Comparison of bio-based products and their fossil-based alternatives: an exergy-based life cycle resource efficiency analysis.

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A key aspect of sustainable processes is the optimized conversion of resources into products. Bio-based products can help to decrease our consumption of non-renewable fossil resources, but they rely more on bio-productive land compared to fossil-based products. Thermodynamics-based resource accounting methods can be used to calculate life cycle resource efficiency (LCRE); however, how to account for bio-productive land as an input during quantification of efficiencies is unclear. In our study, we applied a new framework for calculating LCRE while (i) accounting for bio-productive land resources and (ii) addressing the non-renewable character of fossil resources. Two cases, regarding bioenergy and bioplastic, were studied and compared with the fossil-based alternatives. Bio-productive land was included by accounting for the solar radiation on occupied land. Different system boundaries for the solar energy input in the primary biomass production system were applied and the theoretical limit on the conversion efficiency of solar energy into biomass, established by Zhu et al. (2010), proofed to be the best suited for calculating LCRE of bio-based products. It allows one to distinguish between inherent natural inefficiencies and inefficiencies that can be tackled by human intervention. Additionally, as land use equals land occupation during a given period, we performed a sensitivity analysis on the temporal system boundary of the primary biomass production system. Results of the case studies showed that the fossil-based products were convincingly (between 2.2 and 10.7 times) more resource efficient than the bio-based products, irrespective of the chosen temporal system boundary. Finally, we introduced a different way to account for fossil resources based on the work of Dukes (2003) who quantified the ancient solar energy consumption of fossil resources. Using this alternative approach, the bio-based products were between 3.5 and 17.6 times more resource efficient than the fossil-based products. The applied framework is useful to support research on sustainability assessment of bio-based products. A full coverage of natural resources and a distance-to-target approach to measure the distance reduction from the potential optimum that can be achieved by human intervention without changing the photosynthetic mechanism are the key aspects of this framework.

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