Sustainability risks and consequences of innovative redox flow battery electrolytes

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1 | Problem Definition

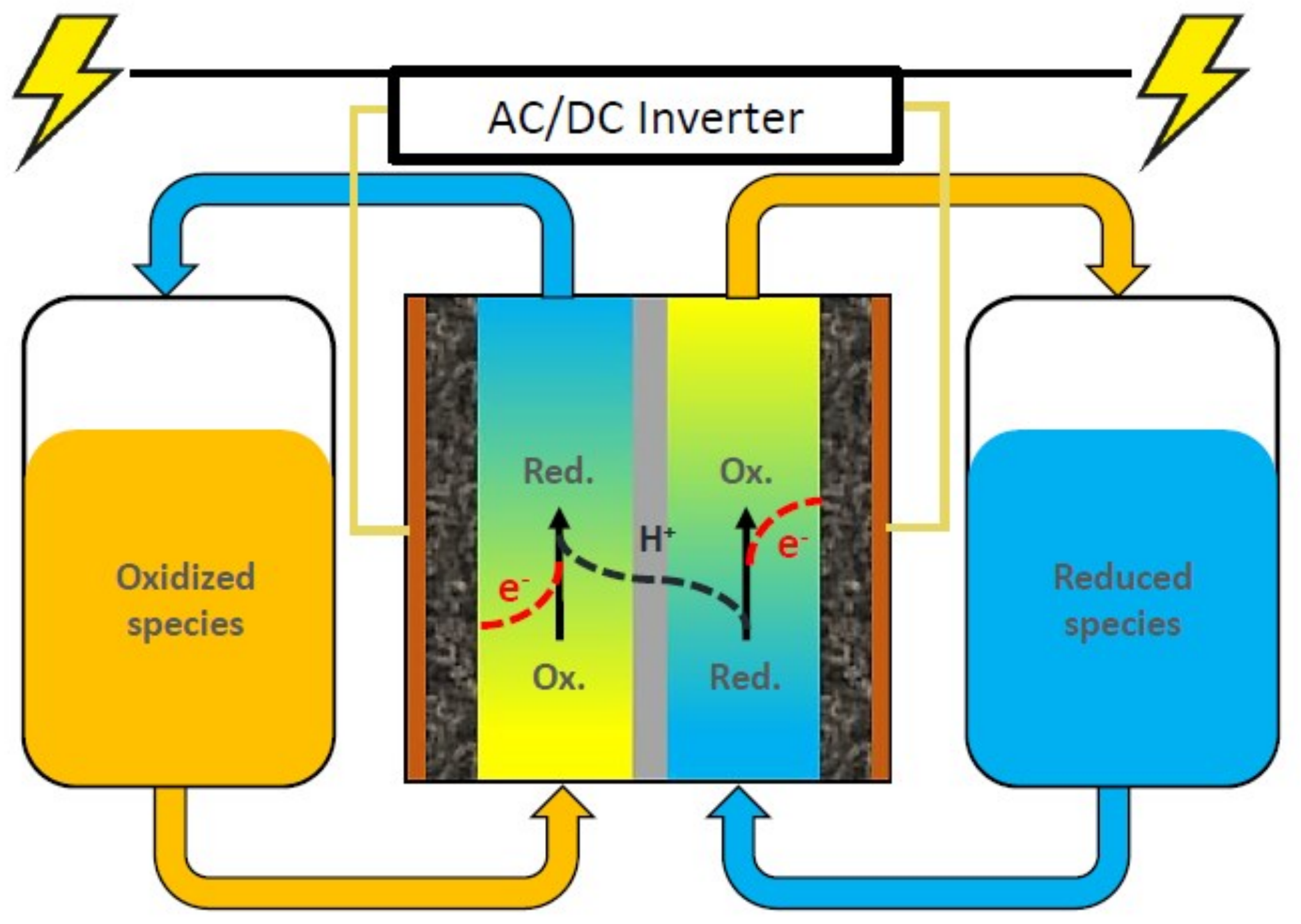

Figure 1: Redox Flow Battery System

A major challenge of renewable energy originates from fluctuations in energy production and a mismatch between supply and demand, compromising grid stability. This will require robust energy storage devices, of which **Redox Flow Batteries (RFBs)** are recognized as one of the most realistic candidates amongst electrochemical technologies (Leung et al., 2017). Currently, the most developed system is the all-vanadium RFB, however, organic active materials would be an advantageous alternative because of their abundance and the possibility of their extraction from diverse sources (Leung et al., 2017; Zhang et al., 2020).

Vanillin is such a commodity and was recently shown to be an excellent precursor for the production of a suitable electrolyte for RFBs (Schlemmer et al., 2020). Vanillin can be extracted from **lignin**, which is a major wood component and in theory available in large quantities as a by-product from the pulp and paper industry (Wenger et al., 2020). Whether **organic RFBs**, in particular lignin-based electrolytes are beneficial from a sustainability perspective compared to state-of-the-art metal-based electrolytes has not yet been subject to a thorough analysis. The environmental impacts of metal-based electrolytes, i.e., vanadium, zinc/cerium, zinc-bromine or all-iron electrolytes have already been investigated (Fernandez-Marchante et al., 2020; He et al., 2020; Weber et al., 2018). Although, the lignin-based electrolyte is at a low technological readiness level (TRL), it is still important to identify unintended environmental, social, and economic substitution effects. Therefore, the potential sustainability effects need to be assessed as early in the product development process as possible to prevent or reduce possible adverse effects (Mair-Bauernfeind et a., 2020).

2 | Research Aim

The objective of the present work is to investigate the **environmental hotspots** as well as the **social risks and opportunities** (on a country level) of the novel lignin-based 2-methoxyhydro-chinon (**MHQ**) electrolyte.

Approximately 98% of the technical lignin is burnt on-site for the purposes of chemical recovery and energy generation (often providing an energy surplus) (Wenger et al., 2020). Therefore, it is also important to investigate the potential **consequences** of using lignin-derived materials in redox flow battery systems instead of using the lignin (black liquor) for chemical recovery and energy generation, which is also an objective of this work.

The sustainability impacts will be compared to a state-of-the-art vanadium-based electrolyte.

3 | Method and Data

Investigating the sustainability impacts and consequences in a holistic and multidimensional approach can be done by using the **Life Cycle Sustainability Analysis (LCSA)** framework (Mair-Bauernfeind et al., 2020). Applying this framework in early TRL stages means to perform prospective assessments relying mostly on generic data. Hereby, the environmental hotspots are analysed by performing **a streamlined environmental Life Cycle Assessment (ELCA).** The social risk and opportunities are investigated employing a **generic social LCA (SLCA)** on a country level and the potential consequences of using lignin-derived materials in storage technologies are analysed by applying **consequential LCA**.

Assessment approach	Environmental LCA	Social LCA	Consequential LCA
Software and tools	Simapro	Social Hotspots Database	Simapro
Data sources	Project partners, ecoinvent, scientific literature	SHDB, public databases like WHO, ILO, FAO, ...	Ecoinvent, scientific literature, IO tables

Figure 2: Main characteristics of the approaches applied in this study

4 | System Definition

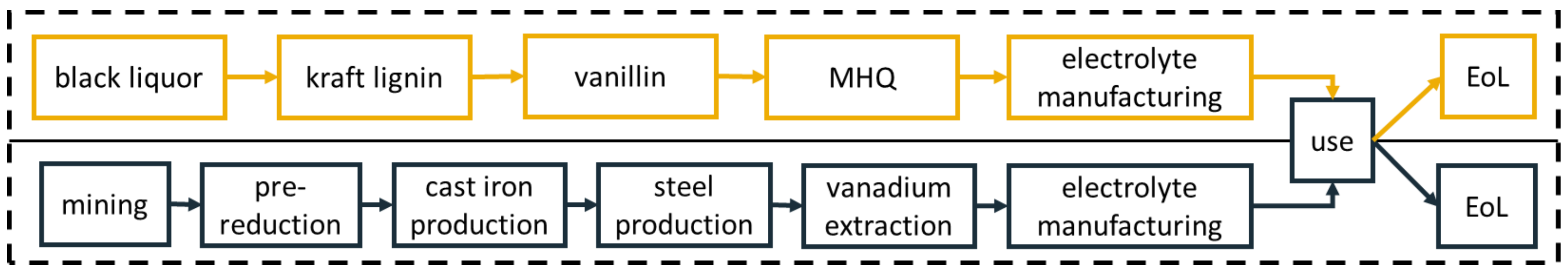
black liquor
kraft lignin
vanillin
MHQ
electrolyte manufacturing
use
EoL
mining
pre-reduction
cast iron production
steel production
vanadium extraction
electrolyte manufacturing
EoL

Figure 3: System boundaries for the environmental LCA (cradle2grave)

The **functional unit** for this assessment is the electrolyte for a redox flow battery system providing 1 MW of electricity for the lifetime of 20 years. The **system boundaries** for the streamlined ELCA is cradle2grave (figure 3) and for the (generic) SLCA and the consequential LCA is cradle2gate. The environmental impacts are investigated on a product (micro) level as well as on a sector (meso) and country (macro) level. The social substitution effects are analysed on a country level.

5 | Preliminary Results

So far, only a first draft model of the attributional LCA from the MHQ electrolyte was developed. The results of this first model are illustrated in figure 4, where the relative contributions of three reference flows (MHQ electrolyte, MHQ and vanillin) are shown. The life cycle inventories (LCIs) for the Kraft lignin and the vanillin process are taken from Culbertson et al. (2016) and Khwanjaisakun et al. (2020), respectively. The LCI for the MHQ process is based on process simulation data developed within the research project **SABATLE** (safety assessment of flow battery electrolytes). As figure 4 clearly shows, the vanillin process is responsible for appr. **87% of the total GHG emissions** of the MHQ electrolyte. However, the vanillin process does not include the avoided energy production through the incineration of the residual lignin yet.

The social risks and opportunities for a few subcategories are illustrated in figure 4. So far, only countries upstream of the vanadium production (Russia, China, South Africa) and MHQ production (Sweden, Finnland, USA, Canada) are considered. The results in this figure show that the **social risks** in the countries affected by the MHQ electrolyte system are **lower in most subcategories** as compared to the countries affected by the vanadium electrolyte system.

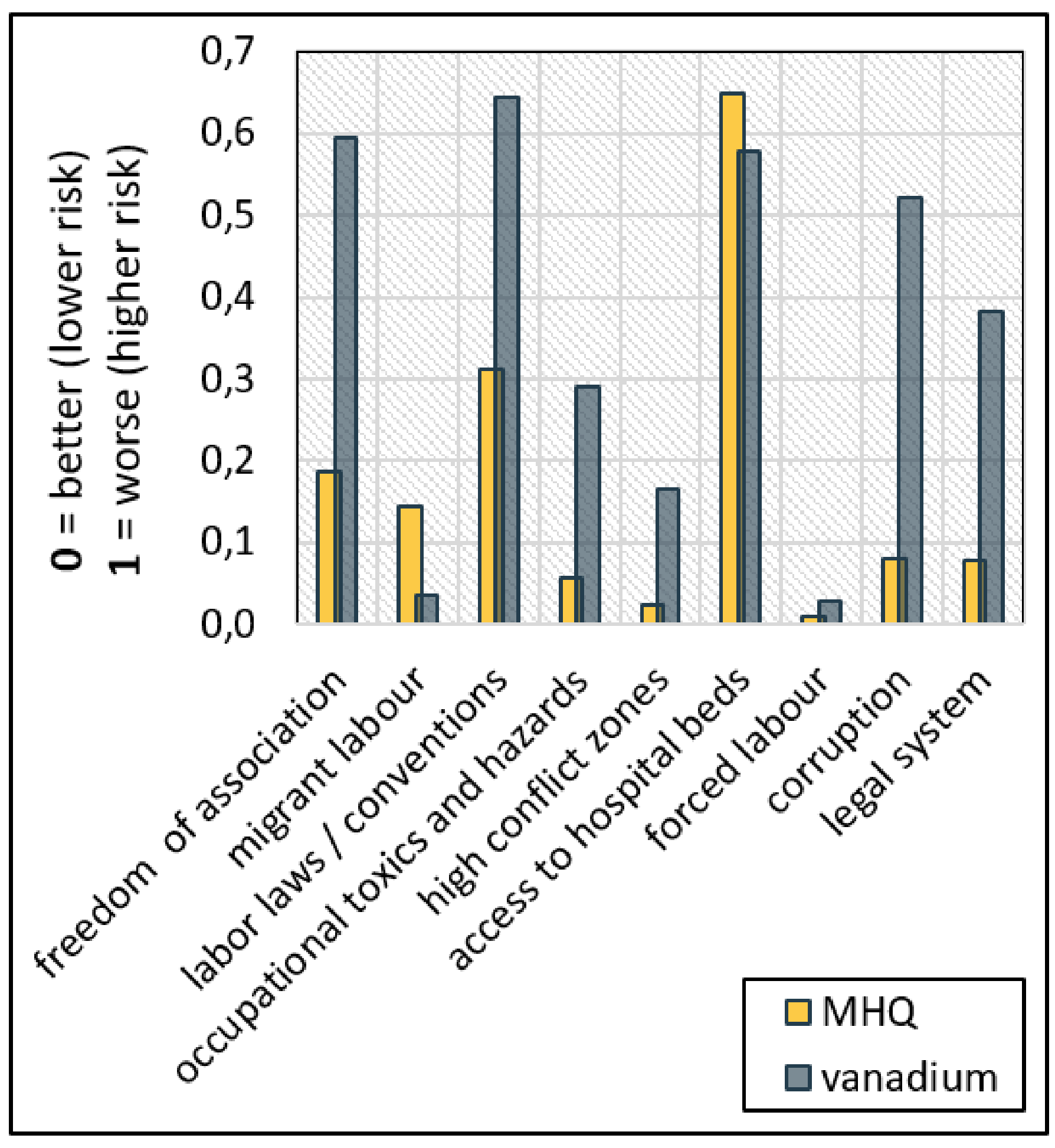

Figure 4: Social risks and opportunities of the vanadium versus MHQ electrolyte

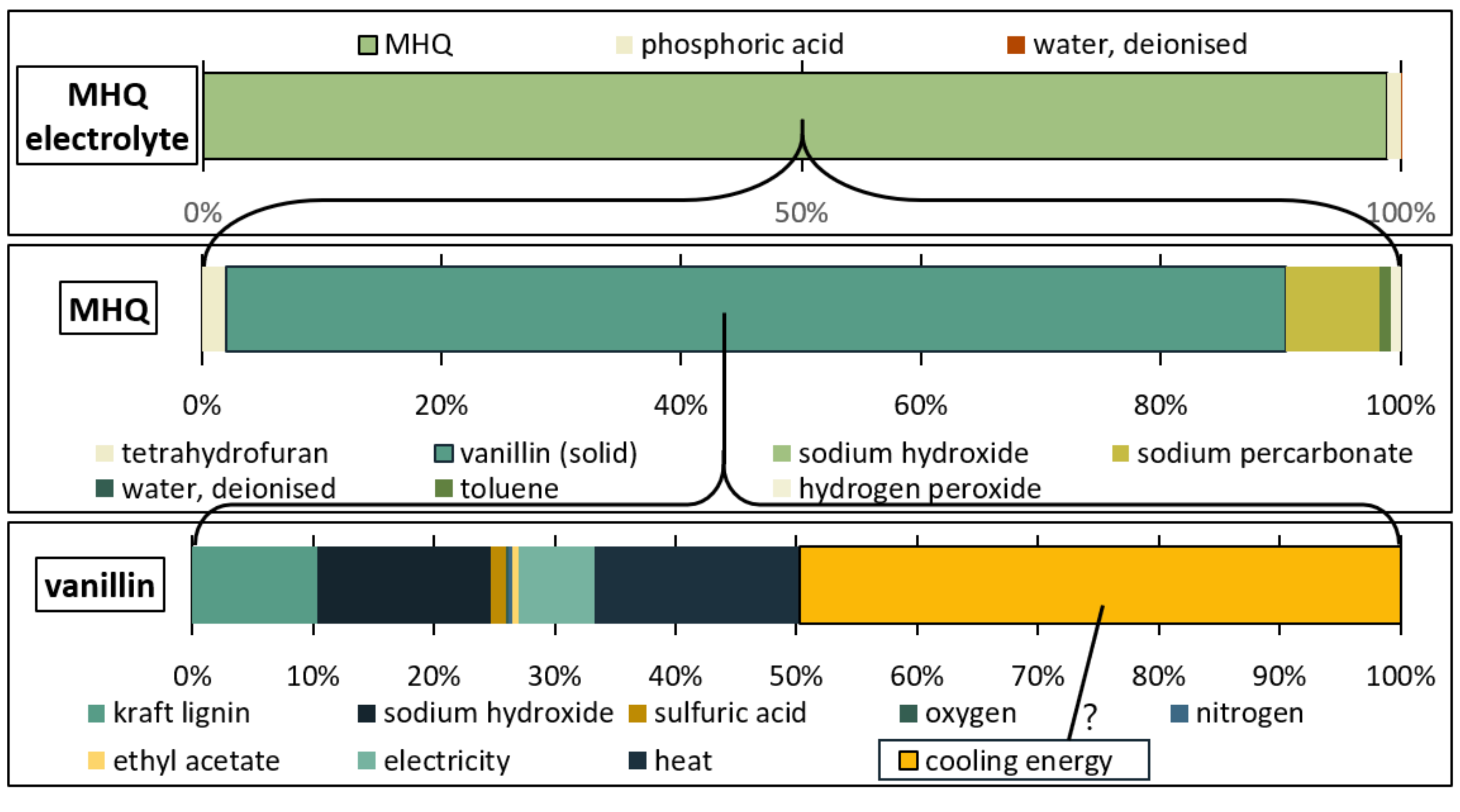

Figure 5: Global warming potential hotspots of the MHQ electrolyte. Relative contribution of unit processes to the respective reference flows.

6 | Discussion

The preliminary results show the environmental hotspots of the MHQ electrolyte as well as the social risks and opportunities when substituting the vanadium electrolyte with the MHQ electrolyte for redox-flow battery systems. Regarding social risks and opportunities, the new technology (preliminary mass and energy balances) appears to be beneficial in most of the subcategories investigated. In terms of environmental hotspots, vanillin production currently seems to be by far the largest hotspot due to its high energy demand. However, since the energy balances and potentials for closed-loop operations as well as waste recycling have not yet been fully identified, it remains to be seen whether these impacts will be significantly reduced.

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