Reuse of bituminous pavements : a mini-review of research, regulations and modelling

REUSE OF BITUMINOUS PAVEMENTS: A MINI-REVIEW OF RESEARCH, REGULATIONS AND MODELLING

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Abstract

Bituminous pavement can be recycled – even multiple times – by reusing it in new bituminous mixtures. If the mechanical properties of the binder get worse, this reclaimed asphalt is often used in the sub-structure of the road. Apparently, up till now no end-of-life phase exists for the material. Actually, defining the end-of-life and the end-of-waste stage of a material is important for life cycle assessment modelling. Various standards and scientific studies on modelling life cycle assessment exist, but the crucial stages are not yet defined for reclaimed asphalt pavement. Unlike for iron, steel and aluminium scrap, at this moment, no legislative end-of-waste criteria for aggregates are formulated by the European commission. More research is necessary in order to develop valuable end-of-life criteria for aggregates. This contribution is a mini-review article of the current regulations, standards and studies concerning end-of-life and end-of-waste of reclaimed asphalt pavement. The existing methodology in order to define end-of-waste criteria, a case study on aggregates and the argumentation used in finished legislative criteria are the basis to clarify some modelling issues for reclaimed asphalt material. Hence, this contribution elucidates the assignment of process' environmental impact to a life cycle stage as defined by EN15804 i.e., end-of-life stage (C) and the supplementary information module D with benefits and loads beyond the system boundary.

Keywords:

End-of-life (EOL), end-of-waste (EOW), life cycle assessment (LCA), bituminous pavement, reclaimed asphalt pavement (RAP), closed loop recycling, regulations, Flanders

ABBREVIATIONS

CDW	Construction and demolition waste
COPRO	(control of products) Belgian impartial certification body in the construction sector
CW	Construction products waste
DW	Disposal waste
EAPA	European Asphalt Pavement Association
EOL	End-of-Life
EOW	End-of-waste
EPD	Environmental product declaration
JRC	Joint Research Centre
LCA	Life cycle assessment
OVAM	The public Waste Agency of the Flemish region
PCR	Product category rules
PW	Production waste
RAP	Reclaimed asphalt pavement
SB250	Flemish Road Standard
UW	Use waste
VLAREMA	Decree of the Flemish Government adopting the Flemish Material Cycles and Waste Regulations
WFD	Waste Framework Directive

1 INTRODUCTION

An enormous expansion of the global demand for construction materials, caused a strong increase of the raw material prices and even partial shortages during the first years of the 21th century (Chowdhury et al. 2010, Huang et al. 2007, Tölle 2007). The reduced availability, high prices and long transport distances, led to a search for alternatives. The asphalt sector therefore has a growing interest for the whole material cycle and uses reclaimed asphalt pavement (RAP) as well as secondary materials from other sectors in new bituminous mixtures.

Life cycle assessment (LCA) studies are used to investigate the environmental impact of using these materials as an alternative for virgin raw materials in bituminous mixtures for road pavements. The end-of-life (EOL) status of bituminous pavement and the end-of-waste (EOW) status of reclaimed material (i.e. RAP) should be known in order to make an adequate model for LCA calculations.

To date, plenty of research has been done on life cycle assessment of bituminous pavements. Nevertheless, at this moment, the definition of EOL for bituminous road pavement and EOW for RAP was not found in literature.

The goal of this research is therefore to make a well-founded decision on both EOL and EOW for bituminous road pavements, by conducting an extensive literature review of both European and Flemish legislations and research. The main focus of the current research is Flanders, a region in Belgium. However, depending on the subject and publisher, this research includes Belgian and European figures and regulations as well.

2 BACKGROUND

2.1 Materials in the asphalt sector

Asphalt is constituted for about 95% of aggregates. These aggregates can be i) natural aggregates, produced from mineral sources; ii) secondary aggregates, arising from industrial processes; or iii) recycled aggregates. According to estimates of production data by the European Aggregates Association (European Aggregates Association 2013), an average of 81 million tons aggregates were produced annually in Belgium between 2006 and 2012, of which ±81% is natural, ±18% is recycled and ±2% is secondary aggregates. As a European average, 10% of all produced aggregates are used in asphalt products.

Delgado et al. (2009) state that in 2006, about 9 million tons construction and demolition waste (CDW) was produced in Flanders, of which 92% is reused or recycled and 8% has an unknown disposition. Together with the Netherlands, Denmark and Germany, Flanders already reached a high rate of reuse and recycling of CDW.

The asphalt production sector is inseparable from other sectors in the product chain, with which energy and material streams are exchanged (Leyssens et al. 2013). The output of one sector can be the input for another sector. In Flanders, materials from other sectors are being used in asphalt mixtures: steel slag can replace mineral aggregates and roofing felt waste can replace binder (Leyssens et al. 2013, Van den bergh & Stoop 2009). With regard to sustainable material management, it is important to take into account the impacts from both the studied sector and the interaction with other sectors.

Table 1: figures for Belgian asphalt sector in 2012, 2013 and 2014

	2012		**2013**		**2014**	
	EAPA	**COPRO**	**EAPA**	**COPRO**	**EAPA**	**COPRO**
Number of production sites	38	21	38	21	38	22
HMA and WMA production (million tons)	5.6	3.7	5.3	3.3	5.2	3.3
Available amount of RAP (million tons)	1.5	1.9	1.5	2.0	1.5	1.6
Available RAP used in asphalt (%)	61	50	61	43		61
Mixtures containing RAP (%)	49	58	51	58		61
RAP content in mixtures with RAP (%)		39		45		43

Reference: (COPRO, 2015, 2014, 2013; European Asphalt Pavement Association, 2015, 2014, 2013)

For the Belgian asphalt sector, two organisations keep a record of production data: EAPA (the European Asphalt Pavement Association) and COPRO (abbreviation of ‘Control of Products’ representing the Belgian Impartial Certification Body in the Construction Sector). The data from EAPA are an estimation of the national industry sector, made by the Belgian association of asphalt producers. COPRO publishes the results of measurements on certified asphalt mixtures and certified asphalt plants. In December 2015, 17 Flemish and 4 Walloon asphalt production plants are COPRO certified (meaning 1 Flemish, 1 Brussels and 15 Walloon asphalt plants are not and thus excluded from this COPRO data collection). The annual reports of both organisations from 2012, 2013 and 2014 are summarized in Table 1. The figures from EAPA and COPRO vary significantly, due to the different scopes of the reports. Nevertheless, the figures indicate the order of magnitude of production figures.

The Flemish Road Standard SB250 prescribes the requirements (from material characteristics till performance tests on the pavement) for all public road works in Flanders. Before 2013, the SB250 limited the amount of RAP for base course mixtures to 50%. Since 2013, performance requirements were integrated in SB250 for the specification of asphalt mixtures for base courses according to the fundamental method as an alternative for the empirical method. The EAPA and COPRO data (see Table 1) show that, more than half of all produced asphalt mixtures contained RAP. Hence, the use of RAP in new asphalt mixtures became common practice; even recycling rates up to 100% would be possible in the future by fractionating the RAP and adding a natural resin (Leyssens et al. 2013).

2.2 Environmental impact of RAP and secondary materials in asphalt

Peuportier et al. (2011) defined under which condition the use of RAP (or recycling in general) is beneficial: if the impact from the processes in order to recycle the product (I_r) and the impact from the transport (I_t) is smaller than the avoided impact from the production of a virgin alternative (I_n) and the impact from the waste treatment (I_w), then recycling should be promoted (see equation (1)).

$$I_r + I_t < I_n + I_w \qquad (1)$$

LCA is used in order to assess the environmental impact of these different aspects. As recognized by Silvestre et al. (2014), a detailed LCA approach for a building material is complex because of its long life cycle and the dynamics during the execution, in-service and EOL phases. The analysis of the EOL is particularly difficult due to the high uncertainty of e.g. service life and waste management in the future.

Recently, Butt et al. (2015) stated that no EOL phase exists for a pavement because the material will be used in the substructure when the bitumen is no longer useful as a binder material for the road surface. As a consequence, the boundaries of an LCA study are defined in various ways whether or not to include the use phase or the EOL phase. For road pavements, the most common scopes of an LCA study are: cradle-to-gate (all impacts until the asphalt mixture reaches the gate of the asphalt plant (Anthonissen et al. 2014)), cradle-to-laid (variant of cradle-to-gate specific for road pavements; all impacts until the road is constructed (Huang et al. 2012)), cradle-to-grave (all impacts until the road reaches end-of-life (Hoang et al. 2005)), or cradle-to-cradle (all impacts, including the reuse, recovery and/or recycling potential (Silvestre et al. 2014)).

Multiple LCA studies (Chiu et al. 2008, Ventura et al. 2008, Vidal et al. 2013, Wayman et al. 2012) investigated the environmental impact of including RAP into new bituminous mixtures. Some LCA studies (Chiu et al. 2008, Chowdhury et al. 2010, Huang et al. 2007) investigated the environmental impact of using secondary materials (i.e., rubber, glass, steel slag, coal fly/bottom ash, recycled concrete pavement, or plastics) in asphalt mixtures. The LCA study by Mladenovič et al. (2015) found that the use of steel slag aggregates for the construction of asphalt surface courses is more sustainable compared with the use of virgin siliceous aggregates.

Nevertheless, none of these studies clearly describes the EOL stage with the definition of the EOL of the pavement and the EOW of the reclaimed materials or how the EOL stage is modelled in the LCA study.

2.3 Definition of waste

When a construction product is replaced, dismantled or deconstructed from a building or a road, it reaches the end-of-life stage. All outputs of this stage are at first considered to be waste. Demolition or maintenance of roads is mainly carried out by a contractor, and hence, the material released (i.e. RAP) is considered to be industrial waste and is catalogued as construction and demolition waste (CDW).

Silvestre et al. (2014) defined three waste flows in CDW, which are also applicable for a bituminous road pavement (see Figure 1):

- Production waste (PW) [1] at the asphalt plant e.g., batches from production cycles with aberrant mixture composition and insufficient quality

- CDW outputs [2] at the work site
  - Construction products waste (CW) e.g., surplus material when the quantity of asphalt mixture for the road construction is overestimated
  - Use waste (UW): due to maintenance operations e.g., reclaimed material from repaving surface course
  - Disposal waste (DW): at the end of the service life of the pavement.
- Secondary material input [3]
  - Production, construction or demolition waste (PCODW): secondary material input from the construction industry (can include both [1] and [2])
  - Industrial symbiosis (IS): secondary material input from other industries e.g., waste tires, waste glass, waste plastic, steel slag or roofing felt waste (Huang & Bird 2007, Huang et al. 2007, Van den bergh & Stoop 2009)

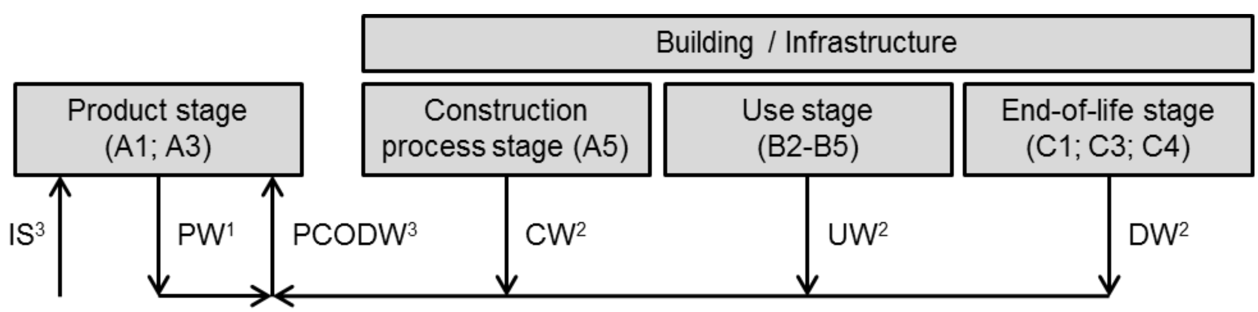

Figure 1: construction and demolition waste input and output flows with reference to the European Standard EN 15804 (Silvestre & Lasvaux 2012)

During the asphalt production process, production waste is limited (Leyssens et al. 2013). Few packing materials are involved because most raw materials are bulk, except some additives like fibres. Furthermore, most of the residues are reused. Waste coming from offices and laboratories of the asphalt plant are not considered in the current study.

Waste can cease to be waste and attain the status of product or secondary raw material if they reach the end-of-waste state (see §2.5). It is important to know if a product is waste or ceased to be waste and is considered as a secondary or raw material again. This makes an important difference in the perception of people towards a certain material and there are some regulatory differences involved.

2.4 Trade of waste

While one of the European Union founding principles is the free trade among its members, the trade of waste is strictly regulated. In Belgium, the responsible authorities for the international trade of waste are the regional authorities. Hence, the procedures may vary for Flanders, the Walloon Region and Brussels, but the differences will be small due to the binding European legislation.

Each shipment of waste crossing a border, is subjected to the regulation (EC) number 1013/2006. For reclaimed asphalt pavement, this involves two different situations (see Table 2) (OVAM 2007). Export of RAP containing tar, destined for recovery in countries where the OECD (The Organisation for Economic Co-operation and Development) decision does not apply, is prohibited. Trading RAP without tar across borders is possible, but there are some general information requirements: i) the treated waste material should be accompanied by an information document (see Annex VII of

1013/2006/EC), prepared by the person who arranges the shipment; ii) at the moment the shipment starts, there shall be an effective contract between the person who arranges the shipment and the consignee for recovery; iii) in accordance with national legislation, Member States may require more information.

Table 2: regulations on the international trade of waste

	RAP without tar	**RAP with tar**
Basel Convention (22 March 1989)	Annex IX	Annex VIII
Regulation 1013/2006/EC	Annex III	Annex IV
	Green listed waste	Amber listed waste
	General information requirements laid down in article 18	Prior written notification and consent (Annex II)
	Annex V – Part I – List B	Annex V – Part I – List A
		Export prohibition in article 36

2.5 End-of-waste principle

The concept of end-of-waste was introduced in 2005 by the thematic strategy on the prevention and recycling of waste (European Commission 2005), and was adopted by the European Parliament and the Council in 2008 in the revised Waste Framework Directive (WFD) (European Commission 2008).

The revised WFD introduces the possibility that certain waste streams having undergone a recovery operation and fulfilling certain criteria – so-called end-of-waste criteria – can cease to be waste and could be regarded as a non-waste material to be freely traded as such on the open market (Delgado et al. 2009, Villanueva et al. 2010).

The purpose of defining EOW criteria and the clarification of the quality and applications of such streams, contribute to create more transparent market conditions, protect human health and the environment, and promote the recycling of the streams by reducing the consumption of natural resources and the amount of waste sent for disposal (Delgado et al. 2009, Villanueva et al. 2010). The study by Srour et al. (2013) emphasizes the significance of establishing markets for recycled CDW. Materials not fulfilling the EOW requirements can be recycled and reused under the waste regime (see § 2.4).

The lack of harmonisation creates legal uncertainty for waste management decisions and for the different actors dealing with specific waste streams, including producers and users of the recycled material (Delgado et al. 2009). Some Member States have developed different, and not always compatible, frameworks for regulating the recovery and reuse of secondary materials. In some cases, materials generated in one country are not considered to be waste, however if transported to countries with different regulatory approaches, they might be considered waste and require waste management control. Consequently, producers and users tend to restrict themselves to national markets avoiding administrative and judicial costs or risks of an unclear waste status of the materials.

3 RESEARCH AND REGULATIONS

Research and regulations concerning waste are published at European level as well as at international or Flemish level.

3.1 Europe

3.1.1 Standards related to sustainability aspects

CEN/TC 350 (Comité Européen de Normalisation, technical committee) is responsible for the development of standardized methods for the assessment of the sustainability aspects over its life cycle of new and existing construction works and for standards for the environmental product declaration of construction products (Afnor Normalisation 2012). The purpose of this series of European Standards is to enable comparability of the results of assessments. CEN/TC 350 includes environmental as well as social and economic performances at framework, building and product level (see Figure 2). However, the current study only focuses on the environmental impacts during the life cycle of the bituminous pavement.

The newest of the seven workgroups in CEN/TC 350 works on civil engineering works. A standard that will be relevant for road construction works is under enquiry (CEN 2015), namely prEN 15643-5 “Sustainability of construction works – Sustainability assessment of buildings and civil engineering works – part 5: framework on specific principles and requirement for civil engineering works”.

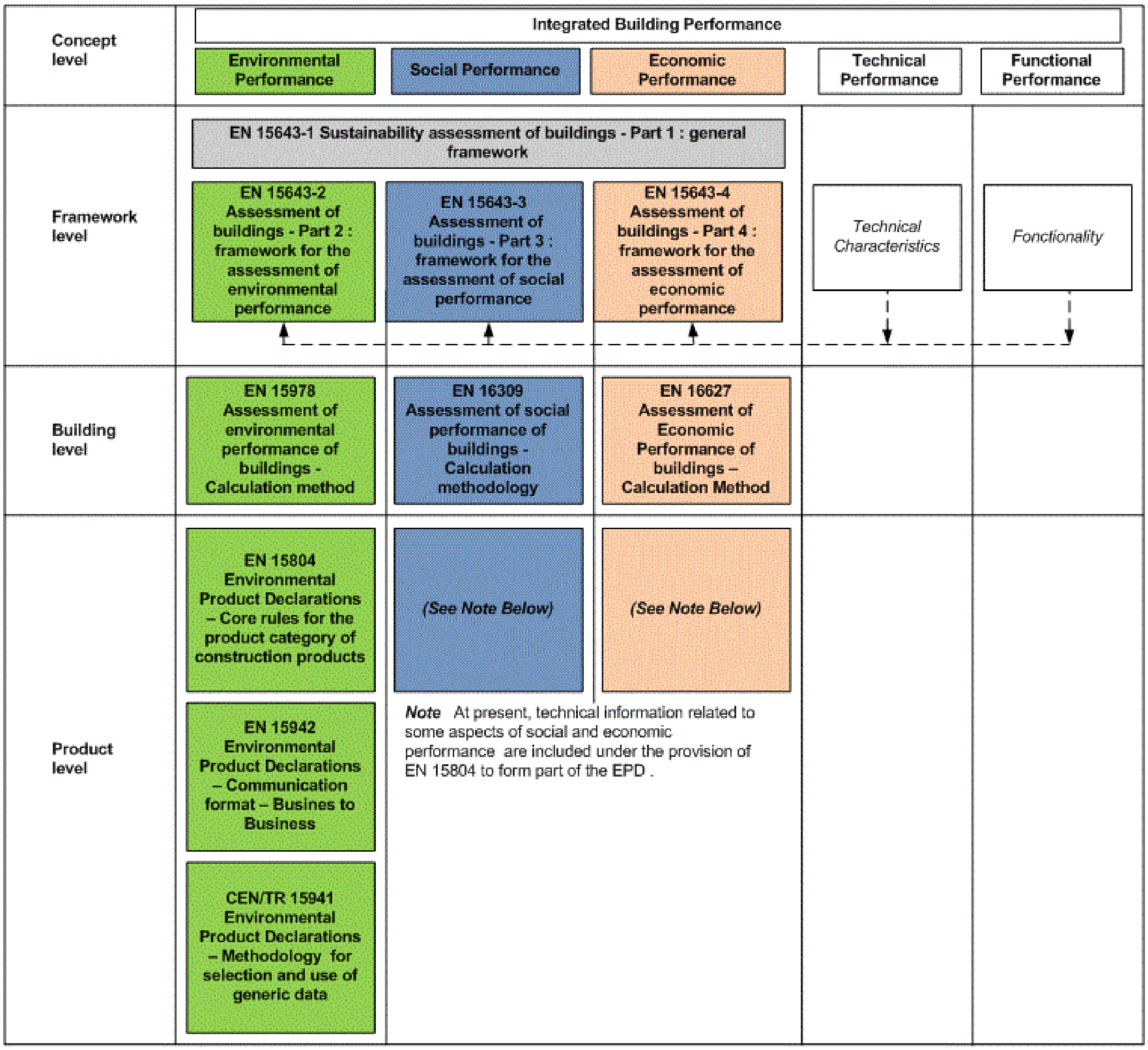

Figure 2: overview of standards written by CEN/TC 350 (Afnor Normalisation 2012)

Standard EN 15804 is most related to the current research and provides core product category rules (PCR). These core PCR describes, among others, which stages of a product's life cycle are considered in Environmental Product Declarations (EPD) and which processes are to be included in the life cycle stages.

An important modelling issue is the allocation of processes between the end-of-life stage (C1-4 in EN 15804) and the supplementary LCA information module D: 'benefits and loads beyond the system boundary'. The definition of EOL and EOW is crucial for this modelling issue.

Generic LCA data (like the Ecoinvent database) do not contain data about the benefits and loads beyond the system boundary (module D). These types of data are sometimes included in EPD. As described by Silvestre et al. (2014) and in CEN (2012) the net impacts in module D are calculated applying a justified value-correction factor in order to reflect the difference in functional equivalence where the output flow does not reach the functional equivalence of the substituting process. This aligns for RAP because there is not a total functional equivalence due to the aging of the binder inducing different rheological and mechanical properties.

Besides, as explained by Buyle et al. (2015), stages A, B and C applies a cut-off approach whereby the benefits and burdens of recycled products are assigned to the production phase (recycled content), while module D relies on the concept of system expansion (or avoided products or substitution methodology). In order to avoid double counting of the impacts of the recycling process, this substitution methodology in module D is only calculated for the net flow of secondary fuels or materials exiting the product system. The net output flows of the system under study is the amount of secondary material exiting the product system minus the amount of secondary material entering the system, assuming the same properties. The amount of secondary material that replaces one to one the input of secondary material as closed loop is allocated to sub-stage A1 of the system under study.

3.1.2 Waste framework directive and Joint Research Centre

As Figure 3 illustrates, the revised Waste Framework Directive (European Commission 2008), Article 6(1-2) defines four conditions that should be fulfilled in order to achieve the end-of-waste state. These conditions are general and applicable for all waste streams. EOW criteria should be set for specific materials using the procedure described in the committee procedure, Article 39(2) of the WFD.
A methodology to develop the EOW criteria for specific materials has been elaborated by the Joint Research Centre (JRC) (Delgado et al. 2009, Villanueva et al. 2010) and has been agreed on with the Member States. The interaction between both scientific JRC reports and the WFD is illustrated in Figure 3.

The report by Villanueva et al. (2010) proposes a list of material streams that qualify for an assessment on their suitability for the development of EOW criteria. Bituminous mixture; asphalt; bricks, tiles and ceramic; and concrete are grouped into CDW aggregates. Villanueva et al. (2010) assigned CDW to the first category with waste streams that are in line with the basic principles of EOW and suited for further EOW criteria assessment. The heterogeneous CDW stream should be disaggregated into subcategories with high value recyclables and low value sub fractions that contain contaminants (Kourmpanis et al. 2008). When applicable, EOW criteria will be restricted to specific applications and not to all the outputs of the stream. Some of the materials are almost always recyclable without much further processing, some others are not.

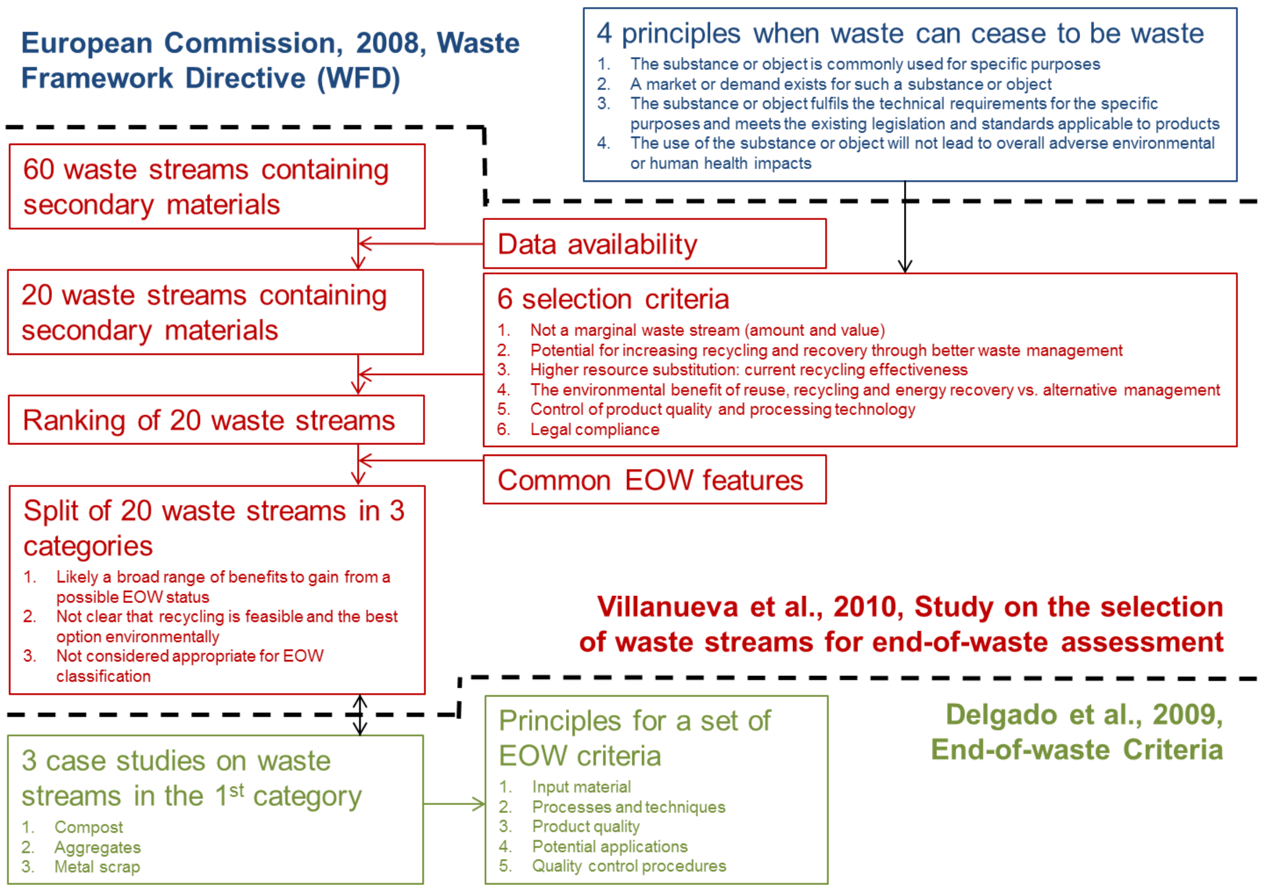

Figure 3: European research and regulations on the end-of-waste principle

Delgado et al. (2009) looked into a possible methodology for developing EU wide EOW criteria and applied this to three different case studies e.g., on aggregates. The methodology contains three parts: i) five principles for the definition of a set of EOW criteria; ii) guidelines for impact assessment and iii) an operational procedure guideline in order to develop EOW criteria.

The five principles for the definition of end-of-waste (see Figure 3, first part of the methodology) are listed and clarified with examples for road residues (RAP).

1. Input material: Hazardous substances should be identified and an assessment should reveal in which way the hazard can be controlled (during processing or need to be removed at source). An initial assessment on the composition of the road must be done, prior to the recovery process e.g., with a marker for the detection of tar (Opzoekingscentrum voor de Wegenbouw 2006). Different rules apply to different categories of road residues: i) RAP containing tar; ii) RAP containing mineral wastes (e.g., bottom ash from municipal waste incineration); iii) RAP not containing tar nor mineral wastes.
2. Processing: Process control parameters to guarantee quality may be used as part of the EOW requirements. For example, i) defining the maximum temperature for RAP as 130 °C (Leyssens et al. 2013) in order to avoid further oxidation of the binder and associated worse mechanical behaviour of the mixture or ii) the size fraction of the RAP: large pieces are broken in order to reach a certain level of homogeneity and the foreseen quality of the new asphalt mixture (De Lira et al. 2015, Lopes et al. 2015).
3. Product requirements: Often the material will need to be tested to demonstrate compliance with the applicable quality standards e.g., EN 13043 for RAP (CEN 2013). Additional product quality

requirements, such as pollutant limit values (e.g., study for aggregates by Saveyn et al. (2014)) or maximum content of impurities may be part of the end-of-waste requirements, in order to ensure that risks are reduced or minimized.

4. Product application: An analysis of potential uses is required in order to conclude on a potential market or demand and to assess the environmental risks associated with such uses. RAP is used in new mixtures or as foundation material or for unpaved tracks. An LCA study on the environmental impact of using RAP as applied in Flanders should be part of this analysis.
5. Quality control procedures: If conditions on source control, processing parameters and product quality standards are defined as part of end-of-waste requirements, these should be under acknowledged quality control procedures in order to guarantee the actual fulfilment of end-of-waste product quality requirements. Quality requirements for asphalt mixtures for public works are described in the Flemish road standard SB250 and are verified by COPRO and BENOR.

In accordance with the third principle, the European Joint Research Centre investigated how pollutant limit values could be elaborated in a possible EOW framework for aggregates (Saveyn et al. 2014). Compliance with the limit values for acceptance of waste at inert waste landfills has been evaluated for recycled asphalt (and others) and the potentially most critical substances (on this basis) have been identified. The potential final EOW criteria may be more stringent than the EU leaching limit values for landfilling of inert waste.

Based on 10 datasets with the release as a function of pH and 38 datasets with the release as a function of L/S, the potentially most critical substances from leaching of recycled asphalt are evaluated. The selenium amount is consistently close to the limit value if tested with the pH-dependence test, but strictly, the recycled asphalt do not exceed the EU leaching limit values for landfilling of inert waste.

Flanders, Finland, Netherlands and Sweden use a leaching test according to CEN/TS 14405, while most other EU Member States use a test based on EN 12457. Flanders includes fewer substances than other EU Member States for the leaching limit values for waste-derived aggregates. Additionally, the substance selenium is not included in the Flemish regulation.

The second part of the general methodology (Delgado et al. 2009) includes the assessment of the potential impacts of an end-of-waste scenario compared with a waste scenario. Such impact assessment should include impacts in various domains: environmental and health, economic, market, legislative and other socioeconomic impacts. Examples of such studies were found in literature: Butera et al. (2015) evaluated the environmental impact of the EOL phase of CDW, either used as unbound aggregate in road construction or landfill disposal; Weil et al. (2006) investigated closed loop recycling of CDW in concrete production; and the validity of the waste hierarchy by using life cycle assessment on recycling, incineration and landfilling was investigated by Moberg et al. (2005) for newsprint and PET waste fractions and by Huysman et al. (2015) for plastics from small domestic appliances or for household plastics waste.

Delgado et al. (2009) includes also an operational procedure guideline as the third part of the general methodology for developing EU wide EOW criteria. Although the procedure includes nine steps, these can be summarized to four iterative steps:

1. Initial investigation and selection of relevant waste streams (Villanueva et al., 2010)
2. Methodology and pilot case studies (Delgado et al., 2009)
3. Technical proposal
4. Drafting and voting regulation

Steps 3 and 4 should be completed for the development of EOW regulations for aggregates. Nevertheless, elements from completed studies will be used (Delgado et al. 2009, Saveyn et al. 2014, Villanueva et al. 2010). The iterative procedure is guided by a technical work group, consulting an expert group for feedback. Finally, the regulation could only become effective after formal adoption process following the regulatory procedure foreseen in the revised WFD, Article 39(2).

The first EOW Regulation was adopted and entered into force in 2011 and was on steel and aluminium scrap (333/2011). Other technical studies have led to the development of regulations on glass cullet (1179/2012) and copper scrap (715/2013).

3.1.3 REACH regulation

REACH regulation of the European Parliament and the Council is the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals. The REACH regulation includes specific obligations on manufacturers, importers and downstream users of substances on their own, in preparations and in articles. The main principle of the legislation is that the product cannot be placed on the market if no data are provided.

The function of aggregates from construction and demolition waste is mainly determined by the shape and surface of the particles rather than by the chemical properties (e.g. maximum of allowed solubility).These particles are therefore considered to be articles and hence may be exempted from registration under REACH (Delgado et al. 2009).

3.2 Flanders

The European Waste Framework Directive (European Commission 2008) has been converted by the Flemish region into a Material Decree (23 December 2011) (Flemish Government 2011) and the connected implementation decision VLAREMA (17 February 2012): Decree of the Flemish Government adopting the Flemish Material Cycles and Waste (Sustainable Management) Regulation (Flemish Government 2012). In Flanders, the management of waste is legally regulated by VLAREMA. Besides, the Public Waste Agency of the Flemish region (OVAM) is responsible for the achievement of waste management objectives. In general, Flanders follows the European waste hierarchy: prevention, re-use and recycling.

The Material Decree and VLAREMA use the same assessment framework for waste materials ceasing to be waste and for residual materials qualifying for being secondary materials and aims to substitute primary raw material by recycled materials or residual materials in an environmentally safe way (OVAM 2013). VLAREMA merely makes the distinction between ‘waste materials’ and ‘resources’. There is no longer a way in between, formerly defined as ‘secondary raw materials’.

In Flanders, there is a certain hierarchy of regulations considering the waste status of a material. No European EOW Regulation for recycled asphalt is into force and hence the waste stream should comply with specific Flemish regulations. The Flemish region specified some criteria for four utilisation areas of materials for a specific purpose (fertilizer or soil improver, building material, soil, or artificial waterproofing layer in alkali silicate on landfill sites) and two materials streams (resources produced by or for use in metallurgic production processes for non-ferrous metals; and resources produced by metallurgic production processes for ferrous metals). Recycled asphalt is classified to the utilisation area 'building materials'. The compliance of the materials with the criteria might be proved based on a declaration of raw material or another control system e.g., unity rules for recycled aggregates.

The Flemish Government has a considerable progressive waste legislation. For example, the Flemish target is to recycle 90% of the CDW by 2020. Furthermore, Flanders has carried out specific scenario-based risk and impact assessment instead of following the EU leaching limit values for landfilling of inert waste as a basis for the leaching criteria for the use of waste-derived aggregates as construction materials. In Flanders, the use of waste-derived aggregates is governed by waste legislation.

Dierckx et al. (2014) gives more information related to recycled asphalt, the use in asphalt and other applications and the related legislation in Flanders.

Recycled asphalt, which will be used in new asphalt mixtures, is not assessed to be waste and hence the material is not subjected to VLAREMA or the unity rules for recycled aggregates. Nevertheless, a maximal aggregate size is defined as 40 mm for homogeneity class HE and H+, which must be reached when using the fundamental method to design an asphalt mixture for a base course. Furthermore, a voluntary technical certification by COPRO is possible according to TRA13 (4.0).

Recycled asphalt, used for other applications, is subjected to the VLAREMA Articles 2.3.2.1; 2.3.2.2; 5.3.3 and the unity rules. In some cases, a declaration of raw material might be necessary and a voluntary technical and environmental certification by COPRO or Certipro is possible according to TRA10, TRA11, and CRT-LB001.

Recycled asphalt, containing tar is subjected to VLAREMA 5.3.3.4 and can only be used with a user certificate from OVAM and only in cold applications like foundation in asphalt cements. This is only applicable for big projects (at least 1500 m^3 tar containing asphalt) that should be inventoried. OVAM aims to remove tar from the material cycle and by 2020 tar must no longer be entering the material cycle through recycling. Thermal processing of tar containing asphalt gives a granulate without tar. This processing is investigated in a Flemish pilot project.

4 DISCUSSION

The discussion on end-of-life and end-of-waste state is important for (LCA) modelling. As stated by Allacker et al. (2014), there is currently no single, widely accepted approach to modelling EOL for environmental assessment of products. The influence of different EOL allocation methods (to allocate the impacts and benefits of recycling within the life cycle) on the environmental of a product are investigated by different researchers. The differences between the cut-off and the substitution approach were illuminated in the study by Huang et al. (2012). Nicholson et al. (2009) include additional allocation methods (loss of quality, closed loop and 50/50) and found that these different approaches can result in different rank ordering of materials preference.

The authors of the current contribution generated Figure 4 for bituminous road pavements, based on the principles as described in the literature (Leroy et al. 2012, Silvestre et al. 2014). The end-of-life and the end-of-waste stage, the different stages of EN 15804 and the different waste and material streams as defined by Silvestre & Lasvaux (2012) are indicated. Figure 4 is only designed in analogy with the metal scrap regulations, but is not based on EOW regulations on aggregates or CDW.

If the asphalt material is released from the road construction by milling the old pavement, it has reached the end-of-life stage. A material can only reaches the end-of-waste state after a sequence of treatment processes that prepares it for use as a direct input into the next product system. Crushing and sieving RAP are seen as processes before the EOW state and thus assigned to the end-of-life stage C of EN 15804. The end-of-waste state is indicated on Figure 4. Only the impacts from the net material flow (RAP) are assigned to module D.

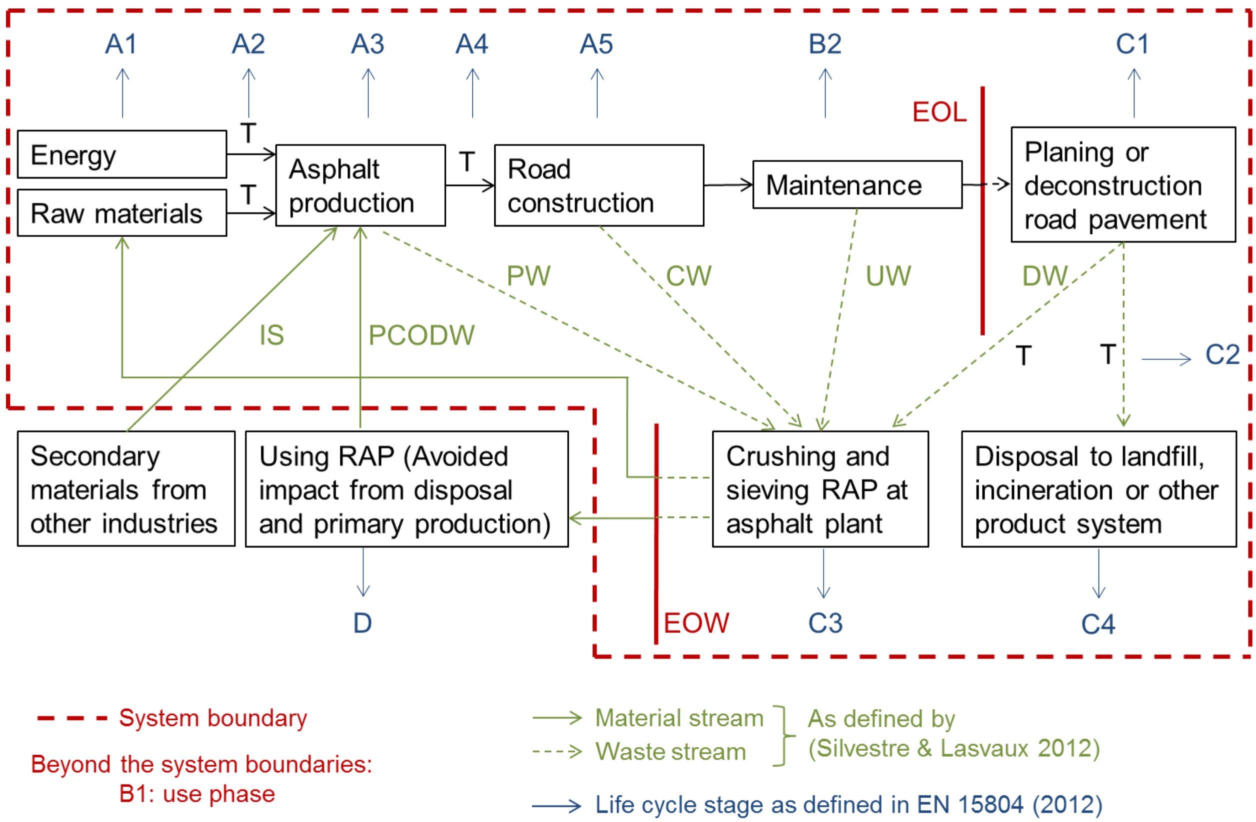

Figure 4: life cycle of bituminous road pavement with the indication of the stages as defined in EN 15804

The authors recognize an inconsistency in Figure 4 since the material flows PW, CW and UW never passed the EOL stage and therefore, theoretically these are not waste streams. Moreover, according to the standard, the impact of the waste processing operations of these material streams are not included in stage C, but are accounted for in the remaining life cycle stages A3, A5 and B2. However, in practice, crushing and sieving is applied for PW, CW and UW before they are reused in new asphalt mixtures. According to the standard, only the impact from crushing and sieving DW is assigned to stage C3.

In the first place, RAP seems to be 100% recyclable. New asphalt mixtures can contain 50% and more RAP, without decreased performance characteristics. However, if RAP is multicycled, the binder will be aged and no longer fulfil the required performance characteristics for a bound asphalt mixture. RAP can then be used as unbound material in the sub-structure of the road or has to be rejuvenated. Based on the figures of COPRO 2014 in Table 1, the estimated recycled content in asphalt mixtures is 26% (=0.61*0.43) and the recycling rate from bituminous road pavements is 61%. As an example for the calculation of the net output flows of the system under study as described in §3.1.1, for the asphalt production of 10 ton, the end of life recycling will generate 6.1 ton of RAP, while only 2.6 ton of RAP has been used at the production stage (module A1). Hence the product system is a net producer of 3.5 kg of RAP, of which the environmental aspects will be reported in module D.

As described in §3.1.1, a justified value-correction factor must be applied in order to reflect the difference in functional equivalence. Although this is applicable to RAP, it is not clear how to calculate this value-correction factor.

In Flanders, the use of tar containing RAP is allowed in cold bound applications if some specification are met e.g., a user certificate from OVAM. In this way, tar remains in the material cycle. Therefore, a technique with definitive exclusion of tar is preferable. In the Netherlands, tar containing RAP is burned. In practice, RAP is rarely if ever traded internationally and even the trade of RAP between different Flemish asphalt plants is limited.

5 CONCLUSION

At this moment, no European end-of-waste regulations for construction and demolition waste aggregates are into force. Implying that European Member States make up own regulations causing incommensurability. The authors of this contribution suggest the definition of the EOL stage as the moment before the milling or deconstruction of the road pavement; and the EOW stage as the moment after crushing and sieving the RAP (at the asphalt plant) and before the RAP is heated (in the parallel drum) in order to add in a new asphalt mixture. Therefore, this heating of RAP in the parallel drum is beyond the system boundaries and is assigned to module D as described in EN 15804. All processes between the EOL and the EOW are assigned to life cycle stage C (end-of-life stage as defined by EN 15804) i.e., i) planning or deconstruction the pavement; ii) incineration, disposal to landfill, or to another product system; and iii) crushing and sieving the RAP at the asphalt plant.

Although Flanders has at this moment a good waste strategy and a high recycling rate compared with other European countries, an effort is necessary in the field of tar containing bituminous road residues. The ambitious, Flemish objective to refuse tar to enter the material cycle through recycling by 2020 needs a practical approach.

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