Comparative Assessment of Early-Stage social and critical raw material assessment (CRM) in the SSbD Framework: Addressing current generic databases

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Introduction

Achieving truly sustainable lubricant development requires moving beyond traditional environmental assessments. The Safe and Sustainable by Design (SSbD) framework enables early integration of social and critical raw material considerations into technology development. Yet, challenges remain significant, especially given the reliance on generic databases (e.g., PSILCA, ecoinvent, SOCA) that lack precision for emerging technologies. This research, part of the SiToLub project, critically evaluates bio-based versus petroleum-based lubricants, revealing contrasting profiles in social risks, opportunities, and critical raw material impacts. Addressing these data limitations and understanding their implications is essential for accurate and actionable sustainability evaluations.

What industry is facing:

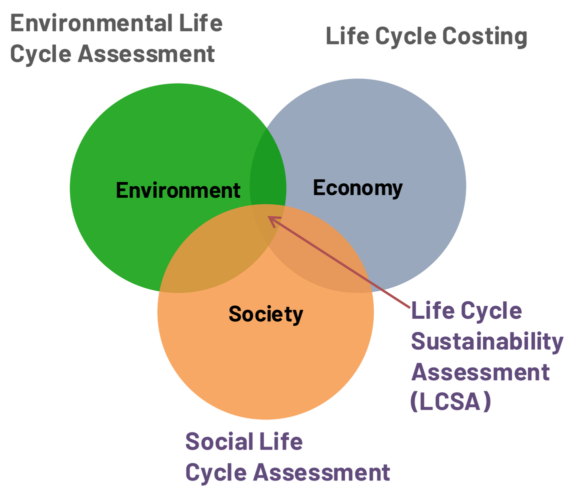
What customers want:

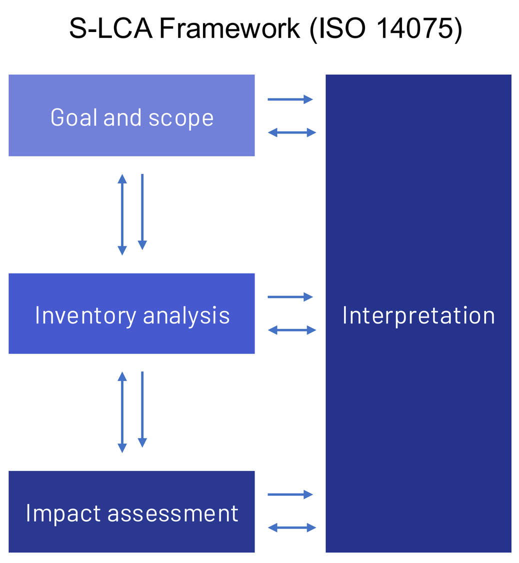
sLCA Methodology

S-LCA evaluates the potential and actual social and socio-economic impacts associated with a product or technology throughout its lifecycle, from raw material extraction to end-of-life disposal. Unlike environmental LCA, S-LCA focuses explicitly on stakeholder impacts, such as workers, local communities, and consumers, assessing both risks and opportunities for social sustainability.

In this study, the S-LCA methodology was applied using the **SOCA database** (version 3) [1] which combines PSILCA and ecoinvent 3.10 database in openLCA software and it follows four main phases adapted from ISO 14075.

Goal	Comparative analysis of bio-based and petroleum-based lubricants
Declared unit	1 kg of Lubricant
Scope	Cradle-to-gate
Stakeholder	Workers and Society
Activity variable	Worker hours
Impact assessment	Direct raw value approach weighed by activity variable





CRM Methodology

The EU defines CRMs as substances that are both economically significant to the EU economy and subject to high supply risks, primarily due to their extraction being concentrated in regions with weak governance and regulatory oversight. When designing safe and sustainable chemicals, companies should track the use of CRMs in their supply chains to better understand and reduce potential risks. When replacing harmful substances with safer alternatives, it's also important to consider how critical the new materials are and try to reduce dependence on CRMs where possible.

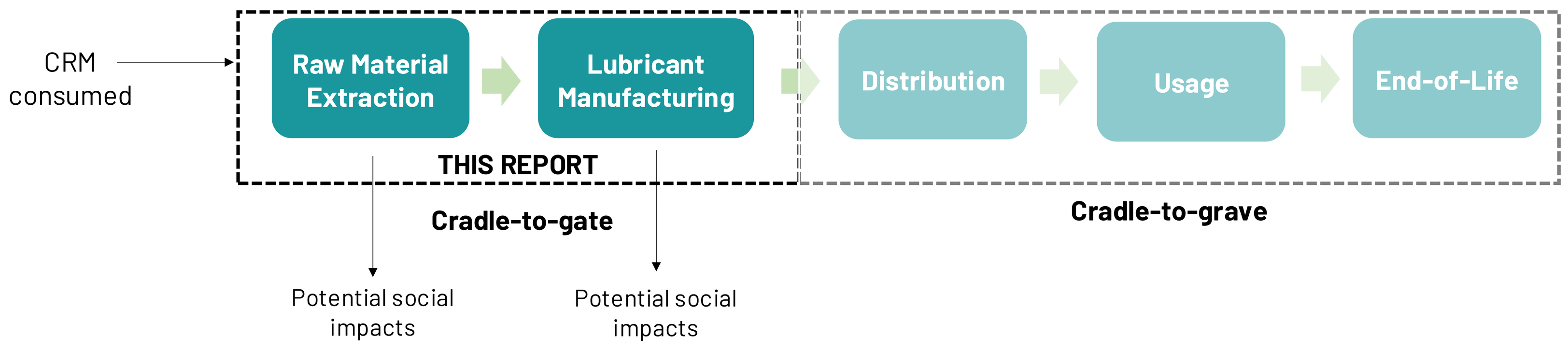
Bargiacchi et al. [2] and Zapp and Schreiber [3] proposed a criticality indicator, part of the SH2E EU project [4], where characterization factors (CF) can be calculated using the following equation:

$$CF = \frac{SR_i}{c_i(1 - IR_i \cdot (1 - EoL_{ROR}))}$$

Equation 1: Characterization factor of criticality indicator

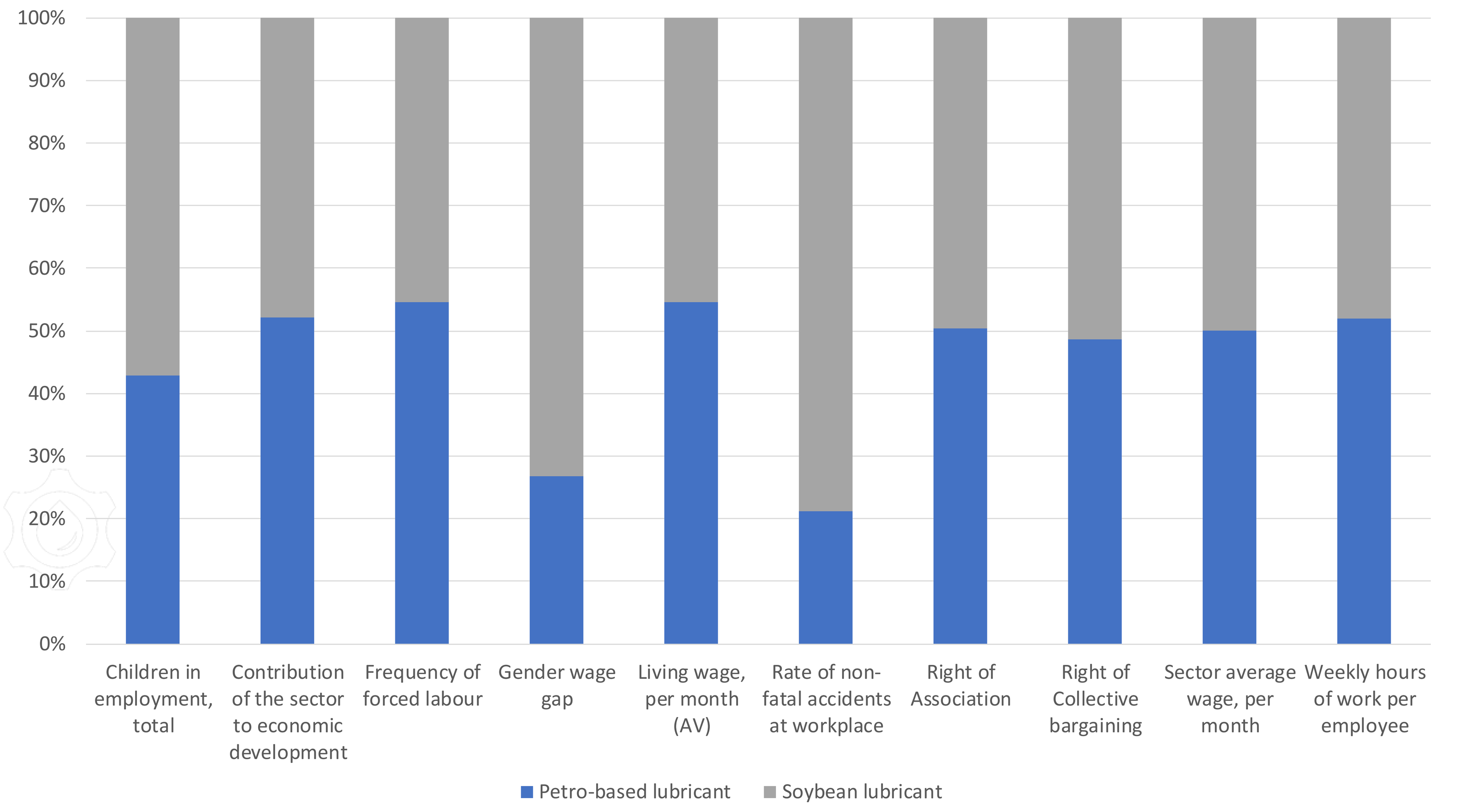
SR_i Supply Risk of resource i
c_i European consumption of resource i
IR_i Import reliance of resource i
EoL_{RIR} End-of-life recycling input rate

The final criticality indicator is the product of the mass (M) of a material (m) in the product system and the CF. This method was implemented across the ecoinvent database (v10 cut-off) to calculate the consumption data from the background data.



sLCA Results

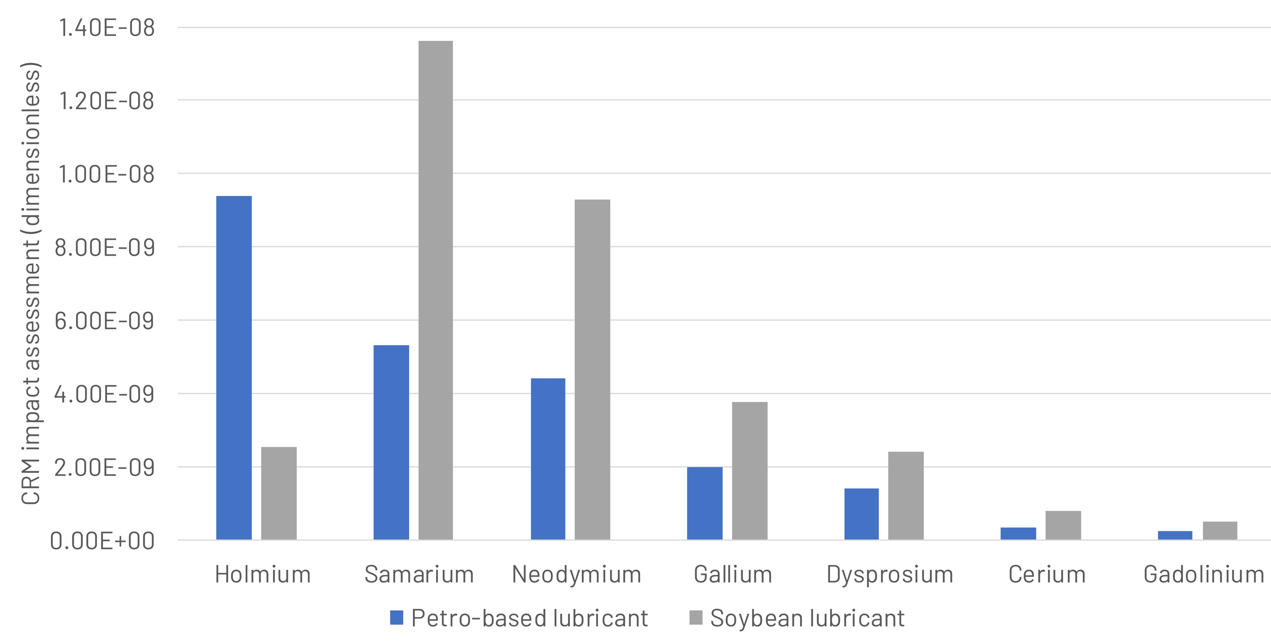
When comparing petro- and soybean-based lubricants, results reveal trade-offs across social indicators. The soybean-based supply chain shows a significantly higher rate of non-fatal workplace accidents and a wider gender wage gap, suggesting more pronounced occupational and gender-based vulnerabilities. It also scores slightly worse on child labour prevalence and earns a lower average living wage. Conversely, it performs marginally better on collective bargaining rights and forced labour frequency. Despite similar sector wages and working hours, the petro-based chain demonstrates stronger alignment with economic development metrics. Overall, neither supply chain is socially benign, underscoring the need for socially informed innovation beyond environmental substitution alone.



Notably, these results are derived entirely from the SOCA database, which maps sectoral-level PSILCA data onto ecoinvent. This introduces limitations, such as loss of regional and supply-chain specificity, highlighting the risk of over-relying on generic social databases. Social LCA must be complemented by context-aware, ground-truthed, foreground insights to ensure meaningful sustainability claims.

CRM Evaluation

The analysis compares the criticality of two lubricants, one petrobased and the other soybean-based, using the SH2E EU criticality indicator, which accounts for supply risk, European consumption, import reliance, and recycling rates. While the soybean-based lubricant shows higher criticality for most of the assessed elements, the overall values for both lubricants are in the range of 10^{-8} or lower. This indicates that, although there are differences in the specific contributions of certain critical raw materials, the absolute criticality impact per kilogram of lubricant produced remains very low. Therefore, from a criticality perspective, the use of either lubricant does not present a significant burden, reinforcing the importance of considering both relative and absolute impacts in sustainability assessments.



Conclusion

01 Environmental trade-offs extend beyond emissions, bio-based alternatives like soybean lubricants may reduce carbon footprints but can exhibit higher critical raw material dependencies and social risks.

02 To ensure the low criticality observed holds in practice, high-quality, product-specific foreground data is essential, particularly for decision-making in sensitive or high-volume applications.

03 While social LCA offers valuable signals, relying solely on generic databases like SOCA limits precision, social impacts must be contextualized with foreground data to reflect real supply chain conditions and support credible sustainability decisions.

[1] SOCA v3 Add-on – Adding Social Impact Information to ecoinvent, [Online]. Available: https://nexus.openlca.org/database/soca .[2] E. Bargiacchi, G. Puig-Samper, F. Campos-Carriedo, D. Iribarren, J. Dufour, A. Ciroth, et al., "D2.2 Definition of FCH-LCA guidelines WP2 Reformulation of current guidelines for Life Cycle Assessment," 2022. [3] P. Zapp and A. Schreiber, D3.1 Material criticality indicator, Brussels: Clean Hydrogen Partnership, 2021. [4] SH2E, "Guidelines for Life Cycle Sustainability Assessment and Prospective Benchmarking," [Online]. Available: https://sh2e.eu/.

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