Life Cycle Assessment

Asphalt-, and concrete pavement

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ABSTRACT

Life Cycle Analysis (Life Cycle Assessment, LCA) examines the potential impacts on the environment in a process, product or service during its entire life span. Our study is within the field infrastructure for road transport, where we have compared asphalt and concrete pavements. The implementation of a specific road transport facility is recognized to have positive economic and social impacts. However, it is also having significant effect on the natural environment during its entire life, both directly or indirectly. These effects appear in the design, construction, operation and during reclamation, so their importance are essential.

The two most commonly used pavements in the world are asphalt and concrete (EAPA). There are notable differences between them, from both a financial, material, volume, and life-time perspective. Sometimes the conditions don't allow stakeholders to choose between the two options, due to specific requirements on e.g. natural soil, function of the pavement, and traffic load. But in some cases both both asphalt and concrete pavement are possible. Out study should be seen as a decision making tool, which entities can use as a support in the decision making process.

Our functional unit is to produce a 6 lane highway, with [W*L] dimension 21 * 1000 m and a life span of 40 years, with 140,000 vehicles per day.

To compare the pavement types, we need to built a cradle-to-grave SimaPro model for both asphalt and concrete. The flowchart includes raw materials, production, construction, use, maintenance and waste management. To assess the study, we chose the ReCiPe Midpoint (H) method in SimaPro, which includes impact categories such as climate change, human toxicity or metal depletion. Although we chose to focus on natural land transformation climate change.

From this study we expect to have a better understanding of which impact categories asphalt and concrete pavement have on the environment. The result is also expected to provide a reference tool for decision makers, when planning and constructing a sustainable road infrastructure.

Keywords: LCA, asphalt- and concrete pavement, SimaPro model, decision support

Dictionary and abbreviations

LCA – Life cycle assessment

EAPA- European Asphalt Pavement Association

ACPA - American Concrete Pavement Association

JPCP - Jointed plain concrete pavement

JRCP - Jointed reinforced concrete pavement

CRCP - Continuously reinforced concrete pavement

Dowel – Steel reinforcement bar

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Introduction

During the past decade, transportation by land has transformed the way we move and produce our goods. A growing population, in primarily urban areas, forces us to build better and more durable traffic network for our everyday travels, and it requires us to think and act in accordance with the environmental boundaries. In this study, we wish to compare the full life cycle of asphalt-, and concrete pavement. Both types are frequently used in various networks and situations all over the world, and it is therefore vital to know what the environmental impact it will have during a specific time period. By doing such investigation, it will be possible for stakeholders to choose an alternative that promotes a balance between financial-, environmental-, and social sustainability.

Background

Asphalt

In the Cambridge dictionary, asphalt is defined as: "a black, sticky substance, often mixed with small stones or sand, that forms a strong surface when it becomes hard".

We can find deeper information about it in the website of European Asphalt Pavement Association (EAPA, 2016).

When we travel to work or school, or doing our shopping we can find asphalt roads, it belongs to our everyday life. Asphalt is used in roads, railway beds, airport runways, taxiways, bicycle paths, playgrounds, running tracks, tennis courts, barn floors, greenhouse floors, ports, bridges, tunnels, landfill caps, etc. But what is asphalt made of? Asphalt is a mixture of binder (bitumen), filler (limestone) and aggregates (crashed rocks, gravel and sand). There are many types of asphalt, each having specific characteristics; some are designed to be porous and very silent, waterproof or colored. They can also be produced in different ways; hot, warm, half warm or cold.

Concrete

Concrete pavements are also used for all types of pavement as roadways, highways, parking facilities, industrial facilities and airfields (PCA, 2016). Typically, when there are heavy traffic and heavy vehicles as well. The concrete is a mixture of 60-75% aggregates (coats the surface) and paste, what is usually 10-15% Portland cement and 20% water. The mixture also contains 5-8% air. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. It is also featuring reinforcing steel to keep cracks tight between the joints.

Concrete pavements have been refined into three primary structural types (ACPA, 2016):
Jointed plain concrete pavement (JPCP)
Jointed reinforced concrete pavement (JRCP)
Continuously reinforced concrete pavement (CRCP)

Literature review

Asphalt

As mentioned, asphalt is a mixture of different materials and it is produced in an asphalt plant. This can be a fixed plant or even in a mobile mixing plant (EAPA, 2011). The capacity is up to 800 tons per hour. The average production temperature of hot mix asphalt is between 150 and 180°C, but new techniques are available to produce asphalt at lower temperatures. Different temperature means different amount of energy use and CO_2 emission during the mixturing.
Normally, pavements are made of different layers. Starting at the road surface, the first layer is called the surface course, second layer is mostly called the binder course and the lower layers are the base courses.

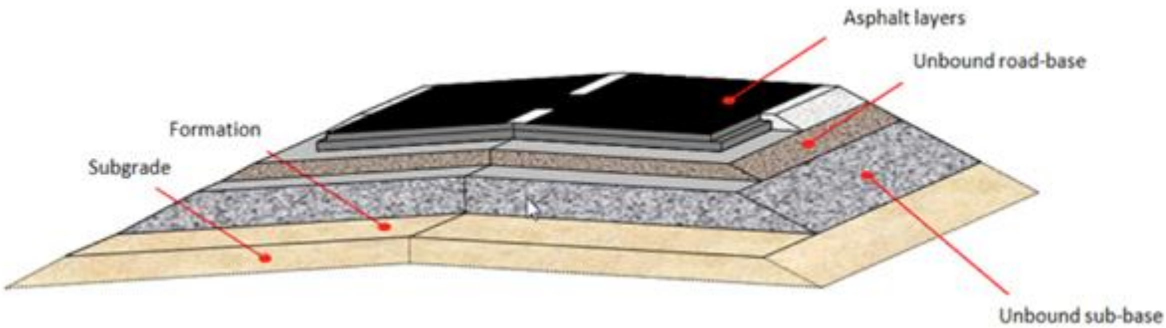


Figure 1: Asphalt pavement layers (EAPA, 2011)

Since asphalt is the most common used material in road networks in Europa (EAPA, 2011), our group wanted to compare asphalt and concrete. During our literature searching we could find several studies about asphalt LCA like:

- *Sofia Miliutenko - Consideration of life cycle energy use and greenhouse gas emissions for improved road infrastructure planning* (Miliutenko, 2016)
- *Ali Azhar Butt - Life Cycle Assessment of Asphalt Roads* (Butt, 2014)
- *Håkan Stripple - Life Cycle Assessment of Road* (Stripple, 2001)

The first and second document are doctoral thesis written at the KTH Royal Institute of Technology. The last one is written for in co-operation with the Swedish National Road Administration, the Swedish Environmental Research Institute (IVL) has performed a basic life cycle assessment covering the inventory part for road construction, road maintenance and road operation.

Sofia Miliutenko - Consideration of life cycle energy use and greenhouse gas emissions for improved road infrastructure planning (Miliutenko, 2016)
The study is focused on road infrastructure planning in Sweden and it is consists three main parts. Firstly it is assess the GHG emission and the energy use. The next part is about implementation in planning what shows how LCA can be implemented in the early stages of road infrastructure planning. In the last sections the writer is examine the opportunities of improve the method for LCA of road infrastructure.

Ali Azhar Butt - Life Cycle Assessment of Asphalt Roads (Butt, 2014)
The main aim of the study is to develop a life cycle assessment framework for the asphalt roads that could be used for decision support in the late project planning stage. The framework takes into account the construction, maintenance and end of life phases and focuses on energy and GHG emissions. The thesis is contains a standalone life cycle assessment of a typical Swedish road, examine the environmental threshold settings for the asphalt additives and evaluate the aggregate quality in a life cycle perspective.

Håkan Stripple - Life Cycle Assessment of Road (Stripple, 2001)
The study is a complete LCA of a 1 km long road what includes the extraction of raw materials, the production of construction products, the construction process, the maintenance and operation of the road and finally the reuse of the road at the end of the life what is 40 years.
The writer analyze three different type of pavement like concrete, hot mix asphalt and cold mix asphalt. The study also examine the differences between two different engine alternatives for

vehicles and machines. One type is the conventional diesel engines and the other one is a modern low emission diesel engines.

Concrete

In order to have an idea of what quality can be expected of a highway concrete road, it is of importance to study the performance of existing examples. One of such being the 28 km long highway section of E6 close to Falkenberg, southwest coast of Sweden (Dolk, et al., 2011). The climate of Falkenberg is comparable to the one of Södermanland, emphasizing the high number of freeze and thaw cycles during winter, demanding a high quality pavement withstanding the stress.

After 20 years of use, the wear caused by studded tires is measured to be 5 mm, which is a relatively insignificant damage (Dolk, et al., 2011). However, the major issue with this kind of pavement is the risk of longitudinal faults. This is partly thought to be an issue of reinforcement bars (dowels), either being absent or placed incorrectly; the latter reducing load transfer and acting as a crack inducer.

To limit the cracks occurring, a method of applying a two-layer dowel reinforcement has been shown successful (Chen, et al., 2014). During a two-year period, no faulting has been observed on the reinforced section of highway US75 in Dallas, which has a designed life length of 18 more years. Bearing in mind that the method is new, leaving the long term performance unknown.

The main reason to deal with the cracks and faulting of concrete pavement, is the poor ride quality it can cause, which also affects the road safety (Chen, et al., 2014). In order to improve these aspects and extend the pavement service life, Full Depth Repair (FDR) is a reliable method, where damaged sections are replaced. In similar LCA studies a 4% full depth repair of the highway is assumed to be needed after 20 years of use (Santero, et al., 2011)

Figure 2: FDR performed in Texas, USA, where the road is improved with two layers of steel reinforcement in an effort to prevent future cracking (Chen, et al., 2014)

Goal and scope

Goal of the study

The goal of the study is to compare the life cycle impacts from two types of pavements for a highway road. The pavement types are asphalt and concrete, and we measure it in terms of primarily climate change and natural land transformation. Our study is meant to enlighten the emission and energy use during the whole life time.

This is an attributional comparative LCA, where we wish to compare and describe two systems as they are, and to identify the potential environmental impacts. Both asphalt-, and concrete pavement provide the same function, i.e. allowing for transportation. The next table (1) shows some of the differences and benefits between the two types of pavement.

Table 1: Asphalt vs concrete pavement (EAPA, 2011)

?	Asphalt	Concrete
Financial part-Price	Dependts on oil prices; less expensive to install initailly	More expensive to install (2x); less expensive over its service life
Life-time	Up to 15-25 years with proper maintenance	Up to 40 years with proper maintenance
Volume of needed maintenance	Requires resealing every 3-5 years	Minimal maintenance requried
Usability	Few hours later	Days later with special mic designs
Durability	Susceptible to demage in extreme temperatures	Gains additional strenght during lifetime; cracking
Other benefits	Flexible pavement mix designs can be tailored to suit heavier or lighter traffic areas	Highly rigid pavement gains 10% additional strength during its lifecycle and reduces the need for deep strength base materials
	Smooth, quiet pavement for modern high-speed roadways	Ideal choice for areas with difficult subgrade conditions and heavy loading

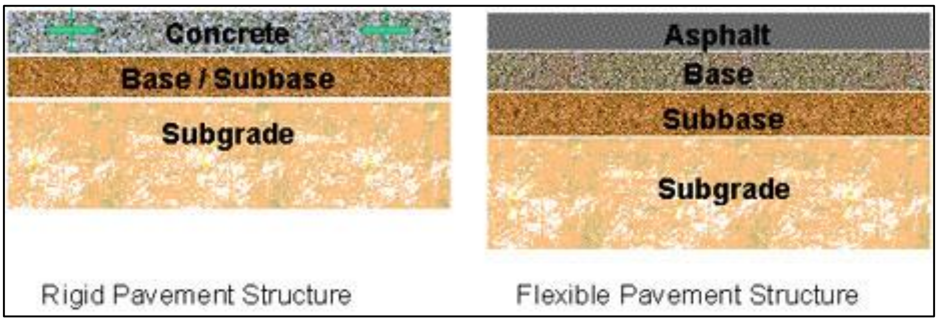


Figure 3: Typical Flexible and Rigid Pavement Layers (Concrete, 2016)

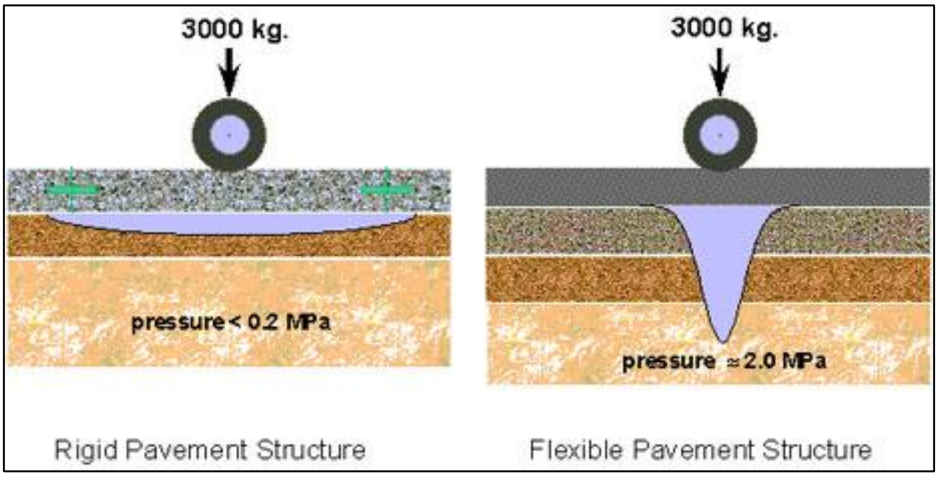


Figure 4: Typical Load Distribution For Flexible and Rigid Pavement Layers (Concrete, 2016)

Functional unit

The functional unit is a 6 lane highway, with dimension 21*1000 m and a life span of 40 years with 140.000 vehicles per day. A performance characteristic that needs to be taken into consideration is the required amount of maintenance needed for the two pavement types.

System boundaries

Our study is a comparative, attributional LCA with cradle-to-grave system boundaries. It contains the raw materials like aggregates, fillers, Portland cement and binders. After the raw materials acquisition the next level is the production as asphalt and concrete mixturing then the construction, use (maintenance) and at the end the waste management like recycle and depot or landfill placement.

The LCA includes transport of material needed for creating the pavement types. It includes construction, where energy use of machines are taken into account. Although, emissions during use phase through car and other transports, will not be taken into account. Partly because we believe that the emissions would be fairly alike, and the differences would be difficult to point out. However, during the use phase we will account for maintenance. The amount of maintenance will vary between the two types.

The simplified flowchart is the same for both type of pavement. It contains the emissions and resources. However, the detailed flowchart is not the same. The differences are in the part of raw materials, the different type of construction, maintenance, and waste management as well.

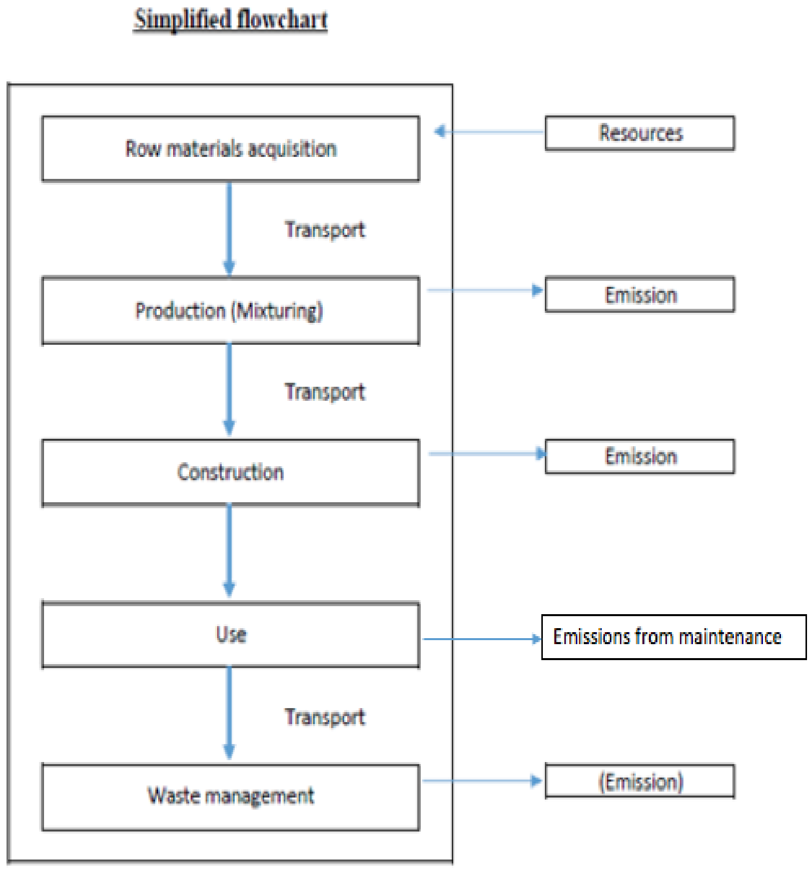


Figure 5: Simplified flowchart for asphalt and concrete pavements

Geographical boundaries:

Effects of temperature, weather are some of the geographical aspects that will be important in the choice of pavement characteristics. These effect will mostly have a significant impact during use phase when water infiltrate the pavements and cracks it by freezing. We have focused on the region of Södermanland to find suitable pavements. Here we also have expertise close by for further consultation.

Time horizon:

The life time for asphalt pavement is approximately 20 years from new construction to repavement of the top layer. For the concrete it is 40 years from new construction to repavement of the road (Santero, et al., 2011). In our functional unit we have looked at it from a 40-year perspective. This means that we will in our model account for a whole repaving of the top layer of the asphalt pavement after 20 years. There are different indications regarding asphalts technical life time, but in this LCA we have used 20 years for asphalt. We will after 20 years account for a new repaving of the top layer. In real life this type of re-construction/maintenance depends on how much the pavement is affected (wear) by traffic loads, weather conditions, and new traffic requirements. However, after 20 years of using the concrete pavement there will only be a need of repairing a certain percentage, as mentioned in the literature review.

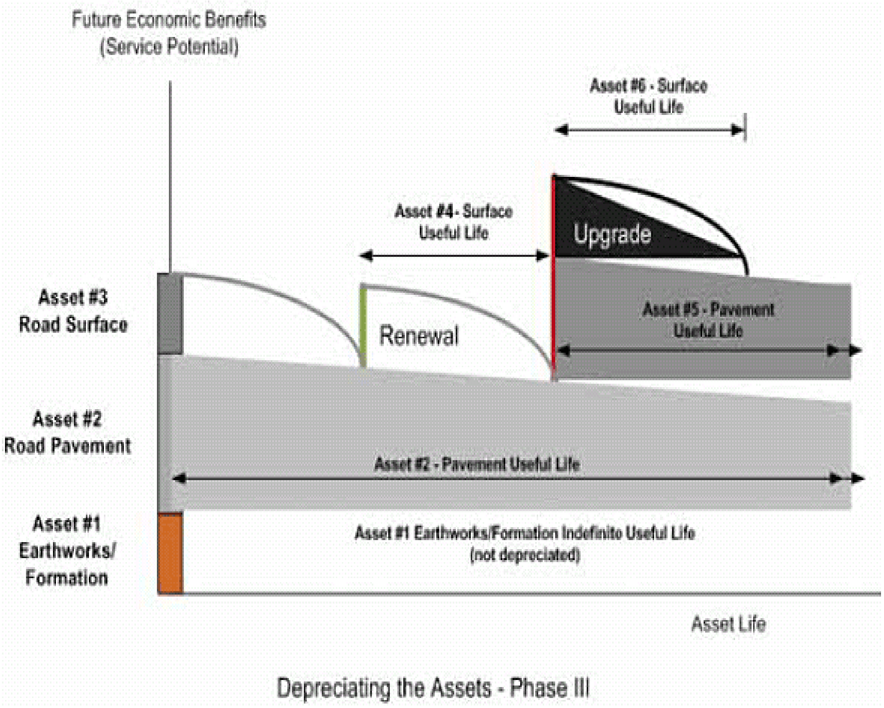


Figure 6: Asphalt pavement life in economic aspects

Flowchart

In the next page you can see the detailed flowcharts of the asphalt and concrete pavements. In contrast of the simplified flowchart, here the differences are more visible. However, you have to remark there are also differences between the use parts, what is in our case means the maintenances. We are also counting with the recycle part of the flowchart, because the asphalt pavements are recycled in 100% in Sweden, but in our study we transfer it to the asphalt plan where it will be reused in another project framework.

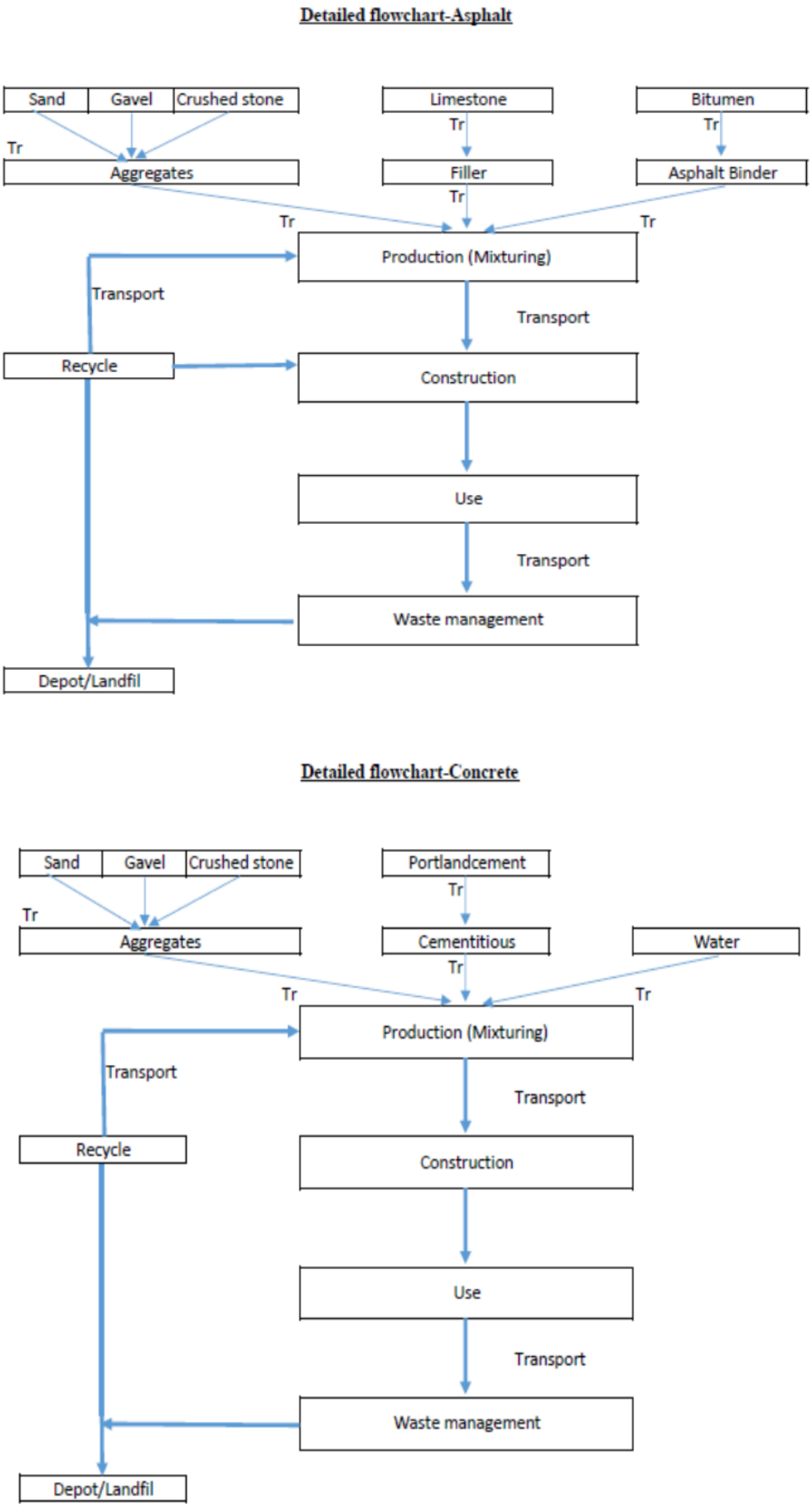


Figure 7: Asphalt and concrete detailed flowchart

Allocation

We do not need take into account any allocation.

Assumptions and limitations

A reinforcement of steel might be necessary during the construction phase of the concrete. The assumptions were that heavy vehicles may travel on the highway and therefore that this kind of reinforcement is important to take into account (140.000 vehicles per day). Moreover, we assume that FDR as maintenance is done once after 20 years and concerns 4 % of the road.

The assumption we used for transportation was a truck with the load capacity of 16-32 tons, and with a EURO4 emission classification, due to Sweden´s relative healthy transportation policies, in terms of emission standards.

During production of asphalt and concrete we used natural gas, and market group dataset. We used also used GLO, i.e. the market of markets, instead of RER, i.e. “market groups are created for convenience and ease of use”.

A transportation simplification made is that we calculate the energy use of a regular truck instead of a rotating one, for delivering the concrete paste to the construction site, as a more realistic alternative not is found in EcoInvent.

In order to place the concrete and asphalt on the road a number of machines will be needed, which are listed here together with the diesel consumption:

For Concrete:

2 Pavers = 41.6L⁄h each, 1 Tiner⁄cure machine=13.2L⁄h each, 2 Pickup Trucks = 4.2L⁄h each, 1 Small loader (CAT950size) = 26.5L⁄h

For asphalt:

(1) 1 asphalt paver=15.1L⁄h

(2) 3 rollers(if in Oregon, two anywhere else) = 17.0L⁄h

(3) 1 tack truck=26.5L⁄h

(4) 3 pickup trucks=4.2L⁄h each

(5) 1 small loader(CAT950size)=26.5L⁄h

(6) 1 small broom=17.0L⁄h

We also assumed that all materials sent for waste management will be recycled and used in another project. The assumption also includes that our project doesn't use any recycled material, i.e. only new raw materials. For waste management only transportation from the construction site to the production site is calculated.

There are a few new inventions in pavement construction which could fit to our project as well. For example, companies could use other more sustainable way for asphalt construction like Warm Mix Asphalt (WMA) instead of the normal Hot Mix Asphalt (HMA). That technology needs less energy during the mixturing part because it is not important to heat the aggregates the same temperature like HMA (180°C) just around 120-150 °C. Our study doesn't contain that type of production, but we recommend it as a topic for further studies.

Impact categories and impact assessment method

The assessment method chosen in SimaPro is ReCiPe Midpoint, which includes impact categories such as climate change, human toxicity or metal depletion. Although we chose to focus on natural land transformation climate change. These are some impact categories we think the construction of road will mostly influence.

Life Cycle Inventory Analysis

Process flow

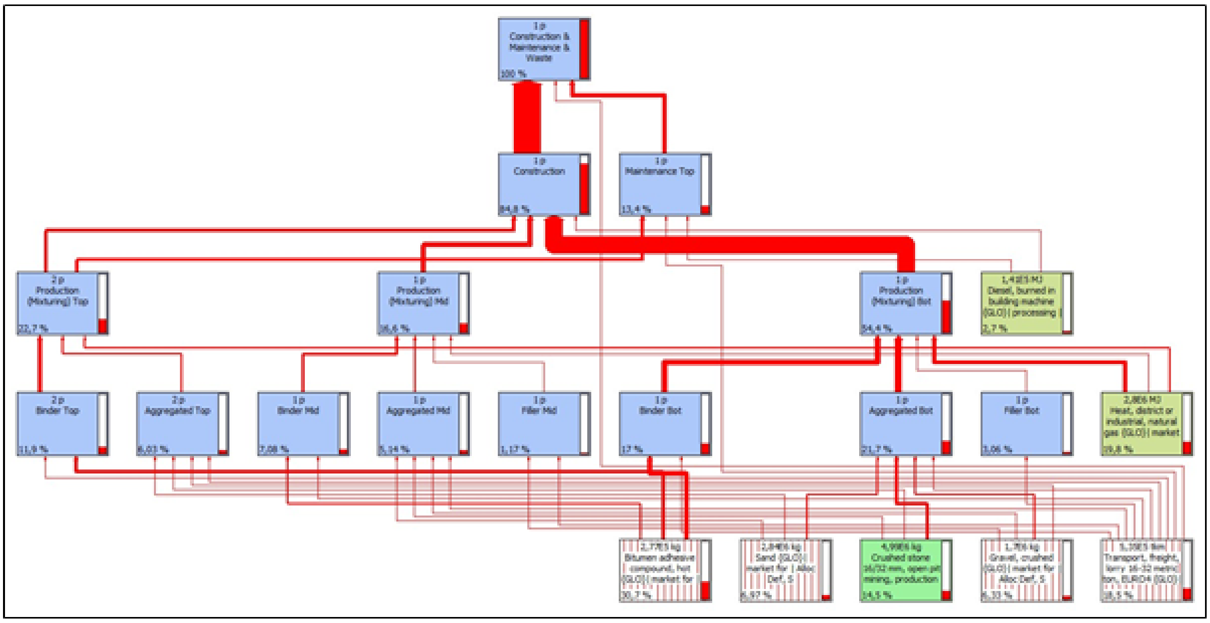


Figure 10:Asphalt construction flowchart from SimaPro – node cut-off 0,01%

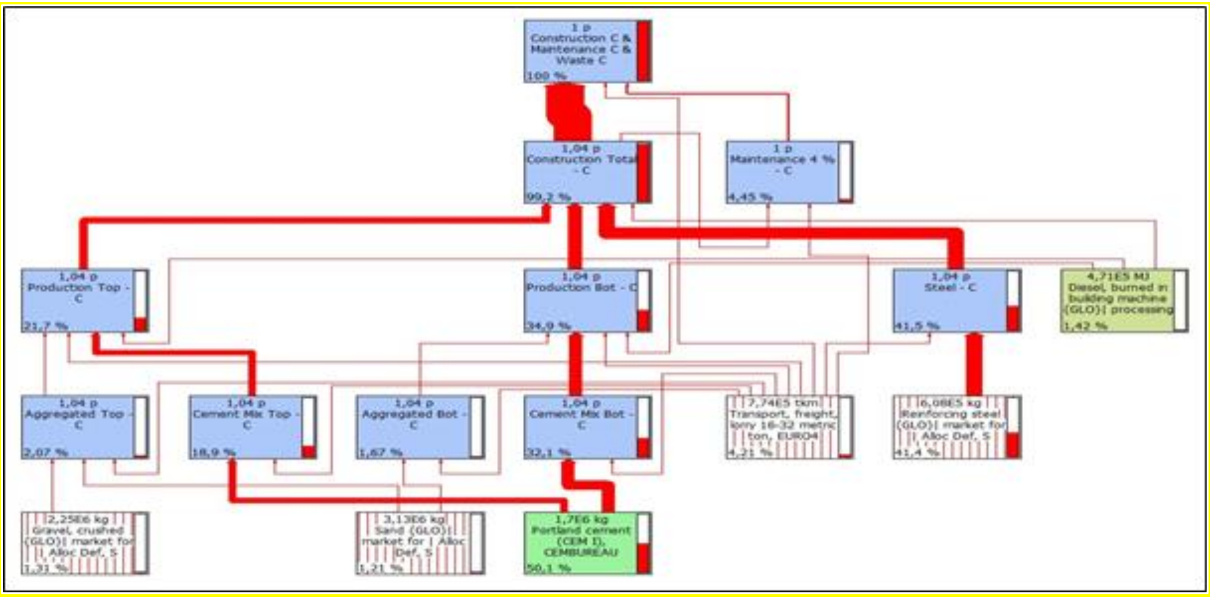


Figure 11: Concrete construction flowchart from SimaPro – node cut-off: 0,4%

Data

There are several assumptions regarding the material choices and construction of the pavements. First, we assumed that the dimensions of the road would be 21 meters wide, and contain 6 lanes, where each lane would be 3,5 meters wide. This assumption was made according to the standard dimensions of a highway (between 3.5 and 3.75 meters). We also divided the production of the asphalt and concrete in two different site: the mixing site and the construction site. We assumed that the distance between both was 17 and 25 km.

The concrete recipe for highway roads have been received from the Concrete Institute in Stockholm, and is assumed to be fitting the criterion regarding geography and dimensioning.
As there are endless of concrete types, we have consulted experts from the institute to choose a concrete with suitable properties. We received a recipe for a highway concrete which includes plasticizer. This is beneficial in our case as it decreases the need for water in the concrete mixture, making it extra resistant against freeze damages, otherwise common in Södermanland. We assume that reinforcement steel will be necessary to minimize cracking damages. However, we could not follow the recipe fully in SimaPro, where simplifications had to be done. For instance, the gravel sizes in the recipe were divided in three different categories, which we couldn't find in the datasets in SimaPro. Therefore, all these categories were put together.

Table 2: Recipe of Concrete of E4 Uppsala (Kraft, 2016)*)*

Components	Top layer [kg/m^3]	Bottom layer [kg/m^3]
Cement	360	350
Water	140,0	140
Sand	660	648
Gravel	1 285,0	1 231
Dispersant	0,38	-

The concrete will be made in two layers, one bottom layer of 140 mm and one top layer of 80 mm (Dolk, et al., 2011). By multiplying the volume of the two layers of concrete, we find the necessary amount of each component. The volume of the top layer is 1680 m^3 and the bottom layer is 2940 m^3.

Table 3: Used materials for the concrete layers I.

Layer	Sand	Gravel	Cement	Dispersant	Water	TOTAL
Bottom layer [kg]	1 905 120	3 616 000	1 029 000	0	411 600	6 964 860
Top layer [kg]	1 108 800	2 158 800	604 800	638	235 200	4 108 238

Table 4: Used materials for the concrete layers II.

Layer	Aggregates Total	Cement + Dispersant
Bottom layer [kg]	93 912	105 987,4
Top layer [kg]	55 549,2	62 294,4

Both concrete layers will be reinforced with steel, in three dimensions x,y, z.

Figure 12: Steel reinforcement for concrete pavements, x-, y- direction

Table 5: Steel specifics

Components	Number of bars	Length of each bar	Diameter [mm]	Steel volume [m^3]	Weight [t]
Longitudinal bars (x-direction)	2 x 1667	21	12,00	7,92	62,41
Longitudinal bars (y-direction)	2 x121	1 000	18,50	65,00	510,25
Longitudinal bars (z-direction)	20 x 1667	0,18	15,80	1,613	12,66

In order to calculate the amount of steel needed to reinforce the highway, we use a distance between each y-bar of 175 mm and 600 mm for the x-bars. To make it easier, we assumed the y-bars are 1km long (length of the highway) and the x-bars are 21m long (width of the highway). We use for the steel a density of 7850 kg/m^3. According to our method of maintenance, we made the assumptions that 2 layers of longitudinal bars are necessary. Transversal bars are used to connect these two layers.

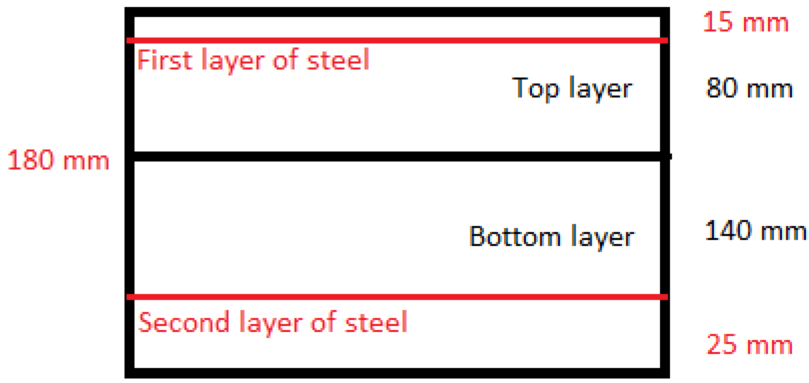


Figure 13: Steel reinforcement in the concrete layers

As we can see on the picture above, the assumed length of each transversal bar is approximately 180 mm. Each 20 year, the thickness of the concrete pavement decreases by 5 mm. As our life time is 25 years, we assumed a safety distance of 15mm between the first layer of steel and the top of the pavement. Moreover, we assumed a distance of 25mm between the bottom of the pavement and the second layer of steel. This distance corresponds to the height of each bar support in the following picture.

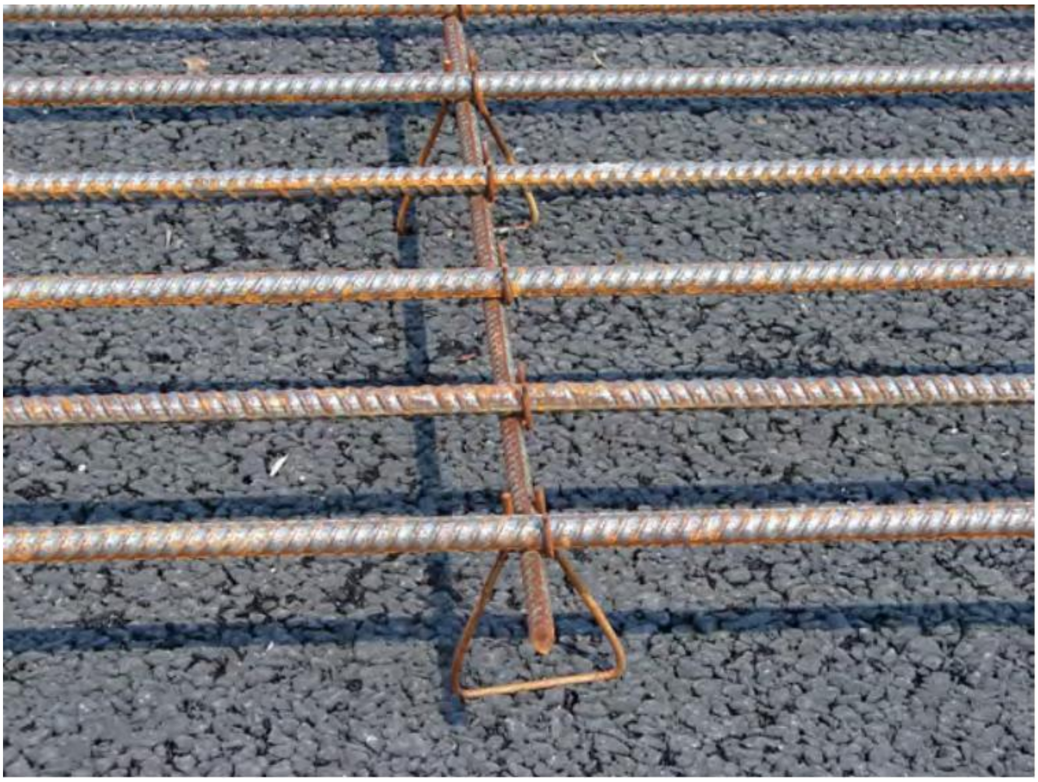


Figure 14: Steel dowel support for distance to bottom

Asphalt

The dimensions for each asphalt layer are shown below. These are for asphalt, and each column represent the different layers. The content and ratio for each layer are presented in the tables Top-, Mid-, and Bottom layer.

Table 6: Asphalt layers dimensions

Layer dimensions

	Top [m]	Mid [m]	Bottom [m]
Length	1000	1000	1000
Thickness	0,03	0,05	0,2
Width	21	21	21
Volume	630	1050	4200

The ratio between different materials are expressed in percentage. From this data, and from the layer dimensions above, we can derive volumes, weight, and eventually tkm. Tkm is tone kilometres, and the kilometres are the distance for each layer is transported. The distances are presented in Appendix I. From the energy table in Appendix I we get the amount of energy that is needed to produce each layer. The energy use are in SimaPro expressed in mega joule, MJ.

Table 7: Asphalt top layer data

Top layer

	Content	%	Volume [m³]	Weight [kg]	tkm
Binder	Bitumen	7%	44	45 864	25 133
Aggregated	Sand	33%	205	328 104	5 578
	Crushed Stone	47%	293	468 720	7 968
	Gravel	9%	59	89 057	1 514
Filler	Limestone	5%	29	80 239	11 314
		100,00%	**630**	**1 011 984**	**51 507**

Energy use [kJ/t]	**270 889**
Energy Use [MJ]	**274 135**

Table 8: Asphalt middle layer data

Mid layer

	Content	%	Volume [m³]	Weight [kg]	tkm
Binder	Bitumen	5%	53	54 600	29 920,80
Aggregated	Sand	33%	349	558 600	9 496,20
	Crushed Stone	48%	499	798 000	13 566,00
	Gravel	10%	100	151 620	2 577,54
Filler	Limestone	5%	50	136 608	19 261,68
		100,00%	**1050**	**1 699 428**	**74 822,22**

Mid - Energy use [kJ/t]	**267 372**
Mid - Energy Use [MJ]	**454 379**

Table 9: Asphalt bottom layer data

Bottom layer

	Content	%	Volume [m³]	Weight	tkm
Binder	Bitumen	3%	126	131 040	71 809,92
Aggregated	Sand	24%	1019	1 629 600	27 703,20
	Crushed Stone	49%	2037	3 259 200	55 406,40
	Gravel	19%	815	1 238 496	21 054,43
Filler	Limestone	5%	204	557 934	78 668,74
		100,00%	**4200**	**6 816 270**	**254 642,69**

Bottom - Energy use [kJ/t]	**263 855**
Bottom - Energy Use [MJ]	**1 798 507**

Table 10: Asphalt transportation in contact of production, maintenance and waste management

Production - Maintenance - Waste Management

	Production	Maintenance Top	Waste Management
Diesel - Machines [MJ]	127 671	13 561	N/A
Machine - Miller [h]	N/A	2,00	N/A
Transport - Maintenance [tkm]	*	51 507	N/A
Transport - Waste [tkm]	*	N/A	51 507

** = See individual table*

Total energy use during production have been calculated, and the results are presented above. In the same table we have included data related to maintenance, and waste management.

During the construction, rollers are used to build the highway. In our study, we assumed that a roller of 1,5 width has to travel the length of the road 3 time, (forth, back, and forth). These assumptions were made in order to calculate the fuel consumption of one roller, that we multiply by 14 afterwards (21/1,5 = 14). We also assumed that the velocity of one roller were 7,5 km/h, based on estimations from videos and other sources online. This data is used to calculate the time to construct one section of road (1,5*1000 m). The calculated time for the entire road depends on how many rollers we decide to include in the construction phase. In our case, the assumptions made was that 3 rollers would be enough. All of the process above is repeated for the finisher, machines used to smooth the highway's surface, 7 meters wide and an assumed velocity of 1,5 km/h.

It is the production part (mixturing) what consumes most energy during the life cycle. We don't find data about it in SimaPro, so we calculated it in Excel. The next table shows the the results of the calculation in each asphalt layer. We also counting the emission during the process to compare it with the result of SimaPro.

After the end of life time, we need to take care about the pavements as well. One part of it is getting recycle or it will use by a bottom layer for the new pavement, and the other part does a removal to a depot or landfill.

Cut off

The node cut off for asphalt has been set to 0,01 %, to ignore the data with zero value. In the case of concrete we have chosen a higher node cut off (0,4%), in order to remove the insignificant components, such as the plasticizer and certain grain sizes of gravel. These components impacts are considered insignificant as their value are so low.

Life Cycle Interpretation

Results

Climate change

Greenhouse gases emitted through the process of producing, constructing and transporting material, will have an effect on the climate change. A high level of emission could contribute to higher temperatures, and more unpredictable weather. This is negative in many ways, with results such as droughts or a increased frequency of storms (NASA, 2016)

Natural land transformation

Natural land is defined as the environment untouched by man. By producing material and proceeding with constructions, a certain degree of affected natural land can be expected.

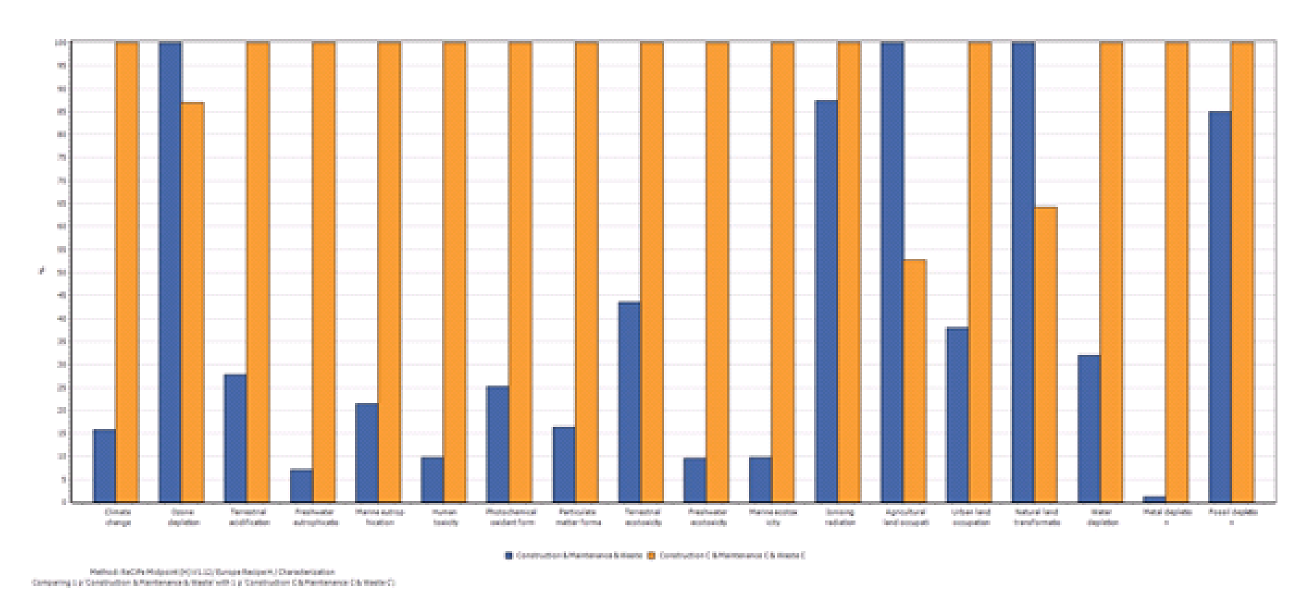


Figure 15: Impacts of asphalt and concrete pavement I.

In the *Figure 15.* we can see the asphalt (blue) and concrete (yellow) impacts in different impact categories.

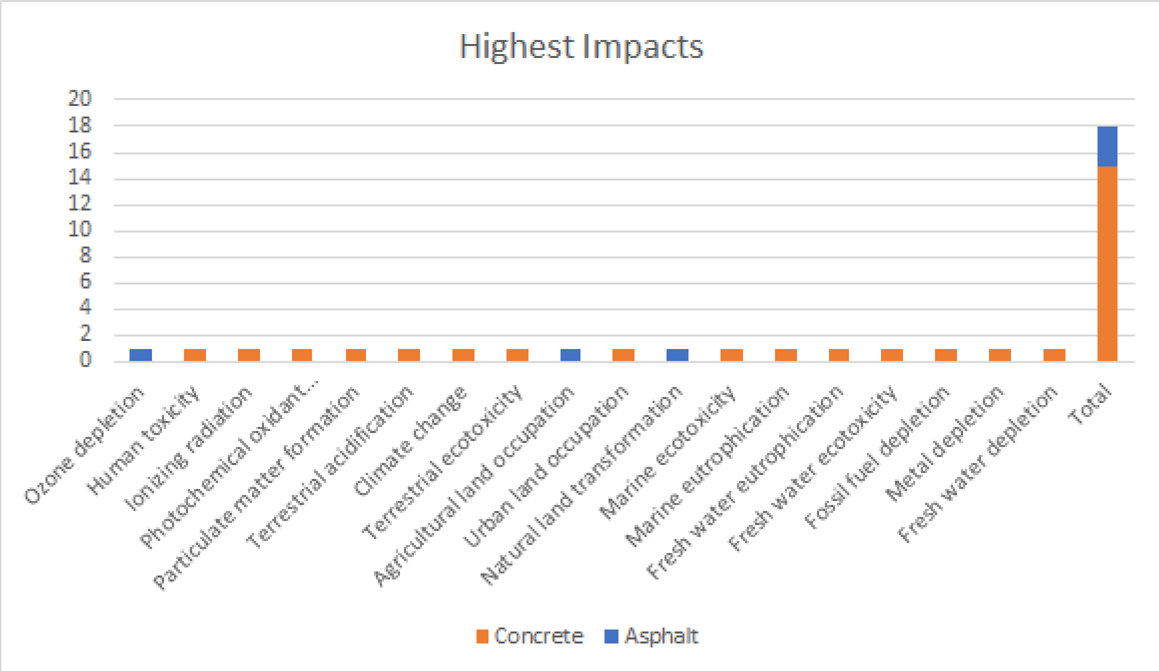


Figure 16: Impacts of asphalt and concrete pavement II, where concrete can be seen to have a higher total of highest impacts

We can see that asphalt has the highest impact in three categories, including Ozone Depletion, Agricultural land occupation and Natural land transformation. The rest of the categories, 15 of the total, is dominated by concrete. Bearing in mind that ozone depletion, ionizing radiation and fossil depletion only had a difference of 15 percent or less according to chart X, making these quite equal.

Asphalt

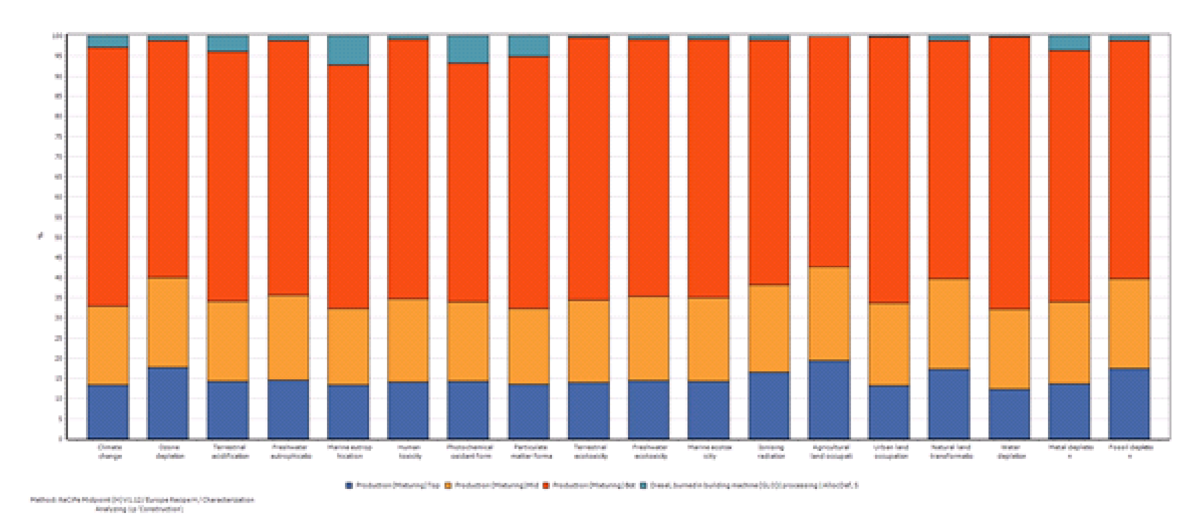


Figure 17: Impacts of asphalt pavement

We can see that the production of the mid layer (orange) causes the major impacts.

Concrete

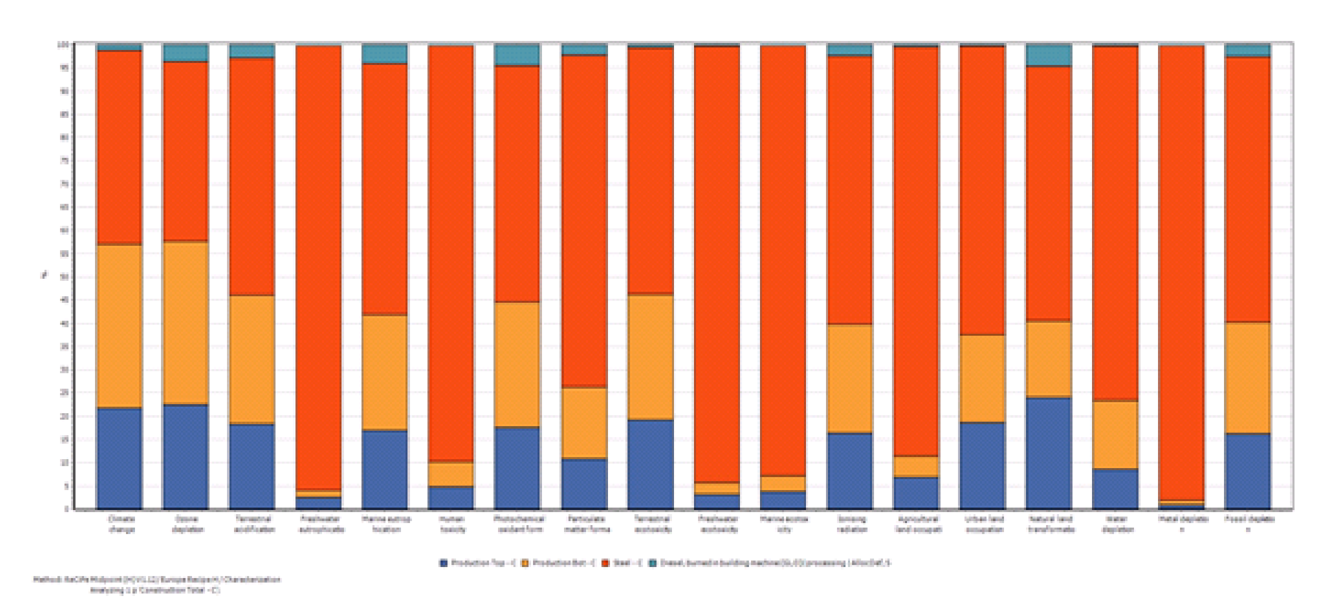


Figure 18: Impacts of concrete pavement

We have identified the steel (orange) as a significant process for the concrete construction.

Climate change

The results show that the concrete has a significantly higher impact on the climate change by releasing more greenhouse gasses. We however want to highlight the impact of the steel in this matter which contributes with approximately 40 % of the impact. While the production of both layers roughly represent 57 %, and the few percent less corresponds to the diesel burnt during construction.

Within the production of the aggregates, the extraction stands for approximately 68 percent with the rest being a result of transportation to the construction site in the center of Stockholm. Which concludes that the procedure of extraction and producing the materials needed emits far more than the transport. Regarding the production of cement roughly 97 % of the emissions are due to production of Portland cement, with the transportation only corresponding to 2 %.

Regarding asphalt, approximately 60 % of the contribution to climate change is attributed to the production of the bottom layer, which is understandable due to the thickness. Within the aggregate production, the highest contributor is the process of extraction. Further analyzing the result of the binder we can see that the production stands for 85 % of the emissions, while the rest is due to the transport to the construction site.

Natural land transformation

With the natural land transformation the roles are turned, where asphalt is seen causing the major impact. This is mainly due to extraction and production of aggregates and binder, with the transport only corresponding to a minor part, around 3 %. Regarding the concrete the same can be said for the aggregates, but not the binder which in this case is cement. The cement contributes very little to this category, and around 99 % is due to transportation.

Discussion

By analyzing the results we see that there is a big difference between the environmental impacts related to concrete compared to asphalt. By removing the steel for the study, the environmental impacts evens out dramatically between concrete and asphalt. This shows that steel have a great environmental impact on concrete roads, compared to asphalt. However, by removing steel we should in reality change some variables in the concrete model, since the ratio for different materials would change slightly. However, this has not been done, since the goal of the project was to compare asphalt and concrete pavement for a specific type of road. This road would in our project contain steel reinforcement, so we leave the comparison between asphalt and concrete pavement, free from steel reinforcement, for another group to investigate However, we find it important to acknowledge its impact on the result.

Assumptions and quality of data:

We realize that our assumptions and simplifications has an effect on the end result. By assuming the need of steel reinforcement, the impact in all categories rise significantly. A concrete without the assumed reinforcement would have been far more equal to the impacts of asphalt. In fact, far from all concrete highways are reinforced which would make it a reasonable comparison. Although we defend our use of reinforcement, as studies show a more resilient pavement, at least in the short term. This will effectively reduce the need of maintenance and repairs, reducing these costs and traffic blocks. What can be discussed, is if the cost of the reinforcement dowels is overcome by the savings from less repairs. In other words, is the reinforcement economically viable? This could be a question for another report.

Another assumption due to lack of data is the composition of the different asphalt layers. We have made qualified guesses in order to fill the data gap, bearing in mind that it will bring large uncertainties. By using more qualitative data we can further improve the reliability of the end result and comparison. Regarding concrete, more simplifications than assumptions have been made. Due to data with high quality the results can be trusted to relatively high degree. The simplification simply regards grain size of the aggregates, which can be assumed as insignificant regarding difference in impacts.

Information about constructing a correct steel reinforcement for concrete has been difficult to acquire. Since there are various methods, with different amount of layers, dowel diameters etc.

Although the exact construction has little meaning for the LCA. We have focused on the main aspects, which has resulted in what we consider, a reasonable amount of steel.

Regarding transport we have assumed that it will be carried out with lorries, which due to combustion engines will contribute to climate change amongst other impacts. Another possibility could be to use train, although it is only applicable for greater distances with a need for a transportation change to reach the construction site. As it would be a more complex solution, and the distances used are relatively short, we keep our assumption of lorry use in this study.

Cut-off and limitations

The node cut-offs have been chosen to ignore components with small or insignificant percentages of the end product. This brings a risk of overlooking some significant impacts, as even small proportions of a material can bring large impacts. Even though we are aware of the risk, we see it as a necessary measure. It would otherwise consume too much time and effort to expand the analysis, and time has been very limited. However we can see a further developed LCA where all the processes are included, for more detailed results in the future.

Regarding the limitations, we might also miss some important factors. As we exclude the use phase we ignore impact aspects arriving from the different pavement characteristics. For example, the concrete is usually brighter, which could decrease the need of lighting and even increase reflection of sun light. Thus, the use phase could benefit a further study.

Waste is also a subject that has been less prioritized, where we state that the waste during maintenance is handled and recycled. Although the waste at the end of the life time is overlooked, which basically means ignoring the transportation. Nevertheless, revising the impacts made by transportation of materials to construction, it can be assumed that a very similar impact will be made during the end of life waste transportation.

Conclusion and Recommendations

We can conclude that a reinforced concrete pavement for a high way road in Södermanland will have a higher impact in most categories including climate change. Although an asphalt pavement will have a larger effect on natural land transformation. Depending on which area is considered most important, a choice can be made with this LCA as a base. Although we strongly recommend a further development of the study, including what has been cut off, and perhaps even investigating alternative methods.

References

ACPA, 2016. *wikipave.org/.*
Available at:
http://wikipave.org/index.php?title=Welcome_to_ACPA%27s_Concrete_Pavement_Wiki
[Accessed 16 12 2016].
Butt, A. A., 2014. *Life Cycle Assessment of Asphalt Roads (2014),* Stockholm: KTH.
Chen, D. H., Zhou, W., Yi, W. & Won, M., 2014. *Full-depth concrete pavement repair with steel reinforcements,* Texas, USA: ELSEVIER.
Concrete, 2016. *www.cement.ca.*
Available at: http://www.cement.ca/en/Highways/Description-of-Concrete-Pavement.html
[Accessed 16 12 2016].
Dolk, E., Silfwerbrand, J. & Erlingsson, S., 2011. *Concrete pavement Falkenberg, Sweden - a 20 year review,* Stockholm: The Swedish Cement and Concrete Research Institute.
EAPA, 2011. *www.eapa.org.*
Available at: http://www.eapa.org/promo.php?c=173
[Accessed 16 12 2016].
EAPA, 2016. *www.eapa.org.*
Available at: http://www.eapa.org/asphalt.php
[Accessed 16 12 2016].
Kraft, L., 2016. *Reasercher in the Concrete Institute* [Interview] (18 November 2016).
Miliutenko, S., 2016. *Consideration of life cycle energy use and greenhouse gas emissions for improved road infrastructure planning,* Stockholm: KTH.
NASA, 2016. *climate.nasa.gov.*
Available at: http://climate.nasa.gov/evidence
[Accessed 16 12 2016].
PCA, 2016. *www.cement.org.*
Available at: http://www.cement.org/home
[Accessed 16 12 2016].
Santero, N., Loijos, A., Akbarian, M. & Ochsendorf, J., 2011. *Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle,* Cambridge: Concrete Sustainability Hub.
Stripple, H., 2001. *Life Cycle Assessment of Road* , Stockholm: IVL.

Appendix I

The following table show where the raw materials for asphalt have been transported from the extraction site, to the production site.

Acquisition to production facility

Company	From	Company 2	To	Distance
TOTAL HBG	Helsingborg	Peab	Hägersten	548
Swerock	Huddinge	Peab	Hägersten	17
Swerock	Huddinge	Peab	Hägersten	17
Swerock	Huddinge	Peab	Hägersten	17
Nordkalk	Köping	Peab	Hägersten	141
				740

Total weight * distance [tkm]	**7 050 484**

The table below show where the raw materials for asphalt have been transported from the production site, to the construction site.

Production facility to construction site

Company	From	Company 2	To	Distance
Peab	Hägersten	*Construction site*	Drottningholm	17
Peab	Hägersten	*Construction site*	Drottningholm	17
Peab	Hägersten	*Construction site*	Drottningholm	17
Peab	Hägersten	*Construction site*	Drottningholm	17
Peab	Hägersten	*Construction site*	Drottningholm	17
				85

Total weight * distance [tkm]	**809 853**

Regarding transport for concrete:

Sand and gravel from Swerock Huddinge 17 km

Cement and Dispersant from Cementex in Nyköping 103 km

Water is tap water.

Appendix II

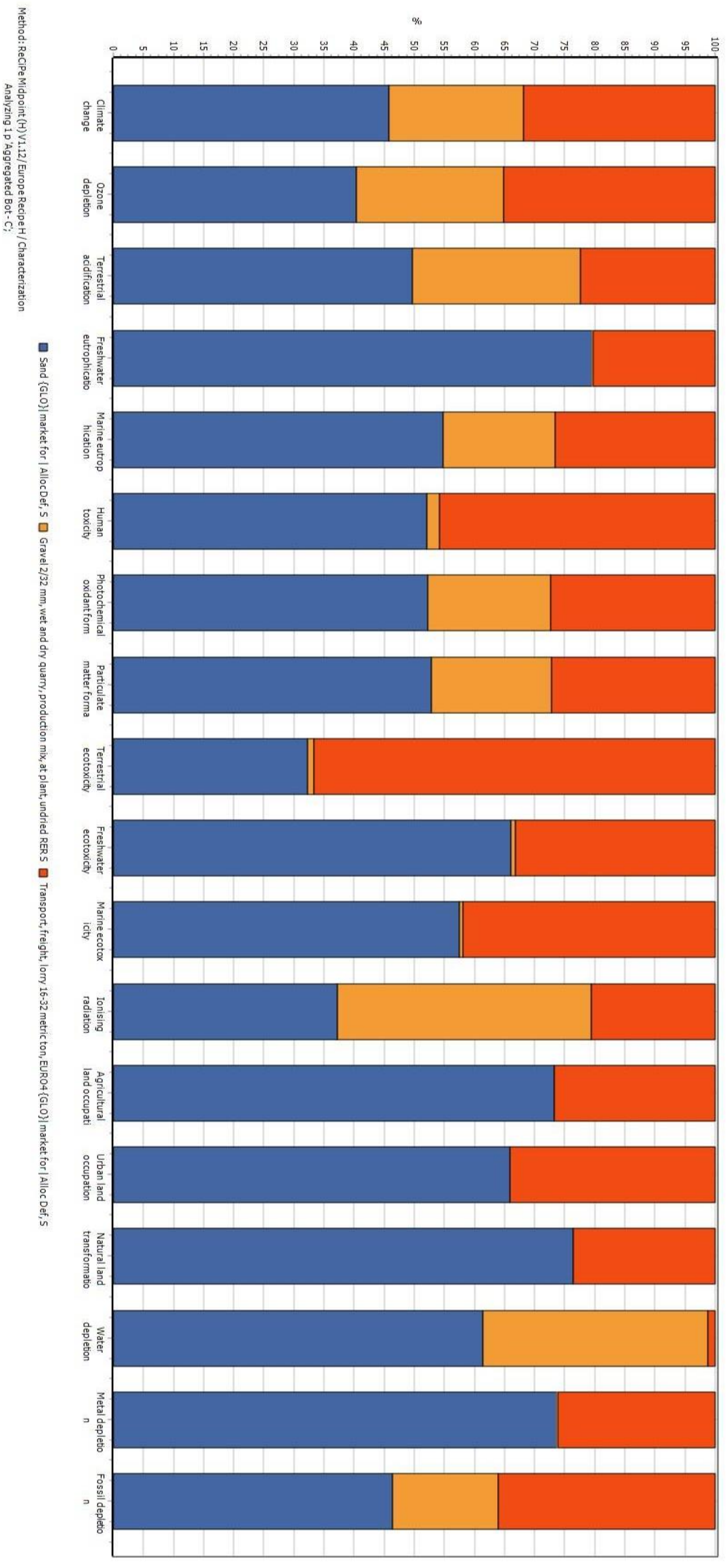
These tables shows how we calculated the energy use during the production part. It is means how many energy needs to heat the asphalt plant from natural average middle temperature (20°C) to 160°C where the asphalt mixture is prepare.

HMA-Top									
Composition [in 1 ton asphalt]		Composition [%]	Warm-up value	Energy demand [kg]	Fuel	Starting temperature [°C]	Warm-up temperature [°C]	System energy demand [kJ/t]	CO_2 emission [kg/t]
% of the dry weight of asphalt	Stone	55	1°C	0,837 kJ	Gas	20°C	160°C	64449	3,242
% of the dry weight of asphalt	Sand	33	1°C	0,837 kJ	Gas	20°C	160°C	38669	1,945
% of the dry weight of asphalt	Limstone	5	1°C	0,837 kJ	Gas	20°C	20°C	5859	0,295
% of the dry weight of asphalt	Bitumen	7	1°C	2,093 kJ	Gas	20°C	160°C	20511,4	1,032
% of the dry weight of asphalt	Steam		1°C	1,010 kJ	Gas	20°C	160°C	141400	7,112
							All:	270 889 Ft	13,6

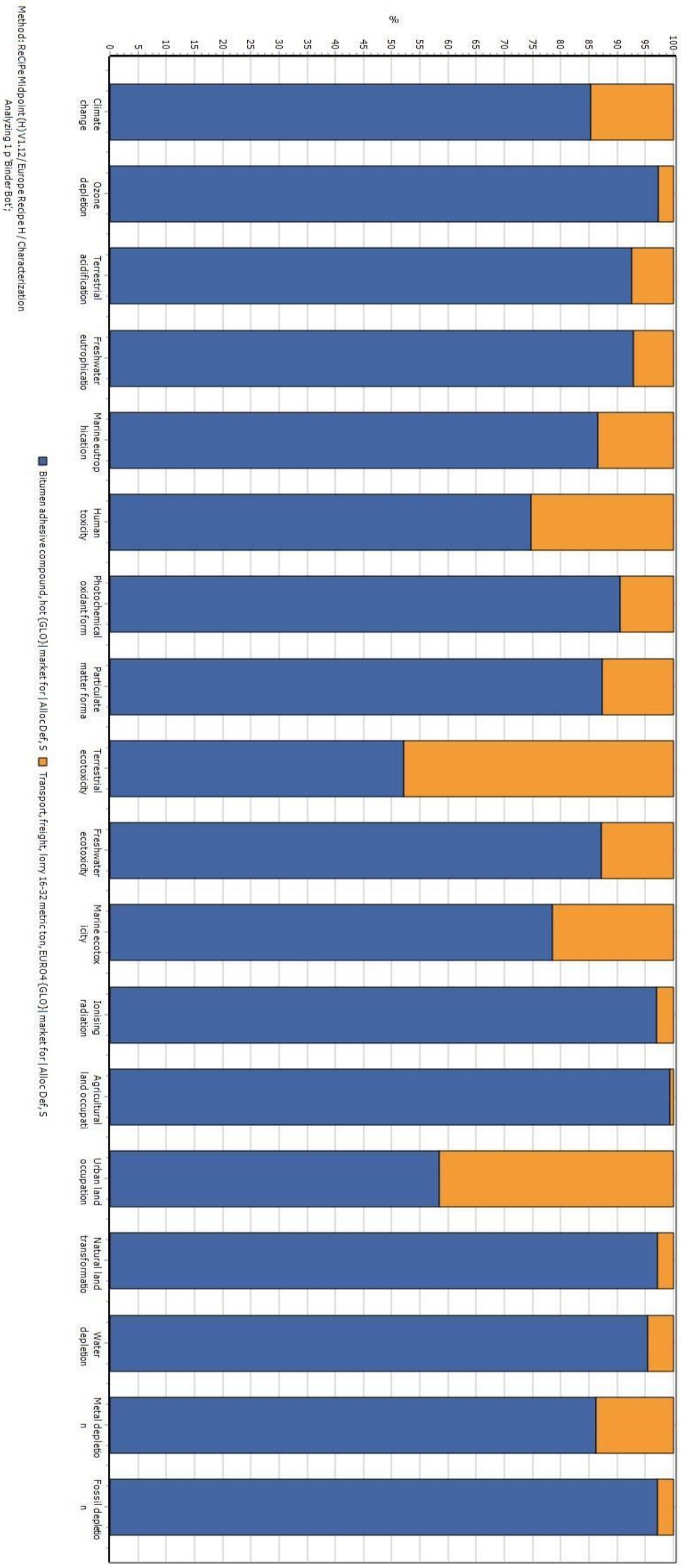
HMA-Mid									
Composition [in 1 ton asphalt]		Composition [%]	Warm-up value	Energy demand [kg]	Fuel	Starting temperature [°C]	Warm-up temperature [°C]	System energy demand [kJ/t]	CO_2 emission [kg/t]
% of the dry weight of asphalt	Stone	57	1°C	0,837 kJ	Gas	20°C	160°C	66793	3,360
% of the dry weight of asphalt	Sand	33	1°C	0,837 kJ	Gas	20°C	160°C	38669	1,945
% of the dry weight of asphalt	Limstone	5	1°C	0,837 kJ	Gas	20°C	20°C	5859	0,295
% of the dry weight of asphalt	Bitumen	5	1°C	2,093 kJ	Gas	20°C	160°C	14651	0,737
% of the dry weight of asphalt	Steam		1°C	1,010 kJ	Gas	20°C	160°C	141400	7,112
							All:	267 372 Ft	13,4

HMA-Bot									
Composition [in 1 ton asphalt]		Composition [%]	Warm-up value	Energy demand [kg]	Fuel	Starting temperature [°C]	Warm-up temperature [°C]	System energy demand [kJ/t]	CO_2 emission [kg/t]
% of the dry weight of asphalt	Stone	68	1°C	0,837 kJ	Gas	20°C	160°C	79682	4,008
% of the dry weight of asphalt	Sand	24	1°C	0,837 kJ	Gas	20°C	160°C	28123	1,415
% of the dry weight of asphalt	Limstone	5	1°C	0,837 kJ	Gas	20°C	20°C	5859	0,295
% of the dry weight of asphalt	Bitumen	3	1°C	2,093 kJ	Gas	20°C	160°C	8790,6	0,442
% of the dry weight of asphalt	Steam		1°C	1,010 kJ	Gas	20°C	160°C	141400	7,112
							All:	263 855 Ft	13,3

Appendix III



Appendix IV.



Method: ReCiPe Midpoint (H) V1.12 / Europe Recipe H / Characterization
Analyzing 1 p 'Binder Bot';
%
Climate change
Ozone depletion
Terrestrial acidification
Freshwater eutrophicatio
Marine eutrophication
Human toxicity
Photochemical oxidant form
Particulate matter forma
Terrestrial ecotoxicity
Freshwater ecotoxicity
Marine ecotoxicity
Ionising radiation
Agricultural land occupati
Urban land occupation
Natural land transformatio
Water depletion
Metal depletion
Fossil depletion
Bitumen adhesive compound, hot {GLO}| market for | Alloc Def, S
Transport, freight, lorry 16-32 metric ton, EURO4 {GLO}| market for | Alloc Def, S