Climate change impact compared to life cycle assessment results: a pilot case in Flanders

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ABSTRACT

In 2013, a pilot project 'Carbon Free-Ways' was elaborated in which the Flemish government included both price and CO2 emissions as award criterion in a public tender for the reconstruction of a field case in Kontich (Belgium). The road works include the construction of a base course with 50% reclaimed asphalt pavement and a surface course with 100% virgin split mastic asphalt, both are warm asphalt mixtures. Data was measured during the execution of the works for raw materials, transport and asphalt production. This real live data is used for all calculations. The approach used in the pilot project (Carbon Counter tool) to assess the emissions from the road construction is compared to a comprehensive environmental analysis following the life cycle assessment methodology. This paper aims to answer the following four main research questions. What is the difference between the results from the Carbon Counter and the life cycle assessment calculation? What is the contribution of climate change impact to the total single score environmental impact? Which materials or processes have the highest environmental impact? What is the environmental impact of processes which are beyond the scope of the pilot project? It was found from the current study that CO2 emissions or climate change impact is for sure not the only important environmental impact. Fossil depletion was found to majorly contribute to the total single score impact and transport by lorry and the raw material bitumen are processes and materials with an important contribution to the environmental impact.

Keywords: Climate change, Green procurement, Life cycle assessment, Warm Asphalt Mixture

1. INTRODUCTION

Since all installations with a net heat excess of 20 MW or more are subjected to the Kyoto Protocol and hence the European Union Emissions Trading System, 13 of the 18 Flemish asphalt plants have to monitor and report on their CO_2 emissions. This system only accounts for the emissions due to fuel consumption by a particular company. Hereby the reduction of the asphalt production temperature is encouraged.

The last decade, the warm mix asphalt (WMA) technology for Belgian plants was illustrated mainly in its characteristics of performance (De Visscher et al. 2009; Bogaert 2010). There were few studies carried out about the environmental impact of WMA in Flanders (Gonda 2011).
In 2011, the University of Antwerp in co-operation with the Flemish asphalt pavement sector and authorities started a preliminary study focussing on the CO_2 emissions of Flemish asphalt producers. In this study, several CO_2 software are used for different cases of asphalt production, e.g. using reclaimed asphalt (RAP) in wet and dry condition, the effect of different energy resources and transport methods. These results were published (Anthonissen et al. 2013).
However, there was a need for a more detailed investigation of the environmental impact of WMA in Flanders. The environmental analysis should be based on practical data, measured in situ and with broadened system boundaries to be able to include multiple environmental parameters and as much as possible processes of the life cycle of the pavement.

The Flemish Agency for Roads and Traffic together with the Dutch and British highway agencies jointly investigated in which ways they can contribute to the reduction of CO_2 emissions from road works. The project is called Carbon Free Ways. One of the opportunities to stimulate contractors for CO_2 efficient road works was found to be the inclusion of a parameter related to the emissions in the public tender. In Flanders, this approach was implemented for the first time in a pilot study, which contains the construction of a field case.

The current paper briefly describes the methodology used in the pilot project Carbon Free Ways. The main goal of this contribution is the comparison of the results to a more comprehensive environmental life cycle assessment (LCA) study. Chapter 2 describes the field case which was the subject of the pilot and which is the subject of the current case study. Some environmental issues which were investigated in the preliminary study (Anthonissen et al. 2013) or found in other literature were compared to the execution of the field case. In section 3, the life cycle assessment methodology which is applied for the analysis of the case study is clarified. Some results of the LCA analysis are discussed in chapter 4. Finally, conclusions and recommendations are formulated.

2. FLEMSICH FIELD CASE

In 2013 the Flemish Road Agency initiated a call for a public tender for the maintenance works of a road pavement in which carbon dioxide emissions are included as an award criterion. The tender was evaluated by price for 50% and by CO_2 emissions for the other 50%. Two software tools were introduced to estimate the CO_2 emissions of the project: the Carbon Counter (original Dutch name: *Koolstofteller*) and the Traffic Tool. Both tools are Excel® workbooks and calculate a theoretical amount of emissions based on measurable and controllable input data. This Flemish pilot project and both calculation tools are described in (Anthonissen et al. 2015).

The Carbon Counter tool uses the emission factors from the Inventory of Carbon & Energy version 2.0 (Hammond & Jones 2011). The result is weighted for 30% for the public tender. The analysis includes three different aspects i.e.:

- Emissions from raw materials mining and production;
- Emissions from transport of raw materials supply to the asphalt plant and transport of asphalt mixture and reclaimed asphalt pavement (RA) between asphalt plant and work site; and
- Emissions from energy consumption for asphalt production at the asphalt plant.

The result from the Traffic Tool is weighted for 20% for the public tender. The tool calculates the additional amount of CO_2 emitted by road users of the considered road section and traffic diversions during road works. These results are not discussed in the current contribution.

The field case under the pilot project is situated on a Flemish primary road (N171 in Kontich), is 1.15 km in length and consists of two lanes and a paved emergency lane in each direction. The work, monitored in the context of the pilot study, includes repaving the base (7 cm) and surface (3 cm) layers.

Figure 1: localization of the studied field case

2.1 Materials and transport

For the surface course, split mastic asphalt (SMA) was used with polymer modified bitumen, without reclaimed asphalt (RAP). An asphalt concrete with performance requirements (APO), defined according to the fundamental method was used for the base course. The APO mixture contained a paving grade bitumen and 50% RAP. Both mixtures are warm mix asphalt (WMA), with a production temperature between 100 °C and 130 °C. The foaming technology is used in order to reduce the viscosity of the binder by injecting water in the hot bitumen before it is added to the mixture.

In order to further reduce the CO_2 emissions from the project, the contractor optimized the transport processes. All aggregates (virgin raw materials) are supplied to the asphalt plant by ship (sea ship and/or barge). The transport of the asphalt mixture to the work site and the transport of the RAP from the work site to the asphalt plant were geared to one another in order to reduce the number of empty journeys by truck between the asphalt plant and the work site.

2.2 Asphalt production at plant

Various studies (Anthonissen et al. 2013; National Technology Development 2009; Wayman et al. 2012) describe the effect of moisture in aggregates (virgin and recycled) on the fuel consumption for the asphalt production. The moisture in the aggregates has a major influence on the energy consumption compared to the production temperature. Additional moisture content is sometimes speculated as a factor to be associated with RAP because water is used when breaking up old pavement. In Flanders, the difference between the moisture content in RAP and in virgin aggregates is small because most of the virgin aggregates are washed at the quarry. Therefore, both virgin and reclaimed aggregates are wet when they arrive to the asphalt plant. The asphalt plant has two big sheds in order to store aggregates (mostly reclaimed asphalt) to prevent them from rain.

Figure 2: shed to store aggregates in order to reduce the moisture content

In Flanders, all asphalt plants are batch plants and use a parallel drum in order to dry and heat RAP before it is added to the mixture. A Dutch study (van den Berk 2004) found that the energy consumption per ton asphalt mixture increases for mixtures with RAP due to the use of the additional parallel drum. An increase in energy consumption of 14 to 17% is pretended, however the temperature in the parallel drum is lower compared to the white drum. This finding was not confirmed by the current case study, where the average gas consumption per ton SMA (without RA) was higher compared to the energy consumption per ton APO (with 50% RA). This observation might be caused by the significant higher production temperature of SMA (137.8 ± 2.4 °C) compared to the production temperature of APO (121.8 ± 3.5 °C). Hence, the production temperature of the SMA mixture was not within the temperature range for WMA as defined by the contracting authority. Anyhow, the production temperature of SMA was decreased compared to the production temperature of conventional hot mix asphalt (HMA). No requirements on the production temperature were imposed in the tender, but the measured energy consumption is used to calculate the related CO_2 emissions.

Various studies (Olsen et al. 2012; Read & Whiteoak 2003; Gasthauer et al. 2008) state a reduction of the emissions if the asphalt production temperature is reduced. Nevertheless, previous measurements of stack emissions in a Flemish asphalt plant during HMA and WMA production did not reveal a decrease of the concentration of pollutants. Moreover, an increase of the CO concentration in the stack emissions was measured, which could be attributed to an incomplete combustion of gases. No measurements of emissions were accomplished during the asphalt production for the field case investigated, and hence this assertion could not be verified.

3. LIFE CYCLE ASSESSMENT METHODOLOGY

Life cycle assessment methodology was used in order to investigate the environmental impact of the current field case. In this section, the applied LCA methodology is described following the different steps as defined by ISO 14040:2006. Chapter 4 describes the LCA results.

3.1 Goal and scope

The goal of the LCA part in this research was to analyse, on the basis of the field case described, whether the used method (CO_2 emissions calculated with the Carbon Counter) is representative for the assessment of the environmental impact. Therefore, the results of the pilot project were compared to the results of an LCA study.

The functional unit used for this investigation was a 1.15 km long dual carriageway with two lanes and an emergency lane in each direction. The road structure investigated includes a base course of 7 cm and a surface course of 3 cm.

The system boundaries of the LCA are presented in Figure 3 and are based on the system boundaries of the Carbon Counter. Not the full life cycle of the materials was considered. Several processes are excluded from the assessment e.g., filler and additives production and transport, empty return journey from raw material delivery to the asphalt plant, emissions from equipment on site (milling of the old pavement, compaction of the new pavement…), etc.

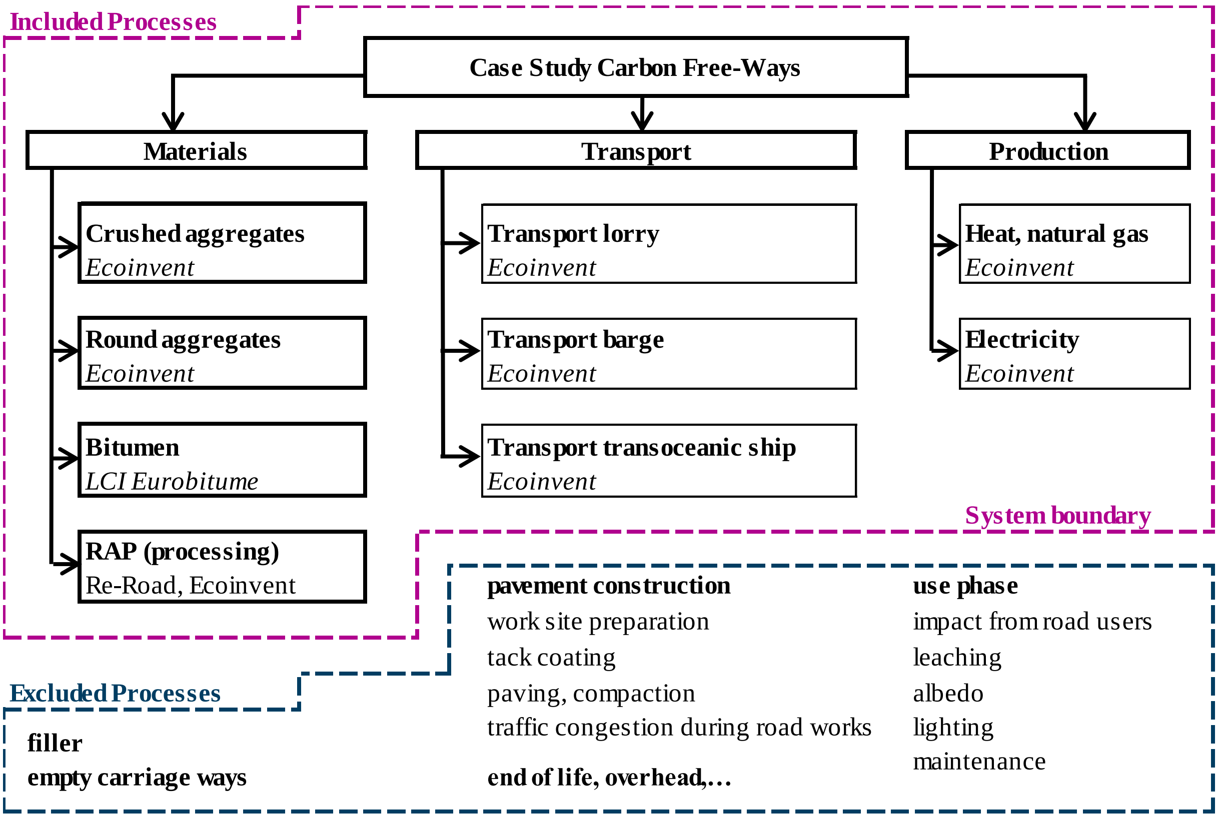

Figure 3: system boundary and data sources for LCA calculation

The research questions can be summarized as follows:

- What is the difference between CO_2 calculations in Carbon Counter and an LCA calculation (only including climate change) when using the same system boundaries?
- What is the contribution of the calculated climate change impact to the single score environmental impact (including various environmental issues)?
- Which materials or processes have the highest environmental impact?
- What is the share of the environmental impact from processes which are beyond the scope of the pilot project?

3.2 Life Cycle Inventory

All data needed, related to the quantity of materials, energy consumption, transport distance, transport method, etc. was information verified or measured in practice. For the environmental data (e.g. environmental impact of transport, gas combustion, raw material extraction etc.) the Ecoinvent database was mostly used, excepted for the raw material bitumen and polymer modified bitumen (see Figure 3). The life cycle inventory from Eurobitume (Blomberg et al. 2012) was used for the environmental data for the bituminous binders because this data are specific for the geographical area Amsterdam, Rotterdam Antwerp and were more recent compared to the Ecoinvent data.

3.3 Methodology and Life Cycle Impact Assessment

The SimaPro software, developed by Pré-consultants BV, was used for the LCA calculations. SimaPro includes the Ecoinvent database and multiple life cycle impact assessment (LCIA) methods. Environmental impacts and used resources are quantified based on the inventory analysis in the LCIA step in order to understand the environmental relevance of all the inputs and outputs. The selected LCIA-method is ReCiPe, created by RIVM, CML, PRé Consultants, Radboud Universiteit, and CML-IA. This method, implements both midpoints (problem-oriented approach; impact categories) and endpoints (damage-oriented approach; damage categories) (Buyle et al. 2015). The three endpoint categories (damage to human health, ecosystems, and resource availability) are normalized, weighted, and aggregated into a single score. The hierarchist perspective is applied since it is based on the most common policy principles with regards to time-frame and other issues and therefore considered as the default model. Furthermore, the European normalization set and the average weighting set were used. More information about the LCIA-method can be found in literature (Sleeswijk et al. 2008; Goedkoop et al. 2013).

4. LIFE CYCLE ASSESSMENT RESULTS AND DISCUSSION

As a rule, it is important to keep in mind that the commonly accepted precisions of LCA calculations are between 10 and 20% for single score results and about 10% for characterized results. Hence, some of the results discussed below might fall outside the validity range of the ReCiPe method. Besides, most of the quantitative input parameters are measured in situ and hence case specific. So we need to be careful with the interpretation and firm conclusions are not always allowed.

4.1 Comparison of results from Carbon Counter and SimaPro

In a first comparison, results on climate change impact from the Carbon Counter are compared with the results from SimaPro, using the LCA methodology as described above.

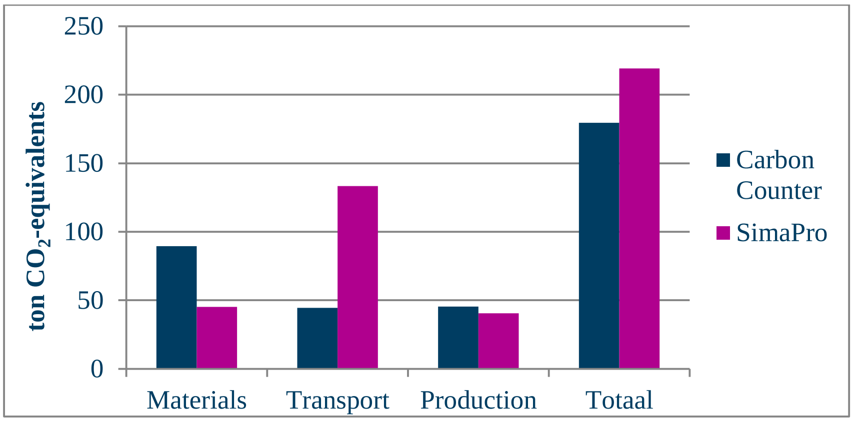

Figure 4: CO_2 emissions calculated with Carbon Counter and SimaPro

Results from both tools are presented in Figure 4. It is seen that there are significant differences in each category. Detailed analysis revealed that for the materials part the emission factors (in kg CO_2e/ton material) are higher in the Carbon Counter (using the ICE version 2.0 (Hammond & Jones 2011)) for all constituents. Besides, the inclusion of RAP in the calculations is different in both tools. The Carbon Counter uses a default reduction of the emissions by 50% compared to the virgin aggregates and bitumen. In SimaPro, only the emissions are included from processing (breaking and sieving) the reclaimed material in order to make the waste material suitable for reuse. Other burdens from RAP have not been included because this material is declared as waste and therefore has no direct burdens associated to it (Vidal et al. 2013).

4.2 Contribution to the single score environmental impact

In this section, the share of the CO_2 emissions or the climate change impact to the single score environmental impact is expound, based on results from SimaPro. The single score impact of different (groups of) processes is also discussed in this section. Figure 5 is a legend applicable for Figure 6, Figure 7 and Figure 8. The methodology used for the calculations with SimaPro is specified in section 3.3.

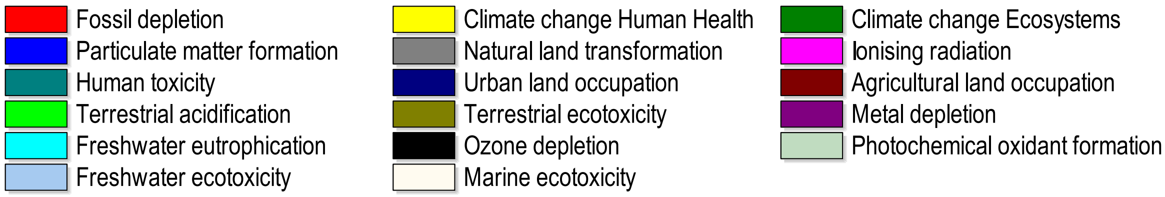

Figure 5: legend of SimaPro results (figures 10, 11 and 12)

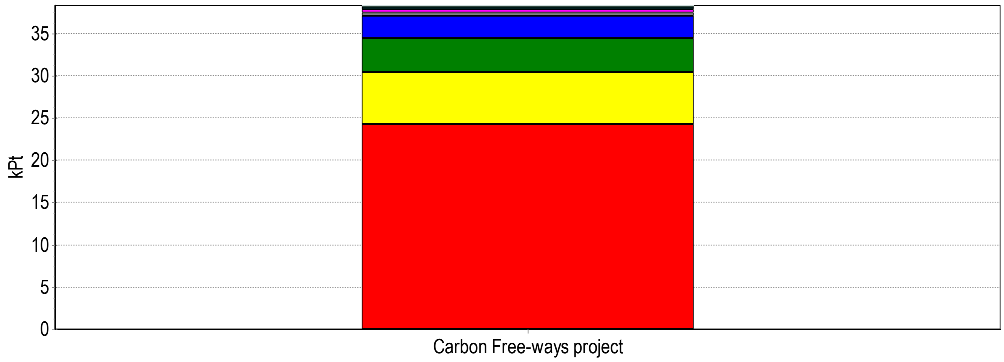

Figure 6: contribution of climate change (yellow and green) to the environmental impact of the case study

Figure 6 illustrates the contribution of various impact categories to the single score impact.
The single score impact in ReCiPe includes 17 different impact categories (see Figure 5), of which two are related to climate change i.e., climate change human health and climate change ecosystems (respectively yellow and green). It is apparent from this figure that not climate change (human health and ecosystems together), but fossil depletion is the major contributor to the environmental impact. 63% of the single score impact is caused by the impact from fossil depletion. The main contributors to fossil depletion are the raw material bitumen and all transport by lorry (supply of raw materials to asphalt plant and transport of RAP and asphalt mixture between plant and work site). Climate change represents 26% of the single score impact and is mainly caused by all transport by lorry, natural gas for heat production and the raw material bitumen. The next significant environmental impact category is particulate matter formation (7%), mainly coming from transport by lorry, transoceanic freight ship and the raw material bitumen. Finally, the last environmental impact category with a contribution to the single score of more than 1% is natural land transformation (1%). This impact majorly comes from transport by lorry, crushed gravel, transport by barge and natural gas for heat.
These results reveal the importance of integrating more environmental issues in an analysis. It is also seen from the results that transport processes and the raw material bitumen importantly contribute to most of the four discussed impact categories.

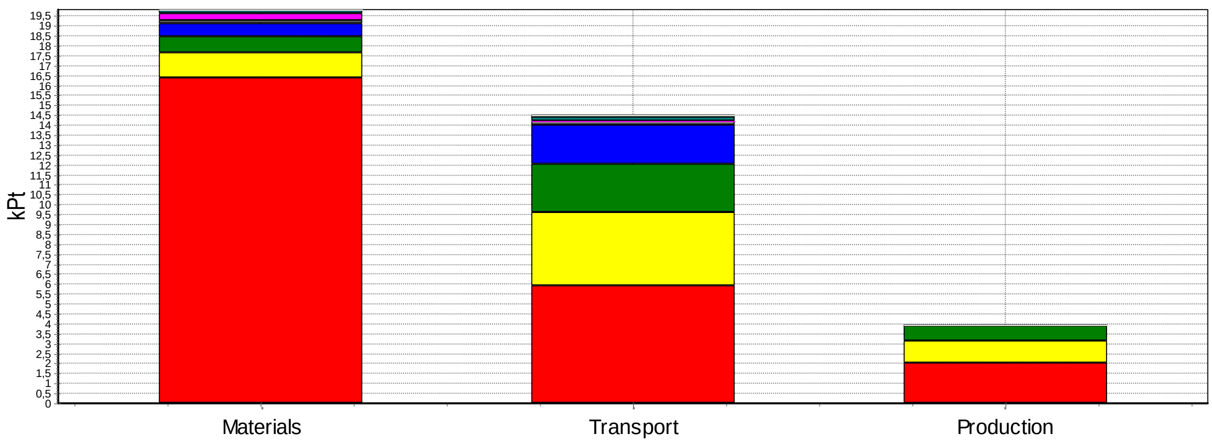

Figure 7: single score impact of groups similar as in the Carbon Counter

Figure 7 includes three groups analogue to the breakdown in the Carbon Counter.
It is seen that the ranking of the three groups is different compared to the analysis of the CO_2 emissions. The materials part has the largest single score impact while the transport had the largest climate change impact (see §4.1, Figure 4 results from SimaPro). The impact from fossil depletion was the largest in each group, followed by climate change and particulate matter formation.

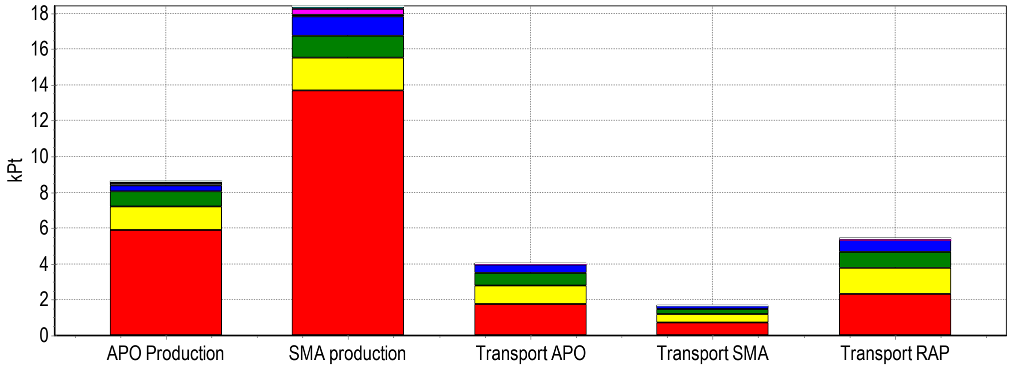

Figure 8: single score impact of groups based on the chronological execution of the works

Figure 8 provides an overview of five groups of processes, based on the chronological execution of the works.
The APO production and SMA production includes the raw materials, the transport of the raw materials to the asphalt plant and the energy consumption for the asphalt production. It is seen from the figure that the impact from the SMA production is more than double the impact from the APO production, despite the thicker base layer (7 cm) compared to the surface layer (3 cm). This higher impact is due to the higher virgin bitumen consumption in SMA because no RAP is used. It is also seen from the figure that the transport between asphalt plant and work site (sum of the three transport groups) yields a higher single score environmental impact compared to the production of APO. It should be noticed that the distance between asphalt plant and work site (68 km) in this pilot project is rather high compared to the average in Flanders.

4.3 Environmental impact of processes beyond the scope of the pilot project

Some processes are not included in the analyses with the Carbon Counter because they are behind the scope of the pilot project i.e., filler production and transport to the asphalt plant; and empty carriage ways. In this section, the CO_2 emissions from these processes and the contribution to the single score impact are examined.
In the LCA calculation with SimaPro, the filler is represented by a limestone powder because the specific composition of fillers in asphalt mixtures is unknown due to confidential business information. It was found that including the filler production, and the transport from the production plant to the asphalt plant and including empty transports by lorry between asphalt plant and work site increases the impact on climate change (CO_2 equivalent) by 15% and the single score impact by 9%.
It is important to note that even with the inclusion of the filler and the empty transport between the asphalt plant and the work site, not all environmental impact caused during the pilot project is covered. During the asphalt production, some batches reached not the desired quality. Therefore these batches were not used for the road construction. Hence all impacts from raw materials, energy consumption and transport, related to those wasted batches are not taken into account. The return journeys after the delivery of raw materials to the asphalt plant is excluded as well, because it is unknown if this journey is empty or could be assigned to another project. Furthermore, the environmental impact from the road construction itself (tack coating, paving, compacting, etc.) is not included.

5. CONCLUSIONS AND RECOMMENDATIONS

The public tender describing the construction of the field case in the scope of the pilot project Carbon Free-Ways was a first for the Flemish government due to the inclusion of CO_2 emission as an award criterion.
It was seen that there are significant differences between the results from Carbon Counter and SimaPro. These differences are mainly due to different emission factors (e.g., ton CO_2/km or ton CO_2/m³ energy source) which confirm the importance of the selected data source, in relation to the goal and scope of the research. Another important conclusion from the current study is the fact that climate change is not the dominant impact factor in bituminous pavement LCA. It is seen in this case study that fossil depletion has a major contribution to the single score impact. It is also concluded that the distance between the asphalt plant and the work site is an important factor considering the environmental impact of a work. It is suggested to limit this. Finally it was found that, at first sight negligible processes, like filler production and transport and empty journeys, might have a remarkable environmental impact.

In the literature, some parameters with an effect on the environmental impact of asphalt production are described, but not all of them could be verified during the current case study. Therefore, additional research with field cases is required on e.g., the relation between the use of the parallel drum and the fuel consumption, and the stack emissions during WMA production.

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