# Life cycle evaluation for reusing Reclaimed Asphalt with a bio-rejuvenating agent

**Laurent Porot[1, a], Maria Di Nolfo[1], Enrico Polastro[2], Sonia Tulcinsky[2]**

*[1] Roads and Construction, Arizona Chemical BV., Almere, Netherlands*
*[2] Arthur D. Little, Brussels, Belgium*

[a] laurent.porot@azchem.com

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## ABSTRACT

*Reusing Reclaimed Asphalt (RA) in new pavement imparts both economic value and environmental benefits to the industry. Environmental impact is an important parameter to be addressed in Environmental Product Declarations, which may be requested in the near future in Europe. As part of these environmental impact determinations, carbon footprint calculations are a key element for estimating climate change drivers.*
*This paper discusses the life cycle evaluation of an asphalt mixture with a high RA percentage. Percentages of RA above 30–40 % require specific technologies to overcome technical challenges, and in this study, the use of a bio-based rejuvenating agent was taken into account. The use of such a rejuvenating agent ensures that the end performance of the asphalt mixture is equal to or better than a standard asphalt mixture without RA.*
*Calculations were based on a specific study for one metric ton of Hot Mix Asphalt (HMA) produced with 70% RA. Although the contribution of the bio-rejuvenating agent to the carbon footprint is limited, the results clearly highlight the benefits of reusing high volumes of RA in HMA by reducing the overall carbon footprint for production of the mix.*
*Key words: Reclaimed Asphalt, recycling, asphalt, bio-rejuvenator, carbon footprint, Life Cycle Assessment, sustainable development*

**Keywords:** Additives, Asphalt, Life cycle assessment, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators

# 1 INTRODUCTION

Reusing Reclaimed Asphalt (RA) in new pavement imparts both economic value and environmental benefits to the industry. Environmental impact is an important parameter to be addressed in Environmental Product Declarations, which may be requested in the near future in Europe. As part of these environmental impact determinations, carbon footprint calculations are a key element for estimating climate change drivers.
The pavement industry has been considering environmental impact through life Cycle Assessment for almost 20 years [1], and numerous studies have been carried out to improve methodology and outcomes [2]. This is seen as a powerful approach to better understand the environmental impact of pavement construction and develop new technology that can reduce those impacts either with lower energy technology or the valorization of Reclaimed Asphalt [3].
The goal of the study was to conduct life cycle evaluation of an asphalt mixture containing a high percentage of RA. As a consequence of aging, asphalt pavement materials become stiffer and more brittle. There are some concerns about the potential negative effect of the aged RA binder on the field performance, especially cracking resistance, of the high RA mixtures. Thus usually RA percentages above 30–40% require specific technologies to overcome technical challenges. In this study, the use of a bio-based rejuvenating agent was taken into account, enabling the inclusion of 70 % RA, and in theory even up to 100 % RA. This study compares a reference Hot Mix Asphalt (HMA) with 0 % RA, and a HMA with 30 %RA as is currently used, to a HMA made with 70 % RA containing a rejuvenating agent.
The aim of the project was to evaluate the overall environmental impact of the bio-based additive, and of its use in HMA with high RA content. The results presented here focus only on Green House Gases (GHG) from the asphalt mix material. In particular, it presents the following:

- Goals and scope
- Inventory analysis
- Sensitivity analysis

# 2 GOALS AND SCOPE

The methodology used was based on the EU (European Union) Commission recommendations of April 9, 2013, related to the use of methods to measure and communicate the life cycle and environmental performance of products [4]. To model and compute the data, Simapro 8 software was used. The carbon footprint was calculated with the IMPACT 2002+ method where the Global Warming Potential (GWP) for a 100-year time horizon is used. With regard to the emission factors data, the EcoInvent 3 and European Life Cycle Database (ELCD) databases [5] were used in addition to publicly available data sources. For example, for bitumen, the Life Cycle Inventory from Eurobitume was used [6]; for the aggregates, the data was obtained from the ELCD [7] for crushed stone 16/32 and open pit mining; and for transportation, data from EcoInvent 3 were used.
The study was conducted based on an example of HMA as produced in the Netherlands. Input-output data came from a typical operating batch asphalt mix plant. Finally, for the bio-based rejuvenating agent, the data used were extracted from the specific inventory for this commercial product.

## 2.1 Boundaries

The entire life cycle of a pavement is relatively complex [8], and includes the production of raw materials, transportation, manufacturing of pavement materials, transportation, construction of the pavement itself, use of the pavement, and the end of the life or dismantlement.
In the present study, the carbon footprint of asphalt mixes has been assessed from the cradle up to the gate of the mix plant. This consists of phase A1 - Raw material Supply, A2 – Transport and A3 – Manufacturing, and does not include the other phases (A4–5, B, and C) used for life cycle assessment for building products. This does not consider the construction, use, and end-of-life of the pavement. Thanks to the effect of the bio-based additive, RA can be reused into HMA, with a performance similar to that of pavement made with virgin asphalt mixture without any RA [9, 10]. In other words, only the manufacturing process of the asphalt mixture containing RA differs; the paving, compaction, and performance of the road during its use and at the end of its life is similar to that of virgin asphalt mixture.
Figures 1 and 2 describe the system boundaries for the virgin asphalt mixture with 0 % RA and for asphalt mixtures made with RA.

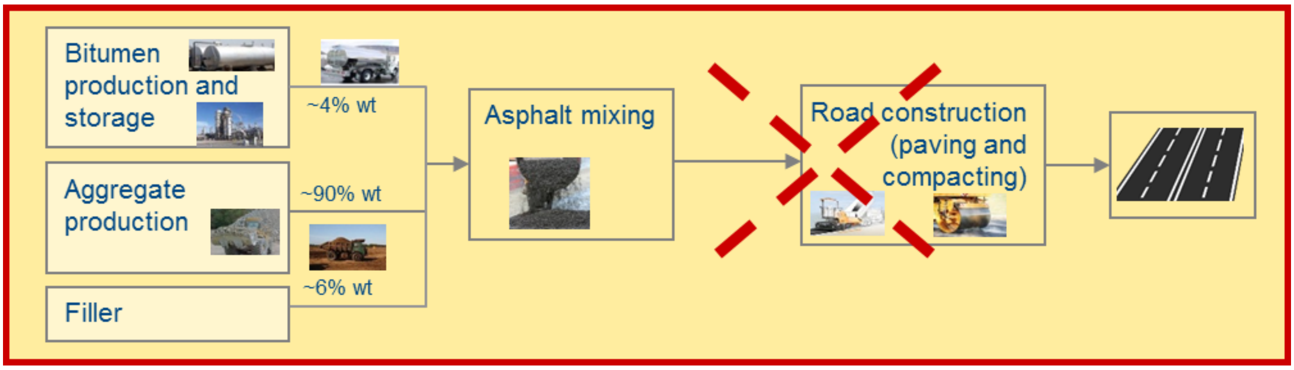


**Figure 1. System boundary for asphalt mixture without RA**

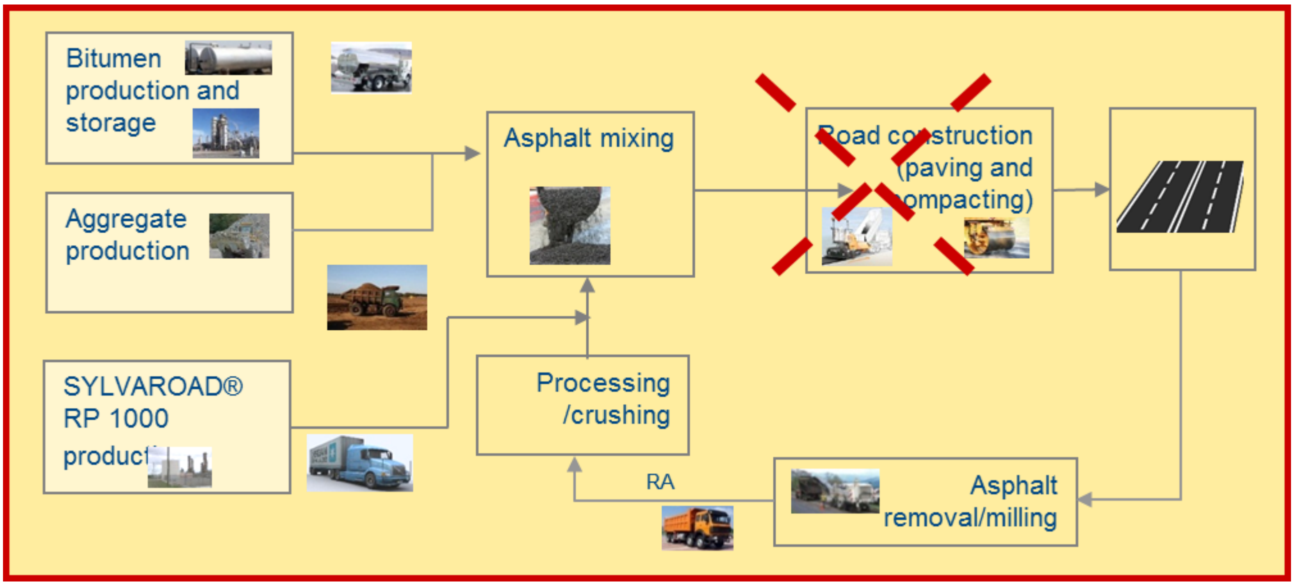


**Figure 2. System boundary for asphalt mixture with RA**

Emissions associated with the building of the infrastructure/machinery required to produce, transport, and refine products, such as the crushers at the quarry, the trucks for transportation, the asphalt mix plants, and any other machinery were explicitly excluded from the scope of the analysis.

## 2.2 Unit

The unit used to compare the different asphalt mixtures was one metric ton of asphalt mix at the gate of the asphalt mix plant.

## 2.3 Assumptions

The virgin asphalt mixture consisted of almost 90 % virgin aggregates, the rest being represented by bitumen ~4% and a calcium carbonate filler ~6%.
Two other types of asphalt mixtures containing Reclaimed Asphalt were considered:

- An asphalt mixture with 30 % RA, which does not require the use of a rejuvenation additive
- An asphalt mixture with 70 % RA treated with the bio-based additive

The processing of mixtures with high RA content requires a different configuration for the asphalt mix plant, including a separate parallel drum to dry and warm the RA separately. The virgin asphalt mixture and mix made with 30 % RA does not require the double parallel drum.
The additive evaluated was a liquid pine-based additive designed to be highly effective on aged asphalt binder. A dosage of 5 % restores the properties of aged binder by 2 grades, causing it to behave more like virgin asphalt binder. The typical dosage is 3–7 % of aged binder content, depending on its properties.
The aggregate used was crushed stone obtained from crushing/sieving of blasted rock from Northern Europe e.g. Germany or Belgium (~250 km) with material supplied by truck in the base scenario. An alternative scenario was tested with virgin aggregates being produced in Scotland and transported by ship over 1260 nm. The RA was assumed to be

removed/milled from an existing road about 50 km from the asphalt plant. Finally the bitumen was considered as being from a refinery sourced within a radius of 200 km.

## 3 INVENTORY ANALYSIS

Figure 3 displays the carbon footprint of 1 t of asphalt mixture produced at the gate of the mix plant. Assuming that aggregates are sourced ‘locally’, the cradle-to-gate carbon footprint of the various asphalt mixes produced ranges from 69.7 kg $CO_2$ e/t to 51.4 kg $CO_2$ e/t for virgin asphalt and 70% RA-based asphalt mixes, respectively.
The raw materials account for 70% of the $CO_2$ equivalent emissions of the virgin asphalt, at 49 kg $CO_2$ e/t. This value drops to 39.7 and 27.8 kg CO2 e/t, respectively, for the 30% RA and 70% RA asphalt mixes.
The $CO_2$ equivalent emissions associated with utilities are somewhat higher for the mixes containing RA, reflecting the slightly higher temperatures involved in the process and the impact of moisture content from the RA, which requires more energy.
For the ‘Other’ category, like filler or additive, the emissions are marginal, corresponding to just 0.1 % for both virgin asphalt and the 30 % RA mix and 0.5 % for the 70 % RA mix. The contribution of the bio-based additive, for the latter, corresponds to 0.3 kg $CO_2$ e/t.

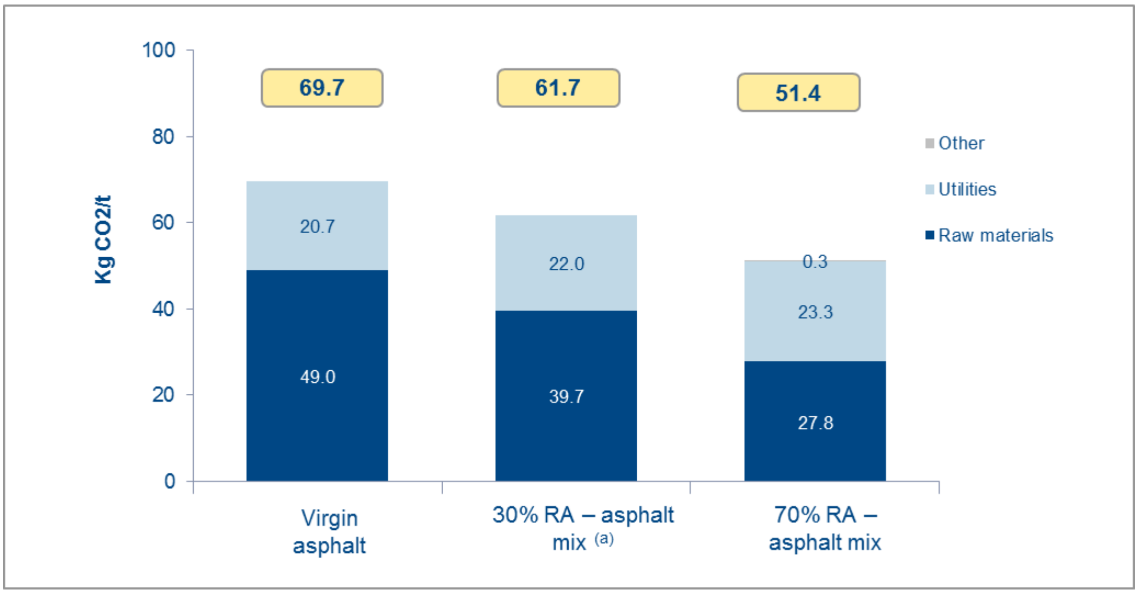


**Figure 3.** **Carbon footprint of the different asphalt mixes based on “locally” sourced aggregates**

Clearly, raw materials are the main contributors to GHG in the asphalt mixing processes. Figure 4 displays the respective weight of the different raw materials for each asphalt mixture in terms of emissions (the first bar), and in terms of mass (the second bar).

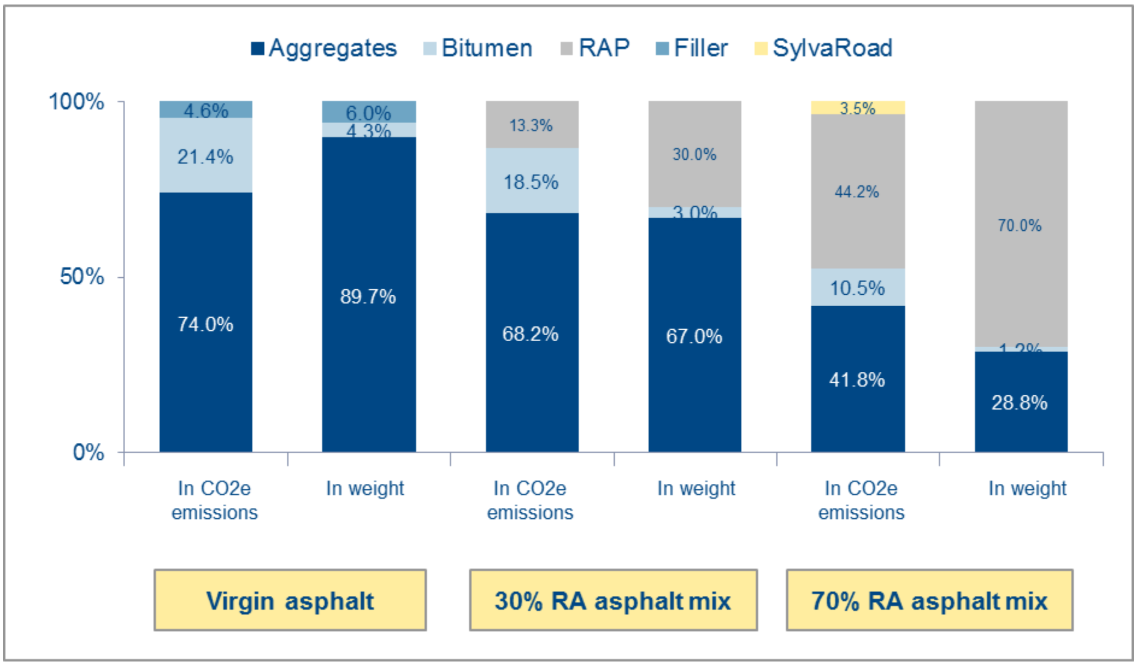


**Figure 4.** **Breakdown of materials' contribution to carbon footprint**

Bitumen, even if it is incorporated in a relatively small amount, contributes significantly to total emissions, given its relatively high emission factor of 202 kg $CO_2$ e/t bitumen [6]. This has to be compared with 13.4 kg $CO_2$ e/t for the aggregates [7], and with 17.6 kg $CO_2$ e/t for the RA, as calculated from the processes of milling, crushing, and sieving the RA. The bio-based additive contributes just 3.5% of $CO_2$ emissions of the 70% RAP asphalt mix.

## 4 SENSITIVITY ANALYSIS

In order to assess the robustness of the outcomes towards the different assumptions, sensitivity analysis was conducted on the major contributors of the carbon footprint, namely

- Transportation of aggregates or RA
- Manufacturing process and the type of energy used
- Production of RA

### 4.1 Impact of aggregate transportation

An important element is represented by the GHG emissions associated with the transport of aggregates. In this sensitivity analysis, "local" sourcing of aggregates, from Germany or Belgium, was compared with long-haul transportation of aggregates by ship from either Scotland or Norway. As a consequence, the carbon footprint for the asphalt mixes based on aggregates sourced from Scotland is significantly higher, particularly for the virgin asphalt, given the high proportion of aggregates in the mix.

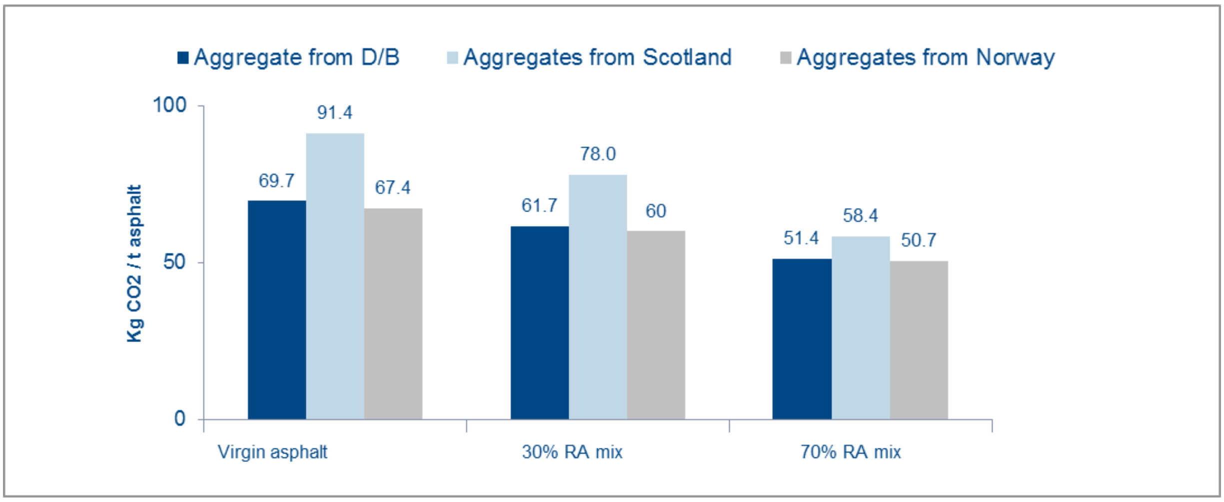


**Figure 5.** **Impact of aggregate transportation**

The assumptions used for transportation were

- 26.9 kg CO2 e/t – assuming road transportation (Euro 4 truck >32 t over 250 km)
- 51.3 kg CO2 e/t when sourced from Scotland (shipped over 1260 nautic miles)
- 24.4 kg CO2 e/t when sourced from Norway through transoceanic ship (over 600 nm)

For water transportation, it was considered that the aggregates were directly delivered by boat as the asphalt mix (ship loading capabilities) and that the vessels would return empty. The impact of the ship returning loaded was also calculated.

### 4.2 Impact of energy type at the mix plant

Figure 6 displays the sensitivity analysis of natural gas vs. heavy fuel oil (HFO) as the main source of energy for the asphalt mix plant.

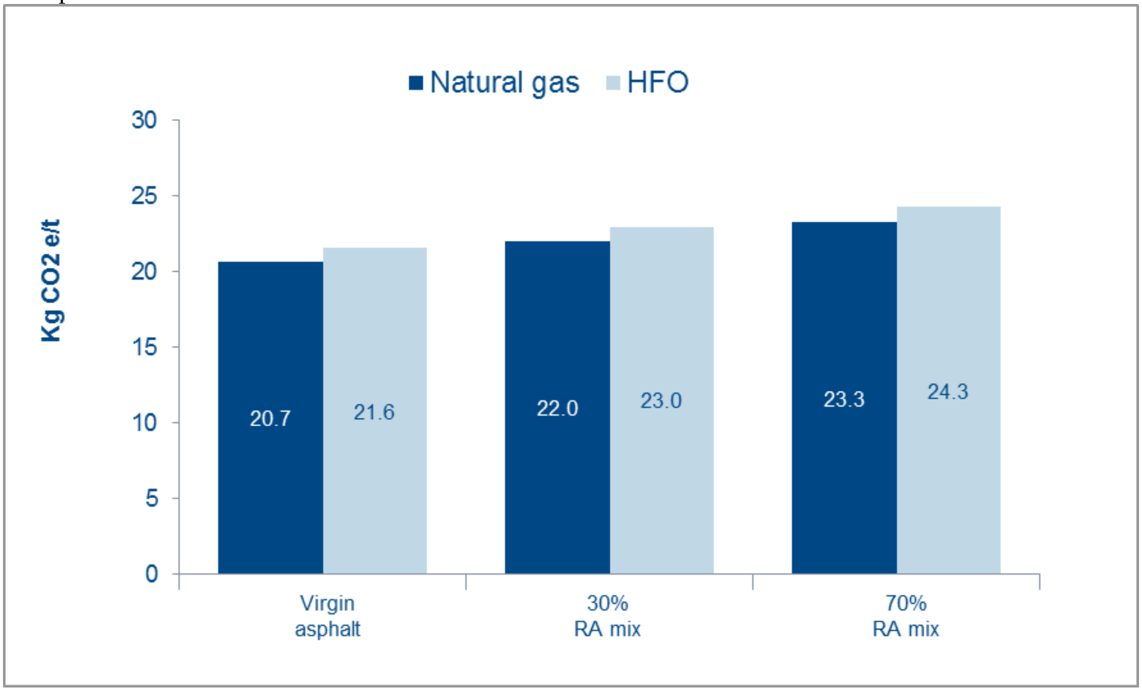


**Figure 6. Impact of energy used at asphalt mix plant**

The $CO_2$ emissions from utilities were comparable for the three asphalt mixes. As expected, CO2 emissions were slightly higher for the mixes containing RA, reflecting the higher processing temperatures and energy required due to the moisture in the RA. The use of HFO as the energy source instead of natural gas yielded only marginally higher emissions of around 1 kg $CO_2$ e/t.

### 4.3 Impact of RA processing

Figure 7 displays the sensitivity analysis of processing the RA from the road to the asphalt mix plant. The milling process on the road had a limited impact, assuming a throughput of 150 t/hour and consumption of 160 l diesel/hour – typical of new-generation milling machines – and consumption factors that were only three-fold higher in the worst scenario. The processing of the RA at the mix plant with crushing and sieving was a minor contributor. Transportation had the greatest impact overall in the carbon footprint of RA production, based on transport over a distance of 50 km and the truck returning empty.

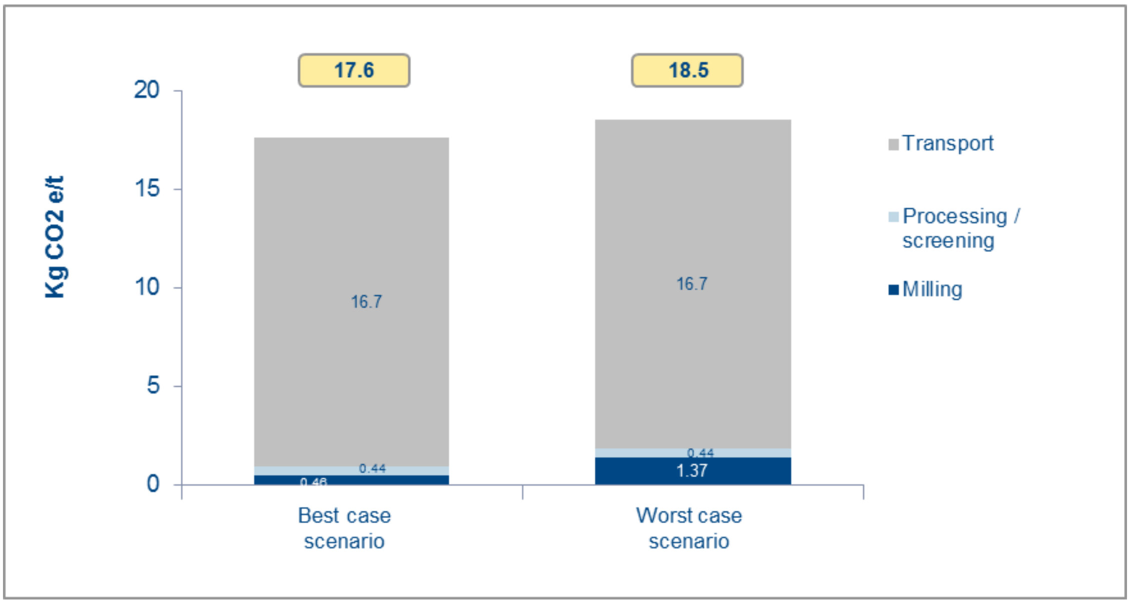


**Figure 7. Impact of RA processing**

### 4.4 Overall sensitivity analysis

Figure 8 displays the different factors evaluated in the overall sensitivity analysis.

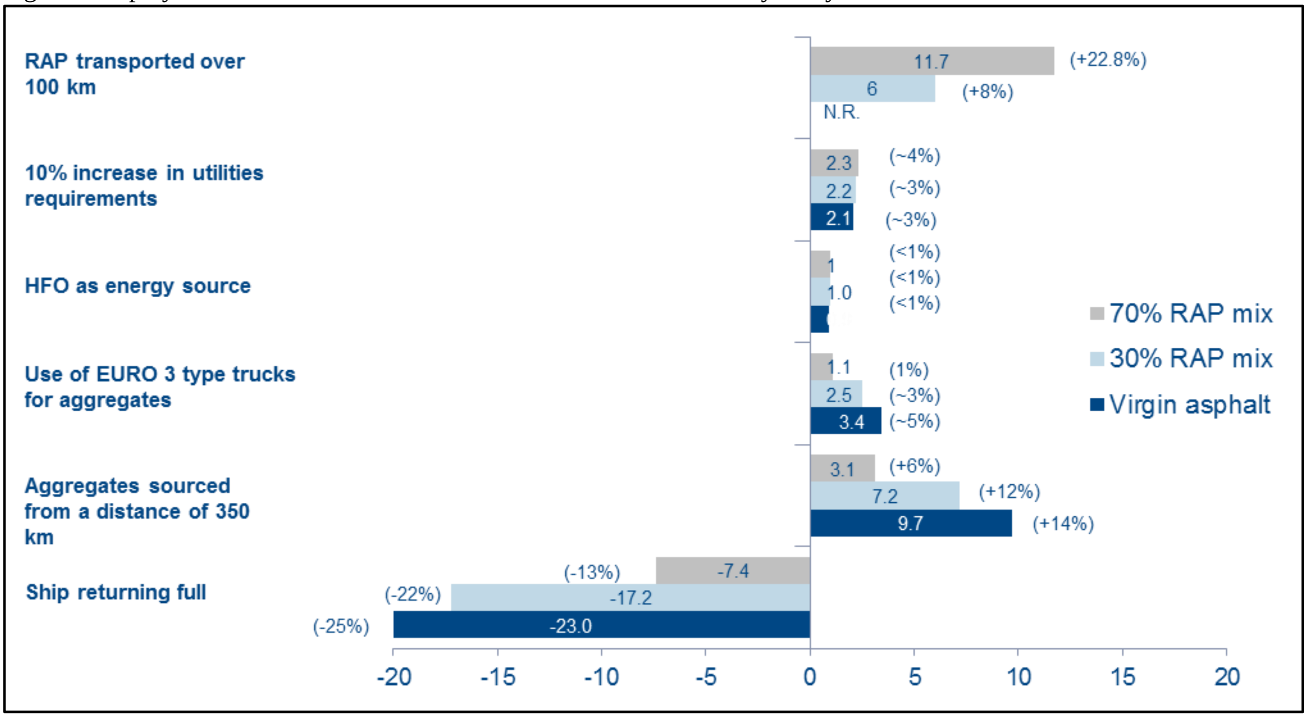


**Figure 8. Overall sensitivity analysis results**

The transportation of raw materials had by far the greatest impact on emissions. The key element was the distance between the asphalt plant and the raw material source. In the case of RA, the milling location needs to be taken into consideration. The type of the truck used for transportation had a more limited impact on the emissions, and the utilities in general are minor contributors.

## 5 CONCLUSION

The purpose of the study was to assess the carbon footprint of an asphalt mix made with 70 % RA, compared to a virgin asphalt mix with 0 % RA, as well as a mix with 30 % RA, which is the current practice when reusing RA. The use of a high RA content requires specific technologies for processing at the mix plant with a double parallel drum, as well as specific products allowing at least the same level of performance for the road. Thus, in this case study, a specific bio-

based rejuvenating agent was used in order to compare the products—the asphalt containing RA, and standard virgin asphalt material that had similar performance.
For the comparative analysis, as the main differences between the different options are in the recipe and the manufacturing of the mix, only these stages were considered in the life cycle evaluation. The paving, compaction of the pavement, and the use and end-of-life of the road were similar.
On a cradle-to-gate basis, the outcome of the study shows that substituting virgin asphalt or a mix containing 30% RA with a mix containing 70 % RA rejuvenated with the bio-based additive, results in a reduction of GHG emissions by18.3 kg $CO_2$e/ton and 10.3 kg $CO_2$e/ton, respectively
The contribution of the additive to these emissions is negligible, but its contribution to the end performance of the pavement is crucial, as the road would otherwise fail prematurely through cracking.
The sensitivity analysis clearly showed that transportation of raw materials is the major contributor to Green House Gas emissions, whereas the processing and utilities are important contributors, but are comparable for the different options.

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