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Environmental Potentials within the Production of Asphalt Mixtures

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Abstract**—**The paper shows examples for the (environmental) optimization of production processes for asphalt mixtures applied for typical road pavements in Austria and Switzerland. The conducted "from-cradle-to-gate" LCA firstly analyzes the production one cubic meter of asphalt and secondly all material production processes for exemplary highway pavements applied in Austria and Switzerland. It is shown that environmental impacts can be reduced by the application of reclaimed asphalt pavement (RAP) and by the optimization of specific production characteristics, e.g. the reduction of the initial moisture of the mineral aggregate and the reduction of the mixing temperature by the application of low-viscosity and foam bitumen. The results of the LCA study demonstrate reduction potentials per cubic meter asphalt of up to 57 % (Global Warming Potential–GWP) and 77 % (Ozone depletion–ODP). The analysis per square meter of asphalt pavement determined environmental potentials of up to 40 % (GWP) and 56 % (ODP).

Keywords**—**Asphalt mixtures, environmental potentials, life cycle assessment, material production.

I. INTRODUCTION

TRANSPORT causes about 25% of the carbon emissions (Global Warming Potential – GWP) emissions of the EU-27 countries, with fuel consumption causing the biggest part of transport emissions [1]. Therefore, a great research effort is put on energy efficient transport vehicles.

In recent years several Life Cycle Assessment (LCA) [2] studies aiming to analyze and optimize transport infrastructure itself regarding a variety of environmental indicators have been carried out [3]-[5]. Thereby Life Cycle Inventory (LCI) datasets offered by the most common LCI-databases, e.g. ecoinvent or GaBi, have been applied. These datasets generally reflect average national, European or international processes needed to construct and maintain the transport infrastructure. Thus, for a first analysis modeling the construction and maintenance (C&E) phases of the infrastructure and showing the influence of C&E in comparison to (changed) traffic characteristics of the analyzed transport system, these average standard processes are suitable.

If in a next step of the LCA study the C&E processes should be optimized, a deeper look into all relevant life cycle phases needs to be taken. Thereby the involved processes can be analyzed on a local, regional or national level, depending on the set system boundaries enclosing the transport system within which the infrastructure is built.

The material production phase offers great reduction potentials due to the great energy intensity of production processes and due to a lot of materials embedded in the infrastructure. The application of

- alternative raw materials,
- secondary (recycling) raw materials,
- alternative and secondary fuels and
- optimized production technics and characteristics

can be named as "set screws" to optimize the production of materials applied to construct the infrastructure [6].

This paper shows examples of the (environmental) optimization of production processes of typical asphalt mixtures applied for road pavements in Austria and Switzerland [7], [8]. Asphalt mixtures for the different layers of asphalt pavements (from the wearing course on top down to the road base layer) will be considered. The subbase layers in both countries generally consist of unbound mineral aggregate and is nit considered in this study.

The results of the conducted "from-cradle-to-gate" LCA study will first be demonstrated for the unit of "one cubic meter" of asphalt. In a second step, results will be shown for exemplary highway pavements applied in Austria and Switzerland, i.e. for a functional unit of "one square meter of road pavement".

II. PAVEMENTS AND MATERIALS

A. Pavements

The LCA study analyzes asphalt mixtures applied for typical road pavements applied for highway constructions. The general superstructure of the analyzed pavements can be seen in Fig. 1.

The asphalt mixtures applied for the different layers need to fulfill a variety of characteristics depending on the layer type, traffic load, required noise and safety properties and further project specific requirements. In order not to get into great detail concerning the material selection for each pavement layer asphalt pavements recently applied for highway constructions in Austria and in Switzerland were selected to be analyzed by the LCA study. The material type and the size of each layer of these pavements can be seen in Table I.

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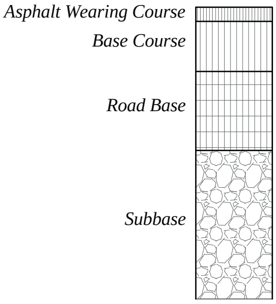

Fig. 1 Pavement superstructures

The asphalt mixtures and their production processes are analyzed as detailed as possible and reasonable. The LCA methodology and LCI datasets applied to limit the level of detail for example due to the fact that there are just one dataset for bitumen describing the average bitumen production in Europe. Therefore, the influence of production process of the specific bitumen types applied within the different asphalt mixtures cannot be determined. Thus, the bitumen type is not stated in the mixture abbreviation (as required in the European standard EN 13108-1) [9]. A detailed study of the bitumen production needs to be carried out in cooperation with the bitumen industry and would be too extensive for this study. Furthermore, the grading curve of the applied mineral aggregate cannot be modeled in detail since there are simply datasets for “crushed gravel”, “round gravel”, and “sand”.

TABLE I
ANALYZED PAVEMENTS

Asphalt pavements	***Austria***	*[cm]*	***Switzerland***	*[cm]*
Wearing Course	SMA 11	3,5	AC MR 8	3
Base course	AC 22 binder	9	AC 22 binder	9
Road base	AC 22 binder	12,5	AC 32 trag	14
Subbase	Unbound subbase	50	Unbound subbase	40

Note: AC = asphalt concrete; 11, 22, 32 = upper face value of the largest used mineral aggregate; MR = rough-textured wearing course; binder = asphalt mixture for base course; trag = asphalt mixture for road base

B. Asphalt Mixtures

Data on asphalt production was gathered by a survey, analyzing 25 % of all Swiss asphalt production companies producing 22 % of the overall Swiss sales. In Austria, the survey is in a kick-off phase at the moment. The Austrian production characteristics for asphalt mixtures can be seen as akin to the Swiss asphalt production due to the similar (asphalt) industry characteristics and the geographic situation. Thus to model the asphalt production in Austria the data of the Swiss data is adapted to the Austrian situation (e.g. electricity mixture). The questionnaire used for the survey in Switzerland was prepared in cooperation with the Swiss Bituminous Mixture Association to collect data regarding production volumes, mixture compositions, energy use, internal transports, transport distances of sub-suppliers, emissions and auxiliary materials.

Asphalt mixtures generally consist of mineral aggregate, asphalt binder (i.e. bitumen), and optional additives (e.g. limestone filler). The survey showed that the analyzed mixtures have a density between 2’327 and 2’409 kg/m3 and a bitumen content of 3.9 to 6.6 %. The utilized mineral aggregates for the asphalt mixtures contain 95 % crushed gravel and 5 % round gravel. The applied filler consists of 50 % internally generated filler and 50 % limestone filler. As mentioned before, for this LCA study production data for average Swiss bitumen was applied, as no specific data for the specific bitumen types are available at the moment.

Batch mixing plants can be seen as a state of the art for asphalt production. The survey demonstrated an average heat requirement of 316.4 MJ for one ton of asphalt and average initial moisture of the mineral aggregate of 4 %. A furnace heated by light fuel oil or gas provides the needed energy to dry and heat the mineral aggregate and perhaps applied reclaimed asphalt pavement (RAP). For this study, the fuel types used are assumed to be 50 % gas and 50 % oil. At the moment 35 % of the required heat is used for drying the mineral aggregate and 51 % for heating it up to 180 °C. 4 % of the heat is lost through insulation and 10 % of emissions. The bitumen is heated in an electrically heated tank.

C. Reduction Potentials for Asphalt

The Austrian and the Swiss asphalts base on European standard EN 13108-1, which generally does not limit the amount of reclaimed asphalt pavement (RAP) replacing primary raw materials. It is mentioned that the amount of RAP applied needs to be coordinated with the required material properties. However, the Swiss asphalt standard mentions in a national appendix specific amounts of primary material, which can be replaced by RAP [10].

TABLE II
MAXIMUM SHARE OF RAP

Maximum share of reclaimed asphalt pavement	**Cold recycling**	**Warm recycling**
Wearing courses	0	0
Base courses	≤ 15	≤ 30
Road bases	≤ 25	≤ 60

The options for the usage of RAP for asphalt production are either warm or cold recycling. During the warm recycling process, RAP is heated up in a parallel process to the heating of the mineral aggregate. Cold recycling means that RAP is added to the already heated mineral aggregate before the mixing process. The two options do not exclude each other and can be applied at the same time.

An optimized storage i.e. covered storages or silos, reduces the initial moisture of the mineral aggregate to 2 % and with the use of low viscosity bitumen or foam bitumen the mixing temperature could be reduced from 180 °C to 115 °C. This production optimization lowers the required drying and heating energy as well as the losses throughout insulation and emissions.

III. LIFE CYCLE ASSESSMENT

A. Methodology

Life Cycle Assessments (LCA) [2] analyze products and services regarding environmental impacts over their entire life cycle. This LCA study applies the "from-cradle-to-gate" approach, which comprises all environmental impacts from the primary resource extraction to the finished product, i.e. the warm asphalt mixture leaving the production plant.

Life Cycle Inventory (LCI) is the part of the LCA, which quantifies all relevant inputs (energy and resources) and outputs (waste and emissions) connected the analyzed product system (i.e. the production of asphalt mixtures). All inputs and outputs are related a functional unit, which describes the specific function and therefore generated a benefit of the analyzed product system. For this study the functional unit was set as "the production of one cubic meter of asphalt mixture" and the production all asphalt mixtures applied within one square meter of asphalt pavement".

Concerning the allocation of recycled materials, the cut-off rule is applied for this study, i.e. for the analysis of the production processes it is assumed that the upgrading to usable recycling materials (RAP) is part of the previous life cycle system. Hence, the first process included in the analyzed system is the transport from the RAP storage to the place of production. The milling of the deconstructed asphalt pavement and the transport to the storage is not included in the analysis.

The Life Cycle Impact Assessment (LCIA) sorts, characterizes, weights and aggregates the inputs and outputs quantified in the LCI in accordance with the selected environmental indicators and their characterization factors. The environmental indicators used for this study are:

- Global Warming Potential (GWP) [kg CO_2-eq]
- Ozone depletion (ODP) [MJ-eq]

B. Analysis of Asphalt Production

The study analyzes a "no recycling mixture" (NR) and a "maximum recycling mixture" (MR) for each asphalt type analyzed according to the recycling limits given by the national appendix of the Swiss asphalt standard, in order to demonstrate the reduction potentials given by this limitation of the recycling content. As already mentioned before, the optimized production characteristics require the application of low-viscosity or foam bitumen. Due to the fact that there is only one dataset for bitumen covering the average European production, the impact of the application of the alternative bitumen types cannot be determined in the LCA study.

The emissions to air stated were also determined by survey analyzing 25 % of all Swiss asphalt producers. Table III shows the compositions of all asphalt mixtures analyzed. Furthermore, two different production scenarios, one with standard (SP–180 °C mixing temperature, 4% initial moisture) and one with optimized production conditions (OP–application of low-viscosity or foam bitumen, 115 °C mixing temperature, 2 % initial moisture), will be studied.

Table IV shows energy resources, operating materials and emissions are taken into account for the asphalt production. It is assumed that there is no difference between the standard scenarios and the optimized scenarios for the different asphalt mixture types.

TABLE III
ASPHALT MIXTURE COMPOSITIONS

	SMA 11	**AC MR 8**	**AC 22 binder**		**AC 32 trag**	
Material [kg/m³]	**(NR)**	**(NR)**	**(NR)**	**(MR)**	**(NR)**	**(MR)**
Filler - limestone	120,5	93	76,5	42	72,5	11
Filler - internal	120,5	93	76,5	42	72,5	11
Sand	385	470	567	299	527	76
Gravel, crushed	1543	1462	1505	839	1554	236
Gravel, round	81	77	78	45	81	12
Bitumen	159	132	102	55	93	14
RAP - cold	0	0	0	361	0	600
RAP - warm	0	0	0	722	0	1440
Density [kg/m³]	**2409**	**2327**	**2405**	**2405**	**2400**	**2400**

TABLE IV
PRODUCTION CHARACTERISTICS FOR ALL ASPHALT TYPES

Inputs pro m³	**Standard production**	**Optimized production**
Electricity, medium voltage, supply mix CH/ AT [kWh/m³]	20,6	20,6
Heat, natural gas, at industrial furnace >100kW [MJ/m³]	366,5	211,0
Heat, light fuel oil, at industrial furnace 1MW [MJ/m³]	366,5	211,0
Diesel, burned in building machine [MJ/m³]	26,6	26,6
Transport, lorry 20-28t, fleet average [tkm/m³]	137,0	137,0
Concrete mixing plant [p/m³]	6,0E-07	6,00E-07
Lubricating oil [kg/m³]	7,2E-03	7,20E-03
Tap water, at user [kg/m³]	20,4	20,4
Emissions to air pro m³		
NMVOC, non-methane volatile organic compounds [kg/m³]	1,2E-04	1,20E-04
Nitrogen oxides [kg/m³]	2,9E-05	2,90E-05
Particulates, < 10 um [kg/m³]	1,1E-06	1,10E-06

TABLE V
RESULTS OF THE "FROM-CRADLE-TO-GATE" LCA STUDY PER M³

Asphalt type	**SMA 11**		**AC MR 8**	
Production Option	SP	OP	SP	OP
Recycling Scenario	NR	NR	NR	NR
GWP 100a kg (kg CO_2-eq/m³)	187	184,5	166	163,5
Ozone depletion (kg CFC-11-eq/m³)	2,9E-08	2,9E-08	2,9E-08	2,9E-08
Asphalt type	**AC 22 binder**			
Production Option	SP		OP	
Recycling Scenario	NR	MR	NR	MR
GWP 100a kg (kg CO_2-eq/m³)	144	99,5	141,5	97
Ozone depletion (kg CFC-11-eq/m³)	3,2E-08	1,9E-08	3,2E-08	1,9E-08
Asphalt type	**AC 32 trag**			
Production Option	SP		OP	
Recycling Scenario	NR	MR	NR	MR
GWP 100a kg (kg CO_2-eq/m³)	136,5	61	134	58,5
Ozone depletion (kg CFC-11-eq/m³)	3,2E-08	7,3E-09	3,2E-08	7,3E-09

C. Results

Table V demonstrates the results of the conducted LCA study per cubic meter of the asphalt mixture. The results showed that production characteristics in Austria and Switzerland are very similar and that the difference between the results for the two countries is marginal. Therefore, the results in Table V represent the results for both countries.

Due to great recycling content, AC 32 trag offers the biggest reduction potentials given by the application of RAP (GWP – 55 %, ODP – 77 %).

For wearing course mixtures no RAP was applied. Therefore only the reduction potential of 2,5 kg CO2-eq given by the optimized production characteristics can be achieved. The optimized production characteristics do not offer reduction potentials regarding OPD, due to the fact that “gravel, crushed” dataset mainly influences this environmental indicator. The reduction potentials offered by optimized production characteristics are similar for all analyzed asphalt mixtures because it was assumed that the heating energy is reduced by the same amount for all asphalt types. Thus, the maximum achieved reduction of environmental impacts by the application of RAP and optimized production characteristics can be stated as 57 % (GWP) and 77 % (ODP) for the AC 32 trag mixture.

TABLE Table VI demonstrates the result for the typical Austrian and Swiss highway pavements and shows the differences between the “standard pavements” (NR, SP) and the “optimized pavements” (MR, OP)

TABLE VI
RESULTS OF THE “FROM-CRADLE-TO-GATE” LCA STUDY PER M^2

Country	**Austria**		**Switzerland**	
Pavement type	*Standard*	*Optimized*	*Standard*	*Optimized*
GWP 100a kg (kg CO_2-eq/m^3)	37,5	27,5	37	22
Ozone depletion (kg CFC-11-eq/m^3)	7,9E-09	5,1E-09	8,2E-09	3,6E-09

The results demonstrate reduction potentials of up 40 % (Switzerland, GWP) and 56 % (Switzerland, ODP) given by the application of RAP and the optimized production characteristics.

The difference between the Austrian and the Swiss pavements is not discussed in detail because the Swiss pavement applies the AC 32 trag mixture with a higher RAP content and therefore higher reduction potentials. As mentioned before the analyzed pavements are examples for recently applied pavements for highway constructions in each country. Austrian pavements do not necessarily contain a “binder mixture” as the third layer and could also use “trag mixtures”, which would lower the results for the “optimized pavement” due to a higher RAP content.

IV. CONCLUSION

The determined environmental reduction potentials demonstrate the general possibilities regarding environmental improvements within the asphalt industry sector. Some of these reductions of environmental impacts can be achieved without substantial financial investments, e.g. covered storages to lower the initial moisture of the mineral aggregate. Other reduction potentials, such as the application of RAP, are connected with technical improvements of the asphalt mixing plants and therefore with financial burdens for the asphalt producer. However, the saving of primary raw materials and possible financial incentives (for asphalt producers and construction companies) offered by road administrations for the application of recycling asphalt (as it is done for example by the Tyrolean Road Administration in Austria) can amortize these investments.

This study did not consider a number of details connected to asphalt production, which might be of importance for the environmental results. For example, the production of low-viscosity and foam bitumen might cause more environmental burdens than the production of standard bitumen due to the application of additives and additional production processes. Furthermore, the study did not consider the influence of lower mixing temperatures on construction processes. The lower temperature might influence the workability of the asphalt mixture, what might affect the construction process of the specific asphalt layers. Transport distances from the mixing plant to the building site also have their environmental effect. If for example recycling asphalt produced with optimized production technology needs to be transported over long distances, the transport process will compensate the environmental reduction potentials of the asphalt production.

This paper demonstrates results two different environmental indicators. In order to get a widespread environmental analysis, the materials and pavements need to be analyzed regarding more indicators (e.g. cumulative energy demand, photochemical oxidation, etc.).

Therefore, in order to get more significant results, the road infrastructure needs to be analyzed over its entire life cycle focusing on a variety of environmental indicators. However, this study showed that production processes of asphalt mixtures can contribute their (environmental) part to more sustainable (road) infrastructures.

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