LCA Wise 2023/24
Prof. Dr. Timo Hartmann

LCA Assignment 2

November 14th 2023, Berlin

Contents

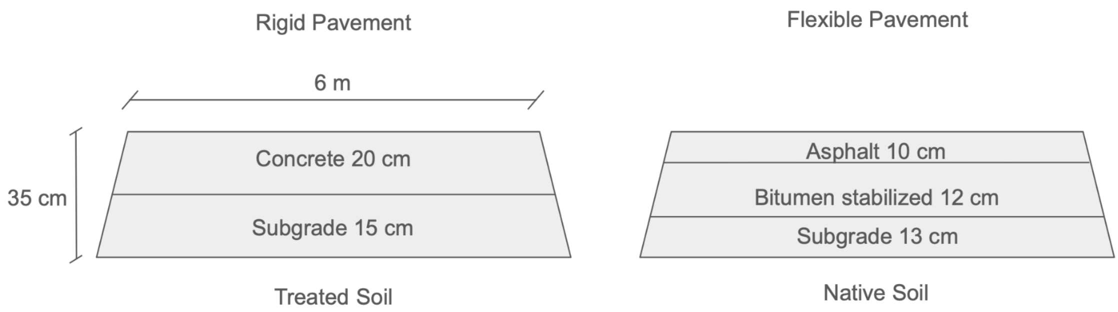
1. Introduction

In the times of climate change, it's increasingly important to minimize environmental impacts. This can be achieved by enhancing road design, taking into account the entire life cycle of various designs. This approach enables making well-informed choices using decision-making frameworks. Utilizing specific indicators can help in quantifying criteria, assisting maintenance planners in evaluating the impact of each option. Since various designs involve different materials and maintenance strategies, their environmental effects change as well.

2. Functional unit and design options

In this case the functional unit is a 1 km long, 6 m wide and 0.35 high segment of pavement. Each pavement option has individual layer thicknesses as well as materials, which directly impacts their performance. The first option is a type of flexible pavement. Its deck is made of hot mixed asphalt and its base layer is bituminized aggregate. The subgrade layer is a coarse aggregate made of crushed stone. Similarly, option 3 has the same structure but different materials. The deck uses reclaimed asphalt, the base is also from bituminized aggregate and the subgrade is made of recycled aggregate from demolition. On the other hand, option 2 is a type of rigid type pavement. It's made for heavier traffic and does not flex. Its deck is made of concrete and its subgrade is coarse aggregate. It does not need a base course layer like the flexible options [2].

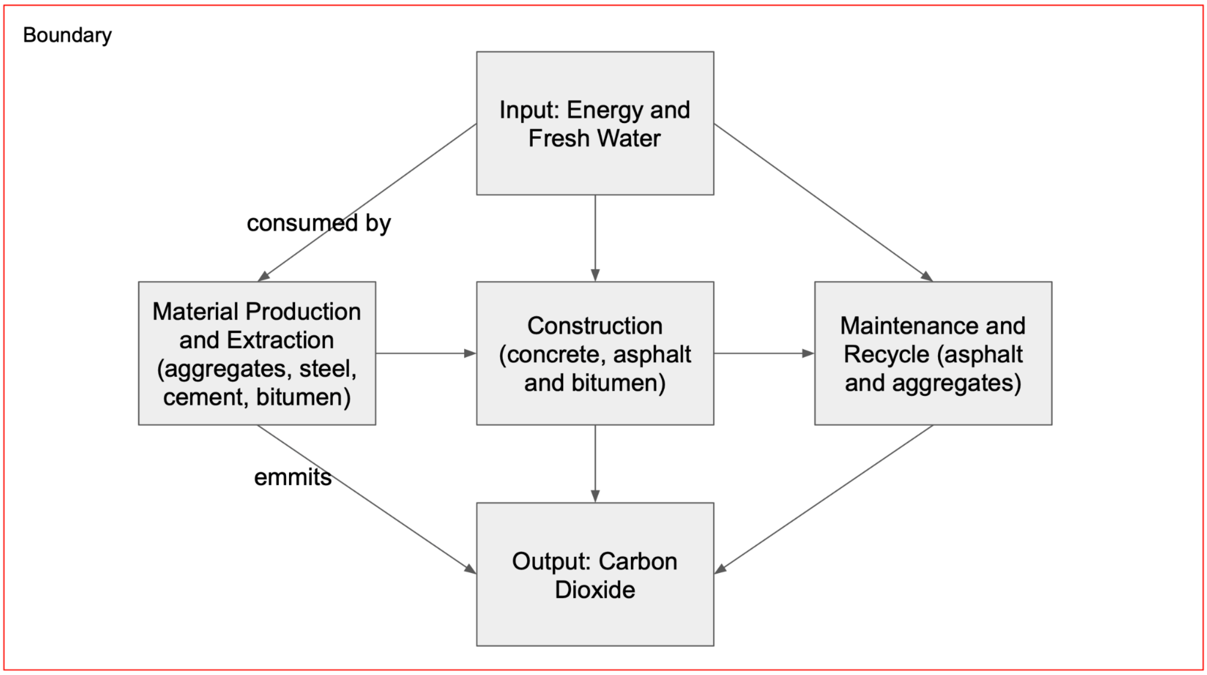
Option	**Deck Surface**	**Base Course**	**Subgrade**
1	asphalt	stabilized aggregate	coarse aggregate
2	concrete	-	coarse aggregate
3	reclaimed asphalt	stabilized aggregate	recycled demolition aggregate



Element	**Cross Section (qm)**	**Material**
Concrete layer 20 cm	1.2	Concrete C30/37, XF4, XM2 (RStO 12)
Asphalt layer 10 cm	0.6	Asphalt hot mix or reclaimed asphalt
Subgrade layer 13 cm (15)	0.78 (0.9)	Coarse aggregate or reclaimed demotion aggregate
Stabilized aggregate layer	0.72	Bitumen and crushed stone aggregate

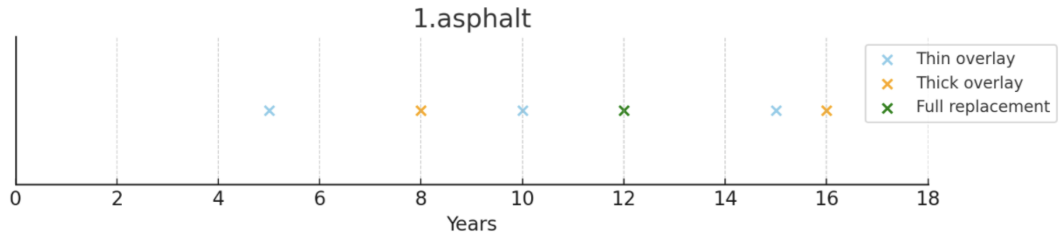
3. Goal and scope

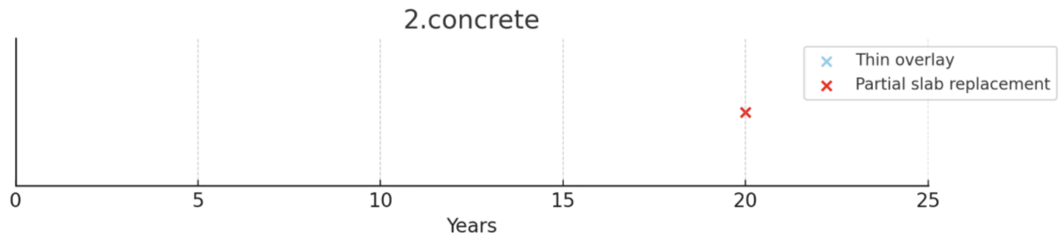
The goal for the analysis is to evaluate the environmental impact of road construction and maintenance of different pavement options. This can help to understand the implications of material production, construction, and recycling practices in the early design stage, where the biggest impact can be made. Comparing energy consumption is important, because road construction generally requires a lot of energy and using techniques that need less energy is favorable, as it contributes to greenhouse gasses. Selecting the least energy demanding option can mitigate climate change. Measuring greenhouse gas emissions is a key environmental indicator as it directly influences climate change, due to their gasses warming potential. Fresh water is a limited source and gets more scarce the more climate change progresses. It also requires a lot of effort to process it. Reducing that also makes a positive impact on the environment.
The boundary outlined in red shows the entire process, starting from the extraction and production of materials like aggregates, steel, cement, and bitumen, moving to the construction phase involving concrete, asphalt, and bitumen application and finally covering maintenance and recycling processes for asphalt and aggregates.

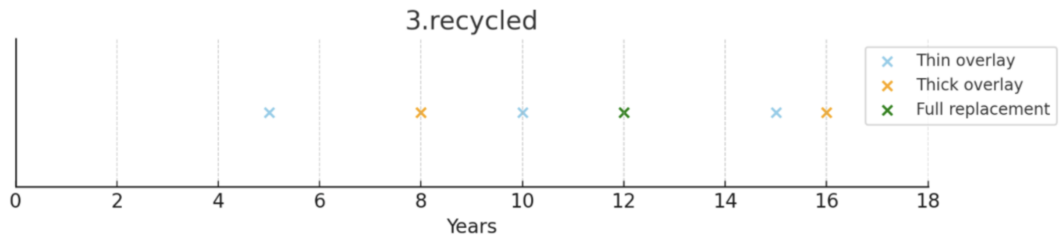


4. Life cycle time span

The timeline below shows the different maintenance actions over the years [3]. It stands out that flexible pavement needs more frequent repair due to the fact that concrete is more durable that the asphalt layer. The time span for material calculation has been selected for 18 years. Option 1 and 3 have the same frequency as they are both flexible pavement.







DesignOption	**Event**	**Frequency**	**Service life**	**Events over 18 years**
1.asphalt	Thin overlay	5	18	3,6
1.asphalt	Thick overlay	8	18	2,3
1.asphalt	Full replacement	12	18	1,5
2.concrete	thin overlay	20	25	0,9
2.concrete	Partial slab replacement	20	25	0,9
3.recycled	Thin overlay	5	18	3,6
3.recycled	Thick overlay	8	18	2,3
3.recycled	Full replacement	12	18	1,5

5. Life cycle inventory

The table below shows factors of all compositions of the options [3]. Composition density describes how much mass is in one cubic meter of each composition.

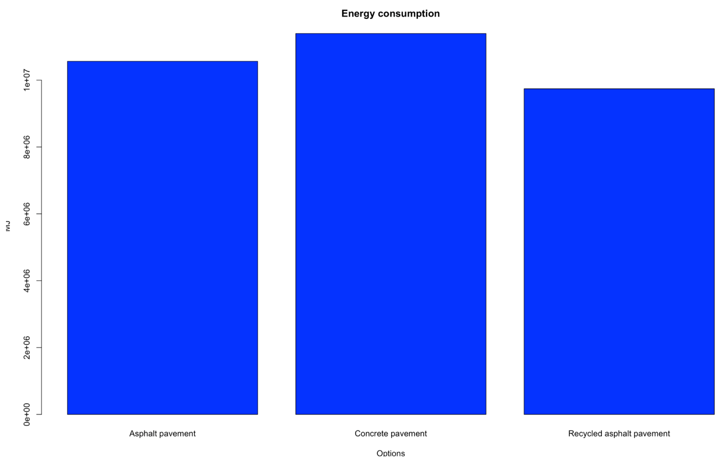
Material	Composition	compDensity	Energy	CO2e	FreshWater
concrete	RC	2.600	806.89	159	319.61
reinforcement	RC	0.130	20000	1263.6	527.9
HMA process	HMA	2.322	480	39.34	19.68
HMA	HMA	2.322	723.20	69.36	76.05
reclaimed asphalt	RA	2.322	620.15	50.82	25.43
reclaimed asphalt process	RA	2.322	620.15	50.82	25.43
bitumen	SA	90	2201.4	221.89	681.61
coarse aggregate	SA	1.710	72.99	14.38	16.46
coarse aggregate	CA	1.800	72.99	14.38	16.46
recycled demolition aggregate	RDA	1.710	22.33	4.4	5.04

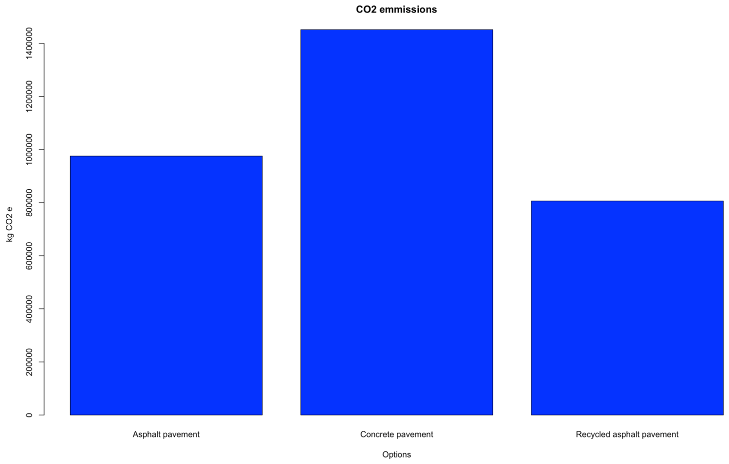
RC = reinforced concrete
HMA = hot mixed asphalt
RA = reclaimed asphalt
SA = stabilized aggregate
CA = coarse aggregate
RDA = recycled demolition aggregate

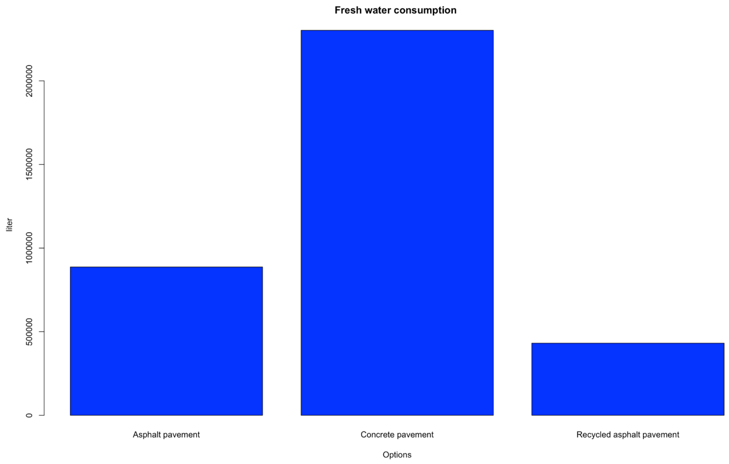
density of composition in t/m³, energy in MJ/t, CO2 in kg CO 2 e/t and freshwater l/t.

6. Life cycle cost analysis

The images represent the results of the life cycle cost analysis. For each option the mass of each layer has been calculated and multiplied with their corresponding factors. This results in the total amount for each indicator to build one kilometer of pavement. The materials mass for maintenance has been implemented by adding the additional materials for each intervention and multiplying with its frequency for the selected time span.
Looking at the results in energy consumption the third option is the most viable with around 7 million megajoules compared to 8 million and 9 million. In greenhouse gas emissions recycled asphalt is also the most favorable with 800.000 kilogram carbon dioxide equivalent compared to 900.000 and 1.2 million. The concrete road stands out with much higher emissions than the asphalt options. Looking at freshwater, recycled asphalt has also the least consumption with 250.00 liters fresh water compared to 1 million liters and almost two million liters for concrete. In all three categories the regular asphalt option is the second best. The concrete option is in all three categories the worst performing, considering the previous boundary. In energy consumption all three options are arguably similar. In carbon dioxide equivalent emissions, asphalt variants outperform the concrete pavement significantly but being similar compared to each other. In fresh water consumption asphalt variants are substantially less than concrete. Recycled asphalt performs significantly better than regular asphalt in this case.







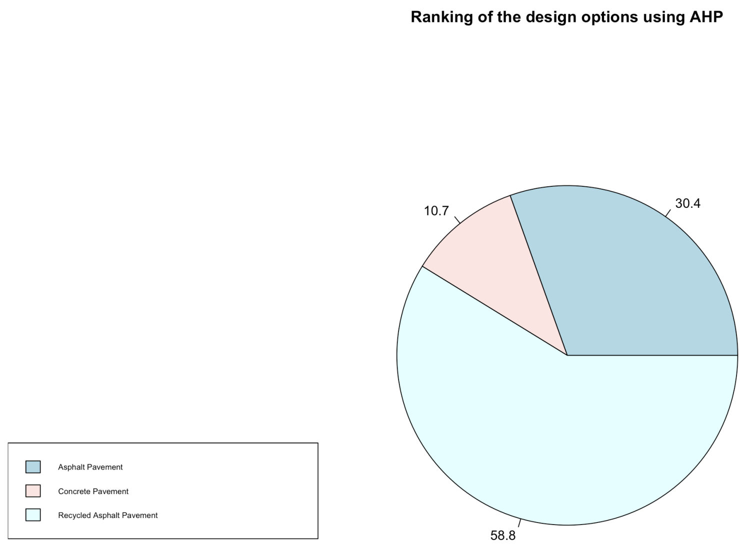
7. Multi criteria decision making analysis

Below the pairwise comparison is presented in the image. The weights are selected based on the analysis of the bar plots rather than using the exact values from the LCC analysis. Here for energy option one is slightly better than option 1 and two. For greenhouse gas emissions recycled asphalt is significantly better than both at a different scale having the score of 2 and 5. In terms of water score alternative 3 is substantially better than concrete significantly better than option being assisted 8 and 9 to it. The indicator weights are selected as shown in the image below. Energy Consumption is the most important to mitigate environmental impact as it is linked to greenhouse emissions and depletion of sources . Greenhouse gas emissions are more important than water consumption but less important than energy because change also affects water depletion due to dryness . Water consumption is the least important because it is linked to regional issues while others are global.

The pie chart below represents the result of the AHP method. With a total score of 59 it is the best performing option 3 achieving the goal under the set of criteria and under given weights.

With a score of 30 points the option 1 is the second best and with a score of 10 the option 2 is the worst of the given.

```
> energy
                         Asphalt Pavement Concrete Pavement Recycled Asphalt Pavement
Asphalt Pavement                1.0000000                 3                      0.50
Concrete Pavement               0.3333333                 1                      0.25
Recycled Asphalt Pavement       2.0000000                 4                      1.00
> co2
                         Asphalt Pavement Concrete Pavement Recycled Asphalt Pavement
Asphalt Pavement                     1.00                 4                       0.5
Concrete Pavement                    0.25                 1                       0.2
Recycled Asphalt Pavement            2.00                 5                       1.0
> water
                         Asphalt Pavement Concrete Pavement Recycled Asphalt Pavement
Asphalt Pavement                1.0000000                 6                 0.1250000
Concrete Pavement               0.1666667                 1                 0.1111111
Recycled Asphalt Pavement       8.0000000                 9                 1.0000000
> CWPC
          energy co2 water
energy 1.0000000 3.0     5
co2    0.3333333 1.0     2
water  0.2000000 0.5     1
```



8. Discussion

Overall, recycled asphalt is clearly the best option if the goal is to mitigate environmental impact considering materials extraction, production, construction and maintenance. Even the fact that concrete is more durable does not provide enough savings to outperform asphalt. The reason is mainly that concrete and reinforcement has such high factors. In the category greenhouse gasses bitumen is higher, but the required mass is significantly lower than for reinforced concrete. In general asphalt has significant energy use and emissions but the

concrete layer is much thicker, therefore it does not perform well environmentally. The expensive layer has much more volume. In contrast most of the asphalt road is aggregate, which is less expensive.
What makes recycled asphalt so environmentally friendly is that it reduces the price for each material, especially the asphalt layer, which contributes the most to the negative impact. It is because resources and emissions from materials extraction and production are cut.
Also, as the aggregate is recycled it also contributes to better performance.

Using RAP it must be considered that this asphalt has to be handled differently than regular hot mix asphalt and its quality is dependent on the recycled material [4]. Also rising bitumen prices can ultimately reduce its cost effectiveness as it still relies to some extent on new materials. This is where the results of the AHP process might differ especially for regular asphalt. If fiat cost would be part of the boundary the ranking would be different.

The ranking would also change if the importance of criteria would change. Therefore if a country with a lot of renewable energy sources plans to build a road, its environmental impact would be different from a country which relies more on non renewables. Therefore, the weighted criteria matrix would look different. Energy use would potentially have less significance in environmental impact. This would put more weight on greenhouse gas emissions, therefore concrete would fall short, again.

In regions with water shortage concrete is also not recommended, as it has a significant fresh water usage. In those areas the focus would be to reduce that, and recycled asphalt would be recommended instead.

References

[1] RStO. (2012). Richtlinien für die Standardisierung des Oberbaus von Verkehrsflächen. [Title in English: Guidelines for the Standardization of the Superstructure of Traffic Areas].

[2] Khazanovich, L. (n.d.). Cracking of the PCC Layer in Composite Pavement. ResearchGate. Retrieved December 19, 2023, from [URL]

[3] Bauuw, (2021) Life Cycle Inventory for Pavements - A Case Study of South Africa. (doi: https://doi.org/10.1016/j.treng.2021.100049)

[4] Zaumanis, (2016) 100% Hot Mix Asphalt Recycling: Challenges and Benefits (doi: https://doi.org/10.1016/j.trpro.2016.05.315)