Development of an approach for the comprehensive life cycle assessment of an epoxy resin system in relation to toxicity categories

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Missing Life Cycle Inventory data for CFRP

Carbon Fibre Reinforced Polymers (CFRP) are crucial for lightweight constructions. The selection of materials and production processes is vital for best results. Current Life Cycle Inventory (LCI) databases lack the variability of different fiber and polymer variants [2]. This study aimed at detailing two epoxy resin variants by incorporating data for additives and hardeners, and examines the deviations from an existing Ecoinvent (EI) database dataset, using a cradle-to-gate approach with equal resin system masses.

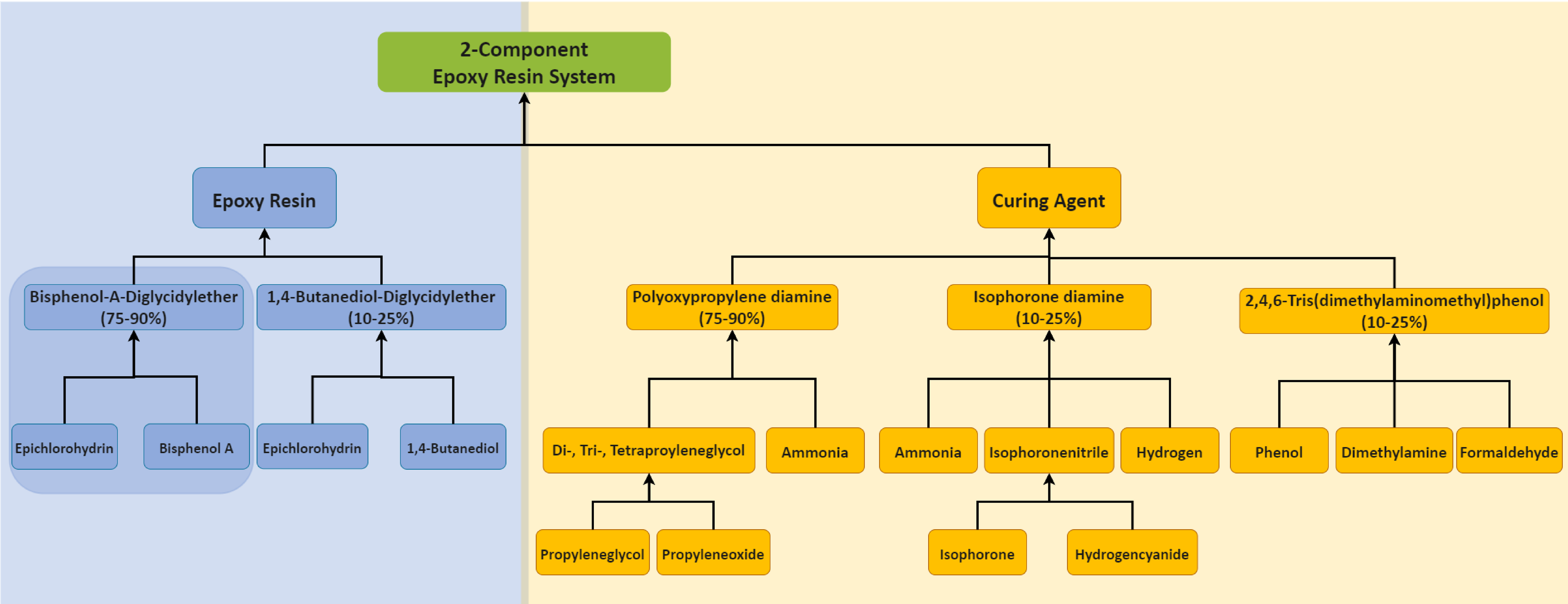

Figure 1: Graphic representation of the 2-component epoxy resin system under investigation

Impacts of reactive diluents and curing agents

The study initially analyzed a 2-component epoxy resin system which corresponds to the reference epoxy dataset in the database [1]. The precursors of the various components in the resin system were determined and modelled (Figure 1). The impact indicators for Climate Change (GWP100), Human Toxicity cancer (HTOX_c) and -non-cancer (HTOX_nc), and Ecotoxicity, freshwater (ECOTOX) were examined using the software Umberto 11 according to the UseTox model in EF 3.1 [3]. The results showed significant differences, particularly in the HTOX_c and HTOX_nc impact categories, in comparison to the reference dataset as shown in Figure 2.

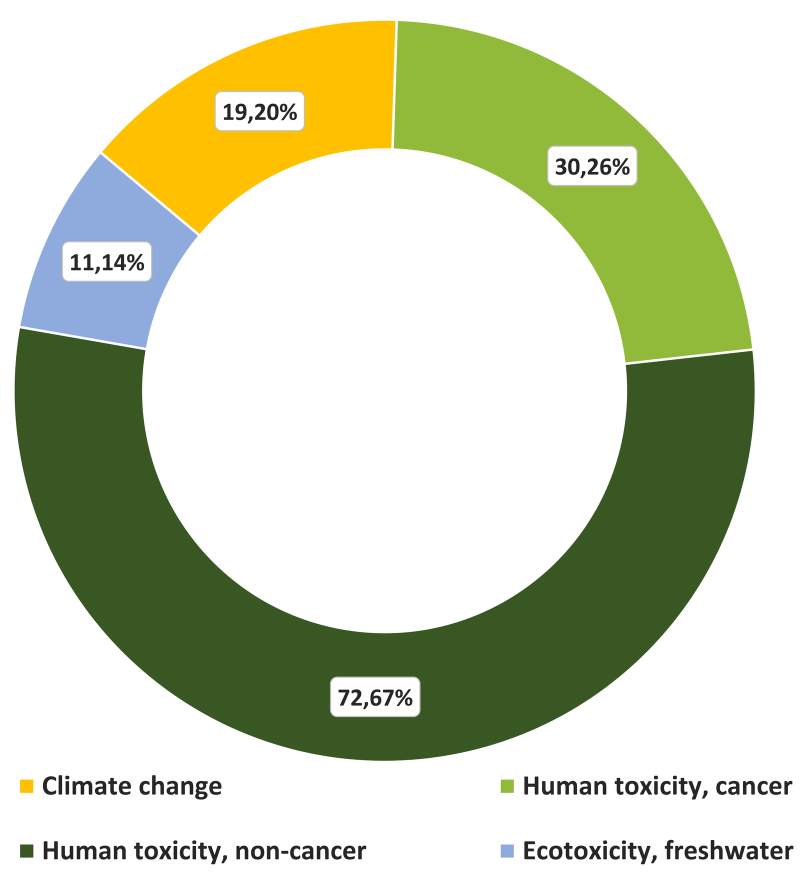

Figure 2: Deviations in selected impact categories

Impacts of different mass fractions

Imprecise information on mass fractions in safety data sheets (SDS) from resin suppliers can complicate the modelling. A sensitivity analysis was performed based on the mass fractions range (10-25%) for the reactive diluent in the resin component. Changes in this fraction significantly affect results in the impact categories on Human Toxicity cancer and -non-cancer, as well as Ecotoxicity, freshwater (Figure 3). Thus, inaccuracies in specifying mass fractions for reactive diluent in a polymer system introduce uncertainties that must be considered in the Life Cycle Assessment (LCA).

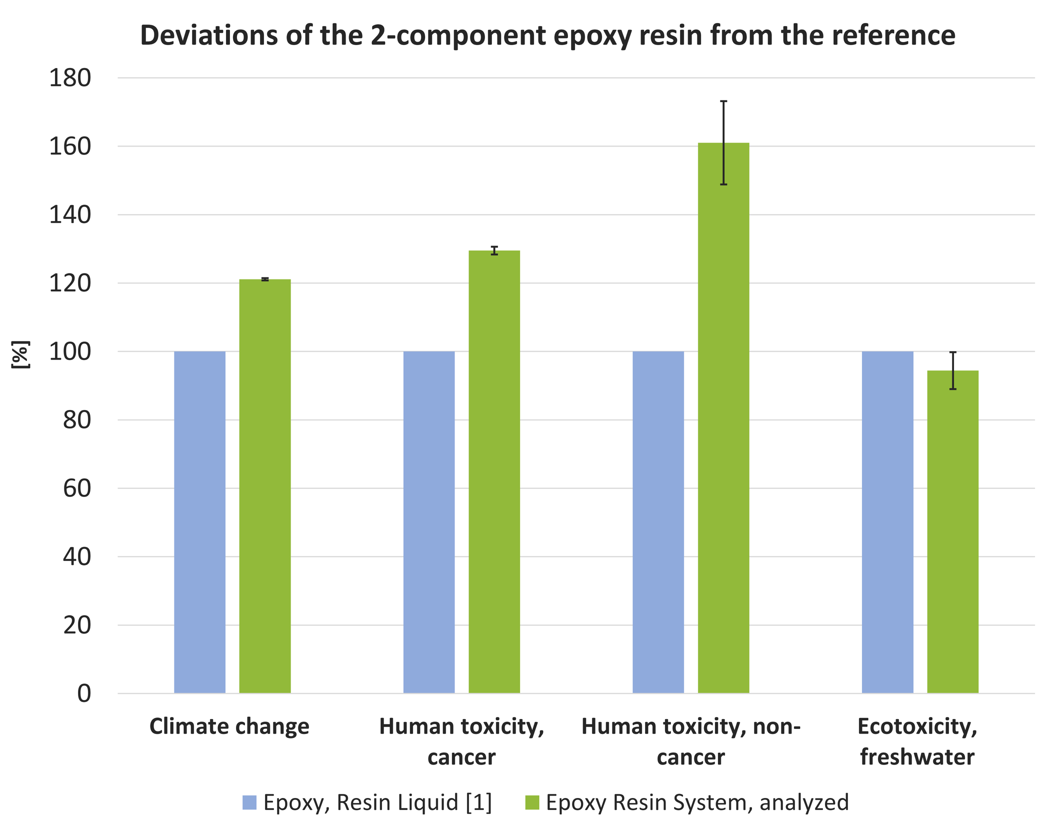

Figure 3: Impact indicator results for different mass fractions

Impacts of upstream production chains

In addition to different mass fractions, different production processes for primary products, like epichlorohydrin, significantly influence LCA results. Epichlorohydrin, used for the epoxidation of bisphenol-A, can be produced either by reacting allyl chloride with hypochlorous acid or glycerol with hydrochloric acid. The study compared the effect of these processes on the LCA results using the reference system from the EI database and a modified system with a 9:1 production mix of the two processes. The modified system showed deviations of up to 83% from the reference system (Figure 4).

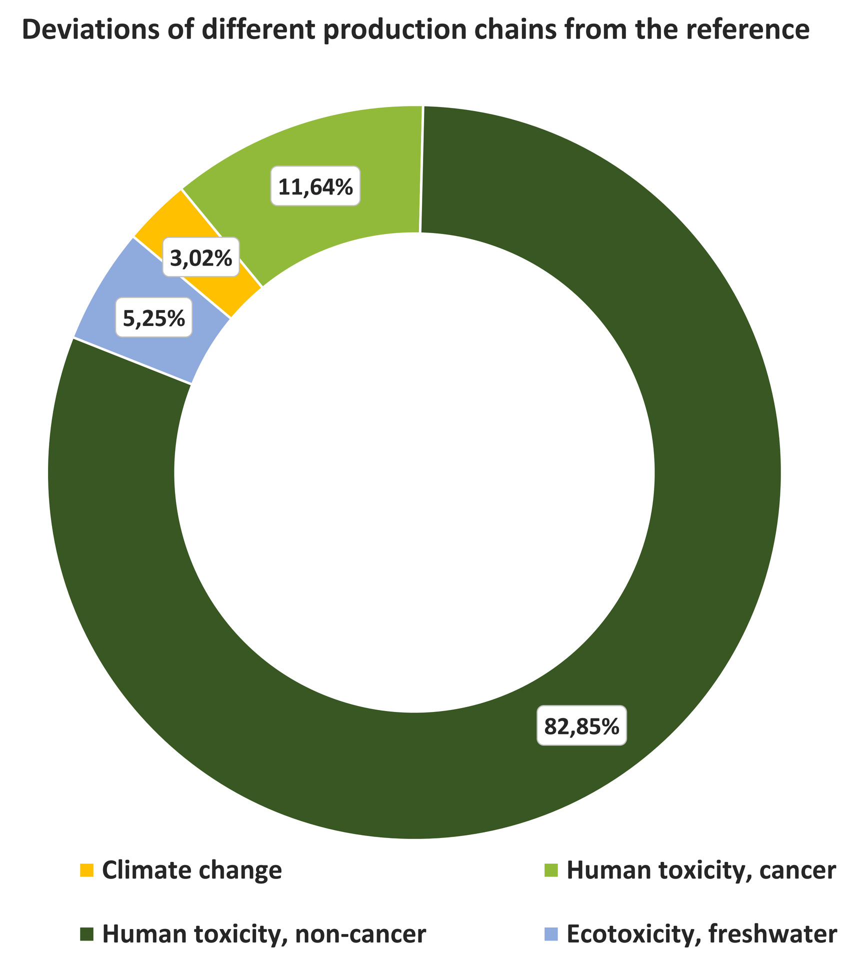

Figure 4: Deviations due to different production processes

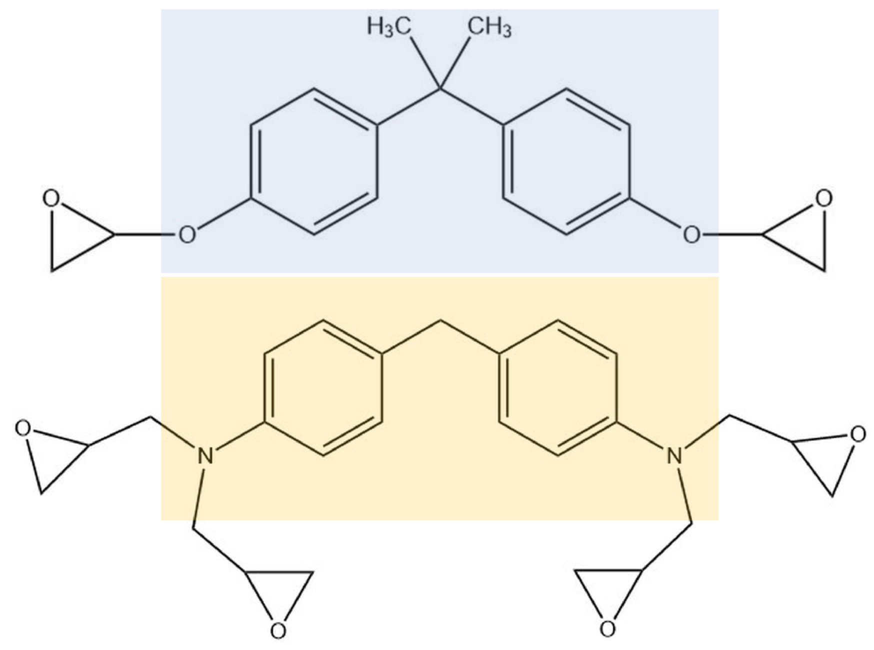

Figure 5: Chemical structure of the analyzed epoxy resins [4]

Impacts of different chemical backbones

In addition to the system similar in structure to the reference, a further epoxy resin system with a different chemical backbone was examined as shown in Figure 5. This is a 1-component system, which is conventionally used in aviation and has a 4,4'-methylenedianiline backbone instead of BPA. Here, too, significant deviations between the reference and the system under investigation were identified (Figure 6).

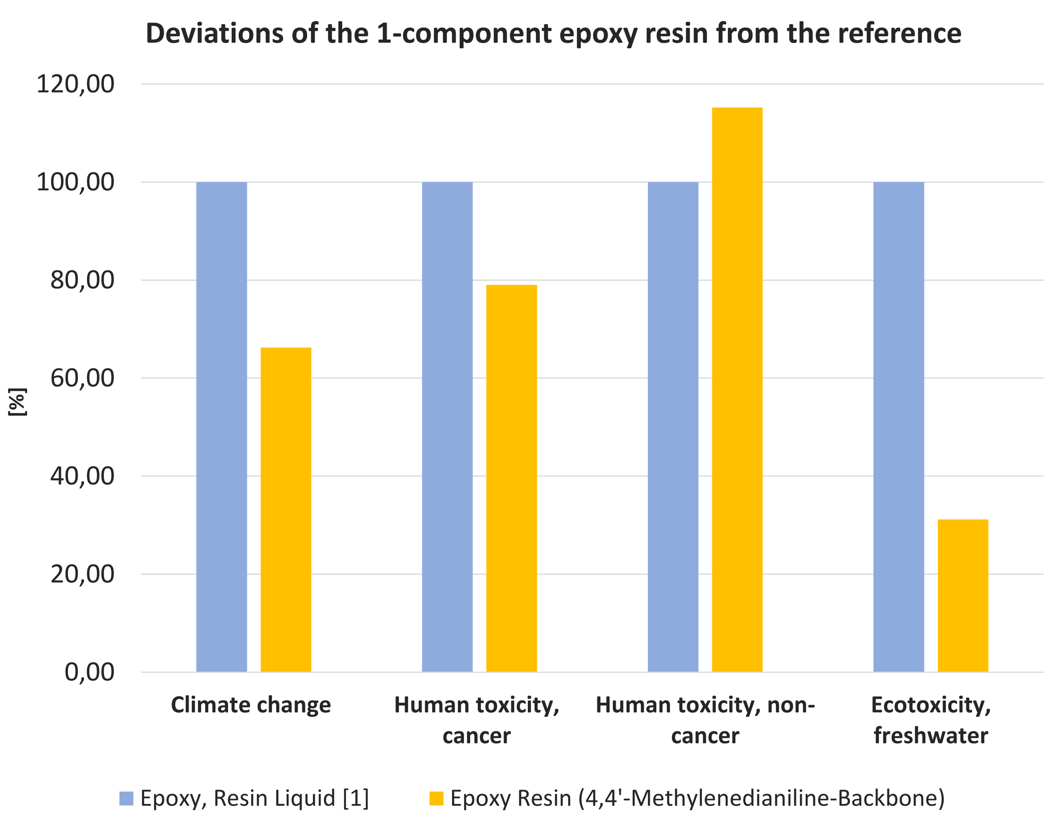

Figure 6: Impact indicator results for the two epoxy-systems

Conclusion

With the help of this study, it was possible to identify gaps in current Life Cycle Assessments and data sets. The influence of different additives, mass fractions and production processes should be particularly emphasized here, as this can help to better understand the impact indicator results of the LCA in the future.

[1] Ecoinvent, epoxy resin production, liquid, RER, Allocation, cut-off by classification, ecoinvent database version 3.8
[2] Epoxy Europe. European Industry: Socio-Economic Value of Epoxy Resins. https://epoxy-europe.eu/epoxies/european-industry-socio-economic/
[3] Rosenbaum, R. K.; Bachmann, T. M.; Gold, L. S.; Huijbregts, M. A. J.; Jolliet, O.; Juraske, R.; Koehler, A.; Larsen, H. F.; MacLeod, M.; Margni, M.; McKone, T. E.; Payet, J.; Schuhmacher, M.; van de Meent, D.; Hauschild, M. Z. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int J Life Cycle Assess [Online] 2008, 13 (7), 532–546. https://link.springer.com/article/10.1007/s11367-008-0038-4#citeas
[4] Ullmann's Encyclopedia of Industrial Chemistry; Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany, 2000.

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