Life Cycle Assessment (LCA) of Headlamp & Rear lamp

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1 Abstract

The potential for reducing greenhouse gas (GHG) emissions drives us to transition to electric mobility, though will electrification in itself not fully eliminate emissions. Our challenge is to reduce it as much as possible.

Based on the LCA of the Volvo C40 Recharge, its carbon footprint is at least 15% lower than XC40 internal combustion engine vehicle and reaches 54% reduction if the car is charged with renewable energy, with a breakeven at around 79,000 km of driving distance. Despite the overall reduction in GHG emissions, the share of the materials production phase has increased, and the use phase emissions became highly dependent on the electricity mixes. When it comes to exterior lighting, our lights contribute with 0,4% to the materials production and manufacturing phase and with 3,3% to the use phase emissions of the car. Internal analysis of the latter shows that further decrease can be achieved through power optimization. In total head and rear lamps contribute between 1% and 2% to the total carbon footprint of the car.

Regarding the materials production phase, aligning with our goal, to have a minimum of 25% recycled materials in our newly launched Volvo cars by 2025, we are investigating the use of biobased and recycled content in PMMA and other materials. The use of sustainable materials can save us around 7% in the carbon emissions in the materials production phase, based on in-house measurements of tiers 2, aligning with the Volvo Cars guideline for carbon footprint calculations. This paper illustrates our work in conducting the LCA of our lamps, to understand their share in the vehicle production and use phases, take actions towards carbon footprint reduction, and define our new sustainable requirements. The study is still ongoing and the results presented in this paper may be considered as incomplete and preliminary.

2 Introduction to Sustainability

The automotive industry is facing many challenges in the context of global environmental threats (eg. climate change, loss of biodiversity, energy, deforestation, …), material shortages, new regulations related to sustainability in the automotive industry, end customer interest in eco-responsibility and rising competition.

It is important to understand the environmental impact of our vehicles - as they are part of the problem – so that we can drive solutions. We all share responsibility for limiting climate change and need to work together to address this issue.

3 Volvo Cars Targets

Volvo Cars is taking actions and intends to become a **climate neutral** company by 2040, conduct **circular business** and become a recognized leader in **responsible business**.

By 2025, the aim is to reduce overall CO_2 emissions per vehicle throughout their lifecycle, by 40% (baseline 2018). This will involve substantial reductions in tailpipe (-50%), supply chain (-25%) and operational emissions (-25%). As verified by the Science-Based Targets initiative (SBTi), this is in line with the 1,5-degree pathway of the Paris Agreement[1] to limit global warming. Global car sales shall be 100% electric by 2030. [1]

By adopting circular material flows, Volvo Cars aims to reduce CO_2 emissions until 2025, by 2.5 million tons per year. 25% recycled or bio-based materials in new vehicle models has been set as an ambitious target until 2025 as well as 40% reduction in production waste and production water usage. [1]

The third pillar of Volvos sustainability ambitions - "ethical and responsible business" – is putting words into action when it comes to safeguarding human rights, sustainable finance, ethical & responsible business conduct, new global people standard and responsible sourcing – everything is happening with sustainability in mind. Regarding the latter, responsible sourcing, sustainability is put on par with cost and quality by selecting and collaborating with suppliers that support our ambitions and help drive sustainability throughout our supply chain. For example the introduction of an internal carbon price of 1000 SEK/ ton CO_2 in 2021 along with requirements on suppliers to disclose carbon footprint estimates and energy sources used in production, became an important part of the design and strategic decisions, like supplier sourcings. [1], [2]

1 *https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement*

Volvo Cars also committed to communicate actions and improvements transparently, including the disclosure of the carbon footprint (LCA) of all new models. [1]

Where are we today?

The latest annual report shows the numbers for 2022 – the total CO_2 emissions per vehicle decreased by -14,8% compared to 2018, but a lot still needs to happen to reach the ambitious goal of -40% in 2025. The increase in supply chain emissions is due to the increased weight and materials in the "recharge vehicles" compared to internal combustion engine cars.

Emissions per average vehicle	2022	2021	2020	2019 Base year	2018 Base year
Total CO_2 emissions per vehicle[1,2,3)] (tonnes)	46.8	49.7	51.6	54.3	54.9
Tailpipe CO_2 emissions per vehicle[1,2,3)] (tonnes)	24.4	27.9	31.1	34.5	35.6
Supply chain CO_2 emissions per vehicle[1,2,3)] (tonnes)	18.7	18.1	16.8	16.1	15.6
Operations CO_2 emissions per vehicle[1,2,3)] (tonnes)	3.7	3.7	3.7	3.7	3.7
SBTi target – Scope 1 and 2[2,7)*] (%)	–50.2	–46.3	–18.9	Baseline	–
SBTi target – Scope 3 Use of sold products[2,3,7)*] (%)	–16.6	–10.2	–5.2	Baseline	–
Emission intensity (tonnes CO_2/MSEK revenue)	115	–	–	–	–

* These 2030 climate action ambitions are in line with the 1,5-degree scenario as verified by the Science-Based Targets initiative (SBTi) – a partnership between CDP, the United Nations Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF).

For further definitions and reporting principles see page 194–196.

Figure 10: CO2 emissions per vehicle and SBTi targets over the last years [1]

To further understand the impact of our vehicles the following chapter summarizes the LCA of the Volvo C40 Recharge.

4 LCA Report for C40 Recharge

The LCA report published by Volvo Cars in 2021 "[…] represents the carbon footprint of the new fully electric Volvo C40 Recharge with production start in autumn 2021, in comparisons with the fully electric Volvo XC40 Recharge and Volvo XC40 ICE, both launched in 2020". [3]

Methodology

ISO standards ISO 14040 and ISO 14044 were considered for the LCA study. The "functional unit" is assumed as "The use of a specific Volvo vehicle driving 200 000 km". The data for the final LCA was retrieved through four main sources: [3]

- LCI databases: theoretical data from the LCI databases ecoinvent 10 3.7.1 and GaBi LCA database 2021.1 version (GaBi Professional)
- Supplier specific data: LCA results performed by suppliers according to Volvo guidelines (eg battery module data)
- Internal data: logistics, manufacturing processes, fuel and energy consumption
- IMDS (International Material Data System): material data per component representing a specific vehicle. The ~10 000 incoming materials are aggregated into ~70 materials.

Results

The results of the LCA study show that the C40 Recharge has a 15% lower or even up to 54% lower carbon footprint than the XC40 ICE, depending on the electricity mix for driving (compare **Error! Reference source not found.** and Table 4).

The increased materials of the C40 Recharge and the increased share of aluminum causes the ~30% higher emissions for the C40 Recharge compared with the XC40 ICE in the "Materials production and refining" phase (excluding Li-ion battery modules production). [3]

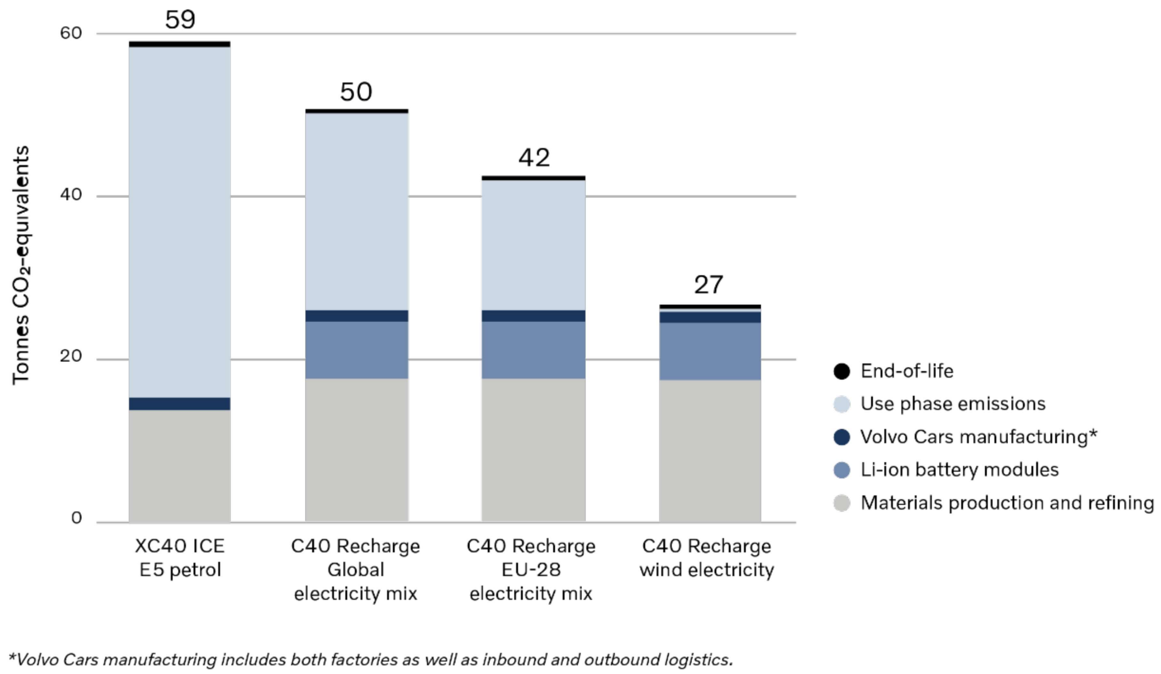

Figure 11: Carbon footprint for C40 Recharge and XC40 ICE with different electricity mixes used for the C40 Recharge*. Results are shown in tons CO2-equivalents per functional unit (200,00km total distance, rounded values); from LCA report [3]*

Table 4: Carbon footprint for XC40 ICE and C40 Recharge, with different electricity mixes used for the C40 Recharge*. Results are shown in tonnes CO_2-equivalents per functional unit (200,00km total distance, rounded values) and per phase in the life cycle; from LCA report [3]*

Vehicle type	Materials production and refining	Li-ion battery modules	Volvo Cars manufacturing	Use phase emissions	End-of-life	Total
XC40 ICE (E5 petrol)	14	-	1.7	43	0.6	**59**
C40 Recharge (global electricity mix)	18	7	1.4	24	0.5	**50**
C40 Recharge (EU-28 electricity mix)	18	7	1.4	16	0.5	**42**
C40 Recharge (wind electricity)	18	7	1.4	0.4	0.5	**27**

So, over the span of its lifetime the C40 Recharge will cause less emissions thanks to lower emissions in the use phase. Where the break even occurs can be seen in **Error! Reference source not found.**. [3]

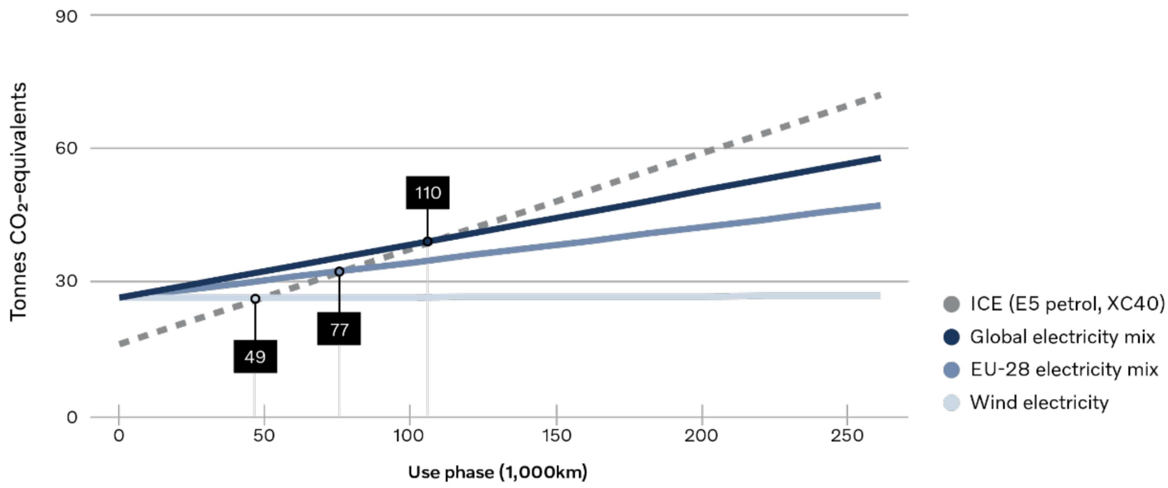

***Figure 12: Break-even diagram**: Total amount of GHG emissions, depending on total kilometers driven, from XC40 ICE (dashed line) and C40 Recharge (with different electricity mixes in the use phase). Where the lines cross, break-even between the two vehicles occurs. All life cycle phases except use phase are summarized and set as the starting point for each line at zero distance; from LCA report [3].*

"Testing of alternative electricity mixes for the C40 Recharge in the use phase shows that the choice of electricity source when charging the car is a crucial factor in determining the total life cycle carbon footprint. Scenarios for the European market indicate that the carbon intensity of electricity production may further decrease there." (compare Figure 13) [3]

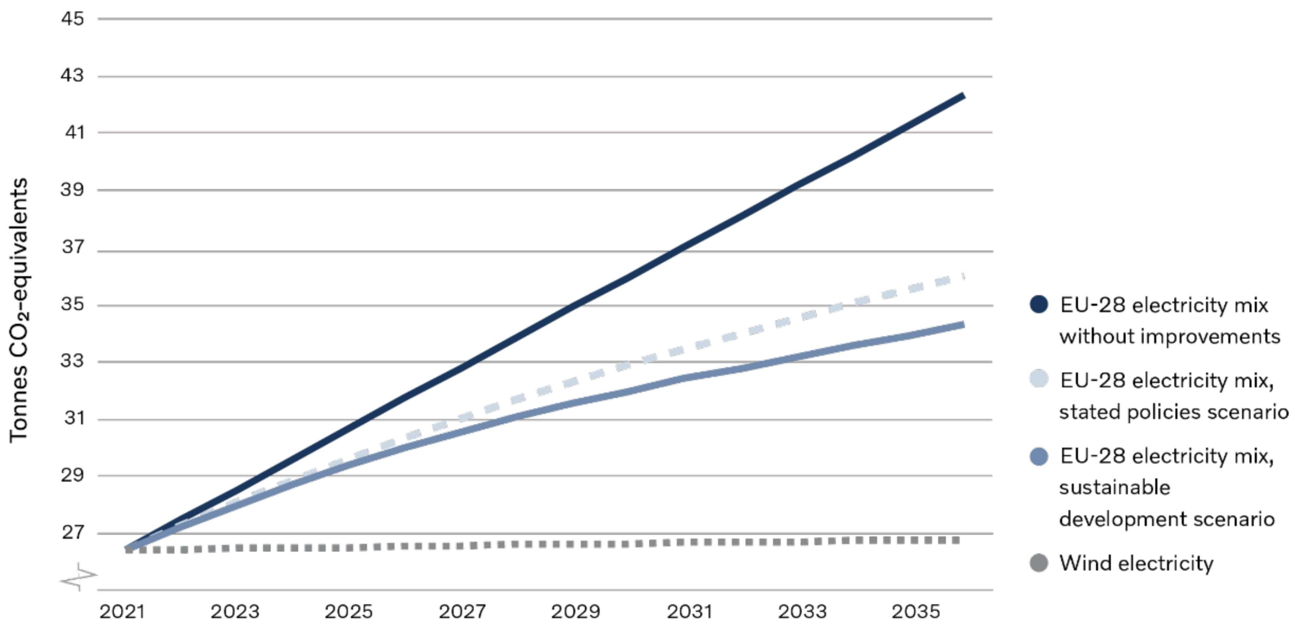

***Figure 13: The total GHG emissions for the estimated lifetime of C40 Recharge**. All life cycle phases except use phase are summarised and set as the starting point for each line at year 2021; from LCA report [3]*

When choosing electricity from renewable sources, we can read from **Error! Reference source not found.** that the focus shifts immediately to the "Materials production and refining" phase which dominates then. That is why Volvo cars is working towards achieving 25% reduction per average vehicle in 2025 compared to 2018 in that phase. "Sourcing from suppliers that have products and materials with a lower carbon footprint today has a great potential to reduce the overall carbon footprint of the vehicle. […] Reducing the impact of materials requires more efficient production, increased use of recycled content and more renewable energy in production. […] The GHG emissions from production of polymers for different plastics are currently also significant. These emissions can be reduced by increasing the use of recycled plastics and bioplastics which in turn also would reduce the emissions of fossil GHGs when incinerated after use." [3]

5 LCA study for Headlamps and Rear Lamps

To learn more about the detailed life cycle and carbon footprint of our headlamps and rear lamps a sustainability study was started during 2022, with the ambition to generate an LCA report, investigate sustainable materials for lighting components and define hotspots, improvements and new requirements. This article is not a final report as the study is still ongoing.

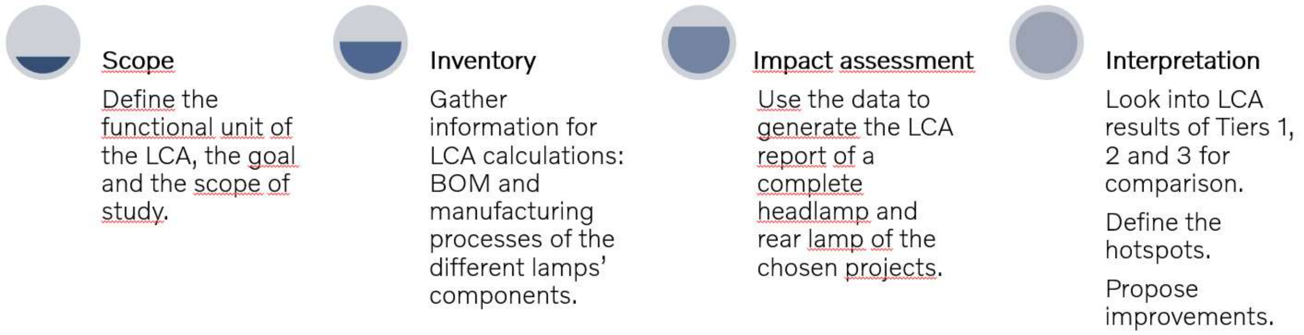

Figure 14: Steps of the LCA analysis

Step 1: Scope

As "functional units" the production of 1 specific headlamp and 1 specific rear lamp have been chosen (not C40 Recharge lamps). For being able to compare the results the C40 lamps are also studied. The processes taken into consideration are from cradle-to-(supplier)gate. This is including raw material extraction, material processing, manufacturing processes (including Printed Circuit Boards (PCB) and LED manufacturing) and lamp assembly. A use phase calculation of the lamps shall also be included to understand the relation between the power consumption and the CO_2 emissions of the lamp in the use phase.

Step 2: Inventory

In this step information was gathered by tier 1 (lamp suppliers) and tier 2 suppliers (PCBs, LEDs, material):

Preliminary*[2] carbon footprint calculations by tier 1 suppliers identify in cradle-to-gate calculations of headlamps PCBs, Poly carbonate (PC) and aluminum as hot spots. Electrical and electronic components make up to about 20% of the weight of a lamp but can contribute up to around 80% of the emissions.

Cradle-to-grave calculations identify use phase emissions as biggest part of the total CO_2 emissions (75-89%).

Inventory of sustainable materials with about 16 different companies (tier 1 and tier 2 suppliers) resulted in several lists of materials including carbon footprint calculations by

*[2]: *the gathered carbon footprint calculation results by tier 1 suppliers are not (yet) following Volvo guidelines*

material suppliers which need to be investigated further to be compliant with Volvo guidelines. Below a high level overview.

Table 5: Material proposals in general for headlamps and rear lamps

Material proposals	Applications
PC with renewable/biobased feedstock	Headlamp lenses, bezels and filters; is identical twin to fossil-based grades
Chemically recycled PC	Headlamp lenses
PC with different recycling contents (PCR*[3]/PIR*[4])	Reflectors
PP with minimum 25% recycled content (PCR/PIR)	Headlamp housing, bumper lamp housing, cable ducts
Thermal plastic	Replacement of Aluminium heatsink in headlamps
PC + ABS with different recycled grades	Rear lamp housing
Chemically and mechanically recycled PMMA	Headlamps and rear lamps parts
PMMA: biobased & chemically recycled	Rear lamps outer lens and reflectors

Discussions with sub suppliers for electronics revealed that PCB production is a much more emissive process than the PCB assembly process. As the list of semiconductors and ICs used in lamps is extensive only the ones with the higher estimated impact according to other studies realized at Volvo or by the suppliers will be considered. Volvo guidelines have been communicated with PCB and IC suppliers, feedback and results are pending to date, especially from Chinese suppliers.

As PCB processes are complex a lot more focus would be needed than was possible in this study. But this example by one supplier could be used for the time being, but still needs to be verified: 1,7kg PCB component of 1 square meter emits 35 kgCO_2eq in manufacturing process.

*[3] : *Post Consumer Recyclate: scrap generated by consumers, reused to manufacture a new part*

*[4] : *Post Industrial Recyclate: scrap which is a by-product of the manufacturing process, reused to manufacture a new part*

Step 3: Impact assessment

Use phase

Based on usage factor values from the European Commission [5] and internal analysis at Volvo, we can calculate the total power consumption of our lamps, thus their emissions in the use phase.

Table 6: Rear lamps average power consumption in use phase per function. *Note: WLTP consumption does not include every function.*

Function	usage factor %	C40 rear lamps WATT/lamp	Other Rear lamps WATT/lamp
Rear turn indicator	6%	3,5 W	6 W
License plate light	100%	1 W	1 W
Reverse	1%	6 W	16 W
Stop	25%	21 W	3 W
CHMSL	25%	3,5 W	3W
Rear PL night	36%	8 W	6 W
Rear pos light day	64%	17 W	6 W
Weight (kg/car)		6,8 kg	5,3 kg
Average consumption (WATT per car)		**49 W**	**16 W**
WLTP consumption (WATT per car)		**11 W**	**2 W**

Table 7: Headlamps average power consumption in use phase per function. *Note: WLTP consumption does not include every function.*

Function	% usage	C40 headlamps WATT/lamp	Other headlamps WATT/lamp
DRL	61%	26 W	14 W
Passing Beam town light without street light	9%	55 W	15 W
Passing Beam town light with street light	9%	55 W	15 W
Passing Beam country light	8%	55 W	20 W
Driving Beam (LB+HB)	10%	87 W	54 W
Front Position light	33%	2 W	1,5 W
Front Turn indicator	6%	30 W	9 W

Weight (kg/car)	10,5 kg	8,6 kg
Average consumption (WATT per car)	**61 W**	**38 W**
WLTP consumption (WATT per car)	**52 W**	**28 W**

Table 8: Headlamp and Rear lamp emissions compared to use phase emissions of complete vehicle *(C40 Recharge values for complete vehicle are taken from Table 4). WLTP test cycle and global electricity mix (emission factor taken from Sphera's database) considered. Rounded values.*

	C40 recharge	Lamps under study
WLTP power consumption of the HL and RL	63 Watts/car	30 Watts/car
Energy consumed for lifetime	1260 kWh/car	600 kWh/car
Emissions of the lamps use phase by average power consumption of the lamps, considering a global electricity mix	721 kgCO_2eq	343 kgCO_2eq
Adding the emissions for the weight of the lamps, considering a global electricity mix	60 kgCO_2eq	48 kgCO_2eq
Total emissions of the lamps use phase, considering a global electricity mix	**780 kgCO_2eq**	**391 kgCO_2eq**
% lamps use phase from the whole car's use phase emissions	**3,3%**	**1,6%**

We can say that the C40 Recharge lamps contribute with about **3,3%** to the use phase emissions of the C40 Recharge vehicle shown in the LCA study when considering a global electricity mix and WLTP test cycle. When comparing to the other lamps from the study, they would make only 1,6% of the use phase emissions of a C40 Recharge car (considering a global electricity mix and WLTP test cycle) due to reduced power consumption and weight.

Internal estimations of the head lamps average energy usage, as presented in Table 6 and

Table 7, is much higher than in WLTP (110 W/car instead of 63 W/car), so it's not unlikely that 3,3% is a conservative conclusion.

Figure 15 and Figure 16 illustrate the impact of the functions and the weight to the average emission values.

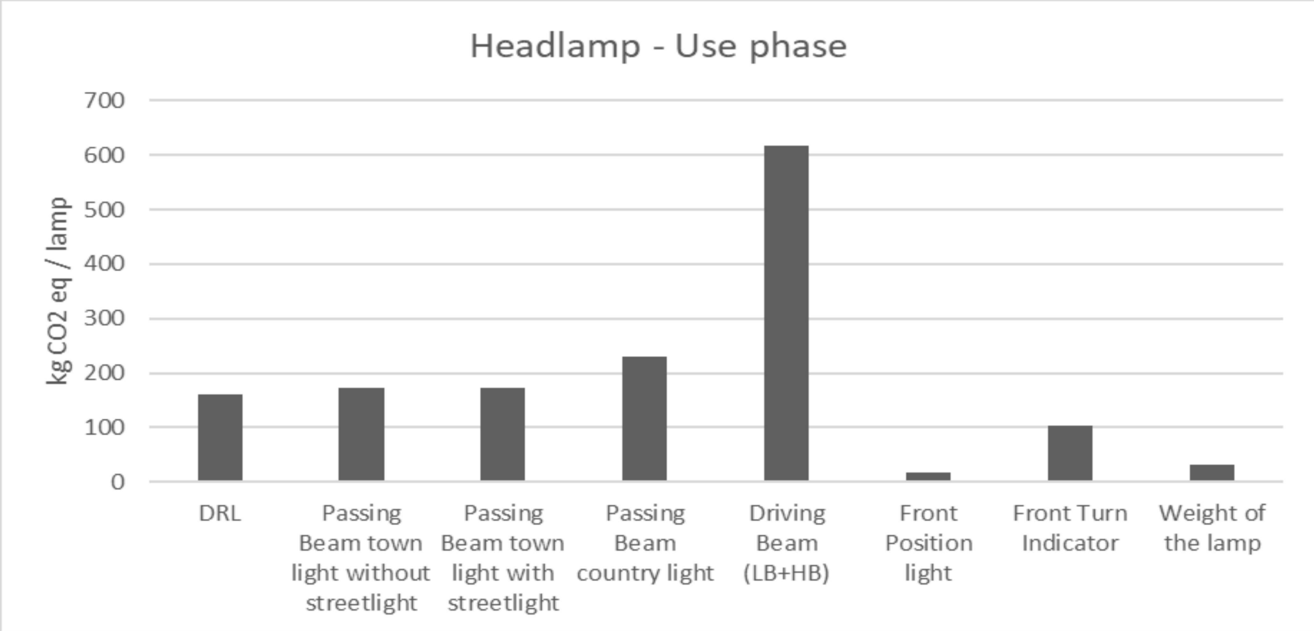

Figure 15: Headlamp use phase emissions including weight *("lamps under study")*

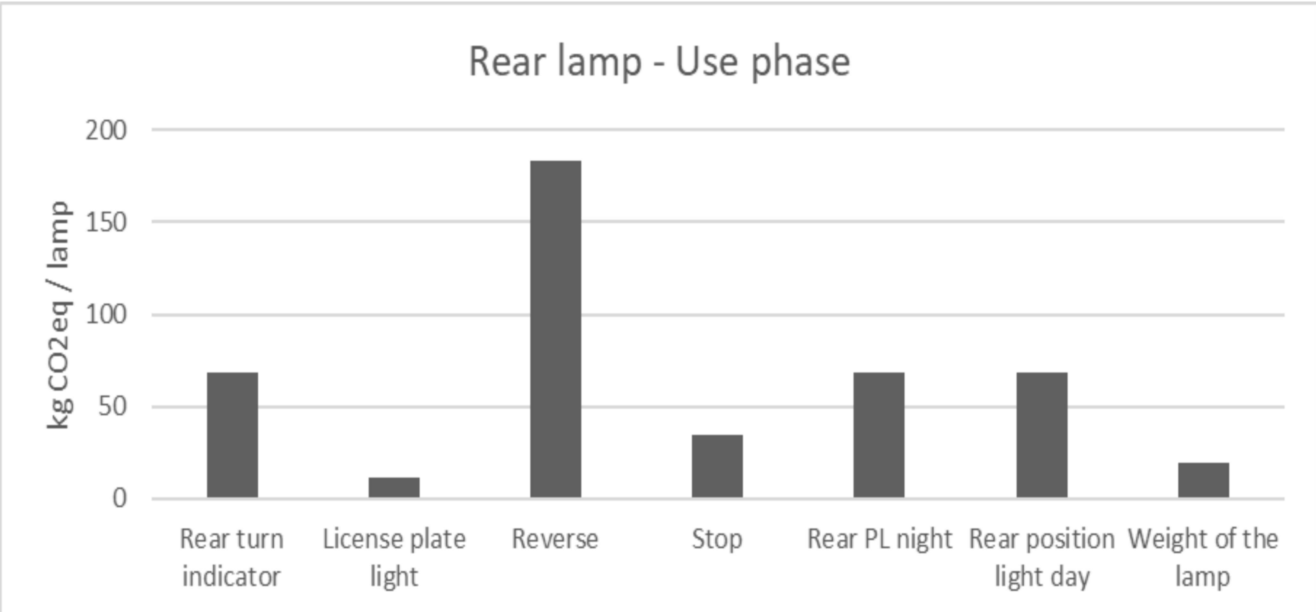

Figure 16: Rear lamps use phase emissions including weight *("lamps under study")*

The total emissions of the lamps use phase for average consumption, considering a global electricity mix, including weight, is calculated to ~1318 $kgCO_2eq$ for C40 lamps and to ~666 $kgCO_2eq$ for the other lamps in the study.

When considering the European electricity mix it becomes ~811 $kgCO_2eq$ (C40 lamps) and ~410 $kgCO_2eq$ (other lamps) instead.

Materials production and manufacturing phases

Most of the results for this stage are pending due to ongoing studies and some missing input. Below you can find some preliminary results for the rear lamps of the study (some data for electronic components are still pending), see also Figure 17 for main materials, 43 $kgCO_2$ eq per car.

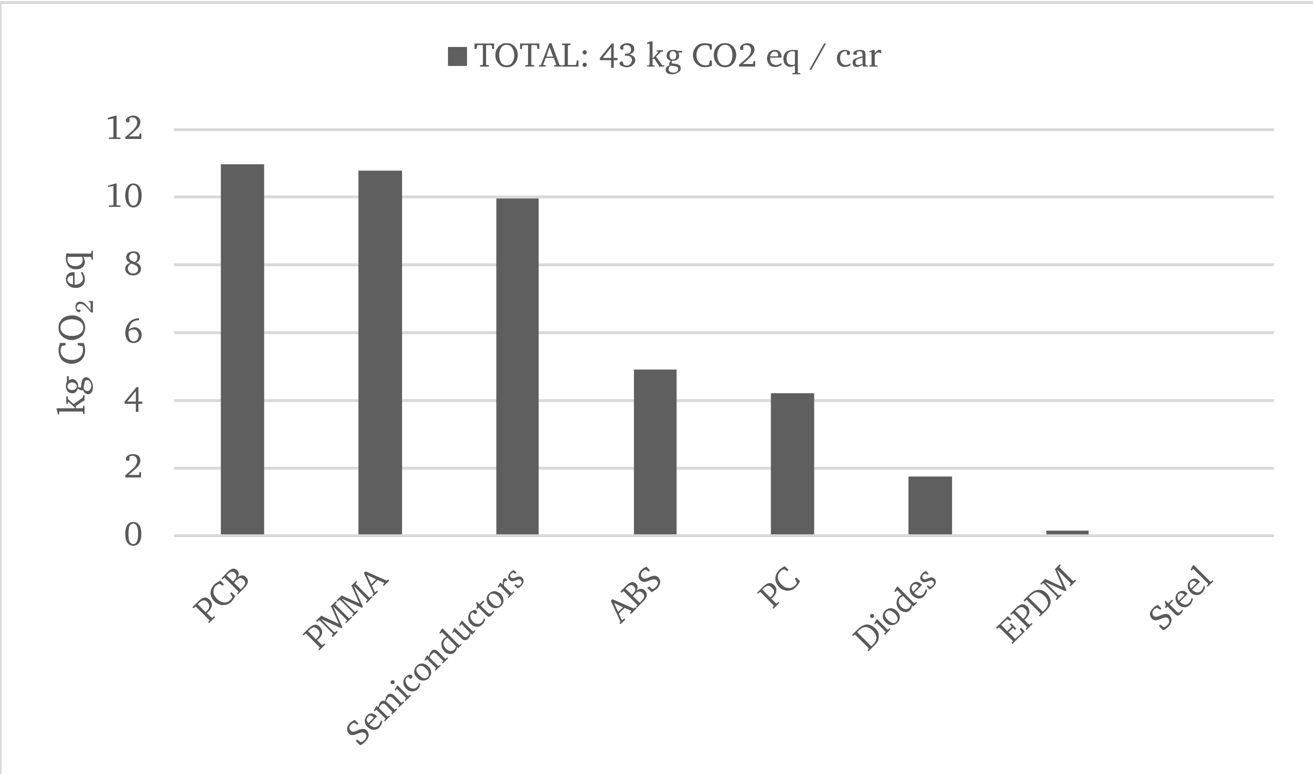

Figure 17: Carbon footprint for rear lamps in the study, per main material group.
Values per car in $kgCO_2$ eq.

Step 4: Interpretation

Use Phase

As we see from our use phase calculations and also in tier 1 calculations, we need to act towards our carbon footprint reduction in the use phase of the lamps, especially due to the current global electricity mix. The lamps under study have already much lower power consumption in many functions than the C40 Recharge lamps and could reduce the lamp share of the average power consumption value in the use phase of a car by half (fictive value with figures from C40 Recharge study). In the example lamps of the study the high beam function has (naturally) the highest impact on the use phase (note: this is considering average consumption, not according to WLTP) and should be considered for power consumption reductions. For rear lamps it is more dependent on the specific lamp design and consumption – all possibilities to reduce power consumption are welcome of course.

Materials production and manufacturing phases

If we assume similar numbers that we found for the rear lamps under study, for headlamps with about 50 kgCO_2eq per car (assumption made with help of supplier), both head and rear lamps would make about **0,4%** of the emissions of the materials production and manufacturing phase of a C40 Recharge vehicle (compare **Error! Reference source not found.**). This would be equivalent to almost 10 000 h of DRL use phase when assuming a global electricity mix.

Together with the *use phase* results from above, the lamps under study (391 kgCO2eq, see

	C40 recharge	Lamps under study
WLTP power consumption of the HL and RL	63 Watts/car	30 Watts/car
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Emissions of the lamps use phase by average power consumption of the lamps, considering a global electricity mix	721 kgCO2eq	343 kgCO2eq
Adding the emissions for the weight of the lamps, considering a global electricity mix	60 kgCO2eq	48 kgCO2eq
Total emissions of the lamps use phase, considering a global electricity mix	**780 kgCO2eq**	**391 kgCO2eq**
% lamps use phase from the whole car's use phase emissions	**3,3%**	**1,6%**

Table 8) would make 1% of the total carbon footprint of the C40 Recharge and the C40 lamps would make 1,7%.

When comparing the results for the lamps with the total car the number might look small but when the electricity mix will become decarbonized in future (compare also Figure 13) the material and manufacturing phase of the car and lamps will be much more important.

To understand the advantage of using recyclable or biobased materials we would like to look at an example, based on data collected from suppliers:

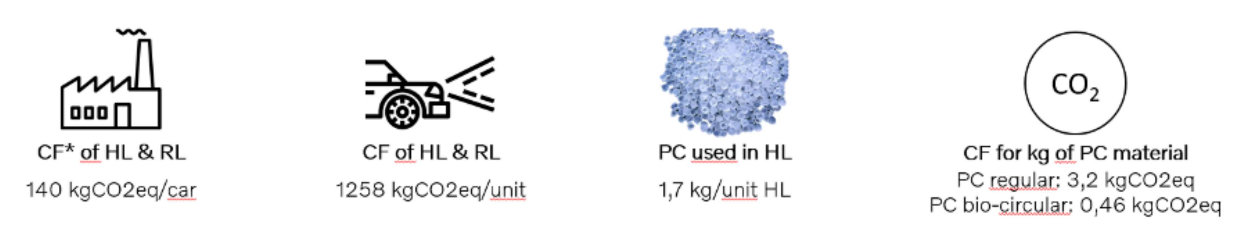

Figure 18: Example for using biobased material in a headlamp. ***CF=carbon footprint*

By doing the calculation for this example, we estimate a reduction of 6,7% in the carbon footprint of the materials production and refinement phase of the lamps and 0,7% reduction in the total carbon footprint of the HL & RL.

6 Summary and Outlook

In summary, we are convinced that a reduction of the carbon footprint of head and rear lamps should be focused on continuously together with suppliers. We showed a way to calculate the LCA for head and rear lamps and will continue with the study and refining our requirements so that we can reach our ambitious sustainability targets.

For that much more data is necessary and we need help by all suppliers, especially for receiving supply chain data for electronical parts (eg. LED IC and semiconductors) foremost from Chinese suppliers. The weight of electronics in head and rear lamps is small (~20%) but the carbon footprint is very high (~80%).

The lighting teams at Volvo Cars will continue working on reducing the use phase emissions of our lamps and also reducing the material manufacturing emissions by using recyclable or biobased materials and working towards circular business.

7 Reference

[1] Volvo Car Group, "Annual and Sustainability Report 2022," 2023. [Online]. Available: https://vp272.alertir.com/afw/files/press/volvocar/202303076447-1.pdf.

[2] Volvo Cars, "Volvo Cars Global Newsroom," 10 11 2021. [Online]. Available: https://www.media.volvocars.com/global/en-gb/media/pressreleases/290035/volvo-cars-signs-zero-emission-road-transport-declaration-at-cop26-reveals-groundbreaking-internal-c.

[3] E. Evrard, J. Davis, K.-H. Hagdahl, R. Palm, J. Lindholm and L. Dahllöf, "Carbon footprint report Volvo C40 recharge," 02 11 2021. [Online]. Available: https://www.volvocars.com/images/v/-/media/Market-Assets/INTL/Applications/DotCom/PDF/C40/Volvo-C40-Recharge-LCA-report.pdf.

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