Preliminary summary of the eco-balance of Granulate Rubber Modified (GRM by CTS)

The modification of bitumen is to give traditional road construction bitumen changed properties in order to meet the increased requirements of road traffic (e.g. increased heavy traffic volumes, climatic conditions). For example:

1. Increase in viscosity
2. Expanded plasticity span, i.e.:
   - Increase of the ring and ball softening point
   - Improvement of the low-temperature behaviour
3. Increase in elasticity
4. Improved adhesive behaviour on adhesion-critical aggregates
5. Increased cohesion
6. Improved ageing behaviour
7. Improved resistance towards climatic effects (e.g.: solar radiation)

Currently, approximately 25 – 30% of the usual binding agents in Germany are modified (this includes all possibilities and forms of modification).

In the area of modified road construction bitumen, the group of elastomer-modified binding agents has established itself - in Germany, nota bene. Plastomers for exclusive modification have never really been used across the board. These have remained “on the fringes”, both technologically and economically (despite good asphalt-technological properties). Although these have even been specified in the regulations (TL Bitumen StB 07/13, Table 3).

Therefore, the umbrella term PmB (polymer-modified bitumen) essentially describes the group of elastomer-modified binding agents (see TL Bitumen StB 07/13, Table 2). Usual road construction bitumen is mixed with synthetically manufactured polymers, e.g.: SBS, SBR, BR.

Even mixed modification of bitumen with elastomers and plastomers were quite successful a few years ago; however, they were not able to establish themselves in the long term (economically).

A further group of elastomer-modified bitumens is the group of rubber-modified binding agents. In Europe, these have been used successfully since the 1980s. However, in the last few years, the advantages of these former “niche products” in many applications have become increasingly evident. As a result, demand is rising constantly.

The basis in the case of rubber-modified bitumen is formed by rubber granulates or buffing dusts made of recycled used tyres. This basis, with additional additivation, shows special properties in the modification of road construction bitumen. Especially when the buffing dusts come from selected lorry tyres and are optimally connected with the bitumen matrix. Here, it is the positive properties of the polymers from the natural rubbers that give the thus manufactured binding agents and/or asphalts – for example, regarding the useful life – demonstrably astonishing qualities. And, from an ecological perspective, optimal material use.

CTS Bitumen GmbH began manufacturing hot-liquid rubber-modified bitumen successfully in 1983. The main area of use was the design of open-pored asphalt top layers. These asphalts were so successful in technological asphalt terms that they even received their own - legally protected - name: Flüsterasphalt®. For this reason, the term "Flüsterasphalt®" has since established itself in general language use as a synonym for any noise-reducing asphalt pavement. A nice success.

Thanks to many years of experience, combined with a lot of practical knowledge and the high quality level of the rubber-modified binding agents, CTS Bitumen managed to increase the lifespan of the "Flüsterasphalt®" significantly. Traditional, noise-reducing asphalts designed with polymer-modified bitumen, achieved (and still achieve) useful lives of only around 8 – 10 years. Flüsterasphalt®, however, achieved an average lifespan of approximately 13.5 years. The longest lay time/useful life established so far is approximately 19 years.

Although very successful, the hot-liquid rubber-modified binding agents also had a series of rough edges. Transport, storage and ultimately its dosage at the asphalt mixing plant. Rubber-modified bitumen has a high proportion of insoluble components from the buffing dusts used. During the loading into the tanker, these already began to sediment systemically. At most, this process can be slowed down. Unfortunately, it cannot be stopped, not to mention reversed. Thus, the storage time at the asphalt mixing plant is heavily restricted. Even powerful mixing equipment in the storage tank cannot prevent the demixing. And in the end, due to the high product viscosity (even at a binding agent temperature of approximately 200 °C), very powerful bitumen pumps are required that are able to convey and ultimate dose these (optimally digested) binding agents at all.

For environmental protection reasons, today the temperatures for all hot-liquid binding agents are limited to max. 180 °C. However, since no manufacture of rubber-modified binding agents with the previously usual and necessary performance is possible at this temperature level, all renowned manufacturers have by now discontinued production in Germany.

But CTS Bitumen can offer a strong alternative. Since 2005, it has produced a specially developed rubber-modified bitumen granulate. CTS GRM (Granulate Rubber Modified).

Fortunately, it already fulfilled all the requirements/specifications of the later (2010) introduced TL RmB-StB, By Table 2. It also conforms to other regulations (e.g. to E GmBA). CTS GRM and/or the resulting binding agents (RmB G) established themselves in many different applications on the market. Comprehensive analyses show high efficiency that even outstrips that of the tried-and-tested "Flüsterasphalt®". The first applications with CTS GRM have now just completed 15 years of useful life. An end is not yet in sight.

CTS Bitumen has now mandated Umtec Technologie AG to produce a comparative eco-balance. Here, in accordance with TL RmB-StB By, Table 2 and 3, the RmB G varieties derived from the base product (CTS GRM) (RmB G 25/60-52; RmB G 20/60-55 and RmB G 35/70-55) were compared with commercially available polymer-modified bitumen (PmB A 40/100-65; PmB A 25/55-55 according to TL Bitumen-StB 07/13 and PmB A 25/55-55 RC (+)). The eco-balance is created in 3 stages:

Stage 1: Comparison of the binding agent qualities (PmB A vs. RmB G). Additionally, common distillation bitumen (e.g.: B 50/70; B 30/45) according to TL Bitumen StB 07/13, Table 1 were also considered.

Stage 2: Asphalt production. Exemplary comparison of four common asphalt varieties. PA 8; SMA 8 S; AC 11 D S and AC 16 B S. The formulae of the asphalts took place along the lines of TL Asphalt-StB 07/13 and can be called typical of the respective varieties. As binding agent varieties, common PmB A varieties were compared with the corresponding RmB G qualities in each case. In the case of the asphalt concrete and the asphalt binder layer, formulae with traditional road construction bitumen were also analysed. Consequently, the respective PmB A acted as a reference.

Stage 3: Eco-balance/environmental effect of the entire life cycle of the asphalt varieties considered variance of the binding agent varieties. Here, the eco-balance is produced on the basis of the following functional units: A tonne of installed asphalt per year. In the process, the following aspects of the life cycle phases were taken into account:

- Raw material recovery for asphalt production
- Installation of the asphalt
- Use phase
- Removal of the asphalt / deconstruction
- Disposal / recycling of the asphalt granulate

Since specially modified asphalts also have a positive influence on the useful life of asphalt, the lay times were also taken into account. Therefore, the result is marked with the unit: environmental effect per tonne and year.

The following effect estimation methods have been used to calculate the eco-balance:

- ILCD method (scientific weighting pursuant to EU27)
    - o ILCD = International Reference Life Cycle Data System, unit ILCD-Points Pts:
        - Holistic environmental analysis → total of 16 effect categories (water pollutants, climate, ozone hole, water body overfertilisation, resources, human health, etc.)
        - Eco-balance method of the European Commission – Joint Research Center
        - Evaluation on middle stage per environmental aspect (not aggregated completely to one value) possible, total aggregation to a single value via weighting possible
        - In this study, a weighting of the environmental effect categories based on the proposal of study of the Joint Research Centers in conformity with EU27 was used.
- Greenhouse gas potential (kg CO_2 equivalent)
        - CO_2 = greenhouse gas potential, unit kg CO_2 equivalent:
        - This environmental effect category takes climate protection-related emissions into account
        - Assessment using characterisation factor in the unit kg CO_2 eq, e.g. 1kg methane corresponds to approx. 28 kg CO_2 eq.

    - However, non-climate-effective pollutant emissions cannot be mapped with this method
- Additionally as ancillary assessment methods:
    - <u>Method of the environmental load points ELP</u> (Swiss weighting, based on legislation, political objectives and obligations) [ELP = method of ecological scarcity, also known as the environmental load point method. Unit environmental load points (ELP):
        - Holistic environmental analysis → emissions in air, water and soil, resource, energy and land consumption as well as climate
        - Swiss methodology from the Federal Office for the Environment BAFU, developed especially for decision makers (macroaggregated result, thus goes beyond ISO standard 14.040 et seq.)
        - Weighting using eco-factors based on Swiss policy (laws, regulations and international agreements)
    - <u>Cumulated total energy demand CED</u> (incl. embodied energy)
        - Unit MJ oil equivalent:
        - This environmental effect category takes into account all energy demands, incl. embodied energy of a product or process
        - The results is expressed as the MJ oil equivalent
        - Only energy consumptions from renewable and non-renewable sources can be mapped with this method

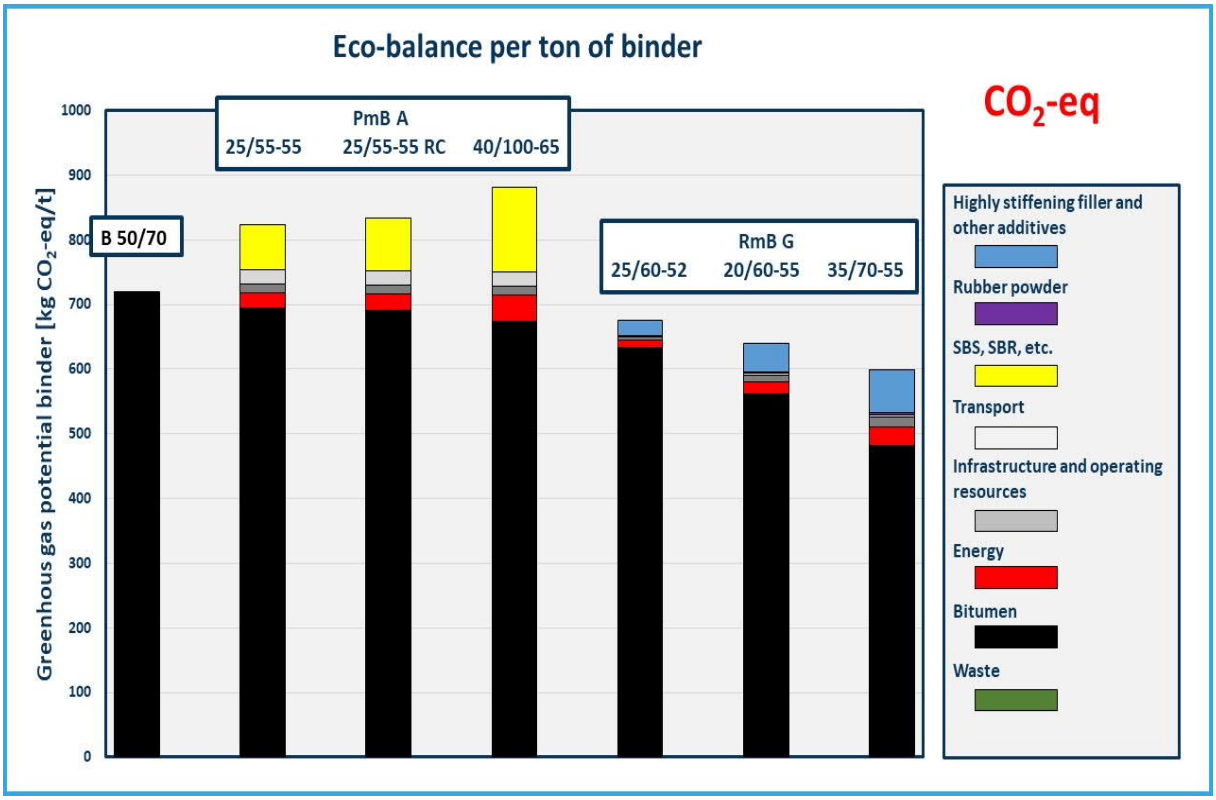


Figure 1-1: Eco-balance comparison of various binding agents, evaluated using the greenhouse gas potential method. (Stage 1: Raw material recovery up to production of the respective binding agent)

The results of the three-stage eco-balance are summarised step by step below. However, due to the current discussion on climate warming, the focus here is on the evaluation of the greenhouse gas potential. Further evaluation is to be found in the main part of the report.

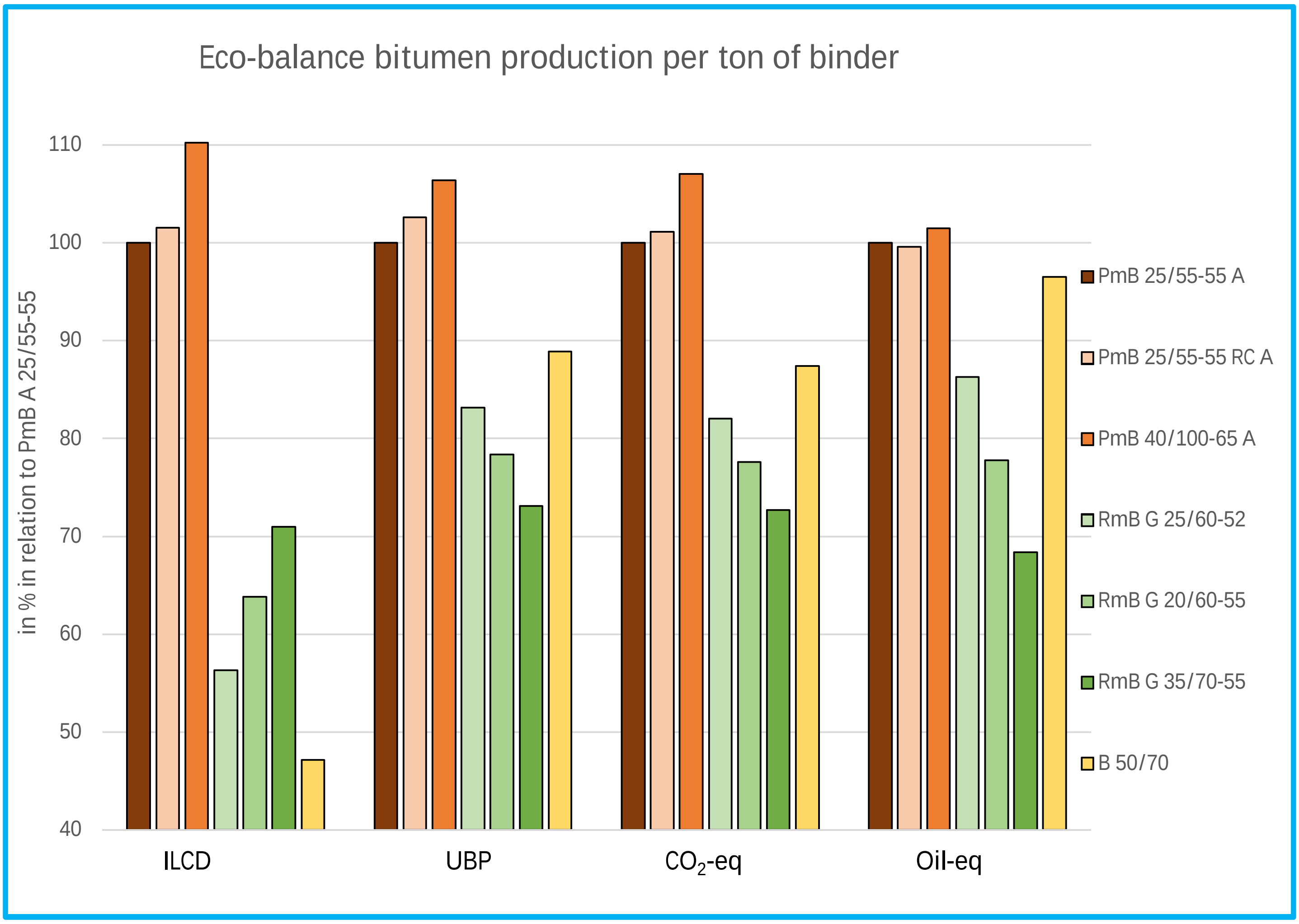


Figure: 1-2: Eco-balance bitumen production. Variance of the binding agents.

Functional unit: Variance of following binding agents: B 50/70, PmB 25/55-55 A, PmB 40/100-65 A according to TL Bitumen-StB 07/13, Table 1 and 2, RmB G 20/60-55 RC and RmB G 25/60-52; RmB G 20/60-55 and RmB G 35/70-55 according to TL RmB-StB, By – Table 2 and 3. Reference value: PmB A 25/55-55 = 100%

Conclusion of eco-balance stage 1

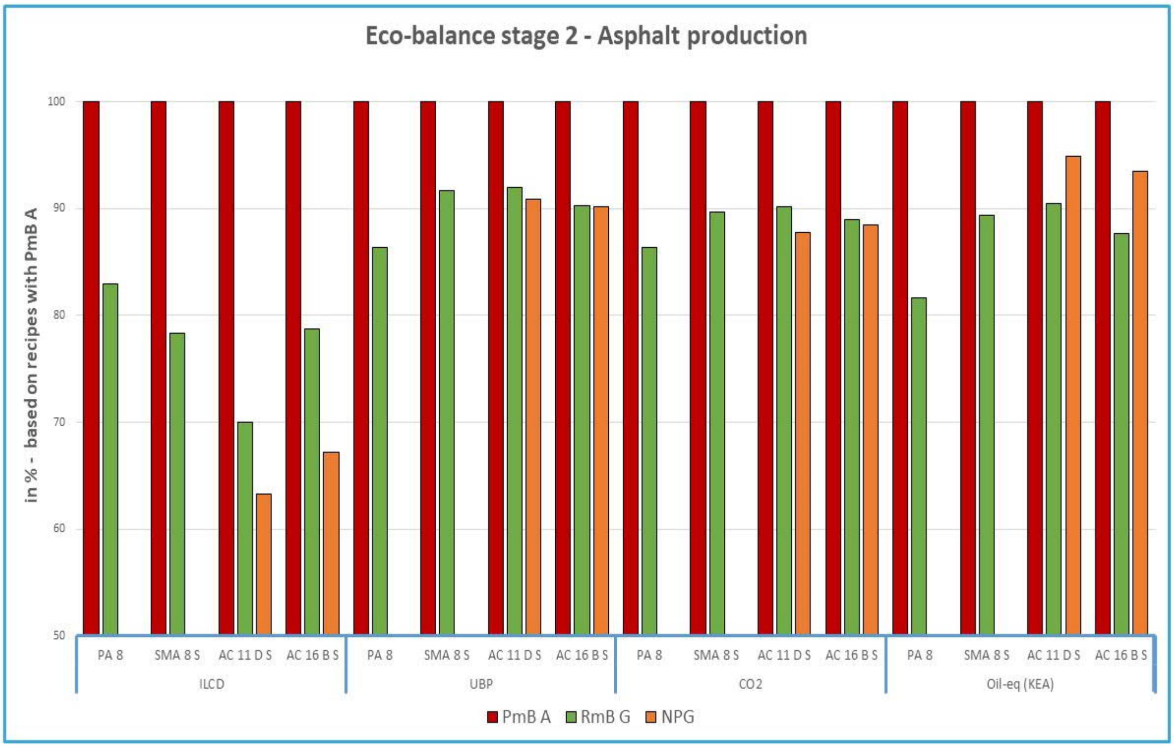
1. In all eco-balances, the RmB G binding agents according to TL RmB-StB, By – Table 2 and 3 perform better compared to polymer-modified bitumen.
2. A quarter more favourable on average. The ILCD assessment even shows an approximately 40% ecologically more favourable behaviour.
3. It becomes clear that a higher modification degree in the case of the PmB A has an ecologically less favourable impact.
4. However, this is not the case with the RmB G binding agents, provided the influence of the basic binding agent heavily dominates the eco-balance. (e.g. energy requirement, greenhouse gas potential)
5. With usual road construction bitumen, the eco-balance – with the exception of according to the ILCD method – is considerably less favourable than with the RmB G binding agents.
6. In turn, however, it is considerably more favourable than in the case of all PmB A types.

Conclusion eco-balance stage 2:

1. In the case of the asphalt varieties PA 8 and SMA 8, the variants with RmB G are clearly in the advantage compared to PmB A when considering the eco-balance.
2. This fluctuates between 10 and 21%, depending on the evaluation criterion.
3. If asphalt granulate were added in the case of stone mastic asphalt and open-pored asphalt (this construction method is not permitted in Germany), the entire level would fall but, in relation, the basic statements regarding the assessments would be confirmed.
4. In parallel, in the case of asphalt concrete and the asphalt binder layer, the variants with distillation bitumen (NPG = normal paving grade) were also subjected to an assessment.
5. In the evaluations according to the ELP method of the energy requirement and the greenhouse gas potential, NPG and RmB G show themselves to be at least on a level playing field. With pronounced advantages for the RmB G in the evaluation of the cumulated energy demand.
6. However, the NPG and RmB G variants are ecologically more advantageous than the formulae with PmB A.
7. Only in the evaluation according to the ILCD method do the NPGs perform better than the RmB G variants. However, both formulae, in turn, exhibit advantages compared to PmB A.
8. The highest environmental load of all the asphalt types considered is in evidence with the stone mastic asphalt with PmB A.
9. The addition of asphalt granulate in the asphalt concrete and in the asphalt binder reduces the respective level; however, the basic statements of the evaluation and assessment remain intact.
10. All asphalt varieties produced with PmB A perform the worst ecologically.

Figure: 1-3: Eco-balance asphalt production. Variance of the binding agents. Functional unit: Variance of the following asphalt types PA 8; SMA 8 S; AC 11 D S; AC 16 B S. Bindier: B

50/70, PmB 25/55-55 A, PmB 40/100-65 A according to TL Bitumen-StB 07/13, Table 1 and 2, RmB G 20/60-55 RC. RmB G 25/60-52; RmB G 20/60-55 and RmB G 35/70-55 according to TL RmB-StB, By – Table 2 and 3. Reference value asphalt production with PmB = 100%. Evaluation according to ILCD method, UBP method, greenhouse gas potential (CO_2-eq) and the cumulated energy demand (KEA).



<u>Table 1-1</u>: CO_2 saving in the use of RmB G according to TL RmB-StB, By – Table 1 and 2 compared to PmB A according to TL Bitumen-StB – Table 2 and PmB A 25/55-55 RC (+).

Asphalt production	CO_2 saving in kg CO_2 eq/t – without asphalt granulate	CO_2 saving in kg CO_2 eq/t – with asphalt granulate
<u>PA 8</u> RmB G 35/70-55 vs. PmB A 40/100-65	11.6 kg	
<u>SMA 8 S</u> RmB G 20/60-55 vs. PmB A 25/55-55	9.6 kg	
<u>AC 11 D S</u> RmB G 25/60-52 RmB G 20/60-55 vs. PmB A 25/55-55 PmB A 25/55-55 RC (+)	7.6 kg	5.2 kg

AC 16 B S RmB G 25/60-52 RmB G 20/60-55 vs. PmB A 25/55-55 PmB A 25/55-55 RC (+)	7.9 kg	3.1 kg

For the evaluation of the third eco-balance stage, the asphalt concrete AC 11 D S is also shown for the other asphalt varieties in Fig. 1-3 as an example.

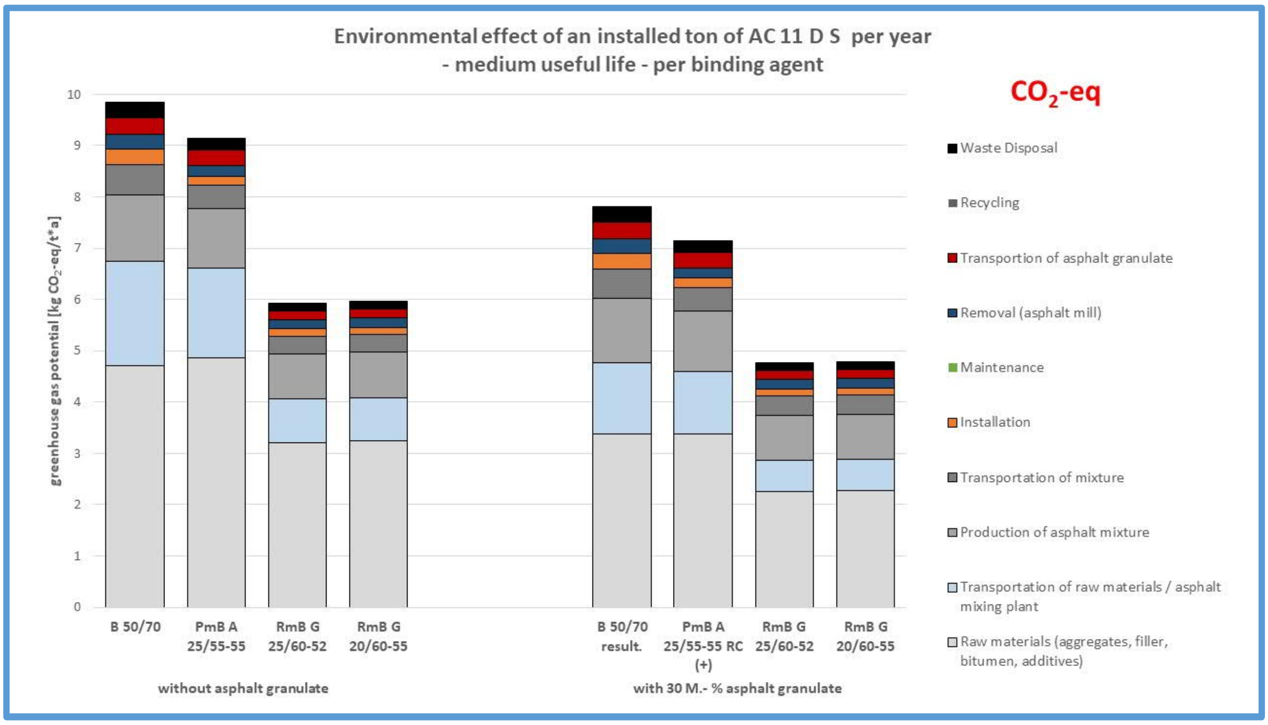


Fig. 1-4: Environmental effect of an installed tonne of AC 11 D S per year. Variance of various binding agents with and without addition of 30 M % asphalt granulate, evaluated for the greenhouse gas potential (greenhouse gases kg CO_2 eq/t*a) Different lay times (i.e. average useful life per binding agent) were taken into account.

Functional unit: Greenhouse gas potential per installed tonne of AC 11 D S and year. Variance of following binding agents: B 50/70, PmB 25/55-55 A according to TL Bitumen-StB 07/13, Table 1 and 2, PmB 25/55-55 RC (+), RmB G 25/60-52 and RmB G 20/60-55 according to TL RmB-StB, By – Table 2 and 3.

Conclusion eco-balance stage 3:

1. In this eco-balance, the length of the useful life plays *the* decisive role.
2. All asphalts formulated with RmB G instead of PmB A or even distillation bitumen, perform significantly better ecologically, regardless of the assessment method.
3. The advantageousness is most evident with the open-pored asphalts.
4. On average, the ecological advantages are between 42 and 48%.
5. Also in the case of SMA 8 S, the RmB G variants can score points heavily compared to the PmB A.

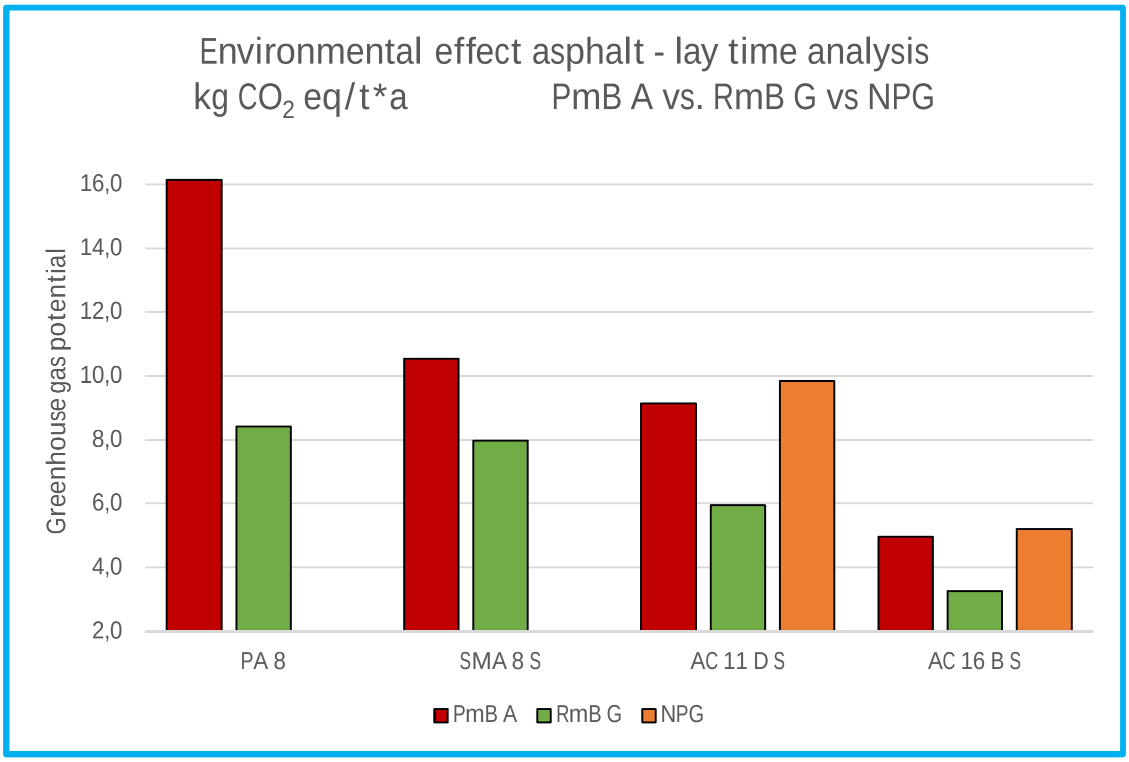
6. Here, the advantage is, on average, approximately 28.5%.
7. If asphalt granulate were added in the case of stone mastic asphalt and open-pored asphalt (this construction method is not permitted in Germany), the entire level would fall but, in relation, the basic statements regarding the assessments would be confirmed, independent of the asphalt-technological performance then still to be achieved.
8. With the asphalt concrete AC 11 D S and the asphalt binder AC 16 B S, similar conditions are evident in terms of the environmental effect as with the SMA 8 S.
9. In parallel, in the case of asphalt concrete and the asphalt binder layer, the variants with usual distillation bitumen (NPG = normal paving grade) were also subjected to an assessment.
10. Due to the lower useful lives, these are again to be assessed as ecologically less favourable than those with PmB A. Depending on the evaluation, an ecological minus in relation to the PmB A in the scale of 5 – 10% must be calculated.
11. The addition of asphalt granulate in the asphalt concrete and in the asphalt binder reduces the respective environmental effect; however, the basic statements of the evaluation and assessment remain intact in relation.

Table 1-2: Eco-balance of various asphalt types with different binding agents. PmB A according to TL Bitumen-StB 07/13, Table 2 (PmB A 40/100-65 and PmB A 25/55-55) and RmB G according to TL RmB-StB, By Table 2 (RmB G 25/60-52 [12 M.-% CTS GRM + 88 M.-% B 50/70], RmB G 20/60-55 [22 M % CTS GRM + 78 M % B 50/70], RmB G 35/70-55 [33 M % CTS GRM + 67 M % B 70/100]). The effect caused by the addition of different quantities of asphalt granulate was also taken into account. The savings of greenhouse gases refer to the eco-balance with consideration of different useful lives.

The different useful lives in each case were taken into account	Savings of kg CO_2 eq per tonne of installed asphalt per year. Savings when using RmB G compared to PmB A	
	without asphalt granulate	with asphalt granulate
PA 8 RmB G 35/70-55 vs. PmB 40/100-65 A	7.7 kg CO_2 eq	
SMA 8 S RmB G 20/60-55 vs. PmB 25/55-55 A	3.6 kg CO_2 eq	
AC 11 D S RmB G 25/60-52 30 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	3.2 kg CO_2 eq	2.4 kg CO_2 eq
AC 11 D S RmB G 20/60-55 30 M % asphalt granulate vs.	3.1 kg CO_2 eq	2.4 kg CO_2 eq

PmB 25/55-55 A and PmB 25/55-55 RC (+)		
AC 16 B S RmB G 25/60-52 35 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	1.8 kg CO_2 eq	1.2 kg CO_2 eq
AC 16 B S RmB G 20/60-55 35 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	1.7 kg CO_2 eq	1.2 kg CO_2 eq

Fig. 1-5: Eco-balance/environmental effect of four asphalt varieties without the addition of asphalt granulate. Evaluation was carried out regarding the greenhouse gas potential in kg CO_2 equivalent/t*a. The different lay times of the individual asphalts were also taken into account. (RmB G = rubber-modified Bitumen; NPG = Normal paving grade)



In the eco-balance of stage 3, the installed asphalt was divided by the average useful life. Accordingly, an asphalt with an above-average lay time performs better than an asphalt with a rather short life expectancy. However, as part of a sensitivity analysis, the eco-balance in the case of an assumed identical useful life was also performed.

The result is summarised in Table 1-3.

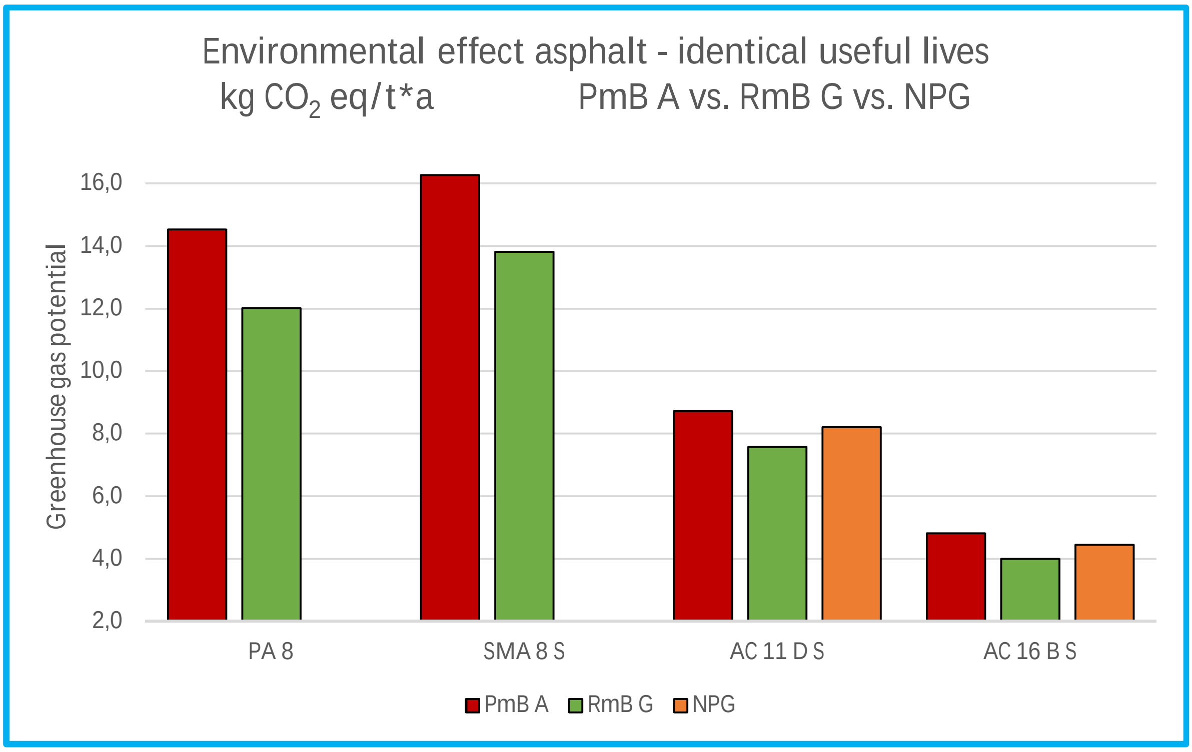
Eco-balance of various asphalt types with different binding agents. PmB A according to TL Bitumen-StB 07/13, Table 2 (PmB A 40/100-65 and PmB A 25/55-55) and RmB G according to TL RmB-StB, By Table 2 (RmB G 25/60-52 [12 M.-% CTS GRM + 88 M.-% B 50/70], RmB G 20/60-55 [22 M % CTS GRM + 78 M % B 50/70], RmB G 35/70-55 [33 M % CTS GRM + 67 M % B 70/100]). The effect caused by the addition of different quantities of asphalt granulate was also taken into account. The savings of greenhouse gases refer to the eco-balance without consideration of different useful lives.

Identical useful lives respectively	Savings of kg CO_2 eq per tonne of installed asphalt pavement per year. Savings when using RmB G compared to PmB A	
	without asphalt granulate	with asphalt granulate
PA 8 RmB G 35/70-55 vs. PmB 40/100-65 A	2.5 kg CO_2 eq	
SMA 8 S RmB G 20/60-55 vs. PmB 25/55-55 A	2.4 kg CO_2 eq	
AC 11 D S RmB G 25/60-52 30 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	1.2 kg CO_2 eq	0.8 kg CO_2 eq
AC 11 D S RmB G 20/60-55 30 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	1.1 kg CO_2 eq	0.8 kg CO_2 eq
AC 16 B S RmB G 25/60-52 35 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	0.9 kg CO_2 eq	0.4 kg CO_2 eq
AC 16 B S RmB G 20/60-55 35 M % asphalt granulate vs. PmB 25/55-55 A and PmB 25/55-55 RC (+)	0.7 kg CO_2 eq	0.4 kg CO_2 eq

Fig. 1-6: Eco-balance/environmental effect stage 3 - sensitivity analysis: environmental load per installed tonne of asphalt without RC proportions per year. In relation to an identical useful life. Evaluation according to the greenhouse gas potential. Variance of binding agents: PA 8: PmB A 100/40-65; RmB G 35/70-55; SMA 8 S: PmB A 25/55-55; RmB G 20/60-55; AC 11 D S: PmB A 25/55-55; RmB G = average of RmB G 20/60-55 and RmB G 25/60-52; B 50/70;

AC 16 B S: PmB A 25/55-55; RmB G = average of RmB G 20/60-55 and RmB G 25/60-52; B 30/45.

(RmB G = rubber-modified Bitumen; NPG = Normal paving grade)



<u>Conclusion:</u>

Even in the case of the same lay times, asphalt pavements with RmB G perform ecologically better than asphalt pavements with PmB A.

The three-stage eco-balance clearly shows the advantage of asphalts with rubber- modified bitumen. Particularly in the analysis across the entire life cycle, pavements with RmB acquire a large ecological advantage due to their very long lay times.

Due to the use of RmB G instead of PmB A, a CO_2 saving

of

approx. 15.100 to CO_2

was achieved in Bavaria in 2020.

This equates to driving around the world in a car approximately 2,265 x.

Outlook / improvement potential eco-balance:

An uncertainty analysis by means of a Monte Carlo simulation would increase the meaningfulness of the results (display of the uncertainty in the charts by means of fault indicators).

In order to increase the statement accuracy further, the existing data gaps should be filled through on-site measurements at CTS Bitumen GmbH as well as measurements upon asphalt installation and use with RmB G pavements. In particular, the air emissions in the case of GRM by CTS production as well as the air emissions caused by the asphalt mixer should be recorded specifically for the use of RmB G in pavements and added to the eco-balance. Currently, the air emissions come from averages of Swiss asphalt production plants. Through the measurement of PARTICULI, an initial estimation of the emission situation in asphalt production as well as in the installation and use was performed in this eco-balance.

No air emission values for asphalt production with PmB and RmB G

In this study, no distinction was made in the level of the RAP proportion between the pavements with distillation bitumen, PmB and RmB G, as the data basis is still missing here as well.