LCC & LCA

S&P Carbophalt G® (200/200)

FOLKBRO
Borgarfjordsgatan 12
164 55 Kista, STOCKHOLM

Mohammed Safi
Tel:+46 70 4987404
mohammed.safi@folkbro.com

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LCC-analysis S&P Carbophalt® G (200/200)

Asphalt pavement in bus stops, stations and paths, logistic and warehouse areas and high-weight trafficked roads are usually suffering from several distresses. These distresses cause extra stresses on the asphalt pavement and can mainly be classified as time induced and load induced extra stresses. These stresses initiate cracks and rutting in the upper asphalt pavement layers. Figure 1 shows examples of cracks and damages such locations.

Figure 1 Examples of asphalt pavement distresses in bus stops, stations and paths, logistic and warehouse areas and high-weight trafficked roads

Case study

Several technologies have been identified to prevent or delay cracks in in asphalt pavement in such locations. These include: designing more crack-resistant asphalt mixtures, selecting alternative pavement structures and improving construction quality control. Concrete pavement and Densiphalt (a semi-flexible and joint-free topping system) are also options to aiming to overcome with pavement damages in such circumstances. This study investigating the feasibility of applying asphalt reinforcement layer S&P Carbophalt® G (200/200), shown in Figure 2.

Figure 2 Typical existing asphalt pavement layers and resurfacing options

Unified unit

Repairing of a square meter of a damaged asphalt pavement in a high-weight trafficked road/ logistic area is considered as a case study. The typical pavement layers of such existing areas are shown in Figure 2, based on the Swedish Transport Administration and Stockholm municipality pavement design manuals. Alt. 1 shown in Figure 2 depicts the conventional wearing course replacement, while Alt. 2 depicts the method of replacing the wearing course and using a layer of asphalt reinforcement grid S&P Carbophalt® G (200/200). Table 1 presents the work activities included in alternatives. Note that same amount of binder coat is needed in both alternatives.

Table 1 Work activities included in the various alternatives

Alt. 1 Conventional resurfacing	Alt. 2 Resurfacing with Carbophalt® G (200/200)
1. Mill-off the existing damaged wearing course	1. Mill-off the existing damaged wearing course
2. Place a binder coat	2. Place a binder coat
3. Place a new wearing course	3. Place a layer of asphalt reinforcement net S&P Carbophalt® G (200/200), and heating it up to burn the thin polymer foil and secure a good bonding.
	4. Place a new wearing course

Initial investment cost assessment

The price (supplier to contractor, installed at site) of asphalt reinforcement grid S & P Carbophalt® G (200/200) is 110-120 SEK/m², depending on the size of the workplace. The average end costumer cost (contractor price to municipalities/transport administration, installed at site) for 1 square meter of S & P Carbophalt® G (200/200) is around 160 SEK. Installation capacity is 1000-2000 m² /hour. A wheel loader with a driver and three workers outside are needed. A small amount of diesel fuel (0.5 kg / 1000 m²) is needed for the installation and burning the thin polymer foil. Estimation of the investment cost is made based on this information, and Table 2 presents a conclusion from this estimates considering a square meter as a case study.

Table 2 Initial investment cost assessment

Item	Alt. 1	Alt. 2
Milling-off the existing damaged wearing course	90	90
Layer of asphalt reinforcement net S & P Carbophalt® G (200/200)	_	160
A new wearing course (ABT 11, 40 mm)	195	195
Traffic disruption and delay cost	50	50
Total, SEK/m²	**335**	**495**

Life-cycle measures

Figure 3 shows the life cycle performance curve for Alt. 1. The 3 years resurfacing interval is an average interval considering feedbacks from a statistical analysis of intensive repair records applied on similar existing asphalt pavement subjected to similar conditions. Similarly, resurfacing using a layer of S & P Carbophalt® G (200/200) is assumed to have an interval of 8 years, shown in Figure 3. This parameter is inherently uncertain, and thus sensitivity analysis will be presented to study the impact of varying this parameter.

As shown in Figure 3, there will be 13 resurfacing action during the service life of the road in case of applying Alt. 1, and each resurfacing action will cost 335 SEK/m^2 based on Table 2. There will be 4 resurfacing action during the service life of the road in case of applying Alt. 2, and each resurfacing action will cost 395 SEK/m^2 based on Table 2, as shown Figure 3.

Alt. 1: Conventional resurfacing

Alt. 2: Resurfacing with Carbophalt® G (200/200)

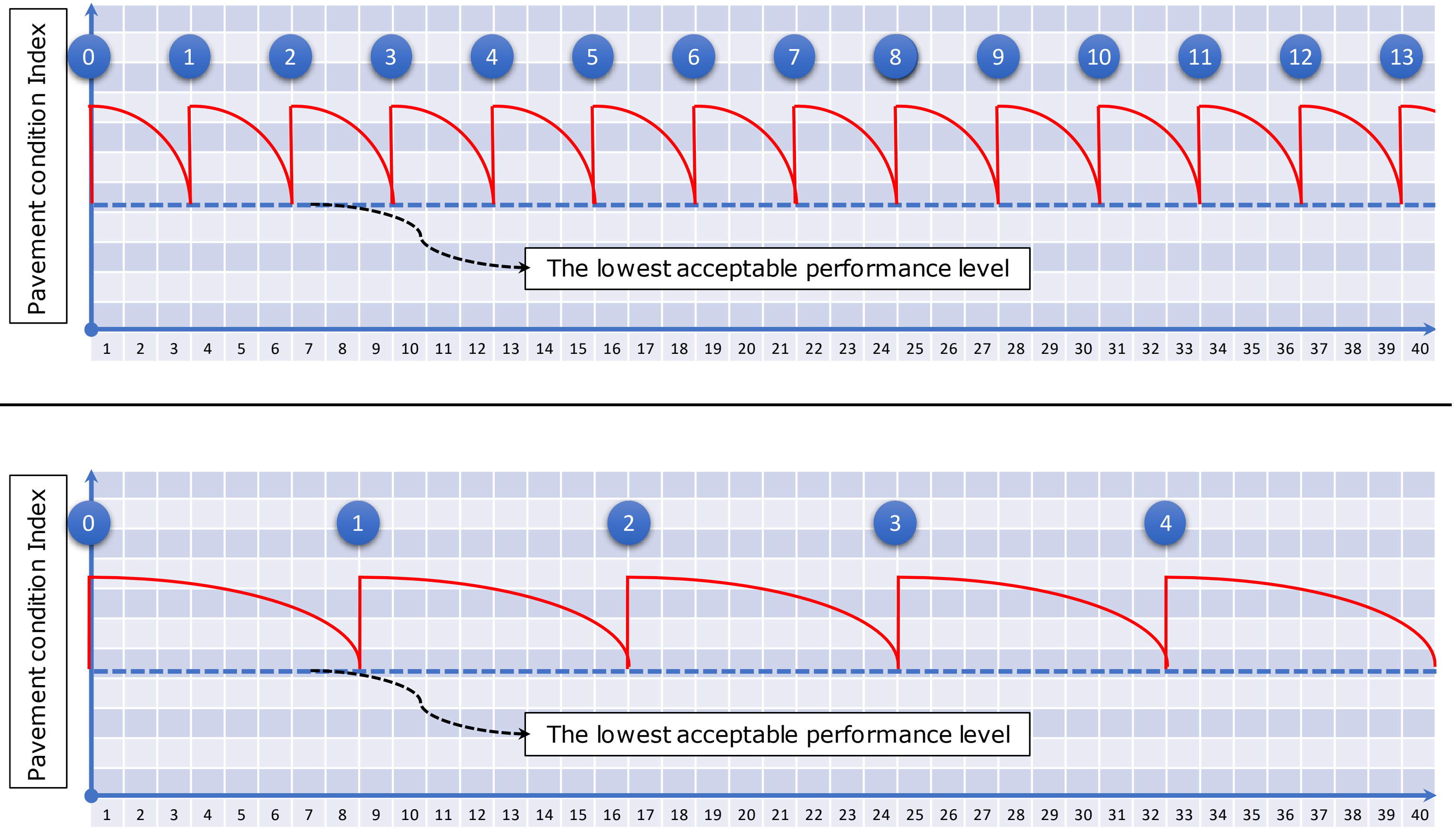

Figure 3 Life-cycle performance curves of Alt. 1 and Alt. 2

LCC-analysis results

LCC-analysis is performed based on Table 2 and the performance curves shown in Figure 3. Figure 4 shows the investment cost and the present value of the life-cycle measures cost at 4% and 2% discount rates. The figure implies that the LCC of Alt. 2 is less than Alt. 2, regardless the discount rate variation. Therefore, Alt. 2 the most cost-efficient. Cost savings in case of applying Alt. 2 in comparison with Alt. 1 is approximately 985 SEK / m2 and 1 381 SEK / m2, considering 4% and 2 % discount rate respectively.

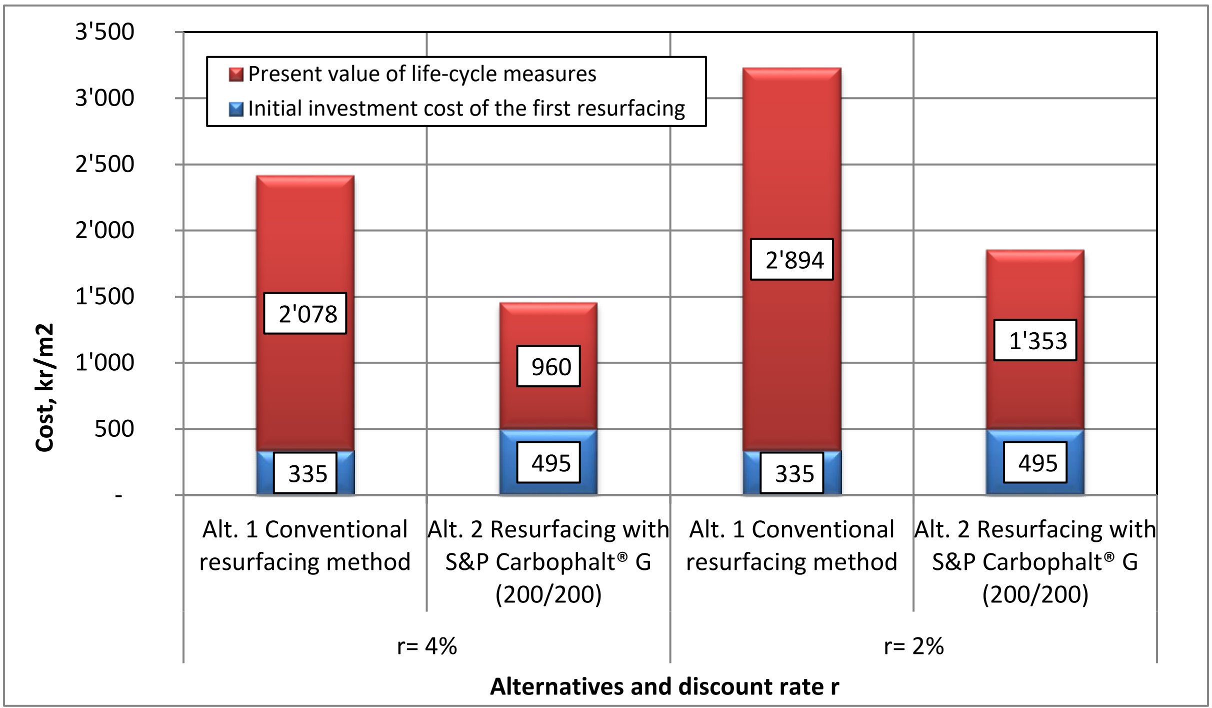

Figure 4 LCC Present value

Sensitivity analysis

Extension of resurfacing interval and discount rate

It is not an easy task to anticipate the actual performance of the asphalt pavement. Uncertainties are involved in the assessment of the resurfacing interval in case of using S & P Carbophalt® G (200/200), Alt. 2, at least 8 years between resurfacing actions. The 8 years resurfacing interval is assessed based on statistical treatment of historical records related to similar road pavements having similar conditions, and laboratory tests examining individual failure mechanism.

Figure 5 shows sensitivity analysis studying the effect of varying the resurfacing interval in Alt. 2 from 3 years to 10 years, considering 4 % and 2 % discount rates. It would be more cost-efficient to implement Alt. 2 (Resurfacing with Carbophalt® G (200/200)) if S & P Carbophalt® G (200/200) layer guarantees a minimum resurfacing interval of 4.4 years considering 2 % discount rate and 4.5 years considering 4 % discount rate, if 3 years is the resurfacing interval of the conventional resurfacing method (Alt. 1). It is well known considering the feedback from the statistical treatment of repair records that S & P Carbophalt® G (200/200) could fulfil this condition. Consequently, this parameter does not have considerable impact on the final decision.

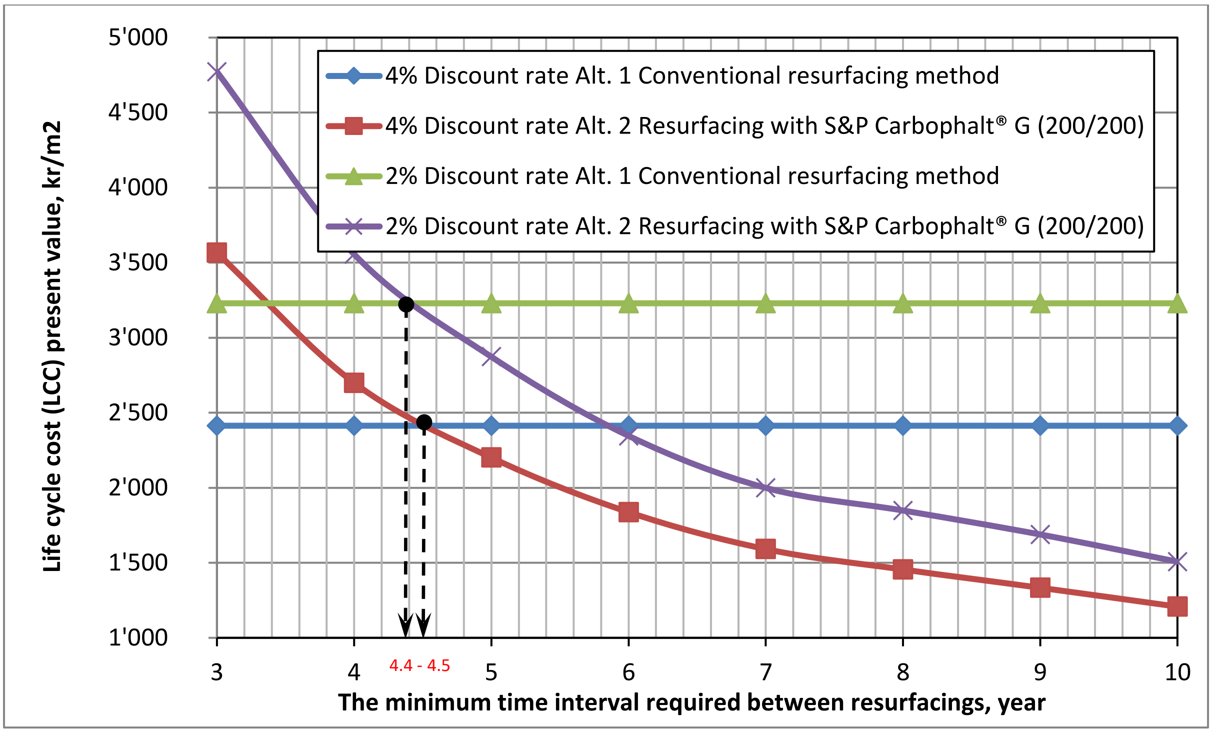

Figure 5 Sensitivity analysis studies the minimum time interval required between resurfacing measures for Alt. 2 to remain more cost effective than Alt. 1, considering 2 % and 4 % discount rates.

Relation between Carbophalt® G (200/200) price and the resurfacing interval

For Alt. 2 (resurfacing with S&P Carbophalt® G (200/200)) being more cost-efficient than Alt. 1 (conventional resurfacing method), Figure 6 depicts the maximum acceptable end-customer cost (contractor price to municipalities/transport administration, installed at site) (SEK/m²) of S&P Carbophalt® G (200/200) in relation with the minimum resurfacing interval that must be guaranteed after using it. Figure 6 considers 4 % and 2 % discount rates. Note that Figure 4 and Figure 5 were built considering 160 SEK/m² as an average end-customer cost of S&P Carbophalt® G (200/200).

As shown in Figure 6 when the end-customer cost of the S&P Carbophalt® G (200/200) is 160 SEK/m², a resurfacing interval of at least 4.5 years has to be guaranteed in order for Alt. 2 being more cost-efficient than the conventional strategy (Alt. 1). It could also be seen in Figure 6 that, if the S&P Carbophalt® G (200/200) can guarantee a minimum resurfacing interval of 8 years, as it is expected, it would be economically feasible to implement it even if its end-customer cost reached 510 SEK/m² instead of 160 SEK/m².

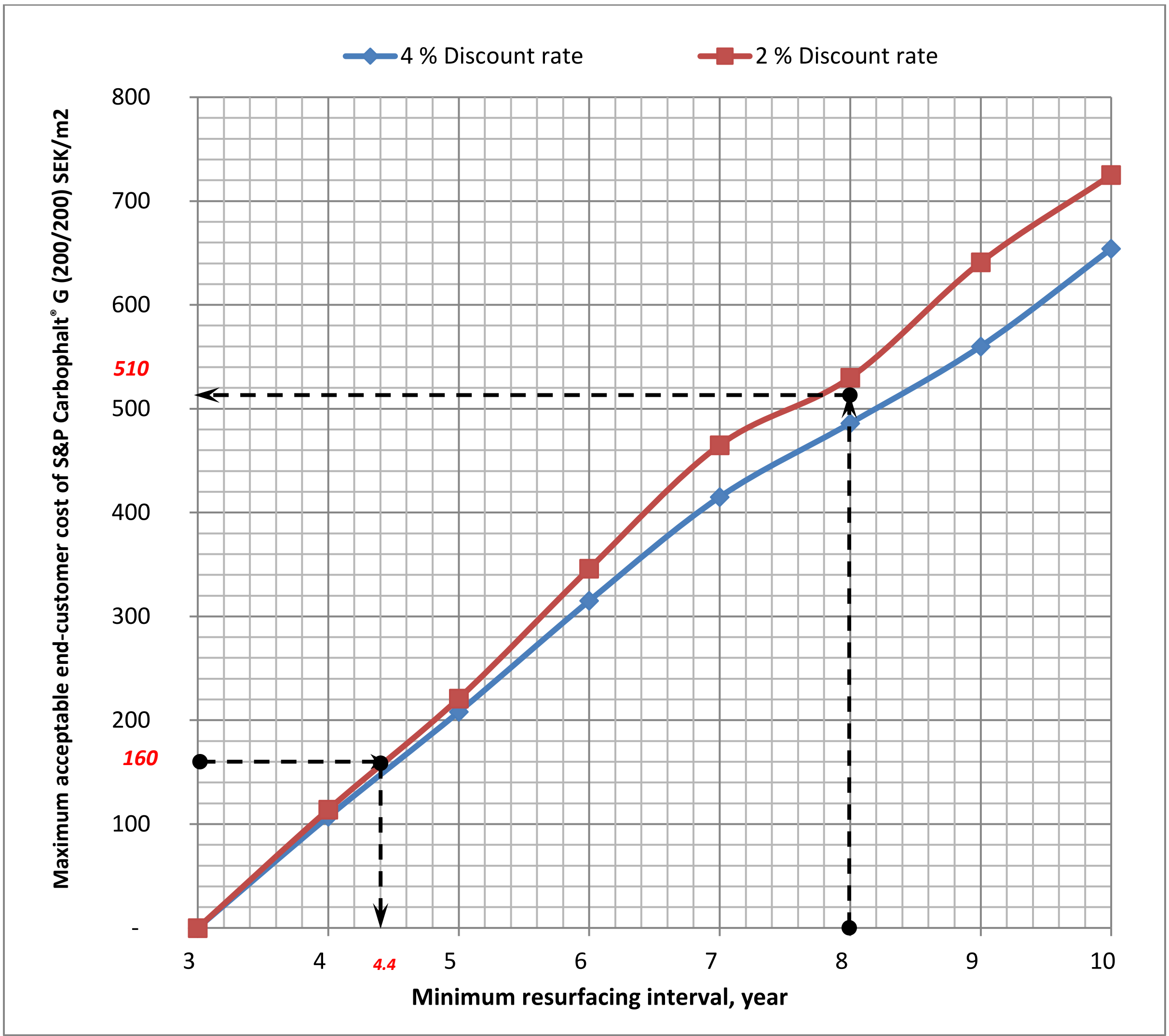

Figure 6 the relation between the maximum end-customer cost of S&P Carbophalt® G (200/200) and the minimum required resurfacing interval that must be guaranteed by S&P Carbophalt® G (200/200) for Alt. 2 being more cost-efficient than Alt. 1

Conclusion

Asphalt pavement in bus stops, stations and paths, logistic and warehouse areas and high-weight trafficked roads are usually suffering cracks and damages due to time induced and load induced extra stresses. This study investigating the feasibility of applying asphalt reinforcement layer S&P Carbophalt® G (200/200) to prevent or at least delay the cracks and damages in such pavement areas. Repairing of a square meter of a damaged asphalt pavement in a high-weight trafficked road/ logistic area is considered as a case study.

The presented LCC-analysis results are based on a comparison between a conventional asphalt pavement resurfacing method that costs 335 SEK/m² and a resurfacing using asphalt reinforcement layer (S&P Carbophalt® G (200/200)) that costs 495 SEK/m², including the potential traffic disruption and delay costs during the execution of the resurfacing work. A discount rate of 2-4 % was considered. If the S&P Carbophalt® G (200/200) layer guarantees a minimum resurfacing interval of 4.5 years, it would be more cost-efficient than the conventional resurfacing method, assuming 3 years as the resurfacing interval of Alt. 1. If the S&P Carbophalt® G (200/200) layer can guarantee a minimum resurfacing interval of 8 years, as it is expected, it would be more cost-efficient to implement it even if its end-customer cost reach 510 SEK/m² instead of 160 SEK/m².

Considering the LCC-analysis as well as the sensitivity analysis presented above, the S&P Carbophalt® G (200/200) layer is recommended for resurfacing asphalt pavements suhc as bus stops, stations and paths, logistic and warehouse areas and high-weight trafficked roads. S&P Carbophalt® G (200/200) is also recommended for even new pavement in such locations. The amount of money that can be saved in case of using S&P Carbophalt® G (200/200) is approximately 1 170 SEK / m², during the road service life-span 40 years. In other words, a layer of S&P Carbophalt® G (200/200) that costs 160 SEK/m² in initial investment cost term, could save 1 170 SEK/m² in LCC terms.

LCA Life-cycle assessment

Life-cycle assessment (LCA) methodology will be used to investigate the environmental impact arises, as per Figure 2 and Table 1, in which two alternatives will be studied; Alt. 1: conventional resurfacing, while Alt. 2: resurfacing using S&P Carbophalt® G (200/200).

Goal and Scope of the study

The goal of the study is to investigate the environmental impacts of the use of S&P Carbophalt® G (200/200) when used in the pavements as reinforcement material during the maintenance of the surface layer or the wearing course. An attributional LCA approach is used and the stages that are the same in both the alternatives are not included in the analysis. It is assumed that the pavement already exists; therefore, the construction stage is not included in the study. Furthermore, the traffic load over the design life of the studied pavement is considered to be the same. However, the road is assumed to be under heavy traffic load. Therefore, it is anticipated that the re-surfacing of the pavement is required after every 3 years due to wear and tear of wearing course, see Figure 3. However, in case S&P Carbophalt G (200/200) is used, the maintenance cycles are reduced to 4 (resurfacing after every 8 years) during the life of the road, see Figure 3. Use stage will remain the same for the two alternatives (no change in traffic) and thus, is not analyzed. It is also assumed that new materials are used and recycling and/or recycled materials are not used in this project. Material stage, and maintenance and rehabilitation (M&R) stage will be included in the LCA.

The functional unit (FU) defined for the study is 1 lane-km road that serves for a nominal design life. Typical lane width in Sweden is 3.5m and the pavement design life of 40 years is considered. It is also assumed that a major rehabilitation of the pavement structure is carried out after 20 years however, as the processes are the same in both the cases, it is not considered in this case study.

Expended energy and greenhouse gases (GHGs) will be quantified in the LCI phase and will be assessed for mid-point indicator, global warming potential (GWP) based on 100-year GWP (AR4), in the impact assessment. Total energy consumption will also be reported.

Life cycle Inventory and Life cycle impact assessment

The asphalt mixture used as wearing course is assumed to be ABT11 and wearing course thickness is 40mm, see Figure 2. The ABT11 is assumed to have a specific gravity of 2.5 ton/m^3 and has a mix design of 4% bitumen and 96% aggregates. Bitumen coating of 5mm is assumed over the structural layer before wearing course is applied. Bitumen production includes energy and emissions during the crude oil extraction, transportation, refinery and storage as reported in Eurobitume (2012). Data was gathered from sources as reported in Table 3. Aggregates and asphalt mixtures are assumed to be from Arlanda quarry site and Arlanda asphalt mix plant, respectively. It is also assumed that 3 MJ of energy is spent to produce I MJ of electricity. The energy production emissions are assumed to be the same for other countries where the material such as carbon fiber is produced.

Table 3 Data sources used to get primary and secondary data for the case study

Stage	Processes	Data sources used
Material Phase	Bitumen and Pmb production	Eurobitume (2012)
	Aggregate production	Stripple (2001)
	S&P Carbophalt production	Primary data from the manufacturer
	Plastic sheet production (LDPE)	Song *et al.* (2009)
	Asphalt production	Butt *et al.* (2016)
	Carbon Fiber	Howarth *et al.* (2014)
Maintenance and Rehabilitation Phase	Milling	Stripple (2001)
	Paving	
	Compacting	
	PMB application	
	Laying S&P Carbophalt	Primary data from the manufacturer
	Heating (plastic sheet)	
Energy	Electricity	Butt *et al.* (2014) & IEA (2013)
	Heating oil (Diesel)	Butt *et al.* (2014)

In Alt. 1, where a conventional resurfacing is done, only bitumen (for asphalt), crushed aggregates and asphalt as materials are used whereas in Alt. 2 where resurfacing is carried out using S&P Carbophalt® G (200/200), all the materials in Table 4 are included in the material stage. Table 4 shows the energy consumed in MJ to produce one tonne of each material (TOM), expended energy in giga joules (GJ) per FU, materials in tonnes per FU and emissions (CO_2, N_2O and CH_4) in tonnes per FU. Embodied energy for Carbon fibers is used in this analysis. Table 5 shows the energy consumed and emissions emitted due to milling, paving and compaction for Alt. 1 and all above plus applying polymer modified bitumen (Pmb) and melting the sheets on S&P Carbophalt® G (200/200). It is assumed that the S&P Carbophalt® G (200/200) is laid using hand operated unrolling equipment.

Table 4 Material production stage process energy and emissions

Material	Energy consumed (MJ/TOM)	Material (Tonnes/FU)	Expended Energy (GJ/FU)	CO2 (Tonne/FU)	N2O (Tonne/FU)	CH4 (Tonne/FU)
Bitumen (for asphalt)	2898	14	41	2.44 [b]	ua	8.33E-03 [b]
Crushed Aggregates	807	336	271	15.90 [a]	4.28E-04 [a]	1.49E-03 [a]
Asphalt	311	350	109	6.43 [a]	1.72E-04 [a]	5.85E-04 [a]
Polymer modified bitumen (PMB)	5569	0.96	5	0.28 [b]	ua	1.04E-03 [b]
Plastic sheet	75000	0.082	6	0.0002 [b]	ua	ua
Bitumen (for Carbophalt)	2898	0.7	2	0.12 [b]	ua	4.2E-04 [b]
Carbon fiber	235000	0.67	156	19.61 [b]	ua	ua
Carbophalt	3732	1.37	5	0.14[a]	7.04E-06 [a]	5.7E-05 [a]

ua=Data Unavailable/Less information to calculate
[a] = emissions calculation based on production and combustion of energy (electricity and fuel)
[b]= emissions from Table 3 sources and literature

Table 5 Maintenance and Rehabilitation stage process energy and emissions

Process	Total Fuel Consumed (lit/FU)	Expended Energy (MJ/FU)	CO_2 (Kg/FU)	N_2O (Kg/FU)	CH_4 (Kg/FU)
Mill	308	10472	827	1.68E-02	5.24E-04
Paving	70	2380	188	3.81E-03	1.19E-04
Compaction	956	32496	2567	5.20E-02	1.62E-03
Apply PMB	0.7	23	1.8	3.73E-05	1.17E-06
Melt Plastic sheet	2	79	6	1.26E-04	3.94E-06

Table 6 shows the transport distances in km, total amount of materials transported in tonnes per FU, total fuel consumed by transport vehicles in liters per FU and total energy consumed in MJ/FU. The manufacturing plant of S&P Carbophalt® G (200/200) is in Poland and the final product is wrapped in plastic sheet before transported to Sweden via road transport. Carbon fibers are produced in Germany and transported to S&P Carbophalt® G (200/200) production plant in Poland on trucks. It is assumed that all the transportation is carried out on 14 tonne load carrying capacity trucks.

Table 6 Transportation of materials related energy and emissions

Transport Material	From	To	Distance (km)	Amount to Transport (Tonne/FU)	Total fuel used (Lit/FU)	Total Energy (MJ/FU)
Bitumen	Refinery (Nynas)	Mixing plant (Arlanda)	100	14	68	2312
Crushed Aggregates	Quarry site (Arlanda)	Mixing plant (Arlanda)	5	336	81.6	2774
Asphalt Mix	Mixing plant (Arlanda)	Construction site (STKLM)	50	350	850	28900
PMB	Refinery (Nynas)	Construction site (STKLM)	60	0.9625	40.8	1387
Carbon fiber	Producer (Germany)	Carbophalt plant (Poland)	760	0.7	517	17571
Bitumen (for Carbophalt)	Producer (Poland)	Carbophalt plant (Poland)	50	0.7	34	1156
Plastic Sheet	Producer (Poland)	Carbophalt plant (Poland)	5	0.081788	3.4	116
Carbophalt	Carbophalt plant (Poland)	Storage (Sweden)	1820	1.4	1238	42078
Carbophalt	Storage (Sweden)	Construction site (STKLM)	50	1.4	34	1156

The LCA results are presented in Table 7. The total energy consumed over the design life (40 years) of the pavement when material stage and M&R stage and transportation is considered for the resurfacing of pavement (Alt. 1) is 6496 GJ per FU and for resurfacing including S&P Carbophalt® G (200/200) (Alt. 2) comes out to be 2953 GJ per FU. The GWP of Alt. 1 and 2 results in 410 and 227 tonnes of CO2-eq per FU, respectively. Figure 7 shows the graphical presentation of the final LCA results of the case study.

Table 7 Total expended energy and Global warming potential for the two studies cases.

Alternative	Stages	Total Expended Energy (GJ/FU)	Total CO2-eq (Tonnes/FU)
Alt. 1: Conventional resurfacing	Material and Maintenance	6054	375
	Transportation	442	35
Alt. 2: Resurfacing using S&P Carbophalt® G (200/200)	Material and Maintenance	2563	196
	Transportation	390	31

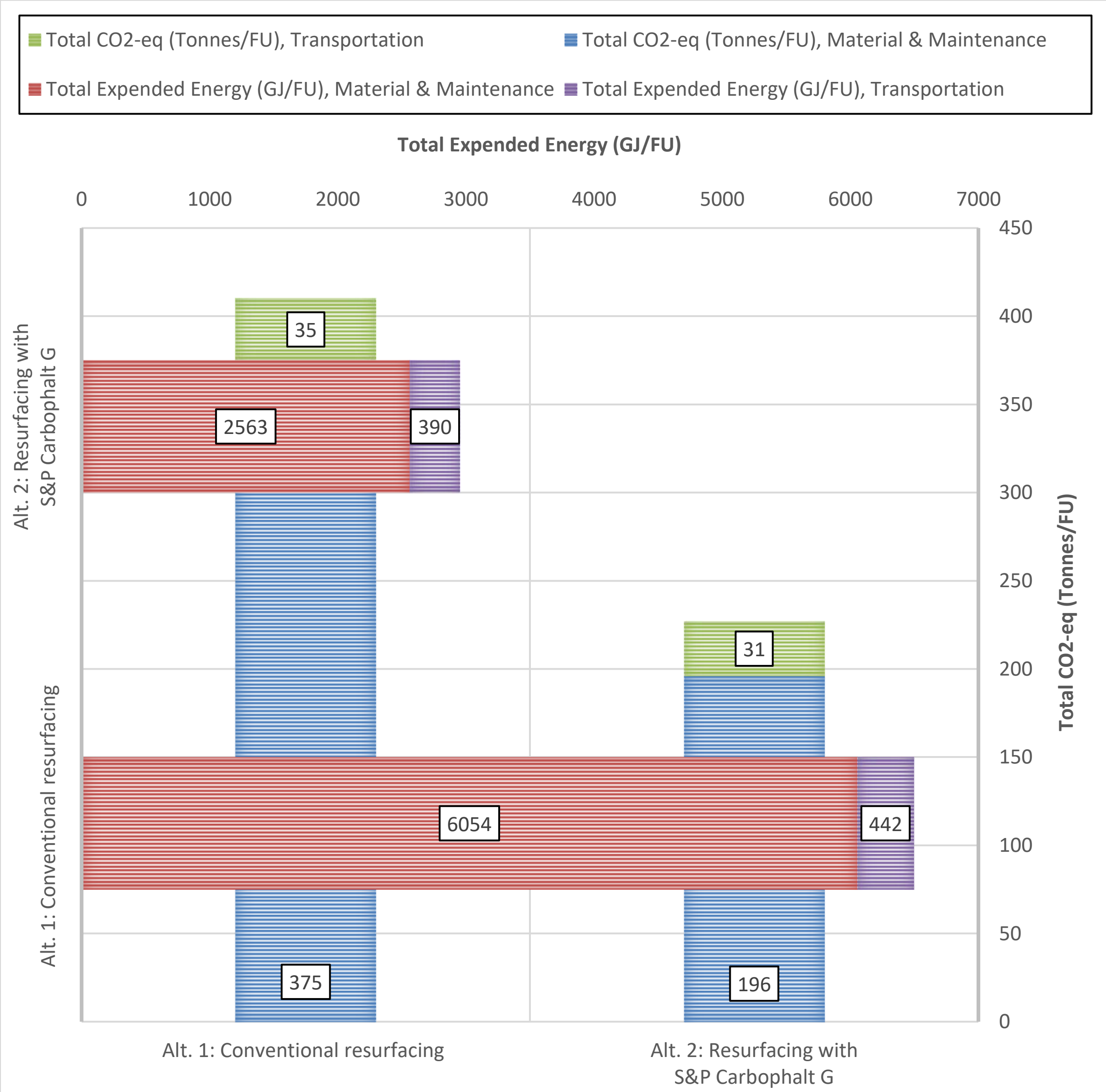

Figure 7 LCA results

LCA Conclusion

An attributional comparative LCA was performed for a conventional asphalt pavement resurfacing versus resurfacing using asphalt reinforcement layer (S&P Carbophalt® G (200/200)). The results of the study show that four cycles resurfacing using S&P Carbophalt® G (200/200) (Alt. 2) versus thirteen cycles conventional resurfacing (Alt. 1) has a savings of 3543 GJ/FU energy and 182 tonnes of $CO_{2\text{-eq}}$ /FU when material and maintenance stages, and transportation are considered for the analyses period of 40 years.

Even though, additional energy is consumed and emissions are emitted during the production and placement of S&P Carbophalt® G (200/200), the assumed reduction in maintenance cycles due to the use of S&P Carbophalt® G (200/200) indicate savings both in terms of energy and emissions. Improvement in production processes and reduction in transporting distances or efficient transportation of materials, can further increase savings not only in terms of energy but also cost. Moreover, this can also contribute to less air borne emissions due to use of less energy.

Conventional resurfacing (Alt. 1) is assumed to take place after every 3 years, whereas it is expected that with the use of S&P Carbophalt® G (200/200) (Alt. 2), the resurfacing will be required after every 8 years. However, based on the results, the use of S&P Carbophalt® G (200/200) remains environmentally feasible (in terms of energy savings) even if the resurfacing is done every 4.5 years, and environmentally feasible (in terms of energy and emissions) if resurfacing occurs every 5.5 years when compared to conventional resurfacing.

References and Annexes

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