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LIFE CYCLE ASSESSMENT FOR ROAD CONSTRUCTION AND USE

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LIFE CYCLE ASSESSMENT
FOR ROAD CONSTRUCTION AND USE

At present the choice of materials and techniques in road construction is dictated by structural requirements and economical aspects. Ecological factors have gained in importance due to environmental considerations in politics and society. To evaluate the environmental impact of motorways, a life cycle assessment (LCA) according to ISO 14040 was carried out for four different pavement types (two concrete pavements and two asphalt pavements). By investigating different case scenarios for construction, use and maintenance over a service period of 30 years, the reduction potential of environmental impact was quantified. The LCA for concrete motorways showed that the potential environmental impact clearly depends on the choice of cement type. The analysis for asphalt motorways showed that the potential environmental impact can be reduced by improving asphalt production. Moreover, the potential environmental impact can be decreased by reducing transport activities. The analysis for the maintenance of the pavement types showed that investment in more durable pavement is worthwhile.

A far greater reduction in air pollution can be achieved by improving pavement properties (e.g. texture, stiffness and flatness) which would significantly reduce the fuel consumption of vehicles.

Therefore, the development of a fuel-saving pavement is more important than a pavement with lower potential environmental impact from construction and maintenance.

1. INTRODUCTION

The present study aims at quantifying the environmental impact of motorways. As well as pavement construction, the ecological impact of a motorway under traffic as well as the effect of maintenance over a period of 30 years have been analysed systematically using the LCA methodology according to ISO 14040. All input and output values for the individual processes in the production and use of pavement for a motorway section were taken into account. This included the production of materials, provision of energy, manufacture of the necessary products, transport services and the employment and disposal of the individual products.

Emissions into air, water and soil were determined and, using the Dutch CML method, assigned to the impact categories global warming potential (GWP), ozone depletion potential (ODP), photochemical ozone creation potential (POCP), acidification potential (AP) and eutrophication potential (EP). The Swiss database "ecoinvent" was used. Processes not available in the database were analysed and modelled on the basis of existing upstream-processes. The data were evaluated with the LCA software "SimaPro". Possible reductions in environmental impact were determined by considering various scenarios.

2. LIFE CYCLE ASSESSMENT FOR ROADS

2.1. LIFE CYCLE ASSESSMENT ACCORDING TO ISO 14040

Life cycle assessment is a standard method widely used to assess comprehensively the potential environmental impact of products or systems of products. All environmental aspects of the product life cycle (emissions into air, water and soil, waste, use of raw material and exploitation of nature) are taken into account. This comprehensive approach avoids the misallocation of environmental effects and provides an overview for possible impact reduction. The LCA method is described in the international standards ISO 14040 and 14044.

A LCA study comprises four phases which affect one another. In the first phase the goal and scope of the investigations and the resulting system boundaries are defined. In the inventory analysis phase, all relevant materials and energy inputs and outputs are included in the system. In the assessment phase, the environmental effects of the system components are assigned to different impact categories. Different materials are weighted according to their damage potential and summarized in total impact indicators. In the final interpretation phase, the impacts are analysed and evaluated in order to draw conclusions or make recommendations. In this study, results are presented for the LCA of the construction, use and maintenance of a motorway section 1 km in length.

2.2. SCOPE

The scope of the investigations is characterized by the system boundaries and the functional unit. In ISO 14040, the system boundary is defined in a spatial context. System boundaries generally include the entire life cycle of a product, i.e. pre-manufacturing (raw material production, manufacture of parts and components), the actual manufacturing process, transport, application and disposal. Fig. 1 shows the system boundaries in this study (dashed lines).

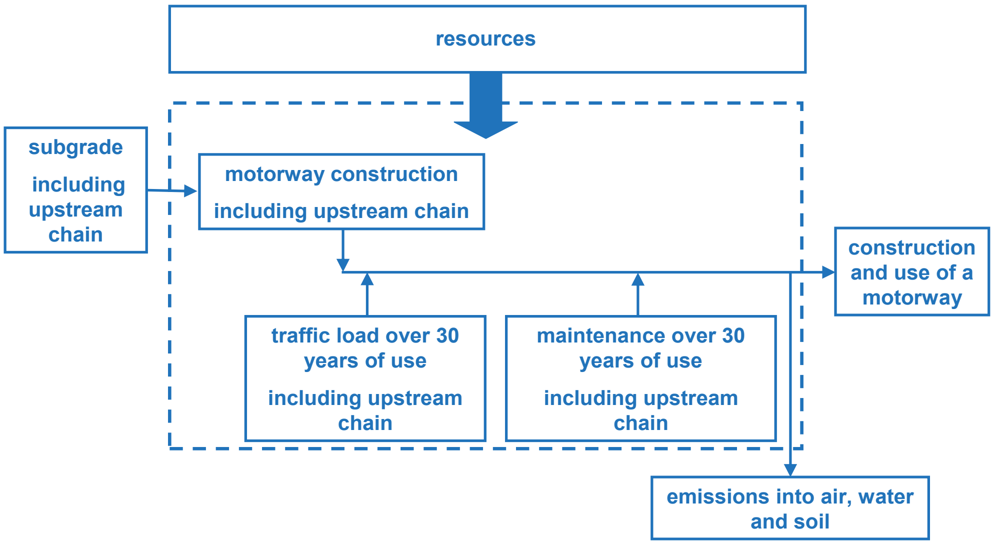

Fig. 1 – System boundaries for the LCA (dashed lines). The term “upstream chain” includes all main parameters for upstream processes with potential environmental impact (i.e. production and processing of raw materials, infrastructure)

The functional unit in the present study was a 1 km long section of a two-lane (on each carriageway) motorway section with a pavement thickness of 85 cm. The concrete pavements investigated were constructions with an exposed aggregate concrete surface layer and with surface texture produced by brushing (artificial lawn). Pavements with a noise-reducing porous asphalt top course and mastic asphalt were included in the study. Subgrade preparation (e.g. ground compaction) and furnishing work (e.g. road marking) were not part of the study. Drainage measures (drains, gullies etc.) were neglected. The asphalt pavement comprising surface, binder and base course layers is supported by a frost blanket. The actual structure depends on the type of surface layer. In the case of porous asphalt (PA), a seal is included, Fig. 2 left. The concrete motorway consists of a frost blanket followed by a hydraulically bound base course, a geotextile interlayer and a concrete surface layer. In the present case, the concrete layer comprises two separate layers in which the surface course is either textured (tC) or is an exposed aggregate concrete (EAC), Fig. 2 right.

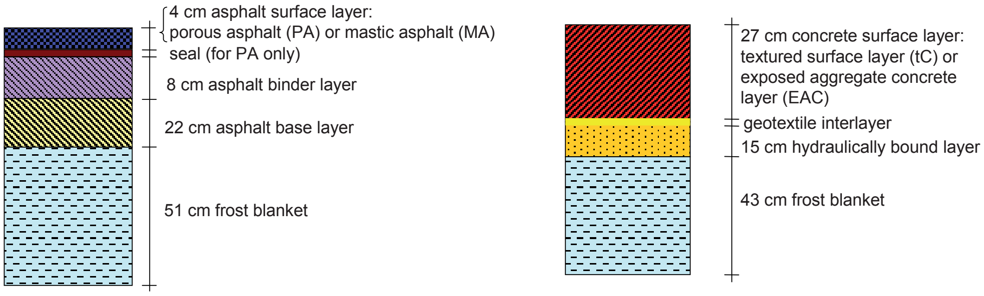

Fig. 2 – Schematic diagram of the investigated pavement structure of an asphalt (left) and concrete (right) motorway

Comparison of different construction methods should always be made in the light of the further technical requirements (cost, construction time, noise protection requirements etc.). The porous asphalt top layer is a special construction method only employed where sound-proofing is necessary, but cannot be achieved by other means. The noise protection barriers which would be needed by the other construction methods to achieve sound pressures equivalent to porous asphalt are not considered here.

The structure of the two-lane motorway section is shown in Fig. 3. Each side of the motorway has a verge 1.5 m in width which is not included in this study. The 3.0 m hard shoulders are separated from the inside lanes by side strips 0.75 m in width which are also next to the outside lanes.

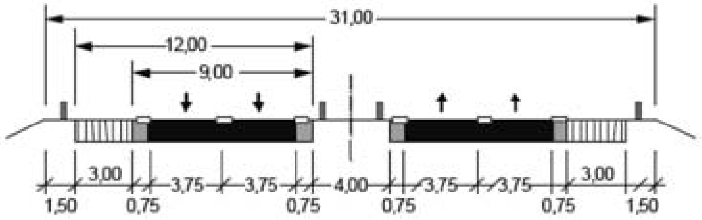

Fig. 3 – Investigated standard motorway cross-section RQ 31 (FGSV 2008). Dimensions in metres.

2.3. ORIGIN OF DATA AND LIFE CYCLE INVENTORY ASSESSMENT

The "ecoinvent" database already contained a number of materials which could be directly used for the life cycle inventory analysis of the production and service use of motorways (e.g. aggregate for the frost blanket, mixing water for the concrete, bitumen for the asphalt). Many data sets had to be adapted to the situation in question (cement, joint filler etc.). Since data were not available on the production of asphalt, curing agents and pavement concrete, the production methods were analysed and presented in a form which enabled modelling with the available basic modules in ecoinvent (e.g. provision of electricity, electric motors etc.).

2.4. ASSUMPTIONS AND LIMITATIONS

Life cycle assessment takes only ecological aspects into account, not the social and economical factors which must be considered for decision-making in civil engineering. LCA only covers standard cases, whereas the choice of a suitable and ecological construction method often depends strongly on local circumstances. In some circumstances, the potential environmental impact could even be less than in the standard case.

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3. LCA FOR MOTORWAY CONSTRUCTION

3.1. SCOPE OF INVESTIGATIONS

The individual pavement layers including the edge regions and the necessary upstream chains were analysed. The system boundaries for the construction phase are shown in Fig. 4.

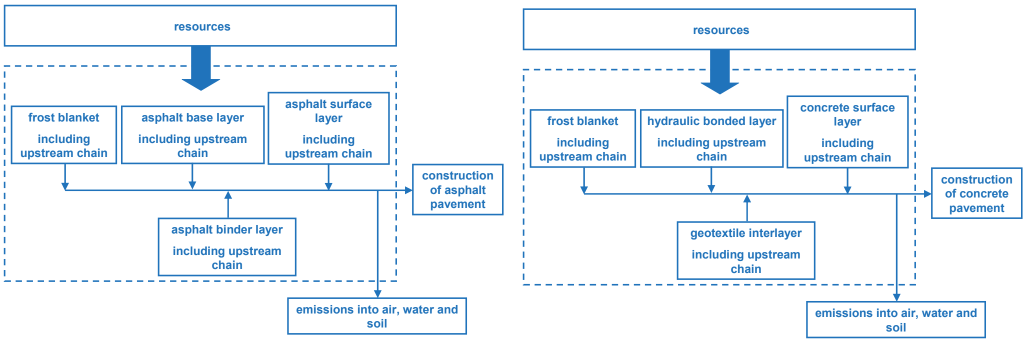

Fig. 4– System boundaries for the construction of a motorway (dashed lines). Left: asphalt pavement, right: concrete pavement

To quantify the potential for the optimization of environmental impact available in the use of different materials, various scenarios were investigated. A summary of the various scenarios is given in Table 1.

The use of recycled material is not considered at all in scenario A. It was not possible to determine a reliable percentage of recycled material because information on the amounts and use of recycled material in road construction vary strongly. In order to identify the potential reduction in environmental impact by reusing construction material it was assumed, in scenario B, that the frost blanket consisted of 100% recycled material. However, scenario B does not comply with field practice because transport processes on site were completely neglected. The concrete surface layer in standard scenario A is made with Portland cement CEM I 42.5 N. The optimization potential in the use of composite cements was quantified by replacing the Portland cement by Portland blast-furnace cement CEM III/A 42.5 R in scenario C. This cement represents the upper limit on the ground granulated blast furnace slag content of cement in German road construction.

TABLE 1 – OVERVIEW OF INVESTIGATED SCENARIOS FOR THE PRODUCTION OF 1 KM MOTORWAY

Asphalt constructions: pavement with mastic asphalt surface layer (MA) or porous asphalt surface layer (PA)	Concrete constructions: pavement with textured surface (tC) or exposed aggregate concrete surface layer (EAC)
Scenario A: 0% recycled material for all layers	**Scenario A:** 0% recycled material for all layers, CEM I for concrete surface layer
Scenario B: 0% recycled material for other layers 100% recycled material for frost blanket	**Scenario B:** 0% recycled material, CEM I for concrete surface layer 100% recycled material for frost blanket
	Scenario C: 0% recycled material for all layers, CEM III for surface concrete layer

3.2. INVENTORY ANALYSIS

Motorway construction is divided into different stages each performed at different times. The construction work considered in this study began with the production of the frost blanket followed by the other layers in turn. The necessary operations with materials and machines were modelled for each layer. Finishing work like surface texturing and curing was also taken into account.


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All input and output streams during the life of each process were determined and compiled for the environmental inventory. The frost blanket was modelled by a mixture of gravel and sand. The use of bulldozers, terrain levellers and vibration rollers was taken into account. A cold milling machine used to remove old layers was included in scenario B. The crushers required for processing the materials were included in the cold milling module.

An overview of the main materials and machines for the production of asphalt and concrete motorway pavement is presented in Table 2 and Table 3, respectively. The process chains determined from this information are in (Milachowski et al., 2010) together with the data sets used and the scatter of the values.

TABLE 2 – OVERVIEW OF THE MAIN MATERIALS AND MACHINES FOR THE PRODUCTION OF ASPHALT MOTORWAY

Layer	Material		Machines	
asphalt base layer	36.7 kg/m³ bitumen 2349.0 kg/m³ aggregate		2 pavers 4 vibration rollers	
asphalt binder layer	0.3 kg/m² bitumen emulsion 45.9 kg/m³ polymer modified bitumen (PMB) 2421.0 kg/m³ aggregate		5 bitumen sprayers 2 asphalt pavers 4 vibration rollers 1 tandem roller	
asphalt surface layer	mastic asphalt (MA): 0.3 kg/m² bitumen emulsion 72.5 kg/m³ low-viscosity bitumen 2415.0 kg/m³ aggregate 8.0 kg/m² chippings (scatter material)	porous asphalt (PA): 2.5 kg/m² PMB 8.0 kg/m² chippings 66.3 kg/m³ PMB 1950.0 kg/m³ aggregate 0.15 kg/m² cellulose fibres	mastic asphalt (MA): 5 bitumen sprayers 4 mastic asphalt boilers 2 pavers 2 finishing machines	porous asphalt (PA): 5 bitumen sprayers 4 chip spreaders 2 feeders 2 pavers 4 smooth drum rollers

TABLE 3 – OVERVIEW OF THE MAIN MATERIALS AND MACHINES FOR THE PRODUCTION OF CONCRETE MOTORWAY

Layer	Material		Machines	
hydraulically bound base course	90.0 kg/m^3 CEM II/B-S 32.5 R 1975 kg/m^3 aggregate 110.0 l/m^3 tap water 1.6 kg/m^2 C60 B1 - N		2 paver 6 rollers 5 bitumen sprayers	
interlayer	0.5 kg/m^2 geotextile		--	
concrete surface layer	pavement concrete with textured surface (tC): 3.36 m^3/km bottom concrete 1.68 m^3/km top concrete 44.8 m^3/km steel for dowels and anchors 9.6 t/km curing agent 4.3 t/km joint filler	exposed aggregate concrete (EAC): 3.36 m^3/km bottom concrete 1.68 m^3/km top concrete 44.8 m^3/km steel for dowels and anchors 6.0 t/km combination agent 4.8 t/km curing agent 4.3 t/km joint filler	pavement concrete with textured surface (tC): 1 slipform paver 1 curing machine 2 groove cutters 3 joint sealing machines	exposed aggregate concrete (EAC): 1 slipform paver 1 curing machine 2 brushing machines 2 groove cutters 3 joint sealing machines

In scenario A, the bottom concrete was mixed using 350 kg/m^3 CEM I 42.5 N and 158 L/m^3 water; the top concrete for the pavement with a textured surface was produced with 360 kg/m^3 cement and 162 L/m^3 water. The top exposed aggregate concrete contained significantly more cement in this case 430 kg/m^3 with a w/c ratio of 0.42 was assumed. All concretes were mixed with an air-entraining agent. The higher requirements placed on the quality of the aggregate in the top concrete were taken into account. An average German concrete plant was assumed for the concrete production.

The distance for the transport of materials was set to 50 km and, based on field experience, the distance from the concrete plant to the construction site was taken as 20 km.

Construction site installation was only taken into account by the delivery and removal of the construction machines; a distance of 100 km was assumed.

Photo : Charlotte Milachowski

3.3. IMPACT ASSESSMENT

The results for the environmental impact of motorway construction with concrete are shown in a spider web diagram, Fig. 5. Each axis corresponds to one of the impact categories (see section 1). The use of 100% recycled material in the frost blanket in scenario B reduces the impact by amounts between 12 (GWP) and 31% (EP), depending on the category. This is due to the neglect of transport processes in this scenario. By replacing CEM I by CEM III, GWP is reduced by amounts of 20 (pavement with textured concrete) or 21% (pavement with exposed aggregate concrete). The reduction is much less for the other categories and ranges from 0.1 to 10%. The exposed aggregate concrete pavement has, in all cases, a slightly higher environmental impact than the pavement textured with artificial grass owing to the higher cement content of the top concrete layer. Differences in curing have a negligible effect.

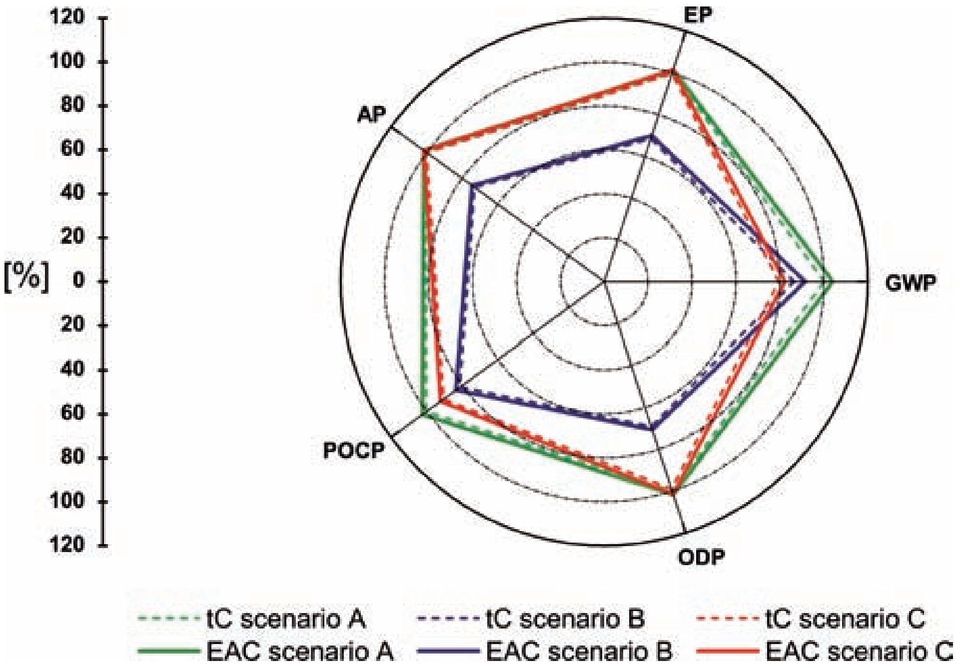

Fig. 5 – Results of impact assessment for the construction of 1 km concrete motorway. The variables are with respect to the textured concrete in scenario A. (tC = pavement with textured concrete surface; EAC = pavement with exposed aggregate concrete surface layer)

Depending on the category, the frost blanket contributes between 14 (GWP) and 38% (EP) to the environmental impact. The contribution from the hydraulically bound base course is between 14 (GWP) and 23% (ODP). Between 0.4% (ODP) and 5% (AP) is from the interlayer geotextile, depending on the construction method. The concrete surface layer contributes between 42 (ODP) and 72% (GWP), again depending on construction method and impact category. Thus the largest contribution to the potential environmental impact of the production of a concrete motorway is from, in all cases examined, the concrete itself. Dominance analysis of this material revealed that the effect of mixing water and air-entraining agent on the environment is negligible. The largest effect is due to the Portland cement and lies between 70 (EP) and 96% (GWP) whereas the potential environmental impact of the aggregate is at most 10%. Other contributions originate mainly in requirements on infrastructure and transport processes. Although the impact contributions vary with concrete composition, cement type and content, the main contribution is, in all categories, always from the cement.

On considering the asphalt construction methods, it was found that the use of porous asphalt leads to the highest potential environmental impact in the categories ODP, POCP, AP und EP. This is due to the high binder content of the asphalt surface layer, the aggregate, and the additional sealing measures. Differences in the environmental impact ODP for the various construction methods are insignificant. The use of 100% recycled material in the frost blanket (scenario B) lowers the environmental impact in all categories by 10 (ODP) to 26% (EP). For all categories, the largest proportion of the potential environmental impact originates in the asphalt itself.

The contribution of the frost blanket ranges from 11 to 31%, depending on the category, and is largest for the eutrophication potential. The base layer yields by far the largest part of the potential impact. It is, depending on the category, between 38 (EP) and 57% (ODP) and is higher for construction with mastic asphalt because sealing is not necessary. The amount for the binder layer lies between 17 (ODP) and 23% (POCP), depending on construction method and category. The sealing measures required by the porous asphalt construction method contribute between 3 (GWP) and 7% (ODP) to the total potential environmental impact. Thus the contribution from the surface layer ranges from 9 to 14%, depending on construction method and category.

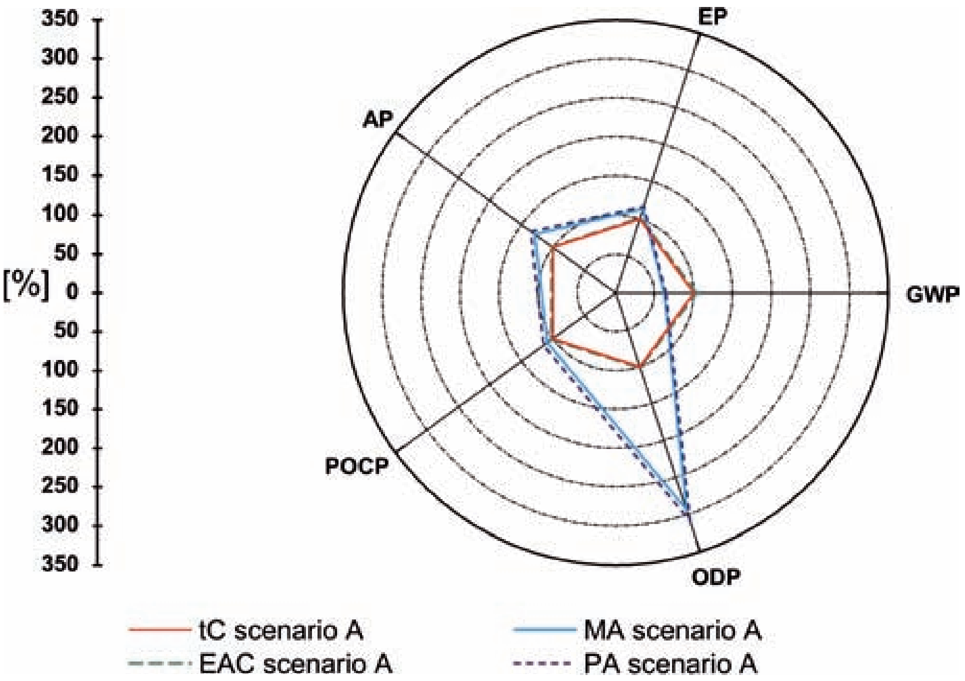

Fig. 6 – Results of assessment of environmental impact for pavement construction with concrete and asphalt, scenario A. (tC = pavement with textured concrete surface; EAC = pavement with exposed aggregate concrete surface layer; MA = pavement with mastic asphalt surface layer, PA = pavement with porous asphalt surface layer)

Fig. 6 shows the impact indicators for motorway production with asphalt and concrete in scenario A. Apart from the global warming potential, the potential environmental impact for construction with concrete was found to be lower than with asphalt. The GWP impact of the concrete construction method is up to 1.66 times higher than the asphalt construction method. The largest contribution to GWP is delivered by the Portland cement in the surface concrete, the Portland composite cement in the hydraulically bound base course and, at about 10%, the transport processes needed for the frost blanket. It should be borne in mind that the asphalt considered is porous asphalt, special asphalt only used to fulfil noise protection requirements when this cannot be achieved by other measures.

An overview of the potential environmental impact for the production of 1 km motorway is presented in Table 4.

TABLE 4 – ENVIRONMENTAL IMPACT INDICATORS FOR THE CONSTRUCTION OF 1 KM MOTORWAY

	Global warming potential (GWP)	Depletion of the stratospheric ozone potential (ODP)	Photo-oxidant formation potential (POCP)	Acidification potential (AP)	Eutrophication potential (EP)
	[kg CO_2-eq.]	[kg CFC-11-eq.]	[kg C_2H_4-eq.]	[kg SO_2-eq.]	[kg PO_2^{3-}-eq.]
MA scenario A	1 694 573	0.39	413	8 191	1 232
MA scenario B	1 425 044	0.35	346	6 623	919
PA scenario A	1 730 430	0.40	431	8 516	1 264
PA scenario. B	1 446 198	0.36	361	6 892	940
tC scenario A	2 710 311	0.13	380	6 374	1 084
tC scenario B	2 339 814	0.09	308	4 644	742
tC scenario C	2 153 620	0.13	344	6 343	1 079
EAC scenario A	2 821 219	0.13	389	6 478	1 100
EAC scenario B	2 474 597	0.09	317	4 748	758
EAC scenario C	2 227 417	0.13	350	6 447	1 094

3.4. EVALUATION

Owing to the large variation in available information, the values chosen for the machines and fuel needed to place the mixtures of materials in the different layers were somewhat pessimistic. Their effect on the total potential environmental impact of the pavement was small, ranging from 2 (GWP) to at most 9% (POCP). The potential environmental impact originates essentially in the materials. Especially the energy-intensive production of cement and asphalt is decisive. It is between about 57 and 66% in scenario A.

The LCA for the production of a motorway section has shown that the use of CEM III/A instead of Portland cement can reduce the environmental impact by up to 21%. The potential for a further reduction in impact by improving the process engineering of cement production is generally considered to be exhausted.

The use of 100% recycled material for the frost blanket reduces the potential impact by amounts of 10 (ODP) and 31% (EP) in the cases examined. Heavy goods vehicles accounted mainly for the transport of materials. As well as reducing transport processes in general, a reduction in impact may be achieved by the partial use of transport which has less adverse effects on the environment (e.g. rail). The ODP is very much affected by the actual transport processes involved.

In the case of the asphalt construction method, further impact reduction may be achieved by process engineering and optimization of the material itself.

Comparison of the different construction methods with concrete and asphalt has shown that their effect on POCP and EP is similar. For ODP the asphalt construction methods cause a potential environmental impact which is 300% more than with concrete. In the case of AP, the impact is 135% more with asphalt. In contrast, the potential impact of concrete construction methods for category GWP is 166% that of the asphalt construction methods.

4. LCA FOR THE USE OF MOTORWAYS

4.1. SCOPE OF INVESTIGATIONS

In this study, motorway usage encompasses use by traffic and maintenance work. A usage period of 30 years was considered in which constructional measures to maintain a motorway were included along with typical traffic conditions, i.e. a traffic scenario with a volume of 52 000 vehicles in 24h (42 000 cars, 10 000 heavy goods vehicles). In scenario A, the standard fuel consumption was taken as the European average of 0.286 kg/km diesel for heavy goods vehicles and, for cars, 0.0125 kg/km diesel or 0.0536 kg/km petrol (Spielmann et al., 2004).

Traffic contributes a major proportion of the total emission of air pollutants in Europe. To quantify the reduction potential of environmental impact caused by traffic, besides scenario A, three additional scenarios were investigated.

- Scenario B: 0.5% fuel saving,
- Scenario C: 2.0% fuel saving
- Scenario D: 10.0% fuel saving for heavy goods vehicles

The additional scenarios chosen were inspired by literature studies which revealed a clear effect of pavement properties on fuel consumption. The system boundaries for the traffic scenarios are illustrated by the dashed lines in Fig. 7. For diesel vehicles merely the combustion process and different types of abrasion were taken into account, whilst for passenger cars also cold start emissions and standstill evaporation were included.

As well as traffic load, constructive maintenance measures were also taken into account in the period of usage. In the case of the asphalt construction methods, the replacement of the complete asphalt surface layer was modelled. For concrete construction methods, maintenance of joints, renovation of broken edges and corners, lifting and fixing of slabs as well as the replacement of complete slabs were taken into account. The system boundaries are shown in Fig. 8. All environmentally relevant factors including all upstream chains (raw materials production, freight, production of materials, production of machines and their use etc.) were determined and analysed.

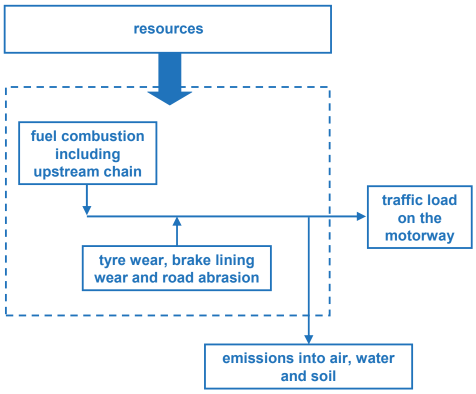

Fig. 7 – System boundaries for use of a motorway by traffic (dashed lines)

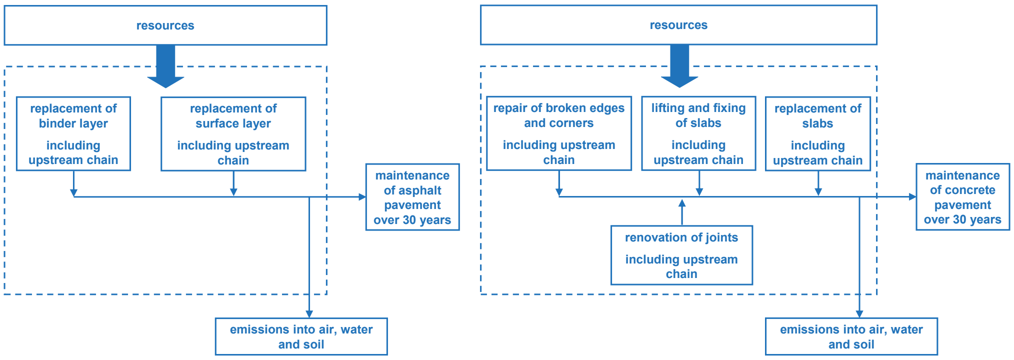

Fig. 8 – System boundaries for motorway maintenance (dashed lines). Left: asphalt pavement, right: concrete pavement

Since constructive maintenance depends on numerous parameters which cannot all be quantified in a LCA study, a minimum maintenance scenario (A) and a maximum maintenance scenario (B) based on field experience were defined. In scenario B, the joints were completely renovated three times in the period of use. In addition, 3% of the slabs were lifted and fixed. A further 3% of the slabs were replaced. 20% of the edges and corners were repaired by injecting a two-component resin. For the mastic asphalt variation, the binder and surface layers were renewed twice in the analysis period. The surface layer of the porous asphalt pavement was renewed after intervals of seven years; the binder layer was replaced once in the period of service studied. An overview of the maintenance scenarios investigated in this study is in Table 5.

TABLE 5 – OVERVIEW OF THE MAINTENANCE SCENARIOS FOR 1 KM MOTORWAY

Asphalt constructions		**Concrete constructions**
Pavement with mastic asphalt surface layer (MA)	Pavement with porous asphalt surface layer (PA)	Pavement with textured concrete surface (tC) or exposed aggregate concrete surface layer (EAC)
Scenario A: 2x replacement of surface layer 1x replacement of binder layer	**Scenario A:** 3x replacement of surface layer 1x replacement of binder layer	**Scenario A:** 2x complete renovation of joints 5% repair of broken edges and corners 1% lifting and fixing of slabs 1% replacement of slabs
Scenario B: 2x replacement of surface layer 2x replacement of binder layer	**Scenario B:** 4,3x replacement of surface layer 1x replacement of binder layer	**Scenario B:** 3x complete renovation of joints 20% repair of broken edges and corners 3% lifting and fixing of slabs 3% replacement of slabs

4.2. INVENTORY ANALYSIS

All environmentally relevant data for processes relevant to the usage of the motorway section were determined and modelled with the ecoinvent database.

In order to model traffic load, the work of (Spielmann 2004) was adapted by the (Umweltbundesamt, 2009) to the current situation in Germany as far as possible. Heavy goods vehicles comprised 40% vehicles with a transport weight between 3.5 and 20 t, 31% with a weight between 20 and 28 t and 29% with a weight between 28 and 40 t. A vehicle utilization of 50% was assumed for all vehicle types. The manufacture and servicing of the vehicles was not included in the LCA. However, the emission of dust from tyres, brake liners and road wear was included in the outputs.

In the case of the asphalt construction methods, the removal of old layers is modelled by a cold milling machine (45 t, 647 kW). The milled surface is cleaned with a brushing machine and sprayed with an adhesive. An application of 0.3 kg/m^2 unstable cationic bitumen emulsion was assumed in this study. The placement of new layers was carried out in the same manner as the original production.

Basically the same materials were employed in the maintenance of the concrete pavement as in construction. A detailed description of the materials and machines considered in the assessment is in (Milachowski et al., 2010). The following table merely lists several of the most important input parameters.

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TABLE 6 – OVERVIEW OF THE MAIN MATERIALS AND MACHINES TAKEN INTO ACCOUNT FOR CONSTRUCTIVE MAINTENANCE OF THE CONCRETE PAVEMENTS

Layer	Material		Machines
1x joint renovation	4.3 t/km joint filler		compact loader, compressors, brushing machines and bitumen cauldron
1% repair of broken edges and corners	0.4 kg/m² adhesive bridge 1.15 kg/m³ two-component resin		jack hammer, shot blasting machine, small compressor and mixer
lifting and fixing of 1% of the slabs	2.95 m³/km repair mortar		compressor, drill, concrete pump and vibration roller
replacement of 1% of the slabs	Pavement concrete: 56.7 m³/km high-early-strength concrete 0.45 t/km steel 0.11 t/km curing agent	Exposed aggregate concrete: Same materials as in production phase	Pavement concrete: concrete cutter, drill, jack, dowel and anchor machine, concrete pump, poker vibrator, smoother Exposed aggregate concrete: in addition one brushing machine

The construction machines used for motorway maintenance were based on information supplied by companies and recommendations in the list of construction appliances published by the Confederation of the German Construction Industry.

A distance of 50 km was taken for the transport of old and new materials to and from the site. In analogy to the production process, only the delivery and removal of the construction machines was considered with regard to the installation of the construction site.

4.3. IMPACT ASSESSMENT

The results of the analysis for the maintenance of asphalt and concrete pavement over a service period of 30 years are shown in Fig. 9. All the impact categories for the maintenance measures show much less environmental impact for the concrete pavement than for the asphalt pavement.

The assumed traffic load of 42 000 cars and 10 000 heavy goods vehicles per day results in an environmental impact which is up to 5 000 times higher than the impact of pavement maintenance. The potential environmental impacts for the 1 km motorway section are presented in Table 7.

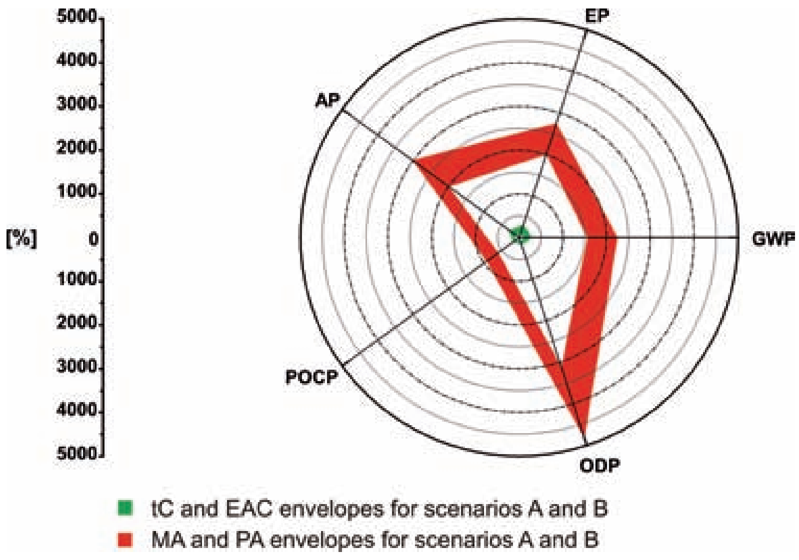

Fig.9 – Envelopes for the results of the impact assessment for the maintenance of 1 km motorway: asphalt and concrete construction methods. (tC = pavement with textured concrete surface; EAC = pavement with exposed aggregate concrete surface layer; MA = pavement with mastic asphalt surface layer, PA = pavement with porous asphalt surface layer)

TABLE 7 –ENVIRONMENTAL IMPACT INDICATORS FOR MAINTENANCE AND USE BY TRAFFIC OF 1 KM MOTORWAY

	Global warming potential (GWP)	**Depletion of the stratospheric ozone potential (ODP)**	**Photo-oxidant formation potential (POCP)**	**Acidification potential (AP)**	**Eutrophication potential (EP)**
	[kg CO_2-eq.]	[kg CFC-11-eq.]	[kg C_2H_4-eq.]	[kg SO_2-eq.]	[kg PO_4^{3-}-eq.]
MA scenario A	944 116	0.21	272	5 249	723
MA scenario B	1 230 617	0.27	352	6 808	943
PA scenario A	1 048 154	0.24	316	6 028	764
PA scenario. B	1 363 116	0.33	423	7 986	3 718
tC scenario A	60 520	0.01	46	265	36
tC scenario B	170 920	0.01	81	742	110
EAC scenario A	63 971	0.01	46	270	37
EAC scenario B	181 274	0.01	82	756	113
Traffic scen. A	230 904 557	29.84	167 980	1 066 521	202 078
Traffic scen. B	229 750 034	29.69	167 140	1 061 189	201 067
Traffic scen. C	226 286 466	29.24	164 620	1 045 191	198 036
Traffic scen. D	220 146 604	28.30	166 410	1 008 952	189 865

4.4. EVALUATION

The impact reduction potential for maintenance measures in scenario A (minimum maintenance) compared to scenario B (maximum maintenance) lies between 20 and 60% depending on the impact category. For the GWP this means a reduction of 110 to 370 t CO_2-eq. Optimization of environmental impact potential for the constructive maintenance of concrete motorways is specified mainly in the durability of the joint fillers. By reducing transport processes the potential environmental impact could be reduced significantly for all types of pavement constructions. Impact reduction potential is also available in the optimization of the construction materials and in the precision of their application. Mixed construction methods could exploit more effectively the advantages of the different types of materials. For example, in construction with asphalt on concrete, concrete provides for the overall durability of the pavement while asphalt has a positive effect on noise reduction.

Motorway pavement maintenance for the concrete construction methods over a service period of 30 years leads, compared with asphalt pavement, to significantly lower potential environmental impacts in all categories. Hence, investment in durable motorway construction is rewarded in the service phase.

The largest potential impact reduction lies in lowering fuel consumption since the impact is mainly due to the combustion of fossil fuel. Fuel consumption is determined by many factors. In the past, numerous investigations concentrated on the effect of road surfaces (rolling resistance, flatness, stiffness) on fuel consumption. Road surface properties such as texture, unevenness (macro and mega texture) and pavement stiffness can reduce fuel consumption by 5 to 20%. Optimization potential is therefore available in pavement construction as well in car and tyre manufacture.

5. CONCLUSIONS

Comparison of the environmental impact of concrete and asphalt pavement for motorway construction and maintenance shows that their effect on GWP is similar. For ODP the asphalt pavement causes a potential environmental impact which is 430% more than with concrete. In the case of POCP, AP and EP the impact is from 160% to 220% more with asphalt.

The present study shows that the environmental impact due to the construction of motorways, their use by traffic and their maintenance can be reduced. The potential environmental impact can be reduced by optimizing the production of the construction materials. In the case of concrete motorways, a reduction in the clinker content of the cement would reduce environmental impact by up to 21%; in the case of the asphalt motorways, the use of secondary fuels and the increased reuse of reclaimed asphalt would also reduce environmental impact. The evaluation of a service period of 30 years shows that durable construction methods and roads with low maintenance requirements offer significant advantages. The potential environmental impact due to traffic load is 100 times more than due to construction and maintenance together – the largest and most effective reduction in impact is possible here. Numerous studies have already shown the effect of pavement surface structure on fuel consumption. A reduction in fuel consumption of about 10 % could be achieved by the improvement of pavement surface texture or evenness as well as pavement stiffness. Further investigations and measures on pavement optimization would lead to more effective reduction of the environmental impact of roads. A reduction of fuel consumption of 0.5% over a service period of 30 years and for a 1 km motorway section would reduce CO_2 emission by 1 154 t CO_2-eq. A reduction of fuel consumption by 2% would lead to a reduction in CO_2 emission (GWP) well above the impact of motorway construction and maintenance together. A reduction of 10% fuel consumption for just heavy goods vehicles would save 10 760 t CO_2-eq. Thus construction methods aimed at lowering fuel consumption are far more environmentally effective than construction methods tailored to low impact during construction and use.

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REFERENCES

DESCORNET, G.: “Road Surface Influence on Tire Rolling Resistance.
Surface Characteristics of Roadways:” International Research and Technologies,
ASTM STP 1031, p. 401-415, Philadelphia, 1990

ISO 14040 (2006): Examples of environmental performance evaluation LCA
(Life Cycle Assessment)

ISO 14044 (2006): Environmental management – Life cycle assessment – Requirements and guidelines

FORSCHUNGSGESELLSCHAFT FÜR STRASSEN- UND VERKEHRSWESEN FGSV (2009):
Richtlinien für die Anlage von Autobahnen (RAA); Ausgabe2008 (German)

http://www.ecoinvent.ch. 2009

KELLENBERGER D., ALTHAUS H.-J.; KÜNNIGER T. (2004): “Building Products Part III:
Concrete Products and Processes”. ecoinvent report No. 7,
Swiss Centre for Life Cycle Inventories, Dübendorf

KELLENBERGER, D.; ALTHAUS, H.-J.; WERNER F. (2004): “Building Products Part XVIII:
Additional Products and Processes”. ecoinvent report No. 7,
Swiss Centre for Life Cycle Inventories, Dübendorf

LAGANIER, R.; LUCAS, J. (1990): “The Influence of Pavement Evenness and Macrotexture on
Fuel Consumption.” Surface Characteristics of Roadways: International Research
and Technologies, ASTM STP 1031, p. 454-459, Philadelphia

LARSSON, R.; ANDERSSON, R. (2004): “Benefit of Reduced Fuel Consumption”.
Economic and Environmental Perspectives – A Novel Approach, 9th International
Symposium on Concrete Roads, Istanbul

LUNDSTRÖM, K.; FINNSEMENTTI, O. (2003): “Environmental Impact of Concrete
and Asphalt Pavements”. 8th International Symposium on Concrete Roads, Lissabon

MILACHOWSKI, C.; STENGEL T.; LOWKE D.; GEHLEN C. (2010) „Erstellung einer Ökobilanz
für die Herstellung und Nutzung eines Autobahnabschnitts“. Forschungsbericht 20-F-0068,
TU München, München

NRC-CSTT (2000): „Effect of Pavement Surface Type on Fuel Consumption –
Phase 2: Seasonal Test”, CSTT-HWV-CTR-041, National Research Council of Canada –
Centre for Surface Transportation Technology, Ottawa

PANTAROLLO, G.; SMITH, T. (2001): “A life-cycle analysis of the environmental impacts of
asphalt and concrete roads”. IRF World Road Congress, Paris

SLAVIK, M.; PERRIE, B.D.; STRAUSS, P.J. (2004): “Life Costing and Reliability Concepts
in Concrete Pavement Design: The South African Approach”,
9th International Symposium on Concrete Roads, Istanbul

SPIELMANN M.; KÄGI T., STADLE P., TIETJE O. (2004): “Life Cycle Inventory
of Transport Services”. ecoinvent report No. 14, Swiss Centre for Life Cycle Inventories,
Dübendorf

UMWELTBUNDESAMT (2009): „Nationale Trendtabellen für die deutsche Berichterstattung
atmosphärischer Emissionen, Emissionsentwicklung 1990-2007 (Endstand 20.02.2009)“,
www.umweltbundesamt.de/emissionen/publikationen.htm

ZANIEWSKI, J. (1989): “Effect of Pavement Surface Type on Fuel Consumption”.
SR289.01P Portland Cement Association, Skokie

Published by :

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July 2011

EUPAVE Managing Director Luc Rens hands over the "Best Marketing Paper Award" to Mrs. Charlotte Milachowski.

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The study presented in this document was ordered by the German Concrete Marketing Organisation "*Betonmarketing Deutschland GmbH – Erkrath, DE – www.beton.org*" at the Centre for Building Materials, Technische Universität München, Germany.

EUPAVE wishes to thank both institutions for granting the permission to reproduce the research report in this brochure.

Mrs. Charlotte Milachowski presented the study in a paper and presentation during the 11th International Symposium on Concrete Roads, that was held in Seville, Spain, 13-15 October 2010 . For this outstanding contribution, she was given the "*BEST MARKETING PAPER AWARD*".