Life cycle assessment of silicon metal by aluminothermic reduction

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INTRODUCTION

- Silicon is conventionally made by carbothermic reduction of quartz, reaction simplified as:

$$SiO_2 + C \rightarrow Si + CO_2$$

- The aluminothermic reduction of silicon is an alternative, carbon-free production route that can make use of aluminium waste such as e.g. aluminium dross, mixed Al-waste, etc.

$$SiO_2 + 4/3Al \rightarrow Si + 2/3Al_2O_3$$

- In this paper, the life-cycle environmental performance of silicon produced by aluminothermic reduction is evaluated in comparison with the carbothermic reduction.

METHODOLOGY

- Comparative LCA applying system expansion with Ecoinvent v. 3.5 APOS and Recipe 2016 (H) Midpoint and Endpoint.
- Inventories constructed from thermodynamic process simulations to validate mass and energy balances.
- The functional unit is defined as the production of 1 tonne of silicon after ladle refining in Norway.

RESULTS

- The results of the assessment using aluminium dross as input material are given in Figure 1 (Endpoints). The categories contributing most to the overall impacts are found in Figure 2 (Midpoints).
- The evaluation of Midpoints yields a higher impact for the conventional production route, in all major impact categories. However, at the Endpoint level, the aluminothermic route performs worse for the resources category, which is explained by the fact that ReCiPe Endpoint excludes brown coal and peat from the final analysis.
- The hotspots in the conventional route are the emissions released through the furnace, the carbon reductants used (e.g. hard coal), and the electricity consumed. In the aluminothermic route, the aluminium and carbon dioxide consumed in alumina refining, the use of quicklime and electricity, as well as the management of the final waste streams represent the main impacts.
- The production of alumina as a by-product in the aluminothermic route is able to substantially decrease the different impact categories.

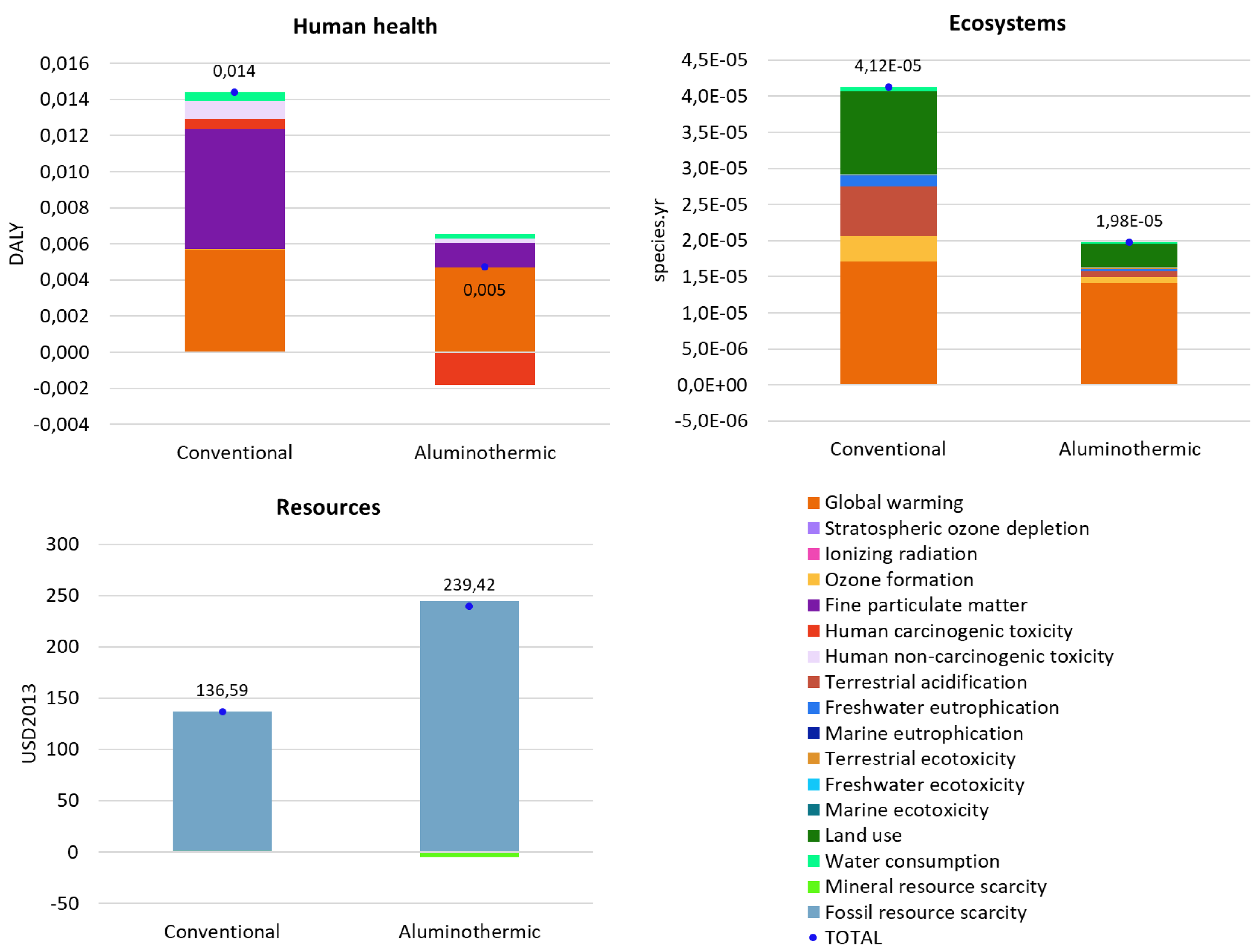

Figure 1: endpoint evaluation of the conventional and aluminothermic silicon production.

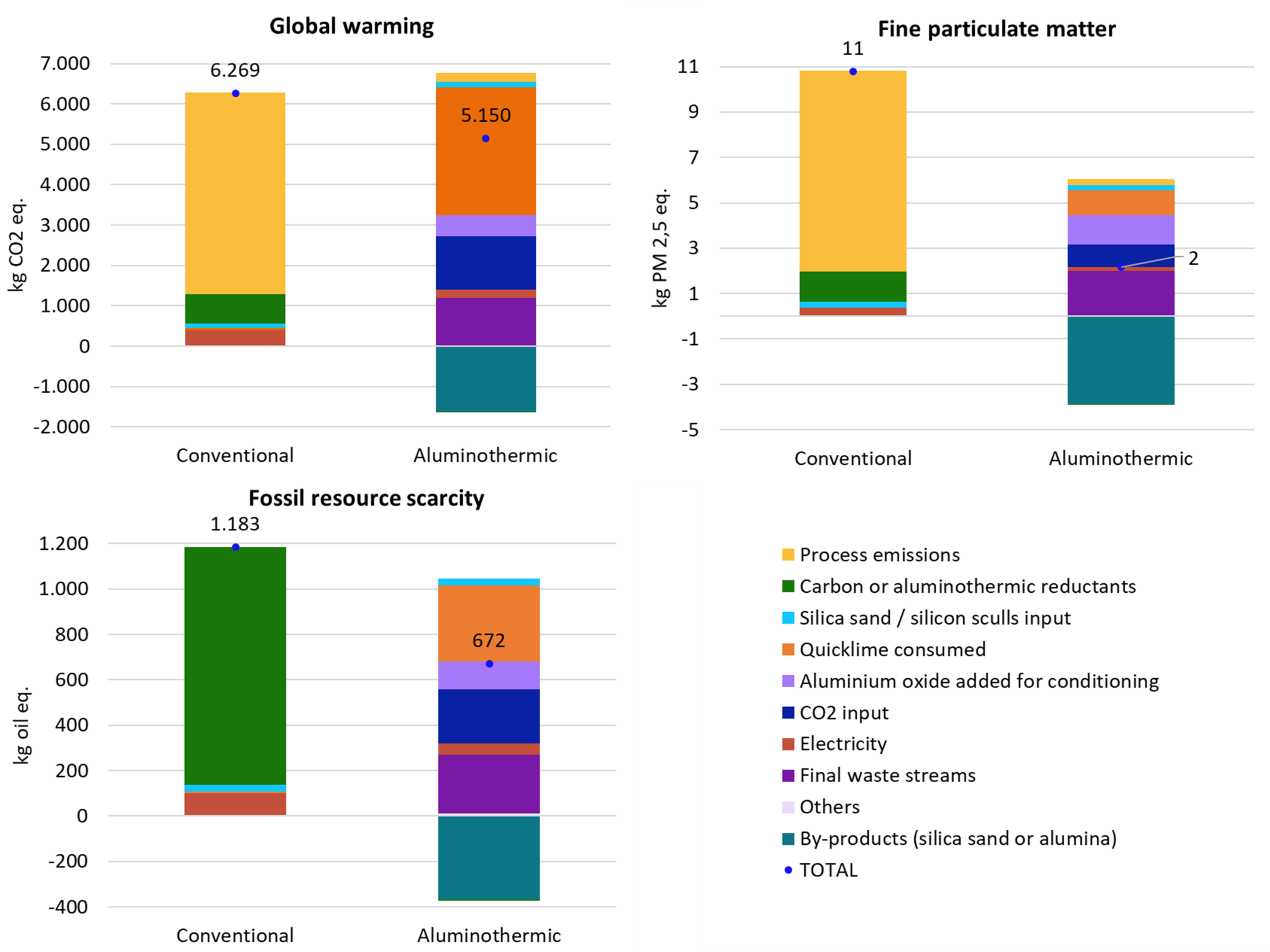

Figure 2: midpoint evaluation for the largest contributors to endpoint impacts.

- The sensitivity analysis showed that a change of the electricity mix to the European average did not greatly affect the assessment results.
- The application of post-consumer aluminium scrap instead of aluminium dross showed an increased contribution for many of the environmental impacts compared to the conventional route, as this holds the negative effect of scrap that is not recycled. However, this situation could change given a surplus of aluminium scrap in the future, or when assessing aluminium that is not easily recycled.
- The contribution to global warming assuming biocarbon in the carbothermic route is lower than that of the aluminothermic route when reductants are substituted by a minimum percentage of 38,68%.
- It is estimated that by 2030 the application of the aluminothermic route using aluminium dross could avoid the release of 127.047 tonnes of CO_2 –eq.

CONCLUSION

- The aluminothermic reduction has great potential to improve impacts when using current waste streams such as dross as a reducing agent, to decrease energy use and pollutants release and to improve the overall waste utilization rate.
- When aluminothermic reduction is based on post-consumer scrap fractions, the comparison between aluminothermic and carbothermic depends on the intended alternative use of the specific aluminium scrap fraction.
- Scenarios for the future indicate possibilities of surplus volumes of aluminium scrap, and also an increased demand for silicon products for electronics and solar energy applications in the coming years. In this lies an opportunity in the aluminothermic route as an example of industrial symbiosis for these two raw material industries.

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