Micro-scale consequential inventory modeling - a case study from metallurgic production

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1. Introduction

The scientific discourse on consequential life cycle assessment (CLCA) is largely focusing on macro- and meso-scale decision settings in political and research contexts. Particular emphasis is mostly placed on the necessity to incorporate consequences due to market dynamics into LCA-models (e.g. [1], [2]). The presented case of a metallurgic production line reveals limitations of attributional life cycle assessment (ALCA) even within "micro"-scale settings: In the considered operative decision context ALCA would lead to erroneous conclusions concerning ecological improvement options. This paper contributes to the collection of consequential life cycle case studies, in particular by exploring the field of micro-scale CLCA and by addressing the challenges of integrating life cycle assessments with actual production and product planning and optimization.

2. Materials and methods

For the metallurgic production line (Figure 1), an inventory model of the foreground system has been built using optimization-aided material and energy flow analysis [3]. The model can be evaluated both in a consequential and in an attributional sense.

In the context of minimizing the system's carbon footprint, the specific decision whether to produce the intermediate IP1 (Calcination process in Figure 1) in-house or to purchase it from external suppliers is considered. Interestingly, the comparison of (attributional) carbon footprints suggests an increase of purchase whereas the consequential model favors in-house production.

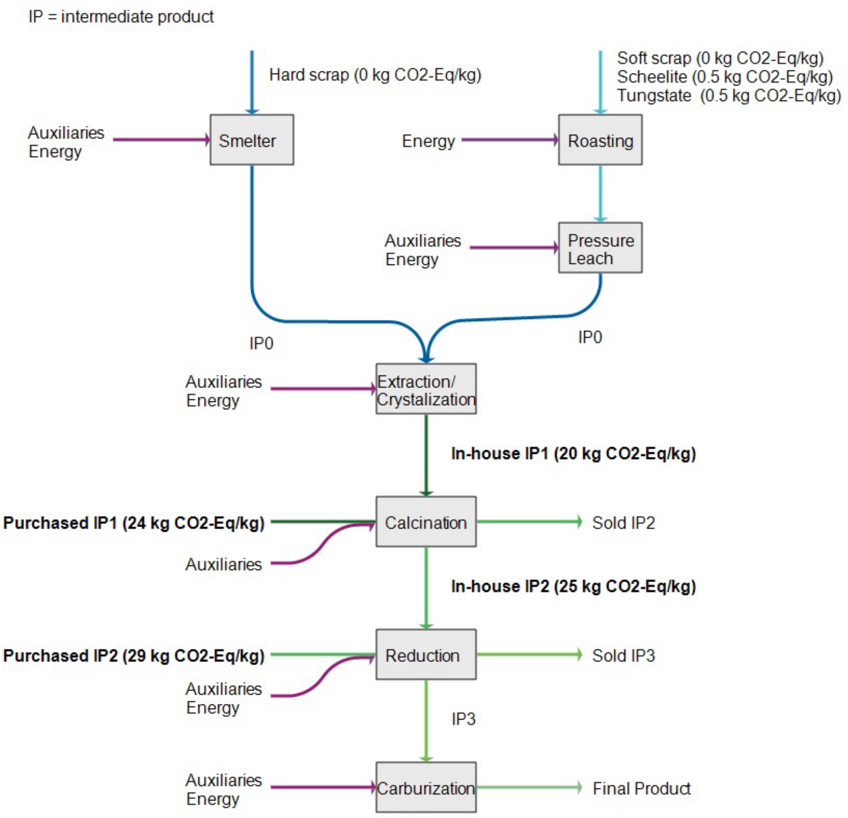

Figure 1: Simplified representation of the tungsten production line (foreground system, status quo)

3. Results and discussion

This paradox can be solved by taking into consideration the fundamentally different system representations in ALCA and CLCA. While ALCA presumes that material and energy flows in the inventory linearly depend on the functional unit and change proportionally [4], the CLCA model enables non-proportional changes depending on the actual consequences of market mix alterations, constraints on technical capacities, availabilities, and so forth. It is only due to these additional degrees of freedom, that an environmental improvement is possible without changing the production volume, i.e. the functional unit. Those properties make the CLCA model a more precise representation of the real production site. Hence, consequential life cycle modeling is necessary to adequately support the operative decision setting of this case study. Optimization-oriented life cycle modeling as well as a closer integration of life cycle models with production planning and control systems are thus possible solutions for feasible CLCAs on the micro-level.

The contradictory results of the ALCA and the CLCA perspective can thus be explained as follows: the carbon footprint obtained by ALCA (red line in Figure 2) relies on the hypothesis that the actual feedstock mix is scaled proportionally, whereas optimization has to take availability constraints into account. As a consequence the real, i.e. marginal, carbon footprint should reflect only one scrap fraction (SS4 in Figure 2) that actually leads to a higher carbon footprint of in-house produces intermediates than purchased intermediates. Hence, only the measures deduced from consequential modeling allow for a reduction of the system's carbon footprint. This is even more true when the volume of production is to be increased.

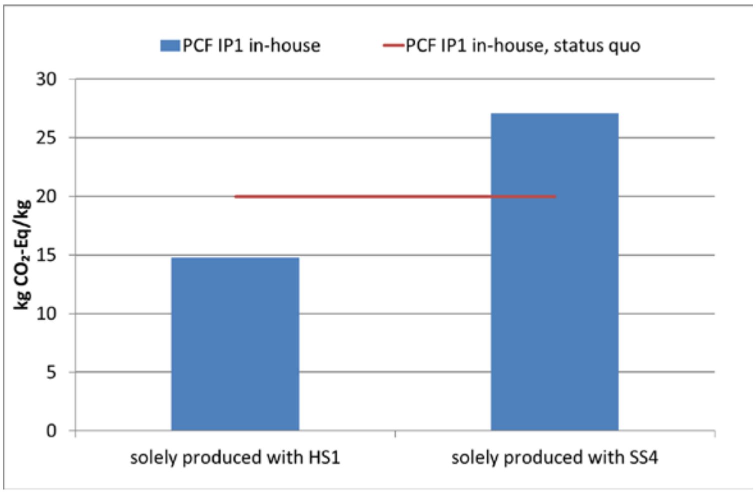

Figure 2 Different carbon footprints of in-house produced intermediate product 1 (IP1) depending on the feedstock used (HS = hard scrap, SS = soft scrap)

4. Conclusions

The comparative analysis of ALCA and CLCA suggestions for the given decision context points out that life cycle assessments aiming at concrete improvements of production systems might require entirely different modeling approaches compared to more accounting and reporting-oriented use cases. The presented case study shows clearly that consequential modeling is not necessarily synonymous with integration of economic models on a macro-scale. Independent of the considered scale, CLCA becomes necessary as soon as decisions require taking into account the degrees of freedom as well as existing constraints in a real system and thus make results obtained by linear extrapolation of ALCA obsolete.

5. References

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