UFRGS - Federal University of Rio Grande do Sul – RS – Brazil*
Postgraduate Program in Civil Engineering: Construction and Infrastructure
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Sensitivity Analysis of Life Cycle Impacts Distribution Methods Choice Applied to Silica Fume Production

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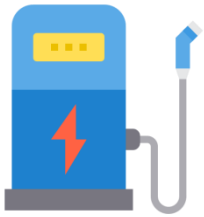
LIFE CYCLE INNOVATION FOR THE BUILT ENVIRONMENT

Introduction

The construction sector is recognized by producing numerous environmental impacts

Natural resources



Energy

Production of waste

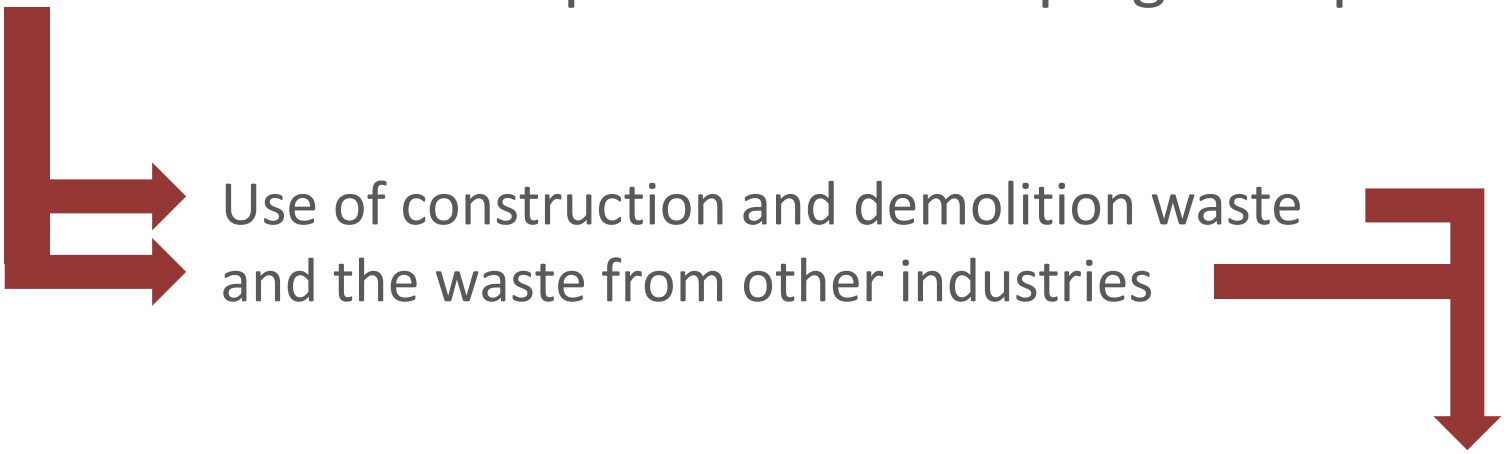
Unsustainable patterns of development and consumption:

- resource depletion
- inability to manage the amount of waste produced.

Images: www.flaticon.com/authors/freepik

Introduction

Efforts to mitigate this problem by improving materials, constructive techniques and developing new products.



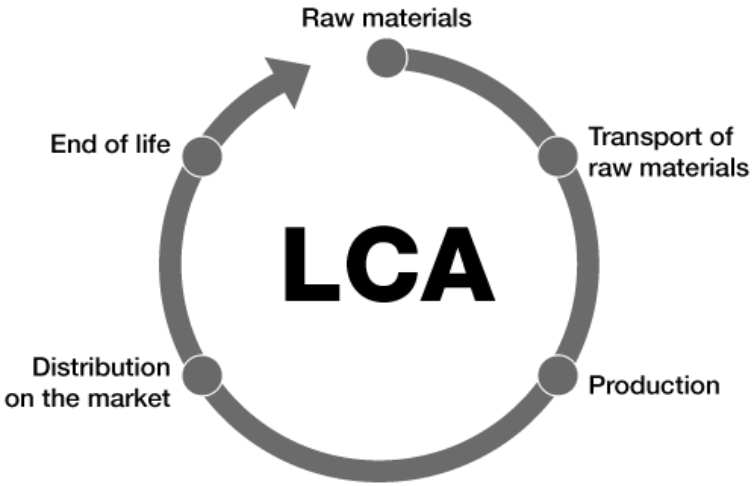
way of handling by-products that would be otherwise disposed of

Introduction

- There are environmental benefits related to the use of by-products in the construction industry.

- However, it is essential to quantify such benefits to provide clear information on the advantages or disadvantages related to their use.

Life Cycle Assessment (LCA)



Introduction

- The environmental evaluation of the by-products used in the construction sector has been much discussed recently.

Concrete production

- one of the most produced materials in the world
- great potential for incorporating by-products[1]

Pozzolanic materials
improve properties
(mechanical strength and durability).

Silica fume (SF):
a pozzolanic admixture that is effective in enhancing concrete mechanical properties[2].

[1] Habert G, D'Espinose De Lacaillerie JB, Roussel N. An environmental evaluation of geopolymer based concrete production: Reviewing current research trends. J Clean Prod 2011. doi:10.1016/j.jclepro.2011.03.012.
[2] Siddique R, Khan MI. Supplementary Cementing Materials. vol. 37. 2011. doi:10.1007/978-3-642-17866-5.
Image: https://www.aiche.org/chenected/2016/12/greener-concrete-possible-through-programmed-nanoparticles

Objective

Enhance the understanding of differences in silica fume life cycle impacts by analyzing three scenarios

- Multifunctional modelling procedures by ISO 14040;
- Three distribution models from Ecoinvent version 3.3;

Scenario 1 - System expansion model;
Scenario 2 - System model Cut-off with allocation by physical relationship (mass);
Scenario 3 - System model Cut-off with allocation by economic value;

Methodological approach

The objective of this LCA is to understand the impacts of choosing a **modelling procedure** to deal with **multifunctionality**, as described by ISO 14040, in the LCA of the by-product SF.

- Functional unit: 1 kg of Silica Fume, produced in Brazil;
- Scope: production system from cradle to gate;
- Impact assessment method CML v.4.4-2001[1];
- According to the CEN EN 15804 recommended categories;
- Support platform: OpenLCA 1.6.3.

[1] Acero AP, Rodriguez C, Ciroth A. LCIA methods: Impact assessment methods in life cycle assessment and their impact categories. Version 1.5.6. 2017.

Methodological approach

Silica Fume is produced during the **silicon metallurgical production** process, being collected in very large filters in the baghouse and then made available for **use in concrete without further treatment.**

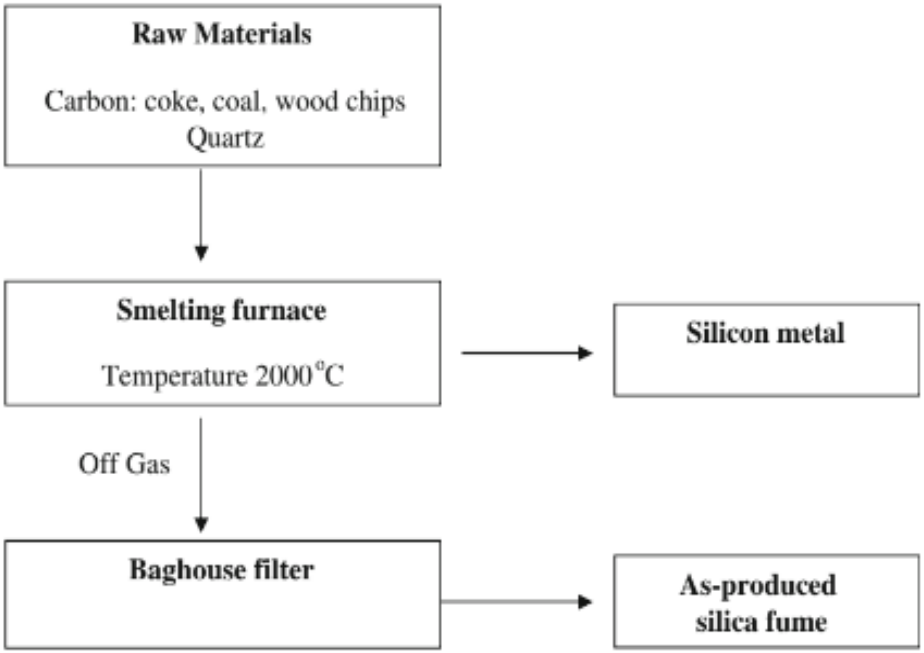


Figure 1. Schematic diagram of silica fume as produced [12].

Methodological approach

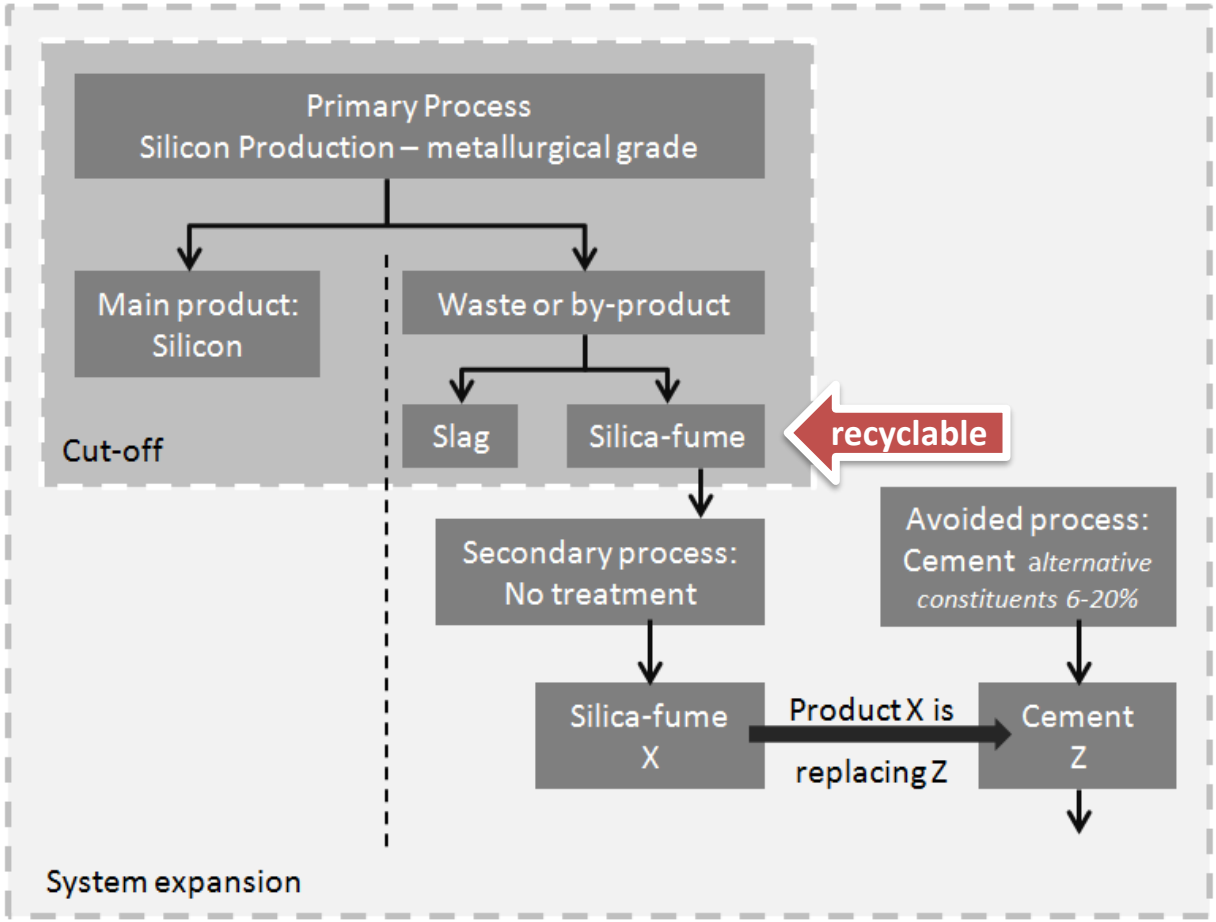


Figure 2. Silicon and silica fume production representation with the available multifunctional modeling procedures. No treatment needed to SF [1].

Methodological approach

Scenario 1 - ISO 14044:2006 - divide the elementary process into two or more subprocesses or make a system expansion.
Scenario 2 - is calculated according to Chen et al., (2010)[1] and considers the percentage production as published by Fidjestol (2008)[2].
Scenario 3 - the by-product represents more than 1% of the economic value of the product (SF accounts for 6.19% of the total economic value.

Table 1. Silica fume allocation percentages by mass and by economic value[1].

	Production (tons)	Market price (1 ton)	Allocation by mass	Allocation by economic value
Silicon	1.00 t	US$ 3145 [a,b]	-	-
Silica fume	0.45 t	US$ 354 [a,b]	31.0%	4.8%

[a] Morales et al. (2016).
[b] Considering that US$ 1.00= R$ 3.82 (price of the currency in march/2019).

[1] Chen C, Habert G, Bouzidi Y, Jullien A, Ventura A. LCA allocation procedure used as an incitative method for waste recycling: An application to mineral additions in concrete. Resour Conserv Recycl 2010. doi:10.1016/j.resconrec.2010.04.001.
[2] Fidjestol P, Dastol M. The History of Silica Fume in Concrete. Ibracon (Congresso Bras Do Concreto) 50CBC 2008.

Results and discussion

Table 2. LCA impacts of 1kg of SF considering three available multifunctional modeling procedures by ISO 14040. Values (in %) represent the comparison between SF and the avoided product impacts.

	Silica fume					Avoided product	
Impacts	Scenario 1 - System expansion	Scenario 2 - Allocation by mass	%	Scenario 3 - Allocation by economic value	%	Cement CEM II/A	%
GWP-100	-8.56E-01	9.38E+00	1095%	1.46E+00	170%	8.56E-01	100
AP	-1.78E-03	4.81E-02	2697%	7.46E-03	419%	1.78E-03	100
EP	-4.32E-04	1.46E-02	3384%	2.27E-03	525%	4.32E-04	100
POCP	-6.98E-05	3.30E-03	4724%	5.12E-04	733%	6.98E-05	100
ODP	-2.13E-08	4.31E-07	2023%	6.69E-08	314%	2.13E-08	100
ADPN	-3.00E-07	2.40E-06	800%	3.73E-07	124%	3.00E-07	100
ADPF	-3.13E+00	8.07E+01	2577%	1.25E+01	400%	3.13E+00	100

GWP-100 - Climate change (kg de CO2-Eq. 100ª)
AP – Acidification potential (kg SO2-Eq.)
EP - Eutrophication Potential (kg PO4-Eq.)
POCP – Photochemical oxidation (kg etileno-Eq.)
ODP – Ozone layer depletion (kg CFC-11-Eq.)
ADPF - Depletion of abiotic resources – fossil (MJ-Eq.)
ADPN - Depletion of abiotic resources – non fossil (kg antimônio-Eq.)

Results and discussion

Scenario 1
system expansion

- 1 kg of Silica Fume (reported as Material for Treatment – not connected) replacement of 1 kg cement CMII/A in concrete production;
- negative results related to the avoided burden.

When we replace the main product with the by-product, we assume **"infinite" availability of the by-product**, which does not always occur because it could belong to a **restricted production market**.

Results and discussion

Silica Fume
1.5 million tons
worldwide generation

today some of these materials are still not captured[1]

optimistic scenario

capture of 70%
would be
1.05 million tons[1]

low availability

=

0.13% of the world's cement production
818 million tons in 2016[2]

large size of the cement market

The market for Silica Fume production is restricted, and that it is therefore not appropriate to consider high cement replacement rates for this material.

[1] Fidjestol P, Dastol M. The History of Silica Fume in Concrete. Ibracon (Congresso Bras Do Concreto) 50CBC 2008.
[2] World Business Council for Sustainable Development. The Cement Sustainability Initiative (CSI) - Publication of the Getting the Numbers Right 2016.

Results and discussion

Scenario 2
allocation by mass value

- the amount of by-product generated increases the percentage of impacts related to Silica Fume
- large impacts on by-products that are used in the cement industry - influencing the interest

Scenario 3
allocation by economic value

- the low sales value of Silica Fume in the generation point results in lower shareholdings

The choice of system boundaries must closely related to the objective, including the activities relevant to the purpose of the study[1].

[1] Tillman AM, Ekvall T, Baumann H, Rydberg T. Choice of system boundaries in life cycle assessment. J Clean Prod 1993;2:21–9.

Final remarks

- The selection and understanding of the proper distribution model is key, due to their great influence on the results obtained;

- The evaluation of modeling choices and allocation systems is decisive, since they may influence the decision-making process;

- When the by-product allocation is not considered, an increase in fluxes in the main product is observed;

Final remarks

- In the system expansion, the avoided burden of by-product replacing a virgin raw material with a by-product contains the assumption that the by-product is available for the entire world market. This inference may not be real;

- The importance of the modelling choice and its understanding must be highlighted, especially in product systems that deal with multifunctionality, to promote results that properly represent the evaluated products.

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Thank you!

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