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A NOVEL PERSPECTIVE ON THE AVOIDED BURDEN APPROACH APPLIED TO STEEL-CEMENT MAKING JOINT SYSTEM

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Abstract
Recycling of ground granulated blast furnace slag (ggbfs), a steelmaking process coproduct, in cement making has been typically seen as beneficial for both industry sectors involved, for the destination of an industrial waste to replace and reduce raw material intake of a second manufacturing process. Within Life Cycle Assessment (LCA) methodology, the distribution of impacts between a product and its coproduct shall follow ISO 14044's guidelines. Impact distribution in multifunctional processes remains, however, as one of LCA's most controversial methodological issues. This paper analyses how multifunctional modelling methods distribute steelmaking environmental loads between pig iron and bfs, and their influence on LCA results for ordinary Portland cement and two types of blended cements with high ggbfs content commercialized in Brazil. SimaPro 7.3 supported LCA using CML 2001 (baseline) impact evaluation method. Impact allocation, by definition, induces considerable impacts on bfs. Using the avoided burden approach, impact values in all categories decreased with increased ggbfs content in cement. Though the 'avoided burden approach' succeeds to a major recycling benefit – raw material preservation – in products' life cycle modelling, it fails to distribute it properly and is not adapted to the waste user. By acknowledging that new loads arise and are neutralized over recycling implementation, this approach not only distributes environmental benefit among the partnering industries that enable recycling, but also provides a more complete and refined description of recycling implications and actual (net) avoided burden, that, among others, can better inform strategic decision-making by the involved industries.

Keywords:
LCA; cement; allocation; system expansion; avoided burden

1 INTRODUCTION

Impact distribution in multifunctional processes is one of LCA's most controversial methodological issues given that it highly influences the study's final result. Ekvall and Finnveden [1] define a multifunctional process as an activity that fulfils more than one function: a production process generating more than one product, a waste management process with more than one waste flow, or a recycling process providing waste management and material production.

The vague nature of ISO 14044:2006 [2] proposed guidelines, combined with a growing desire to follow a "life cycle approach", without a clear notion of what it means, has led to confusion regarding what an LCA might or might not accomplish and how it fits into a strategic approach to assure environmental sustainability [3]. As a result, it has become increasingly common to find conflicting LCA approaches, many times evaluating the same product, but achieving different results due to the lack of common methodological choices among practitioners and of clear scientific background supporting such decisions.

1.1 The challenge of modelling multifunctional process

A multifunctionality problem occurs in LCA when a process fulfils one or more functions for the investigated product's life cycle, and a different function (or functions) for other product(s) [1]. This poses the issue of sharing and distributing

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material and energy flows – and their respective environmental loads – between multiple functions.

To solve a multifunctionality problem, ISO 14044:2006 [2] suggests a three-step procedure. Firstly, the distribution of impacts between a product and coproduct based on a specific criterion (i.e. allocation) should be avoided *"wherever possible"*, either by dividing multifunctional processes into sub-processes or by expanding the product system to include the additional functions related to the by-products. Secondly, in the cases where allocation cannot be avoided, the standard prescribes that system inputs and outputs should be divided based on the *"underlying physical relationships between them"*. Finally, if those physical relationships are not easily identified to enable partitioning, then the inputs and outputs are to be attributed in a way that reflects other relationships between the products and functions, such as their economic value.

Each multifunctional modelling method presents its perks and losses. Mass allocation is quite straightforward, using easily calculated and relatively constant values. However, in some industrial processes the mass of product and coproduct generated is substantial – which is exactly the case for construction sector industries – so a large amount of the environmental load is transferred to the coproduct user, removing a great deal of the main product's loads. Economic value allocation users defend that all industrial activities are guided by economic principles, which justifies adopting the same principles for impact distribution. The most common critic to that method is that economic value information is very sensitive to market fluctuations, which harms results reliability over time. Pelletier and Tyedmers [4] highlighted the current economic system's inability to adequately account for changes in environmental amenities. For that reason, those authors state that market information rarely incorporates relevant environmental information – which justifies their questioning of LCA results that are highly influenced by economic information.

Previous literature review spanning over the past 10 years of LCA practice [5] confirmed the lack of consensus regarding the choice of a given method over others or the appropriateness of one single distribution approach to all multifunctionality cases. It also indicated a massive use of the avoided burden approach, which is most likely related to its application's readiness, and to the fact that it avoids allocation, as is recommended by the international standard.

One relevant argument refers to compliance of the different distribution methods to mass and energy conservation laws. Weidema and Schmidt [6] state that *system expansion always respects the mass and energy conservation laws, while allocation nearly always fails to do so.* According to those authors, since allocation "breaks" the original system into two or more artificial systems according to the allocation criterion adopted, the only balance observed is given by that criterion, i.e. when mass regulates allocation, only mass conservation is respected. On the other hand, Chen et al. [7] justify choosing mass and economic value allocation criteria to assess impacts of using additives in concrete making, by affirming that system expansion (through the avoided impact approach) does not respect mass conservation laws *when the product and by-product are considered together*. The arguments from each side are supported by either one case-specific example [6] or a hypothetical example designed by author-defined equations [7]. Both explanations can be contested in different contexts and perspectives that render them not applicable.

The arguments found in literature regarding compliance with conservation laws are still too scarce to discard a given distribution method. In fact, to minimize the influence of impact distribution on LCA results, published literature gathers suggestions of different approaches for specific sectors, such as the allocation method for the cement industry proposed by [8].

1.2 Research context and justification

The Brazilian cement industry has a tradition of benefiting from the industrial synergy with the steelmaking sector. Normalized in 1964, the replacement of clinker by ground granulated blast furnace slag usually generates two types of Portland cements: the blended Portland cement (CP II-E-32), which contains up to 35%, in mass, of ggbfs, and the blast furnace Portland cement (CP III-32), with up to 70% of ggbfs in mass.

National studies aiming to measure the environmental loads of cement with bfs as clinker replacement so far have typically considered this slag merely as a consequence of the pig iron-making process, therefore with no impact attributed to it [9]. Research that potentially contributes to a better understanding of impacts and or benefits that arise from such a well-established industrial synergy is crucial.

This paper analyses the appropriateness of multifunctional modelling methods predicted in ISO 14044:2006 [1] to distribute environmental loads between pig iron and bfs produced in the steelmaking process; as well as the influence that modelling choices have on LCA results for different blended cement types commercialized in Brazil. We further build upon such analysis to propose an adjustment of the avoided burden approach used in the system expansion method.

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2 METHODOLOGICAL APPROACH

2.1 LCA's Goal and scope definition

The performed LCAs fall into the cradle-to-gate category, i.e., the use and end of life stages are not considered, since the study's main focus is limited to modelling the multifunctional process (steelmaking) and the process that uses the analysed coproduct (cement making). Subsequent phases fall out of the research's scope. SimaPro 7.3 was the support platform chosen and CML 2001 (baseline) was adopted for the impact assessment stage. The adopted functional unit was 1 ton of cement.

2.2 Inventory analysis

Table 1 summarizes technical properties and tools used to model cement making processes.

	CP I-S-32	CP II-E-32	CP III-32
Functional unit		1 ton	
Amount of ggbfs as clinker replacement	5%	30%	66%
National standard	NBR 5732:1991	NBR 11578:1991	NBR 5735:1991
Data input	30 kg $CaSO_4$ 920 kg clinker 50kg ggbfs	30 kg $CaSO_4$ 670 kg clinker 300kg ggbfs	30 kg $CaSO_4$ 310 kg clinker 660kg ggbfs
Impact evaluation method		CML baseline 2001	
LCA platform		SimaPro 7.3	

Table 1: Technical properties, considerations and tools used in the cement LCAs.

Data for the production processes' modelling came from national and/or local reports. When national data were unavailable, the corresponding processes found in the SimaPro built-in Ecoinvent database were adapted to better represent the Brazilian context. To model ggbfs generation, data from one specific steelmaking company were collected from spreadsheets reported to a local environmental agency.

Impact distribution between steel and ggbfs was performed using ISO 14044 [1] predicted methods: (i) mass allocation; (ii) economic value allocation; and (iii) system expansion through the avoided burden approach. Next, authors propose a revised avoided burden approach, so-called the 'net avoided burden approach'.

2.3 Impact assessment

CML 2001 (baseline) method evaluates predefined impact categories covering impacts on natural resources, human health and ecosystem quality. The method allows for results' normalization, but in this paper authors chose to dismiss that feature in order to minimize possible assumptions and uncertainties associated with normalization.

3 RESULTS PRESENTATION AND DISCUSSION

3.1 ISO-recommended impact distribution methods

Data from the steelmaking company indicated that the pig iron production for a given year was 5.6 million tons, while 1.38 million tons of ggbfs were generated. Also, pig iron was sold at $487/ton at the time, while ggbfs was sold at $18,20/ton. These values defined the allocation percentages.

The use of mass allocation implied in an increase in acidification potential, photochemical oxidation and abiotic depletion when increasing the amount of ggbfs replacing clinker Portland. All other impact categories decreased with the reduction of clinker in cement composition. Economic allocation, however, led to the decrease of all impact categories, noting, however, that acidification potential, photochemical oxidation and abiotic depletion presented more discrete decreases. This indicates that these are more intensive categories in the steelmaking process that generates the blast furnace slag. Using the traditional avoided impact approach, all categories decreased in proportion to the amount of ggbfs added to cement. This is expected, since this distribution method focuses on better system modelling other than on partitioning impacts.

3.2 The proposed approach

Allocation simply transfers part of the multifunctional process' impact to the product system that incorporates the coproduct. It does not consider elementary recycling benefits, such as scarcity of the replaced raw material, and avoidance of end of life impacts by reinserting a coproduct into productive uses.

Contrastingly, the avoided burden approach succeeds to include a major recycling benefit – i.e. virgin raw material preservation – in products' life cycle modelling. Still, it fails to distribute it properly and is not adapted to the waste user [5]. On one hand, the avoided impact is discounted only from the multifunctional process that generated the coproduct. The waste user is kept out of the equation and not only does not receive any benefit, but also absorbs processing, transportation and further recycling related impacts, while enabling that material cycle closing. On the other hand, the proposed approach avoids this distortion by adding or deducing from the joint system all loads that are caused or avoided by raw material replacement (Fig. 1, Fig. 2 and Equation 1).

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In Figures 3, 4 and 5, the results, for 1 ton of each type of cement, using the proposed approach are normalized in relation to the avoided burden approach. Due to limited data available at the time of writing, our calculations have only included coproduct processing impacts.

Similar to the avoided burden approach, impacts in all categories decrease proportionally as ggbfs content increases. The processing loads would necessarily be calculated to model cement making, so that there is no added complexity, whereas the net prevented loads embed a more cohesive concept.

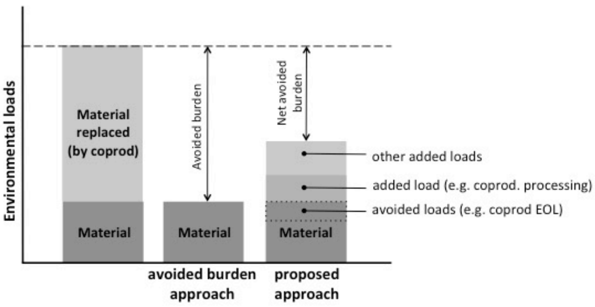

Fig. 1: Proposed vs. avoided burden approach.

$$I_{net} = I_{subst} - \left[I_{proc} + I_{other} - I_{EOL}\right] \qquad (1)$$

Where I_{net} is the 'net' avoided burden; I_{subst} is the impact avoided by replacing a giving product with a coproduct; $I_{proc.}$ is the coproduct processing impact, I_{EOL} is the coproduct's end-of-life impact, if not productively used; and I_{other} are all other loads that may arise from coproduct use, e.g. transportation loads if the coproduct is not locally available.

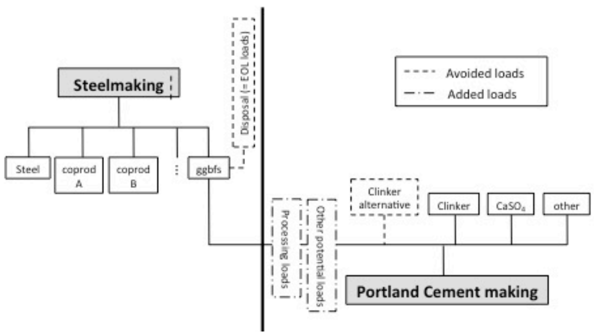

Fig. 2: Joint system according with the proposed approach.

By acknowledging that new loads arise and are neutralized over recycling implementation, this approach not only distributes environmental benefits among the partnering industries that enable recycling, but also provides a more complete and refined description of recycling implications and actual (net) avoided burden, that, among others, can better inform strategic decision making by the involved industries.

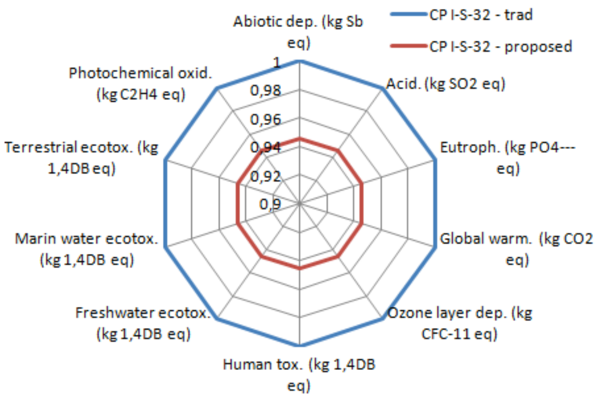

Fig. 3: Impacts of 1 ton of cement CP I-S-32, using avoided burden vs. proposed approach.

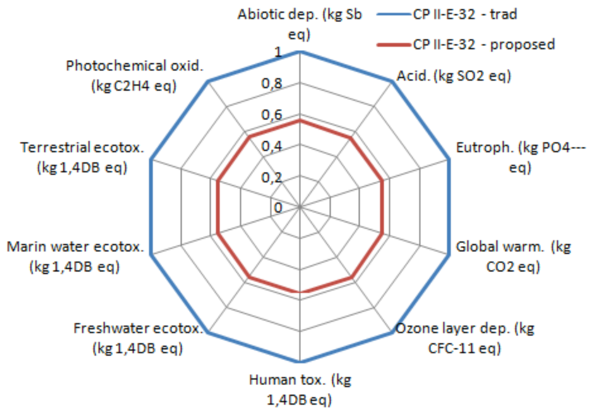

Fig. 4: Impacts of 1 ton of cement CP II-E-32 using avoided burden vs. proposed approach.

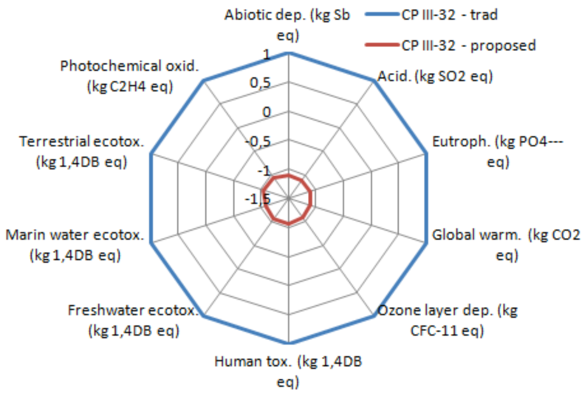

Fig. 5: Impacts of 1 ton of cement CP III-32, using avoided burden vs. proposed approach.

4 CONCLUSIONS

There is still a long way to go before scientific consensus regarding the choice of multifunctional modelling methods is reached. The traditional avoided burden approach manages to capture the virgin raw material preservation, while offering easiness to understand and use. The calculation revision proposed here envisions a more complete overview of the balance between

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avoided (e.g. landfilling) and generated (e.g. coproduct processing) burdens related to coproduct use. Insertion of different aspects in the net avoided burden calculation are currently under study, and are expected to provide a framework for further adjustment propositions.

5 ACKNOWLEDGMENTS

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