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Estimating potentials and trade-offs of material utilization in automotive applications

Milica Savanovic[1*], Theresa Boiger [1] and Claudia Mair-Bauernfeind [1]

[1]University of Graz, Merangasse 18, 8010 Graz, Austria
[*]Corresponding author. milica.savanovic@uni-graz.at

EXTENDED ABSTRACT

The automotive sector has the potential to significantly contribute to the European Union's (EU) circular economy and climate change mitigation pathway (European Commission, 2020). By enabling circularity within the design stage of a passenger car this is a chance to enable the EU to meet their policy-goals.

Regarding our goal, first an introduction to the general problem in automotive industry and sustainability practices is needed. A passenger vehicle consists of multiple components, which again may consist of a mixture of materials (Delogu et al., 2017). One of these components being crash-management-systems (Delogu et al., 2017). These typically consist of aluminium or steel, which are energy intensive to produce (Delogu et al., 2017; IEA, 2023). The technical and design feasibility of using wood-based materials as substitutes for conventional materials in passenger vehicles and the use of wood within automotive industry have already been investigated (Delogu et al., 2017; Mair-Bauernfeind et al., 2020; Müller et al., 2020). We show how shifting biomass in form of wood into the design-stage of crash-management-systems impacts global warming potential (GWP) of these systems, also under different future pathways. A circular economy related factor we want to discuss, is the efficient and cascading use of wood, when applying it to a use case, before it is intended for energy recovery (Mair & Stern, 2017).

For this extended abstract we specifically consider the beginning-of-life stage of the automotive industry, where the materials for a passenger-vehicle are chosen. Here specifically front-crash-management (CMS) systems and their material composition are considered. Meaning that an estimation of the GWP

of different material options for CMS will be made for the time-horizon of 2050. This can be done by deriving material data in already existing databases and using already accessible models, that project the data into the future. Further, a system dynamics model will be used, to estimate trade-offs between sectors, if material usage shifts.

To calculate the difference in GWP for the conventional and novel material compositions, we use the database ecoinvent (v3.8) (ecoinvent, 2021), which provides information on GWP of an abundance of (although not all) materials and processed materials. This estimation is also based on the region the materials are retrieved and processed.

We further consider the possibility that in the future the GWP for the materials changes, especially regarding the evolving energy-mix in a region and technological advancements. This we account for by calculating the GWP for different shared-socioeconomic-pathway scenarios (SSP scenarios). This can be achieved using the model of PREMISE (Sacchi et al., 2022), which allows for calculations of SSP scenarios under different time-horizons. We consider the time horizon of 2050, regarding the GWP of the materials used in the respective CMS.

Within the Project of CARpenTiER the GWP under three different SSP scenarios was determined, by using the model REMIND (Baumstark et al., 2021) within the PREMISE (Sacchi et al., 2022) framework:

- SSP1: optimistic evolvement of the population, also regarding climate change mitigation, with decreased consumption (global mean surface temperature increase (GMST) at 2100y (base 2015y): 2.3-2.8 °C) (Paul Scherrer Institut, Potsdam Institute for Climate Impact Research, 2025; Riahi et al., 2017)

- SSP2: based on historical evidence on how and how fast changes are implemented this constitutes a scenario where some climate mitigation is done, but not as much as in SSP1 (GMST 2100y: ~3.5 °C) (Paul Scherrer Institut, Potsdam Institute for Climate Impact Research, 2025; Riahi et al., 2017)

- SSP5: Development of the economy relies largely on fossil resources, but it is considered that some of the processes we use become more efficient (GMST 2100y: ~4.5 °C) (Paul Scherrer Institut, Potsdam Institute for Climate Impact Research, 2025; Riahi et al., 2017)

The GWP under the SSP scenarios of conventional materials for crash-management-systems (CMS) as well as a novel approach to materials for CMS

(emerging from the Project CARpenTiER) is derived. We chose to calculate the GWP of different wood-processes as well as different coating materials for the wood within the analysis, to make find out whether the choice of (renewable) materials in the alternative CMS would make a considerable difference.

The materials of conventional CMS, where derived using the values of Delogu et al. (2017). Then the GWP for each of the SSP scenarios was calculated.

What we found can be summarized in 3 main points:

1) For each of the alternative CMS options, the GWP is lower than the GWP of the conventional CMS.

2) The GWP of each of the alternative CMS options do not differ significantly, which coating is chosen may be the most relevant factor, when it comes to end-of-life use cases of the alternative CMS.

3) The substitution effect decreases with the SSP-scenario. While all of the SSP scenarios show some saving compared to the conventional CMS, the savings decrease with the climate change mitigation rigidity of the SSP scenario.

The learnings of these results indicate that there is potential of substitution of conventional materials such as steel and alloy with wood-based resources. In any given case the wood-based resources yield a better result regarding their GWP than the conventional materials.

What needs to be considered is the end-of-life stage of the respective compared materials. If the CMS reaches its end-of-life, the renewable materials may not be suitable for re-use or re-cycling, depending on the coating materials used. The processing of the renewable materials may be complex and costly (if it is not used for reclaiming energy), while the re-cycling of the conventional materials may be energy-intensive but in other ways efficient (monetary cost or yield of re-cycled material).

For the next steps the WOODSIM system dynamics model (Boiger et al., 2024) is a helpful tool to estimate the trade-offs between sectors, if wood was to be implemented into CMS in the automotive sector.

When estimating the trade-offs between different sectors within the system dynamics model, we can show additional more complex connections regarding wood use. Such complex aspects can be emerging side-streams, in production of wood-based CMS and the evolution of trade-offs.

We discuss the aspects of changing to wood-based solutions in automotive design stage. We estimate the potential of sustainability-by-design in CMS under multiple future pathways. The system dynamics approach will allow us to discuss the issues arising from cascading use of wood in the wood-based sector.

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