	Paving	0.1	0.1	0.6	0.2	0.0	0.1
	Rolling	0.2	0.1	0.4	0.1	0.0	0.0
	Total	**0.4**	**0.3**	**1.5**	**0.5**	**0.0**	**0.2**

In their study, Wang et al., 2012b have analysed the impacts of the construction phase of 4 flat rural road segments in California, applicable to the highway network (see functional unit in Tab. 3.7), including an analysis on material production and pavement construction.

- Asphalt production and asphalt pavement construction. The feedstock energy of bitumen in asphalt can be up to 3 times higher than the energy actually used in the asphalt mixing process. Ignoring the feedstock energy, the main contributors to GHG emissions in asphalt production are mainly from the type of mixing process used and binder production, for example Hot Mix Asphalt (45-60% mixing process and 15-30% binder production) or for Rubberised Hot Mix Asphalt (35-60% mixing process and 27-43% binder production). In the construction phase, the transport of HMA and RHMA accounts for approx. 55 % of both energy consumption and GHG emissions.
- Cement concrete production and construction. The Portland cement (PC) component accounts for 54-57% of the total energy consumption in the material production and construction phase, or 37-45% where calcium sulfo-aluminate cement (CSA) is used instead of PC. The remainder of energy consumption is split between transport and construction equipment operation. Material production using Portland cement accounts for 60-80% of GHG emissions in the material production and construction phase, or 50-75% where CSA is used instead of PC. Cement binder production accounts for 70-75% of energy consumption and 84-92 % of GHG emission in the case of PC (the rest are from chemicals admixtures) and approx. 50-75 % for both impacts in the case of CSA cement.

3.1.4.2.2 Hot-spots identified in the construction phase

<u>**Materials production and selection of materials with lower impacts**</u>

Hot-spots in the construction phase are related to the materials production and transportation. The main environmental impacts are consumption of non-renewable resources, global warming, acidification, photochemical ozone formation and eutrophication in the majority of the investigated studies. In particular:

- In concrete pavements, cement production and concrete mix (including aggregates) are responsible for the main impacts
- In asphalt pavements, bitumen production and asphalt mix (including aggregates) are responsible for the main impacts
- Materials transportation could account up to 50% of the energy consumption and emissions in the construction phase, depending on the local conditions (ECRPD, 2010; Wang et al., 2012b).

In the literature review no general rules have been found on the choice of the materials for the pavements construction, for example asphalt or concrete. This choice is related to the specific features of the individual project. The environmental impacts could also differ greatly according to the energy mix used in different countries. Some studies indicate that potential environmental savings can be reached:

- By reducing the clinker content (i.e. the use of CEM III/A instead of Portland cement) in concrete pavements. This measure has reduced the environmental impacts up to 21% in the case study evaluated by Milachowski et al. (2011). According to Wang et al., 2012b, energy savings could be obtained through the employment of calcium sulfo-aluminate cement (CSA) instead of Portland cement.
- By using recycled/secondary materials in different pavement layers, both for asphalt and concrete (Milachowski et al., 2011; Mroueh et al., 2000)
- By selecting materials or activities with lower impacts, for example choosing warm mix asphalt in substitution of hot mix asphalt or selection of materials with higher durability. Some examples are listed below:
    - According to ECRPD (2010), selecting a hot-in-place recycling method instead of recycling by the hot method at an offsite asphalt plant during maintenance, energy savings of about 30% could be achieved for motorways and single carriageway.
    - According to Wayman et al. (2012), of use of warm mix asphalt has a substantial benefit across most of the impact categories considered. They highlighted that the benefits of using WMA were around one third of the benefit achieved with moderate recycling (15%) of RAP. Any additives used for lowering the mixing temperature could further diminish the benefits of using WMA. In a minor way, the moisture in RAP material may slightly reduce some of the benefits of recycling.

<u>**Use of recycled materials**</u>

According to the literature review, the increase in the recycling content of construction materials and products generally lowers the environmental impacts as recycling processes are generally less energy and resource intensive than primary production processes (Carpenter and Gardner, 2009; Blengini and Garbarino, 2010). Some studies have assessed specific by-products and recycled/secondary materials that can be advantageous, according to the specific nature of the project, such as the source of materials, transportation distances and potential leaching of hazardous substances.

The majority of studies include some consideration on transportation of recycled/secondary materials in comparison to natural materials as well as other benefits like avoiding depletion of natural resources and landfilling. In the LCA studies reviewed, different recycled/secondary materials have been assessed with reference to their use in road construction, particularly in road sub-base as unbound materials. A non-exhaustive list is:

- **Recycled aggregates from C&DW, crushed concrete and excavation soil** (evaluated in: Mroueh et al., 2000; Mroueh et al., 2001; Blengini and Garbarino, 2010; Chowdhury et al. 2010; Milachowski et al., 2011). These materials present reduced potential environmental impacts compared to natural aggregates. According to Blengini and Garbarino, 2010, referring to the whole recycling chain (waste collection, recycling, avoided landfill, transportation, and avoided quarrying), the avoided impacts are higher than induced impacts for all the selected indicators (see examples in Figure 3.9).

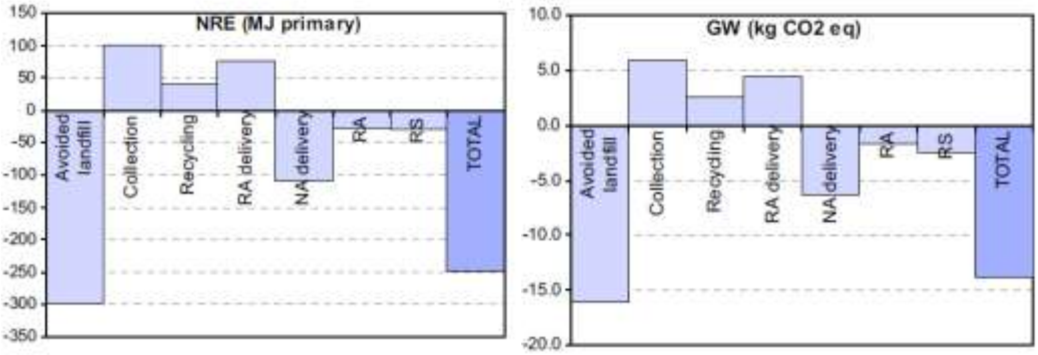


Figure 3.9: Impact indicators (non-renewable energy and global warming) considering within the evaluation of the production chain of 1 t of recycled aggregates (NA natural aggregates, RA recycled aggregates, RS recycled steel) (Blengini and Garbarino, 2010)

- **Reclaimed asphalt pavement (RAP)**. According to Wayman et al., 2012, the main benefits coming from the reuse and recycling of RAP are related to avoiding the need for bitumen production. Results demonstrate that greater benefits are achieved by means of bound RAP recycling rather than unbound. With reference to the potential hazardous substances arising from the use and stockpiling of RAP, the study indicates that higher levels of PAH could be associated to the use of RAP in comparison with the use of natural aggregates and bitumen.
- **Ashes** (evaluated in: Carpenter and Gardner, 2009; Mroueh et al., 2000; Mroueh et al., 2001). According to Mroueh et al., 2000, using fly ash to substitute natural aggregates in road sub-base would lead to similar levels of emissions and energy consumption. According to Chowdhury et al. (2010), the employment of coal fly ashes or bottom ashes in road sub-base in substitution of natural aggregates was not beneficial in all the evaluated categories. Furthermore, the transport distances are very influential on results. On the contrary, in another study (Carpenter and Gardner, 2009), the impacts of road sub-base constructed by means of a combinations of by-products (foundry sand and slag) and natural aggregate mix had half the environmental impacts of road-base using only natural aggregate. This means that the benefits of the employment of recycled/secondary materials have to be evaluated case by case. (see Figure 3.10)
- **Blast furnace slag (BFS)**. According to Mroueh et al. (2000), the employment of BFS in road sub-base reduces potential environmental impacts compared to a reference construction with the use of natural aggregate. This result cannot be generalized to other studies since transport distances can alter the conclusion.
- **Municipal Solid Waste Incinerator (MSWI) bottom ash** (evaluated in: Birgisdottir 2005; Olsson et al., 2006; Birgisdottir et al., 2007).
    - According to Birgisdottir (2005), the difference between a road with and without MSWI bottom ash as a base-layer is insignificant in all environmental impact categories. The largest potential environmental impacts occur from the combustion of fossil fuels during all phases of the road construction. In terms of risks to groundwater quality, it is considered that impacts from road salting are more significant than those from MSWI bottom ash leaching during service life.
    - According to Olsson et al. (2006), the use of MSWI bottom ash instead of natural aggregates in the sub-base of a road would lead to less energy use and energy derived emissions. On the other hand, leaching of some metals can be expected to be larger if MSWI bottom ash is used. Transportation distances influence results. The authors emphasise that results depend on several assumptions and estimates used in the case; in particular the leaching estimates are uncertain.

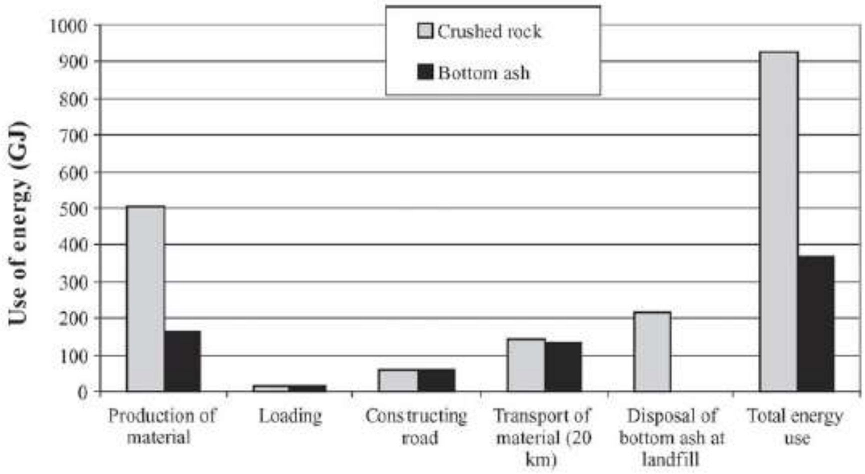


Figure 3.10: Impact on energy use by substituting crushed rock aggregates for bottom ash

<u>**Transportation**</u>

In many studies the influence of transportation distances of recycled/secondary materials is highlighted as one of the main hot-spots (Mroueh et al., 2000; Olsson et al., 2006; Blengini and Garbarino, 2010; Chowdhury et al. 2010) and it is linked to their sustainable use.

- According to Blengini and Garbarino (2010), transportation distance of recycled aggregate can increase 2-3 times with respect to the transport distance of natural aggregates before the impacts of extra transport outweigh the avoided impacts in the recycling chain. The ratio of transportation of natural aggregates versus recycled aggregates is therefore up to 1:2 or 1:3.
- According to Chowdhury et al., (2010), when the ratio of transportation distance of natural aggregate versus industrial by-products is narrower than 1:3, the industrial by-products have an advantage over natural aggregate with regards to energy use, global warming and acidification.
- According to Chowdhury et al., (2010), when the ratio of transportation distance of natural aggregate versus RAP is narrower than 1:4, the natural aggregate has the highest impacts related to global warming, energy use and toxicity. Overall, it is important to assess the transport distance of the potential materials for road construction before decisions are made regarding the choice and origin of the aggregates.

<u>**Earthworks**</u>

In the literature review some papers (7 of 28) have considered the impact of earthworks in the construction phase. In Barandica et al. (2013), the environmental impacts related to the construction and maintenance of 4 different real highway and local road projects in Spain have been analysed over a service life of 50 years (see the functional unit in Fig. 3.7). In these particular studies, the impacts related to earthworks accounted for 60-85% of the total emissions and dominates the materials production impacts. The authors justify these huge values due to the complex Spanish orography and thus the need for embankments and ground works in the sub-grade. Earthworks also accumulated the highest percentage of road project costs (between 20 and 40% of total road construction cost in the 4 case studies). The authors suggest that when the orography is complicated, the exclusion of the earthworks from the LCA of a road construction could lead to an important underestimation of the environmental impacts. The same results are also reported in the study by Hampson et al., (2012) in which for major roadworks, one of the most significant components is the mass movement of materials on site (soils, aggregate, rocks). They state that mass haulage/earthworks operation can cost up to 30% of the project.

From a GPP development perspective, the information in this section highlights the potential importance of planning a closed-loop reuse of excavated soils in or near the site in order to minimise environmental impacts.

Mroueh et al. (2000) also included the evaluation of earthworks in their study, in particular for alternative foundations for the sub-grade (a weakly bearing and compressible soft clay extending to a depth of 5 m). For the shallow layer of weak soil they evaluated two options: replacement with a better soil and stabilization of site soil with cement. Energy consumption and emissions were greater by factors of about 10 and 4, respectively, when cement stabilisation was used.

3.1.4.2.3 Focus on traffic signs and road furniture

Traffic signs are specifically analysed in 2 of the 28 papers (Stripple, 2001; SUSCON, 2006). Stripple (2001) estimated the influence of traffic signs to be <1% of the impacts of materials production, construction and maintenance phases. If the use phase with traffic is taken into account (including the fuel consumption of cars and trucks), traffic signs contribute to <0.1% of the total potential environmental impacts during the full life cycle of a road. Traffic signs were not identified as hot-spot in SUSCON (2006) either.

In Loijos et al., 2013, the following elements are considered insignificant (i.e. <1% of impacts) to the road life cycle: capital goods production, traffic signs, road paint production and application and joint sealant.

3.1.4.3 Key environmental impacts in the maintenance phase

With reference to the results of the market analysis and the stakeholder consultation, it can be highlighted that nowadays maintenance is gaining an increased relevance due to decreases in new road construction. Maintenance has to be evaluated not as a simple repetition of restoration and repairing activities, but on the contrary as a complex network of design strategies including evaluation on rolling resistance, congestion and durability of road surface materials.

3.1.4.3.1 Congestion (traffic delays)

Congestion is caused by lane and road closures necessary for road construction and/or maintenance. It can greatly influence vehicle fuel consumption due to queues and associated slowdown (Taylor P. et al., 2012).

Santero et al. (2011a) hypothesize that congestion could be a much greater portion of a pavement's environmental impact than construction materials and equipment and conclude that the environmental impacts associated with congestion are dependent upon the project and site characteristics. For low traffic rural and local roads, the impacts of congestion are likely to be negligible. Conversely, on motorways and highways, the extra fuel consumption and related air emissions can easily become a prominent component of the pavement life cycle. From an environmental perspective, a long-life pavement with high durability has less need for lane closure and thus reduces the impacts of congestion.

According to Huang et al., (2009), in order to reduce the environmental impacts of road maintenance works, effective traffic management (lane closure, traffic diversion) and phasing of the roadwork into off-peak hours (night shifts) have to be planned.

3.1.4.3.2 Maintenance and rehabilitation strategies

Zhang et al., (2008), have analysed the environmental performance of a high performance concrete (ECC) overlays with a service life of 40 years in comparison to the environmental performance of traditional concrete and HMA overlays (with a service life of 20 years) (see the functional units in Table 3.7). Maintenance is dominated by material production energy (for HMA the larger amount of energy is due to the feedstock energy), congestion related energy (traffic delay) and roughness-related energy (see Figure 3.11).

In the case study analysed, compared to concrete and HMA, ECC reduces the total life cycle energy by 15% and 72% and the GHG emissions by 32% and 37%, respectively. The three overlays have been compared also by means of a LCC model, which enables the long term evaluation of pavement projects. Despite higher initial construction costs, the lower maintenance frequency over 40 years results in an accumulated cost savings for ECC compared to concrete and HMA overlay systems 40% and 58%, respectively.

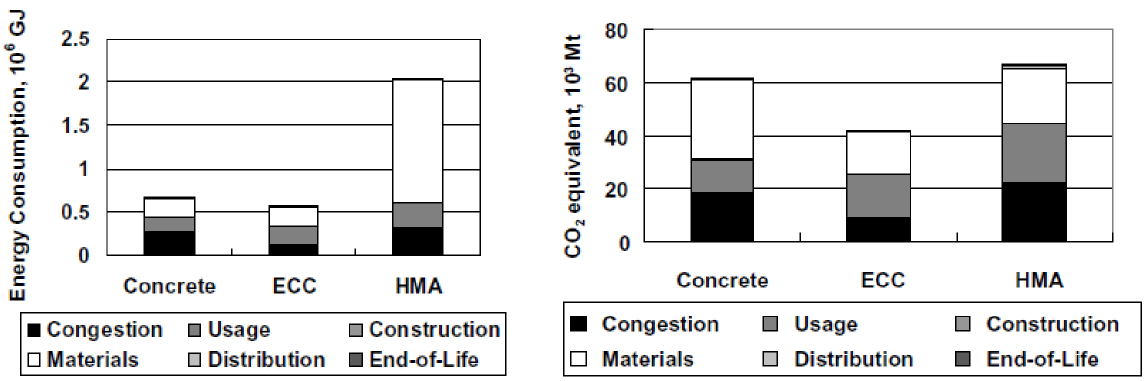


Figure 3.11: Energy consumption and CO2 emissions of the maintenance study of Zhang et al. (2008)

The results of Yu and Lu (2012), also concerning pavement maintenance - shown in Figure 3.12 show a similar degree of importance of material production, congestion and roughness-related energy (respectively 13-21%, 11-18%, 60-76% on the energy consumption and 11-31%, 11-20% and 48-78% of the GHG emissions) as Zhang et al., (2008) in Figure 3.11 above.

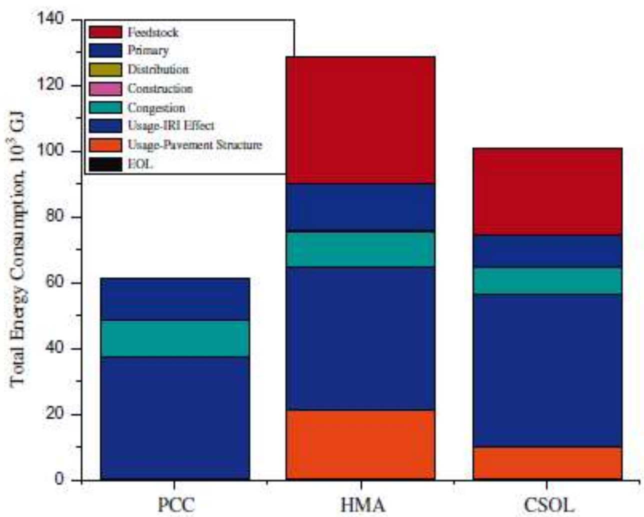


Figure 3.12: Energy consumption by life cycle phase in the study of Yu and Lu (2012)

PCC Portland cement, HMA hot mix asphalt, CSOL crack and seat

Wang et al., 2012a have compared the impacts and resource consumption of two reference scenarios where the minimum level of maintenance work is performed annually to keep the pavement condition deterioration rate very slow: one where a rehabilitation involves a rougher surface, coarse with an IRI of 1.67 m/km, and one 'where a smoother surface course is used in rehabilitation, with an IRI of 1.00 m/km (considering also a 3% of increased traffic growth). The study concludes that large savings in GHG emissions and fuel consumption are obtained when the roughness of the road is reduced: a 10% reduction in the rolling resistance can generally lead to 1-2 % improvement in fuel economy. Also in maintenance strategies, the energy consumption in the materials production phase is very small compared to the use phase with high traffic volume. In the low volume traffic cases, the materials production phase gains increased importance.

3.1.4.3.3 *Hot-spots identified in the maintenance phase*

- Evaluation of congestion, particularly for motorways and highways
- Selection of materials with a lower impact during the life cycle
- Maintenance strategies

3.2 Conclusions of the LCA literature review

A common result of the LCA literature review is the conclusion that all roads are unique and have their own specific conditions. According to Carlson (2011) and Santero et al., (2011a), it is impossible to perform straightforward comparisons of the results in reviewed LCA studies due to the differences in approach, scope, functional units, analysis periods, system boundaries, regional differences, input data (LCIs) (see section xxxx and Annex III Literature Review). This means that a flexible method is needed that can be adjusted to suit the road that you want to study.

A large range of impacts are possible for all the components of the road life cycle. Santero and Horvath (2009) stated that GHG emissions could range from negligibly small values to 60,000 t of CO_2e per lane-kilometre over a service life of 50 years. The main environmental impacts arising from daily traffic (fuel consumption by cars and heavy trucks) during the use phase of a road (Häkkinen and Mäkele, 1996; Mroueh et al., 2000; Stripple, 2001; Huang et al., 2009; Milachowski C. et al., 2011, Wang, 2012a). According to Wang et al. (2012a) "*…omission of the use phase can lead to a major error in the analysis of the alternative pavement activities*".

Rolling resistance associated to the pavement structure and roughness generally has the highest-impact potential, because it is directly related to the vehicle fuel consumption. According to Wang et al., (2012a), a 10% reduction in rolling resistance could lead to 1-2% of improvement in fuel economy.

Congestion due to traffic delay, both in the construction and maintenance phases, materials production and transportation are the other important factors, even though it has to be considered their huge variability related to the project details (such as pavement location, structure) and the traffic levels.

Congestion is caused by lane and road closures necessary for road construction and/or maintenance. It can greatly influence vehicle fuel consumption due to queues and associated slowdown, both in the construction and in the maintenance phase. The environmental impacts associated with congestion are dependent upon the project and site characteristics. For low traffic roads, the impacts of congestion are likely to be negligible. Conversely, on motorways and highways, the extra fuel consumption and related air emissions can easily become a prominent component of the pavement life cycle. In order to reduce the environmental impacts of road maintenance works, effective traffic management (lane closure, traffic diversion) and phasing of the roadwork into off-peak hours (night shifts) have to be planned and will be considered as a GPP criterion.

An important factor is the influence of **traffic flow** on the relative importance of the identified hot-spots:

- In high traffic roads (i.e. example motorways, highways, and main national roads), rolling resistance and congestion have the highest impacts on energy consumption and emissions. Materials production and transportation is the third most important aspect to be taken into consideration.
- In low traffic roads (i.e. secondary and other roads): higher impacts on energy consumption and emissions come from materials production and transportation rather than from rolling resistance and congestion. The relative importance of materials production and transportation increases with the decrease of the traffic volume.

Internationally, roads with a traffic volume of up to 2000 vehicles per day are denoted as low volume roads (AASHTO, 1993).

Road alignment is also a prevailing parameter on the fuel consumed by traffic during the use phase. Alignments are decided upon in the preliminary phase of the procurement route, specifically during road planning and environmental impact assessment. Therefore, road alignment should not be considered as a possible GPP criterion. Anyhow, it is recommended that the public authorities are aware of the importance of this parameter and include this knowledge when choosing the alignment of the road construction. There are also tools that enable Public Authorities in this evaluation.

The road life cycle stage with the second largest environmental impacts is indicated to be the construction phase, in which the hot-spots are related to the **materials production and transportation**. The main environmental impacts are consumption of non-renewable resources, global warming, acidification, photochemical ozone formation and eutrophication in the majority of the investigated studies. In particular:

- In concrete pavements, **cement** production and **concrete** mix (including **aggregates**) are responsible for the main impacts

- In asphalt pavements, **bitumen** production and **asphalt** mix (including **aggregates**) are responsible for the main impacts
- **Materials transportation** could account up to 50% of the energy consumption and emissions, depending on the local conditions.

In the literature review no general rules have been found on the choice of the materials for the pavements construction, for example asphalt or concrete. The choice of materials depends on the uniqueness of the local conditions, as geotechnical and hydrogeological conditions, common practices of the road administrations, climate conditions, availability of natural resources and recycled/secondary resources and by-products, transportation distances, prices, weather conditions. It has to be underlined that the final choice of materials will be based on the project specific characteristics and on the needs and indications of the public authority. As a guidance of the main results from the literature review, a non-exhaustive list of the different possible materials with lower environmental impacts highlighted by some studies is reported below:

- **Warm mix asphalt** in substitution of hot mix asphalt
- **Fly ash or calcium sulfo-aluminate cement (CSA)** instead of Portland cement

1. **Recycled/secondary materials and by-products.** According to the literature review, the increase in the recycling content, both for asphalt and concrete, generally lowers the environmental impacts as recycling processes are generally less energy and resource intensive than primary production processes (Carpenter and Gardner, 2009; Blengini and Garbarino, 2010; Milachowski et al., 2011; Mroueh et al., 2000). The majority of studies include some consideration on transportation of recycled/secondary materials in comparison to natural materials, as well as other benefits like avoiding depletion of natural resources and landfilling. Moreover the hazardous substances leaching has also been evaluated A non-exhaustive list is:
    - **Reclaimed asphalt pavement (RAP)**. The main benefits from the reuse and recycling of RAP, especially bound, are related to avoiding the need for bitumen production (Wayman et al., 2012).
    - **Recycled aggregates from C&DW, crushed concrete and excavation soil** (Mroueh et al., 2000; Mroueh et al., 2001; Blengini and Garbarino, 2010; Chowdhury et al. 2010; Milachowski et al., 2011) particularly used in road sub-base as unbound materials
    - **Ashes** (Carpenter and Gardner, 2009; Mroueh et al., 2000; Mroueh et al., 2001, Chowdhury et al., 2010), particularly used in road sub-base as unbound materials.
    - **Blast furnace slag (BFS)**. (Mroueh et al. 2000), particularly used in road sub-base as unbound materials
    - **Municipal Solid Waste Incinerator (MSWI) bottom ash** (Birgisdottir 2005; Olsson et al., 2006; Birgisdottir et al., 2007). The use of MSWI bottom ash instead of natural aggregates in the sub-base of a road would lead to less energy use and energy derived emissions. On the other hand, leaching of some metals can be expected to be larger if MSWI bottom ash is used.

Transportation of materials during the construction and the maintenance phase is also important when natural aggregate is compared to recycled or secondary aggregates or by-products (Mroueh et al., 2000; Olsson et al., 2006; Blengini and Garbarino, 2010; Chowdhury et al. 2010) and it is linked to their sustainable use. According to the literature review, transportation distance of recycled aggregate can increase 2-3 times with respect to the transport distance of natural aggregates before the impacts of extra transport outweigh the avoided impacts in the recycling chain. The ratio of transportation of natural aggregates versus recycled aggregates is therefore up to 1:2 or 1:3

According to the literature review, in complex orography condition, when embankments and ground works are needed, the impacts related to **earthworks** can accounted for the main part of the total emissions. Moreover, the mass movement of materials on site (soils, aggregate, rocks) and earthworks can cost up to 30% of the project. From a GPP development perspective, the information in this section highlights the potential importance of planning a closed-loop reuse of excavated soils in or near the site in order to minimise environmental impacts.

With reference to the results of the market analysis and the stakeholder consultation, it can be highlighted that nowadays **maintenance and rehabilitation** is gaining an increased relevance due to decreases in new road construction. Maintenance has to be evaluated not as a simple repetition of restoration and repairing activities, but on the contrary as a complex network of design strategies including evaluation on rolling resistance, congestion and durability of road surface materials. This has been highlighted in several studies particularly focused on the study of the maintenance phases (Zhang et al., 2008; Yu and Lu, 2012; Wang et al., 2012a), this phase is dominated by material production and congestion, similarly to the construction phase. Several studies indicate that there is a clear connection between durability and sustainability aspects including environmental impacts. Thus when durable materials are used, the need for maintenance is reduced.

Summarizing the conclusions developed based on the LCA literature review the main parameters can be prioritized:

- Interaction between pavement and the environment during the use phase (rolling resistance)
- Congestion due to traffic delay
- Sustainable construction materials including recycled materials
- Transport distances of materials used for road construction

3.3 Tools for the LCA of road construction

According to the literature review, several LCA tools have been developed in Europe to be applied in the road infrastructure sector; most of them are carbon footprint calculation tools aimed at identifying low CO_2 emission solutions in road constructions. A non-exhaustive list of tools is proposed in Table 3.19: Example of tools for the LCA of road construction From a first screening, it appears that the existing tools are more focused on construction and less in maintenance, none of these tools is taking into consideration the use phase. Database on materials, mixing operation, equipment, transport distances, electricity generation related to single Member State are used. It has to be mentioned that the EU research project CEREAL (CO2 Emission Reduction in roAd Lifecycles) in the ERANET network (CEREAL, 2012) is developing a tool that will be concentrated on maintenance and rehabilitation activities in Europe. This tool is supposed to use existing databases and calculation rules from the existing models, with available country specific databases on e.g. maintenance measures, asphalt mixes, transport distances, electricity generation and particularly will be designed to calculate carbon footprints for projects in North-Western Europe.

Table 3.19: Example of tools for the LCA of road construction

Tools*	
asPECT (asphalt Pavement Embodied Carbon Tool)	
	Resulting from the 2008-11 collaborative research programme. Collaborative research is a joint initiative of the Highways Agency, Mineral Products Association, Refined Bitumen Association and TRL Limited. The project was further endorsed by the WRAP Waste & Resources Action Programme and Adept. http://www.sustainabilityofhighways.org.uk/
Region in which the tool is suitable	UK
GHG emissions protocol	PAS 2050
Program	Free download Program language: MS excel
Database	Accessible database. Available in the published project report
Pavement types	Flexible pavements
Road lifecycle phases	Construction and maintenance and rehabilitation measures
Inputs	Types of bitumen, cement, fibres, hydrated lime and water for the UK market. Yearly data on electricity, other fuel, water usage, emulsion, explosive
Results	Total GHG-emission per tonne (kg CO2e). calculated for different phases of the project: materials and processing, transport to plant, asphalt production, transport to site, laying and compacting
	AfwegingsModel Wegen
	Software developed by CROW. The use of this tool is also allowed in the Dutch GPP criteria for roads http://www.crow.nl/publicaties/afwegingsmodel-wegen-(amw-1-1)
Region in which the tool is suitable	Mainly the Netherlands
GHG emissions protocol	CML2-baseline, GWP100
Program	Download by payment. Program language: MS excel
Database	DuboCalc database
Pavement types	Flexible pavement, concrete and block pavement
Road lifecycle phases	Construction and maintenance and rehabilitation measures
Inputs	pavement design or pavement maintenance both in amounts of square meters and layer thickness and materials amounts
Results	

Aggregain	
	The tool gives an estimate of the climate change contribution saved by selecting different construction techniques and supply alternatives (use of primary or recycled and secondary aggregates). It has been developed by TRL Limited, (UK's Transport Research Laboratory) and funded by WRAP Waste & Resources Action Programme http://aggregain.wrap.org.uk/sustainability/try_a_sustainability_tool/co2_emissions.html
Region in which the tool is suitable	UK
GHG emissions protocol	
Program	Free download (AggRegain CO2e emissions estimator tool, version 2.0, May 2010) Program language: MS excel
Database	Accessible database. Where possible, UK specific data is used. The ECRPD report is used for data on equipment operation and some references still remain to the EAPA/EuroBitume Life Cycle Inventory. The ECRPD report was compiled by European partners representing The Netherlands, Czech Republic, France, Ireland, Finland, Portugal and Sweden. Data from the EAPA/EuroBitume LCI
Pavement types	Types of construction applications: bitumen bound, concrete, hydraulically bound, unbound
Road lifecycle phases	Procurement phases for materials and construction technique
Inputs	Amount of materials (concrete, bituminous mixtures etc.) and components used (coarse and fine aggregates, binders and minor constituents), distances travelled and processes used
Results	CO_2 emissions
Changer	
	CHANGER is a tool which has been developed by The International Road Federation (IRF) to assess the potential environmental impacts of road projects by estimating the total amount of greenhouse gas emissions released during selected phases of a road construction project http://www.irfnet.ch/environment.php?id=47
Region in which the tool is suitable	
GHG emissions protocol	IPCC2007
Program	
Database	
Pavement types	
Road lifecycle phases	CHANGER currently contains two modules: 1) Pre-construction including a. Clearing and piling: based on the ground surface area cleared per unit of road surface, an estimation can be generated for both machine use and fuel consumption. Transportation of trees removed is also taken into account (the tool does not account for either the loss of CO_2 absorption by the removed trees or for their replacement with new or replanted trees in the areas concerned). b. Cut exports and fill imports transport to and from the road site: based on a simplified diagram, the user selects the relevant sites and enters the respective distances, tonnages and transport modes (road, rail or inland water). 2) Pavement a. On-site impacts: electricity and fuel consumption on the construction site as identified and evaluated. b. Pavement construction materials: this section encompasses several menus (unbound materials, hydraulically bound materials, bituminous bound materials, metals, rubber and plastic, etc.), from which the user can easily select the materials required for construction of the different layers of the given pavement. c. Materials transport: A simplified diagram has been set up to help visualise and assess the emissions generated by transportation of the materials identified: d. Construction machines: The total consumption of fuel is determined on the basis of the number

	of working hours per type of machine and type of pavement layer. Work is underway on complementing the existing pre-construction and pavement modules with a new module devoted to maintenance activities.
Inputs	
Results	kg of CO_2
Dubocalc and CO2 ladder	
	Rijkwaterstaat (RWS) funded and developed the LCA tool Dubocalc based on materials and energy. The objective of DuBocalc is the comparison of tender-bids or variants, by mean of the calculation of the environmental effects of the different infrastructure designs, based on material en energy use during the whole lifecycle. It can be used according to these options: 1) As a awarding criterion in MEAT. The bidder with the lowest ECI (the most sustainable design) is awarded. 2) As a process requirement: optimizing during the design process 3) As a optimizing desing tool and verification tool 4) As a minimum performance requirement (expressed in ECI). The CO_2 performance ladder enables the Public Authorities to assess the CO_2 emissions due to a project and use it as an award criterion for calls to tender. The CO2 ladder is a CO2 management tool used at organisational level, but also applied in the procurement of projects, as it is compatible with European regulations and the Public Procurement Directive. There are five levels reflecting the state of maturity of the company involved in the project. At the first stage insight is gained about the energy flows and potential savings. At the next steps of the ladder the company improves and reduces the CO_2 emissions gradually. The public and private sector organisations in the Netherlands use the tool to reward the tenderers in the call for tenders process by giving the tenderers with high score an advantage. (SKAO, 2013). The effort is rewarded by giving tenderers a nominal discount on the tender price (5-10% on level 5).
Region in which the tool is suitable	The Netherlands
GHG emissions protocol	the Dutch standard *NEN 8006:2004 Environmental data of building materials, construction products and building elements for inclusion in an environmental statement - Determination method according to the life cycle analysis (LCA*) and ISO 14040
Program	Unclear if it is free download
Database	LCA database and an Environmental cost calculator. According to CEREAL (2012), the database is managed by SBK (Stichting Bouwkwaliteit), data layer is owned by Conesco and RWS is the main user and overall manager
Pavement types	All kind of pavements
Road lifecycle phases	•Building (excavation, production, building) •Use •Maintenance •Demolition
Inputs	The project information, meaning tons of materials, transport distance, etc, is the input of the tool, which applies a LCA calculator built
Results	The outputs of the tool are the CO2eq emissions of the project and the Environmental Cost Indicator MilieuKostenIndicator (MKI) for materials and processes, which takes into account environmental cost related to: • Effect on ozone layer • Human toxicity • Ecological toxicity, sweet aqua • Ecological toxicity, salt aqua • Ecological toxicity, land • Photochemical reactivity (smog) • Acidification • Over fertilization • Depletion of non renewable materials
GreenDot	
	GreenDOT was requested by the American Association of State Highway and Transportation Officials (AASHTO), and conducted as part of the National Cooperative Highway Research Program (NCHRP) Project 25-25. GreenDOT was developed by the ICF International and Venner Consulting. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2621

Region in which the tool is suitable	US
GHG emissions protocol	
Program	Free download at: NCHRP website. Excel spreadsheet
Database	GreenDOT calculates emissions in four separate modules: • The Electricity Module • The On-Road Module calculates emissions from cars and trucks, based on either fuel consumption or detailed data on VMT and vehicle types • The Off-Road Module calculates emissions from construction and maintenance equipment • The Materials Module calculates emissions embodied in roadways, based on volumes and types of materials used. Embodied emissions are associated with energy used in the extraction, processing, and transportation of materials. The module estimates the impact of mitigation strategies including using recycled materials and warm mix asphalt
Pavement types	Concrete panels, asphalt, Cement Treated Aggregate, Base Aggregate
Road lifecycle phases	GreenDOT calculates carbon dioxide (CO2) emissions from the operations, construction, and maintenance activities
Inputs	• Electricity module: Input electricity use in MWh OR Input detailed data on type, number, and usage of electrical appliances • Materials module: Metric tonnes of the different materials OR Alternative mixing ratios • On-road module: Fuel use OR Vehicles miles travelled • Off-road module: Aggregate data of fuel use OR Aggregate data of fuel use by equipment type OR Input detailed data on activity by equipment type.
Results	tons of CO_2
JOULESAVE	
	JouleSave is a specific software product of an earlier European program 'ECRPD Energy Conservation in Road Pavement Design, Maintenance and Utilisation', co-funded by the EC and undertaken by Waterford County Council, Ireland and other partners from the Czech Republic, Finland, France, Portugal, Sweden and the United Kingdom. The project stopped, the website included and it is not possible to find other information
Region in which the tool is suitable	EU
GHG emissions protocol	
Program	JouleSave software developed by Bentley Systems Europe B.V., Netherlands. It operates with their MX Road design package by detailed (road) designers. The accessibility to this program is limited
Database	Machinery Energy and Materials Energy data was gathered from site visits. Quantities of aggregate and bitumen per kilometer (tonne/km) and total Material Energy per kilometer were calculated. Traffic using the roads was split into three categories: cars, trucks and trucks with trailers. Road geometry, road surface, road surface conditions, meteorological conditions, vehicle details and driving behavior were input into the Veto program. Standard weather and road surface conditions were used for all routes. Current and predicted traffic data was known for each route.
Pavement types	JouleSave calculates the amount of energy used in the construction of a particular road design and also the energy which would be used by vehicles on that road over a 20 year lifetime.
Road lifecycle phases	The construction energy is divided into Machinery Energy and Materials Energy.
Inputs	predicted traffic volumes, speed limits, type of surface
Results	energy, not CO2-eq.
PALATE	
	LCA tool of environmental and economic effects of pavements and roads developed by the Departement of Civil and Environmental Engineering, University of California, Berkeley (Prof. Arpad Horvath) and funded by the Recycled Materials Resource Center of the University of New Hampshire and the University of California Transportation Center
Region in which the	US

tool is suitable	
GHG emissions protocol	
Program	Excel-based tool
Database	The data is for the US
Pavement types	Concrete and asphalt pavement
Road lifecycle phases	Different sheets for: design, initial construction, maintenance, equipment, and costs Materials production, construction, transportation, and maintenance of asphalt and portland cement concrete pavement, subbase, embankment and shoulders materials
Inputs	• the general design of the roadway initial construction materials • material transportation distances • modes maintenance materials • on-site construction equipment (e.g., asphalt paver) and off-site processing equipment (e.g., rock crusher) • life-cycle economic costs
Results	• energy consumption • CO2 emissions • NOx emissions • PM10 emissions • SO2 emissions • CO emissions • Leachate information
ROAD-RES	
	The model has two purposes: (i) to evaluate the environmental impacts and resource consumption in different life cycle stages of road construction with virgin materials and residues from waste incineration; (ii) to evaluate and compare two disposal methods for waste incineration residues, namely landfilling, and utilization in roads. It was developed by the Technical University of Denmark, in collaboration with the Danish Road Directorate, Amagerforbraending (incineration plant), Vestforbraending (incineration plant) and Aalborg Portland A/S
Region in which the tool is suitable	The Nordic Regions
GHG emissions protocol	EDIP97 (also Eco-Indicator 99 and CML2001)
Program language	C++ and PARADOX database
Database	Unit process datasets: including environmental exchange data for production of materials, upgrading of residues, road construction, landfilling, transport etc. Leaching profiles for construction materials: including leaching data for both monolithic and granular residues as well as conventional materials (asphalt, concrete and gravel pit material). Transfer coefficients for the distribution of the constituents into different environmental compartments are a part of the leaching profiles. LCA databases: including impact categories, characterization factors and assessment methods
Pavement types	Scenario-modules: Road (Motorway, Primary road, Secondary road, Urban road, Gravel road), parking area, embankment
Road lifecycle phases	Construction phase, operation and maintenance phase, and demolition phase
Inputs	
Results	
SEVE	
	Software for all businesses participating in the French voluntary agreement between USIRF and the Ministry of Infrastructure to promote other environmental solutions among public contractors. Each company can use SEVE on tenders to compare the impact of ecological technical alternatives with the intial specifications. The aim of the eco-systems comparators is to compare the environmental impact of contractors. SEVE has been developed by USIRF. It is now used by 80 companies including 66 entities by more than 2 160 users in favor of 3 280 projects studied. http://www.usirf.com/site/La-route-et-le-Grenelle/Eco-comparateur-SEVE
Region in	France

which the tool is suitable	
GHG emissions protocol	
Program	Available on line to all members of USIRF
Database	• Central database for resources (materials, equipment, etc.) managed by USIRF • Materials : plants' database for asphalt and common data base • asphalt mixing plants database and hot and warm mix asphalt formulations for each plant • Pieces of equipment and equipment spreads • Transport modes : trucks (9, 14, 24 tons double haul or not), train, river transport, sea transport
Pavement types	
Road lifecycle phases	• Raw materials and energy (production of aggregates, binders…) • Manufacturing (asphalt plant, concrete plant, cement plants) and transportation • Construction • Recycling at End of life. • Use phase is not taken into consideration
Inputs	
Results	• Energy consumption (MJ) • t CO_2 eq. • natural resources consumption (t) • Valorisation of reclaimed asphalt pavement (t) • Transportation (t-km)
CO2nstruct	
	A database and Web application called CO2NSTRUCT has been developed starting from a research, analysis and data collection.
Region in which the tool is suitable	
GHG emissions protocol	
Program	
Database	
Pavement types	
Road lifecycle phases	
Inputs	• Planned operations: reaming, tack coat, earthwork, base layer, surface layer,…) • Planned quantities of materials in tons to be used in the worksite • Pieces of equipment or spreads and the duration (days) of planned works • Types and distances for transport to the worksite And put one or several variants
Results	
* Some data are taken from CEREAL, 2012	

3.4 Technical analysis

As illustrated in the previous chapters, road construction is a very complex process involving numerous decision parameters making generalisations difficult since several parameters are determined by factors related to the local environmental/geographical situation, traditions in the individual Member State or local municipality. However, some generic environmental impacts/parameters relevant for almost all road types can be identified.

3.4.1 EU projects considered within the study

Table 3.20: EU projects considered within the study

OVERALL ROAD ASSESSMENT	
2006	**ERA-NET for transport** In 2006 11 European, national road administrations (ERA) acknowledged a common need to share their road research initiatives: • ERA-NET ROAD I (2006-2009) • ERA-NET ROAD II (2009-2011) • Continued work (no framework has yet been defined) Several research projects have been finished within ERA-NET from 2006 to 2011. Selected projects are: • LCA of open-graded asphalt • Performance management for low-noise pavements • Optimization of thin asphalt layers • Rapid and durable maintenance methods • Sustainability and energy efficient management of roads From 2008 to 2012 ERA-NET has submitted yearly call for cross-border funded joint research programmes. Especially interesting for EU GPP for Road Construction is the call in 2011 which focused on three subjects: mobility, design and energy. These subjects are described in detail at the homepage of ERA-NET (www.eranetroad.org). Especially interesting is the call for Energy "Sustainability and Energy Efficient Management of Roads". This programme is based on three objectives: A. Sustainability: Develop a common understanding of sustainability and development of a rating system B. Provide an Energy Efficient Road Infrastructure (construction, maintenance and operation) C. Determine the most important Road Infrastructure Characteristics which influence Vehicle Energy Consumption Four projects were selected to fulfil the objectives of the Energy-programme: • SUNRA – **Su**stainability – **N**ational **R**oad **A**dministrations • CEREAL – **CO₂** **E**mission **Re**duction in ro**a**d **L**ifecycles • LICCER – **Li**fe **C**ycle **C**onsiderations in **E**IA of **R**oad Infrastructure • MIRAVEC – **M**odelling **I**nfrastructure influence of **R**o**a**d **V**ehicle **E**nergy **C**onsumption
2010	**HEROAD_Road_assessment**
	Partners in ERA-NET ROAD (ENR) are United Kingdom, Finland, Netherlands, Sweden, Germany, Norway, Switzerland, Austria, Poland, Slovenia and Denmark (www.eranetroad.org).
2011	**SUNRA_Sustainable Road Administration** During the SUNRA project sustainability measurements will be developed including a road-project level rating system. The project ends in 2013.
2012	**LICCER EIA** The LICCER project finalises in December 2013. It is expected the output of the project is an easy-to-use model for analysing energy use and GHG emissions from road infrastructure during the full life cycle of a road. The model will be developed on the basis of existing models and processes e.g. the Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment (SEA) (Finnveden, 2011).
LCA	
	CEREAL project The CEREAL project was planned to be finalised in May 2013. During the project time a tool for assessment of CO_2 emissions from pavement construction and maintenance works will be developed. At the time of writing this preliminary report the tool is not ready for use but will be ready at august/September 2013 (Snoek, 2013). The project also provides guidance for the national road authorities when the CO_2 emission from design, construction, maintenance and rehabilitation must be reduced.

	COOEE The COOEE (CO_2 Energy Efficiency) project is funded by the Danish Strategic Research Council and performed in collaboration between the Danish Road Directorate, Roskilde University, The Technical University of Denmark and NCC Roads (Schmidt, 2013). The objective of the project is to exploit the emission reduction potential of rolling resistance modelling of pavements. During the project duration measurements of rolling resistance and a number of other parameters predicting the rolling resistance will be carried out to assess the strengths and weaknesses of the measurement equipment. Furthermore, the collected data will be used for modelling of the tyre-road contact zone which is very important for developing a robust model of the rolling resistance. During the project duration it has been estimated that 25% of the CO_2 emitted on the roads is caused by rolling resistance. Furthermore, assessment has shown that approx. 3-5% on fuel consumption can be saved (Schmidt, 2013).
	Sustainable highways Sustainable highway (http://www.sustainablehighways.dot.gov/) is an initiative which supports programs and activities to enable the decision makers to balance among environmental, economic and social aspects. Sustainable Highways are financed by the Federal Highway Administration in the U.S. Department of Transportation. To facilitate relatively easy evaluations of transportation projects, Sustainable Highways has developed a self-evaluation tool, Infrastructure Voluntary Evaluation Sustainability Tool (INVEST https://www.sustainablehighways.org/). The tool assesses the environmental, social and economic sustainability of highways. The environmental assessment includes resources, emissions and ability to recycle materials. Acknowledging that transportation projects differ (type of road, location, sustainability goals, ground conditions etc.) the user of INVEST can tailor a project specific list of relevant criteria based on a gross long-list of criteria developed by Sustainable highways.
ROLLING RESISTANCE	
2007	**Tyre and Road Surface Optimization for Skid Resistance and Further Effects (TYROSAFE)** TYROSAFE is a Coordination Action funded by the European Community's Seventh Framework Programme (FP7/2007-2013). One of the main objectives of the project is to optimise the assessment and management of essential tyre/road interaction parameters in order to reduce greenhouse gas and noise emissions. (Haider, 2013) The two following aspects are assessed in relation to environmental effects: • The influence that the provision of harmonised/optimised skid resistance could have on the environment. • The effect of climate change on skid resistance.
2010	**MIRIAM** MIRIAM (http://miriam-co2.net/) is a project for investigating rolling resistance initiated by 12 partners from Europe and USA. The objective of the project is to "provide a sustainable and environmentally friendly road infrastructure by developing an integrated methodology for improved control of road transport CO_2-emissions". The first phase of the project (2010-2011) investigates the characteristics of pavements. This includes investigations, tests, literature review etc. of the following aspects: • Measurement methods (review of existing methods and planning of new measurements) • Investigate the influence of pavement characteristics on energy efficiency (determination of the parameters which causes energy losses) • Investigate the importance of rolling resistance • External funding and raising awareness • Constraints/requirements to implementation projects to reduce rolling resistance The results from this work are published via 10 papers and several presentations at workshops etc. (Schmidt, 2009) The main papers to be included in the development of GPP criteria have been described in chapter 4.
2011	**MIRAVEC Modelling Infrastructure on RoAd Vehicle Energy Consumption** Modelling Infrastructure on RoAd Vehicle Energy Consumption (MIRAVEC) is a project run by the Forum of European National Highway Research Laboratories (FEHRL) (FEHRL, 2013). The project aims at assess the relative importance of different road infrastructure characteristics for different settings (topography, network type etc.). Furthermore, MIRAVEC assesses the parameters of the road infrastructure which effects the vehicle energy consumption etc. The project ends in October 2013. *Report on the road infrastructure effects contributing to road vehicle energy consumption and their governing parameters* This publication is published in 2012 by Manfred Haider and Marco Conter as a deliverable to the MIRAVEC

	project under the ERA-net initiative. The aim of the publication is to describe the road infrastructure parameters which affect the energy consumption of the vehicles. Five groups of parameters were identified: A. Effects of pavement surface characteristics (rolling resistance, texture, longitudinal and transversal unevenness, cracking, rutting, other surface imperfections) B. Effects of road design and layout (e.g. road curvature, gradient and crossfall, lane provision) C. Traffic properties and interaction with traffic flow (e.g. free flowing traffic vs. stop-and-go, speed limits, access restrictions) D. Vehicle and tyre characteristics including the potential effect of technological changes in this area E. Meteorological effects (e.g. temperature, wind, water, snow, ice) It is concluded that mainly A and B are under the control of the road administrations. The properties described in A are believed to be easier to change – and can be done in a shorter time frame than B. The publication also described methodologies to test the rolling resistance according to ISO 28580. Still, there is no standardised method for determining the pavement contribution to the rolling resistance. The on-going projects MIRIAM and COOEE investigated the possibilities of using trailers for measuring the rolling resistance. Overall, this paper supports that addressing rolling resistance in relation to developing GPP criteria for road construction seems relevant.
RECYCLING	
2009	**RE-ROAD** The RE-ROAD project aims to develop knowledge and innovative technologies for enhanced end of life strategies for asphalt road infrastructures. The project was funded by the European Commission's Seventh Framework Programme. The project will cover the following aspects which are needed before an end of life strategy is developed: • Dismantling strategies • Characterization strategies for the waste types • Handling strategies and optimization of recycling (avoiding downgrading of materials) • Environmental criteria. LCA will be used as a tool for this assessment • Cost-effective recycling • Industrial processes (reduction of environmental impacts during recycling). Several reports have been published; one of them is "Optimization of Reclaimed Asphalt in Asphalt Plant Mixing" by Marjan Tusar et al from 2012. In this publication the barriers for recycling are identified and a Best Practice guide was produce to enhance surface course recycling.
2009	**SARMa Aggregates**
2012	**SNAP-SEE**
MAINTENANCE	
2009	**ERAnetI_Climate_Change** ***P2R2C2*** ***RIMAROCC***
2009	**ERAnetI_PO3_Maintenance**
2011	**ENR**
2013	**POTHOLE**
NOISE	
2005	**SILVIA Pororoelastic Asphaly Noise**
2006	**SPENS Noise Air Emission**
2007	**ERAnetI NOISE low-noise pavements**
2009	**PERSUADE Noise**

3.4.2 Pavement-vehicle interaction

3.4.2.1 Rolling resistance

Description of the effect of rolling resistance due to pavement surface conditions

For the purpose of this study, the focus shall be on the pavement contribution to rolling resistance. The features of the road surface which influence the rolling resistance are road surface irregularities in the macro- and megatexture and unevenness range (see Figure 3.13) (Haider et al, 2012)

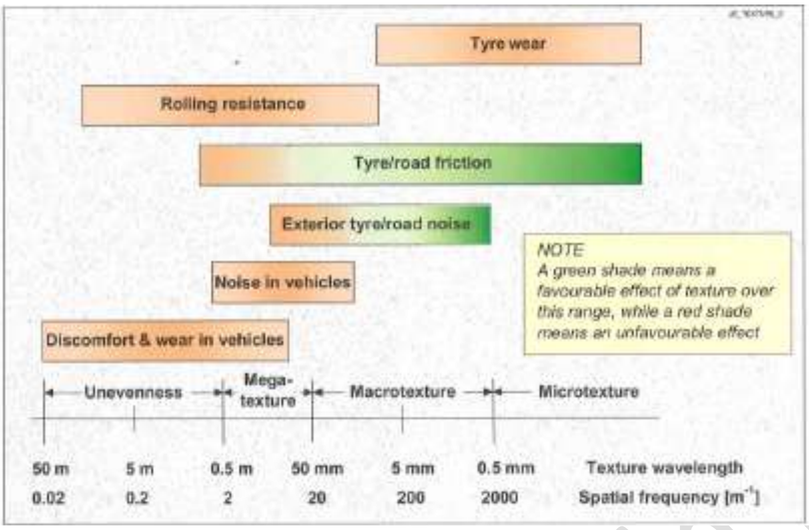


Figure 3.13: Texture and unevenness wavelengths and spatial frequencies with the most significant anticipated effects (Haider et al, 2012)

The rolling resistance force F_{roll} depends on the tyre load and weight and is expressed as a rolling resistance coefficient C_R by relating it to the force component F_Z normal to the pavement, which is pressing the tyre against the pavement surface:

$_{roll} = C_R F_Z$

The differences in rolling resistance induced by different pavement types can be measured if all other influencing parameters can be kept sufficiently constant or are accounted for. These include e.g. tyre type, tyre loads and pressures, temperatures, gradients, or wind speed.

Formulas for the determination of rolling resistance from other road surface properties typically take the following form:

One possible model has been used in the ECRPD project:

$$F_{roll} = m \cdot (\eta_0 + \eta_1 \cdot (25 - T) + \mu_0 \cdot MPD + \mu_1 \cdot v \cdot MPD + \lambda_0 \cdot IRI + \lambda_1 \cdot v \cdot IRI)$$

Where

MPD is the macrotexture measure (mm)

IRI is the road roughness measure, as International Road Index (mm/m)

m is the vehicle mass (kg)

v is the velocity (m/s)

T is the air temperature (C)

$\eta_{0,}$ $\mu_{0,}$ $\mu_{1,}$ $\lambda_{0,}$ λ_0 are constants coefficients

Methods to measure the rolling resistance

The rolling resistance of tyres is typically determined as a tyre-specific property by testing on a steel drum according to ISO 28580, "Passenger car, truck and bus tyres -- Methods of measuring rolling resistance -- Single point test and correlation of measurement results" (ISO, 2009). The resulting values characterize the tyre itself, but cannot be used to make a statement about the pavement influence on rolling resistance. Rolling resistance on a real road surface can be measured using one of the following methods:

a) Force or torque measurements in specialized trailers

b) Force or torque measurements in the wheel suspension or transmission

c) Coast-down measurements of vehicles including precise measurements of the (negative) acceleration

d) Measurements on drums fitted with a replica road surface

e) Fuel consumption measurements in closely controlled drive cycles

The trailer method (a) conducts measurements of rolling resistance using special tyre(s) mounted on a dedicated trailer. The trailer may be towed by a passenger car, a van or a truck as illustrated in Figure 3.14 and Figure 3.15.

Figure 3.14: Trailer method – equipment from The Technical University of Gdansk (picture from Sandberg, 2011).

Figure 3.15: Trailer method – equipment from IPW, Germany (picture from Sandberg, 2011).

In the coastdown method (c), a vehicle is allowed to roll in neutral gear from one velocity to a lower velocity. During the movement, deceleration and other parameters are measured and the rolling resistance can be derived. The coastdown method can be performed by speeding a car up to a certain driving velocity, shift to neutral gear and then let the car run (coast) until it comes to a halt. An example of the coastdown method is given in Figure 3.16.

Figure 3.16: Coastdown method – Nokian Tyres, Finland (picture from Sandberg, 2011)

The laboratory drum method (d) has test tyres rotate on drums. The drums may be equipped with sandpaper or asphalt/concrete, or the tests may be conducted using the steel surface of the drum. An example of a large steel drum is the tyre/pavement interaction facility at BASt in Germany (shown in Figure 3.17).

Figure 3.17: Laboratory drum – Tyre/pavement interaction test facility at BASt, Germany (picture from Sandberg, 2011).

The fuel consumption method (e) uses cars with special on-board monitoring devices, which allow the calculation of rolling resistance.

Methods a) and b) are in principle suitable for rolling resistance monitoring of pavements for longer road sections. The MIRIAM project has compared rolling resistance trailers from Germany, Poland and Belgium and has concluded that although the principle is promising further development is needed (Sandberg, 2011)

<u>*Primary parameters to feed rolling resistance models*</u>

1. Texture

The texture of a pavement is defined as the deviation of the pavement surface from a true planar surface within certain specified spatial wavelength ranges. ISO 13473-1 "Characterization of pavement texture by use of surface profiles – Part 1: Determination of Mean Profile Depth" defines the following ranges:

- Microtexture: Deviations of the pavement surface from a true planar surface with a spatial wavelength of less than 0.5 mm. These surface structures are typically smaller than both tyre tread features and pavement aggregate grain sizes.

- Macrotexture: Deviations of the pavement surface from a true planar surface with a spatial wavelength between 0.5 mm and 50 mm. These surface structures are in the size range of tyre tread features.
- Megatexture: Deviations of the pavement surface from a true planar surface with a spatial wavelength between 50 mm and 500 mm. These surface structures are comparable in size to the tyres and wheels themselves.
- Unevenness: Deviations of the pavement surface from a true planar surface with a spatial wavelength above 500 mm.

The texture wavelength ranges that contribute to a deformation of the tyre and induce rolling resistance losses are mainly in the macro- and megatexture. Texture parameters can be used in modelling rolling resistance and other surface parameters. Texture measurements could potentially substitute the direct measurement of several road surface properties like rolling resistance, skid resistance or noise emission if sufficiently accurate models were available. Texture measurements are typically easier to perform than the specific measurements for these individual properties, and some NRAs already include them in their pavement monitoring.

The ISO 13473-n series of standards covers the measurement of pavement texture with profilometers and associated indices. All indices are based on filtered longitudinal height profiles of the pavement surface typically recorded with a mobile or stationary laser profilometer.

The most commonly used parameter is the MPD (mean profile depth) as defined in ISO 13473-1 for an evaluation over lengths of 100 mm (see Figure 3.18). It is designed to indicate the typical elevation of profile peaks above an average profile baseline.

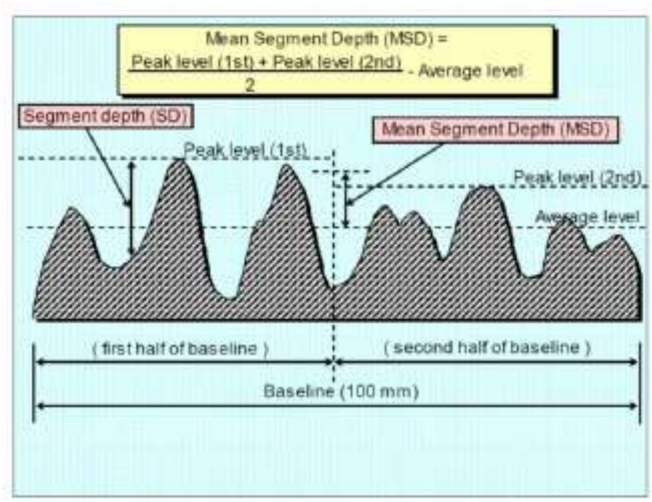


Figure 3.18: : Derivation of the MPD (which is equal to MSD) from texture profiles (Sandberg et al., 2002)

As such it gives a certain indication of the possible penetration depth of tyre features, but can also be used to ensure sufficient skid resistance and surface drainage. Other methods for Infrastructure effects on vehicle energy consumption analysis in the macro- and megatexture ranges are based on the spectral analysis of the profiles (Figure 3.19).

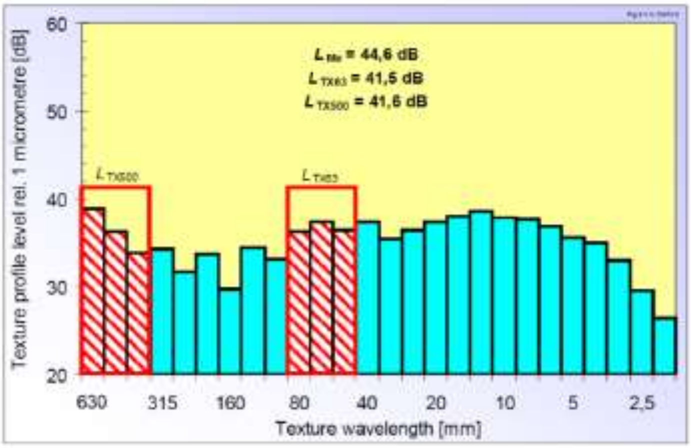


Figure 3.19: Example of spectral texture analysis using one-third octave bands (Sandberg et al., 2002)

The correlation of road texture profiles to rolling resistance can be improved by enveloping the texture profiles (Figure 3.20), which highlights the fact that tyres will not fully penetrate into the texture profile.

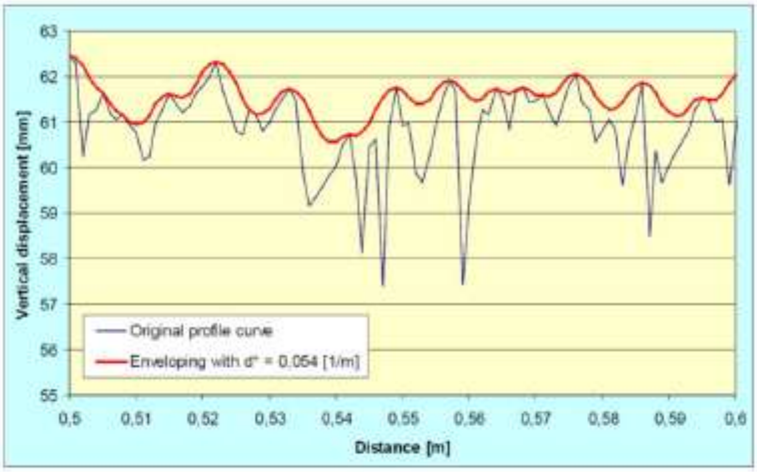


Figure 3.20: Enveloping of a texture profile to simulate the limited penetration depth of tyres (Sandberg, 2011)

The investigation of this technique in the MIRIAM project (Sandberg, 2011) has shown a marked increase in the correlation of MPD calculated from an enveloped profile with the rolling resistance coefficient CR compared to correlation analysis performed without enveloping. Further investigation in this direction could yield texture parameters which have even more significance for rolling resistance.

The MPD is also the texture parameter most frequently used for modelling rolling resistance (Haider, 2012) and pavement influence on vehicle fuel consumption. Figure 3.21 shows an example of modelling the impact of changes in MPD on fuel consumption, which was found to be 2.8% per unit of MPD in the presented case (IRI=1, v=90 km/h).

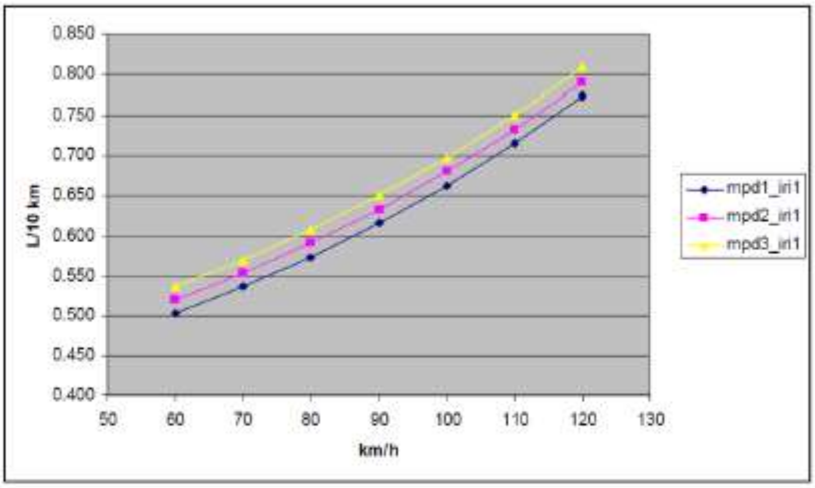


Figure 3.21: Modelling of changes in passenger car fuel consumption with MPD (MPD = 1,2,3 mm) in VETO (Hammarström et al, 2012)

The COST Report "Selection and assessment of individual performance indicators" (COST, 2008) gathered information about MPD requirements in EU Countries. It is important to highlight that the limit values within the Table 3.21 are aimed at keeping a MPD safety level, since texture directly affects how well tyres stick to the pavement in moist or wet conditions, and thereby indirectly affects skid resistance. Therefore, the limit values are minimum MPD that the road pavement shall comply with:

Table 3.21: MPD requirements in some EU Countries

COUNTRY	NAME	Performance indicator	THRESHOLD		WARNING		ACCEPTANCE		TARGET	
			TP	INDEX	TP	INDEX	TP	INDEX	TP	INDEX
CZECH REPUBLIC 1	Texture depth MPD	MPD	0,54		0,64					
CZECH REPUBLIC 2	Texture depth MPD	MPD	0,44		0,54					
FRANCE 1	Sand patch value MPD	MPD		40		60				

These thresholds and warning levels of MPD suggest that MPD is expected to decrease during the use phase, so just minimum values are foreseen, or that the monitoring of MPD is focus on the safety risks related to the decrease of this indicator.

Further information about the evolution of MPD was found in the MIRIAM project (Wang et al., 2012b) where a function to model MPD along the road lifetime was defined taking into account the climate conditions, particularly wet and dry freezes. An example of the results is shown in Figure 3.22.

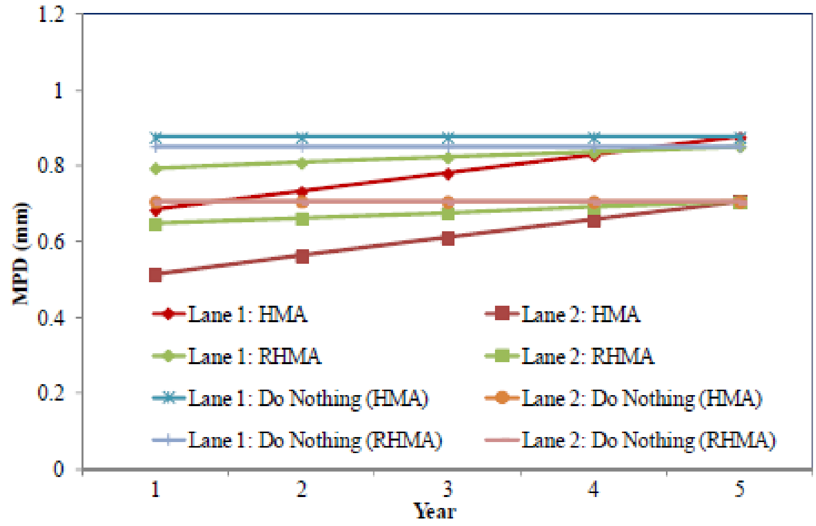


Figure 3.22: MPD evolution along the road lifetime (Wang et al., 2012b)

The study concluded that the MPD increases due to the road aging, and its progression is dependent on the material (HMA is hot mix asphalt and RHMA is reclaimed hot mixed asphalt) and the heavy traffic that the road bears (lane 2 bears more heavy traffic than lane 1, and thus the MPD is lower).

In the case of Sweden, COST 353 found that also maximum MPD thresholds were set, as shown in Table 3.22 :

Table 3.22: MPD thresholds in Sweden (under consideration)

MDP interval	90 - 110 km/h Motorways and other primary roads	70 km/h Secondary roads
0 - 0,3	Not suitable/very poor	Not suitable/very poor
0,31 - 0,5	Not suitable/very poor	Bad/poor
0,51 - 0,7	Bad/poor	Ok/very good
0,71 - 1,0	Ok/very good	Acceptable/good
1,01 - 1,50	Ok/very good	Bad/poor
1,51 - 2,00	Acceptable/good	Bad/poor
2,01 -	Bad/poor	Not suitable/very poor

When COST 354 report was released, these limits were not in use in Sweden, but under consideration.

2. Longitudinal unevenness

Longitudinal unevenness is defined as deviations from an ideally flat road surface in the range of spatial wavelengths between 0.5 m and 50 m (Figure 3.13).

Longitudinal unevenness is an important parameter for the ride comfort on road pavements.

It contributes to the overall road vehicle energy consumption via three mechanisms:

1) The longitudinal unevenness of pavements contributes to the rolling resistance of the tyre, albeit to a smaller degree than texture.

2) Longitudinal unevenness induces vibrations in the wheel suspensions. These vibrations have to be dampened to ensure ride comfort, which results in a conversion of mechanical energy into heat energy.

3) High levels of longitudinal unevenness will induce drivers to reduce the vehicle speed.

The effect of longitudinal unevenness on rolling resistance is considerably smaller than the effect of texture. This is to be expected due to the long wavelengths involved, which correspond to movements of larger sections of the whole vehicle than tyre tread elements (Haider et al., 2012).

However, the vibrations in the wheel suspensions lead to energy conversion into heat, and thus they should be considered when modelling the energy losses due to the interaction car-pavement

Longitudinal unevenness of pavements is closely related to ride comfort and is therefore a key parameter in pavement management. The European standard EN 13036-6 "Road and airfield surface characteristics - Test methods - Part 6: Measurement of transverse and longitudinal profiles in the evenness and megatexture wavelength ranges", specifies the measurement of longitudinal unevenness and the calculation of unevenness indices. It requires the measurement of a longitudinal road height profile with a sampling interval of 0.05 m. This profile is the basis for the calculation of different possible unevenness indices. The most common index is the IRI (International Roughness Index), which is intended to represent the reaction of a specific quarter-car model (golden car) to the road Infrastructure effects on vehicle energy consumption profile (Figure 3.23). The quarter-car model of the golden car includes a wheel with a tyre, a suspension spring with vibration dampener and the associated masses.

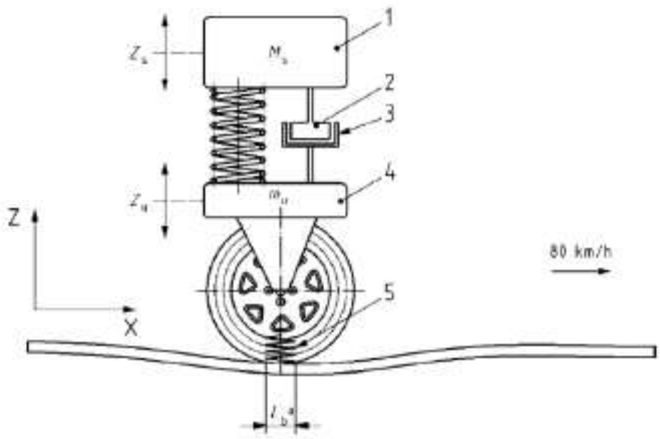


Figure 3.23: Golden Car model for the determination of the IRI (EN 13036-6)

IRI values are given as m/km. The IRI includes transfer functions representing the action of a suspension system; however, it is mainly designed as a measure for ride comfort.

The IRI is used for modelling the unevenness impact on vehicle fuel consumption (Hammarström et al., 2012). Figure 3.24 and Figure 3.25 show an examples of modelling the impact of changes in IRI on fuel consumption, which was found to be 0.8% per unit of IRI for a passenger car and 1.3% per unit of IRI for a truck (v=90 km/h in both cases).

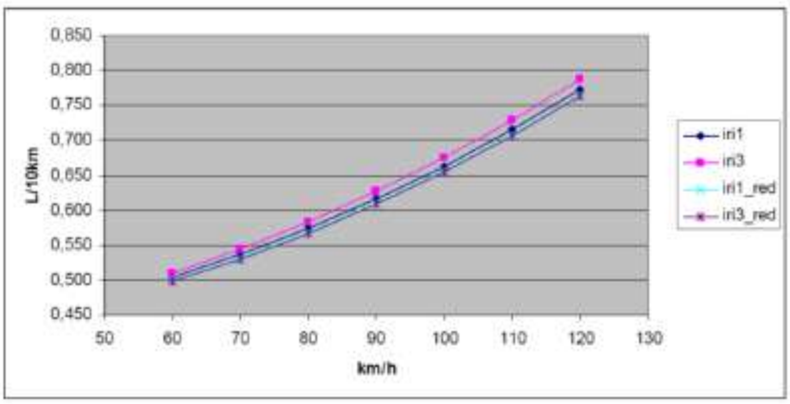


Figure 3.24: Modelling of changes in passenger car fuel consumption with IRI (IRI = 1,3) with (_red) and without IRI speed effect in VETO (Hammarström et al., 2012)

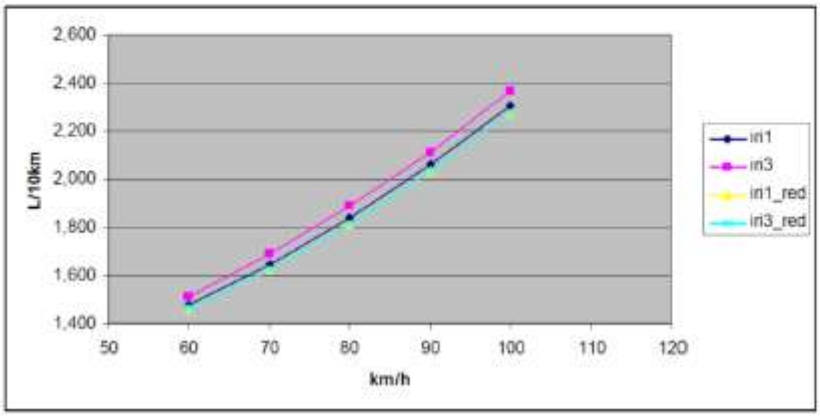


Figure 3.25: Modelling of changes in truck fuel consumption with IRI (IRI = 1,3) with (_red) and without IRI speed effect in VETO (Hammarström et al., 2012)

Apart from IRI, there are other types of technical parameters describing longitudinal evenness, albeit IRI is the most widely used across the EU countries (COST, 2008):

- wave length
- evenness
- longitudinal profile variance
- longitudinal profile
- spectral density
- standard deviation.

There are national requirements on the IRI value of roads across EU Countries, which were studied by COST (2008) Road Performance Indicators. The results of this study regarding the thresholds and classification based on IRI are gathered in Table 3.23, which does not comprise an all-inclusive list of IRI requirements in all EU countries:

Table 3.23: IRI limits across EU

	CROATIA (HR)	DENMARK (DK)	FINLAND (FI)	HUNGARY (HU)	ITALY (IT)	NETHERLANDS (NL)	PORTUGAL (PT)	SERBIA AND MONTENEGRO (CS)
NAME OF TECHNICAL PARAMETER	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index	International roughness index
MOTORWAYS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
OTHER PRIMARY ROADS	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
SECONDARY ROADS	YES (*)	Yes	Yes	Yes	No	No	No	Yes
SECTION LENGTH	100 m	1000 m	100 m	100 m	20 m	100 m	N/A	25 m
NUMBER OF CLASSES	5		5	5	5		3	5
SCALE VERY POOR	5		1	5	E			10
SCALE VERY GOOD	1		5	1	A			1
NAME CLASS 1	very good		very good	1	A – Excellent		Good	very good
NAME CLASS 2	good		good	2	B – Good		Fair	good
NAME CLASS 3	fair		fair	3	C – Sufficient		Poor	fair
NAME CLASS 4	poor		poor	4	D – Mediocre			poor
NAME CLASS 5	very poor		very poor	5	E – Poor			very poor
CLASSIFICATION CRITERIA 1			AADT < 1500					
CLASSIFICATION CRITERIA 2			AADT 1500 - 6000					
CLASSIFICATION CRITERIA 3			AADT > 6000					
THRESHOLD TP 1	5		4.1			3.5		
THRESHOLD TP 2			3.5					
THRESHOLD TP 3			2.5					
WARNING TP 1	3.5					2.6		
ACCEPTANCE TP 1	2.5							
TP LIMIT 1 (CRITERIA 1)	1	0		0	0		0	1
TP LIMIT 2 (CRITERIA 1)	1.5	1.5		1.5	1.5		2	2.5
TP LIMIT 3 (CRITERIA 1)	2.5	2.5		2.2	2		3	3.5
TP LIMIT 4 (CRITERIA 1)	3.5	5		3	2.5			5.5
TP LIMIT 5 (CRITERIA 1)	5			4.5	3			7

(*) information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

Some countries use transformation to a dimensionless Index, IRI (Table 3.24), which needs a transformation functions from IRI to Index IRI (see rows "Classification functions" in Table 3.24)

Table 3.24: Index IRI (dimensionless) limits across EU

	AUSTRIA (AT)	POLAND (PL)	SLOVENIA (SI)
NAME OF TECHNICAL PARAMETER	International roughness index	International roughness index	International roughness index
MOTORWAYS	Yes	Yes	Yes
OTHER PRIMARY ROADS	Yes	Yes	Yes
SECONDARY ROADS	No	No	Yes
SECTION LENGTH	50 m	1000 m	100 m
INDEX NAME	Index roughness	Index roughness	Index roughness
INDEX DESCRIPTION	Index_IRI	Representative IRI	Index IRI
NUMBER OF CLASSES	5	4	5
SCALE VERY POOR	5	D	5
SCALE VERY GOOD	1	A	0
NAME CLASS 1	1 – very good	A – good	very good
NAME CLASS 2	2 – good	B – fair	good
NAME CLASS 3	3 – fair	C – poor	fair
NAME CLASS 4	4 – poor	D - bad	poor
NAME CLASS 5	5 – very poor		very poor
CLASSIFICATION CRITERIA 1	1.0<=I_IRI<=5.0; road category A and S		AADT>2000 Or ESAL82kN/day>80
CLASSIFICATION FUNCTION 1	1+0.7778*IRI	10*IRIp	
THRESHOLD TP 1	4.5	5.7	
THRESHOLD IND 1	4.5	57	
WARNING TP 1	3	4.5	
WARNING IND 1	3.5	44	
CLASSIFICATION CRITERIA 2	1.0<=I_IRI<=5.0; road category B		AADT<2000 Or ESAL82kN/day<80
CLASSIFICATION FUNCTION 2	1+0.5833*IRI		
THRESHOLD TP 2	6		
THRESHOLD IND 2	4.5		
WARNING TP 2	3.8		
WARNING IND 2	3.5		
INDEX LIMIT 1	1	0	0
INDEX LIMIT 2	1.5	20	1
INDEX LIMIT 3	2.5	44	2
INDEX LIMIT 4	3.5	57	3
INDEX LIMIT 5	4.5		4
INDEX LIMIT 6	5		5
TP LIMIT 1 (CRITERIA 1)	0	0	0
TP LIMIT 2 (CRITERIA 1)	1	2	1.2
TP LIMIT 3 (CRITERIA 1)	1.8	4.4	1.5
TP LIMIT 4 (CRITERIA 1)	3	5.7	2.2
TP LIMIT 5 (CRITERIA 1)	4.5		3.1
TP LIMIT 1 (CRITERIA 2)	0		0
TP LIMIT 2 (CRITERIA 2)	0.9		2.6
TP LIMIT 3 (CRITERIA 2)	2.6		3.5
TP LIMIT 4 (CRITERIA 2)	3.8		4.3
TP LIMIT 5 (CRITERIA 2)	6		4.9

	Very good – Good	Good – Fair	Fair – Poor	Poor – Very poor
More restrictive group				
ITALY (IT)	1,5	2,0	2,5	3,0
NETHERLANDS (NL)			2,6	3,5
PORTUGAL (PT)		2,0	3,0	
SLOVENIA (SI)	1,2	1,5	2,2	3,1
MIN	**1,2**	**1,5**	**2,2**	**3,0**
MAX	**1,5**	**2,0**	**3,0**	**3,5**
AVERAGE	**1,3**	**1,8**	**2,6**	**3,2**
Less restrictive group				
AUSTRIA (AT)	1,0	1,8	3,0	4,5
CROATIIA (HR)	1,5	2,5	3,5	5,0
DENMARK (DK)	1,5	2,5		5,0
FINLAND (FI)		2,5	3,5	4,1
HUNGARY (HU)	1,5	2,2	3,0	4,5
POLAND (PL)		2,0	4,4	5,7
SERBIA AND MONTENEGRO (CS)	1,0	2,5	3,5	5,0
MIN	**1,0**	**1,8**	**3,0**	**4,1**
MAX	**1,5**	**2,5**	**4,4**	**5,7**
AVERAGE	**1,3**	**2,3**	**3,5**	**4,9**

Although the majority of European countries use IRI as technical parameter describing the longitudinal evenness of a pavement, some countries use other technical parameters:

- Wavelength,
- Evenness
- Longitudinal Profile Variance

The same report also provides classifications and criteria of longitudinal unevenness based on these parameters (other than IRI) used in EU Countries, as shown in Table 3.25

Table 3.25: Classifications and criteria of longitudinal unevenness based on these parameters (other than IRI) used in EU Countries

COUNTRY	NAME OF TECHNICAL PARAMETER	INDEX NAME	INDEX DESCRIPTION	NUMBER OF CLASSES	SCALE VERY POOR	SCALE VERY GOOD	TRANSFORMATION							
							CRITERIA 1	FUNCTION 1	CRITERIA 2	FUNCTION 2	CRITERIA 3	FUNCTION 3	CRITERIA 4	FUNCTION 4
BELGIUM (BE) 1	Evenness	Index roughness	index evenness	5	0	1	Motorways	1-VLI/U400	Primary	1-VLI/U400	Secondary	1-VLI/U400		
BELGIUM (BE) 2	Evenness			5	E	A								
BELGIUM (BE) 3	Evenness			5	E	A								
CZECH REPUBLIC (CZ)	Evenness	Index roughness	index IRI	5	5	1	for all	1.23*C^0.23						
FRANCE (FR) 1	Wave length	Index roughness	Short wavelength index	5	E	A								
FRANCE (FR) 2	Wave length	Index roughness	Long wavelength index	5	E	A								
FRANCE (FR) 3	Wave length	Index roughness	Medium wavelength index	5	E	A								
GERMANY (DE) 2	Wave length	Index roughness	Index Periodical Unevenness	5	5	1	v<=0, function class 1	IF(v<=-0.549;1;3.5+v^4/(ln3))	v>0, function class 1	IF(v>0.549;5;3.5+v^2/(ln3))				
GERMANY (DE) 3	Wave length	Index roughness	Index Single Obstruction	5	5	1	v<=0, function class 1	IF(v<=-0.549;1;3.5+v^4/(ln3))	v>0, function class 1	IF(v>0.549;5;3.5+v^2/(ln3))				
UNITED KINGDOM (UK) 1	Longitudinal profile variance	Index roughness	3m LPV Index	4	4	1	3mLPV <0.7 (1), <0.8 (2), <1.4 (3)	1	3mLPV >=0.7 (1), >=0.8 (2), >=1.4 (3)	2	3mLPV >=2.2 (1), >=2.2 (2), >=3.8 (3)	3	3mLPV >=4.4 (1), >=5.5 (2), >=9.3 (3)	4
UNITED KINGDOM (UK) 2	Longitudinal profile variance	Index roughness	10m LPV Index	4	4	1	mLPV <1.8 (1), <2.8 (2), <6.1 (3)	1	3mLPV >=1.8 (1), >=2.8 (2), >=6.1 (3)	2	3mLPV >=6.5 (1), >=8.6 (2), >=16.3 (3)	3	3mLPV >=14.7 (1), >=22.8 (2), >=36.5 (3)	4
UNITED KINGDOM (UK) 3	Longitudinal profile variance	Index roughness	30m LPV Index	4	4	1	mLPV <22 (1), <30 (2), <48 (3)	1	3mLPV >=22 (1), >=30 (2), >=48 (3)	2	3mLPV >=66 (1), >=75 (2), >=97 (3)	3	3mLPV >=110 (1), >=121 (2), >=193 (3)	4

3. Transversal unevenness

In addition to the its intentionally designed crossfall, the road surface will also exhibit deviations from this ideal transversal profile in the form of ruts, steps, ridges, bumps and edge slumps (Figure 3.26). Ruts typically form in the wheel paths as a result of the action of the wheels on the pavement material.

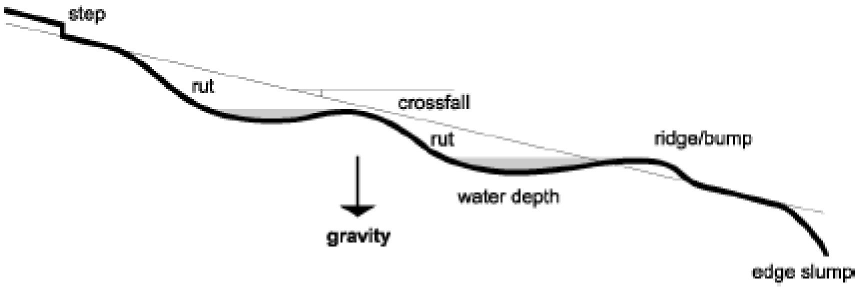


Figure 3.26: Crossfall and transversal unevenness features

Both crossfall and transversal unevenness have the potential to induce an increase in vehicle fuel consumption. Transversal unevenness can act similar to longitudinal unevenness by inducing increased tyre deformation and suspension losses. This will especially be true if the lateral position of transversal unevenness features changes considerably, which either introduces additional encountered longitudinal unevenness or the need for frequent steering corrections. Transversal unevenness does also have a similar effect on driving speed as longitudinal unevenness, inducing drivers to reduce speed with increasing transversal unevenness.

The measurement of transversal unevenness is defined in EN 13036-6 and EN 13036-8. While no specific measurement device is prescribed, typically a straightedge or a laser profilometer is used. The parameters used to describe the transversal unevenness are the rut depth, the height of the different irregularities and the theoretical water film depth for water accumulating in the ruts. These parameters are typically determined every 5 to 10 m and averaged for longer intervals of e.g. 100 m. Crossfall and rut depth typically constitute the major deviations from an ideal horizontal road surface and are therefore the best candidates for the inclusion in models. The main parameter used for transversal unevenness is average or maximum rut depth.

4. Surface irregularities

The presence of surface irregularities like joints or surface defects like cracks, ravelling, potholes, loss of material may introduce additional features of longitudinal and transversal unevenness as well as texture. This means that the impacts on fuel consumption can in general be described by the parameters associated with these surface properties. However, in the case of severely damaged surfaces there may be additional energy dissipation. These types of surfaces will in general have to undergo maintenance for safety reasons in any case.

In addition to the already mentioned parameters for longitudinal and transversal unevenness an area or longitudinal density of surface defects could be defined. This would include the identification and classification of relevant surface defects in the course of already performed crack detection surveys. The classification would have to take the predicted impact of the identified type of surface defect on fuel consumption onto account and determine the number of these defects per unit area or per km of road length. This can then be converted into an indicator for the predicted additional fuel consumption.

3.4.2.2 Road strength and bearing capacity

Description of the mechanism

In the tyre-road contact zone the road surface will be deformed as well as the tyre. If the pavement material exhibits a hysteresis, energy will be lost. It is in principle to be expected that this effect is larger for flexible pavements than for rigid pavements. The details of this effect will depend on the layer structure of the pavement. However, the energy dissipated in the tyre deformation was found to be substantially larger than that of the pavement deformation (Schmidt et al., 2010).

The bearing capacity of pavements, which is a measure of the road strength, can be measured with a falling weight deflectometer (FWD), deflectograph and other devices.

It was found, that rolling resistance due to pavement deformation was only a few percent of the overall rolling resistance, which is a much lower impact that the effect of e.g. texture. If very accurate models will be available in the future, they may have to take this effect into account at least for very weak road pavements.

Regarding the measurement of this parameter, COST (2008) explored the methods applied in the EU countries, resulting in the folmuchovalowing ones gathered in Table 3.26:

Table 3.26: Methods to measure deflection used in EU Countries

Country	Standard [NS = national standard; IS = international standard; TS = technical specification]	Technical Parameter
Austria	NS: Evaluation according to RVS 11.066-Teil III, Deflektionsmessung Benkelmanbalken, optische Methode und Deflectorgraf Lacroix	Deflection
Croatia(*)	NS: HRN U.E4.016: Equipment and methods of deflection measurements HRN U.E4.018: Determination of relevant elastic deflection for flexible pavements	Deflection
Denmark		Deflection velocity
	NS: Konstruktion og vedligehold af veje og stier, Hæfte 4, Vedligehold af færdselsarealet, Juni 2004.	Deflection
France	NS: Méthode LPC n° 39	Deflection
Greece	TS: FWD measurements and evaluation: Draft report of NTUA for the Greek Public Ministry	Deflection
		Structural number
Hungary	TS: ÚT 2-2.121/2000 Dinamikus behajlásmérés méretezéshez (KUAB) (Dynamic bearing capacity meassurement by KUAB apparatus)	E-Modulus
Italy	TS: ASTM D 4694-96; ASTM D 4595-96; ASTM D 5858-96	Deflection
Portugal		Deflection
Serbia and Montenegro	NS: JUS U.E8.016 (1981), JUS U.E8.018 (1981)	Deflection
Slovenia	NS: TSC 06.630 Pavement surface properties, Deflections	Residual life
Spain	NS: NLT 338/98 Medida de las deflexiones de firmes con deflectómetro de impacto. 6.3 I.C. Instrucción para la rehabilitación de firmes	Deflection
		Deflection
Switzerland	NS: SN 670 362a "Poutre de Benkelman"	Deflection
United Kingdom		Deflection
		Deflection

* information not in the COST database used for the analysis, obtained during the WG2 work. It is not included in the following distribution analyses.

3.4.3 Asphalt

Standard asphalt is hot mix asphalt (HMA), which is produced by means of drying and heating aggregates and bitumen at temperatures between 120° and 190°C. Energy consumption required to produce 1 t of HMA about 400 MJ and GHG emission of 22 kg CO2e according to Stripple (2001).

The scientific and technical community have developed a number of new technologies for asphalt materials, generally referred to as warm mix asphalt (WMA), which require lower production temperature than the hot asphalt mixes (HMA) (D'Angelo et al., 2008; Capitão et al., 2012; Rubio et al., 2012) These asphalt mixes can be classified in terms of the manufacturing temperature used to produce them (Figure 3.27):

- cold mix asphalt (CMA), manufactured at a temperature lower than 60°C;
- half-warm mix asphalt (HWMA) manufactured at less than 100°, usually at 70-95°C;
- warm mix asphalt (WMA) manufactured at temperatures of 110-140° (EAPA, 2010).

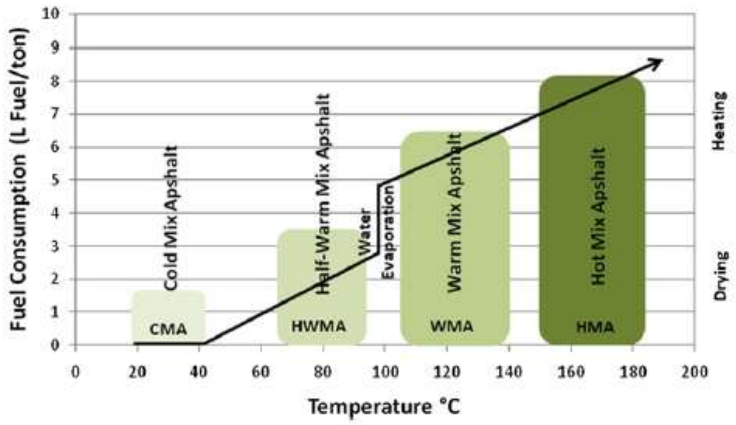


Figure 3.27: Asphalt mix classifications according to manufacturing temperature (Rubio et al., 2013)

The asphalt mixing temperature is reduced using organic additives, chemical additives and foaming bitumen technologies (by adding small amount of cold pulverized water into preheated bitumen), which improve the viscosity of the material. The energy consumption in producing and transporting these additives is not known, but it should be included in a full life cycle analysis.

3.4.3.1 Warm mix asphalt

WMA holds a potential for energy savings compared to HMA since the former requires less energy for heating of the materials during production. According to the market analysis the production of WMA was around 7 Mt in Europe (EAPA, 2012), corresponding to about 2% of the total production of bituminous mixtures. The trend in employing WMA is increasing. France[9] has increased the WMA production by 5 times in 2008-2012 (up to 2.6 Mt) and it account by 7.3% of the French production (against 15% in Switzerland and 30% in the United States). USIRF reported that the goal of 10% reduction in CO2 emissions would be largely achieved through the increased WMA production (as it is shown in Figure 3.28).

9 Personal communication of USIRF

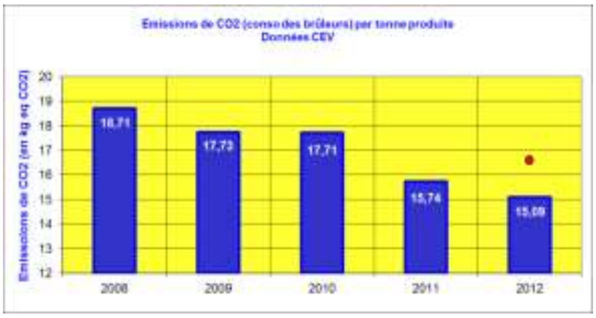


Figure 3.28: CO2 emissions reduction due to WMA production

A significant reduction on GHG emissions has been reported. Evaluations carried out in a number of European countries made it clear the decreasing of various emissions throughout the production process in plant, as follows: 30–40% for CO_2 and SO_2, 50% for VOC, 10-30% for CO, 60-70% for NO_x, and 25-55% for dust (EAPA, 2010; D'Angelo et al., 2008). Reductions from 30% to 50% for asphalt aerosols/fumes and polycyclic aromatic hydrocarbons (PAHs) have also been reported.

Lowering the production temperature allows reducing the energy consumption typically in a range from 10 to 30%, depending on the WMA process applied, despite higher values can be found in the literature (D'Angelo et al., 2008). EAPA (2007) states that on average an asphalt plant employs 75-110 kWh to produce 1t of asphalt, while a reduced mix temperature of 35°C may reduce energy consumption by approximately 10 kWh per 1 t of asphalt. In addition, dry aggregates and optimized methods and equipment may help reducing energy consumption at asphalt plants. According to Rubio et al. (2013), HWMA consume up to 50% less energy than HMA.

Laying and compaction operations are generally improved, as workability of WMA is adequate and the release of fumes and odours for workers is much lower. Even if paving conditions are challenging WMA is usually a good contribution to help paving operations.

The WMA technique can be applied on all the traditional types of asphalt and it can also be used with recycled asphalt as aggregate. In the US, WMA is often used on mixtures containing rubber. In detail, according to Rubio et al. (2012), the main advantage of WMA is the potentially greater use of Reclaimed Asphalt Pavement (RAP). Because of the increased workability of WMA mixes, it can contain a higher percentage of RAP (Bonaquist, 2011; Brown, 2008). Certain studies even recorded RAP percentages of over 50% (Vaitkus et al., 2009; D'Angelo et al., 2008).

According to different authors (D'Angelo et al., 2008; Capitão et al., 2012; Rubio et al., 2012; Rubio et al., 2013) WMA and HMA show similar quality, workability and mechanical performances. EAPA (2010) reports experience from Germany and Norway with performance of WMA similar to HMA. Although originally invented in Europe, WMA has primarily found use in the USA, where experience is building up (Jones et al., 2009). Moreover, the generally good workability of WMA results in a lowered void content compared to conventional HMA (Capitão et al., 2012). Resistance to fatigue (evaluated according to the EN 12697-24) and to cracking at low temperature of WMA is apparently generally good. WMA shows the benefit of being employed in cold weather paving, stemming from the fact that mix temperature is closer to ambient temperature. In hot climates, permanent deformation performance (evaluated in Europe according to the EN 12697-22 by means of the wheel-tracking test) is crucial: this performance behaviour appears very dependent on the production lowering temperature achieved. Rubio et al. (2012) have also indicates possible drawbacks of WMA as following listed:

- Rutting, mainly caused by the less ageing of the binder because of the lower production temperatures, as well as moisture susceptibility of WMA mixes
- Cost effectiveness: Although WMA promises a significant reduction in energy consumption, initial costs, in addition to royalties, could discourage contractors
- Moisture susceptibility: the lower compaction temperature used may increase the potential for moisture damage. To prevent this susceptibility, a proper mix design is thus essential. Of the many ways to prevent stripping in a pavement, the use of anti-stripping agents (ASAs) is the most common method

- Long term performance: due to the relative newness of these products, field test sections are still few in number, and they also have a short life (seven years in the USA and over ten years in certain European countries). For this reason, it is not as yet possible to talk about-long term performance. To date, in the USA no significantly negative long-term performance has been reported (Chowdhury and Button, 2008), and in Europe the trial sections of WMA have performed as well as or better than HMA overlays (D'Angelo et al., 2008).

3.4.3.2 Cold mix asphalt

Another low-energy option is CMA, which is produced without heating the aggregate and with a bitumen emulsion as binder (EAPA, 2007). According to Rubio et al. (2013), even though these new technologies are more environmentally friendly, CMA is not as yet a serious alternative to HMA since its performance is somewhat less effective. CMA is thus limited to the rehabilitation of deteriorated pavement on roads with a low vehicle traffic load.

3.4.3.3 Reclaimed asphalt pavement (RAP)

RAP is produced by milling the overlay and demolishing the surface course and is re-used by adding to the asphalt mix together with new aggregates and new bitumen. RAP can also be used as road base material, in this case this case, recycled aggregates are stabilised with bitumen emulsion and/or cement. In some cases sand and/or water are added. It can also be recycled as an unbound material in the road sub-base. RAP grains play a similar role as natural aggregates and binder and their re-use allows natural resources saving and environmental impacts reduction.

According to EAPA (2013), in Europe are nowadays produced 56 Mt of RAP and more than 85% of the asphalt is re-used back into pavement materials (EAPA, 2013). This high re-use/recycling percentage is related to the current trends and legislation stimulating reuse of materials (WFD 2008 see Section 1.3.1.4). It has to be underlined that data greatly varies from member state to member state. The range of recycled materials is from approximately 4% of the available RAP in Poland to 100% in Hungary. Furthermore, the percentage of the new hot and warm mix production that contains RAP varies from 0.01% to 80%. The wide range expresses the fact that the Member States have very different approaches towards the use of recycled materials. France[10] has increased the re-use and recycling of RAP: in 2007 the percentage of RAP reintroduced into the asphalt mixing plants was 24% and it has been increased up to 61.9% in 2012, compared to the estimated total stock of materials resulting from the demolition bituminous roads (6.5 Mt/y). The production of RAP has reached therefore 4Mt in 2012 and it represents 12% of the aggregate need for HMA in France.

10 Personal communication of USIRF

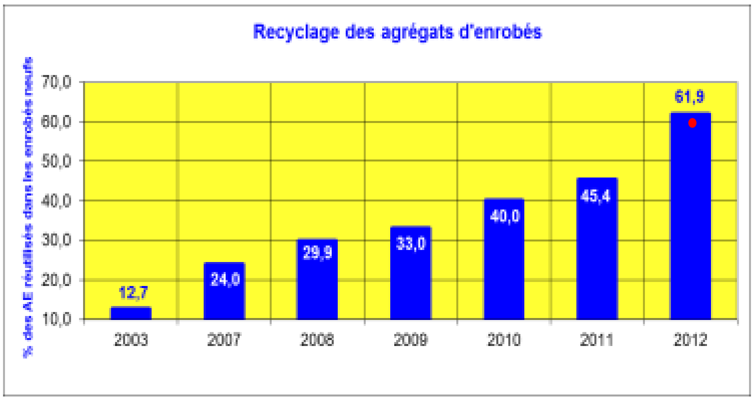


Figure 3.29: Production of RAP in France

The EU research project Re-road (http://re-road.fehrl.org/) focused particularly on the analysis of end of life strategies of asphalt pavements (Kalman et al., 2013). According to the outcomes of this project, in Europe the experience in reusing RAP in new asphalt production is well consolidated, even if there is a significant variation in the member states and the consequence is that nowadays a large amount of demolished asphalt pavement is still down cycled as unbound granular material in the sub-base layers, where neither the bituminous binder nor special aggregates are used at their full potential. A RAP grain is composed by a natural aggregates grain wrapped by a thin layer of bitumen; when including these grains in a new asphalt mix, less amount of bitumen is needed in comparison to a mix without RAP, due to the fact that a quantity of bitumen is already wrapped to the RAP grains.

Figure 3.30: RAP grain

It is reported that in off-site asphalt mixing plant, a percentage of 20-30% of RAP is usually employed. Percentage up to 40% of RAP have been analysed in the project, but only for short time performances (3 years). With reference to the RAP reused in close cycle in situ, it is mentioned the example of 300 km of road in Sweden, in which high content of RAP have not led to a decrease of the pavement performances. It is concluded that optimum content of RAP in asphalt mixtures varies from country to country, from 7 to 50% in mass. In the Netherlands in wearing course optimum content of RAP is 30% and in the base course 50%.

From an environmental point of view, it has to be underlined that old pavements potentially could contain unwanted materials. For example, in the project Re-road it is estimated that in Sweden at least 10% of the yearly handled demolished asphalt pavement is contaminated. This figure could be representative of Western Europe, while the problem with contaminated RAP could be higher in Eastern Europe, due to the use of tar until the '90s. Three potential source of contamination, that might be able to leach into the water run off or infiltrate the road surface, have been analysed, by means of a risk assessment analysis, within the Re-road project:

- Contaminants in bitumen, aggregates and additives
- Contaminants that built up on the surface of the road during its previous pavement life
- Contaminant that built up during the life of the newly laid pavement containing RAP

The highest leaching levels, exceeding the limit value considered in the project (guidelines of the Environmental Protection Agency of Ireland, 2003. Towards setting guidelines values for the protection of groundwater in Ireland) were associated to RAP containing tar. According to the definition in the EURAL waste list: "Reclaimed Asphalt containing more than 0.1 % coal tar should be regarded as hazardous waste. In case of asphalt containing tar, the waste is considered hazardous and the hot recycling is not allowed. In some countries it is allowed to rely on cold techniques with or without binders (emulsion, foam bitumen, and or hydraulic binders)" (EAPA, 2007).

From a LCA point of view (see literature review Wayman et al., 2012), it has been evaluated that a low level recycling (15-30% of RAP in the bound course) is significantly more environmentally beneficial employing the RAP in the sub-base course (Figure 3.31). More advantages can be demonstrated taking into account that RAP can substitute high specification aggregates (natural resources savings). Moreover, it is evaluated that RAP is significantly more environmentally beneficial than WMA.

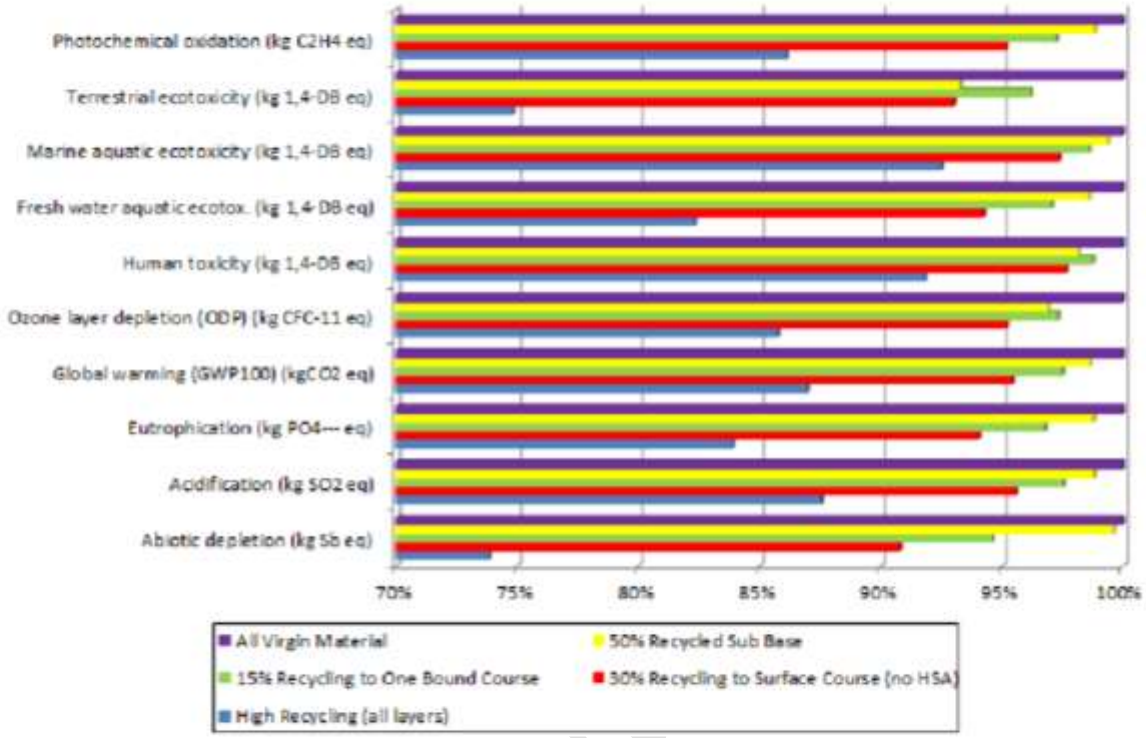


Figure 3.31: Effect of varying recycling routes and rates on different impact categories

3.4.4 Cement

Cement is basically a dry powder that, when mixed with water, forms a fluid paste that can be combined with aggregates before setting and hardening into a solid concrete mass with useful technical properties. There are different types of cement available such as Calcium Aluminate cement (CAC) or Calcium-Sulfo-Aluminate cement (CSA). However, by far the most dominant cement used in road construction, is Portland cement (PC). Unless otherwise specified, the data in this chapter refers to PC.

Typical ranges of cement content are 250-400kg/m^3 of concrete or, assuming a general concrete density of 2400kg/m^3, cement accounts for 10-17% of concrete mass. Despite the relatively low content of PC, the environmental impacts of concrete are dominated by the cement component (Marceau et al., 2007). The precise cement content used in a particular application will depend on the concrete properties required and the nature of the PC category (see section 3.4.4.3).

As a very general rule 1 tonne of CO_2 is emitted for the manufacture of 1 tonne of Portland cement. Approximately half of this emission is due to decarbonation of limestone during firing and the other half is due to energy consumption in heating the kiln and operation of other ancillary equipment. Traditionally, PC has consisted of around 95% cement clinker and 5% gypsum ($CaSO_4.2H_2O$) – i.e. CEM I type formulation. However, the cement industry has improved significantly in a number of aspects which has led to a reduction in CO_2 emissions in modern plants. The main factors that affect the environmental impact of PC production are:

- The kiln technology used to manufacture the clinker.
- The fuel types used to fire the kiln (and pre-calciner where relevant).
- The clinker content of the cement.

When deciding on the best environmental choice of cement for a particular road construction, the transport of cement may also be important.

3.4.4.1 Portland cement production and kiln technology

Portland cement manufacture involves burning ground mixtures of approximately 80% limestone and 20% clay/shale at temperatures of 1450°C to form cement clinker. The clinker is then cooled and ground together with a controlled quantity of gypsum to for Portland cement. All cement plants use a rotary kiln to fire the feed material but these can be split into four broad categories of kiln:

- **Wet process**: (long wet kilns) where raw materials are fed to the kiln as slurry. The kilns had to be very long to account for evaporating all the water plus the later clinker formation reactions.
- **Semi-wet process**: (long kilns) where the raw material slurry is dewatered to a "cake" before being fed to the kiln.
- **Semi-dry process**: (long kilns) where dewatered "cake" enters a pre-heater chamber before passing to the kiln.
- **Dry process a)**: (short kiln with pre-heater) where "dry" feed material is dried and heated up by contact with kiln exhaust gases.
- **Dry process b)**: (short kiln with pre-heater and pre-calciner) where "dry" feed material is dried and heated up by contact with kiln exhaust gases and calcined prior to entering kiln.

The rotary kiln is the heart of the cement production process and is where the majority (up to 90%) of primary energy consumption occurs (Worrell, 2000). Historically, the evolution of cement kiln technology worldwide has been from wet to dry processes. Wet processes were favoured (in the UK at least) for many decades due to use of wet raw materials (moisture content >20%) because the use of slurries as kiln feed greatly simplified the milling and blending of raw materials and avoided problems of dust blow-off from earlier kiln designs. The specific energy consumption is lowered as the kiln feed becomes "drier", for obvious thermodynamic reasons. According Habert et al., (2010), the following specific energy consumptions can be generally applied to each kiln type.

Table 3.27: Specific primary energy consumption values for Portland cement production by different types of kiln.

Kiln type	Wet process	Semi-dry process	Dry process with pre-heater	Dry process with pre-heater and pre-calciner	Theoretical minimum thermodynamic energy requirement
Specific energy consumption	5000-6000 (GJ/t clinker)	3300-4500 (GJ/t clinker)	3100-4200 (GJ/t clinker)	2900-3000 (GJ/t clinker)	1800 (GJ/t clinker)

It is generally accepted that there is little potential to significantly improve the thermal performance of the best available cement kiln technology any further (Gartner, 2004). According to Schorcht et al., (2013), there were 377 cement kilns in the EU-27 in 2008 of which only 268 were in operation. They state that almost 90% of PC produced in the EU was via dry process kilns, 7.5% via semi-dry or semi-wet type kilns and just 2.5% via wet kilns.

As fuel costs continue to rise, the shift towards dry kilns is inevitable. One reason why wet process kilns may still be in operation in the EU is due to the lack of "dry" raw material availability. Another factor is that cement kilns are capital intensive and have long periods of return on investment (meaning they have to run for decades to justify the original capital investment).

3.4.4.2 The use of wastes/industrial by-products as alternative fuels

Traditionally cement kilns were fired with fuel oil or natural gas - fuels of consistent quality and easy to control. Following the OPEC oil embargo in 1973, the cement industry shifted more towards coal as a fuel source and also underwent a period of rapid innovation into not only more energy efficient kilns, but also the potential for using alternative fuels.

In theory, any waste that possesses a calorific value can be used as an alternative fuel. However, it is better if the calorific value is similar to those of traditional fuels such as coal (26-30MJ/kg) and fuel oil (40-42MJ/kg) (Williams, 2005). In the EU, there is an increasing tendency of using alternative fuels derived from waste in cement kilns. There are examples of both non-hazardous and hazardous wastes. The nature of the rotary kiln process offers a number of advantages over traditional waste incinerators or energy recovery plants, which can be summarised as follows:

- Gas retention times of about 8 seconds at temperatures >1200°C. Maximum temperature of 2000°C in the primary burning zone of the main burner.
- Solid material temperatures of around 1450°C in the sintering zone of the kiln.
- Oxidising environment, which coupled with temperatures and residence times, can guarantee thermal destruction of persistent organic pollutants.
- Waste heat from kiln is efficiently re-used in dry kilns with pre-heaters.
- Any inorganic ash wastes from solid alternative fuels can be incorporated into the cement clinker (this can be an advantage or a disadvantage).

According to CEMBUREAU, an average of around 34% of fossil fuel requirements in the cement industry was met by the use of alternative fuels in 2011. There was considerable difference between member states, where some had exceeded 60% of fossil fuel requirements on average and some individual plants achieved 100% reliance on alternative fuels. Pet coke is a very common fuel used in the cement industry although since it is a by-product of crude oil refining, it is debatable whether it could be considered as an "alternative" fuel. Some examples of alternative fuels are given below.

- Rubber tyres (either whole or shredded).
- Secondary liquid fuels (recycled inks, solvents, thinners, oils and residues).
- Animal meat and bone meal.
- Wood and packaging wastes (non-recyclable paper, cardboard and plastics).

- Sawdust impregnated with hazardous substances (from industrial processes)

Whether or not these alternative fuels can be considered as "carbon neutral" or not is a matter for debate. However it is certain that for many of these wastes, their use in a cement kiln is the Best Practicable Environmental Option and that a considerable difference may exist between one plant and another.

3.4.4.3 The clinker content of cement

In general, cement plants in the EU have already made much progress in the shift towards lowering kiln energy consumption and embracing the potential for using alternative fuels. Do to the relatively low bulk value of cement, road transport is limited to 200-300km before transport begins to significantly influence the product price. However, longer distances may be possible where rail and boat transport is available.

Regardless, in a number of examples for road construction projects, it will be likely that, due to geographical limitations, the choice of cement provider is limited to only a few different producers. In these cases, the third major impact on the emissions associated with Portland cement becomes the most important – the clinker content of the cement. It is envisaged that this factor will also be most relevant to later GPP criteria development.

Traditionally, Portland cement consisted of around 95% Portland cement clinker and 5% gypsum. However, the content of clinker can be partially substituted by other materials which in many cases can improve the cement/concrete performance. Decades of experience in the use of coal fly ash (FA) and ground granulated blast furnace slag (GGBFS) as clinker substitutes has led to the development of the EN 197-1 standard, which was most recently revised in 2011.

The standard specifies compositions for five broad categories of cement (CEM I, CEM II, CEM III, CEM IV and CEM V). Amongst these groups, 27 specific categories are defined based on the composition. The table presented in EN 197-1 is reproduced in Annex III.3 for reference. The potential clinker substitutes specifically mentioned are:

- Blast furnace slag (**0-95%** of total blended cement mass)
- Silica fume (**0-10%** of total blended cement mass)
- Natural pozzolana (**0-55%** of total blended cement mass)
- Natural calcined pozzolana (**0-55%** of total blended cement mass)
- Siliceous coal fly ash (**0-55%** of total blended cement mass)
- Calcareous coal fly ash (**0-55%** of total blended cement mass)
- Burnt shale (**0-35%** of total blended cement mass)
- Limestone (**0-35%** of total blended cement mass)
- Other minor constituents (**0-5%** of total blended cement mass, including pigment etc.)

All of these materials present significantly lower environmental impacts in their production than that of Portland cement clinker. Some occur naturally (e.g. natural pozzolana and limestone) while others are industrial by-products (coal fly ash, blast furnace slag and silica fume).

As a general rule, the lower the clinker content, the lower the overall impact of the cement. This is highlighted by example data from real life examples of cement produced in the EU provided by Josa et al., 2004 and represented in order of clinker content in Figure 3.32 below.

Manufacturers are not obliged to reveal the precise percentage of clinker in their cement formulations since this may be commercially sensitive information. However, they must state which category the cement belongs to, which will indicate which range the clinker content lies in (i.e. 95-100%, 80-94%, 65-79%, 45-64% or 20-34% for example).

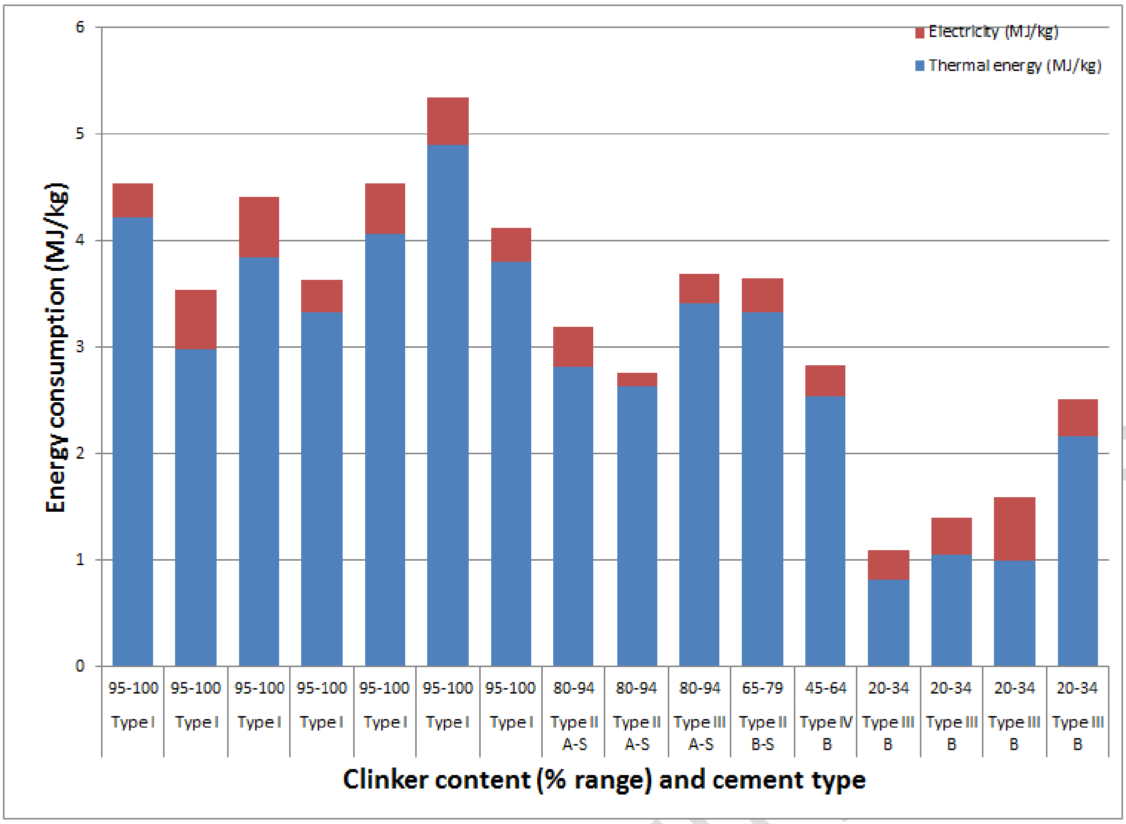


Figure 3.32: Real life energy consumption data for cement produced in Europe as a function of cement type and clinker content (adapted from Josa et al., 2004).

The exact categories of cement available in one geographic location will also depend on the availability of these substituting materials (e.g. blast furnace slag, coal fly ash, natural pozzolana etc.). However, one material that should **always** be available is limestone, given that it is a key ingredient in cement clinker manufacture. Therefore it should always be possible to specify Portland cement concretes with up to 35% of the clinker replaced by limestone.

3.4.4.4 Conclusions regarding cement technical specifications

The marketing of different categories of PC in the EU is well established and blended products are usually sent directly from the same site as where the Portland cement clinker is produced. In some cases due to logistics, cement clinker may be sent to an intermediary plant where it is blended (ground) with any supplementary cementitious materials and where tests with the aggregates to be used in the project may be carried out.

The final concrete product must be shown to comply with the technical specifications as per EN 206 and EN 13877 where relevant. Generally speaking, the requirements for road construction should not present any obstacles to the use of many of the lower environmental impact blended cements listed in EN 197-1 although this should always be confirmed with the supplier beforehand.

3.4.4.5 Aluminous cements

The cement industry is dominated by Portland cement although niche applications and markets exist for Calcium Aluminate cement (CAC) and Calcium Sulfo-Aluminate cement (CSA). It is uncertain if these cements are commonly used in road construction or maintenance. Due to the smaller scales of production, they generally cost considerably more per unit mass than Portland cement.

If the stakeholders state that these cements are indeed important in road construction, or especially in road maintenance due to the possibility of rapid-hardening properties, then we will provide some degree of technical analysis here in this section.

3.4.4.6 Lime

The first point to make in this section is the distinction between Lime or Quicklime (CaO), hydrated lime ($Ca(OH)_2$) and Limestone ($CaCO_3$). Quicklime does not exist in nature but is formed by the decarbonation of limestone in kilns at temperatures of 850-950°C. Hydrated lime is formed via a highly exothermic reaction simply by adding water to quicklime under controlled conditions. In terms of CO_2, like cement, emissions come both from fuel combustion and decarbonation of limestone. However, much of the CO_2 emitted by decarbonation will sooner or later be reabsorbed by the quicklime or hydrated lime depending on its final use.

It should be noted that limestone is generally regarded as $CaCO_3$, but in reality deposits can also contain substantial quantities of $MgCO_3$ (dolomite) or clays. The purity and grade of a hydrated lime product in the EU is assessed and classified according to EN 459. Although both limestone and hydrated lime are used in road construction, this section is dedicated solely to hydrated lime. According to market data provided by EULA, it is estimated that around 300,000-500,000 tonnes of hydrated lime are used in road construction each year. The two main uses of hydrated lime are:

- As a binder in soil stabilisation.
- As a mineral filler/additive to asphalt

3.4.4.6.1 Hydrated lime in soil stabilisation

During road construction, soil has to be excavated (cut) for the pavement layers or to simply minimise the longitudinal slope. In other cases the soil can be used as subgrade (fill), again to help maintain the desired longitudinal slope of the road. Most road alignments are designed to minimise the net surplus or deficient of earthworks (cut = fill). However, in many cases the soil will not be of a suitable nature for use as sub-grade, for example soft clayey soils. In such cases three main options exist:

i) Send the unsuitable soil offsite and transport in suitable subgrade material (very expensive).

ii) Incorporate the unsuitable soil into stabilised embankments onsite and ship in suitable subgrade material (less expensive).

iii) Stabilise the soil in-situ so that it can be useful as subgrade (most economical option).

Lime in general is regarded as an extremely useful material for soil stabilisation, either alone or in combination with Portland cement. Whether or not lime is suitable will depend on the soil properties. Where lime is used, it will typically be in doses of 4-6% by mass of the soil to be stabilised. Quicklime (powder) or hydrated lime (as powder or slurry) can be used in stabilisation processes. The choice will depend on the moisture content of the soil to be treated.

The stabilisation reaction occurs at a highly alkaline pH (>12) due to the basicity of lime. It is considered that stabilisation occurs via the physical flocculation of clay particles in the soil and possibly to some degree by weak pozzolanic-type chemical reactions between the soluble Ca from lime and Si, Al and Fe species from the soil minerals precipitate to form C-S-H or C-A-H type cementitious gels. Carbonation will also be important over longer time scales. The temperature on site is a very important consideration when using lime since reaction kinetics are very slow in cold conditions.

A number of different standards for soil stabilisation have been employed in the EU (VSS, 1987; CNR, 1992) but a common approach is detailed in EN 14227-11.

3.4.4.6.2 Hydrated lime as a filler in asphalt

The use of hydrated lime in asphalt mixes owes its origin to the 1973 oil crisis and in particular in the United States where innovative research was carried out regarding the use of additives to enhance the performance of poor quality bitumen.

Mineral fillers are used in asphalt to help provide the optimum grading of solid particles amongst aggregates added to bitumen binder, they are used as fine aggregates, typically <0.2mm. However, hydrated lime does not simply behave as inert mineral filler, but has a number of chemical and physical effects on the bitumen and aggregate interaction that change the properties of the asphalt mix.

Lime-treated HMA is generally observed to exhibit higher stiffness at elevated temperatures, an effect that correlates well with the degree of porosity of the hydrated lime filler (Vansteenkiste and Vanelstraete, 2008;

Grabowski et al., 2009) and can be linked to the general reduction of rutting of pavements made with lime-modified HMA. Chemical reactions have been demonstrated to take place between the acidic functional groups of bitumen and the basic hydroxyl groups of hydrated lime (Sebaaly et al., 2006; Petersen et al., 1987). Other effects such as the bonding adsorption of acidic functional groups to hydrated lime particle surfaces, making them less prone to oxidation reactions have been postulated (Sebaaly et al., 2006; Petersen et al., 1987; Plancher et al., 1976).

Lime can be added directly as a pure filler at the asphalt plant, as a pre-mixed filler including other inorganic materials or premixed directly with the aggregate. When the lime is added as a powder, care has to be taken with dosing systems to ensure that the correct quantity is obtained in the product due to the risk of loss as dust. In terms of quantity of hydrated lime in asphalt mixes, total content is typically only around 1-2% of the asphalt mix mass. Comparing this level to the bitumen binder content (around 5% of total asphalt mass), additions of hydrated lime can also be stated as around 20-40% of the bitumen binder mass. The leading country in the EU with lime-treated hot mix asphalt is the Netherlands. However, even there, such binders only represent around 7% of all hot mix asphalt (HMA) used (EULA, 2011).

The main reason for the use of lime treated-HMA in the Netherlands is the fact that it helps improve the durability of bitumen in porous asphalt surface courses. This is especially important because in porous courses the bitumen is more exposed to the atmosphere and thus also to degradation via oxidation, moisture and freeze-thaw phenomena. Lime has been shown to reduce the "*chemical ageing*" of bitumen. In the laboratory, this has been correlated with reduced rate of formation of asphaltenes (Petersen et al., 1987; Hopman, 1998; Plancher et al., 1976; Verhasselte and Puiatti, 2004; Wisneski et al., 1996).

A significant quantity of research has shown that lime treated HMA exhibits a series of performance improvements over normal HMA that can lead to increases in pavement lifetime of 20-50%. However, the benefits of hydrated lime and the optimum dosing rate will depend on the specific chemical nature of the bitumen used, its grade and crude oil source. Furthermore, it is uncertain how such filler material would behave in WMA or CMA. Therefore it is not recommended to state any particular criteria for hydrated lime but to encourage investigations into the potential of this filler in enhancing asphalt pavement durability. In general, there is much more experience with hydrated lime in HMA in the US than in Europe at present.

3.4.5 Aggregates

Aggregates can be defined as granular material used in the manufacture of construction products such as ready-mixed concrete (made of ca. 80% aggregates), pre- cast products and asphalt (made of ca. 95% aggregates).

The EU Public Procurement Directive requires public sector procurement specifications to use European standards, such as those in the Construction Products Regulation (CPR 305/2011, in force since July 2013), which establishes EU wide minimum requirements on the performance of construction products; with respect to hygiene, health and the environment the construction work must be designed and built in such a way that it will not be a threat to the hygiene or health of the occupants or neighbours. According to the CRP, recycled products and materials complying with the harmonized standards must be considered equal to products based on primary materials. Indeed, in the harmonised standards reporte in Table 3.28, aggregates are classified as:

- natural aggregates, produced from mineral sources;
- recycled aggregates, produced from processing material previously used in construction;
- manufactured aggregates (i.e. secondary aggregates), secondary materials arising from industrial

Table 3.28: EN Standards for aggregates

EN 13242	Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
EN 13285	Unbound mixtures specifications
EN 13043	Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas
EN 12620	Aggregates for concrete
EN 13139	Aggregates for mortar

Aggregates are often locally available, therefore during the planning phase of each road project, an important activity is the definition of the Sustainable Supply Mix (SSM) of aggregates: "*a procurement of aggregates from multiple sources, according to criteria of economic, environmental and social efficiency*" (Blengini *et al.* , 2012).. SSM therefore requires procurement from multiple sources and try to foster the employment of recycled, secondary materials and by-products.

As it is shown in Figure 3.33, aggregates can be used bound or unbound in the different pavement layers (road sub-base (3) and road base (2)) or in embankments (5: shoulders, landscaping, berms) according to the harmonized standards of reference. In literature, data on the need of aggregates per km of road show that 20,000 t/km for a two-lane road (BRE, EC, 2011) and 30,000 t/km for a motorway (EC JRC, 2009) are needed.

Figure 3.33: Use of aggregates in pavement layers

3.4.5.1 Waste derived aggregates and by-products

Member States in Europe have developed individual guidelines and regulation regarding the use of waste products in Europe (EC JRC, 2009). This fact prohibits a general listing of waste products used for road construction at the European level. This is reflected in the differences in leaching criteria for waste and by-product derived aggregates in different Member States as summarised in *Annex III.3 Leaching tests* are, with one small exception (the Catalunya region in Spain), based on EN 12457 or CEN/TS 14405 methods. However, the limit values vary widely and some Member States have split limits into various different categories for aggregates depending on the waste/by-product tested and/or the final use of the aggregate. Nevertheless, examples of waste products and industrial by-products used as unbound materials in different pavement layers include: C&DW, RAP, coal fly ash, coal bottom ash, municipal solid waste inceneration MSWI bottom ash, slags from iron and steel production (blast furnace slag and steel slag) and reclaimed rubber from tyres.

Recycled aggregates from C&DW, including crushed concrete, excavated soil and recycled asphalt aggregates, appear to be the waste derived materials with the highst improvement potential (PE EC DGENV, 2013).

According to UEPG (2012), 2.8 billion t of aggregates are produced per year, 20% of which used in road construction and railways. Only a fraction of this quantity is recycled aggregates (ca. 180 Mt/y). At the same time 531 Mt/y of C&DW are generated (BIOIS EC, 2011). Approx. 40% of this amount of C&DW consisted of concrete. The WFD has designed the following target on re-use and recycling of C&DW (art. 11.2): *(b) by 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste* (C&DW) *excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.* C&DW has been identified as a priority waste stream by the European Union because there is a high potential for recycling and re-use of this waste type. Furthermore, the technology for the separation and recovery of C&DW is well established, readily accessible and in general inexpensive. The potential is assessed to be large due to the existing level of recycling and re-use of C&DW which varies greatly (between less than 10% and over 90%) in the Member States (EC JRC, 2009). BIOIS EC (2011) has reported an average recycling percentage of 46%.

Within the construction sector, the use of recycled aggregates from CDW can potentially play a key role in the delivery of environmental policy and green public procurement objectives ETC/SCR (2009):

- Mineral / aggregates used in construction are among the largest material consumption streams in the EU
- Within Europe, CDW is the largest waste stream by volume. Recycling of CDW can significantly reduce the demands on landfill capacity.
- A significant amount of energy could be saved by replacing primary material with recycled CDW. Life cycle analyses show that, for example, concrete containing recycled aggregate has 20 to 30 % less environmental impact than concrete made purely from primary raw materials (Kuemmel, 2000).

According to the European Commission’s ‘Handbook on Environmental Public Procurement’ (EC, 2010), the right to specify materials or the content of a product in public tendering also includes the right to demand a minimum percentage of recycled or reused content where possible. In the Green Public Procurement Training Toolkit (EC, 2008), the Commission also recommends that:

- At least 5 % of construction material should derive from recycled or re-used content
- Recycled material must be accompanied by test documents indicating that they contain no hazardous substances.

Within the guidelines of WRAP on recycled roads (WRAP, 2005a) for local authority, several benefit are highlighted by using recycled and secondary materials in road construction:

- Economic benefits:
  - the use of recycled materials for maintenance is often cost neutral at least, and in many cases can deliver good financial returns. Specific cost savings include the avoidance of waste disposal charges and Landfill Tax. Moreover, some maintenance techniques such as ‘crack and seat‘, cold-lay foamed bitumen asphalt mix and reprocessing with hydraulic road binders have lower costs
  - The use of recycled products can shorten the time needed for maintenance work and, therefore, cutting the costs. The consequent easing in traffic congestion will also help the local economy. For example, in situ recycling can reduce the duration of traffic disruption by around 50% and foamed concrete can allow faster trench filling with fewer people
- Environmental benefit: the use of recycled materials and products can deliver clear environmental advantages by substituting for virgin materials, decreasing energy consumption, and diverting waste from landfill sites. Some of the most successful local authorities have ‘closed the loop‘ by utilising waste materials produced locally
- Social benefit: recycling locally delivers social benefits such as local jobs. Moreover reduces in road haulage activities, congestion and, therefore, increase road safety and cut air pollution

According to WRAP (2005a), the recycled content could be required with confidence. Almost every highways maintenance application can utilise recycled and secondary materials. These include aggregates for the various layers of road pavement structure, fill material, drainage media and landscaping materials. Key actions are identified in:

- Use prequalification to encourage tenderers to define how they will help to deliver corporate objectives on sustainability
- Set requirements and incentives for the use of recycled materials in your tender invitation and specification
- Use tender evaluation to give credit for greater recycling and the associated benefits
- Set targets and key performance indicators for the reduction of waste and the use of recycled content as part of any highway works
- Consider early involvement of the supply chain in order to improve predictability, time and quality, reduce whole-life costs, and increase the opportunities for innovation – such as increasing the use of recycled materials

3.4.5.2 Examples of performance criteria set in EU Member States

Performance criteria for recycled CDW can be sub-divided into physical properties (such as particle size distribution or frost-susceptibility) and chemical properties. The same physical criteria requirements are applied to both recycled CDW and natural material, while chemical properties for recycled aggregates from CDW relate to substances or elements, which if found in soil, ground or surface water, could potentially harm the environment. Key criteria thus relate to possible contamination from recycled mineral CDW and the associated potential to cause pollution during construction and use. In order to ensure that this is minimised, several Member States have defined limiting values in terms of chemical contamination in relation to possible leachate. These often have an associated labelling / classification schemes and / or quality assurance to certify that the recycled end product complies with these limits.

Austria

In Austria, there is a well-established market for recycled material for use in construction. However, there is still considerable resistance to using recycled material particularly in public procurement. Even when treated and quality assured, recycled material still carries the label "waste" and individuals responsible for public procurement often are not confident in using these materials. In order to guarantee the quality of recycled building materials and to assure their quality, assured through quality certification / marks, issued a series of guidelines on recycled mineral CDW have been published (BRV et al., 2007a,b,c). The guidelines establish the minimum requirements (regarding the production and use of recycled construction materials and regarding environmental compatibility) and to specify the kind and extent of tests required for recycled mineral CDW.

The environmental standards contained within these guidelines can be comprised as follows:

- Maximum contaminant concentration limits, which in turn determine a quality / use classification, as indicated in Table below, and
- Maximum content for additional pollutants which could potentially leach from the material (see chapter on leaching)

These quality-related use classifications are then used in conjunction with the leaching value to select the most appropriate material for particular applications (see Table 3.29).

Table 3.29: Fields of application of recycled construction material according to quality classes (BRV et al., 2007a,b)

Area of application	Hydro-geologically sensitive areas			Hydro-geologically less sensitive areas			On non-hazardous waste land-fill site / restoration of existing structure or inherited damage
Allowed way of application	In unbound form without cover layer	In unbound form with cover layer	In bound form	In unbound form without cover layer	In unbound form with cover layer	In bound form	
Class A+:	√	√	√	√	√	√	√
Class A		√	√	√	√	√	√
Class B			√		√	√	√
Class C							√

Source: BRV et al. (2007a, b).

Denmark

In Denmark, the use of recycled road surfacing requires no approval - it is accepted through the Danish Environmental Act – Part 5 (cited by Montecinos and Holda, 2006) for use as a sub-base and the paving of roads, paths, public spaces etc., irrespective of whether the surface is waterproofed or not. In the year 2000 the Danish Ministry of Energy and Environment stipulated Statutory Order No 655 regulating the use of residual waste and soil in building materials, allowing the use of recycled material for the construction of roads, paths, sound-absorbing walls, ramps, dykes, dams, railway embankments, pipe/cable trenches and foundations if certain leachate values are not exceeded. These limiting values vary, depending on the potential for penetration of rainwater. Based on a similar system to Austria, recycled mineral CDW is classified on a scale of 1 to 3, but based only on limiting leachate values, where:

- Category 1, which contain only a limited concentration of heavy metals and exert only low leachate values must be used in water sensitive areas;
- Category 3, with relatively high, but still restricted leachate values, can be used in all areas, provided the surface is not porous, i.e. is not subject to rainwater penetration

Germany

In Germany the legal frame for the recycling CDW is provided by the Kreislaufwirtschaftsgesetz 1994 (Act on Closed Loop Economy), supplemented by a series of federal and regional ordinances and norms (Technische Anleitungen). Until the year 2002 the standard "LAGA 20" (LAGA, 1998) defined the requirements for the recycling of mineral CDW in Germany. In 2002 a revision of the "LAGA 20" was undertaken, introducing higher environmental standards. An ordinance is planned for the application of mineral recycling material for building construction (Henkes, 2008) aimed at facilitating the use of recycling materials while protecting specifically soil and groundwater. The ordinance specifies which parameters need to be analysed and which limit values must not be exceeded. These limiting values are used to classify the material in terms of its potential future use, on a scale of 1 to 3, in this instance based on both chemical content and limiting leachate values, where:

- RC-1 material, which has to comply with the most stringent limit values, may be used in most applications, even in hydrologically sensitive areas, and
- RC-3 material, which has to comply with more lenient limit values, is much more restricted.

United Kingdom

The UK Waste and Resources Action Programme (WRAP) in conjunction with the Highways Agency and the Quarry Products Association, established a Quality Protocol for Aggregates in 2004, with a revised edition released in 2005 (WRAP, 2005b). The Protocol has two main purposes, to:

- Identify the point in the recycled material ceases to be classified as waste and
- Give adequate assurance that recovered aggregate products conform to standards common to both recycled and primary products.

The Quality Protocol for the production of aggregates from inert waste has established a quality management scheme for aggregate processing to defined standards. This provides purchasers and users with assurance that recovered aggregate products conform to the standards that are common to both recovered and primary aggregates, increasing confidence in performance

The WRAP Quality Protocol for Aggregates places a responsibility on the producer of recycled CDW to:

- Define acceptance criteria in order to ensure that all incoming waste which is not inert is rejected.
- Establish a factory production control system in accordance with the norms for recycled construction material issued by the British Standards Institute (such as BS EN 13242 and PD 6682-2). Following initial type testing the producer is responsible for process control.
- Prove that there is a demand / market for his product, which must meet the end-of-waste criteria specifications defined in www.aggregain.org.uk/specifier/index.html.
- Test aggregate composition weekly, including organics and grading, although not necessarily through a third party. Further parameters may be tested to either decide or illustrate suitability for a particular end use.
- Provide test results, test procedures and outline details of the factory production control manual (WRAP, 2005b), when requested.

France

The Ministry of Ecology, sustainable development, transport and housing in France has also developed a methodological guide for the assessment of the environmental acceptability of alternative materials produced from waste and intended for road construction (Setra, 2011). The guide can be used by road designers and pubic authorities

3.4.5.3 Transportation

In the practical method for greening road procurement proposed by Hampson et al., (2012), one of the most significant components in road works is the mass movement of materials (soils, aggregate, rocks) around the site, as well as to and from the site. They state that mass haulage/earthworks operation can cost up to 30% of the project. In this practical guidance it is recognized that mass haul, defined as *the movement of soil, aggregate and rock,* is a significant producer of GHG emissions related to fuel consumption. One way of reducing fuel consumption is to motivate and enable contractors to reduce both the amount of material moved and the total distance the materials travel. Currently, as part of the tendering process for major road projects, it is believed that contractors will undertake mass-haul optimization and as part of their price calculations, however the evidence suggest this is generally either not the case, or only to a limited extent.

In the ITT, the Client requests plan with a table of mass-haul information. The example of mass haul table proposed by Hampson et al., (2012) is reported in Table 3.30.

Table 3.30: Example of mass haul table (Hampson et al., 2012)

Materials	Source	Destination	V Volume	g density	d Transport distances	Eventually uphill and downhill Δz	Rolling resistance μr	Work W
			(m^3)	(kg/m^3)	(m)	(m)		(MJ)

$W = \gamma * V * (\Delta z + \mu r * d)$ Where

- W = work (MJ)
- V = volume (m^3)
- g = density (kg/m^3) [stockpiled volume]
- γ = specific weight (N/m^3)
- Δz=gradient difference (m) [negative if the elevation of the first point is higher than the elevation of the destination point (downhill)
- μr= coefficient of rolling resistance
- d= transport distance (m)

3.4.6 Excavated soils

Soil is a vulnerable and essentially non-renewable resource. Some of the most significant impacts on soil properties occur as a result of activities associated with construction activities (DEFRA, 2009), which can have adverse impacts on soil in a number of ways by:

- covering soil with impermeable materials, effectively sealing it and resulting in significant detrimental impacts on soils' physical, chemical and biological properties, including drainage characteristics;
- contaminating soil as a result of accidental spillage or the use of chemicals;
- over-compacting soil through the use of heavy machinery or the storage of construction materials;
- reducing soil quality, for example by mixing topsoil with subsoil; and wasting soil by mixing it with construction waste or contaminated materials, which then
- have to be treated before re-use or even disposed of at landfill as a last resort

The use of soils is a strategic factor in the Waste Framework Directive WFD 2008/98/EC (EU, 2008) and will consequently contribute to breaking the link between economic growth and waste growth with the dual benefits of reduced environmental impact and the preservation of natural resources. According to art. 2 are excluded from the scope of the Directive (therefore are not waste): *(c) uncontaminated soil and other naturally occurring material excavated in the course of construction activities where it is certain that the material will be used for the purposes of construction in its natural state on the site from which it was excavated*. The re-use in the same worksite is, therefore, one of the main hint. Outside from the worksite, excavated soil can be employed as by-products or recycled or recovered materials. There is no definitive lists of what is waste and what is not. It depends on each Member States national legislation and technical specifications. Some examples are:

- Italian technical regulation (decree n. 161 of 10.08.2012 on the use of excavated soils and stones as by-products (according to the WFD definition) in layer of fill materials, environmental filling, land leveling and road base in civil works. The regulation includes procedures of chemical-physical characterization and investigation of the environmental quality of soils, referred to the land use and the remediation law, and indication of the sampling procedures during the working phase and for inspection and controls
- DEFRA (2008). Definition of Waste: Development Industry Code of Practice (DoWDICoP), a voluntary code applicable to England and Wales. DEFRA (2009). Construction Code of Practice for the Sustainable Use of Soils on Construction Sites
- The Dutch Decree of 22 November 2007 containing rules with respect to the quality of soil (Soil Quality Decree).

Data from BIOIS (BIOIS EC, 2011) reveal that the inclusion of excavation waste in the statistics of the total production of C&DW would significantly increase the quantities involved, from 341-531 Mt to a total of 1,350-2,900 Mt of C&D and excavation waste per year. This quantity has the same order of magnitude of the EU production of aggregates (2,800 Mt in 2010) and shows that there are great possibility of the re-use, recycling and recovery of waste derived materials in the construction sector.

According to DEFRA (2009), although planning approval is a pre-requisite to all development proposals and consideration of the impact on soil is an integral part of the EIA process, there is no typical specific direct planning control on the sustainable use and management of soil resources on construction sites or a requirement for the monitoring of soil protection and sustainable reuse.

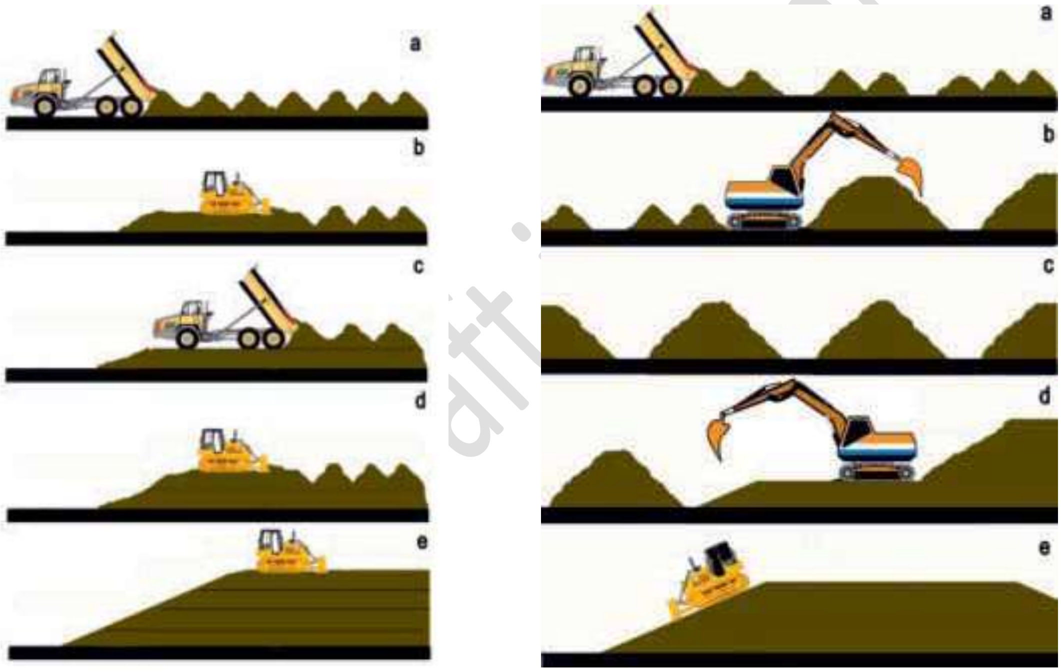
In general, according to DEFRA (2009), three interconnected management plans can be required:

- <u>Site waste management plan</u> (SWMP), required for all construction projects exceeding £300k to reduce the amount of waste generated. It must:
  1. describe all waste types that are expected to be produced in the course of the project;
  2. estimate the quantity of each different waste type expected to be produced;
  3. identify the waste management action proposed for each different waste type, including re-using, recycling, recovery and disposal
- <u>Materials management plan</u> (MMP) should form part of a remediation strategy or design statement derived using an appropriate risk assessment. This plan should provide:
  1. a description of the materials in terms of potential use and relative quantities of each category underpinned by an appropriate risk assessment;
  2. details of where and, if possible, how these materials will be stored;
  3. details of the intended final destination and use of these materials;

4. details of how these materials are to be tracked;
5. contingency arrangements that must be put in place prior to movement of these materials.

- Soil Resource Plan (SRP) should be produced on all construction sites where re-usable reserves of topsoil and/or subsoil have been identified by a soil resource survey. This can form a sub-section of the MMP, where implemented, and should be factored into the SWMP if surplus soils will be generated. The SRP should include:

1. areas of soil to be protected from earthworks and construction activities;
2. areas and types of topsoil and subsoil to be stripped, haul routes, stockpile locations;
3. schedules of volumes for each material
4. methods for stripping (minimizing the damage of topsoil)
5. methods for stockpiling: soil should be stored in an area of the site where it can be left undisturbed and will not interfere with site operations
6. methods for re-spreading and ameliorating the soils
7. expected after-use for each soil whether topsoil to be used on site, used or sold off site, or subsoil to be retained for landscape areas, used as structural fill or for topsoil manufacture
8. identification of person responsible for supervising soil management



Method 1 of stockpiling – Dry non-plastic soils **Method 2 of stockpiling– Wet plastic soils**

Figure 3.34: Methods of soils stockpiling (DEFRA, 2009)

3.4.7 Stockpiled fly ash/pulverised fuel ash (PFA)

3.4.7.1 3.4.6.1. Background

As mentioned earlier in the market analysis, ECOBA estimate that approximately 100 Mt of coal fly ash (FA) is produced each year. Of this quantity, only around 44% is re-used in normal re-use applications although a much higher re-use rate of 93% was calculated if use in land restoration and land reclamation projects is to be included.

Regardless of current re-use rates, historically FA production has exceeded re-use, leading to the accumulation of huge stockpiles of FA in the vicinity of now abandoned and currently operating coal fired power plants. Due to a lack of records, no estimates of the quantity of stockpiled FA in the EU exist. Even if this quantity were known, it may be uncertain if the FA has been combined with other waste materials such as flue-gas desulphurisation sludge at bottom ash.

In the EU market today, recently produced fly ash is often stored in silos ready to be loaded into trucks for transport to clients. Silo storage capacity may be tens of thousands of tonnes (Brennan, 2013). There is a disparity between demand for fly ash in cement, which is highest in the summer (since most construction occurs in the summer) and the supply of fly ash, which is normally highest in the winter (because energy demand is higher in the winter).

Storage on larger scales may occur by mixing FA with water to form slurry, which is then pumped to purposely created lagoons located next to the power plant. Lagoon storage prevents the loss of fly ash as dust but will also result in the dissolution of soluble ash fractions and elements. These elements may leach to surrounding groundwater bodies in unlined or poorly lined lagoons (Choi et al., 2002; Ugurlu, 2004) or simply dissolve and re-precipitate or be re-deposited elsewhere as the moisture content in the lagoon varies. Sedimentation of the particles may lead to segregation of fly ash particles based on their density and fineness.

3.4.7.2 Use in blended cements

The re-use of lagoon stored or "conditioned" fly ash in blended Portland cements was generally not considered until the last decade. This was following research that showed no major problems with the use of conditioned FA so long as the water content was accounted for correctly (McCarthy et al., 2000; McCarthy et al., 2001).

For use in cement or concrete, fly ash characteristics must conform to EN 450 requirements. Many small to medium enterprises are now operating in Europe regarding the beneficiation of low value fly ash to higher value fly ash that complies with EN 450 (refs). Such beneficiation processes may include milling, rinsing, floatation or magnetically induced sedimentation.

Considering the recent introduction of the Waste Framework Directive (2008/98/EC), the fraction of marketable fly ash formed after beneficiation processes could technically meet the End of Waste (EoW) requirements of Article 6 so long as:

(a) The substance or object is commonly used for specific purposes;

(b) A market or demand exists for such a substance or object;

(c) The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products (e.g. EN 450, EN 197, EN 206 etc); and

(d) The use of the substance or object will not lead to overall adverse environmental or human health impacts. The criteria shall include limit values for pollutants where necessary and shall take into account any possible adverse environmental effects of the substance or object.

The only real concern with conditioned fly ash is the sulfate content, which should be verified prior to any re-use, due to itself potential impact on cement hydration and stability.

3.4.7.3 Use as fine aggregate/filler

A lower value re-use is as a fine aggregate or filler in concrete or soil stabilisation applications. In terms of aggregates, where the fly ash is not beneficiated, or specifically involves the unwanted fraction of fly ash after beneficiation processes, Article 5 of the Waste Framework Directive may be relevant regarding the definition of this type of fly ash as a by-product when:

(a) Further use of the substance or object is certain;

(b) The substance or object can be used directly without any further processing other than normal industrial practice (e.g. blending with other graded aggregates as per EN 13285 for example);

(c) The substance or object is produced as an integral part of a production process; and

(d) Further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

The use of fly ash as fine aggregates and fine in concrete and in structural or engineering fill in the EU is well established and therefore some legal precedent must exist that would enable the use of most FA to be used in road bases.

3.4.7.4 Concluding remarks

The market for high quality FA in the EU is well established and supported by a number of small to medium enterprises that focus specifically on the beneficiation and marketing of fly ash for high value re-use (as a cement substitute). Lower value re-use applications are well established for lower quality fly ash in the EU. Overall, there is little reason why fly ash, either recently produced or previously stockpiled, could be used in road construction either in higher value applications (blended cements) or lower value applications (road base fill and controlled low strength materials).

3.4.8 Maintenance strategies

The maintenance of road network has become a highly important part of the road management since many environmental impacts identified are related to this phase. For example, maintenance activities are implemented to mitigate the noise due to damage pavement, but they also might cause traffic congestion. The road network is quite well developed, and preservation of the asset must be secured.

The objectives of maintenance are upkeep and restoration of road network condition to counterbalance its deterioration due to weather, traffic, aging etc. The results of the maintenance effort must be measured to assess to what degree the objectives are achieved and also to assess the effectiveness of maintenance. In addition, the maintenance activities should be planned and scheduled in time so congestion can be minimized.

Maintenance and maintenance objectives

Maintenance activities can be classified in 3 different groups (Weninger-Vycudil, 2009):

Routine Maintenance (also called road operations): small measures to repair local deterioration (cracks, potholes, repair of damaged guardrails etc.) and operational activities (e.g. winter maintenance / winter operation). The objective of these measures is to keep the road (pavement and the other sub-assets) in a defined (minimum) condition level and to avoid progressive deterioration. They have a limited lifetime and are normally performed on demand based on routinely periodic observations. They are not really planned and therefore they are not taken into account for the evaluation of the maintenance backlog. These works are either conducted by the road administrations themselves or are contracted out.

Planned (major) maintenance: maintenance measures with a long lasting improving effect to the condition of the sub-asset or component (rehabilitation). The objective is to provide a better condition to the present and future road users. These measures are conducted at components or sections close to or below an unacceptable condition level. They are planned as soon as the condition of the component falls below a given warning level and they have to be conducted according to a priority rating (e.g. LCC-analysis)using the relevant management system taking into account the given budget availability. These measures normally are combined to bigger construction sites and are contracted out following a tendering process.

Upgrade and extension: measures which upgrade the existing sub-asset or component or extend the infrastructure to a higher level than the original new condition (e.g. additional lane, strengthening, higher requirements for retention systems etc.). These measures are also planned depending on the condition of the existing road but taking into account the need and the timeframe for the additional upgrading combining both objectives to one construction measure. Normally only the part of the works which is attributed to the basic improvement (rehabilitation) of the existing part of the road is paid from the maintenance budget and thus contributes to the calculation of the backlog. The extra costs of the upgrade and/or extension are covered by the budget for investments.

Other additional definitions of maintenance are also proposed, based on the definitions provided by the Australian Asphalt Pavement Association (reference):

Routine maintenance is concerned with minor activities required to slow down or prevent deterioration of a road pavement. It tends to be preventive as well as corrective and includes such activities as:

- *crack-sealing*
- *pothole repair*
- *minor correction of surface texture deficiencies*
- *minor shape correction.*

Periodic maintenance primarily involves preservation of the asset using thin surfacings to restore texture or ride quality, protect the surface against entry of moisture, or prevent deterioration through ravelling and weathering.

Rehabilitation includes major work carried out to restore structural service levels. As such, the treatments are corrective in nature and include:

- *non-structural overlays*
- *structural asphalt overlays*

- *reconstruction or recycling of pavement materials, etc.*

Condition and Performance Indicators

For the characterization of the condition or functionality of a sub-asset or component performance indicators should be used and should describe the different characteristics in a balanced way. The selection of adequate performance indicators is strongly dependent on the type of asset.

The following list is a general recommendation of indicators which should be taken into consideration for the assessment of road infrastructure (Weninger-Vycudil, 2009):

- Performance indicators for pavements according to the COST 354 Report (COST, 2008)Performance Indicators for Road Pavements:
  - User related single performance indicators to describe the safety and the comfort of the pavement
    - Skid resistance / texture
    - Rutting
    - Longitudinal evenness
  - Structure related single performance indicators to describe the structural (technical) status of the pavements
    - Cracking
    - Other structural defects (ravelling, bleeding, etc.)
    - Bearing capacity
  - Environment related indicators to describe at least the noise emission
  - Combined performance indicators for:
    - Safety
    - Comfort
    - Structure
    - Environment
    - General performance indicator to describe the overall condition of the pavement
- Performance indicators for structures
  - Component specific single performance indicators to describe the distresses as follows:
    - Type
    - Extent
    - Severity
  - Combined performance indicators to describe the following characteristics of the structures
    - Stability
    - Safety
    - Durability
  - General performance indicator to describe the overall condition of the structure

Monitoring and data acquisition

Subject to the different types of sub-assets the following investigations are recommended (Weninger-Vycudil, 2009):

- Pavements
  - Measurements for user specific performance indicators (skid resistance /texture, rutting, longitudinal evenness), bearing capacity and environmental indicators (noise emission)
  - Visual inspections in combination with video-systems or images for structural performance indicators (cracking and other surface defects)
- Structures
  Visual inspection of sub-components with video- or image documentation
- Road furniture
  Visual inspection and functional testing

In addition, this study also recommends the intervals of monitoring be in coincidence with the local requirements and the given national and/or European standards (especially for bridges and tunnels). The following values are recommended as the maximum intervals of measurement and visual inspections on network level.

- Pavements: max. 5 years
- Structures: max. 6 years
- Road furniture: max. 1 year for functional testing

Additional information needed to find the optimum maintenance strategy of a certain sub-asset or component is also recommended to be collected, updated and checked in a certain interval. This information comprises:

- Inventory data (extent of assets, location and reference, construction types, maintenance history, etc.)
- Input parameter for the definition of the maintenance objectives which are in coincidence with the performance indicators in use (threshold values, percentages of condition classes, etc.)
- Input parameter for finding the optimum maintenance strategy based on LCC analysis (cost, triggers, performance prediction models, economic parameters, etc.)

The Figure 3.35, Figure 3.36 and Figure 3.37 show the indicators that HeRoad report Overall road asset performance (Sjögren et al., 2012) identifies as those parameters actually used in the routine work. According to this report, the details in the strategic level are the common goals found in most countries, regions and EC. Lower levels as functional and operational levels may differ much more between countries and regions. The figures try to link the technical parameters to upper level (strategically) indicators.

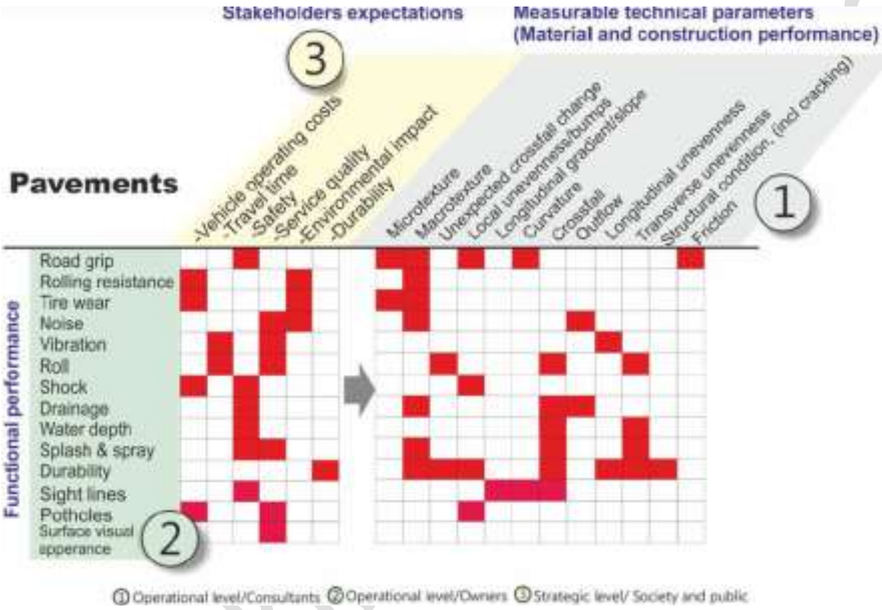


Figure 3.35: Pavement technical parameters

Figure 3.36: Equipment, signs and roadmarkings technical parameters

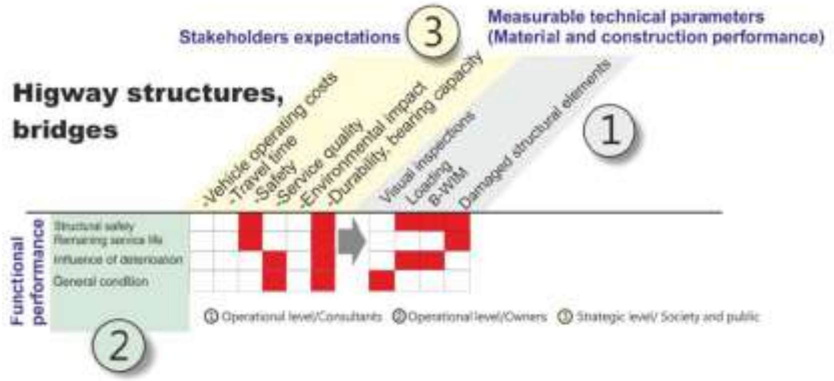


Figure 3.37: Highway structures technical parameters.

Maintenance Standard / Maintenance Goals

The main objectives of maintenance activities to be achieved must be expressed by parameters which are in coincidence with the performance indicators in use. The following are suggested by Weninger-Vycudil (2009):

- Threshold values which define the border line between fulfilled and unfulfilled demands (e.g. in form a condition related value or a maximum deterioration rate)
- Thresholds values which define the lowest acceptable condition (e.g. in form a condition related value or a maximum deterioration rate)
- Target values which define the optimum condition to be achieved after maintenance measures (e.g. in form a condition related value)
- Percentage of condition classes or ranges to be achieved (in case of given condition distribution standards)

These values are related to functional and structural requirements and are laid down in the respective national guidelines or manuals. Ideally they are derived from an analytical relationship between the indicator and the consequences to the road user, but in most cases they are adapted in some way to the given or accepted condition distribution at the network and the related risk assessment (e.g. traffic accidents).

Especially for pavements and structures these input parameters are widely available.

3.4.9 Main areas of innovation in road construction and construction materials and products

According to the contributions from the first stakeholder questionnaire, the following main areas of innovation have been identified:

Asphalt

a. **Warm mix asphalt.** Asphalt produced at reduced temperature (30 to 50°C lower than regular production of bituminous mixtures). The constituents of the asphalt are not altered. This results in:
    - lower energy consumption and lower CO_2 emissions
    - lower emission of fine dust particles
    - reduced smell nuisance and increased comfort for workers and people living in the neighbourhood of an asphalt production unit
    - after installation the new pavement reaches its service temperature after a shorter time allowing the road to be opened for traffic after less time
    - in the future, asphalt manufacturers will need to buy CO_2 emission rights. Reduced emissions can be a substantial economic advantage.

- This technology is proven and is being used for road construction.

b. **Warm mix asphalt.** New warm mix paving process that makes use of recycled plastic and of wax obtained by recycled plastic. The temperature of the paving process is reduced to approx. 121 °C with significant reduction in VOC and CO_2 emissions. This new product is also called Polymix. The wax reduces the aging of asphalt[11]

c. **Use of thin (20 - 30 mm) and ultra-thin (15 - 20 mm) layers** allow a lower consumption of materials and energy.

d. Used of **hydrated lime in hot mix asphalt**. There is evidence that the durability of road is increased with 12 years in average (EULA, 2013)

e. **Noise reducing asphalt**

f. **Photocatalytic Asphalt**. This type of asphalt is able to convert toxic subtances (NO_x, SO_2) into harmless compounds and thus improves the air quality[12].

g. **Cool Pavement**. It is asphalt treated with nano-coatings able to reduce surface temperature, so heat island effect. Moreover, low temperature reduces asphalt aging. Tests are on-going and the technology is not yet ready for use commercially. Experimentation in USA – Arizona, Phoenix. Moreover, low temperature prevent asphalt aging

h. **Asphalt without bitumen** is currently being studied and tested.

i. **Incineration of tar** and the aggregates are being used in asphalt, concrete and base course materials.

j. **Rubber asphalt**: asphalt produced with powder from end-of-life tyres (d > 1mm) which is characterized by higher elasticity and wear resistance, lower maintenance cost, higher rutting resistance and higher acoustic performance. This new type of product is under development and not ready to be diffused into the market (Sandberg at al., 2010)

Concrete

a. Two-lift paving (double-layered concrete): in case of jointed slabs, recycled crushed aggregates can be used in the bottom layer. The toplayer can be optimized in terms of rolling resistance and noise.

b. Self-healing concrete for roads (FP7 - HEALCON project)

New pavement design

a. new assets

b. prefabricated road pavements, long-life pavement materials

c. RAP and increased use of secondary materials. Promote the use of by-products, such as slag, in the public procurement sector, will avoid to smelters and refiners landfill this material. Some by-products e.g. copper slags are being investigated to ensure that copper slags are a reliable and safe product perfect to be used in road construction and embankments.

Maintenance

a. Patching materials eg. pothole repair

Photovoltaic panels in/as the surface

Many of these techniques are promising from environmental point of view. Nevertheless care must be taken to avoid compromising the durability of the road construction. If this would be the case, the initial advantage could quickly have very important negative effects. Thorough research on the durability aspect of these new evolutions therefore seems a necessity.

11 http://www.giteco.unican.es/polymix/Description.html

12 http://ascelibrary.org/doi/abs/10.1061/(ASCE)MT.1943-5533.0000613

3.5 Environmental impacts non covered by LCA

3.5.1 Introduction

Life cycle assessments are defined by system boundaries. The key environmental impacts that have generally been covered by LCA studies of roads have correctly focussed on the biggest impacts that can be quantified to some degree. Examples include the impacts on fuel consumption (via rolling resistance and roughness of road surfaces) and the impacts associated with construction materials (i.e. aggregates, bitumen/asphalt and cement/concrete).

However, there are a range of other impacts that are not so easily defined or quantified. Such impacts include:

- Noise pollution.
- Possible increased risk of flooding.
- Pollution of watercourses (leaching from road materials and particulates).
- Creation of barriers to wildlife.
- Diverse social impacts.

In the following sections, we briefly discuss those impacts that may be relevant to GPP criteria to some extent.

3.5.2 Noise

Noise can be defined as levels of sound that are loud, undesirable and/or unpleasant. It can often be a subjective issue since not all people have the same level of hearing and not all buildings are equally sheltered from noise from a given road.

The direct and indirect effects of noise pollution on the economy and human health are extremely difficult to estimate, but according to a growing number of studies they represent a serious concern. Data from the European Environment Agency estimate that more than 30% of the European population are exposed to 24 hour weighted average levels of road traffic noise in excess of 55dB (EEA, 1999). Weighted night time noise exposure levels above 55dB are considered to cause sleep disturbance by the WHO (WHO, 1999). Links between road traffic noise and incidences of high blood pressure and heart disease have been postulated (DEPA, 2003a). By estimating effects of noise pollution on factors such as health and property values, some very significant economic benefits have been indirectly linked to noise reduction (EEA, 2003; DEPA, 2003a; CEC 1996; DEPA 2003b; Watts et al., 2005). For example, the working group “Health and Socio-Economic Aspects” of the EU estimated that the reduction of noise perceived in households from road transport, within the range of 55 and 75dB (L_{den} values) would equate to economic benefits of **25 €/household/decibel/year** [EU-2003]. Road transport is one of the major sources of noise pollution that people are exposed on a daily basis and merits further discussion in the background report for GPP criteria development in road construction. There are two distinct categories of noise that can be considered: a) noise due to construction and maintenance activities and b) noise due to normal use of the road.

3.5.2.1 The Environmental Noise Directive (2002/49/EC)

Environmental noise is a serious issue in the EU as is reflected by the implementation of *"Directive 2002/49/EC relating to the assessment and management of environmental noise"*. The Directive is applicable to noise from roads and requires the development of common assessment methods for environmental noise, mapping of noise impacts in strategic areas and to develop action plans in areas of interest. For monitoring sites, the common noise indicators **L_{den}** (day-evening-night) to assess annoyance) and **L_{night}** (to assess sleep disturbance) are specified. These are A-weighted long-term average sound levels as defined in ISO 1996-2: 1987. Day is defined as 0700 to 1900, evening as 1900 to 2300 and night as 2300-0700 hours (local time).

Noise maps are required for "*agglomerations*" (urbanised area of population >250,000) and "*major roads*" (more than 6 million vehicle passages per year) and should be reviewed at least every 5 years. The noise from roads can be split into two broad categories:

<u>a) Noise generated during road construction/maintenance activities</u>

During the construction phase, significant noise will be generated by heavy machinery, compaction equipment as well as the movement of large quantities of raw materials. Noise exposure to workers is generally complied with thanks to the appropriate use of personal protective equipment and is covered by relevant Occupational Health and Safety legislation that is outside the scope of GPP. However, environmental noise levels expected to be generated during construction works should be detailed in the Environmental Impact Assessment (EIA) for the project. More details regarding EIA's are included in section _. The temporary nature of these types of emission and the existing legal framework that is already in place mean that this type of noise lies outside of the scope of GPP criteria development.

<u>b) Noise generated during normal road usage</u>

In terms of total environmental noise emission, by far the largest impact occurs during the use phase of the road. Noises from the use of roads are dominated by three main sources:

1. **Engine noise**
2. **Tyre-road surface contact noise**
3. **Air turbulence**

3.5.2.2 Potential of road surface specifications to reduce noise from roads

For the management of road-tyre contact noise, the obvious variable that could be controlled under GPP would be the specification of the road surface.

The precise mechanisms behind the generation of noise from contact between vehicle tyres and road surfaces are complex, although a concise analysis of the issue can be found in the FEHRL (2005). For greater theoretical detail, the reader is referred to the tyre/road noise reference book (Sandberg and Ejsmont, 2002). A number of physical properties of the road surface influence noise generation from tyre contact, namely:

- Texture
- Porosity
- Stiffness

3.5.2.2.1 Texture of road surfaces

The texture of a road is defined by changes in surface elevation that cause deviation from a perfectly smooth planar surface. Texture can be classified based on the scale of such deviations, for example: **microtexture** (<0.5mm), **macrotexture** (0.5-50mm), **megatexture** (50-500mm) and **unevenness** (>500mm). Also texture can be considered as "***positive***" whether the deviations are caused by upwardly protruding particles or "***negative***", where deviations occur as voids or grooves that are etched downwards into the otherwise planar layer. Exposed aggregate concrete surfaces would be a clear example of positive texture. Texture of road surfaces can be measured by laser methods as per ISO 13473 standards. Although microtexture cannot be measured properly except in laboratories, techniques are constantly evolving. The influence of different textures on certain road properties is nicely illustrated in Figure 3.38.

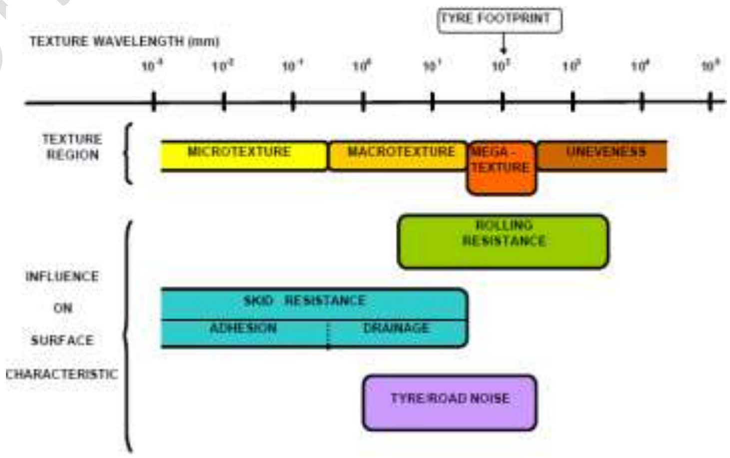


Figure 3.38: Influence of surface texture on road surface characteristics (from FEHRL, 2005).

3.5.2.2.2 Open porosity of road surfaces

The porosity of a pavement can be defined as the volume percentage of open-air voids per unit volume of pavement mix. The FEHRL consortium members have proposed classifying pavement mixes according to the following porosity levels: **dense layers** (4-9% air voids), **semi-dense layers** (9-14% air voids), **semi-open** (14-19% air voids) and **open layers** (>19% air voids). The last category would be considered as "porous". As a general rule porous surface layers reduce tyre-road noise emission due to the absorption of sound waves. However, a number of other factors have influences such as the air flow resistance of pore surfaces and the depth of the porous layer. The measurement of road surface porosity will be according to the relative standards for asphalt materials (EN 13108) or cement concrete materials (EN 13877 and EN 206).

3.5.2.2.3 Stiffness of road surfaces

Finally, the stiffness of a road surface is basically the degree of mechanical impedance to the tyre. Since all road surfaces are orders of magnitude stiffer than tyre rubber, during contact a slight compression of the rubber in tyre treads is caused, which is an important factor in the propagation of sound waves during road-tyre contact. The lower the stiffness of the road surface, the lower the compression of tyre thread rubber and the lower the noise generated. This is the main argument supporting the improved acoustic performance of poro-elastic road surfaces that contain ≥20% rubber by weight. No standard procedure exists for measuring the mechanical impedance of road surfaces although efforts are underway to develop one (Kuijpers and Schwanen, 2005).

3.5.2.2.4 Road surface types with potentially useful noise reduction performance

A number of different road surfaces have been developed that claim to reduce noise emissions from road-tyre contact. Some examples are:

- **Porous Asphalt Concrete (PAC)**. Basically asphalt with gap graded aggregates and low proportion of fines to produce an optimum open and connected air voids content of 20-30%. Different grades can be specified based on the upper limit for coarse aggregates (e.g. 0/10, 0/14, 0/16 and 0/20) and each country tends to have its own preference in this regard.
- **Double layer Porous Asphalt Concrete (DPAC)**. Consists of an upper layer of finer textured porous asphalt (grading from 0/3 to 0/8) laid on top of a coarser layer (grading from 0/11 to 0/16) of porous asphalt. The upper layer effectively acts as a sieve protecting the lower layer from clogging but also reduces tyre vibrations due to its finer texture.
- **Porous Cement Concrete (PCC)**. The same principal as with PAC and DPAC applies where gap graded aggregates are used to create a hardened structure with high open void content. Little or no mortar sand is used in the concrete mix.
- **Thin wearing-courses (TWC) or Thin surfacings (TSF)**. Thin layers that can be as narrow as 6-12mm and up to 30-40mm in thickness. Use gap graded aggregates and higher bitumen contents (possibly modified bitumen) than traditional surface courses that result in improved durability but also negative textures that reduce noise emission.
- **Stone Mastic Asphalt (SMA)**. Often considered as a sub-class of the thin courses mentioned above. Uses a high proportion of coarse aggregates (gap graded) and requires resistant aggregates. Voids content can range from 1.5-8%, much less than PA.
- **Exposed aggregate cement concrete (EAC or EACC)**. Originally developed for improved skid resistance, good noise reduction properties have been found when using carefully controlled gap graded aggregates. Exposed aggregates of size 4-8mm tend to provide optimum macrotexture and unwanted megatexture can be limited by the use of longitudinal smoothing plates prior to exposure and limiting the maximum aggregate size.
- **Epoxy-bound surface dressings (EP-GRIP).** A number of commercially sensitive formulations have been developed such as: EP-GRIP, GRIPROAD, ITALGRIP and PAVETEX. As with EACC, the original motivation for these products was to improve skid-resistance. The effect on surface texture also happens to improve noise reduction. Uses a very narrow grade (2/4) of very resistant chippings.

Application of the liquid formulation smoothens out any megatexture and forms a good and uniform macrotexture for noise reduction. Far more expensive than alternatives and may be limited to road sections where skid resistance is of paramount importance.

- **Poro-elastic road surface (PERS)**. Possess a high degree of elastisicty relative to other road surfaces due to the incorporation of ≥20 wt. % rubber as a main aggregate. The content of interconnected air voids is typically >20% volume. Additional binder or special epoxy resins may be used to improve the coherence of the mixture. Noise reduction in small trials has proven to be promising (Sandberg and Kalman, 2005).

3.5.2.2.5 Comparison of road surface performance

While all the road surfaces mentioned in the previous sub-section can be considered to offer enhanced noise reduction to some degree, there are relatively few studies that directly compare these alternatives. One very useful comparative study was included in the doctoral thesis of Schwarz (Schwarz, 1998) from which the Figure 3.39 is taken:

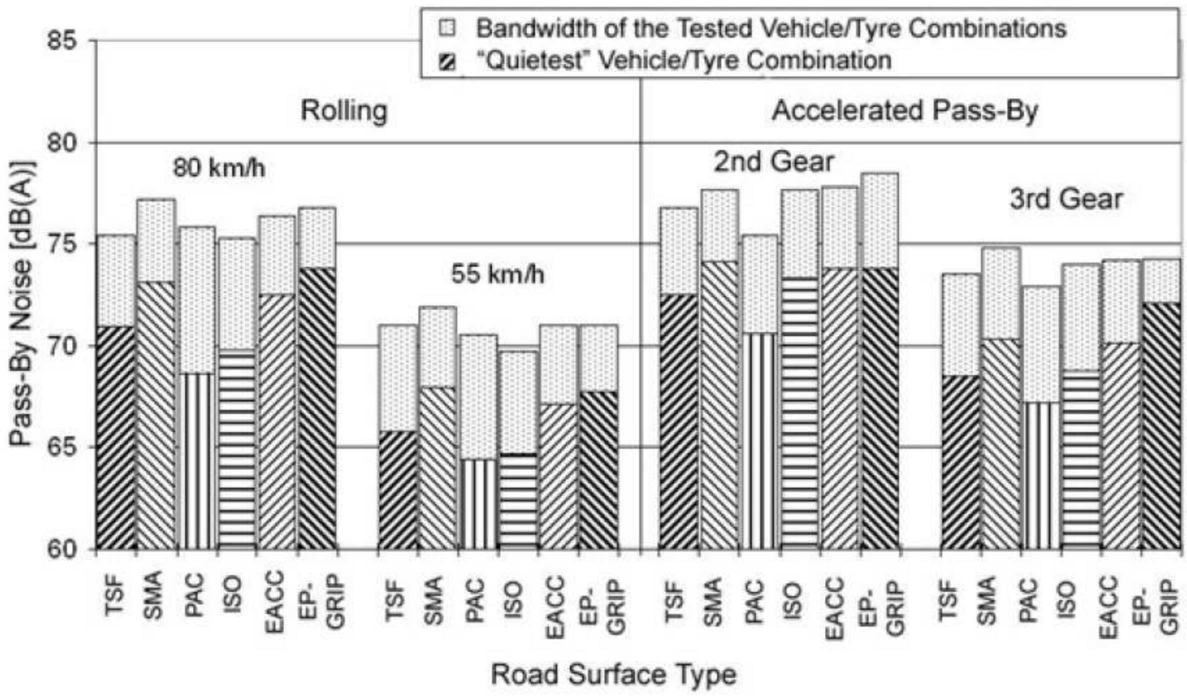


Figure 3.39: Pass-by noise from 18 different tyre/vehicle combinations on 6 road surface types (Schwarz, 1998).

The data in Figure 3.39 regarding acoustic performance of the 5 test surfaces, compared to an ISO 10844 standard track, reveals that the Porous Asphalt Concrete (PAC) surface generally performed best.

However, data reported by SILVIA (2005) (summarised in Figure 3.40) show that surface acoustic performance also depends on the speed limit of the road and the vehicle type.

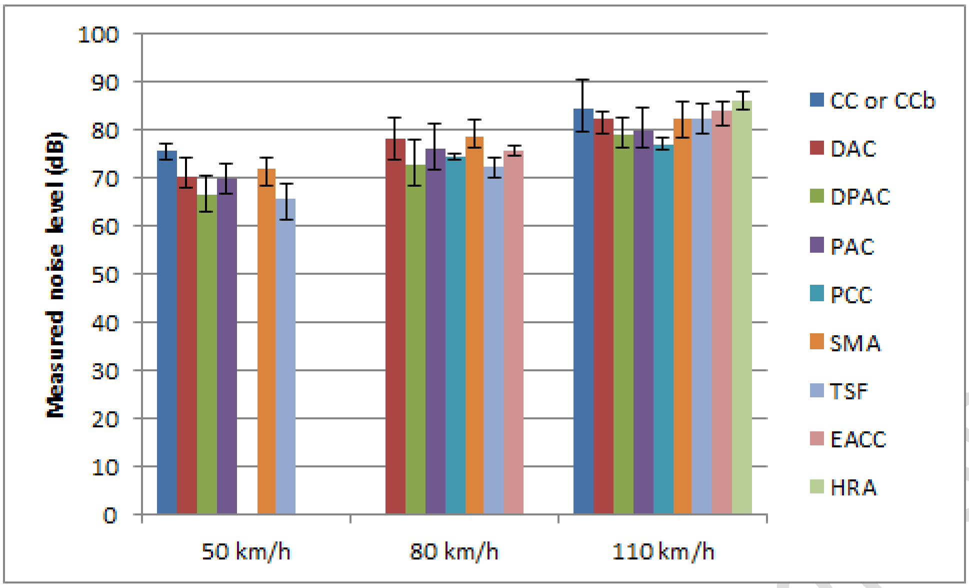


Figure 3.40: Comparison of average SPB noise levels (ISO 11819-1) on roads as a function of vehicle speed (passenger cars) and road surface type.

Note: Columns indicate the average value and error bars show the range between maximum and minimum individual measurements. Abbreviations are as described in the previous sub-section. Additional abbreviations are: CC – Cement Concrete; CCb – burlap textured concrete; DAC – Dense Asphalt Concrete; HRA – Hot Rolled Asphalt.

In Figure 3.40 it is evident that there are other road surfaces that can perform even better than PAC, for example DPAC and perhaps PCC. However, it is extremely difficult to say whether or not one road surface has a statistically significant better performance than another. When the speed limit of the road changes, so too do the relative performances of the road surfaces. Furthermore, this data was only measured for passenger cars. Noise emission from heavy vehicles may respond differently to each individual road surface.

Although there is a certain performance advantage between traditional road surfaces (e.g. HRA, DAC and CC) and more novel surfaces (PAC, DPAC, PCC and TSF) it would not be recommended to use GPP to specify or give preference to one particular road surface in all road construction projects. Where noise is expected to be an issue and noise barriers are not feasible or practical, then perhaps GPP criteria should lend added weighting to those generally lower noise surfaces, based on experimental data under controlled conditions. However, where porous surfaces are preferred, other considerations must also be taken into account.

3.5.2.2.6 Additional considerations with porous road surfaces

These considerations apply especially to PAC, DPAC and PCC, where a large network of open and interconnected voids exists. The aggregates are more exposed in such materials and so it is common to specify higher "*polished stone values*" and other relevant abrasion resistance type properties (PIARC, 1995; Jacobsson and Wagberg, 1995) A number of advantages and disadvantages of porous surface courses are summarised below in Table 3.31:

Table 3.31: Summary of the main advantages and disadvantages with PAC.

Advantages	Disadvantages
Reduced noise emission.	Binder more exposed, likely to age quicker. May require use of 0.3-0.4% fibres in mix for durability purposes.
Improved drainage and thus less splashing during wet conditions.	Voids will eventually block with debris, requiring specialised cleaning.
Potential for stormwater filtration prior to discharge.	Increased need for application of de-icing salts due to ease of ice formation in any poorly drained pores.
Improved skid resistance in wet conditions.	Patched repairs for potholes etc. may not knit well with

	overall drainage of rest of surface

Concerns have been raised with PAC regarding reduced acoustic performance with ageing and weathering of the surface (Sandberg and Ejsmont, 2002), with reduced performance during rainy weather due to pores being full of water (Phillips and Abbot, 2001) and problems of clogging with road debris and even weed emergence in poorly trafficked areas. The expected lifetime of PAC may be less than other surface types as well.

The most unique maintenance problem for porous surface layers is the periodic need for cleaning, which could well explain the gradual loss of acoustic performance observed in some PAC surfaces. Considerable experience with PAC cleaning has been gained in Japan and the Netherlands (Sandberg, 1995; Sanches, 1994; DWW, 1991; Sanches, 2000). Surfaces can be cleaned using high pressure water jets or air streams coupled with a suction capability. Cleaning needs can be estimated to be higher in poorly trafficked lanes due to a degree of self-cleaning action of passing vehicles. In Japan certain roads are cleaned on a weekly basis although a frequency of 2 years was suggested by the OECD (OECD, 1995).

With regards to de-icing treatments, the potential for ice formation in PAC may be higher since they can be around 1°C colder than dense asphalt pavements due to differences in thermal conductivity (Page, 1993; Holldorb, 1997; Litzke, 1997). The use of grit for de-icing is not advisable due to clogging of pores, instead more expensive road salt (soluble) has to be used.

3.5.2.3 Potential of noise barrier specifications to reduce noise from roads

Apart from road surface specifications, the other major impact that GPP for road construction could have on environmental noise emission from roads would be in the specification of noise barriers. These may be most relevant to motorways and rural roads where land availability is less of an issue than in congested urban areas.

Aesthetics is a very important parameter to noise barrier design but is beyond the scope of GPP criteria. The section will discuss some of the basic technical principles behind noise barriers and then focus on the main environmental impact of noise barriers, which is the choice of materials used in their construction.

3.5.2.3.1 Principles of noise barriers

The purpose of a noise barrier is to reduce the transmission of sound from a defined source area to a defined reception area. The placement of a suitable barrier can have the following effect on the transmission of sound waves shown in Figure 3.41 and Figure 3.42

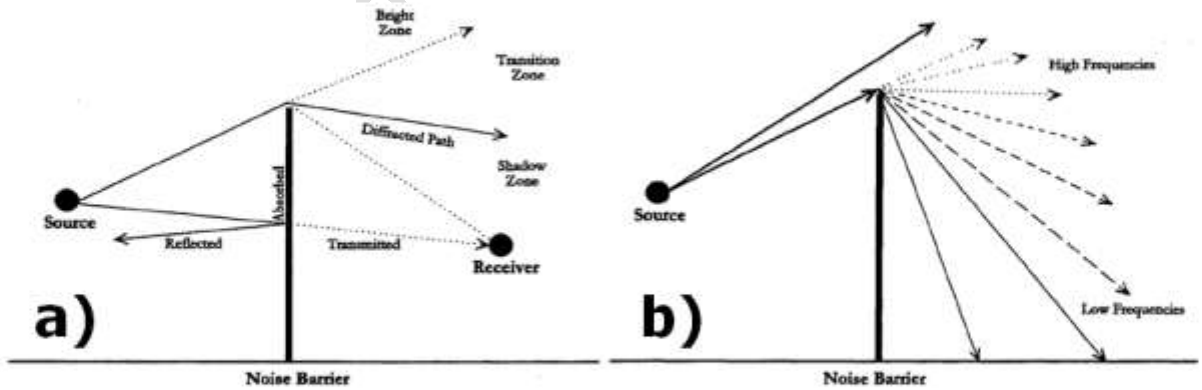


Figure 3.41: Basic principles of sound wave transmission in the presence of a noise barrier: a) barrier absorption, transmission, reflection and diffraction and b) diffraction of frequencies (FWHA, 2000).

In general, the level of noise transmitted is very small compared to the level of diffracted noise reaching the receiver. As a general rule of thumb, any solid and uniform material of mass 20kg/m^2 barrier area will reduce noise levels by at least 10dB (Hendricks, 1998).The higher the barrier, the lower the fraction of diffracted sound that will reach the receiver, as illustrated in Figure 3.42

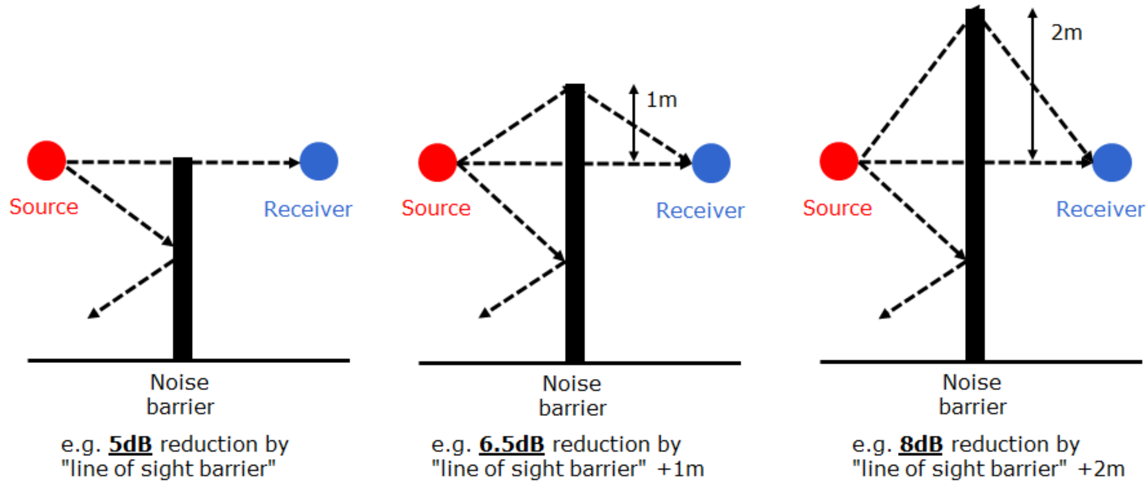


Figure 3.42: Effect of changing barrier height on sound attenuation

Another general rule is that increasing the height of the barrier "above the line of sight" by 1m, is to achieve a further 1.5dB reduction in noise at the receiver (FWHA, 2000). For example, in New South Wales (Australia), the minimum specification is that a noise barrier should be high enough to dissect a straight line between any point 1m above the road surface and a point 1.5m above the floor of an adjacent residence (NSW, 2007). The Australian authority warns about the misconception that vegetation alone presents a useful noise barrier, stating that reductions of only 3dB are typically achieved across 30m of dense woodland.

Finally, other important technical considerations are shown in Figure 3.43

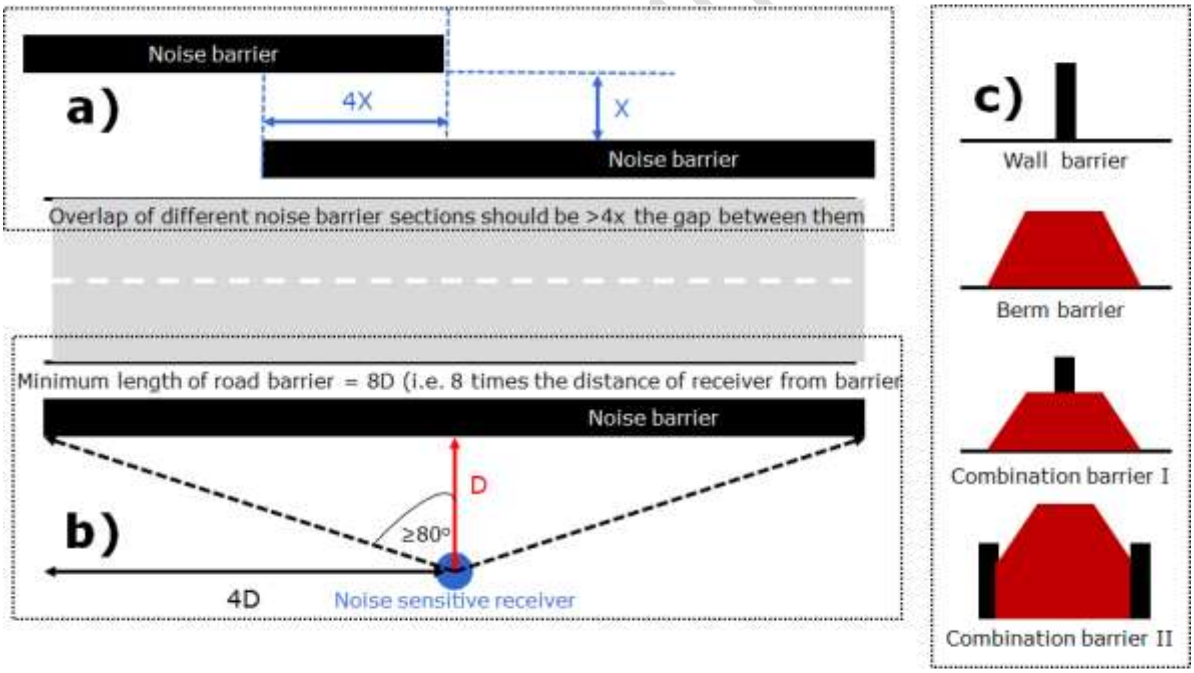


Figure 3.43: Examples of other widely accepted technical requirements for noise barriers a) overlap requirements for separated barriers sections, b) minimum noise barrier length as a function of distance from the receiver and c) different generic barrier types.

Often a single massive barrier will not be possible due to access requirements for pedestrians, cyclists, emergency vehicles or maintenance staff. In such cases, the noise barrier can be split into two or more staggered sections, but the length of overlap between such sections should be at least 4 times longer than the width of the gap between the sections (see Figure 3.43a). The minimum barrier length required is a function of the proximity of the receiver to the barrier (see Figure 3.43b). Finally, a distinction is made between wall barriers (used in sites where space is limited) and berm or combination barriers, where suitable space is available (see Figure 3.43c)

The final technical factor to be mentioned is the difference between sound reflection and sound absorption. Barriers that simply reflect sound may be problematic in situations where, for example the road has a reflective noise barrier on one side, which may result in perceived higher noise emissions on the other side of the road. Another situation is when a road has reflective barriers on both sides – such a situation will lead to a poorer performance of each of the individual barriers.

3.5.2.3.2 Materials used in noise barriers

The choice of material to use will depend on local availability and the specific nature of the road site. A summary of possible materials is provided in Table 3.32.

Table 3.32: Examples of different materials that can be used in noise barriers

Material	Construction	Comments
Earth	Formed as berm barriers.	Such berms may need to be stabilised with small additions of lime or cement. Depending on soil and site factors, a retaining wall or walls may be required. There is also the option to add noise barriers to the top of the berm. Obvious economic and environmental advantage if earth from site excavation can be used.
Rammed earth	Compacted in-situ as wall barriers	Most practical during road construction works. More work involved than with in-situ concrete but significant potential environmental benefits if using excavated soil from site.
Poured concrete	Cast in-situ as wall barriers	Normally only practical during road construction works. A lot of work required in setting up formwork. Casting can be dependent on weather and quality control is not as good as with pre-cast concrete.
Strawbales	Stacked and plastered as wall barriers.	Not much experience with this material. Need to be plastered and topped with an impermeable layer. Bales should also stand on elevated foundations to prevent water ingress from below into bottom bales. Potentially excellent environmental option if earth plaster used, straw bales are locally available and splashing of side walls not an issue.
Pre-cast concrete	Stacked masonry blocks as wall barriers.	Normal concrete blocks may present a significant load on ground and require foundations. Lightweight concrete blocks are better both from an environmental point of view and potentially from a sound absorption point of view.
Clay bricks	Stacked as wall barriers.	Fired bricks are the most common product. Better to use bricks/blocks that can simply be stacked on top of each other – no joining mortar required. Some unfired blocks are available that are much better from an environmental point of view.
Stone crib	Stacked as blocks as wall barriers.	Consists of large stones held together within high tensile steel meshwork. May be environmentally beneficial if stones can be sourced locally. Although the open nature of the structure reduces sound transmission attenuation.
Timber	Post and panel as wall barriers.	When posts are wooden, panels can only be of wood or other lightweight materials. Panels will need to be secured to footings as well but construction is quite rapid and flexible using pre-fabricated panels. Not especially durable materials though and require use of hazardous chemicals as preservatives.
Metal	Post and panel as wall barriers.	Pre-fabricated panels that can be rapidly assembled into post and panel system on site. High embodied energy per unit weight, potential problems with expansion and contraction during hot and cold conditions – generally not recommended.
Plastics	Post and panel as wall barriers.	Pre-fabricated panels that can be rapidly assembled into post and panel systems on site. High embodied energy, although possible potential to use recycled post-consumer plastic. Specified in areas where visibility is important e.g. bridges.
Lightweight concrete	Post and panel as wall barriers.	In particular pre-fabricated autoclaved lightweight concrete panels can be environmentally advantageous where raw materials incorporate high levels of industrial by-products such as coal fly ash.

The list of materials in the above table is by no means an exhaustive one but highlights the range of potential options available to designers and procurers.

3.5.2.3.3 Verification of performance of noise barriers

Tests and contract specifications for noise barriers in general across the EU are covered under EN 14388 (2005). Many noise barrier products are marketed with a certain acoustic performance according to laboratory tests under controlled conditions (EN 1793-1 and EN 1793-2) and classified as; A0, A1, A2, A3, A4 or A5 – based on sound absorption (EN 1793-1) and according to sound insulation as B0, B1, B2, B3 or B4 (EN 1793-2).

However, this does not necessarily equate to equivalent performance in the field. For example, in post and panel constructions, gaps around the post sections and poor sealing with the ground can greatly reduce the effectiveness of any noise barrier barrier. Consequently a new methodology was developed to facilitate the in-situ performance of noise barriers (CEN/TS 1793-5 and EN 1793-6). The long term performance of noise barriers can also now be followed using the procedure specified in EN 14389-1.

Using the procedures laid out in these standards, it would be possible for GPP criteria to be specified for pre-fabricated noise barrier elements. It is unlikely these criteria could be legally applied to unique berm type barriers although the procedures can still be used in order to monitor performance during the lifetime of the road.

3.5.3 Flood risk management

3.5.3.1 Background

According to the European Environment Agency, over 175 major floods were recorded in EU member states between 1998 and 2009, with insured economic losses of around **€52 billion** (EEA, 2010). This figure does not include many localised flood events that will also have occurred or any obviously uninsured losses.

Today there exist two broad types of engineered drainage systems which can be distinguished as "hard engineering" (more concrete based) or "soft engineering" (less concrete based). In terms of flood management, both can be tailored to significantly reduce the risk of flooding downsteam.

3.5.3.2 Run-off rates from developed and undeveloped sites

Developed sites tend to present large areas of impermeable surfaces that need to be drained rapidly (i.e. pavements, roads and roofs). Such drainage systems are generally designed to rapidly convey stormwater off-site and to a downstream watercourse. However, this simply passes the stormwater, and thus the flood risk, to a downstream area. Indeed, the rapid conveyance of stormwater from developed sites is unnatural and can lead to much larger water flows in streams and rivers than would occur if the site was undeveloped, where stormwater first infiltrates the ground and only as the ground is saturated, begins to flow over ground or through the saturated substratum to the nearest watercourse. The difference in drainage tendencies between natural and developed sites is illustrated in Figure 3.44

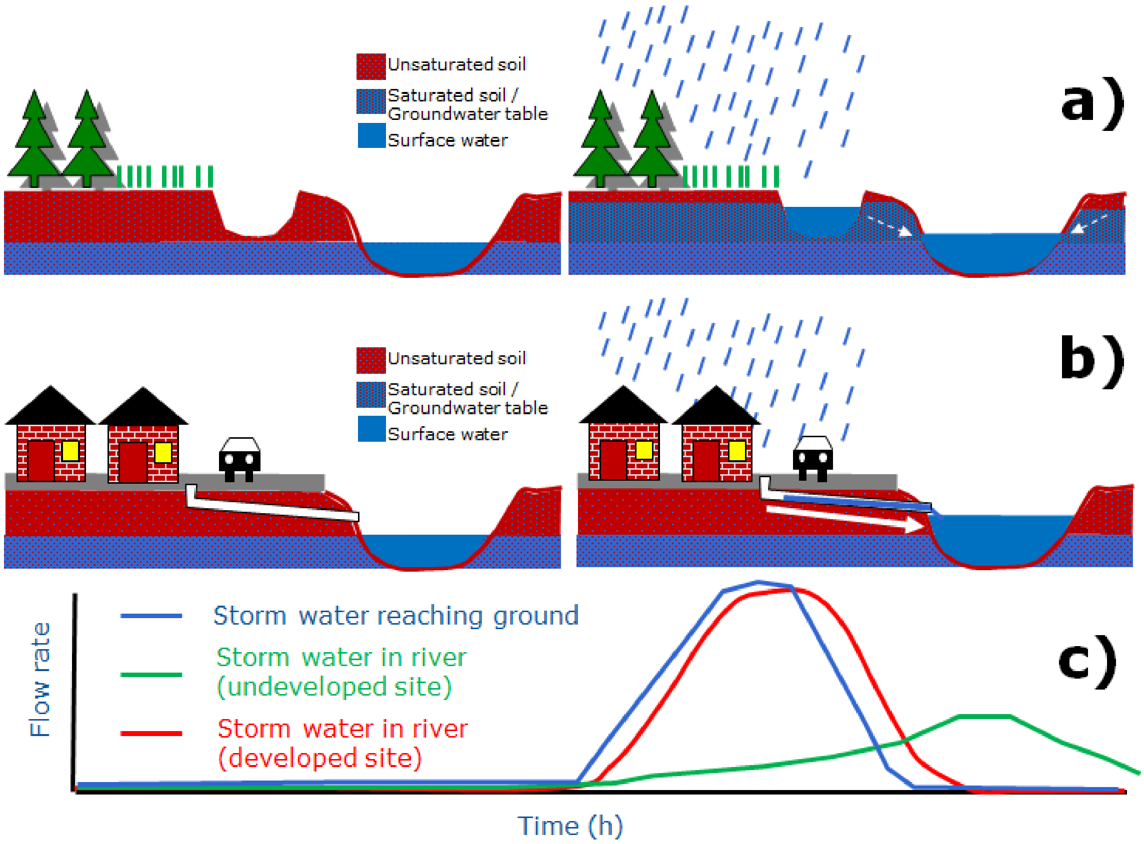


Figure 3.44: Contrast between impact of storm events on river flows in a) natural sites, b) developed sites and c) the general relationship between rainfall rate and river flow rates for both types of site.

Highly developed regions may be more at risk from flooding than ever before. The combination of increased impermeable surface areas, development in areas prone to flooding and the uncertainty over future climate change mean that it is necessary to move away from traditional road drainage designs and towards systems that are able to attenuate peak storm-water runoff rates and provide some degree of temporary storm-water storage close to the point where it originally hits the ground.

3.5.3.3 The EU Floods Directive (2007/60/EC)

This directive requires Member States to have completed a preliminary assessment by 2011, identifying any river basins and coastal areas at risk of flooding. In any areas where a possible risk is identified, more detailed flood risk maps are required by 2013 and detailed flood risk management plans for those areas by 2015. All the flood risk areas have been assessed on the basis of defined river basins. Figure 3.45 below compares the river basins with areas that have experienced flood events during the last 50 years.

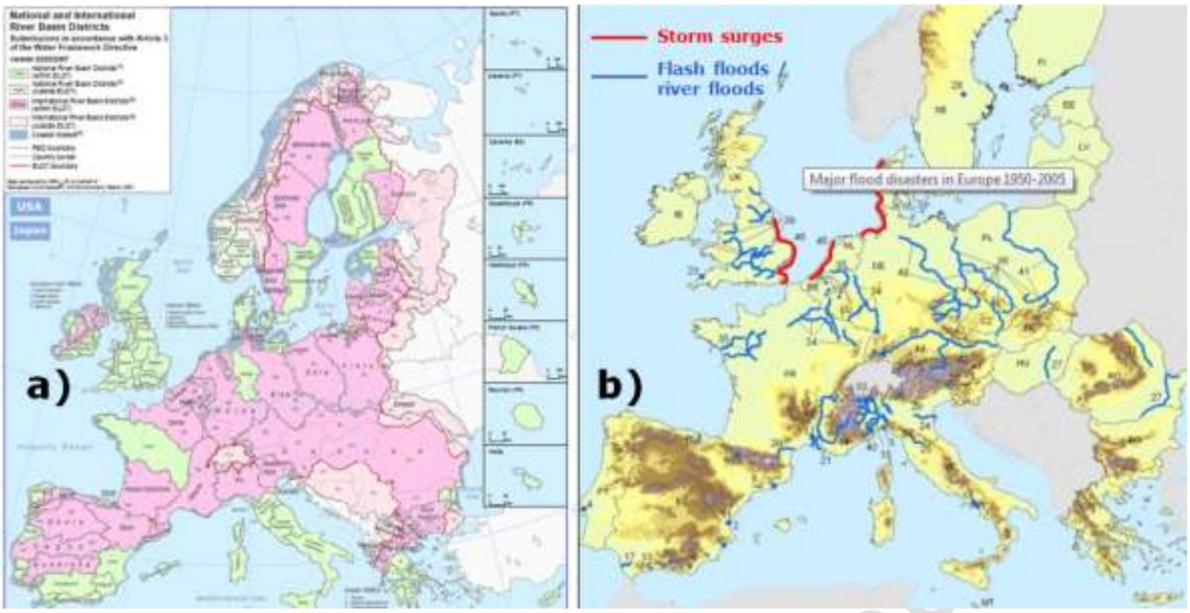


Figure 3.45: Illustration of a) river basins defined across the EU and b) areas where floods have been recorded during the last 60 years. Maps provided by JRC, 2013.

From Figure 3.45 it is clear that flood risk management is an international issue in some catchments which cross Member State borders, particularly with the Danube river basin. Also it is evident that many different Member States have experienced flooding problems in recent history.

Although all new road construction should not contribute to any increase in flood risk in the local area or downstream, there is also an opportunity for road drainage infrastructure to help reduce flood risk through appropriate design.

3.5.3.4 Flood risk assessment procedures

The specific procedure for carrying out flood risk assessments of proposed developments will vary between different Member States and perhaps also at the local authority level within a given Member State. In general, the proposal should include the following elements;

- An overview of the proposed development, stating the planned new impermeable areas.
- Details of the underlying soil geology, groundwater table and nearby surface water courses linking up to the river basin district level.
- Technical drawings for the drainage system, specifying all components such as manholes, culverts, gullies and any detention basins as well as capacities and slopes.
- A modelled hydraulic simulation of the dynamic response of the drainage system to a certain **storm event(s)**.

The storm event is the area of particular interest and potential relevance to GPP. Storms are defined by two factors; **frequency** and **duration**. The rarer a storm is, the more intense the rainfall rate will be and obviously the longer the duration of the storm, the higher the quantity of stormwater that will fall on the ground.

Design storms are defined by statistical analysis of historical rainfall data collected over long periods. For example in the UK, the original procedure involved the use of mapped variables and ratios available via the Flood Studies Report (FSR). These variables and ratios could then be used to calculate other design storm events (Boorman, 1985). The FSR method has now been replaced by the Flood Estimation Handbook approach which also has associated software for carrying out and verifying calculations. In other Member States, different procedures will be used.

If planning authorities want to ensure a development has a suitable drainage system, the may ask that the road will not flood during say, a **1 in 30 year** storm event of 4 hours duration. This can be easily simulated using modelling software and approval given for the construction of the proposed drainage system.

The same procedure can also be used to make more stringent specifications, such as the road will not flood during a **1 in 100 year** storm event of 4 hours duration **and** will not result in increased runoff rates of stormwater to the nearest watercourse compared to the equivalent greenfield site.

To explain what this means exactly, it would be saying that the drainage system has to provide a minimum specified degree of stormwater retention (in tanks or detention basins or in void spaces in surface channels) so that instead of providing a runoff rate like the red line in Figure 3.44c, it produces runoff similar to the green line in the same figure. Hydraulic modelling software can easily run dynamic hydraulic simulations so long as inlets and outlets of any retention structures are defined.

It is obvious that not all road construction projects should have to comply with the same degree of stormwater runoff rate attenuation. The precise criteria are defined by local planning authorities although minimum requirements could be specified in GPP criteria with the potential to increase requirements in areas deemed to be sensitive to flooding.

One vital and often overlooked aspect of road drainage systems is maintenance. There are numerous examples of poorly maintained road gullies almost everywhere (see Figure 3.46 below).

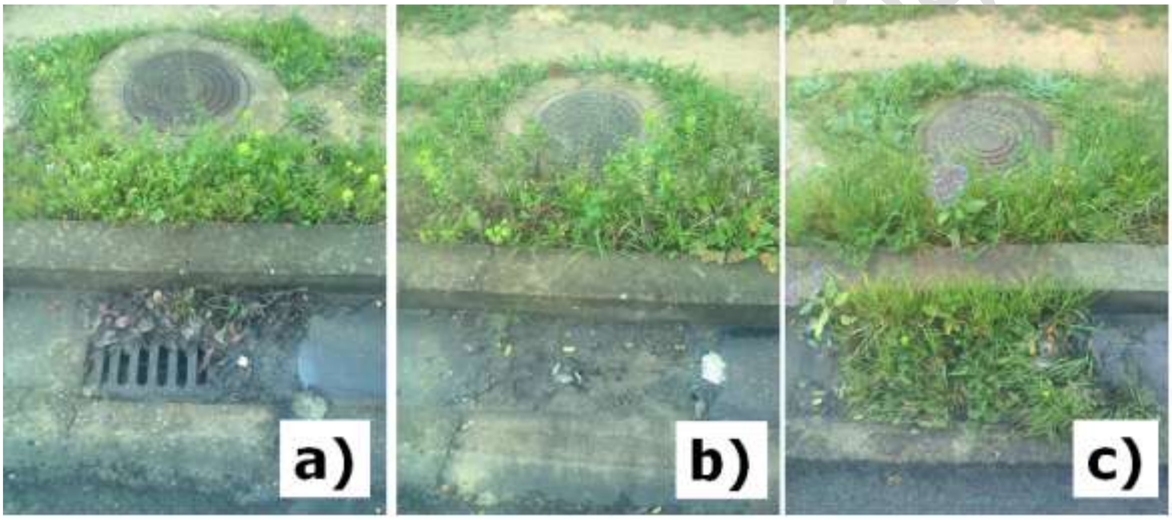


Figure 3.46. Examples of poorly maintained road drain gullies.

Often maintenance is simply by visual inspection once or twice a year. However, surface inspection will not reveal large accumulations of sediment and litter in gully sumps or pipework. Often the need for maintenance in drainage systems is only discovered when localised flooding occurs after short and intense rainfall events.

3.5.4 Watercourse pollution

3.5.4.1 Background

The pollution of watercourses has traditionally been associated with the discharge of untreated sewage and/or industrial effluents. Today in the EU, this is generally not a problem due to the implementation of environmentally stringent laws regulating the treatment of sewage and industrial emissions (the Urban Wastewater Treatment Directive 91/271/EEC and the IPPC Directive 2008/1/EC for example). As these sources of pollution become less severe, more relevance arises to diffuse sources of pollution, for example from road drainage. This section discusses the typical types of pollutants that can be transferred to watercourses via road drains and possible ways to minimise such pollution.

3.5.4.2 Combined sewers versus separate systems

Sewage is not directly related to the construction or use of roads, but it becomes a factor when road drainage systems are connected to combined sewerage systems. The accumulation of water on road surfaces is undesirable for obvious reasons. Road surfaces are generally impermeable and sloped to facilitate the free runoff of rainwater from the road to the embankment where a drainage system is typically installed. The drainage system may be one of two broad types:

- Combined drains (convey both sewage and storm-water to wastewater treatment plants).
- Storm-water drains (convey only storm-water directly to a nearby watercourse).

The main difference between these systems is noticed during wet weather, as is illustrated in Figure 3.47 below.

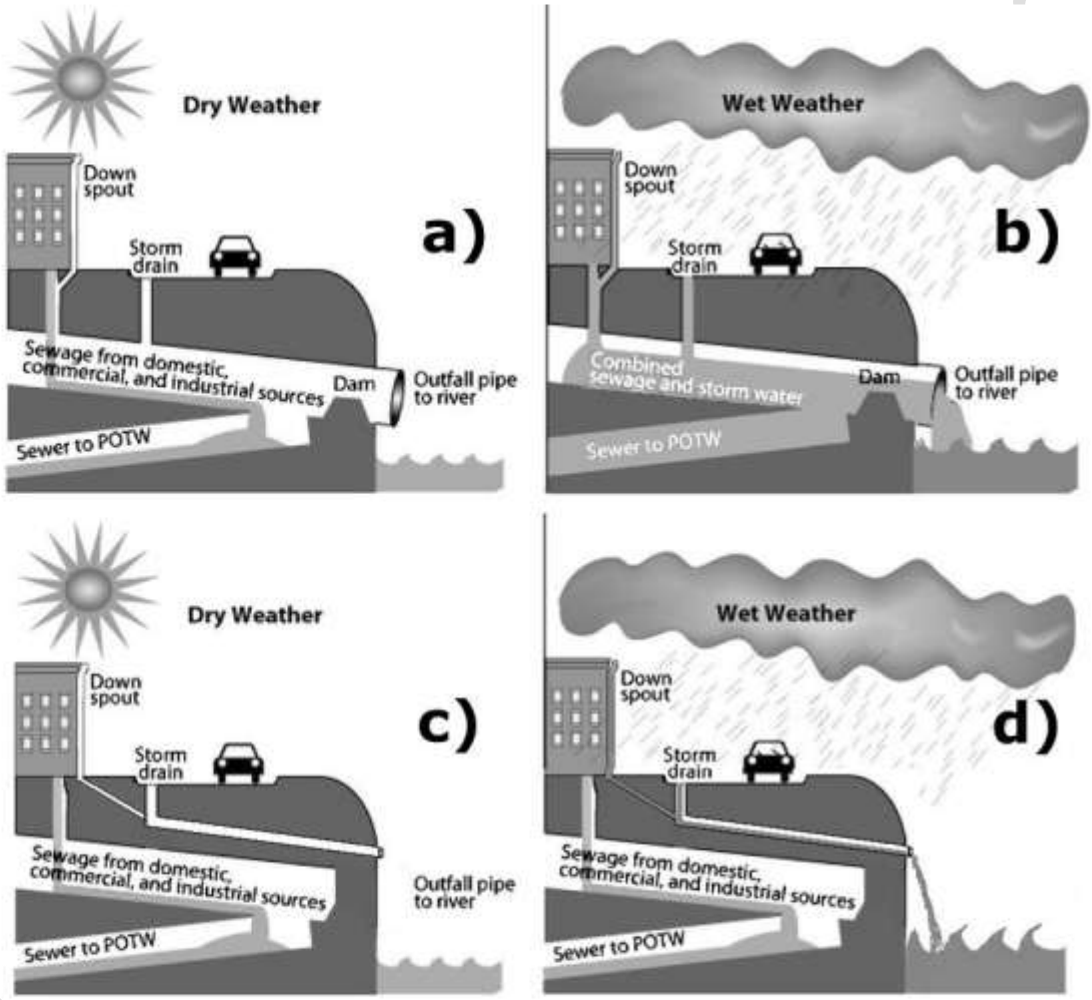


Figure 3.47: Illustration of runoff flow patterns under dry and rainy spells in combined sewers (a and b, top) and in separated sewers (c and d, bottom) – adapted from US-EPA, 2004.

Advantages of combined drainage systems are that they are often more convenient for contractors and periodic flushing with storm-water helps prevent septic conditions arising in the sewerage mains. However, the major disadvantage of these systems is that during heavy storm events, there is a high risk of untreated sewage being discharged directly to watercourses (see Figure 3.46b). Furthermore, combined drains compromise the design and performance of sewage treatment works, which will experience large variations in feed flow rates.

The only way to guarantee against the discharge of untreated sewage into watercourses is to avoid the use of combined sewers. This requirement could easily be inserted into core GPP criteria for road construction.

3.5.4.3 Typical pollutants transferred from roads to watercourses

Pollutant transfer to watercourses from roads can be split into two stages in an analogous manner to impacts due to environmental noise:

a) Potentially large acute loads of exposed soil and sediments being transferred by eolian (wind) or fluvial (water) forces during the construction phase to nearby watercourses.

b) A gradual load over decades of particles from car exhaust emissions, road surface degradation and tyre degradation being transferred to nearby watercourses.

Transfer of solid particles from the construction phase to watercourses can be minimised via good site management, planning and practice. These details can be specified in the environmental impact assessment and easily verified on site. In comparison, the pollutants transferred in smaller loads, but during much longer periods represent the most significant pollutant-load to watercourses but are generally not covered in environmental impact assessments.

Particulate matter and dust (road particles) that accumulate on dry roads contain a number of pollutants that are normally directly attributable to the traffic flows on the road. These particles are removed by storm-water and transferred to the aquatic environment. Some examples of pollutants found in road particles are:

- Zinc (Zn) and Sulfur (S) in tyre particles in concentrations up to 9,000mg/kg and 12,000mg/kg respectively (Kreider et al., 2010).
- Highly variable loads of elements such as Sodium (Na), Potassium (K) and chloride (Cl), due to the use of road grits when snow/ice on roads is expected.
- Polycyclic aromatic hydrocarbons (PAH's), from atmospheric deposition of exhaust gases / exhaust particulates (Dong and Lee, 2009).
- Oils and aromatic compounds from vehicle leaks.
- Metals from brake pad wear such as Copper (Cu) (Hulskotte et al., 2006), Zinc (Zn) (Armstrong, 1994) and where stainless steel brake pads are used, Iron (Fe), Nickel (Ni) and Chromium (Cr) in road particles.
- Precious metals Platinum, Palladium and Rhodium (Pt, Pa and Rh) from catalytic converters can be found in road dust in concentrations up to around 1mg/kg (Pritchard et al., 2009).

Other types of pollutants can be regarded as general litter dumped by road users, including cigarette butts, plastic wrappers, cans, cups and bags. Natural litter such as leaves, twigs and grass cuttings should not be discounted. These items can also be carried into drainage systems and not only pollute downstream watercourses but have the potential to block drainage systems and increase the risk of flooding.

Pollutant transfer from roads to the aquatic environment is an example of diffuse pollution to watercourses. The EU Water Framework Directive (2000/60/EC) aims to introduce statutory tools to limit such pollution. The use of traditional combined sewers/drains is unlikely to continue in new developments following implementation of the Directive. Separated systems must also contain some measures (such as screens or sediment traps) to prevent the direct discharge of litter and suspended solids in storm-water to watercourses.

3.5.4.4 Hard engineering approaches to stormwater treatment

Examples of oil interceptors, gully pots and retention tanks. Explain how capacity can be provided by gutters and oversized conveyance pipes too.

3.5.4.5 Soft engineering approaches to stormwater treatment (SuDS)

3.5.4.5.1 The SuDS concept

The development of SuDS has grown substantially during the last decade in the more environmentally conscientious EU Member States. The aim of SuDS is three-fold

- To attenuate stormwater runoff rates from sites to levels typical of equivalent greenfield sites (see green line in Figure 3.44c).
- To provide a degree of treatment to the water via basic physical processes such as in hard engineered infrastructure but also via biological treatment processes (e.g. microbial breakdown of organics).
- To enhance the aesthetic value of the area and potentially to create wildlife habitat.

SuDS consist of one or more drainage components that can be arranged together to form a "treatment train", through which the storm-water passes prior to final discharge to the receiving watercourse or groundwater table. Each of these components will be more or less suited to different site scenarios. For example, infiltration devices can only work properly if the soil is freely draining and the groundwater table is situated approximately 1m below the bottom of the infiltration bed whereas ponds/wetlands are better suited to poorly draining soils and where the bottom is situated near or even below the groundwater table. A list of different SuDS components that can potentially be used with roads is provided in the Table 3.33:

Table 3.33: List of common SuDS components

Type	Component	Brief description	Further information
Retention (simple peak flow attenuation)	Bioretention pond	Similar to a filter strip. Landscaped garden area with vegetative cover. Allows for up to 0.15m standing water depth. Mulch and soil layers on top of geotextile, then gravel, then perforated pipe for further conveyance. A useful pre-treatment unit and generally designed to handle frequent storm events with an overflow to send excess water to downstream components.	Section 11 of SUDS Manual C697 (CIRIA, 2007).
	Subsurface storage	One particularly efficient means is the use of geocellular modular plastic units that provide structural stability and a high voids ratio (up to 96%). Can be used under public spaces but do not provide any treatment to water. Pre-treatment prior to entry is highly recommended.	Section 13 of SUDS Manual C697 (CIRIA, 2007).
Wetland (best option for ecological aspects)	Shallow wetland	Can combine some deep areas too. Needs pre-treatment and a continuous base flow. Only designed for small frequent storms in general since not very useful for peak flow attenuation.	Section 18 of SUDS Manual C697 (CIRIA, 2007).
	Extended detention wetland	The same idea as a shallow wetland but with deeper areas to provide greater flow capacity in a smaller area.	Section 18 of SUDS Manual C697 (CIRIA, 2007).
	Pond/wetland	A two part system with a permanent pond that provides flow attenuation and may have a forebay for pre-treatment that discharges into a wetland which has high and low marshes in a controlled manner.	Section 17+18 of SUDS Manual C697 (CIRIA, 2007).
	Pocket wetland	Small scale versions of shallow/detention wetlands.	Section 18 of SUDS Manual C697 (CIRIA, 2007).
	Submerged gravel wetland	Wetlands with a gravel base that is designed to be submerged at all time. Excellent potential for biological de-nitrification via bacteria on gravel surfaces.	Section 18 of SUDS Manual C697 (CIRIA, 2007).
	Wetland channel	Similar to swales but designed to have a constant base flow and thus is much closer to the ground water table.	Section 18 of SUDS Manual C697 (CIRIA, 2007).
Infiltration (pre-treatment can be applied via a layer directly on top)	Infiltration trench	Shallow (1-2m) trench excavation filled with rubble. Non-lined, allowing water to soak into ground. Pre-treatment needed to prevent blockage with silts. This may include covering with a geotextile and a layer of pea gravel or vegetation on top of the membrane.	Section 9 of SUDS Manual C697 (CIRIA, 2007).
	Infiltration basin	Large vegetated depressions that provide large storage capacity during storms and that empty via infiltration. Some pre-treatment is preferred.	Section 15 of SUDS Manual C697 (CIRIA, 2007).
	Soakaway	Square or circular excavations. Can be either filled with rubble (basic option) or lined with brickwork, pre-cast concrete or plastic rings that are perforated and surrounded by granular backfill.	Section 6.5 of SUDS Manual C697 (CIRIA, 2007).
Filtration (can be useful intermediate components but require some pre-treatment)	Surface sand filter	Used when especially high pollutant loads are expected. Can provide some temporary storage via ponding on surface. Sand is 0.5-1.0mm and filters are 0.45-0.60m deep. But not suitable for large catchments and potentially problematic with maintenance. Typically designed with a sedimentation forebay.	Section 14 of SUDS Manual C697 (CIRIA, 2007).
	Sub-surface sand filter	Very similar to perimeter sand filters.	Section 14 of SUDS Manual C697 (CIRIA, 2007).
	Perimeter sand filter	Typically constructed around impermeable areas like car parks. Surface is typically covered with grates.	Section 14 of SUDS Manual C697 (CIRIA, 2007).
	Bioretention / filter strip	Vegetated strips of land that receive runoff as overland sheet flow and provide vegetative filtering, settlement of solid particles and allow a degree of infiltration into underlying soil.	Section 8 of the SUDS Manual C697 (CIRIA, 2007)

	Filter trench	The exact same as an infiltration trench except that water enters a perforated pipe at the bottom of the trench instead of passing to soil below.	Section 9 of SUDS Manual C697 (CIRIA, 2007).
Detention (simple flow attenuation)	Detention basin	Large excavated areas that may be lined or not and effectively attenuate peak storm flows but only provide a limited degree of treatment. Can be designed for recreational use as well in some cases.	Section 16 of SUDS Manual C697 (CIRIA, 2007).
Open channels (good balance between pre-treatment and ecology)	Conveyance swale	Linear sloped vegetated channel whose primary function is to transfer storm water from on point to another while providing some degree of infiltration and sediment removal	Section 10 of the SUDS Manual C697 (CIRIA, 2007)
	Enhanced dry swale	Basically a normal swale with a filter trench or infiltration trench below its central section. Result is that the swale will remain dry all but extreme scenarios.	Section 10 of the SUDS Manual C697 (CIRIA, 2007)
	Enhanced wet swale	Similar to a conveyance swale but where soils are poorly drained / liners are used / base is close to the groundwater table – which result in the central ground remaining moist.	Section 10 of the SUDS Manual C697 (CIRIA, 2007)

There are three levels of SuDS drainage control which each may use one or more of the above components:

- **Source control** (where storm-water falls directly onto the component and/or is received from areas immediately adjacent to the component).
- **Site control** (where storm-water is channelled from a number of different source control component(s)).
- **Regional control** (where storm-water is received from a number of different source control and site control components).

An illustration of the treatment train principle as applicable to roads and pavements is shown in Figure 3.48.

Figure 3.48: Example of SuDS treatment train principle. Image adapted from "SUDS for roads".

Conveyance from one SuDS component from another can be achieved by simple pipes but where possible, swales, filter drains or simple ditches are preferred since they provide a degree of pre-treatment to storm-water. SuDS can also be "bolted on" to existing hard engineered drainage systems where retrofitting is specified.

3.5.4.5.2 Designing SuDS

The nature of the site will often determine what SuDS components are necessary and how they should be dimensioned. In order of importance, the main design factors are:

- Impermeable area to be drained.
- Local rainfall data (the drainage system should be sized to handle storm-water for a defined storm event of specific duration).
- Topography of the site and space available (and proximity of groundwater table).
- Soil type (to determine what type of infiltration rates can be expected).
- Sensitivity or surrounding watercourses/groundwater to pollution.
- Budget available for maintenance/landscaping.

In a similar manner to the hydraulic modelling simulations mentioned in section 3.5.3.4, SuDS can be sized and designed to comply with flood risk assessment requirements of planning authorities in the same manner as with hard-engineered systems. All SuDS components operate by the same basic hydraulic principles.

3.5.4.5.3 Common examples of SuDS with roads

a) Swales (for source control / conveyance / pre-treatment)

Swales can commonly be employed with roads so long as sufficient land is available and that the site section is not too flat or too steeply sloped. Maintenance requirements are generally a monthly inspection for litter cleaning and to check when grass cutting will be necessary. Some real life photos and technical drawings of different swale types are included in Figure 3.49 below.

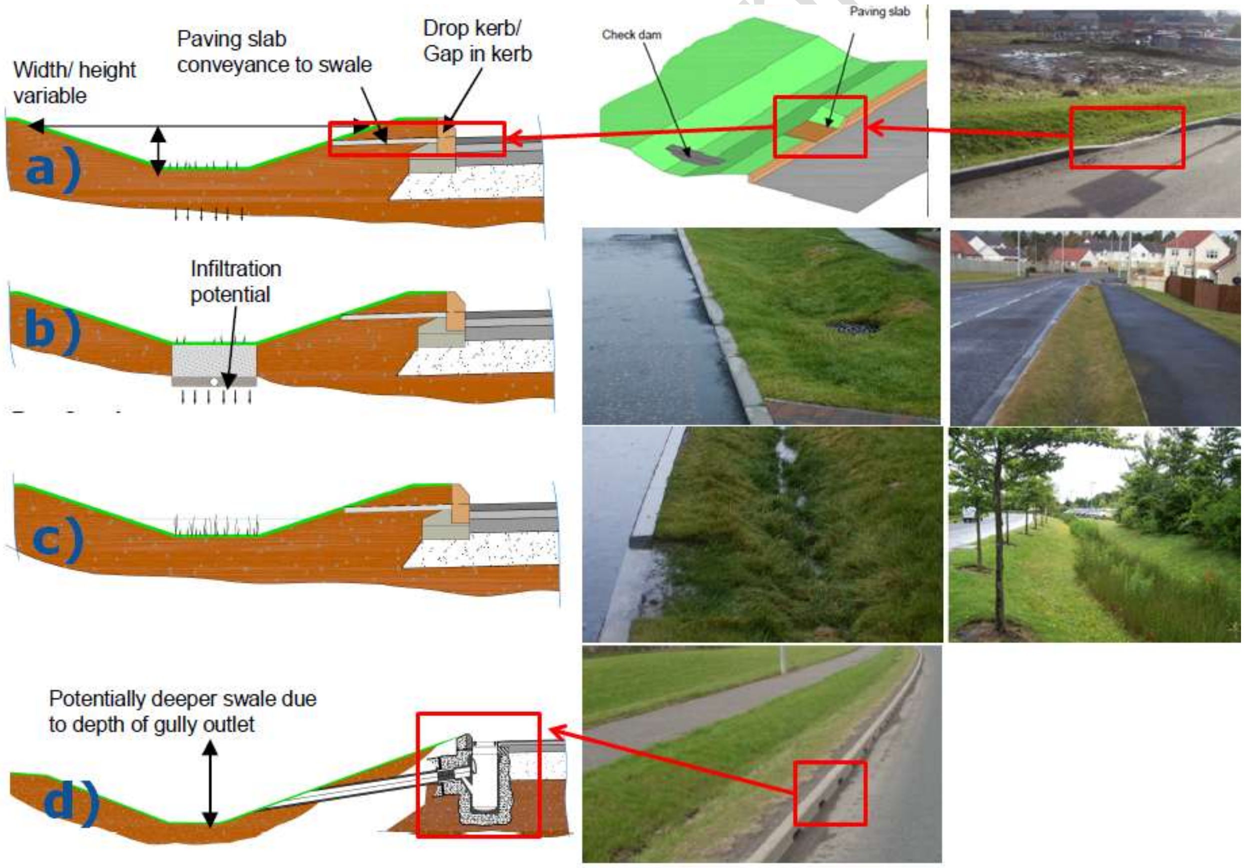


Figure 3.49: Examples of technical drawing of a) normal swales with some infiltration, b) dry swales, with enhanced infiltration, c) wet swales, with very limited or no infiltration and d) swales fed by road gullies

With the exception of wet swales, storm-water may also infiltrate into the ground. Overland passage of storm-water along the length of the swale will receive a reasonable degree of treatment for sediment removal and potential biological uptake of nutrients and adsorption and eventual bacterial breakdown of oils. Common design criteria and guidance are well established and can be found in the SUDS Manual C697 published by

CIRIA (2007) or in the SuDS for Roads publication which is freely available. Particular care must be taken during the immediate post-construction phase when grass cover must be established.

b) Filter drains / infiltration trenches (for source control / conveyance / pre-treatment)

These can also act as conveyance components and provide a degree of filtration treatment and source control as road runoff trickles through the stone trench. They are simpler to maintain than swales although inspection of any blockages in the pipe is more difficult.

The key difference between a filter drain and an infiltration trench is that when the soil is freely draining, the system provides significant infiltration and a collector drain at the bottom may not be necessary. With poorly draining soils, the system is generally referred to as a filter drain and the collector drain is installed to prevent water from potentially staying at the base of the trench for long periods.

An example of a filter drain system is shown in Figure 3.50a. Such systems do not require the use of kerb stones. However, this can lead to another problem where cars may park directly on top of the filter media and potentially compact the media or break the collector pipe, affecting SuDS performance. Suitable deterrents to parking may well be necessary.

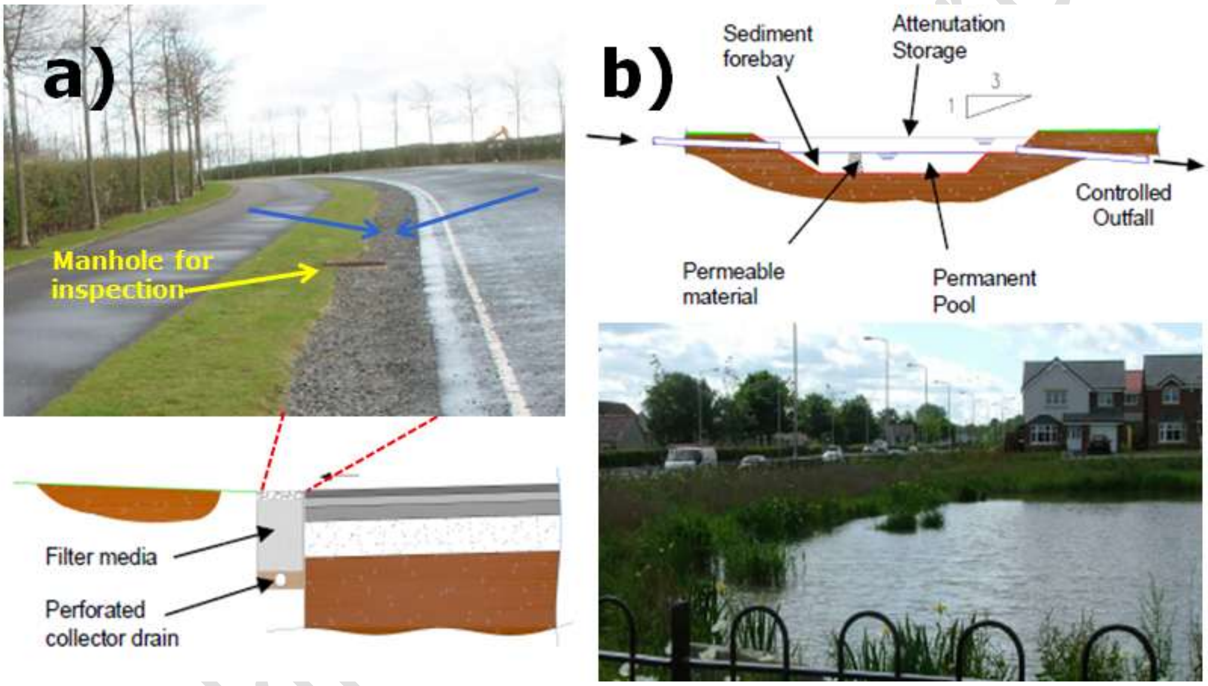


Figure 3.50: Examples of a) a SuDS filter drain and b) a permanent pond (images from SuDS for roads).

c) Ponds / Infiltration basins

The storage capacity provided by source control and conveyance components like swales and filter drains may not be sufficient for larger storms. Where extra storage capacity is required, the use of ponds and retention basins as site control or regional control components is useful. The distinction between ponds and infiltration basins lies in the soil underneath. Ponds are suitable in poorly draining soils near the groundwater table and infiltration basins are suitable in freely draining soils situated well above the groundwater table. Ponds should retain a minimum permanent water level and can be aesthetically pleasing and provide wildlife habitat. A typical SuDS pond diagram is shown in Figure 3.50b.

Depending on the level of pre-treatment received, it may be necessary to design a sediment forebay feature, where a point inlet of storm-water is diffused laterally and the reduced flow velocities encourage sediment deposition.

The permanent water depth may need to be assured by suitable lining of the pond with a geotextile membrane, even in poorly draining soils (as shown in Figure 3.50b).

Finally, the pond outlet should represent a bottleneck in the system (such as an orifice plate) which allows the pond to drain to the minimum water depth level at a rate that is similar to the runoff expected as if the site was undeveloped. Blockage of this small outlet must be frequently checked.

3.5.4.5.4 Potential maintenance issues with SuDS

Many SuDS components such as swales and wetlands present unique maintenance requirements for local authorities. Where such systems are specified, it will be necessary to ensure that maintenance responsibilities are clearly defined and that the budget is sufficient. In many cases the cutting of grasses can be incorporated into other landscaping contracts although this will vary on an individual project basis.

Other SuDS components can present equal or lower maintenance requirements than traditional drainage systems and the extra requirements of cutting grass etc. in overland systems should be offset against the ease of identifying potential problems such as litter accumulation and blockage of inlets/outlets.

3.5.4.5.5 Concluding remarks

In general, SuDS components have been well defined and experience in their design, construction and management is increasing every year. The availability of design manuals mean that many contractors should be perfectly capable of implementing such systems. The appropriateness of SuDS may vary from site to site and possible combinations with "hard engineered" systems may be more suitable in some cases. It is not envisaged that SuDS should be included in core GPP criteria but instead in either comprehensive or award criteria.

3.5.5 Wildlife habitat

In roads that are constructed in rural areas or especially in national parks, there is the dual risk of loss of habitat and the creation of barriers to species migration. Loss of habitat can be directly linked to the land area that is occupied by the road and any pavements. Wetland habitat may also be compromised by road construction if the base and sub-base present barriers to groundwater flows from one side of the road to wetland type habitat on the other side.

Barriers to species migration can occur to insects, frogs and small animals if the traffic loads are sufficient. Any endangered animal populations face a significant mortality risk by the presence of a road. In extreme cases for large animals, wildlife corridors can be created by fencing the roadside off and creating a series of bridges, as has been carried out in the Doñana National Park in southern Spain (see Figure 3.51a).

Frogs and toads are particularly susceptible to high mortality rates when crossing roads and will continue to cross roads if it presents an obstacle to their normal breeding ground. Areas that are affected are highly localised. To determine if any new road construction is likely to affect frog or toad populations, the first contact at EU level would be ENPARTS (European Network for Protection of Amphibians and Reptiles from Transport Systems). There is no universal engineering solution that is proven to help frogs/toads cross the road, but it is possible that box culverts may be more useful (see Figure 3.51b) and certainly would be more helpful than grooved pipe systems (Figure 3.51c) which would be considerably more difficult for frogs and toads to cross through.

Figure 3.51: a) example of a bridge crossing as a migration pathway for large endangered animal species b) a typical box type road culverts for drainage conveyance and c) a typical grooved pipe road culvert.

Minimal disruption to natural stream flows should be created by road construction, particular where these streams normally feed downstream wetland type habitat. As far as is practical, any culverts for streams should not present physical obstacles to fish, frogs or toads.

Criteria covering loss/provision of habitat is not envisaged to be part of core GPP criteria although there is the possibility that some criteria could be implemented if the road construction is to take place in highly specific areas such as national parks and areas of frog/toad migration. This section may be more appropriately covered in the Environmental Impact Assessment and local planning authorities.

4 CONCLUSIONS

The development of criteria for a GPP requires in-depth information about the technical and environmental performance of road construction as well as the procurement processes. For this reason, the European Commission has developed a process aiming at bringing together both technical and procurement experts to develop a broad body of evidence and to develop in a consensus oriented manner, a proposal for criteria which promise to deliver substantial environmental improvements.

Two reports have been prepared for stakeholder consultation prior to the 1st Ad Hoc Working Group (AHWG) meeting. The first is the present preliminary report, which provides an in-depth background information relevant to road construction and describing factors related to potential GPP criteria areas. The **preliminary report** has been split into the following sections:

- Task 1: Stakeholder survey, statistical and legal review, scope and definition proposal
- Task 2: Market analysis
- Task 3: Technical analysis
- Supporting annexes (included in a separate document).

Information on the environmental improvement potential of road construction and maintenance, also including simplified LCC considerations, will be provided in the technical report for the 2nd AHWG.

The second report (the **technical report**) is much more concise, contains an executive summary of the preliminary report and is focussed on draft criteria proposals for GPP and the rationale behind those criteria, which have been developed on the base of the outcomes from the preliminary report. Furthermore, some preliminary information collected in order to prepare a GPP guidance document will also be included.

Contributions from the GPP Advisory Group and interaction with stakeholders form key components of the study. Therefore, aspects of both reports will be discussed at the meeting, which will be organised by the JRC IPTS on 12th of March 2014 in Brussels.

Afterwards, the preliminary and the technical reports will be revised accordingly based on the outputs of the 1st AHWG meeting and on the feedbacks that will be received from the stakeholders. Stakeholders are kindly invited to comment on the material contained in these reports (within the BATIS system) in order to validate, revise and integrate the information presented.

If a new stakeholder would like to be involved in the consultation process, publically available information related to the development of the GPP criteria for road construction can be found at http://susproc.jrc.ec.europa.eu/road/ hosted by JRC IPTS. It is also possible to register at this Internet page in order to be involved in the consultation process.

5 REFERENCES

AASHTO (1993). Guide for Design of Pavement Structures. American Association of State Highway and Transportation Officials. Washington D.C.

AAPA (2010). Flexible pavement maintenance and rehabilitation. Report of the Australian Asphalt Pavement Association. Available online at http://www.aapaq.org/q/qbspp2012p/docs/Sec16_Maintenance_Rehabilitationfinal.pdf [checked on 15.02.2014]

Acciona (2013). EPD of the N-340 road. Reg. no. S-P-00516. On 19.12.2013

Armstrong L.J. (1994). Contribution of heavy metals to storm water from automotive disc brake pad wear, Consultants Report.

Barandica. J.M., Fernández-Sánchez G., Berzosa A., Delgado J.A. and Acosta F.J. (2013). Applying life cycle thinking to reduce greenhouse gas emissions from road projects. Journal of Cleaner Production 57 (2013), pp.79-91

BIOIS, EC (2011). Service Contract on Management of Construction and Demolition Waste – SR1. Final Report Task 2. Available online at http://ec.europa.eu/environment/waste/pdf/2011_CDW_Report.pdf [checked on 15.02.2014]

Birgisdóttir H. (2005). Life cycle assessment model for road construction and use of residues from waste incineration. Ph.D. Thesis. DTU University

Birgisdóttir H., Bhander G., Hauschild M.Z., Christensen T.H. (2007). Life cycle assessment of disposal of residues from municipal solid waste incineration: Recycling of bottom ash in road construction or landfilling in Denmark evaluated in the ROAD-RES model. Waste Management 27, pp. S75-S84

Blengini G A , Garbarino E , Solar S , Shields D , Hámor T. , et al. (2012). Life- cycle assessment guidelines for the sustainable production and recycling of aggregates: The Sustainable Aggregates Resource Management project (SARMa). Journal of Cleaner Production , 28 , 177 – 181

Blengini G.A. and Garbarino E. (2010). Resources and waste management in Turin (Italy): the role of recycled aggregates in the sustainable supply mix. Journal of Cleaner Production 18, 1021–1030

Bonaquist R. (2011). Mix Design Practices for Warm Mix Asphalt. NCHRP Report 691, Transportation Research Board, WashingtonD.C., USA

Boorman, D.B. (1985). A review of the Flood Studies Report Rainfall-Runoff model parameter estimation equations. Institute of Hydrology report.

Brennan, P. (2013). A marketer's view of the future - STEAG. Ashtrans Europe 2013. Accessed online Jan 2014 at: http://www.ashtrans.eu/Ashtrans_2013_-_Steag_m.pdf

Brown, D.C., 2008. Warm Mix: the lights are green. Hot Mix Asphalt Technology-January/February 2008, pp. 20e32

BRV, 2007a. Guideline for Construction Materials made from Recycled Demolition Waste from Aboveground Construction, Red Guideline, Vienna, 1st issue, August 2007.

BRV, 2007b. Guideline for Recycled Building Materials, Green Guideline, 7th edition, Vienna, January 2007.

BRV, 2007c. Richtlinie fuer fliessfaehiges, selbstverdichtendes Kuenettenfuellmaterial mit recycliertem, gebrochenem Material, Vienna, 2nd. edition, September 2007

Buyle M., Braet J. and Audenaert A. (2013). Life cycle assessment in the construction sector: A review. Renewable and Sustainable Energy Reviews 26 (2013), pp.379–388

Capitão S.D. , Picado-Santos L.G. and Martinho F. (2012). Pavement engineering materials: Review on the use of warm-mix asphalt. Construction and Building Materials 36, pp. 1016–1024

Carlson A. (2011). Life cycle assessment of roads and pavements. Studies made in Europe. VTI rapport 736A

Carpenter A.C., Gardner K.H. (2009). Use of Industrial By-Products in Urban Roadway Infrastructure Argument for Increased Industrial Ecology. Journal of Industrial Ecology, 13 n. 6, pp. 965-977

Carpenter A.C., Gardner K.H., Fopiano J., Benson C.H., Edil T.B. (2007). Life cycle based risk assessment of recycled materials in roadway construction. Waste Management 27, pp. 1458-1464

CEDR (2009). Future European Road Network (FERN). Available online at http://www.cedr.fr/home/fileadmin/user_upload/Publications/2009/e_Future_road_networks_FERN.pdf [checked on 23.01.2014]

CEDR (2012). Trans-European road network, TEN-T (Roads): 2011 performance report. Available online at http://www.cedr.fr/home/fileadmin/user_upload/Publications/2013/e_TEN-T_Performances_2011.pdf [checked on 22.01.2014]

CEMBUREAU (2012) Activity Report. The Cement Sector: a Strategic Contributor to Europe's Future". Available online at http://www.cembureau.eu/sites/default/files/category_pictures/AR2012.pdf [checked on 12.01.2014]

CEREAL (2012). Tool assessment for CEREAL. Evaluation of existing CO2 tools for roads. Deliverable work package 3 (draft). Available online at http://www.eranetroad.org/images/eranet/Downloads/cereal_d3_tool%20assessment.pdf [checked on 18.02.2014]

Chappal M., Bilal J. (2003). The environmental road of the future. Life cycle analysis. Energy consumption and greenhouse gas emissions. Colas report

Chester M. V. and Horvath A. (2009). Environmental assessment of passenger transportation should include infrastructure and supply chains.

Chester M.V. (2008). Life-cycle Environmental Inventory of Passenger Transportation in the United States. Dissertations, Institute of Transportation Studies, University of California, Berkeley http://repositories.cdlib.org/its/ds/UCB-ITS-DS-2008-1

Choi, S-K, Lee, S., Song, Y-K. and Moon, H-S., 2002. Leaching characteristics of selected Korean fly ashes and its implications for the groundwater composition near the ash disposal mound. Fuel, 31, p.1083-1090.

Chowdhury R., Apul D., Fry T. (2010). A life cycle based environmental impacts assessment of construction materials used in road construction. Resources, Conservation and Recycling 54, pp. 250–255

Chowdhury, A., Button, J.W., 2008. A Review of Warm Mix Asphalt. Texas Transportation Institute e Technical Report 473700-00080-1 College Station, USA

CIRIA (2007). The SUDS Manual, C697, The Construction Industry Research and Information Association. ISBN 9780860176978

CNR (1992). Determinazione dei moduli di deformazione Md e Md1 mediante prova di carico a doppio ciclo con piastra circolare. Bollettino Ufficiale n.146. CNR Consiglio Nazionale delle Ricerche, Rome, Italy. In Italian.

Commission of the European Communities (2002). Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise. Official Journal of the European Commission, L189/12

Construction Europe (2008). CE-100, 2008-2012, KHL Group. Information available online at http://www.khl.com/servlet/file/CE-100.pdf?ITEM_ENT_ID=29559&ITEM_VERS [checked on 15.02.2014]

COST European cooperation in the field of scientific and technical research (2008). The way forward for pavement performance indicators across Europe – COST-Action 354 (2008) "Performance Indicators for Road Pavements". Final Report, FSV – Austrian Transportation Research Association, Vienna – COST, Brussels

D'Angelo, J., Harm, E., Bartoszek, J., Baumgardner, G., Corrigan, M., Cowsert, J., Harman, T., Jamshidi, M., Jones, W., Newcomb, D., Prowell, B., Sines, R., Yeaton, B. (2008). Warm-Mix Asphalt: European Practice. Report No.FHWA-PL-08-007. American Trade Initiatives, Alexandria, USA

Danish EPA (2005). Waste statistics 2003. Ministry of Environment. Danish EPA, Copenhagen, Denmark (Environmental Review 4-2005)

DEFRA (2009). Construction Code of Practice for the Sustainable Use of Soils on Construction Sites. Available online at https://www.gov.uk/government/publications/code-of-practice-for-the-sustainable-use-of-soils-on-construction-sites [checked on 31.01.2014]

DEPA, 2003a. Danish Environmental Protection Agency. Forslag til strategi for begrænsning af vejtrafikstøj (Proposal for a strategy for the reduction of road traffic noise (in Danish)). The Road Noise Group: Ministry of the Environment, Ministry of Finance, Ministry of Transport, Ministry of the Interior and Health, Ministry of Justice and Ministry of Economy and Enterprise. November 2003. www.mst.dk.

DEPA (2003b). Danish Environmental Protection Agency. Hvad koster støj? – værdisætning af vejstøj ved brug af husprismetoden (What are the costs of noise?– Evaluation by the use of the house-pricing method (in Danish)). Environmental project no. 795, 2003. Environmental Protection Agency. www.mst.dk.

Doll C. and Sieber N. (2011). FP7 WEATHER project. Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions Deliverable 2: Transport Sector Vulnerability Annex 3 Vulnerability Assessment for Road Transport. Available online at http://www.weather-project.eu/weather/inhalte/deliverables.php [checked on 15.02.2014]

Dong T.T.T. and Lee B.K. (2009). "Characteristics, toxicity, and source apportionment of polycyclic aromatic hydrocarbons (PAHs) in road dust of Uslan, Korea", Chemosphere, 74, p.1245-53

DWW (1991). Onderzoek naar de snelheid van vervuilen van zeer open asfaltbeton. Internal memo MAA-S-91008, DWW Afdeling adviezen, 17-1-1991

EAPA (2007) Environmental Guidelines on Best Available Techniques (BAT) for the Production of Asphalt Paving Mixes. Available online at http://eapa.org/usr_img/position_paper/bat_update_version2007.pdf [checked on 23.01.2014]

EAPA (2010). The use of warm mix asphalt – EAPA position paper. Brussels: European Asphalt Pavement Association

EAPA (2011). Asphalt in figures. http://www.eapa.org/userfiles/2/Asphalt%20in%20Figures/Asphalt%20in%20figures%2029-11-2012.pdf

EAPA (2013). Presentation by Egbert Beuving, Director at EAPA about "Asphalt re-use and recycling in Europe, an overview". Available onlina at http://re-road.fehrl.org/?m=38&a=content&id=739 [checked on 15.02.2014]

EAPA (2012). Asphalt in Figures 2011. Retrieved from European Asphalt Pavement Association. Available online at http://www.eapa.org/userfiles/2/Asphalt%20in%20Figures/Asphalt%20in%20figures%2029-11-2012.pdf [checked on 18.01.2014]

EC (2008). Green Public Procurement Training Toolkit. Construction Background Product Report. Brussels.

EC (2010). Green Public Procurement. Road Construction and Traffic Signs. Technical Background Report

EC (2010). International reference life cycle data system (ILCD) hand-book – general guide for life cycle assessment – detailed guidance, EUR 24708 EN. Luxembourg: Publications Office of the European Union

EC (2012a). EU GPP Criteria for Street Lightning & Traffic Signals. Available online at http://ec.europa.eu/environment/gpp/pdf/criteria/street_lighting.pdf [checked on 12.01.2014]

EC (2012b). Road transport. A change of Gear. Available online at http://ec.europa.eu/transport/modes/road/doc/broch-road-transport_en.pdf [checked on 17.01.2014]

EC (2013a). EU transport in figures. Statistical Pocketbook 2013. Available online at http://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2013_en.htm [checked on 12.01.2014]

EC (2013b). Glossary: Classification of types of construction (CC). Available online at http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Classification_of_types_of_construction_(CC) [checked on 12.01.2014]

EC JRC (2009). End-of-Waste Criteria. Final Report. Available onlive at ftp://ftp.jrc.es/pub/EURdoc/JRC53238.pdf [ckecked on 29.11.2013]

EC JRC (2011a). Supporting Environmentally Sound Decisions for Construction and Demolition (C&D) Waste Management. A practical guide to Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) , Luxembourg : European Commission, Joint Research Centre, Institute for Environment and Sustainability

EC JRC (2011b). ILCD Handbook. Recommendations for Life Cycle Impact Assessment in the European context based on existing environmental impact assessment models and factors

EC JRC (2012a). Impacts of Climate Change on Transport: A focus on road and rail transport infrastructures. Available online at http://ftp.jrc.es/EURdoc/JRC72217.pdf [checked on 15.02.2014]

EC JRC (2012b). Product Environmental Footprint (PEF) Guide. Consolidated version

ECOBA. (2009). Production and Utilisation of CCPs in 2009 in Europe (EU 15). Retrieved from European Coal Combusion Products Association: http://www.ecoba.com/evjm,media/ccps/ecoba_statistics_2009.pdf [checked online on 15.02.2014]

ECRPD (2010). Energy conservation in road pavement design, maintenance and utilisation, Intelligent Energy Europe, Feb 2010, www.roadtechnology.se/ecrpd.eu/

EEA (1999). European Environmental Agency. Environment in the European Union at the turn of the century. European Environment Agency. Copenhagen, Denmark

EEA (2003). European Environment Agency. Europe's environment: The third assessment. EEA Environmental Assessment Report No. 10. EEA, Copenhagen, Denmark

EEA (2007). The European Environment Agency. Belgrade Report 2007, chapter 6; Sustainable Consumption and Production (SCP) and Waste Management

EEA (2010). The European Environment: State and Outlook, 2010, Water Resources, quantity and flows. Accessed Jan 2014 via: http://www.eea.europa.eu/soer/europe/water-resources-quantity-and-flows

ENVIRONDEC (2013). PRODUCT CATEGORY RULES DATE 2013-11-21 UN CPC 53211 highways (except elevated highways), streets and roads 2013:20 version 1.01

Environmental Protection Agency of Ireland (2003). guidelines

ERF (2006). The socio-economic benefits of roads in Europe. Available online at http://www.irfnet.eu/index.php?option=com_content&view=article&id=195%3Athe-socio-economic-benefits-of-roads-in-europe&catid=17&Itemid=30 [checked on 18.02.2014]

ERF (2013). European Road Statistics 2012.

ERF and IRF (2007). The socio-economic benefits of roads in Europe. Available online at http://www.irfnet.eu/media/the_socio_economic_benefits_of_roads_in_europe.pdf [checked on 15.02.2014]

ETC/SCR (2009). Green Public Procurement and Product Performance Requirements Case Study on Selected Energy Using and Non-energy Using Products Report n.4/2009 of the European Topic Centre on Resource and Waste Management

EU 2003, Valuation of Noise, Position paper of the working group on health and socio-economic aspects.

EULA (2011). Hydrated Lime – A proven additive for durable asphalt pavements. European Lime Association.

EULA (2013). http://www.eula.eu/sites/eula.eu/files/documents/EN_EuLA_Asphalt_-_literature_review.pdf

Eurobitume (2011a). European Bitumen Consumption 2011. Available online at http://www.eurobitume.eu/system/files/BitumenConsumption2011.pdf

Eurobitume (2011b). The Bitumen Industry. A global perspective. Available online at: http://www.eurobitume.eu/de/node/728 [checked on 19.01.2014]

Eurobitume (2013a). http://www.eurobitume.eu/bitumen/facts-and-stats

Eurobitume (2013b). Available online at http://www.eurobitume.eu/about/members [checked on 29.12.2013].

Eurorap (2013). Crash costs on the Spanish National Road Network. Found at the Internet site http://www.eurorap.org/knowledge-base/news-homepage/2013/crash-costs-on-the-spanish-national-road-network/ [checked on 15.02.2014]

EUROSLAG (2010). Statistics 2010. Available online at http://www.euroslag.com/fileadmin/_media/images/statistics/Statistics_2010_download.pdf [checked on 17.02.2014]

Eurostat (2009). Eurostat Methodologies and Working papers. Illustrated Glossary for Transport Statistics. Available online at http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-RA-10-028/EN/KS-RA-10-028-EN.PDF [checked on 23.01.2014]

Eurostat (2012). Europe in figures – Eurostat yearbook 2012. Available online at http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-CD-12-001/EN/KS-CD-12-001-EN.PDF [checked on 15.02.2014]

Eurostat (2013a). Data available at http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ [accessed on 27.12.2013]

Eurostat (2013b). Data available at http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_na_con_r2&lang=en [accessed on 27.12.2013]

Eurostat (2013c). Data available at http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do [accessed on18.02.2014]

Evans, L.R., et al. (2009). NHTSA Tire Fuel Efficiency Consumer Information Program Development: Phase 2-Effects of Tire Rolling Resistance Levels on Traction, Treadwear, and Vehicle Fuel Economy. National Highway Traffic Safety Administration

FEHRL (2013). Link to the homepage of FEHRL: http://www.fehrl.org/?m=321 [checked on 29.12.2013]

FEHRL, 2005. Forum of European national Highway Research Laboratories. SILVA project report: Guidance manual for the implementation of low-noise road surfaces.

FHWA (2006). Geotechnical Aspects of Pavements. U.S Department of Transportation. Federal Highway Administration. Publication No. FWHA NHI-05-037 Available online at http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/05037.pdf [checked on 23.01.2014]. Especially relevant in this context is chapter 7.5 and 6

FHWA (2009). Urban Drainage Design Manual. Publication number NHI-10-009. Third edition. Available online at http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=22&id=140 [checked on 23.01.2014]

Finnveden G., Brattebø H., Birgisdóttir H., Potting J. and Toller S. (2012). LICCER Life Cycle Considerations in EIA of Road Infrastructure. ENR2011 ENERGY – Sustainability and Energy Efficient Management of Roads

Flood Estimation Handbook, 1999. Centre for Ecology and Hydrology. ISBN 9781906698003.

FWHA, 2000. Federal Highway noise barrier design handbook. US Department of Transportation.

Gartner E., 2004. Industrially interesting approaches to "low-CO2" cements. Cem. Concr. Res., 34, p.1489-96.

Giustozzi F., Crispino M., Flintsch G. (2012). Multi-attribute life cycle assessment of preventive maintenance treatments on road pavements for achieving environmental sustainability. Int. J Life Cycle Assess 17, pp.409–419

Grabowski W., Wilanowicz J. and Sobol T. (2009). "Structural and functional properties of mineral fillers modified with hydrated lime", Proc. 6th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV6), Torino (Italy), paper 78

Greenroads (2011). Greenroads Manual. Version 1.5. Available online at https://www.greenroads.org/366/download-the-manual.html [checked on 23.01.2014]

Habert G., Billard C., Rossi P., Chen C., and Roussel N., 2010. Cement production technology improvement compared to factor 4 objectives. Cem. Concr. Res., 40, p.820-826

Haider (2013). Information found at Tyrosafe's Internet page: http://tyrosafe.fehrl.org/?m=1 [checked on 23.01.2014]

Haider et al (2012). MIRAVEC Project Deliverable D1.1 Report on the road infrastructure effects contributing to road vehicle energy consumption and their governing parameters. Available online at http://www.eranetroad.org/images/eranet/Downloads/miravec_d1.1_effects%20.pdf [checked on 23.01.2014]

Häkkinen T., Mäkele K. (1996). Environmental adaptation of concrete. Environmental impact of concrete and asphalt pavements. VTT Research notes 1752, 61 p. + app. 32 p.

Hammarström, Ulf, Eriksson, Jenny, Karlsson, Rune, Yahya, Mohammed-Reza (2012) "Rolling resistance model, fuel consumption model and the traffic energy saving potential from changed road surface conditions", MIRIAM project, VTI report 748A

Hampson K., Newman P. and Keyley R. (2012). Mass-haul environmental impact minimization. A practical method for greening road procurement available online at http://www.sbenrc.com.au/images/stories/1.8_industryreport_final.pdf [checked on 21.01.2014]

Hauschild M. and Wenzel H. (1997) Environmental Assessment of Products. Vol. 2: Scientific background. Chapman & Hall, London, Weinheim, New York

Henkes W. (2008). Paradigmenwechsel - Wird die geplante Ersatzbaustoffverordnung die heutigen Verwertungswege zu Gunsten des Gewaesserschutzes erschweren. Ein neues Eluationsverfahren scheidet die Geister, Recycling Magazin 17 pp. 20-23

Highways Agency (2013). Business Plan 2013-2014. Available online at http://www.highways.gov.uk/publications/business-plan-2013-2014/ [checked on 15.02.2014]

Hill N., Brannigan C., Wynn D., Milnes R., van Essen H., den Boer E., van Grinsven A., Ligthart T.and van Gijlswijk R. (2012). EU Transport GHG: Routes to 2050 II The role of GHG emissions from infrastructure construction, vehicle manufacturing, and ELVs in overall transport sector emissions at http://eutransportghg2050.eu/cms/assets/Uploads/Reports/EU-Transport-GHG-2050-II-Task-2-draftfinal1Mar12.pdf

Hoang, T., Jullien, A. & Ventura, A. (2005). A global methodology for sustainable road – Application to the environmental assessment of French highway, 10DBMC International Conference of Building Materials and Components, Lyon, 17–20 April, 2005

Holldorb C. (1997). Beitrag zur Bewertung des Einsatzes offenporiger Asphaltdecbchichten au! Autobahnen. Technische Universität Darmstadt, Fachbereich Bauingenieurwesen D 17, Darmstadt, Germany.

Hopman P.C. (1998). Hydroxide in Filler, Netherlands Pavement Consulting Report n°97316, Utrecht (The Netherlands): Netherlands Pavement Consulting, 1998

Huang Y., Bird R., Heidrich O. (2009). Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. Journal of Cleaner Production 17, pp. 283–296

Huang Y., Spray A., Parry T. (2012). Sensitivity analysis of methodological choices in road pavement LCA. Int. J Life Cycle Assess.

Hulskotte J.H.J., Schaap M. and Visschedijk A.J.H., 2006. "Brake wear from vehicles as an important source of diffuse Copper pollution", 10th Int. Specialised Conference on Diffuse Pollution and Sustainable Basin Management, Sep. 18-22, Istanbul, Turkey. (IWA Internation Water Association).

Institute of Environmental Sciences, University of Leiden (2002). Handbook on impact categories "CML 2001". Leiden, The Netherlands

IPCC (2007). IPCC Climate Change Fourth Assessment Report: Climate Change 2007. http://www.ipcc.ch/ipccreports/assessments-reports.htm

Jacobsson T and Wågberg L G (1995). Inventering av dränerande asfaltbetong. Undersökning av borrkärnor (Inventory of porous asphalt. Investigation of core samples). Swedish National Road and transport Research Institute (VTI), Linköping, Sweden

Jones et al. (2009). Warm-Mix Asphalt Study: First-Level Analysis of Phase 2 HVS and Laboratory Testing and Phase 1 and Phase 2 Forensic Assessments, Research Report UCPRC-RR-2009-02, Prepared for Caltrans, University of California, Pavement Research Center, Davis, California, USA. Accessed on the Internet at http://www.ucprc.ucdavis.edu/PDF/UCPRC-RR-2009-02.pdf [checked on 27.12.2013]

Josa A., Aguado, A. Heino, A., Byars E. and Cadrin, a., 2004. Comparative analysis of available life cycle inventories of cement in the EU. Cem. Concr. Res., 34, p.1313-20.

Joumard et al (2007) EMISSION FACTOR MODELLING AND DATABASE FOR LIGHT VEHICLES (Artemis deliverable 3), LTE June 2007. Available online at http://www.inrets.fr/ur/lte/publi-autresactions/fichesresultats/ficheartemis/road3/database32/Artemis_deliverable_3_LTE0523_adobe7.pdf [checked on 15.02.2014]

JRC, 2013. Joint Research Centre of the European Commission. Last accessed Jan. 2014 via: http://floods.jrc.ec.europa.eu/flood-risk/flood-disasters.html

Kalman et al. (2013) Re-Road – Summary Report

Karlsson et al (2012). Karlsson, R., Carlson, A. and Dolk, E. Energy use generated by traffic and pavement maintenance. Decision support for optimization of low rolling resistance maintenance treatments. VTI notat 36A-2012

Keller (2010) HBEFA . Handbook Emission Factors for Road Transport 3.1 – Quickc Reference, INFRAS, Bern, 2010.

Korre A. and Durucan S. (2007). Life Cycle Assessment of Aggregates. WRAP Report (EVA025) at http://www2.wrap.org.uk/downloads/EVA025-MIRO_Life_Cycle_Assessment_of_Aggregates_final_report.414207d5.8879.pdf

Kreider M.L., Panko J.M., McAtee B.L., Sweet L.I. and Finley B.L., 2010, "Physical and chemical characterization of tire-related particles: Comparison of particles generated using different methodologies", Sci. Total. Environ., Vol 408(3), p.652-59.

Kuemmel J. (2000). Ökobilanzierung von Baustoffen am Beispiel des Recycling von Konstruktionsleichtbeton, Dissertation Universität Stuttgart, 2000. http://elib.uni-stuttgart.de/

Kuijpers A.H.W.M. and Schwanen W., (2005). Development of a measurement system for mechanical impedance. SILVIA Project Report SILVIA-M+P-013-01- WP2-230605

LAGA, 1998, Mitteilung 20 - Anforderungen an die stoffliche Verwertung von mineralischen Reststoffen/Abfällen. Dresden. http://www.laga-online.de/

Lehtiranta et al (2012). Evaluation of green public road procurement in Australia: current practices and gaps to fill. Available online at http://eprints.qut.edu.au/51118/3/51118.pdf [checked on 03.02.2014]

Liljenström C. (2013). Life Cycle Assessment in Early Planning of Road Infrastructure. Application of The LICCER-model. Master of Science Thesis at KTH Royal Institute of Technology, Sweden

Litzka J (1997). Austrian experiences with porous asphalt. European Conference on Porous Asphalt, 988-1005.

Loijos A., Santero N., Ochsendorf J. (2013). Life cycle climate impacts of the US concrete pavement network. Resources, Conservation and Recycling 72, 76– 83

Marceau M.L., Nisbet M.A. and VanGeem M.G., 2007. Life Cycle Inventory of Portland Cement Concrete, Portland Cement Association Report.

McCarthy, M.J., Tittle, P.A.J., Dhir, R.K. and Kii, H.K. Mix proportioning and engineering properties of conditioned PFA concrete. Cement and Concrete Research, Vol 31, pp 321-326, 2001.

McCarthy., M.J., Tittle, P.A.J and Dhir, R.K. Influences of conditioned PFA as a cement component in concrete. Magazine of Concrete Research, Vol 52, No 5, pp 329-343, 2000.

Milachowski C., Stengel T. and Gehlen C. (2011). Life cycle assessment for road construction and use. EAPA on-line publication: http://www.eupave.eu/documents/technical-information/inventory-of-documents/inventory-of-documents/eupave_life_cycle_assessment.pdf (accessed 23.12.2013)

Mithraratne N. (2011). Lifetime liabilities of land transport using road and rail infrastructure. NZ Transport Agency research report 462. 100pp

Montecinos W. and Holda A. (2006). Construction and demolition waste management in Denmark – Example of brick, wood, treated wood and PVC management, COWAM, Copenhagen

Mroueh U-M., Eskola P., Laine-Ylijoki J. (2001). Life-cycle impacts of the use of industrial by-products in road and earth construction. Waste Management 21, pp. 271-277

Mroueh U-M., Eskola P., Laine-Ylijoki J., Wellman K. (2000). Life cycle assessment of road construction. Finnish National Road Administration Finnra Reports 17/2000 http://alk.tiehallinto.fi/tppt/lca3.pdf

Muchova L. (2010). Wet physical separation of MSWI bottom ash. MSc thesis. Technical University of Ostrava

NAPA and EAPA (2011). The Asphalt Paving Industry. A Global Perspective. Second Edition. http://www.eapa.org/userfiles/2/Publications/GL101-2nd-Edition.pdf [checked online on 28.12.2013]

NCC Råstoffer (2013). Personnal communication with Lars Møller Nielsen, technical director of NCC Råstoffer in Denmark

NL Agency, VROM (2010). Criteria for Sustainable Public Procurement for Roads. Version 1.4. Available online at http://www.senternovem.nl/mmfiles/Criteriadocument%20Roads.doc_tcm24-330573.pdf [checked on 15.01.2014]

NSW (2007). Noise wall design guideline, 2007. New South Wales Roads and Transport Authority

OECD (1997). Recycling strategies for road works. (Road Transport Research), pg 15

OECD (2013). Glossary of statistical terms. Available online at http://stats.oecd.org/glossary/detail.asp?ID=4005 [checked on 15.02.2014]

Olesen (2013). Information via email from Erik Olesen, coordinator at The Danish Road Directorate [on 15.08.2013]

Olsson S., Kärrman E. & Gustafsson J.P. (2006). Environmental systems analysis of the use of bottom ash from incineration of municipal waste for road construction, Resources, Conservation and Recycling 48,pp. 26–40

Organisation of Economic Cooperation and Development (1995). Roadside noise abatement. Report prepared by an OECD Scientific Expert Group, OECD, Paris, France.

Page G.C. (1993). Open-graded friction courses: Florida's experience. Transportation Research Record 1427, 1-4.

PE EC DG-ENV (2013). Assessment of Scenarios and Options towards a Resource Efficient Europe. Topical Paper 4: Validation of technical improvement options for resource efficiency of buildings and infrastructure

Petersen J.C., Plancher H. and Harnsberger P.M., “Lime treatment of asphalt to reduce age hardening and improve flow properties”, Proc. Association Asphalt Paving Techno logists 56, pp.632-653, 1987

Phillips S.M. and Abbott (2001). Factors affecting statistical pass-by measurements. Proceedings of Inter-Noise 2001, The Hague, The Netherlands, 2031-2036.

PIARC (1995). Flexible roads. Porous asphalt in practice. Proceedings of PIARC XXth World Road Congress, Montreal, Canada, 47-87.

Plancher H., Green E.L., and Petersen J.C. (1976) “Reduction of oxidative hardening of asphalts by treatment with hydrated lime – a mechanistic study”, Proc. Association Asphalt Paving Technologists 45, pp.1-24

Pritchard H.M., Sampson J. and Jackson M. (2009). A further discussion of the factors controlling the distribution of Pt, Pd, Rh and Au in road dust, gullies, road sweeper and gully flusher sediment in the city of Sheffield, UK, Sci. Tot. Environ., 407, p.1715-25.

Rubio M.C., Martínez G., Baena L. and Moreno F. (2012). Warm mix asphalt: an overview. Journal of Cleaner Production 24, pp. 76-84

Rubio M.C., Moreno F., Martínez-Echevarría M.J., Martínez G., Vázquez J.M. (2013). Comparative analysis of emissions from the manufacture and use of hot and half-warm mix asphalt. Journal of Cleaner Production 41, pp.1-6

Sanches F. (1994). Development of a new (air) permeabilitymeter for porous asphalt courses. (in Dutch). Report No. W-DWW-94-512. Directorate-General of Public Works and Water Management (DWW), Delft, The Netherlands

Sanches F. (2000). Doorlatendheidsmetingen op ZOAB voor en na reinigenin Dienstkring Drenthe. DWW-2000-063. DWW, Delft, The Netherlands

Sandberg U (2005). Japanese machines for laying and cleaning of double-layer porous asphalt – Observations from a study tour. Report prepared for the Dutch PG programme. Swedish National Road and Transport Research Institute (VTI), Linkoping, Sweden.

Sandberg U. and Ejsmont J.A. (2002). Tyre/Road Noise Reference Book. Informex, SE-59040 Kisa, Sweden (www.informex.info).

Sandberg U. and Ejsmont J.A. (2002). Tyre/road noise reference book. Informex, Sweden.

Sandberg U. and Kalman B (2005). The poro-elastic road surface – Results of an experiment in Stockholm. Proceedings of Forum Acusticum 2005, Budapest, Hungary

Sandberg U., Goubert L., Biligiri K.P. and Kalman B. (2010). State-of-the-Art regarding poroelastic road surfaces. Deliverable D8.1 of the PERSUADE EU project

Sandberg U. et al (2011). Rolling Resistance – Basic Information and State-of-the-Art on Measurement methods, Report MIRIAM_SP_01, SP 1 Measurement methods and source models, Found on the Internet site: http://miriam-co2.net/Publications/MIRIAM_SoA_Report_Final_110601.pdf on November 29, 2013

Santero N.J. and Horvath A. (2009). Global warming potential of pavements. Environ Res Letts;4:034011

Santero N.J., Masanet E., Horvath A. (2011a). Life-cycle assessment of pavements. Part I: Critical review. Resources, Conservation and Recycling 55, pp. 801–809

Santero N.J., Masanet E., Horvath A. (2011b). Life-cycle assessment of pavements Part II: Filling the research gaps. Resources, Conservation and Recycling 55, pp. 810–818

Sayagh S., Ventura A., Hoanga T., Franc D. & Jullien A. (2010). Sensitivity of the LCA allocation procedure for BFS recycled into pavement structures, Resources, Conservation and Recycling, 54, 348–358

Scarsella M. (2010). Greenroads pilot project report version 1.0.1. Us 97: lava butte – s. Century drive section oregon department of transportation

Schmidt (2009). MIRIAM brochure. Found at the Internet site: http://miriam-co2.net/Miriam_brochure_ver_2.pdf [checked on 23.01.2014]

Schmidt (2013). Available online at: http://www.cooee-co2.dk/index.htm [checked on 27.12.2013]

Schmidt B. and Ullidtz P. (2010). The energy-saving road – Energy savings in road transport as a function of the functional and structural properties of roads. A Development report 1/10, NCC Green Road, 2010technical report

Schorcht F., Kourti I., Scalet B.M., Roudier S. and Delgado Sancho L., 2013. Best Available Techniques (BAT) reference document for the production of Cement, Lime and Magnesium oxide, JRC Reference Report

Schwarz R (1998). Systematische Erfassung der Einflüsse von Fahrban-, Reifen-,und Fahrzeugparemetern auf das Aussengerausch von Pkw (Systematic Analysis of the Influence of Road Surface, Tyre and Vehicle Parameters on the Exterior Noise of Passenger Cars). Doctoral Dissertation, Vienna University of Technology, Vienna, Austria

Sebaaly P.E., Little D.N. and Epps J.A. 92006). The Benefits of Hydrated Lime in Hot Mix Asphalt, Arlington (Virginia, USA): National Lime Association, 2006 (http://www.lime.org/BENEFITSHYDRATEDLIME2006.pdf)

Sétra (2011). Acceptability of Alternative Materials in Road Construction http://www.setra.developpement-durable.gouv.fr/IMG/pdf/Acceptabilit_GB_Web.pdf [checked on 31.01.2014]

Sherwood, P. (2001). Alternative materials in road construction, 2nd edition

SILVIA (2005). Acoustic performance of low noise road pavements. Report code: SILVIA-DTF-DRI-010-02-WP4-290605.

SKAO (2013). CO_2-PERFORMANCELADDER. Working together to cut CO_2.

Sjögren et al. (2012). HeRoad report. Overall road asset performance. Available information on the project at http://www.eranetroad.org/index.php?option=com_docman&task=cat_view&gid=96&Itemid=53 [accessed on 17.02.2014]

Snoek (2013). Information found at the Internet site: http://cereal.dk/[checked on 23.01.2014]

Statistics Denmark (2012). 'Råstofindvinding i Danmark 2011, Miljø og Energi, 2012:1', Danmarks Statistik.

Stripple H. (2001). Life Cycle Assessment of Road. A Pilot Study for Inventory Analysis. Second Rev. Ed.. IVL

"SUDS for Roads (2009), The SUDS Working Group. See link:

http://www.scotsnet.org.uk/documents/SudsforRoads.PublishedAug2009_001.pdf "

SUSCON National Technical University of Athens (2006). Life Cycle Assessment of Road Pavement. SUSCON LIFE05.

Tatari O., Nazzal M., Kucukvar M. (2012). Comparative sustainability assessment of warm-mix asphalts: A thermodynamic based hybrid life cycle analysis. Resources, Conservation and Recycling 58, pp.18– 24

Taylor P., Van Dam T., Fick G., Gress D., VanGeem M., Lorenz E. (2012). Sustainable Concrete Pavements: A Manual of Practice. Report of the NCPTC National Concrete Pavement Technology Center, Iowa State University Funded by the Federal Highway Administration

Tiax et al. (2003). Tiax, L., Ecos Consulting, Ecalifornia Energy Commission, Transportation Technology Office. California State Fuel-Efficient Tire Report. In: Consultant Report, vol. 2. California Energy Commission, Sacramento, CA; USA

Trafikverket (2013). Ökade anslag till väg och järnväg i regeringens budgetförslag. Availablwe online at http://www.trafikverket.se/Aktuellt/Nyhetsarkiv/Nyhetsarkiv2/Nationellt/2012-09/Okade-anslag-till-vag-och-jarnvag-i-regeringens-budgetforslag/ [checked on 15.08.2013]

Transportation Research Board (2006). Tires and Passenger Vehicle Fuel Economy: Informing Consumers, Improving Performance. Transportation Research Board of the National Academies, Washington, D.C.

Treloar G. J., Love P. E. D. and Crawford R. H. (2004). Hybrid Life-Cycle Inventory for Road Construction and Use. Journal of Construction Engineering and Management © Asce, pp. 43-49

UEPG. (2012). Annual Review 2011-2012. Retrieved from European Aggregates Association. Available online at http://www.uepg.eu/uploads/Modules/Publications/uepg---ar2012---en_v1.pdf [checked on 15.02.2014]

Ugurlu, A., 2004. Leaching characteristics of fly ash. Environmental Geology, 46, p.890-895.

Umweltesbundesamt (2008). Aggregates case study – Data gathering. Available online at http://susproc.jrc.ec.europa.eu/activities/waste/documents/Aggregates_Case_Study_Final_Report_UBA_080331.pdf [CHECKED ON 15.02.2014]

UN (2008). European agreement on main international traffic arteries (AGR) ECE/RANS/SC.1/384. Available online at: http://www.unece.org/fileadmin/DAM/trans/conventn/ECE-TRANS-SC1-384e.pdf [checked on 23.01.2014]

Universitá di Pisa, ANPAR, Politecnico di Torino (2013). Costruzione e manutenzione delle strade verdi. Capitolato speciale d'appalto tipo. Available online at http://www.anpar.org/attachments/article/64/ANPAR%20-%20CSA%20Costruzione%20e%20manutenzione%20di%20strade%20-%20Completo.pdf [checked on 22.01.2014]

USEPA, 2004. "Report to Congress: Impacts and Control of CSO's and SSO's". Document No. EPA 833-R-04-001 U.S. Environmental Protection Agency: Office of Water (2004). "Report to Congress: Impacts and Control of CSOs and SSOs," EPA-833-R-04-001, accessed at http://cfpub.epa.gov/npdes/docs.cfm?program_id=5&view=allprog&sort=name.

USGS (2012). Iron and steel slag. Available onlline at http://minerals.usgs.gov/minerals/pubs/commodity/iron_%26_steel_slag/mcs-2013-fesla.pdf «checked on 17.02.2014]

Vaitkus, A., Vorobjovas, V., _Ziliut, L. (2009b). The Research on the Use of Warm Mix Asphalt for Asphalt Pavement Structures. Road Department, Vilnius Gediminas Technical University, Vilnius, Lithuania

Vansteenkiste S. and Vanelstraete A. (2008). Properties of fillers: relationship with laboratory performance in hot mix asphalt", J. Association Asphalt Paving Technologists 77, pp. 361-398

Verhasselt A. and Puiatti, D. "Effect of hydrated lime on ageing behaviour of bituminous mastics", Proc. 3rd Eurasphalt & Eurobitume Congress, Vienna, vol.1, paper 108, pp.746-756, 2004

VSS (1987). SN 640 503a, Stabilisation: Stabilisation à la chaux aérienne. Union des professionnels suisses de la route (VSS), Association Suisse de Normalisation, Zurich. In French

Wang T., Lee I-S., Kendall, Harvey, Lee E-B, Kim C. (2012a). Life cycle energy consumption and GHG emission from pavement rehabilitation with different rolling resistance. Journal of Cleaner Production 33, 86-96

Wang T., Lee I-S., Kendall, Harvey, Lee E-B, Kim C. (2012b). UCPRC Life Cycle Assessment methodology and Initial Case Study on Energy Consumption and GHG Emissions for Pavement Research Preservation Treatment with Different Rolling Resistance. Research Report: UCPRC-RR-2012-02 at the Pavement Research Center at the University of California

Watts G, Nelson P, Treleven C and Balsom M, 2005. An examination of vehicle noise test procedures. TRL Published Project Report PPR044. TRL Limited, Wokingham, UK.

Wayman M., Parry T., Andersson-Sköld Y., Raaberg J., Bergman R., Enell A. and Huang Y. (2012). Life Cycle Assessment of reclaimed asphalt. Re-Road project. Deliverable 3.4

Weninger-Vycudil A. et al. (2009). ERA-NET ROAD report Maintenance backlog – Estimation and use. Available online at http://www.eranetroad.org/index.php?option=com_docman&task=cat_view&gid=57&Itemid=53 [checked on 17.02.2014]

WHO (1999). World Health Organisation. Guidelines for Community Noise

Williams P.T. (2005). Waste Treatment and Disposal. ISBN 0470849126

Wisneski M.L., Chaffin J.L., Davison R.R., Bullin J.A. and Glover C.J., "Use of lime in recycling asphalt", Transportation Research Record 1535, pp.117-123, 1996

Worrell E., Martin N., and Price L., 2000. Potentials for energy efficiency improvement in the US cement industry. Energy, 25, p.1189-1214.

WRAP (2005a). Recycled roads. Overview. Available online at http://aggregain.wrap.org.uk/recycled_roads.html [checked on 23.01.2014]

WRAP (2005b). The quality protocol for the production of aggregates from inert waste, Oxon, United Kingdom. Available online at http://aggregain.wrap.org.uk/quality/quality_protocols/ [checked online on 23.02.2014]

Yu B., Lu Q. (2012). Life cycle assessment of pavement: Methodology and case. Transportation Research Part D 17, pp. 380–388

Zhang H., Keoleian G.A. and Lepech M.D. (2008). An integrated life cycle assessment and life cycle analysis model for pavement overlay systems. Life-Cycle Civil Engineering, pp. 907-912

CEN STANDARDS AND OTHER STANDARD

CEN TC 351 Technical Committee on "Construction Products: Assessment of release of dangerous substances".

CEN/TS 1793-5. (BS) Road traffic noise reducing devices – test method for determining the acoustic performance – Part 5: Intrinsic characteristics – in situ values of sound reflection and airborne sound insulation.

CEN/TS 14405: 2004. Characterization of waste – Leaching behaviour tests – Up-flow percolation test (under specified conditions).

PD 6682-2: 2009. Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas.

EC DIRECTIVES (ordered by year, then number)

Directive CPD 89/106/EEC on the approximation of laws, regulations and administrative provisions of the Member States relating to construction products (the Construction Products Directive).

Directive 91/271/EEC concerning urban waste water treatment (the UWWTD).

Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive).

Directive 96/82 on the control of major-accident hazards involving dangerous substances (the Seveso II Directive).

Directive 1999/31/EC on the landfill of waste (the Landfill Directive).

Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors.

Directive 2000/60/EC establishing a framework for Community action in the field of water policy (the Water Framework Directive).

Decision 2000/532/EC replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Decision 91/689/EEC on hazardous waste.

Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment (the SEA or Strategic Environmental Assessment Directive).

Directive 2002/49/EC relating to the assessment and management of environmental noise.

Directive 2004/35/CE on environmental liability with regard to the prevention and remedying of environmental damage.

Directive 2004/17/EC coordinating the procurement procedures of entities operating in the water, energy, transport and postal services sectors

Directive 2004/18/EC on the coordination of procedures for the award of public works contracts, public supply contracts and public service contracts.

Directive 2005/88/EC amending Directive 2000/14/EC on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors.

Directive 2006/21/EC on the management of waste from extractive industries and amending Directive 2004/35/EC.

Directive 2007/60/EC on the assessment and management of flood risks (The EU Floods Directive).

Directive WFD 2008/98/EC on waste and repealing certain Directives. (the Waste Framework Directive).

Directive 2008/105/EC on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council.

Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (Recast)

Directive 2011/76/EU amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures.

Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment (codification).

Directive 2012/18/EU on the control of major-accident hazards involving dangerous substances, (the Seveso III Directive) amending and subsequently repealing Council Directive 96/82/EC (the Seveso II Directive).

EC REGULATIONS (in order of year then by number)

Regulation 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/115/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (the REACH Regulation).

Regulation 1272/2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (the CLP Regulation).

Regulation 1221/2009 on Eco-management and audit system (EMAS)

Regulation 219/2009 adapting a number of instruments subject to the procedure referred to in Article 251 of the Treaty to Council Decision 1999/468/EC with regard to the regulatory procedure with scrutiny (the Construction Products Regulation, CPR).

Regulation CPR 305/2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC.

EC COMMUNICATION (in order of year then by number)

COM (1996) 540 Future noise policy. European Commission Green Paper

COM(2005) 666 Final , Thematic strategy on the prevention and recycling of waste, Brussels.

COM(2006) 232 establishing a framework for the protection of soil and amending Directive 2004/35/EC

COM(2007) 59 Interpretative Communication on waste and by-products

COM 400 (2008) Public procurement for a better environment. Available online at http://ec.europa.eu/environment/gpp/gpp_policy_en.htm

COM (2008) 699: The Raw Materials Initiative – Meeting Our Critical Needs for Growth and Jobs in Europe , Brussels .

COM(2011) 21, A resource- efficient Europe – Flagship initiative under the Europe 2020 Strategy , Brussels .

COM(2011) 571, Roadmap to a Resource Efficient Europe , Brussels .

Local regulation

Provincia di Trento (2011a). DGP 885/2010

Provincia di Trento (2011b). DGP 1333/2011 - Annex B. Available online at http://www.appa.provincia.tn.it/binary/pat_appa/news/Materiali_riciclati.1310110276.pdf [checked on 22.01.2014]

EN STANDARDS (in order of number, then part)

EN 197-1:2011 Cement - Part 1: Composition, specifications and conformity criteria for common cements

EN 206:2000 - Concrete. Specification, performance, production and conformity.

EN 450:2005 - Fly ash for concrete - Part 1: Definition, specifications and conformity criteria.

EN 459-1:2001 - Building lime - Part 1: Definitions, specifications and conformity criteria.

EN 934: 2001/A2:2005 Part 2- Admixtures for concrete, Definitions, requirements, conformity, marking and labelling.

EN 1317-5:2007 - EN 1317-5:2007 - Road restraint systems - Part 5: Product requirements and evaluation of conformity for vehicle restraint systems.

EN 1338:2003/AC: 2006 - Concrete paving blocks - Requirements and test methods.

EN 1344:2002 - Clay pavers - Requirements and test methods.

EN 1423:1997/A1:2003 - Road marking materials - Drop on materials - Glass beads, antiskid aggregates and mixtures of the two.

EN 1433:2002/A1:2005 - Drainage channels for vehicular and pedestrian areas - Classification, design and testing requirements, marking and evaluation of conformity.

EN 1436 – Road marking materials – road marking performances for road users

EN 1793-1. Road traffic noise reducing devices – Test method for determining acoustic performance – Part 1: Intrinsic characteristics of sound absorption

EN 1793-2. Road traffic noise reducing devices – Test method for determining acoustic performance – Part 2: Intrinsic characteristics of airborne sound insulation under diffuse sound field conditions.

EN 1793-6 Road traffic noise reducing devices – Test method for determining acoustic performance – Part 6: Intrinsic characteristics – in situ values of airborne sound insulation under direct sound field conditions.

EN 1871 – Road marking materials – physical properties.

EN 12457-2:2002. Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges - Part 2: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 4 mm (without or with size reduction).

EN 12457-4:2002. Characterisation of waste - Leaching - Compliance test for leaching of granular waste materials and sludges - Part 4: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction).

EN 12591:2005 Bitumen and bituminous binders — Specifications for paving grade bitumens.

EN 12620:2002/AC:2004 - Aggregates for concrete.

EN 12697-22. Bituminous mixtures. Test methods for hot mix asphalt. Wheel tracking.

EN 12697-24. Bituminous mixtures. Test methods for hot mix asphalt. Resistance to fatigue.

EN 12899: 2007 - Permanent traffic signs, which relates to the construction of traffic signs.

EN 12966:2005 - Road vertical signs - Variable message traffic signs - Part 1: Product standard.

EN 13036-6:2008. Road And Airfield Surface Characteristics - Test Methods - Part 6: Measurement Of Transverse And Longitudinal Profiles In The Evenness And Megatexture Wavelength Ranges.

EN 13036-8:2008. Road and airfield surface characteristics. Test methods – Determination of transverse unevenness indices.

EN 13043:2002/AC:2004. Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas.

EN 13055:2002 - Lightweight aggregates - Part 1: Lightweight aggregates for concrete, mortar and grout.

EN 13055:2002-2. Lightweight aggregates - Part 2: for bituminous mixtures and surface treatments and for unbound and bound applications.

EN 13108-1:2006 - Bituminous mixtures - Material specifications – Part 1: Asphalt Concrete

EN 13108-2:2006 - Bituminous mixtures - Material specifications – Part 2: Asphalt Concrete for very thin layers

EN 13108-3:2006 - Bituminous mixtures - Material specifications - Parts 3: Soft Asphalt

EN 13108-4:2006 - Bituminous mixtures - Material specifications - Parts 4: Hot Rolled Asphalt

EN 13108-5:2006 - Bituminous mixtures - Material specifications - Parts 5: Stone Mastic Asphalt

EN 13108-6:2006 - Bituminous mixtures - Material specifications – Part 6: Mastic Asphalt

EN 13108-7:2006 - Bituminous mixtures - Material specifications – Part 7: Porous Asphalt,

EN 13108-8:2006 - Bituminous mixtures - Material specifications – Part 8: Reclaimed Asphalt.

EN 13139:2002/AC:2004 - Aggregates for mortar.

EN 13242:2002/AC:2004 – Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction

EN 13285:2003 -Unbound mixtures - Specification

EN 13877 :2004 - Concrete pavements

EN 13282-1:2013 – Hydraulic road binders – Part 1: Rapid hardening hydraulic road binders – Composition, specifications and conformity criteria.

EN 13808: 2005 Bitumen and bituminous binders - Framework for specifying cationic bituminous emulsions

EN 13863-1:2003 - Concrete pavements. Test method for the determination of the thickness of a concrete pavement by survey method

EN 13863-2:2003 - Test method for the determination of the bond between two layers

EN 13863-3:2004 - Concrete pavements. Test methods for the determination of the thickness of a concrete pavement from cores

EN 13863-4:2012 - Concrete pavements. Test methods for the determination of wear resistance of concrete pavements to studded tyres

EN 13877-1:2013. Concrete pavements – Part 1: Materials.

EN 13877-2:2013. Concrete pavements – Part 2: Functional requirements for concrete pavements.

EN 14023:2005, Bitumen and bituminous binders – Framework specification for polymer modified bitumens

EN 14216:2004 – Cement Composition, specifications and conformity criteria for very low heat special cements.

EN 14227-1:2013 Hydraulically bound mixtures - Specifications - Part 1: Cement bound granular mixtures

EN 14227-2:2013 Hydraulically bound mixtures - Specifications - Part 2: Slag bound granular mixtures.

EN 14227-3:2013 Hydraulically bound mixtures - Specifications - Part 3: Fly ash bound granular mixtures.

EN 14227-4:2013 Hydraulically bound mixtures - Specifications - Part 3: Fly ash for hydraulically bound granular mixtures.

EN 14227-5:2013 Hydraulically bound mixtures - Specifications - Part 5: Hydraulic road binder ground granular mixtures.

EN 14227-11:2013 Hydraulically bound mixtures - Specifications - Part 11: Soil treated by lime.

EN 14227-13:2013 Hydraulically bound mixtures - Specifications - Part 11: Soil treated by hydraulic road binder.

EN 14388:2005. Road Traffic Noise Reducing Devices – Specifications.

EN 14389-1:2007. Road traffic noise reducing devices - Procedures for assessing long term performance - Part 1: Acoustical characteristics

EN 15804:2012 - Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products

EN 15167-1: 2006 - Ground granulated blast furnace slag for use in concrete, mortar and grout. Definitions, specifications and conformity criteria

ISO STANDARDS

ISO 1996-2: 1987. Acoustics -- Description and measurement of environmental noise -- Part 2: Acquisition of data pertinent to land use. (Revised by ISO 1996-1:2003).

ISO 10844: 2011. Acoustics -- Specification of test tracks for measuring noise emitted by road vehicles and their tyres.

ISO 11819-1: 2001. Acoustics – Measurement of the influence of road surfaces on the traffic noise. Part 1: Statistical Pass-By method.

ISO 13473-1: 1997. Characterization of pavement texture by use of surface profiles -- Part 1: Determination of Mean Profile Depth.

ISO 14021: 1999. Environmental labels and declarations – Type II environmental labelling. Self-declared environmental claims.

ISO 14024: 1999. Environmental labels and declarations – Type I environmental labelling – Principles and Procedures.

ISO 14025: 2006. Environmental labels and declarations – Type III declarations – Principles and Procedures.

ISO 14040: 2006. Environmental management – Life cycle assessment – Principles and framework.

ISO 14044: 2006. Environmental management – Life cycle assessment – Requirements and guidelines.

ISO 18164: 2005. Passenger car, truck, bus and motorcycle tyres – Methods of measuring rolling resistance.

ISO 21930: 2007. Sustainability in building construction -- Environmental declaration of building products.

ISO 28580: 2009. Passenger car, truck and bus tyres -- Methods of measuring rolling resistance -- Single point test and correlation of measurement results.

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new standards, methods and tools, and sharing and transferring its know-how to the Member States and international community.

Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.

Publications Office