Eco-premium solutions with focus on downstream environmental consequences

An assessment of an asphalt additive produced by AkzoNobel

Master of Science Thesis in the Master Degree Programme Industrial Ecology

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Abstract

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As the demand for environmentally sustainable products is growing, there is a need for the industry to adapt. AkzoNobel has developed a method called Eco-premium solutions to benchmark the environmental sustainability performance of the product portfolio.

The metric Eco-premium solutions, is an assessment method intended for internal use. This thesis proposes a recommendation for how to quantitatively assess downstream environmental consequences for Eco-premium solutions. The result of a quantitative assessment could be used both internally for improvements, and if a demand exists, also communicated externally.

The approach recommended is to use life cycle assessment for the purpose of assessing downstream environmental consequences by Eco-premium solutions. A case study of one of AkzoNobel's Eco-premium solutions with the proposed approach is carried out to show an example of results that can be achieved for Eco-premium solutions. The Eco-premium solution is an asphalt additive called Rediset. In the process of paving roads, the most frequently used method is heating the mixture of asphalt to high temperatures to get a workable mass. However, with Rediset in the asphalt mix, fuel will be saved due to the possibility of producing an asphalt mix workable at lower temperatures.

To be able to interpret and compare the results of the life cycle assessment, application of weighting methods is proposed. The weighting methods proposed are the weighting method used for Eco-efficiency assessment and the LCA weighting method ReCiPe.

The results of the comparisons show that using Rediset results in an asphalt mix with improved environmental performance. However, bitumen is a large contributing factor to the environmental impact of asphalt's life cycle which makes the fuel savings when heating warm mix seem comparatively small. Nevertheless, when comparing the impact of Rediset cradle-to-gate with the fuel saved, the advantage is evident. Another advantage of adding Rediset is that the road is expected to last longer. This allows the number of road repaving to be reduced, making Rediset even better to use from an environmental perspective.

The result of this study covers three health-, safety- and environmental aspects. However, the metric Eco-premium solutions assessments include six aspects. The areas not included are land use, toxicity (human toxicity and eco-toxicity) and risk potential. Consequently, more research is recommended in the three areas not yet assessed quantitatively.

KEYWORDS: Sustainable development, Eco-premium solutions, life cycle assessment

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Abbreviations

EPS	Eco-premium solutions
EEA	Eco-efficiency assessment
GE	General Electric
HSE	Health, safety and environment
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
P&G	Procter & Gamble
ReCiPe	A life cycle impact assessment method
Rediset	Rediset WMX solutions
SEK	Swedish krona

1 Introduction

When paving roads with asphalt, energy is required to heat the asphalt mix. To save energy and consequently minimize the environmental impact, there are a variety of different ways to produce asphalt and pave roads to choose from. To compare different methods and identify the most environmentally preferable option, a perspective that covers the whole life cycle of a product needs to be applied. A useful method when assessing the impact of a product's or an activity's life cycle is life cycle assessment (LCA).

When designing products and processes, it is necessary to minimize the environmental impact. At business level, that is part of implementing sustainable development. Companies need to assess their products and the processes in which these are made, to find the most preferable option (Palme, 2011).

The sustainability achievement of a company depends on the sustainability performance of its product portfolio (Ringström, Petersson, & Widheden, 2011). To be able to improve a product's sustainability performance, it needs to be assessed. AkzoNobel has developed a quick scan method called Eco-premium solutions (EPS) to benchmark the performance of their products in terms of health, safety and environmental aspects. In EPS, AkzoNobel products are, in a life cycle perspective, compared to a mainstream solution. A mainstream solution is the most commonly used alternative on the market.

An example of an EPS is an asphalt additive allowing for energy savings when producing asphalt and paving roads. A qualitative EPS assessment has been carried out by AkzoNobel. This master thesis will make the same comparison by use of LCA to get quantitative measures and results.

1.1 Background

AkzoNobel is a large paint, coatings and specialty chemicals company. They are ranked as one of the leaders in the Dow Jones Sustainability Index (Corporate, AkzoNobel, 2012). Within AkzoNobel, a team of professionals called the Sustainable Development Group works in the field of environmental and sustainability assessment. Their work ranges from detailed technical problems to high level strategies. Among many areas, they work with EPS. Their goal is to provide support for decision making in the field of sustainability, and they assist the company in order to achieve sustainability ambitions already set (Corporate, AkzoNobel, 2012). The EPS concept is used to encourage and stimulate development and innovation of more sustainable products (Ringström, Petersson, & Widheden, 2011). It is also used to be able to annually measure the progress by assessing the share of revenue from EPS.

The asphalt additive is produced by Surface Chemistry, which is a business unit producing specialty chemicals. The additive allows the asphalt to be produced, as well as the paving to be performed, at lower temperature. This saves energy and consequently also emissions. In addition, indicators show that adding the additive will result in that the road will last longer. AkzoNobel wishes to quantify the environmental benefits of using the asphalt additive.

1.2 Purpose

The aim of this study is to show an example of how quantitative EPS assessments can be carried out. If quantitative EPS assessments were carried out for more products, areas with opportunity for product development would be visible. Additionally, assessment would show areas with the highest improvement potential and avoiding sub-optimisation would be possible.[1] The result of a quantitative assessment can be communicated to the public, while EPS is originally for internal use.

In addition, another aim is to assess the downstream consequences of using warm asphalt instead of hot asphalt when paving roads. Hopefully, this will lead to a greater extent of using the most environmentally preferable option. The downstream consequences will be assessed in a case study by application of the suggested approach.

1.3 Objective

The main goal of the study is to carry out a quantitative assessment and give recommendation of how to assess downstream consequences of EPS. The use of the approach will identify the best way in terms of environmental performance to produce asphalt for roads with either the conventional method with hot asphalt or the EPS option with warm asphalt. The means for achieving this is to quantify the differences in potential environmental impact caused by the two alternatives. The difference accounted for are in the areas of energy consumption, resource consumption and emissions to air, water and soil.

The base for comparison of the two alternatives, the functional unit, is 1 km of road during 40 years, a unit that has been used in literature (Stripple, 2011).

1.4 Scope and limitations

The study is intended to be used by AkzoNobel Surface Chemistry. Also other business units within AkzoNobel and their EPS teams will be able to take part of the results and conclusions.

Sustainable development covers three main areas, where this project is limited to focus on the environmental part. The two others, social progress and economic growth, will not be evaluated. Additionally, EPS includes six aspects, of which the three aspects of energy consumption, resource consumption and emissions to air, water and soil are evaluated. The three other aspects, area use, toxicity (both human toxicity and eco-toxicity) and risk potential do not belong to this scope of the study due to limitation in time.

In chapter 3.1.2 Case study goal and scope: limitations, assumptions, general simplifications and process specific simplifications, for the case study, are found.

1.5 Methodology

A literature review was carried out to find an approach to quantitatively assess the downstream consequences of using EPS. The literature reviewed concerned the concepts of Sustainable development, LCA and EPS. A literature review was also done for concepts similar to EPS, used by other companies, with the purpose to compare. Furthermore, a review about how the environmental impact assessment results are communicated was made.

As LCA is a useful tool for quantitative assessment of products, it was used in a case study to demonstrate an approach to quantitatively assess the downstream environmental consequences for an EPS in the use phase. Data for the case study was collected with assistance from a reference group at Surface Chemistry in Stenungsund. Further, to perform the LCA study, the LCA software GaBi was used with support from supervisors in the Sustainable Development Group in Gothenburg. The results have been

[1] Optimisation in one part of the life cycle without assessing if other parts of the life cycle are affected, and with the consequence of environmental burden being shifted, is called sub-optimisation.

calculated by the use of two weighting methods. In order to use a weighting method that is frequently used and acknowledged by AkzoNobel, the weighting method in BASF's Eco-efficiency assessment (EEA) is used. Additionally, the new LCA weighting method ReCiPe is used to verify the result.

The results from the LCA were interpreted and a recommendation on quantification and verification of downstream benefits of EPS was proposed. The findings are intended to be submitted to the AkzoNobel business units and their EPS teams. Additionally, a proposal of how EPS results can be communicated is proposed.

2 Theory and concepts

This chapter clarifies concepts and terminology, and describes relevant tools to provide understanding for methodological choices, results, conclusions and discussion.

2.1 Sustainable development

A common definition of sustainable development (SD) is "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland, 1987). Sustainable development implies that companies use processes and produce products with as small environmental impact as nature can handle. The concept sustainable development includes, in addition to environmental sustainability, also social- and economical sustainability. A method to compare solutions is required to find which solutions are preferable in a sustainable development perspective.

2.2 Life cycle assessment

The method

Life cycle assessment (LCA) is a method assessing products' and services' environmental impact from cradle to grave. LCA presents in which life cycle phase a product's or a service's environmental impact takes place. This makes it easier to find a good solution that leads to an improvement without shifting the environmental burden to other fields (Heijungs & Guinée, 2005). In addition, LCA makes visible where in the value chain improvements have the potentials to have the greatest impact (European commission - Joint Research Center, 2010). LCA is a quantitative method.

LCA consists of four stages: goal and scope definition, life cycle inventory, life cycle impact assessment (LCIA) and life cycle interpretation. LCA is an iterative process and the connections between the four phases are described in Figure 1.

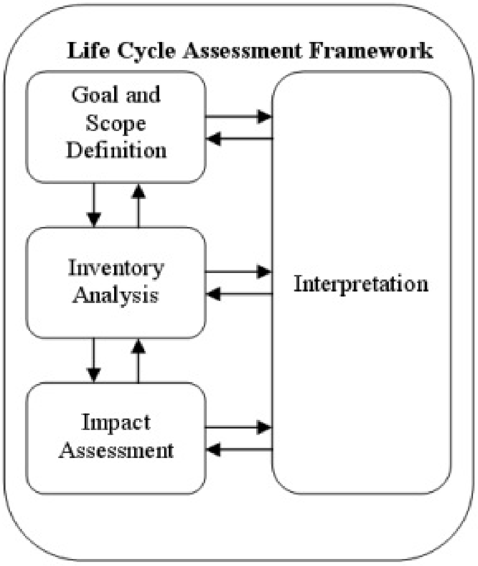

Figure 1 - The four stages of an LCA in the framework developed by ISO 14040 2006

In the first stage, the goal, scope and method are specified along with the product system, boundaries, functional unit, impact categories and allocation methods (Reap, Roman, Duncan, & Bras, 2008).[2] The next step, life cycle inventory, concerns defining material and energy flows that pass into, through and from a product system, and quantifying them. In the third stage, LCIA, the results from the life cycle inventory are converted to environmental impact estimates. This is done in a few steps called classification, characterization and valuation. In classification, material and energy flows are classified into impact categories. The contributions to each impact category are then, in the characterization step, assessed by quantitative or qualitative methods. The impacts are addressed and related to each other in the step of valuation, also known as weighting. The weighting models give a one-dimensional value on resource use and emissions, in order to calculate the total environmental impact. In the fourth step, conclusions are drawn and recommendations formed, based on the inventory and impact assessment data.

Improvement areas

As LCA is a useful tool for many reasons, it is also in need of improvement (Reap, Roman, Duncan, & Bras, 2008). A review in *The International Journal of Life Cycle Assessment* has identified problem areas, a few in every phase of LCA. In the first phase, the problems occur as a result of methodological choices. When comparing different product systems, the definition of a functional unit and the choice of system boundaries cause problems. Other problem areas in LCA are allocation, local environmental uniqueness, spatial variation and data quality/availability. Allocation problems may arise when defining material and energy flows to and from a system. In a system with several inputs or outputs, the environmental impact will need to be divided between the inputs or outputs. The results and conclusions of a study can vary depending on allocation method choices. The ISO 14041 standard about allocation states (Baumann & Tillman, 2004):

- Allocation should be avoided, if possible, by;
    - Increasing the level of detail of the model

[2] The functional unit is described by the International Standard Organization, ISO, 14040, year 1997, as "…a measure of performance of the functional output of the product system."

    - System expansion
- When it is not possible to avoid allocation, it should reflect underlying physical relationships between materials or products
- If a physical relationship cannot be the basis for allocation, a basis which reflects relationships between the materials or products can be used. For example economic value

With regard to local environmental uniqueness, inaccurate estimates of potential environmental damage are the result of not taking into account spatial variation and local uniqueness (Reap, Roman, Duncan, & Bras, 2008). An emission or a material acquisition has the potential to do more damage in some places than in others. Mining in sensitive areas is one example. With regard to data, it may be collected from a variety of sources, some are more accurate than others. Uncertainty arises for example from badly measured data, data gaps, unrepresentative data, and model uncertainty (Björklund, 2001). There are different kinds of quality of data, data from primary, secondary and tertiary sources. Primary data is the most preferable kind, because it derives from the site that is under assessment.[3] Primary data may be collected through surveys, interviews or observation. Secondary sources are often primary data collected by someone else. Sources used for secondary data is often published reports. Tertiary data sources are for example statistics and assumptions (Reap, Roman, Duncan, & Bras, 2008).

LCA concerns the environmental part of sustainability, not social and economic impact. This sets fundamental limits on the comprehensiveness of the method, consequently, complementary methods to assess a product's sustainability are required (Reap, Roman, Duncan, & Bras, 2008). Biological diversity and water usage are examples not routinely considered in LCA. Additional methods are therefore needed to make a fair comparison between alternative solutions compared.

Weighting principles

In LCA, weighting gives a one-dimensional value for the environmental impact. A one-dimensional number is useful in for example decision making when results from LCAs need to be easy to compare.

The indexes for weighting can be prepared in different ways. Panel methods is one alternative. In panel weighting, people, e.g. experts, students or the public, are asked to decide on the most serious environmental impact. Another alternative is monetization methods.[4] Some monetization methods are based on the cost to do something to avoid damage on environment, while others are based on a willingness-to-pay principle. A third alternative is distance-to-target methods. The methods relate a target to the weighting factor. Examples of targets are environmentally critical loads or political goals (Baumann & Tillman, 2004).

Both the environmental weighting method in EEA and ReCiPe uses panel weighting to derive weighting factors. Factors for weighting with ReCiPe is an average of what individualists, egalitarians and hierarchists people in Europe decided. The weighting factors for environmental impact in EEA are based on two factors, one scientific and one societal. The scientific factors derives from impact category scores, and the societal from a group of people.

Awareness of the weighting factors is important for the understanding of the results since transparency may be lost in the process (Svanström, 2012).

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[3] The definition of primary data is process data from specific processes in the products life cycle, such as direct emissions, energy use or physical data.

[4] Panel weighting can be used in monetization methods. Hence, the panel assigns monetary values to items based on willingness-to-pay principle.

Weighting methods

The process of weighting is based on trade-offs and are hence a subjective part of LCA. Different weighting methods may generate different results and it is therefore important to assess the results of an LCA's environmental impact potentials with more than one method (Baumann & Tillman, 2004). An example of a weighting method is a weighting used in Eco-efficiency assessment. Another example is the weighting method ReCiPe.

Eco-efficiency assessment

Eco-efficiency assessment (EEA) is a method used to evaluate the sustainability performance of different products or activities (Widheden, Palme, Tivander, & Pålsson, 2011). A definition of Eco-efficiency was formulated by the World Business Council for Sustainable Development, WBCSD, in 1992. This definition states that: "Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity" (World Business Council for Sustainable Development, 1992). This definition is used as the basis for Eco-efficiency assessment.

In an EEA, environmental impact and cost are weighted for the alternatives compared. The results can be presented in an EEA-diagram (Widheden, Palme, Tivander, & Pålsson, 2011). Figure 2 below illustrates an example of an EEA-diagram. The product or activity with the highest eco-efficiency is placed in the upper right, while products or activities placed further down and to the left corner are worse from an eco-efficiency perspective. Products or activities have the same eco-efficiency if they are placed on the same diagonal, like in Figure 3.

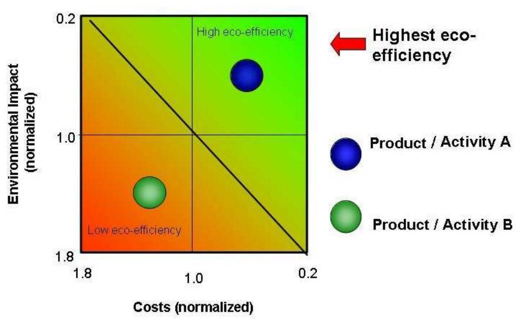

Figure 2- An example of an EEA-diagram. The product closest to the upper right has the highest eco-efficiency.

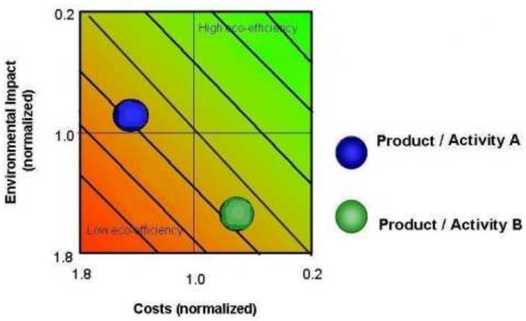

Figure 3 - A second example of an EEA-diagram. The two products have the same eco-efficiency because they are on the same diagonal.

EEA applies a weighting methodology to get a result in the form of a weighted number for both the environmental impact and for costs of the different alternatives assessed. It is possible to use the weighting in EEA for environmental impact without assessing the costs. However, a diagram as in Figure 2 and Figure 3, are not possible to create without the cost assessment.

ReCiPe

ReCiPe is a weighting method resulting in many different indicators at a midpoint level and three indicators at an endpoint level (Goedkoop, Heijungs, Huijbregts, Schryver, Struijs, & Zelm, 2008). Life cycle inventory parameters such as raw material use, CO_2 and SO_2 emissions, are grouped with respect to the environmental impacts they contribute to. Examples of impact categories are ozone depletion, climate change, terrestrial acidification etc. Finally the midpoint categories are grouped to the endpoint categories. The three endpoints are Human health (measured in DALY), Ecosystems (measured in extinct species/year), and Resource cost increase (measured in $) (Goedkoop, Heijungs, Huijbregts, Schryver, Struijs, & Zelm, 2008).

2.3 AkzoNobel Eco-premium solutions

Eco-premium solutions (EPS) is an assessment method used by AkzoNobel. EPS is the name of the method, as well as the name of a solution classified to fulfil the criteria assessed in the method. The method is described below, as well as the criteria for a solution to become an EPS.

The method

AkzoNobel compares selected products with their corresponding mainstream solutions in a life cycle perspective. Mainstream products fulfil the same customer benefit, are commercially available and the most common alternative in the market. A mainstream solution could also be present within the internal product portfolio of AkzoNobel. The method EPS is developed by AkzoNobel to stimulate research & development of more sustainable products and to measure the progress by assessing the share of revenue from EPS (Ringström, Petersson, & Widheden, 2011). The target for AkzoNobel is to have 30 percent revenue from EPS in 2015. In 2011, 22 percent of the total turnover came from EPS (AkzoNobel, 2011).

The solution

An EPS provides the same or better functionality for the customer application while also having a clear eco-efficiency benefit compared to the mainstream product. When eco-efficiency is assessed, health, safety and environment (HSE) are considered. The six HSE aspects are:

- Toxicity (human toxicity and eco-toxicity)

- Energy efficiency
- Use of natural resources/raw materials
- Emissions and waste
- Land use
- Risks of accidents

An EPS has to be significantly better in at least one of the above mentioned criteria and not be significantly worse in any other (Ringström, Petersson, & Widheden, 2011). The list over products that are qualified as EPS is dynamic. Solutions are continuously added while some are removed due to improvements of the mainstream solution. Quantitative assessment is not mandatory. Qualitative and semi-qualitative assessments are often used to decide which products that qualifies as EPS (Andersson Halldén, 2012).

EPS are in most cases compared to a competing product along the whole value chain. Exceptions are if there is no competing product. In the case of no competing products, the assessment is made over the benefits of using the product compared to impacts when using and producing it. With regard to additives, an additive can be EPS if the result of environmental benefits outweighs the environmental impact of production and use (Andersson Halldén, 2012).

One example of an EPS is warm mix. Warm mix is an asphalt mix used in roads containing an additive, Rediset WMX. The corresponding mainstream solution is hot mix. Hot mix is an asphalt mix that requires more energy in the process of paving roads. Other examples of EPS are Dulux Weathershield and Sikkens Autosurfacer UV. Dulux Weathershield is a paint developed to save energy, produced by the business unit Decorative Paints. With a solar reflectance index of double that compared to mainstream paint, the build-up of heat in a house is lower, resulting in energy savings from not using air condition. Produced by Performance Coatings is a solution called Sikkens Autosurfacer UV. It is a filler for the car refinish market. The filler has very short drying time, resulting in less energy use. In addition to the short drying time, the amount of product needed for repairing damages, is almost lowered to 50 percent (Andersson Halldén, 2012).

Methods similar to EPS

While AkzoNobel has developed EPS, General electric, Philips, Procter & Gamble and SKF, to provide some examples, work with other methods.

General electric (GE) has a method called Ecomagination to develop innovative solutions and drive economic growth. To qualify for the Ecomagination portfolio, the product has to improve customers' operating performance or value proposition, and also have an improved environmental performance (GE, 2010). GE will invest $10 billion between 2010 and 2015 in Ecomagination solutions. In 2010, GE generated $18 billion on revenues from Ecomagination products and services (GE, 2010).

Philips has a method called Green Flagships. They claim that a Green Flagship product is the best environmental choice because of being either: the best environmental performing product on the market, the best environmental solution in its application area, or the most innovative environmentally friendly product in their portfolio (Philips, 2007). In 2006, Philips stated a target of 30 percent of total revenue from green products in 2012 from 15 percent in 2006 (Philips, 2007). For a product to be classified as a Green Flagship, it must fulfill being significantly better (>10 percent) in at least one of the following categories:

- Energy efficiency
- Lifetime reliability
- Hazardous substances
- Recyclability
- Packaging
- Weight

The green Flagship products are compared to predecessors or closest commercial competitors (Philips, 2007), (Philips, 2006).

Procter & Gamble (P&G) uses a method called Sustainable innovations. A Sustainable innovation is according to P&G a product that has a more than 10 percent reduced environmental footprint in one of the categories:

- Transportation
- Packaging
- Energy
- Non-renewable resources
- Material use

Sustainable innovations are compared to a previous or alternative version of the product. Additionally, the products are not negatively impacting the overall sustainability profile of the product. The goal for 2012 is to reach a cumulative sale of $50 billion of Sustainable innovations from the start in 2007 (Procter&Gamble, 2011), (Procter & Gamble, 2012).

SKF has developed a method called BeyondZero where the focus is mainly on greenhouse gas emissions. In the BeyondZero portfolio, the solutions are better in one of the categories:

- Energy efficiency
- Natural resources
- Avoids discharges into water

Solutions in the BeyondZero portfolio deliver environmental benefits without serious environmental tradeoffs. The comparison is made between SKF products and an established baseline which is either based on industry average or previously installed solution. The cut-off criterion for inclusion in the BeyondZero portfolio is 10 percent less greenhouse gas emissions. The target for year 2016 is to get 10 billion SEK in revenue from solutions in the BeyondZero portfolio, compared to the 2011 years 2.5 billion SEK (SKF, 2012).

Communication on environmental performance

Companies who have executed LCAs have a basis for communicating the results to stakeholders. EPS is a way for AkzoNobel to benchmark the product portfolio towards the competition in the market. However, ESP is not intended as a marketing proposition/tag line.[5] Ways for a company to communicate environmental performance externally are for example by use of Eco-footprints and Environmental product declarations.

[5] The reason to not use EPS as a marketing proposition or tag line, is that EPS is a quick scan method. It is not mandatory to back up the EPS claim with a quantitative assessment.

Eco-footprint
An Eco-footprint can be made to present the results of a LCA (AkzoNobel Sustainability, 2012). An evaluation of a product's eco-footprint may be used for communicating results in a way easy to interpret. The method for calculating environmental impact with Eco-footprint is standardized, in line with the ISO standard for LCA. To further enhance credibility of a product, service or system, a third party review can be carried out. This would result in an Environmental product declaration.

Environmental product declaration
Environmental product declarations (EPD) are used to provide comparable information about the environmental impact from products and services (The international EPD system, 2012). EPDs of products and services make it possible for the customers to make a comparison. EPD is a way of communicating numbers and may later be used by stakeholders such as customers to make LCAs of their own products (AkzoNobel Sustainability, 2012).

Product brochure
EPS is not intended as a marketing proposition or tag line. One reason for this is that it is not mandatory to back up the claims with a quantitative assessment (Andersson Halldén, 2012). However, SKF with their similar method, BeyondZero, uses their result in communication with the public. They have made product brochures for many products describing advantages in comparison to mainstream products. In the future, this may also be a possibility for AkzoNobel.

3 Case study

This case study is used to show an example of how LCA can be used to quantitatively assess downstream environmental consequences from an EPS and a comparable mainstream solution.

3.1 Case study introduction

The background to this case study, as well as theory about the system assessed, is presented in this introduction. Further, the goal and scope are described in chapter 3.1.2.

3.1.1 Case study background and theory

To pave roads requires a lot of energy. An energy demanding step in the process of paving is the heating of the asphalt mix. A solution to lower the energy use in the paving process is to lower the demand for high temperature in the asphalt mix. An EPS developed by AkzoNobel is Rediset. Rediset is an additive that reduces the energy demand in asphalt mixes. A chemical additive contributes however to the environmental impact. The environmental impact from the life cycle of Rediset is compared to the impact of using the additional energy that is needed to heat the asphalt when Rediset is not present. The method without Rediset is expected from the qualitative assessment in EPS to require more energy. In a quantitative assessment, LCA and weighting methods are used. The weighting methods used are the environmental weighting in EEA and ReCiPe.

LCA for a road
The life cycle of a road consists of raw material production, construction, operation & maintenance and final disposal/removal or reuse of material, as shown in Figure 4. Raw material production is included in the step Production of a road in Figure 4. Instead of final disposal, a road is often replaced by another road or reconstructed. Further, some of the materials are often reused.

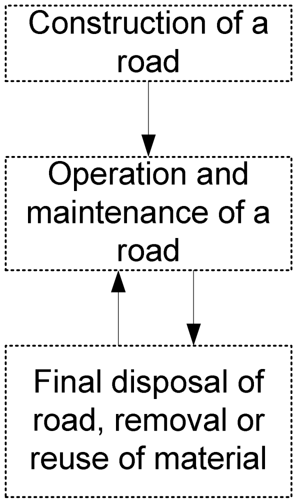

Figure 4 - An overview of a life cycle for a road (Stripple, 2011).

Asphalt

The two main components present in asphalt are aggregate and bitumen (United Kingdom Petroleum Industry Assosiation, 2010). Bitumen is a residue from distillation of crude oil and is in room temperature semi-solid. In road construction, bitumen is used as a binder and is in the normal case heated to 100-200°C until fluent enough to mix with the aggregate (AkzoNobel, 2003). Aggregate on the other hand is a coarse particulate material consisting of rock materials of different kinds and sizes. The rocks have often been crushed and divided into different sizes (Thorstensson, 2012).

The three main solutions to process asphalt are: hot mix, emulsion[6], and solvents. The solvent and emulsion types are used to a small extent, while hot mix is the most frequently used (EAPA, 2010).

Hot mix, the mainstream asphalt mix, consists of approximately 94 percent aggregate and 6 percent bitumen. However, bitumen is hydrophobic while aggregate is hydrophilic. The difference makes the adhesion difficult and is a reason for adhesion promoters to be added in the mix. [7]

An alternative to promote adhesion is the use of emulsion. The emulsion makes bitumen liquefied by dispersion in water. Further, the emulsion works due to that its emulsifiers work as adhesion promoters between bitumen and aggregate. Emulsion is however only recommended for roads that are lightly trafficked, and is therefore only used to a small extent (EAPA, 2010).

With regard to the solution of using hot mix for roads, energy to dry and heat the aggregate is required. The heat derives from light fuel oil which is obtained by burning. The heating process impacts the environment negatively since light fuel oil is consumed. The high temperature in the heating process of hot mix is however required. The heat gives compactness to the asphalt and makes is possible for roads to resist damage from water.[8] To reduce the need for heat in hot mix, additives such as Rediset can be used (AkzoNobel Surface Chemistry, 2010). Hot mix with additives to lower the required temperature, is called warm mix. The temperature demand in warm mix using Rediset can drop the temperatures by 20°C

[6] Asphalt mix with emulsion is also referred to as cold mix. In an emulsion mix, the aggregates are allowed to be both cold and wet (EAPA, 2010).

[7] Adhesion promoters are surface active materials that work as bridges between aggregate and bitumen. The "tails" of the molecules are compatible with bitumen while the head groups bind to the aggregate (AkzoNobel, 2003).

[8] Symptoms of water damage are for example rutting, ravelling, cracking and freeze-thaw damage.

to 40°C (Thorstensson, 2012). However, a problem many warm mix applications suffer from is the ability to compact to resist moisture damage (EAPA, 2010).

The main reason to add Rediset in an asphalt mix is to reduce the asphalt mixing and application temperatures. Except for lowering the temperature at which an asphalt mixture remains workable with around 30˚C, a couple of other benefits such as improved cohesion strength of the mix are achieved. The strengthening of the bonds in the asphalt originates from the change of asphalt that normally is slightly acidic into a weak alkaline substance. The aggregate is usually weakly acidic as well, and one acidic and one alkaline material establishes stronger chemical bonds. As a result, the bond between asphalt and aggregate improves the moisture resistance property of the mix, which prevents water damage in the road. This means that warm mix with Rediset does not have the problem with moisture damage (AkzoNobel, 2012). Further, tests performed in laboratories show that roads containing Rediset may have a longer lifetime. However, since warm mix is a young technology, full-scale tests on the roads' durability have not yet been completed. The amount of adhesion promoters added in hot mix is decreased because Rediset also has adhesion promotion properties (Thorstensson, 2012). Furthermore, Rediset decreases the amounts of fumes produced during manufacturing at the site of mixing asphalt as well as at the road construction site, compare Figure 5 that shows paving with hot mix to Figure 6 that shows paving with warm mix (AkzoNobel Surface Chemistry, 2010). Another benefit from warm mix with Rediset, compared to other additives in warm mix, is the processability. For the staff paving asphalt, the processability of the asphalt mix is of importance to make the job possible to perform. Warm mix asphalt has often worse processability than hot asphalt. However, the warm mix with Rediset is shown to be better in that respect than other types of warm mix (SBUF, 2012).

Rediset comes in pellet form and can be added to the mixing unit or to the bitumen. In one ton final mix of asphalt, approximately 1 kg of Rediset is present (Flomac, 2012).

Figure 5 – In the paving process of hot mix asphalt, the amount of fumes are visible.

Figure 6 – In the paving process of warm mix asphalt with Rediset, the amount of fumes are reduced.

3.1.2 Case study goal and scope

The main goal of the case study is to quantitatively identify whether hot mix or warm mix is the most preferable way to provide asphalt for roads, in terms of environmental performance. In addition, a framework for communication of the results of a quantitative EPS is proposed.

System boundaries

The products have been analyzed from an LCA perspective, with focus on the use phase. The life cycle of a road includes production of Rediset, bitumen, aggregate, asphalt mix, the paving of a road, maintenance and final disposal or reuse. However, due to time limitations, the road's life cycle ranges in this case study from material extraction to the paving of road and maintenance. Final disposal or reuse a step has not been included.

The total environmental impact including resource consumption, energy use and emissions & waste are assessed with the weighting method in EEA, while the three damage areas: ecosystems, resources and human health are assessed with the LCIA method ReCiPe.

General simplifications, limitations and assumptions for the study

In terms of geography, the study is limited to Northern Europe and North America with regard to data on the asphalt additive Rediset and asphalt. Rediset is currently produced in Pennsylvania (USA) and will eventually be produced in Stenungsund (Sweden). The study is based on Swedish conditions and data from the site in Stenungsund is used to assess future downstream environmental consequences in Sweden. However, due to that the production does not take place in Sweden yet, data for Rediset is collected from Pennsylvania. Additionally, transportation distances are estimated. The dependencies on communication with data suppliers situated in different parts of Sweden and in USA has been a limitation due to time constraints for data suppliers to share data.

The expected lifetime of the top layer of a road might differ with the choice of asphalt mix used in the paving process. A conventional road from hot mix lasts for 12 years (Lundberg, 2011) while a road from warm mix is expected to last longer due to improved cohesion strength in the asphalt. Exactly how much longer is not yet defined due to the short time of research in paving road by use of warm mix. Two scenarios with respect to lifetime have therefore been assessed.

- Same lifetime (12 years)
- 3 years longer lifetime for warm mix

The top layer of the road is in focus while the bottom layer, often consisting of gravel, is not included in this study.

Due to limitations in LCA, some aspects are not possible to assess quantitatively. When using different asphalt mixtures, for example, variables like noise, lighting requirements and other parameters contributing to the total performance of a road changes. This is however hard to evaluate in numbers, why these parameters only are mentioned in this thesis. Another limitation set in this study is to not include the monetary part in the EEA. The weighting method in EEA, however, is applied to get a one-dimensional value of the environmental impact. Furthermore, capital goods have been excluded in the calculations.

The conditions for paving a road are different depending on site. The sites may vary with regard to the terrain which might be more or less hilly, as well as with how well the road follows the outline of the terrain (Stripple, 2011). In this thesis, a straight road of 1 km without hills is assessed.

The environmental impact assessment with the weighting method from EEA is based on three out of six impact categories used in EPS:

- Energy consumption
- Resource consumption
- Emissions to air, water and soil (including waste)

The other three are land use, risk potential and toxicity (human and eco-toxicity) potential. These three are difficult to find data for and are due to time limitations not considered in the calculations. However, they are qualitatively assessed below (see chapter 3.4).

ReCiPe has three damage areas which are:

- Resources
- Ecosystems
- Human health

The three impact categories and the three damage areas are included in comparisons between not using additives and using Rediset. Additionally, the results are presented in normalized form. This means that the product with the highest value is assigned value 1 and the product compared to that is assigned a lower value. Consequently, the absolute values of environmental impact are not presented.

Process specific simplifications, limitations and assumptions for the study

The temperature, to which an asphalt mixture needs to be heated, varies with the outdoor temperature. The temperature interval for hot mix is in reality between 140-180˚C, while 120-130˚C is valid for warm mix (Thorstensson, 2012). Hot mix is in the calculations assumed to be heated to 160˚C, compared to warm mix which is assumed to be heated to 130˚C.

In the aggregate production, a blasting agent is used. In this study, as well as in the study *LCA of a road*, it is not included (Stripple, 2011). Another data gap is adhesion promoters used in asphalt. Hot mix asphalt uses more adhesion promoters than warm mix asphalt. This might mean, from an environmental perspective, that warm mix is better than presented in the results.

A road's life cycle often includes recycling or disposal of the road when worn out. This project has not included disposal due to limitations in time.

Functional Unit

The basis for comparison is 1 km of road for 40 years. A road of 1 km consists of approximately 1606 ton asphalt in the top layer, assuming a road that is 13 m wide and a 5 cm top layer of asphalt. The density of asphalt varies slightly with temperature and depending on if it is a hot or warm mix. The difference is however small and 2470 kg/m^3 (Zaumanis, 2012) is a good approximation for both types. The asphalt in the top layer of the road, with a lifetime of 12 years, is in 40 years replaced three times which means that the paving process needs to take place four times. The amount of asphalt mix needed, expressed as mass during 40 years, is consequently 6424 ton. In the scenario where warm mix lasts for 15 years, the top layer only needs to be replaced two times, resulting in that 4818 ton of warm mix asphalt is required for 1 km of road for 40 years.

3.2 Inventory analysis

The inventory analysis describes using flowcharts how asphalt is made for the two cases hot mix and warm mix. Additionally, it defines and quantifies resources and energy used and basic emissions from the processes. The data, data sources and quality of data are also described.

Flowcharts

A flowchart over the process to produce an asphalt road from hot mix is shown in Figure 7. In comparison to the flowchart of warm mix in Figure 8, warm mix in addition includes Rediset. The two ways to produce asphalt also differs in the amount of energy used in the process of drying and heating aggregate; the EPS, warm mix, consumes less oil. In the flowchart, the oil is included in the notation Energy.

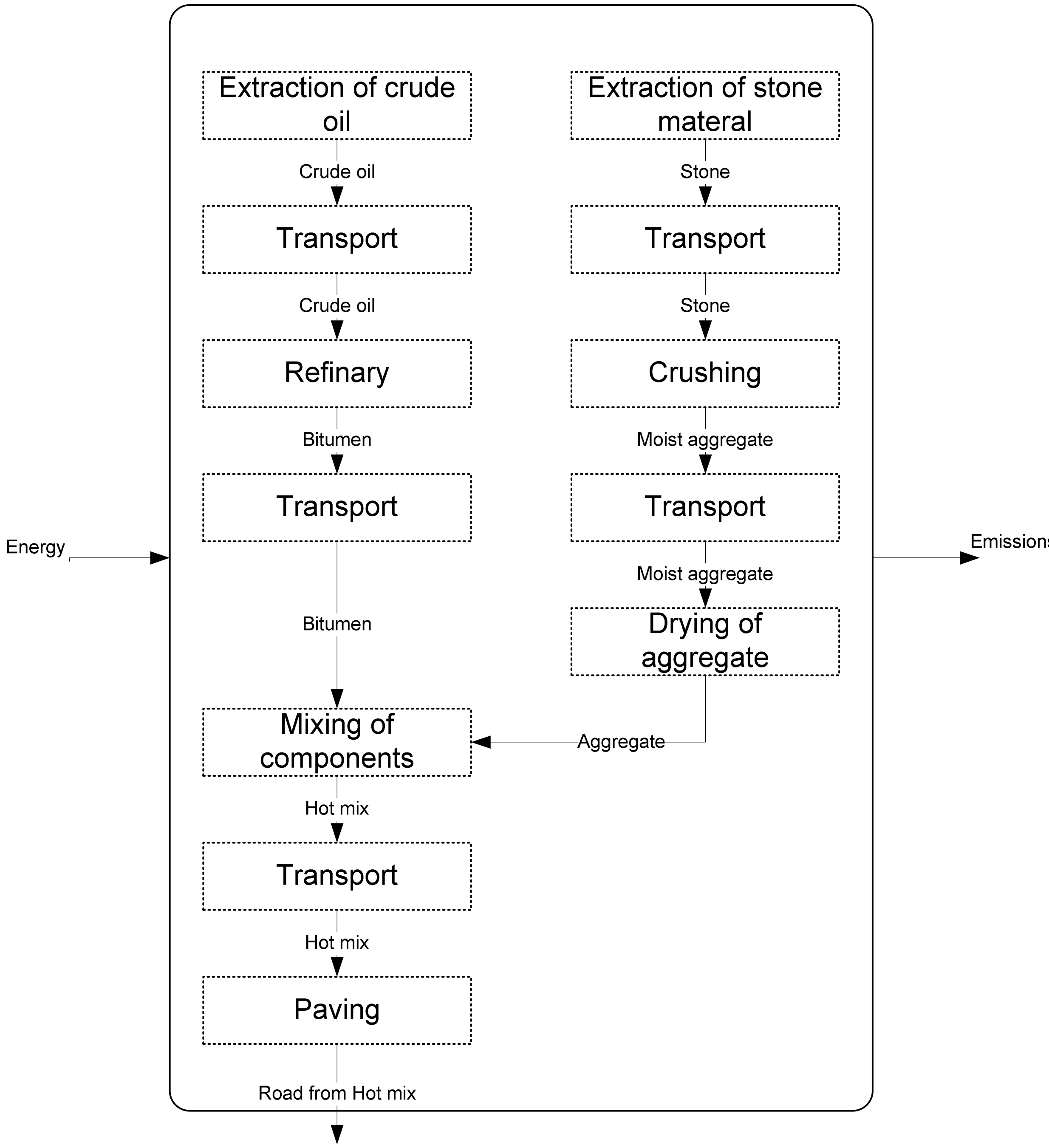

Figure 7 - A simplified flowchart over the process to make asphalt from hot mix.

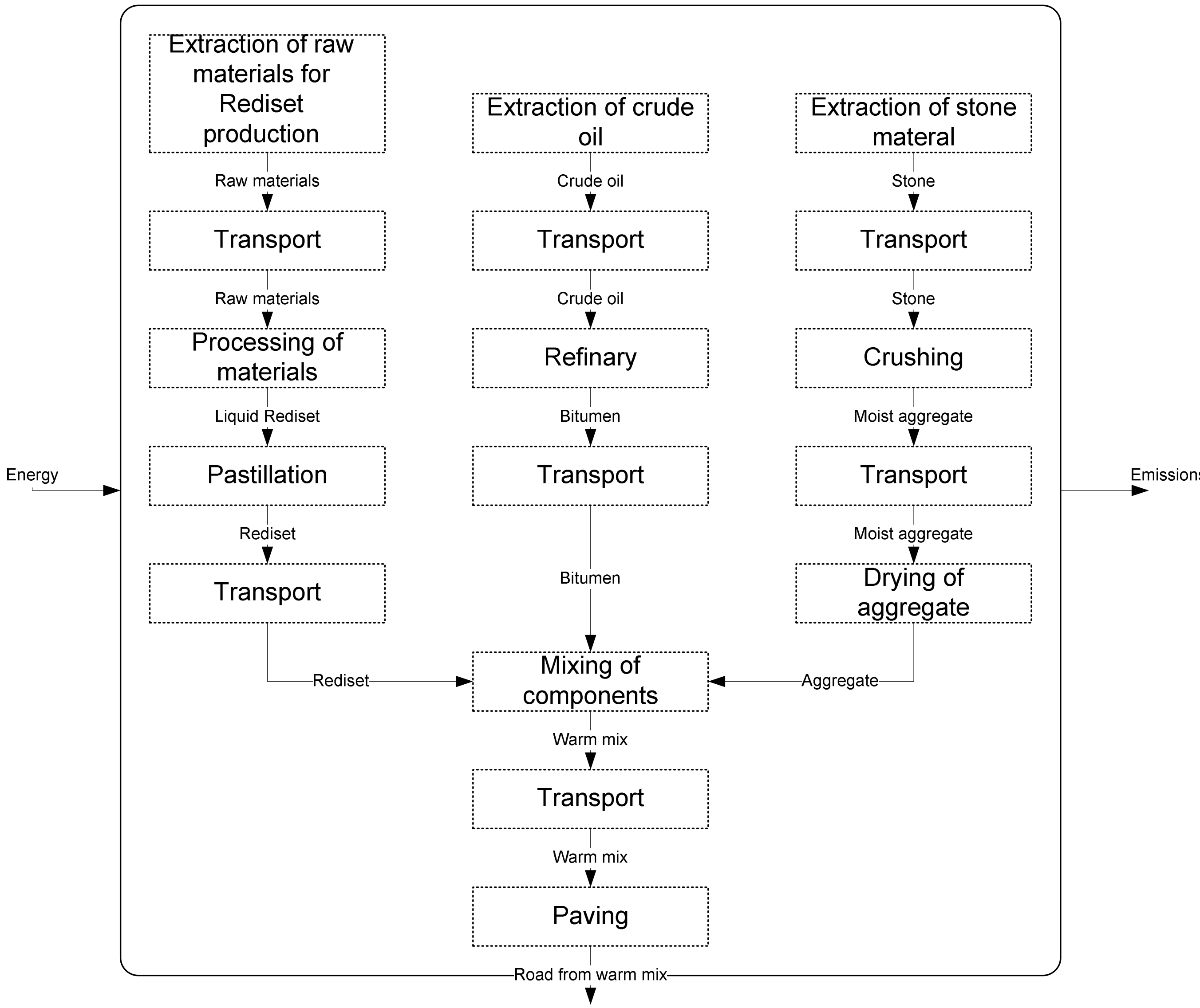

Figure 8 - A simplified flowchart over the process to make asphalt from warm mix.

Data, data sources and quality

Rediset production

Both primary and secondary data sources are used in the modeling of the production of Rediset. For the resources in Rediset, primary data is used while for emissions it is secondary data.

Detailed data about Rediset is not public. Authorized readers can find the data in Appendix 2 in a version not published.

Bitumen production

For bitumen, a data set in GaBi applicable in EU is applied. The provider of the data set is PE International. The quality of the data set is stated to be good and it is valid for year 2012 and earlier. Energy carrier extraction and processing data is written to be sufficient for good data quality. The inventory data is in this data set partly based on primary industry sources and partly on secondary literature data. The refinery emission data is based on literature and the European Pollutant Emission Register.

Bitumen is a fraction of crude oil. Hence, to produce bitumen, oil is extracted and refined (see Figure 9). The environmental impact from the refinery is allocated between the products based on net calorific value.

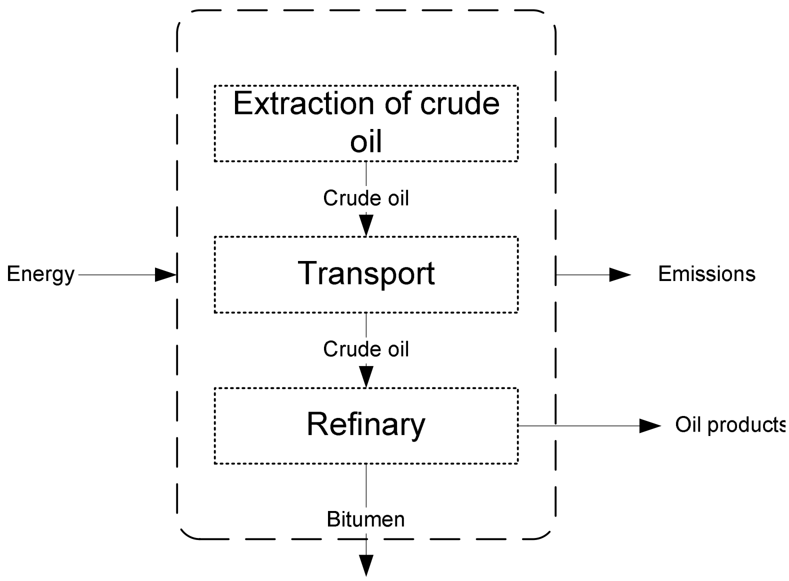

Figure 9 – A simplified chart over bitumen production.

Aggregate production

Aggregate data and data for paving roads are extracted from secondary sources. The data is based on two reports, *Energieffektiv asfaltbeläggning* by Roger Lundberg and *Life Cycle Assessment of Road* by Håkan Stripple.

Aggregate consists of rock mass deriving from mountains. The mountain is uncovered from material lying above the stone material and then drilled before bursting (Lundberg, 2011). The bursting then takes place, giving pieces of stone that fits in the stone breaker, and also pieces too big to use. The big stones are crushed with excavators and finally crushed in a stone-breaker together with the smaller stones. In Figure 10, a simplified picture over the steps from uncovering of mountains to handling big pieces of rock, are summarized as raw material extraction and processing of raw material.

In the inventory analysis of producing aggregate, the consumption of diesel and electricity for vehicles transporting the material between different steps in the process and the stone breaker are included. The crushed aggregate needs to be dried before use in a hot or warm mix and the energy for drying derives from oil (Martinsson, 2012). The aggregate assumed to have a moist content of 3 percent, requires 7.5 liters light fuel oil for 1 ton hot mix. 1 ton warm mix on the other hand requires 6 litres (Lundberg, 2011).

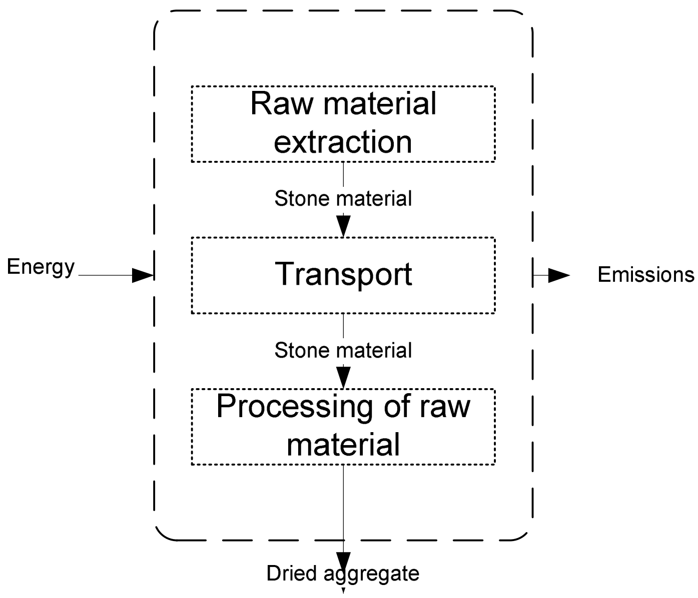

Figure 10 - A simplified chart over aggregate production

Between 1.5 l and 2.5 l fuel oil will be saved per ton asphalt when heating warm mix instead of hot mix. The difference is due to the required temperature for the different mixes. A saving of 2 l of fuel is assumed and it corresponds to a saving of 75 MJ per ton asphalt. For the functional unit of 1 km which uses 4818 ton asphalt, it corresponds to a saving of 361350 MJ.[9] Further, a road using 6424 ton asphalt saves 481800 MJ.[10]

Mixing process

The process of mixing asphalt may be performed in different ways. One way is mixing in a stationary mixing plant, and another is in a mobile mixing plant. Moreover, recycling of old asphalt may be used as well as different additives. In the mixing process of aggregate and bitumen, and Rediset for warm mix, electric power is needed as well as fuel. Outflows from the mixing plant are combustion gases, noise and heat. Under the assumption that a mobile and a stationary mixing plant contributes to the same consumption of fuel and electricity, and with no recycling, the mixing of bitumen, loading of dried aggregate, and additives requires 0.2 l fuel and 8 kWh electricity for 1 ton of asphalt (Lundberg, 2011).

Paving of roads

In the paving process, already heated paving mix from the mixing plant is transported to the area in isolated containers. Asphalt machines use a variety of fuels in the paving process. For the assumption that one big asphalt machine and two steamrollers consuming diesel and propane are used, the fuel consumption for 1 ton asphalt is 0.5 l diesel and 0.7 l propane (Lundberg, 2011).

Transportation

When transportation of different raw materials and chemicals are required, a distance of 500 km with truck is assumed. An exception is applied for the transportation of diesel and propane consumed in the paving process of steamrollers and asphalt pavers. The distance is instead estimated to be 10 km because

[9] A road lasting for 15 years uses during 40 years 4818 ton asphalt in total.
[10] A road lasting for 12 years uses during 40 years 6424 ton asphalt in total.

it is transported from a conventional gas station, often close to the position of paving. Further, a transportation distance of 20 km between the aggregate production and the production of asphalt is applied. 20 km is also applied for the distance from the production of asphalt mix to the paving of road (Stripple, 2011).

Data gaps

Unfortunately some of the required primary data were not possible to acquire due to complicated product systems, processes and time constraints for the data supplier. Data gaps have been filled with estimated values with the help of experts in the sustainability team of AkzoNobel.

Due to non-public information in the section on data gaps, information for authorized readers is found in Appendix 2.

3.3 Impact assessment and case study results

Two comparisons are used to present the results of the impact assessment. For simplicity reasons, all results are normalized since it is the relative contribution of the alternatives that is of importance. Results for the weighting method in EEA are presented and also results from applying ReCiPe (see Figure 11 - Figure 16). Other diagrams give results of the contribution to environmental impact from the different phases of the life cycle, in relation to each other (see Figure 17 - Figure 20). The sources are aggregate, bitumen, energy carriers, transportation and Rediset.

Two comparisons

Both characterization and weighting have been carried out by the use of EEA and ReCiPe, respectively. Results are shown for the following two comparisons:

1. With focus on the differences in the life cycles
2. With life cycle perspective
    a. For a scenario where the lifetimes of warm mix and hot mix are different
    b. For a scenario where the lifetimes of warm mix and hot mix are the same

Comparison 1: When comparing products or systems with the same functional unit, the parts of the life cycle that are different need to be in focus. The differences in a life cycle of warm mix compared to hot mix are the addition of Rediset and the energy consumption in the phase of paving. Environmental impact caused by Rediset cradle-to-gate compared to environmental impact avoided by the use of Rediset, in terms of saved oil for heating, is assessed in the first comparison (see Figure 11 and Figure 14).

Comparison 2: On the other hand, a systems perspective is useful when assessing which parameters that matter in total. Two scenarios in a second comparison focus therefore on the whole life cycle of an asphalt road. Since warm mix roads are expected to last longer than hot mix roads a scenario (scenario a), assesses the environmental impact for when the lifetimes are different. A worst case scenario (scenario b) assesses the environmental impact for when lifetimes are the same. Both scenarios assume a lifetime of 12 years for hot mix. In scenario a, the lifetime of warm mix is assumed to be 12 years and in scenario b it is assumed to be 15 years (see Figures 12, 13, 15 and 16).

Normalized results

The total weighted results are normalized. This means that the results for the different alternatives are presented as a number between zero and one, instead of with absolute numbers. The product with the highest result in each comparison is assigned the value one and the others receive a value in relation to this.

An example of a normalized result: if the first alternative consumes 50 MJ of useful energy and the second alternative consumes 40 MJ, the first alternative is assigned 1 and the second is assigned 0.8 in the energy consumption comparison.

EEA results

Shown in Figure 11 - Figure 13 are results from comparison 1 and 2, with the environmental weighting in EEA applied.[11]

Comparison 1 with EEA

Figure 11 describes the comparison between the usage of Rediset and the oil saved from heating to a lower temperature, due to that Rediset is used.[12] The total environmental impact is divided into the categories emissions & waste, energy, and natural resources.

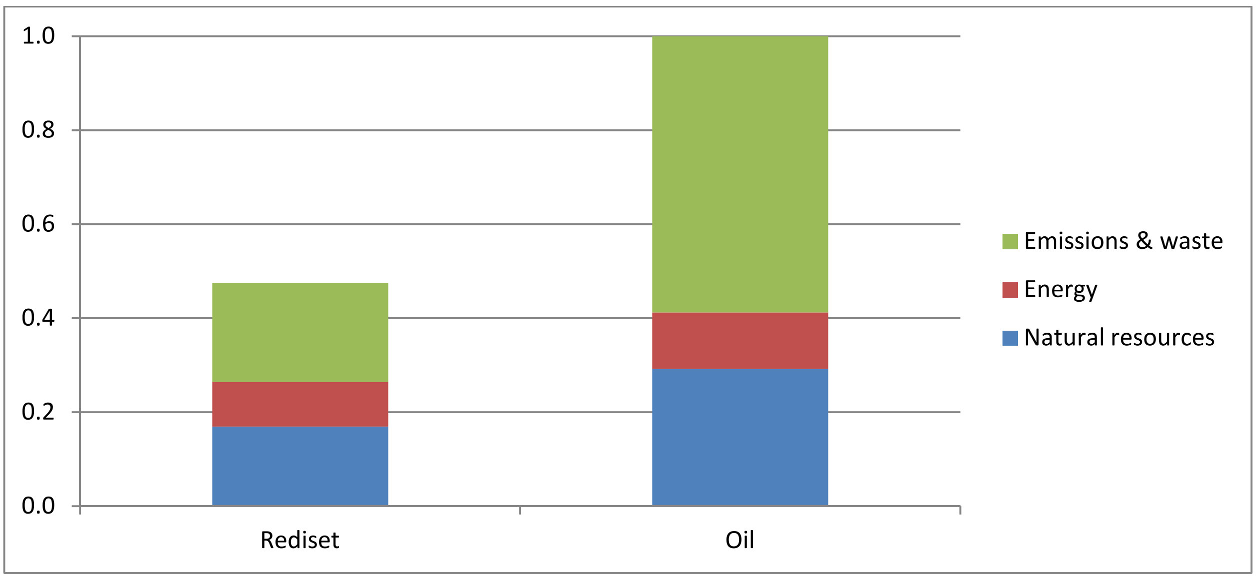

Figure 11 – Normalized, weighted results assessed with EEA method. For Rediset cradle to gate vs. oil savings when using warm mix asphalt.

Comparison 2 with EEA

In comparison 2, warm mix and hot mix asphalt as road top layer are assessed from a life cycle perspective. Results for the first scenario in comparison 2 are presented in Figure 12. It is the scenario where warm mix has a somewhat longer lifetime.

[11] Additional results, over contributing factors to environmental impact, are found in Appendix 1.

[12] In warm mix where Rediset is used, the asphalt mix does not need to be heated to as high a temperature as would be required if Rediset was not present.

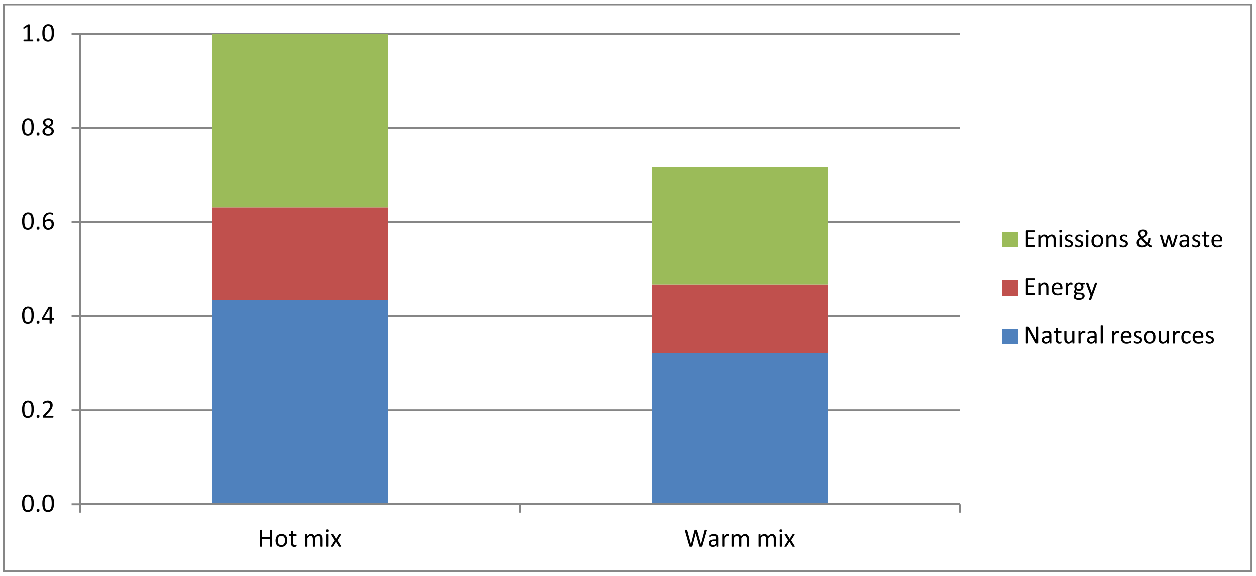

Figure 12 – Normalized, weighted results assessed with EEA method. For the comparison between hot mix and warm mix asphalt in road top layer with different lifetimes.

Results for a worst case scenario, where the warm mix road only lasts as long as a hot mix road, are presented in Figure 13.

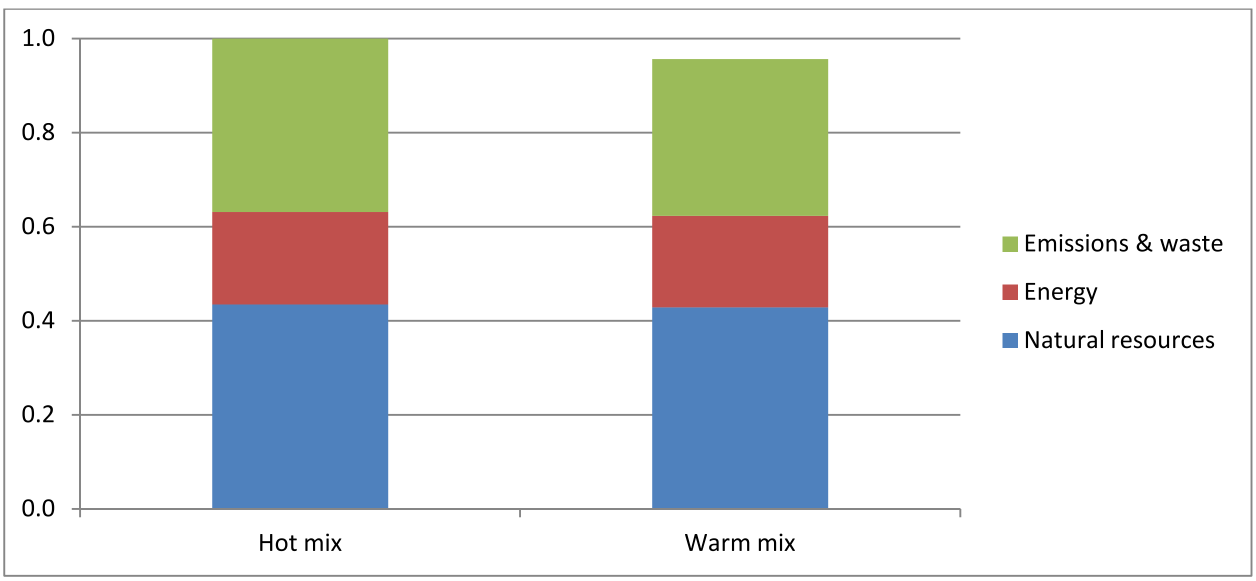

Figure 13 – Normalized, weighted results assessed with EEA method. For the comparison between hot mix and warm mix with same lifetimes.

ReCiPe results

In Figure 14 to Figure 16 ReCiPe results from comparison 1 and 2 are shown.

Comparison 1 with ReCiPe

Results for impact on damage areas caused by Rediset cradle-to-gate compared to the impact saved when using less oil in warm mix, is shown in Figure 14. [13]

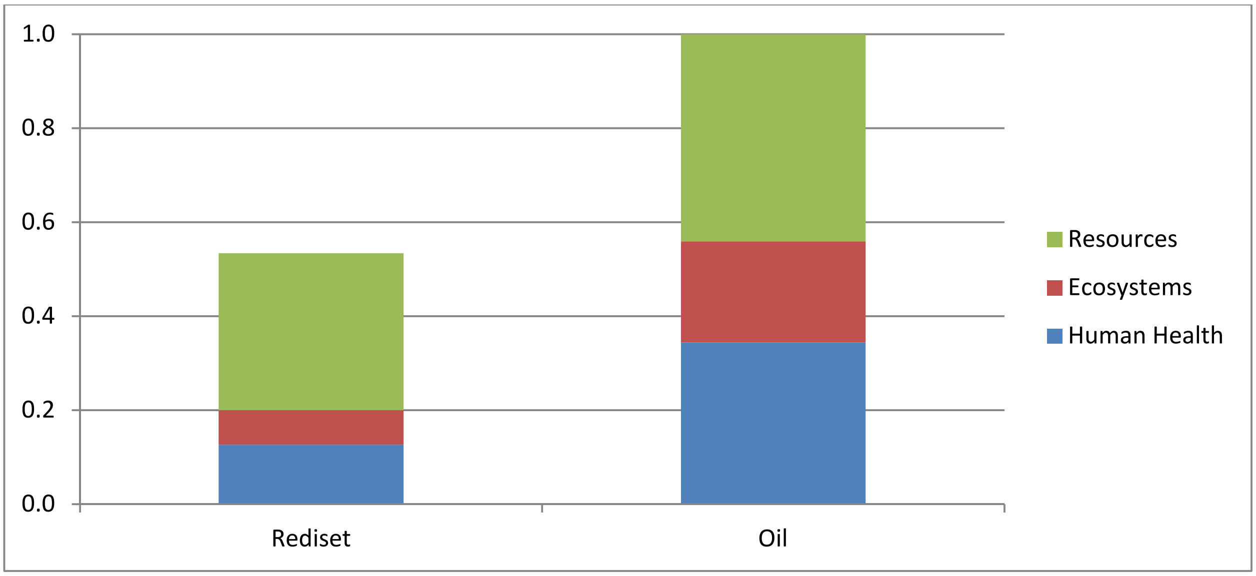

Figure 14 – Normalized, weighted results for the comparison Rediset cradle-to-gate impact versus oil savings when using warm mix asphalt assessed with ReCiPe.

[13] In July 2012, a new version of weighting parameters for oil was released. The first version of ReCiPe had then already been used to calculate damage areas results. Due to limitations in time, and that the work of assessing damage areas already was done, the new weighting parameters were not applied.

Comparison 2 with ReCiPe

Results for the first scenario in comparison 2 are presented in Figure 15. It is the scenario where warm mix has a somewhat longer lifetime.

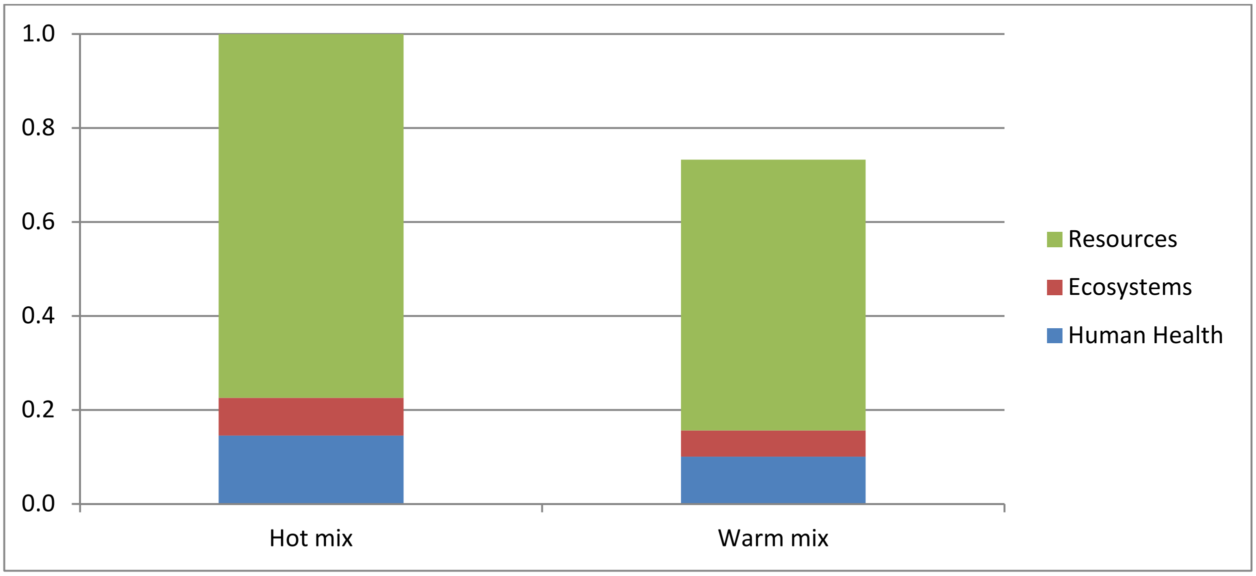

Figure 15 – Normalized, weighted results for the comparison between hot mix and warm mix asphalt in road top layer. Impact on damage areas are assessed with ReCiPe for different lifetimes of hot mix and warm mix.

In Figure 16, scenario b in comparison 2 is presented. It shows the results for hot mix compared to warm mix asphalt in road top layer when the same lifetime is assumed.

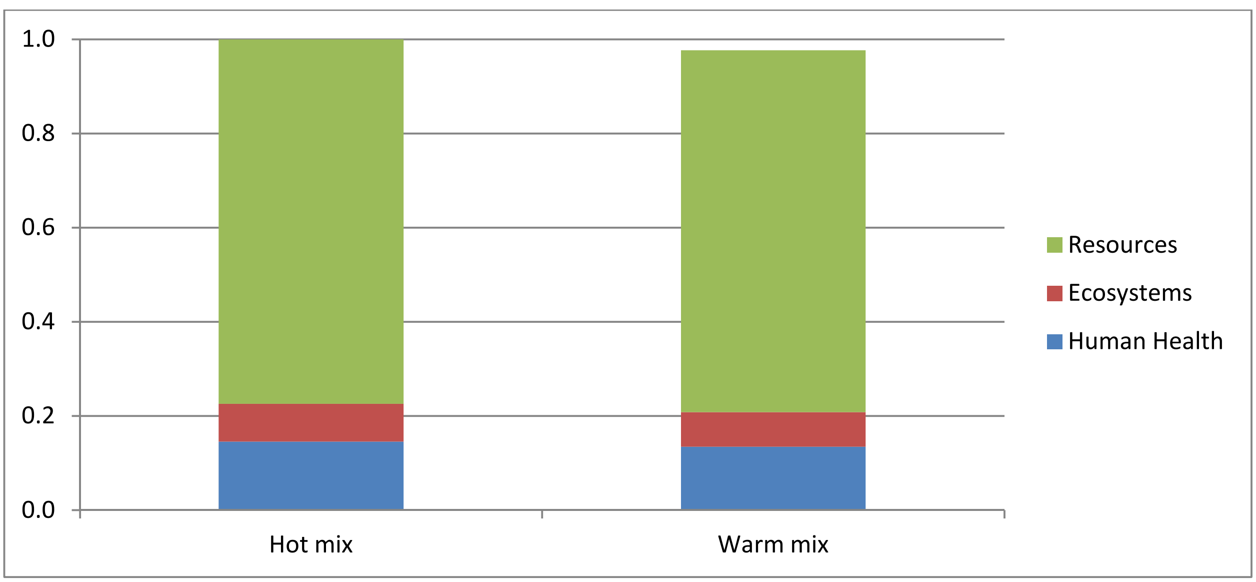

Figure 16 – Normalized, weighted results for the comparison between hot mix and warm mix asphalt in road top layer. Impact on damage areas are assessed with ReCiPe for same lifetimes of hot mix and warm mix.

Contributors to the environmental impact in the life cycle of asphalt with EEA weighting

In the life cycle of a hot mix road, contributors to the total environmental impact can be divided into the sources: aggregate, bitumen, energy carriers and transportation. For a warm mix, Rediset is added to the contributors. Figure 17 shows how much the different sources contribute to the total environmental impact for warm mix when EEA weighting has been applied. The result were extracted for warm mix with a lifetimes of 12 years, however because of the normalization, the graph would be the same for road of warm mix lasting 15 years. Figure 17 therefore describes the sources of the environmental impact for the life cycle of warm mix in both Figure 12 and Figure 13.

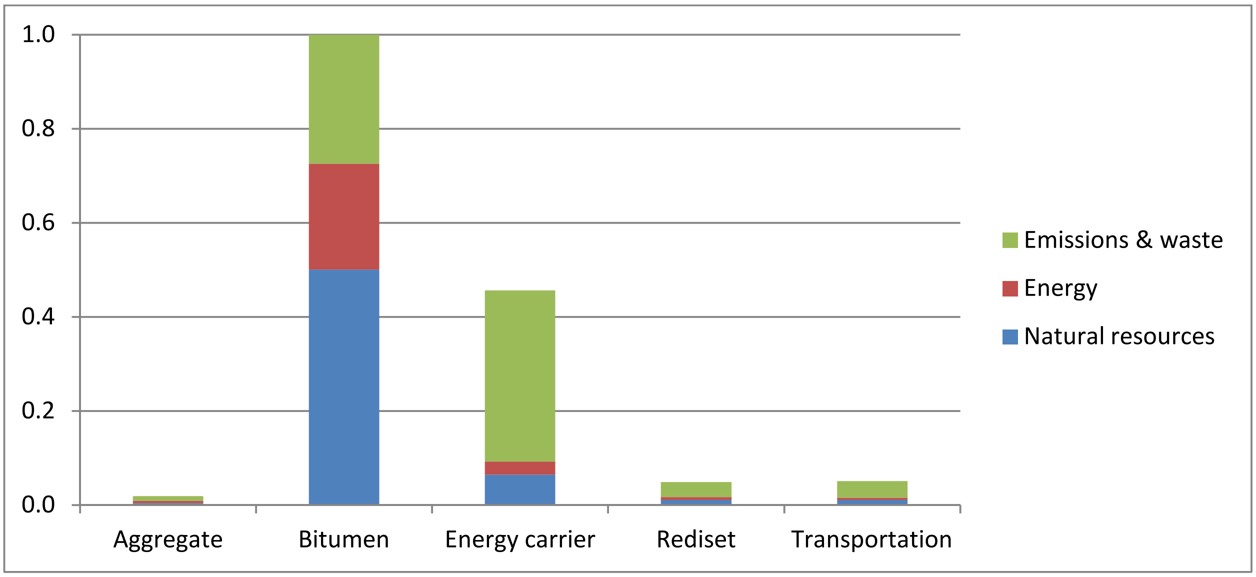

Figure 17 – Sources of the total environmental impact of warm mix asphalt.

Figure 18 describes the sources of the environmental impact for the life cycle of hot mix found in Figure 12 and Figure 13.

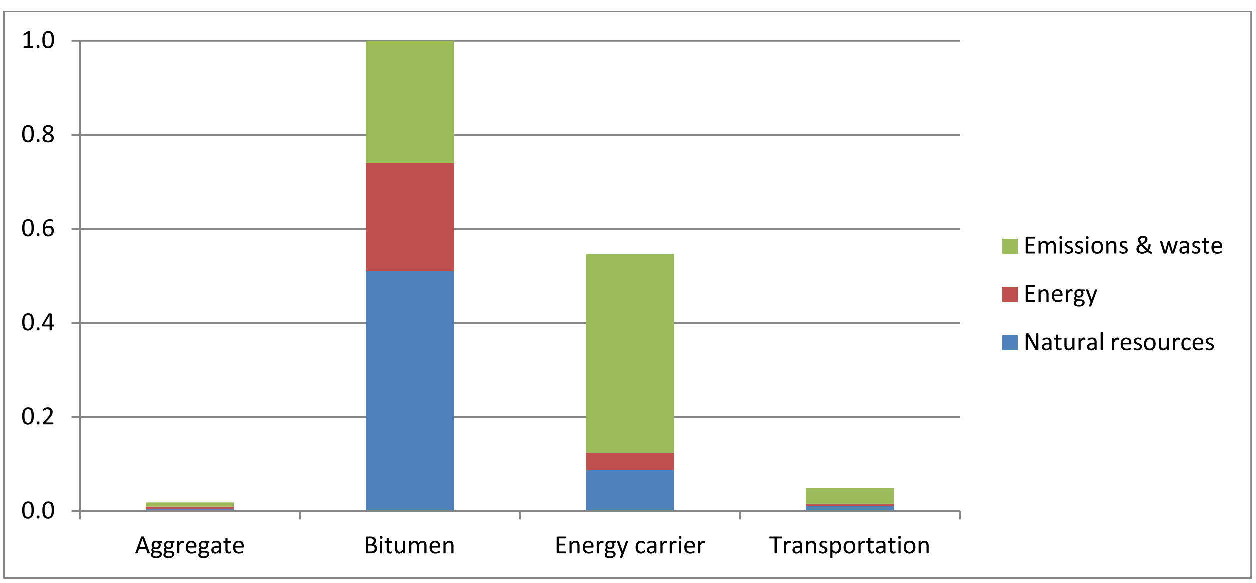

Figure 18 - Sources of the total environmental impact of hot mix asphalt.

Contributors to the environmental impact in the life cycle of asphalt with ReCiPe weighting

The contribution to damage areas in the life cycle of asphalt using the method ReCiPe is caused by, aggregate, bitumen, transportation and energy carriers, such as fuel for heating and electricity. Also in this case, Rediset is an additional source in the case of warm mix. Figure 19 and Figure 20 show the normalized results for sources contributing to damage areas using the weighting method in ReCiPe for warm mix and hot mix asphalt respectively.

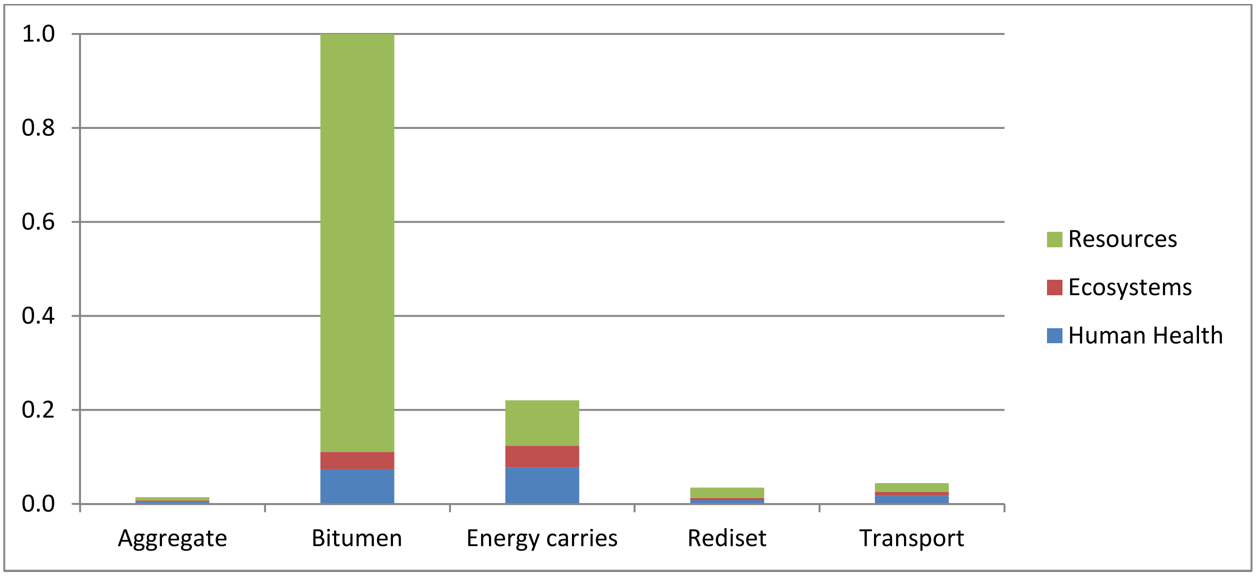

Figure 19 – Normalized results for sources of contributions to damage areas of warm mix asphalt using ReCiPe.

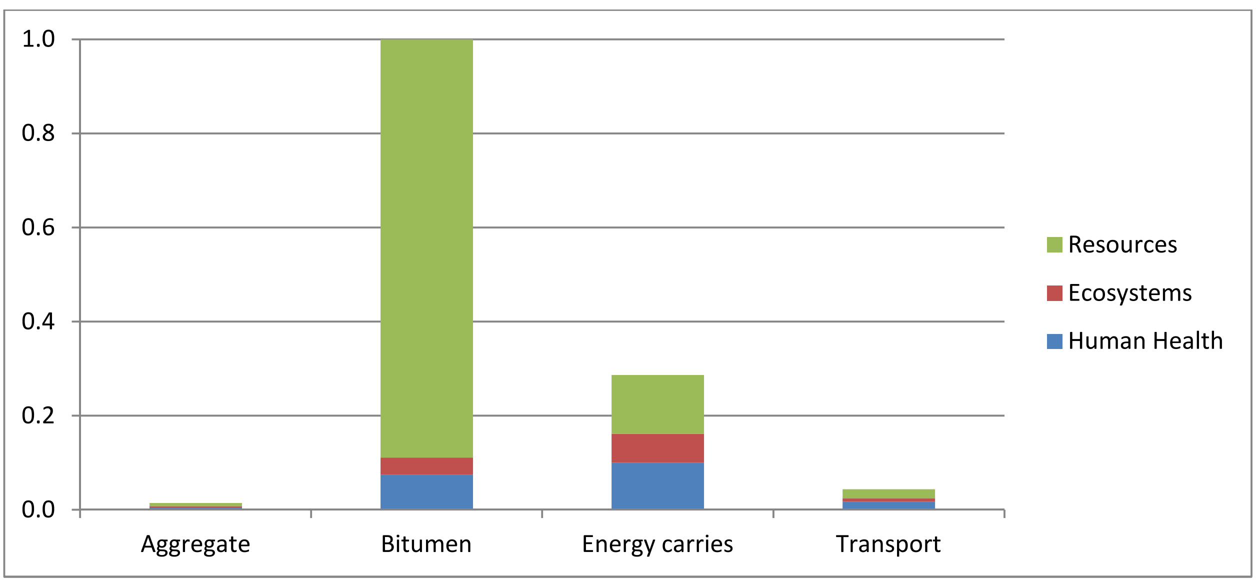

Figure 20 - Normalized results for sources of contributions to damage areas of hot mix asphalt using ReCiPe.

3.4 Case study discussion

The choice of functional unit together with the life expectancy of the road determines how many times the top layer of the road needs to be replaced. With a 12 year life expectancy for hot mix, and a 15 year life expectancy for warm mix, the road has to be replaced three times and twice, respectively. If the functional unit would be 1 km of road for 20 years, the number of replacements would be the same for the two alternatives and the result for the environmental impact would be equal to the result described by Figure 13 and Figure 16. However if the functional unit would be 1 km of road for 80 years, the number of top layer replacements and consequently also the environmental impact would differ even more for hot mix and warm mix with different lifetimes in the favor of warm mix. If the roads however have the same lifetimes, the same amount of asphalt mix, 6424 ton, in total is required for each of them. The resource consumption, emissions and total environmental impact of the two alternatives, would then be the same as the result in Figure 13, which have similar impacts because the same amounts of asphalt are compared. However, due to the choice of functional unit as 1 km of road for 40 years and combining this with a case with life expectancy for the warm mix of 15 years, the road will be paved one time less in the case of using warm mix. This means that the comparison is made between 6424 ton hot mix and 4818 ton warm mix, when the lifetime of warm mix is 15 years.

In comparison 2, for the scenario where the lifetime of the two asphalt mixtures are the same, the saving in environmental impact appears to be small for using warm mix instead of hot mix (see Figure 13 and Figure 16). This is a consequence of the large environmental impact from bitumen (see Figure 17 - 20). The data set for bitumen uses allocation of the environmental impact based on net calorific value. Allocation based on a physical value, such as net calorific value, is in general to prefer instead of an economic value. However, since bitumen is not used for heating, the net calorific value may not be an appropriate base for allocation in this case. If an allocation based on economic values of the different fractions of crude oil would be applied, the environmental impact of bitumen might become smaller. This would result in that the saving of environmental impact by using Rediset in comparison 2 would be somewhat larger. However, if the allocation with net calorific value of bitumen is used together with the scenario of the same lifetimes, some factors should not be forgotten. To start with, the scenario works as a worst case scenario, tests carried out implies warm mix to last longer than hot mix. Secondly, this worst case scenario shows that warm mix contributes to an improvement in environmental impact, even though it is small. Further, Rediset contributes to many other benefits in the process of producing asphalt and paving roads. Health benefits for the personnel manufacturing and paving the road and environmental benefits in terms of decreased exposure of fumes is one example and improved cohesion strength of the asphalt is another. Due to the improved cohesion strength, and that this is rare amongst warm mix application additives, Rediset has a large advantage compared to other additives. If however the scenario where the lifetime is longer for warm mix turns out to be true, the differences in environmental impact is large (see Figure 12 and Figure 15). Additionally, assessment of the small system of comparing the environmental impact of Rediset with environmental impact saved when using Rediset (in terms of oil saving) is large (see Figure 11 and Figure 14).

Problem areas in LCA about allocation, data, system boundaries and local environmental uniqueness also need to be discussed. Allocation is not occurring as a problem in this study due to the use of already allocated data from a reliable data base. Data, however, has in some processes been difficult to verify. Process specific data is only possible to collect from one site, making it impossible to compare with other sources. With regard to system boundaries, choices are complicated. For this study, the system could also have included recycling or disposal of the road. The result of including recycling or disposal would show, in the case of large environmental impact, that it is even more important to have a road with longer lifetime. On the other hand, if the impact would be small, the addition of Rediset to warm mix would still be important because the impact from Rediset is still less than the impact avoided from saving of oil in the heating process. Adhesion promoters could also have been included in the study, making the result of comparison between hot mix and warm mix even better.

In a system where a different energy carrier would be used, the result might change slightly. Looking at Figure 11, about 30 percent of the total environmental impact comes from natural resources. If for example wood would be used for heating instead of oil, the natural resource part would change. For wood to be better in that perspective, a sustainable forestry, which is a matter of definition, would be necessary. The energy part would be similar due to that the same amount of energy is required in both cases. The emissions and waste part would be significantly lower due to a lower carbon footprint,[14] and carbon footprint being a large contributor.

Local environmental uniqueness and spatial variation, is a problem in LCA. The problems can be solved by using specific weighting factors for different areas. That solution is however not considered in this project. Sweden is the country of study due to that the possible production of Rediset in the future may take place there. However, it would be interesting to assess a road paved in other parts of the world where the transportation distance for Rediset is longer and perhaps also the transportation distance for aggregate is longer.

Two different weighting methods are used to interpret the life cycle inventory results. In a comparison between the weighting methodology in EEA and ReCiPe (compare Figure 12 to Figure 15, and Figure 13 to Figure 16 etc.) the differences are not significant. The two weighting methods both indicate benefits of using Rediset in warm mix, compared to hot mix. Further, if one weighting method is to be chosen in future work of quantifying environmental benefits, it is important to understand how the method works. How the method uses characterization and inventory result are important. A recommendation in general is for a company to not change weighting method in a short time. Instead, if one method is used from the beginning and there is a reason to use a different method, both can be used during a period of time.

Area use, risk and toxicity assessment

Even though area use, risk and toxicity are not part of the quantitative assessment, some aspects are still worth discussing. For Rediset, land use is qualitatively assessed to be small since the use of materials which require land are low (Andersson Halldén, 2012). Additionally, Rediset is a very small part of the asphalt mix. The road itself occupies a large area of land that would be occupied even without Rediset. In a comparison between the land occupied by roads and the area required to produce Rediset, the estimations would indicate that the area use of Rediset is negligible. With regard to risk, there is no indication a road from warm mix implies a larger risk than a hot mix asphalt road. For toxicity, a risk assessment of toxicity is based on level of exposure and actions taken to reduce risk of exposure in a life cycle perspective. Rediset is classified as corrosive, sensitizing and toxic to aquatic organisms. However, the risk of causing harm by toxicity when using Rediset in asphalt is controlled since exposure to humans and environment is very low (Dihne, 2012). Rediset is already in use in some test areas, and a detailed risk assessment will be completed during 2013 (Dihne, 2012).

[14] Most of the CO_2 from biomass fuel is biogenic.

3.5 Case study conclusions

The assessment shows, in terms of environmental performance, that warm mix is the most preferable way to pave 1 km of road for 40 years. This is regardless choice of perspective in this study; lifetime expectancies are varied and comparison is made for the whole life cycle or only comparing impact from Rediset cradle-to-gate to impact from oil saved (see Figure 11, Figure 12, Figure 13, Figure 14, Figure 15 and Figure 16).

In the comparison of positive versus negative environmental impact of using Rediset (comparison 1), the positive impact clearly outweighs the negative impact. However, great differences are not visible in the comparison of warm mix and hot mix with the same lifetime expectancy. This is due to that bitumen contributes to the total environmental impact to a large extent (see Figure 17 - 20). However, in the scenario where warm mix has high durability and the road replacement process takes place more seldom, the differences between adding Rediset or not, are significant.

The recommendation to quantitatively assess the downstream consequences of using EPS is the following:

- Assess the Eco-premium and mainstream solution from cradle to grave with LCA
- Use weighting to make results easily comparable, apply preferably at least two different weighting methods for the sake of credibility
- Compare the results for the environmental impact in the categories assessed
- If the results are going to be public and not only for internal use, make a product brochure describing clearly why the solution has been found to be Eco-premium

The case study shows that the suggested approach serves the purpose of comparing EPS quantitatively. It is not to be forgotten that further work in the field of toxicity, risk potential and area use may be added to the model when assessing impacts. Additionally, many of the uncertainties remain when using a quantitative method for the EPS assessment. However, in future work, the LCA method can be further improved.

EPS is very similar to methods used by other companies. To tell whether one is better than another is not possible, however EPS does not miss anything that the other methods include.

Communication of results from quantitative studies of EPS in terms of a product brochure could be introduced. SKF presents their BeyondZero products in product brochures describing the product's benefits compared to mainstream technology, which also would be possible for AkzoNobel to do. A product brochure for Rediset could look like the one in Appendix 3. However, a third part evaluation would be good to make the assessment credible.

3.6 Future work on Rediset and warm mix

The aspects of area use, toxicity and risk potential could in future work be assessed in more detail for warm mix and hot mix, to get a more complete quantitative picture of EPS. More aspects to consider when a road is paved and ready to run tests on are noise and grip, tearing of tyres and fuel consumption, which depend on whether the friction is affected by Rediset or not. Additionally, sustainability aspects like how the road affects biodiversity, corridors for wild life, risk for accidents and brightness of the asphalt (need for lightening) might be assessed.

An evaluation of the economic perspective would also be interesting for future studies. For example, an assessment of how long a road from warm mix needs to last compared to hot mix before the cost of Rediset is repaid. An assessment of how social aspects are affected would in addition also be good.

4 Conclusions and recommendations

To be able to improve a product's sustainability performance, environmental impact has to be measured. Qualitative EPS is a useful method for internal use. However quantitative EPS is even more useful because of the possibility to get even more detailed results on the environmental impact. Unfortunately, to measure all EPS' environmental impact quantitatively is not possible due to the large amount of work it implies. However, applying quantitative EPS on strategically important products (that for example represents a group of products) to get an overall picture can give insight in which parts of the system that are contributing to environmental impact to a high or low extent.

In an assessment of a large system consisting of many different processes with different raw materials and energy sources, there are many contributors to the total environmental impact and damage areas. A mindset of that a product is not EPS in a life cycle perspective if the savings are less than 10 percent may be bad for the overall saving in environmental impact. In the worst case scenario (scenario 2.b) the saving is about 5 percent, however in absolute numbers that is a great saving. The approach in scenario 1 where the environmental impact for the additive is calculated and compared to the savings it contributes to is good to make the change in environmental impact visible. However, comparison 2 gives a valuable insight about how important a life cycle perspective is in order to get the whole picture about what is large and small.

5 Future research in the field of downstream environmental consequences

To further develop the method of quantitative EPS, more aspects needs to be taken into account as well as additional tools for addressing the problems that LCA do not cover. Interesting to see would be methods like quantitative EPS to become available for and used by other companies. Collaboration between companies in the same value chain is necessary when assessing the downstream potential benefits would be possible which would be a gain from an environmental perspective. Additionally, more research to develop methods and tools for environmental consequences, would be beneficial.

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Color photo at front page have kindly been provided by photographer Bruce Dale. Permission to use the picture was granted via e-mail. See more of his photos at: http://v1.brucedale.com/Roads/index.htm.

Appendix 1 – Additional results from the case study

In chapter 3.3 results are presented for the case study. Additional results for contributing sources to environmental impact for Figure 11 to Figure 14 are presented in Appendix 1.

Contributions to the total environmental impact for comparison 1 assessed with EEA
Natural resources that give the contribution to the total environmental impact in Figure 11 are shown in Figure 21.

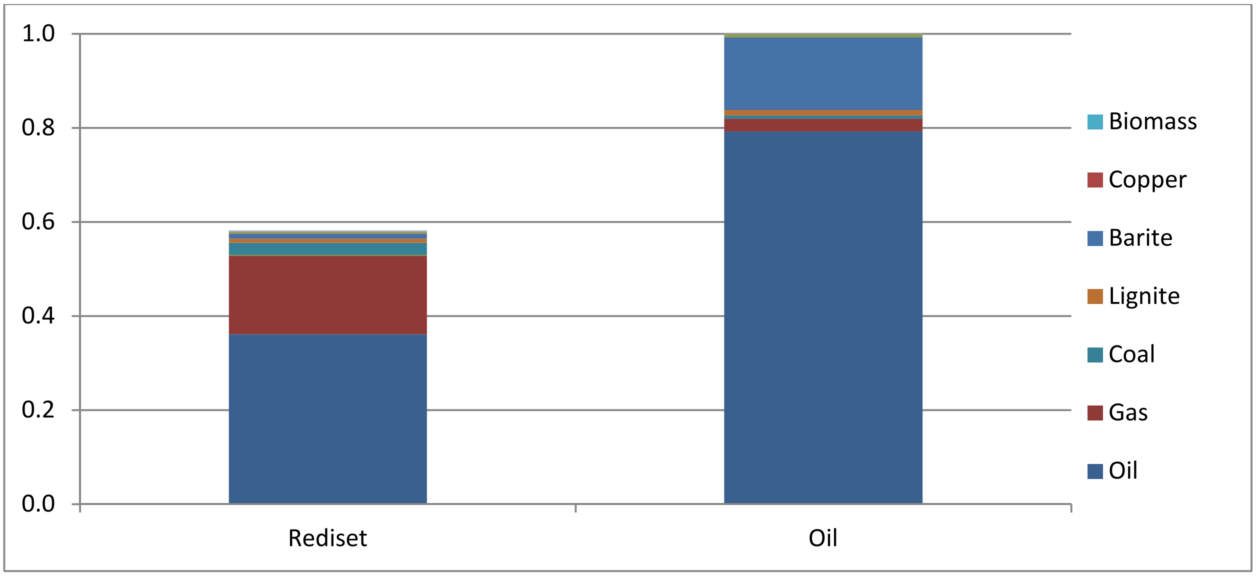

Figure 21 - Normalized resource consumption for Rediset cradle-to-gate compared to the oil saved.

The sources of primary energy that give the contribution to the total environmental impact in Figure 11 are shown in Figure 22. Additionally, how much primary energy that is used is expressed as normalized result.

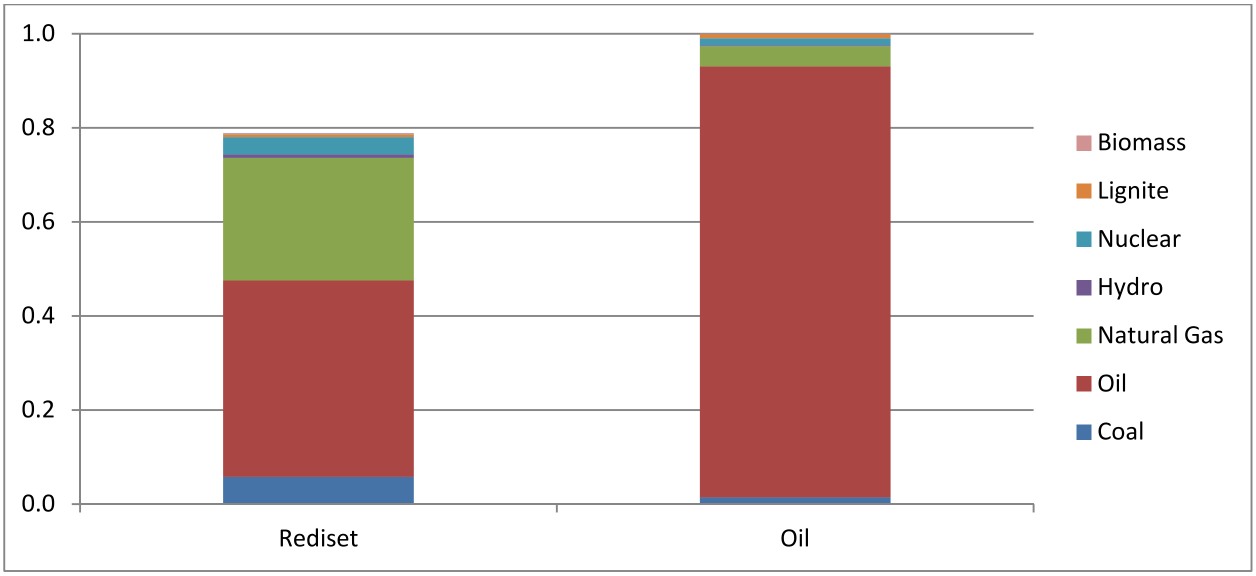

Figure 22 – Normalized results for the primary energy use in comparison between production of Rediset cradle-to-gate and saving of oil that would have been consumed in hot mix.

The emissions that contribute to the total environmental impact in Figure 11 are shown in Figure 23, divided into water emissions, air emissions and waste.

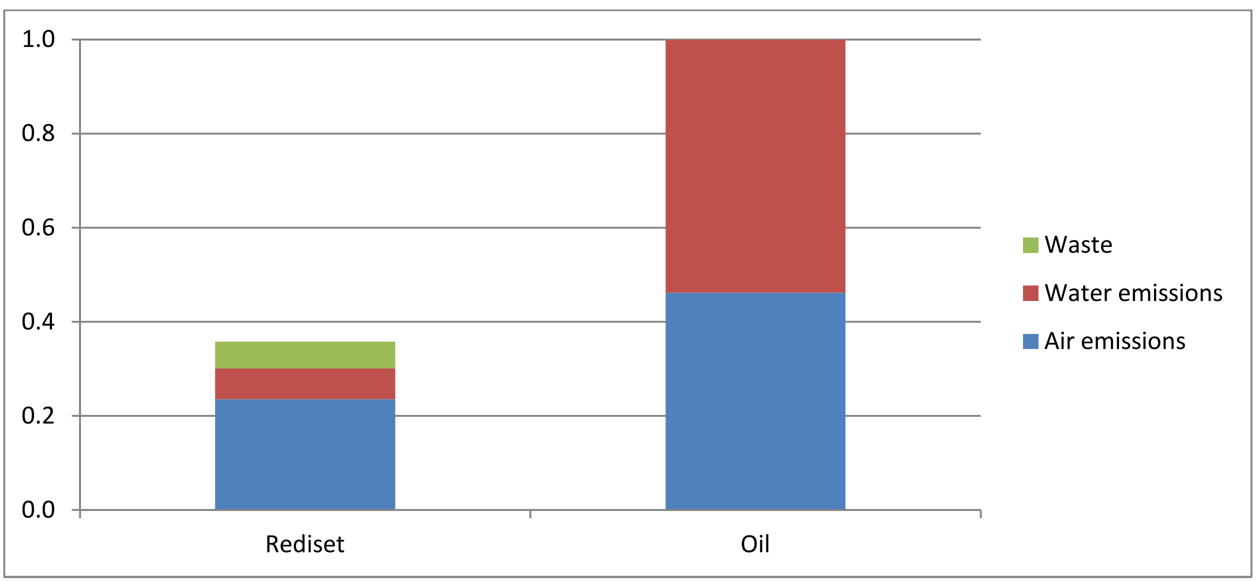

Figure 23 - Normalized results for the different types of emissions and waste in comparison 1.

Contributions to the total environmental impact for comparison 2.a assessed with EEA

The main natural resources used in hot mix and warm mix contributing to the total environmental impact in Figure 12, is shown in Figure 24.

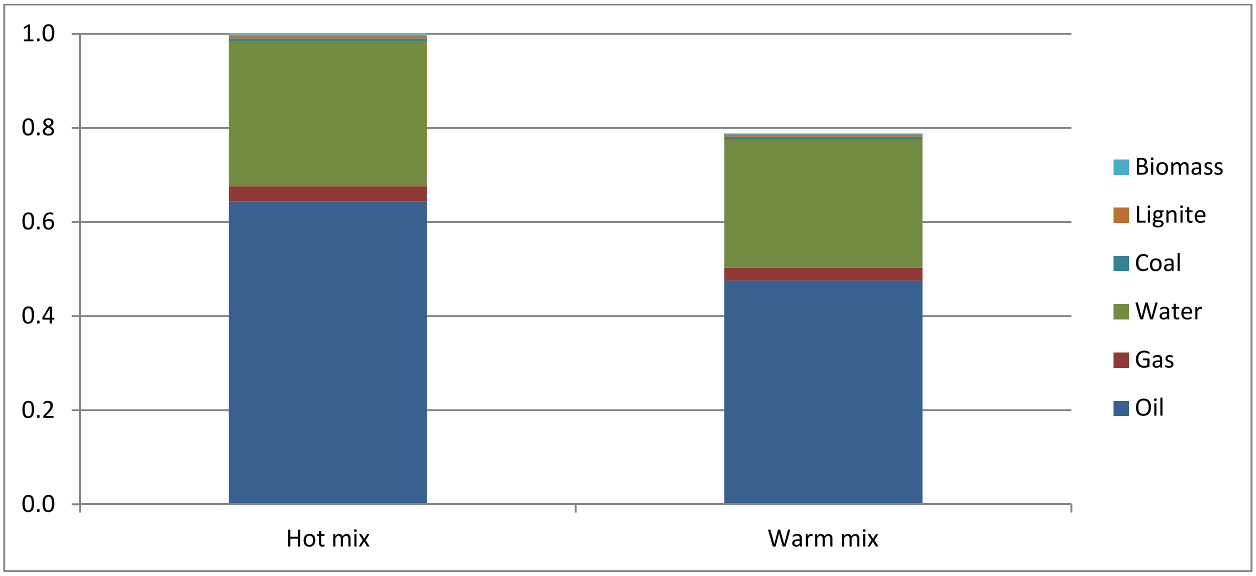

Figure 24 - Normalized resource consumption for 1 km asphalt road for 40 years made from hot mix and warm mix asphalt in the scenario where warm mix has a longer lifetime compared to hot mix.

The sources of primary energy that give the contribution to the total environmental impact for hot mix and warm mix in Figure 12 is shown in Figure 25.

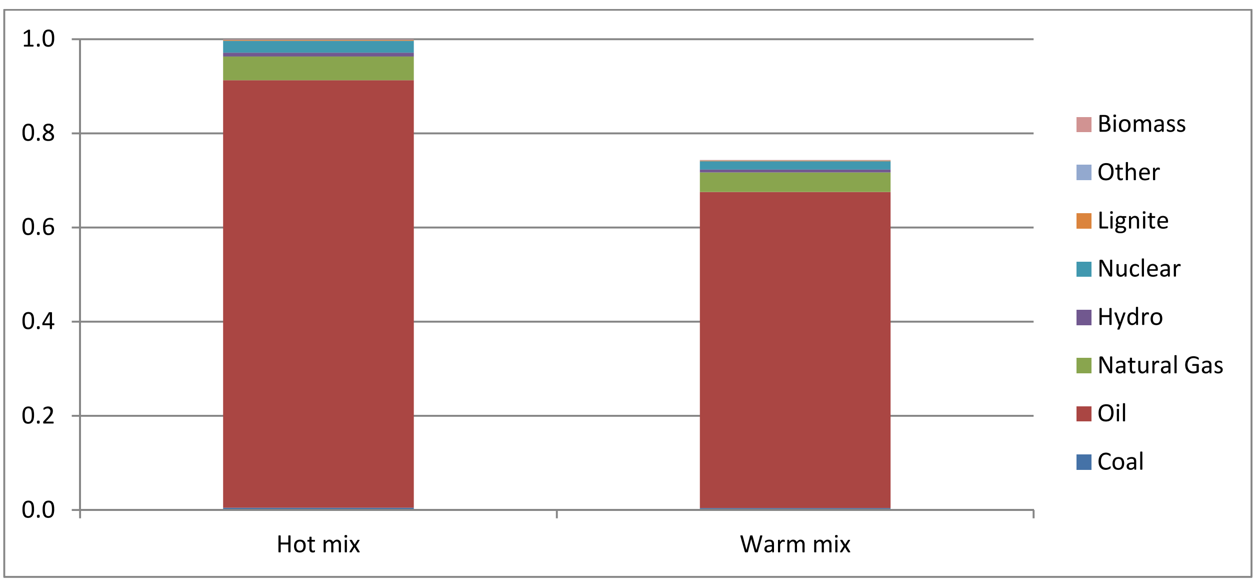

Figure 25 - Normalized results for the primary energy use in comparison 2.a.

The emissions that contribute to the total environmental impact for hot mix and warm mix with different durability, are shown in Figure 26, as well as if the emissions go to water, air or waste.

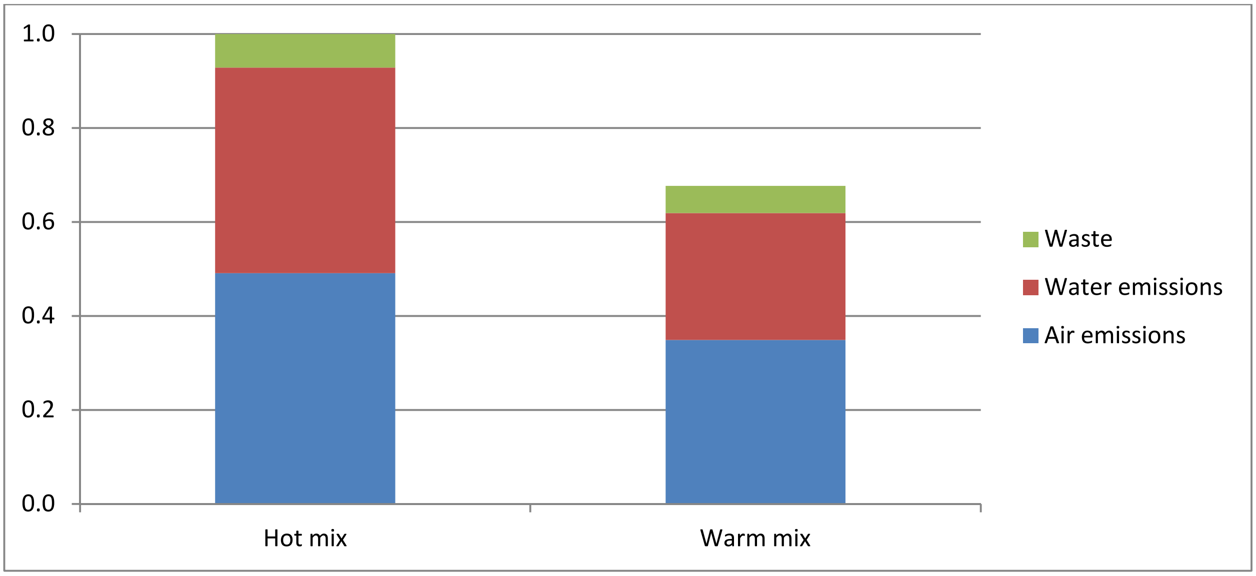

Figure 26 - Normalized results for the different types of emissions and waste in comparison 2.a.

Contributions to the total environmental impact for comparison 2.b with the weighting method in EEA

Contributions to the total environmental impact in scenario b in comparison 2 are shown in Figure 27 - Figure 29. Figure 27 presents the resource consumption in hot mix and warm mix contributing to the total environmental impact in Figure 13.

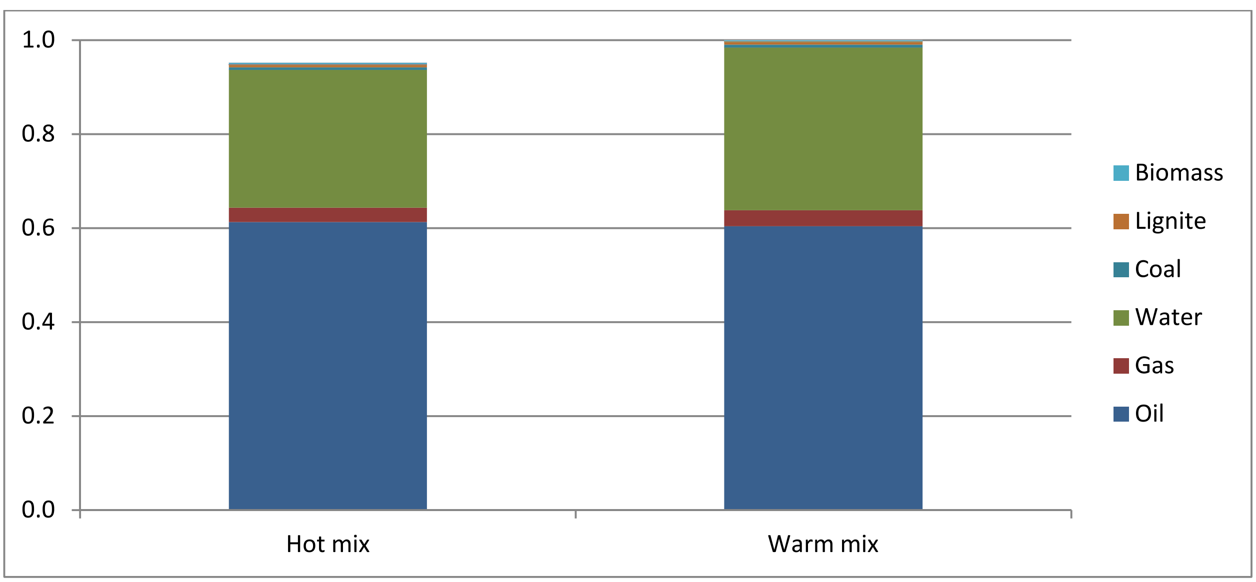

Figure 27 - Normalized resource consumption for 1 km of asphalt road for 40 years in comparison 2.b (same lifetime).

The sources of primary energy that contribute to the total environmental impact for hot mix and warm mix in Figure 13 is shown in Figure 28.

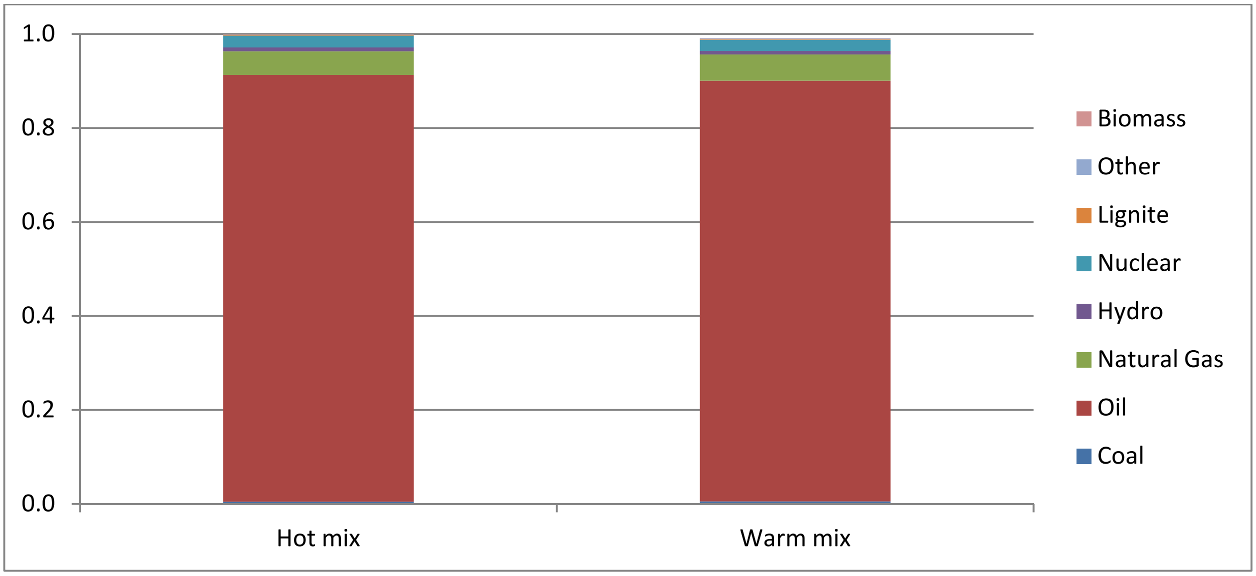

Figure 28 - Normalized results for the primary energy use in comparison between production of 1 km asphalt road for 40 years made from hot mix and warm mix with the same lifetime.

The emissions that contribute to the total environmental impact for hot mix and warm mix asphalt with the same lifetime in Figure 13 are shown in Figure 29, as well as if the emissions go to water, air or waste.

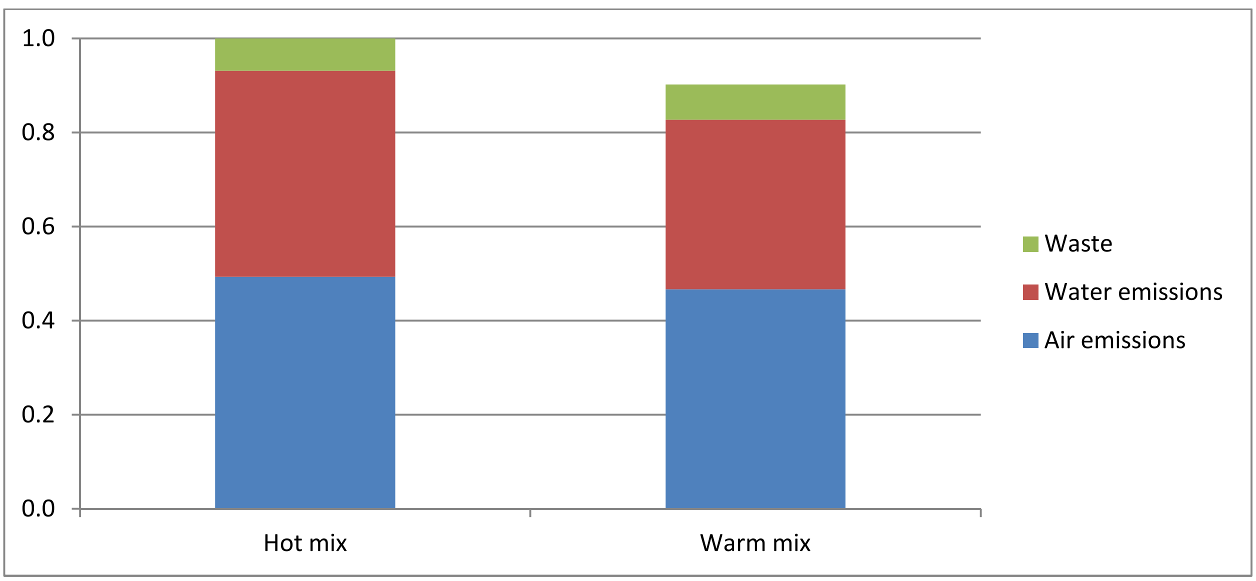

Figure 29 - Normalized results for emissions and waste for the production of 1 km asphalt road for 40 years made from hot mix and warm mix in the scenario where warm mix and hot mix have the same lifetime.

Appendix 2 – Model data for Rediset WMX

The data in appendix 2 are not published in this public version.

Appendix 3 – Product brochure of Rediset WMX

A proposal to communicate results of a quantitative EPS is to perform a product brochure. An example of a brochure for Rediset is presented below.

2012-07-25

Annica Isebäck

Eco-premium solutions

Rediset WMX

Environmental benefits

- Reduced CO_2 emissions
- Reduced energy use
- Reduced amount of fumes

Rediset WMX solutions make it possible to reduce the energy use and consequently the CO_2 emissions in the road construction industry

Rediset WMX solution is an additive to asphalt added in the process in which components in asphalt are heated to create a compact mixture resistant to moisture. Conventional asphalt is heated with light fuel oil to a high temperature. With Rediset VMX solution added, the temperature demand is decreased and consequently also the amount of oil consumed in the process.

Compared to asphalt without additive, Rediset WMX reduces the energy demand in the heating process with approximately 20 percent. In the comparison between the production of Rediset WMX and the light fuel oil saved when using Rediset, a reduction of CO_2 emissions equal to more than 60 % is calculated.

A consequence of heating the asphalt mixture to a lower temperature is that a reduced amount of fumes is created. Personnel manufacturing and paving roads, as well as the adjacent environment, experience a decreased exposure of fumes compared to asphalt not using Rediset WMX.

AkzoNobel
Tomorrow's Answers Today

Operational benefits

- Compatible with current equipment
- Easy to add
- May improve lifetime of roads

Lower temperature demand before paving roads

Rediset makes compaction of asphalt with lowered temperature possible in existing equipment

A key factor in determining strength and durability of paving is the ability to compact the asphalt mix. Conventional asphalt needs to be heated in order to become compact and to resist water intrusion. With Rediset WMX solution, the asphalt becomes compact at a lower temperature. Rediset WMX solution is added to the asphalt mix in the current equipment already in use.

The cohesion strength of the asphalt is improved due to stronger chemical bonds in the asphalt mix. This is an indicator that asphalt mixture with Rediset WMX products gives roads with longer life-length. A road which lasts longer does not have to be replaced and maintained as often as others, and plenty of work and environmental impact caused by maintenance and paving are avoided.

AkzoNobel
Tomorrow's Answers Today