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# Integrating $CO_2$ Reporting with Physically Consistent Material and Energy Flow Analysis to Improve Circularity of Steel Products

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Improving the circularity of steel products requires reliable tools for ECO design that integrate key environmental properties, such as $CO_2$ footprint and embodied energy. These data are typically de-rived from environmental reporting and Life Cycle Assessment (LCA) analyses. However, ensuring physically consistent and traceable information - grounded in fundamental principles such as mass and energy conservation - is essential for accurately assessing complex process flows and supporting reliable sustainability decisions.

This work introduces a novel approach that ensures physically consistent modeling of material and energy flows while integrating $CO_2$ accounting. A new graphical notation for substance and energy flow modeling has been developed, designed to handle both known and uncertain data. This notation enables serialization into a structured JSON format, providing a standardized and flexible data repre-sentation. By translating this representation into a mathematical model, optimization-based data rec-onciliation ensures consistency, even when faced with contradictory or incomplete input values.

The newly developed software application includes a graphical user interface combined with a mathe-matical solver. It is presented with the example of an Electric Arc Furnace (EAF) steelworks case study. This example showcases how ECO-relevant flows can be modelled - including raw material inputs, energy consumption, emissions, and byproducts - while maintaining physical consistency. The system is designed to be compliant with ESRS reporting, enhance ECO reporting and support deci-sion-making to improve resource efficiency and reduce environmental impact. In addition to process modeling, the system incorporates materials selection based on ECO properties derived from ESRS data, enabling informed decisions on resource efficiency and sustainability.

This presentation underscores the significance of physically consistent modeling for sustainable process design. It highlights the practical advantages of this approach embedded into a scalable and transparent framework, providing actionable insights for industries striving to meet stringent environmental standards while advancing circularity and innovation in steel production.

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