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Assessment of regional Building Material Producers combining Material-Flow-Analysis and Life-Cycle-Assessment

Ronny Meglin M.Sc.[1,2]; Prof. Dr. Guillaume Habert [1]; Prof. Dr. Susanne Kytzia [2]

[1] ETH Zurich, Dept. of Civil, Environmental and Geomatic Engineering, Zurich, Switzerland

[2] University of applied sciences Rapperswil, Institute for Civil and Environmental Engineering, Rapperswil, Switzerland

Introduction

In the building material industry, sustainability concerns are dominated by the role of raw materials, especially in the production of cement (e.g. fuels) and concrete (e.g. recycled aggregates). As raw materials become increasingly scarce globally, this is an accelerating challenge faced by both individual companies and countries. Driven by this challenge, public pressure and stricter regulations, companies started to extend their business models with additional services in waste management and logistics to start a transition towards a sustainable construction industry.

To quantify the impacts of alternative processes or materials to the ecology of building materials, Material-Flow-Analysis (MFA) and Life-Cycle-Assessment (LCA) are widely used tools (Bovea & Powell, 2016; Dossche, Boel, & De Corte, 2017; Moriguchi & Hashimoto, 2015). However, to validate a sustainable performance of a single sector, these tools are not individually suitable, due to different system boundaries, benchmarks and calculating techniques (Joshi, 1999; Nakamura, Nakajima, Kondo, & Nagasaka, 2007). Therefore, an integrated assessment model must be developed (Moriguchi & Hashimoto, 2015).

Integrated assessment methods for the sustainable built environment combine indicators for environmental impacts of building materials with indicators for regional economic benefits (Kytzia, 2009).We develop a methodology that allows us to evaluate a region or company in terms of economics and ecology. For this purpose, we combine Material-Flow-Analysis, Input-Output-Analyses (IOA) and Life-Cycle-Assessment to overcome the disadvantages of the individual tools as described above.

Methods

We propose an integrated assessment method for a sustainable built environment. The method considers indicators for environmental impacts of building materials with indicators for regional economic benefits by combining MFA and LCA with an IOA as connecting element (see Figure 1).

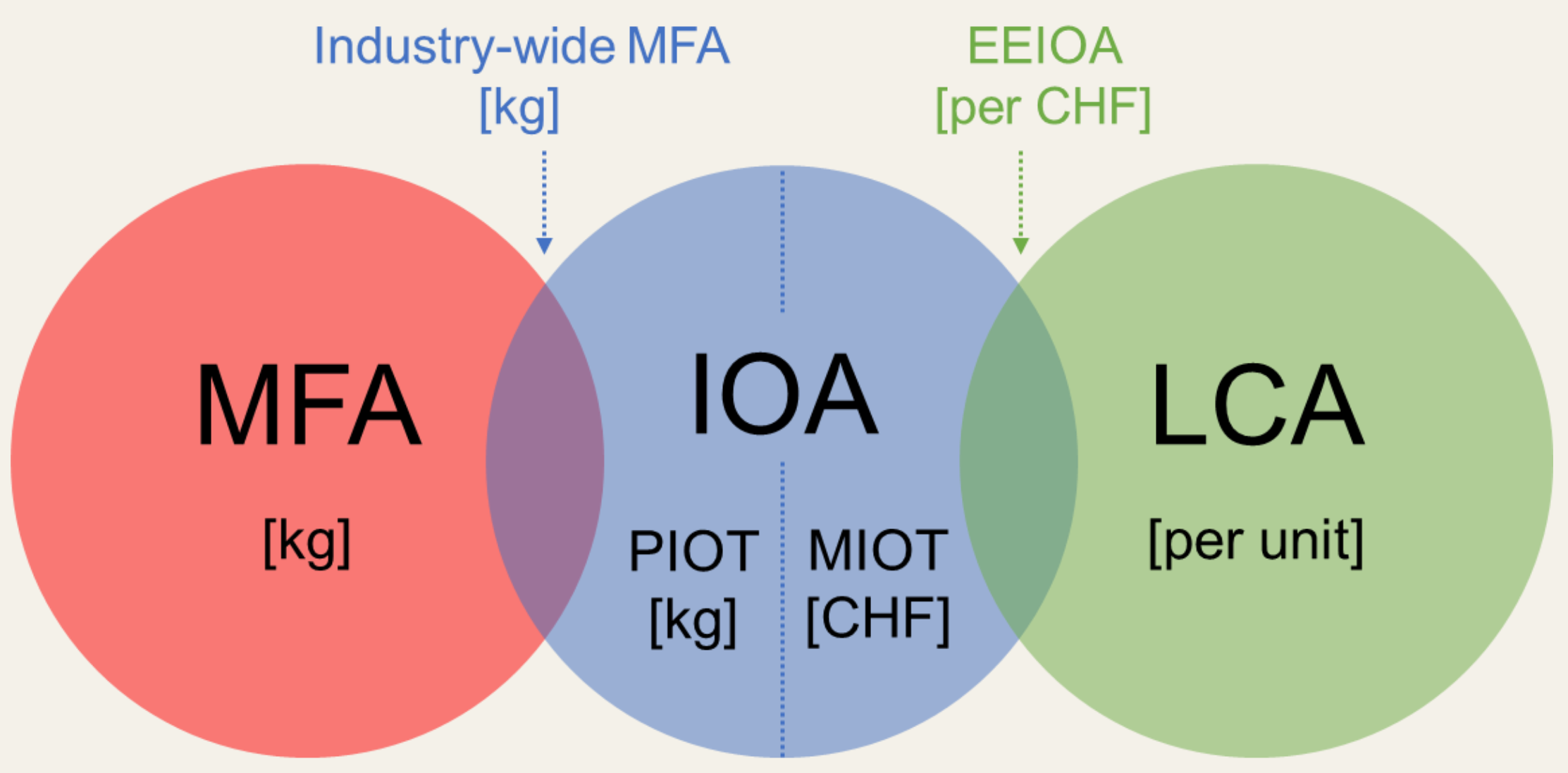

Figure 1: Relationship of used methods following (Teh et al., 2018)

Material-Flow-Analyses are produced for the region or company under investigation. The data of these MFAs are collected from existing databases or in interviews. The Material-Flow-Analyses is translated into a Physical-Input-Output table (PIOT), which represents the processes and interindustrial dependencies of the region under investigation in mass units.

Economic and environmental assessment

The **economic assessment** of the region or company is based on turnover and value-added. The value added represents factor income generated by labour and capital on regional scale. On a company scale, this factor income is analysed for each process in the production chain by subtracting material costs from material turnover. Any upstream chains and the resulting costs outside the system boundary are not considered. Costs and Turnover are both estimated by multiplying material flows with material prices to obtain a monetary Input-Output table (MIOT).

$$\mathrm{X_{mon}} = (\mathrm{I} - \mathrm{A_{mon}})^{-1} \times \mathrm{Y_{mon}} \qquad (1)$$

$\mathrm{X_{mon}}$	vector of output of each process in monetary units
$\mathrm{Y_{mon}}$	vector of final demand of each process in monetary units
I	identity matrix
$\mathrm{A_{mon}}$	matrix of input-output coefficients.

The factor income can then be obtained as follows:

$$\mathrm{FI} = \mathrm{X_{mon}} \times \mathrm{VA} = (\mathrm{I} - \mathrm{A_{mon}})^{-1} \times \mathrm{Y_{mon}} \times \mathrm{VA} \qquad (2)$$

FI	vector of factor income in monetary units
VA	vector of value added coefficients in monetary units.

To assess the **environmental impacts**, the material flows are linked with the corresponding emissions by extending the MIOT with emission coefficients. The emission coefficients correspond to the emissions of the individual processes, which are obtained from data from LCA inventories (e.g. ecoinvent).

$$\mathrm{u} = \mathrm{X_{mon}} \times \mathrm{e} = (\mathrm{I} - \mathrm{A_{mon}})^{-1} \times \mathrm{Y_{mon}} \times \mathrm{e} \qquad (3)$$

u	vector of emissions caused by each process in mass units of the emission used for environmental assessment
e	vector of emission coefficients defined as the amount of emissions (in mass units of the chosen emission) related to the input into each process in monetary units.

Case Study

A current study in cooperation with a Swiss cement producer is used as case study, where we investigate alternative uses of concrete fines from construction and demolition waste (C&DW) and evaluate their benefits from an environmental and an economic perspective.

Possibilities to use construction and demolition waste in the value chain of the cement and concrete production can be seen in Figure 2. In this study, we use the ground concrete fine as a substitute for raw material for the clinker production as input for the assessment model.

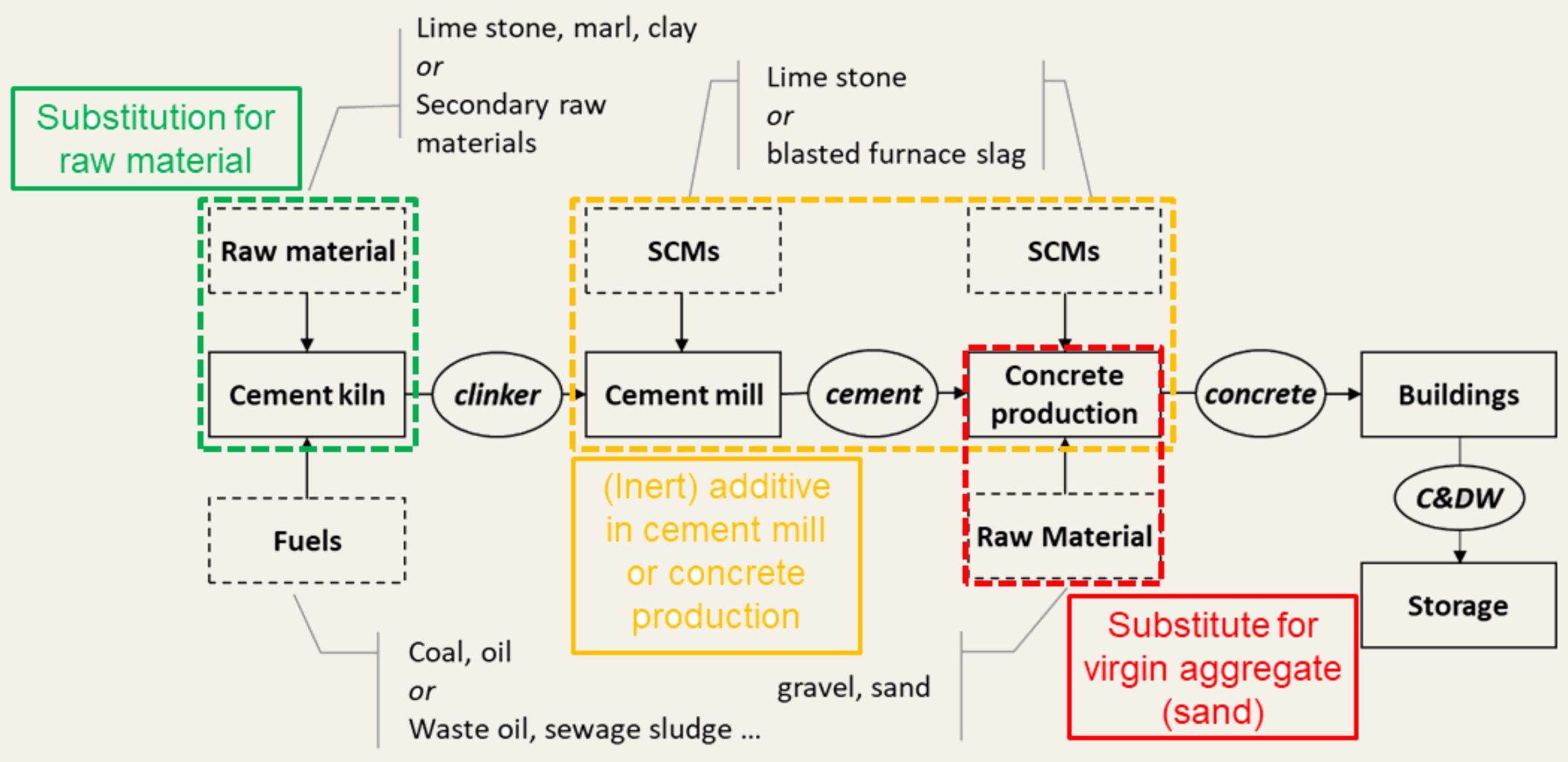

Figure 2: possible applications of C&DW in the value chain of the building materials industry

Data

We use existing data of the canton Aargau (Rubli, 2018) to assess the **regional** impacts of a cement producer (Table 1).

Table 1: characteristic values of the canton Aargau

Canton Aargau	**2016**	
Residents	662 224	
	Volume	Mass
Production of building materials (aggregates, concrete, asphalt)	2 541 000 m³	5 331 198 to
Production of concrete	1 090 000 m³	2 609 000 to
Generated construction and demolition waste C&DW	437 000 m³ in total concrete waste 100 000 m³	905 240 to in total concrete waste 250 000 to
Returned C&DW in material production	265 000 m³	557 000 to
Directly at construction sites (down)-cycled material	124 000 m³	250 000 to
C&DW into landfill	24 000 m³	50 000 to
Depleted raw materials for cement production	940 000 m³	2 256 000 to

In 2016, around 4.55 million tons of cement were sold in Switzerland, of which 4.39 million tons were produced and the rest were imported. In Switzerland, there are six cement plants owned by three producers. If we assume that the production capacities of all plants are evenly distributed, the following key figures result for the production, which we use for our assessment on **company** level (Table 2)

Table 2: characteristic values of one cement plant

One average cement plant	**2016**	
Cement sold	730 000 to	
Average clinker content	73.6 %	According swiss cement association
Clinker production	539 000 to	
Used primary raw materials	845 000 to	Lime and marl
Used alternative raw materials	70 000 to	
Used SCM in the cement mill	166 000 to	

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Scenarios

In order to investigate the influences of the changing material flows on a regional and company level, different scenarios are selected as follows

- Status Quo: Business as usual
- Scenario 1: 100 % of the available concrete fine (0/4 mm, 35 % of total concrete C&DW) is ground and used as substitute of raw material in the cement kiln
- Scenario 2: 100 % of the available concrete C&DW is ground and used as substitute of raw material in the cement kiln

Results

Table 3 shows the changes in turnover, value-added (turnover minus material costs) and global warming potential in relation to the status quo (base 100%). For better clarity, only the processes to produce cement and concrete are shown. Processes in which the two scenarios do not lead to any change (e.g. construction or demolition) are not examined in more detail.

Table 1: Results of the assessment

	Regional level Canton Aargau		**Company level one average cement plant**	
	Turnover			
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**
Gravel Pits	102.75%	107.86%		
Gravel Plant	101.98%	105.68%		
Recycling Plant	103.02%	108.59%		
Quarries	96.46%	89.82%	89.59%	70.41%
Cement Plant	100.00%	100.00%	100.00%	100.00%
Concrete Plant	100.00%	100.00%		
Sum	100.57%	101.62%	98.96%	97.04%
	Value Added			
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**
Gravel Pits	102.75%	107.86%		
Gravel Plant	103.96%	111.31%		
Recycling Plant	103.02%	108.59%		
Quarries	96.46%	89.82%	89.59%	70.41%
Cement Plant	100.51%	101.32%	102.75%	107.82%
Concrete Plant	97.52%	94.53%		
Sum	100.68%	102.03%	100.00%	100.00%
	GWP 100a IPCC 2013 per Turnover			
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**
Gravel Pits	99.29%	98.08%		
Gravel Plant	100.00%	100.00%		
Recycling Plant	97.1%	92.1%		
Quarries	100.15%	100.47%	100.00%	100.00%
Cement Plant	90.10%	90.10%	90.10%	90.10%
Concrete Plant	100.00%	100.00%		
Sum	92.68%	92.29%	90.11%	90.11%
	GWP 100a IPCC 2013			
	Scenario 1	**Scenario 2**	**Scenario 1**	**Scenario 2**
Sum	93.21%	93.79%	89.17%	87.45%

Discussion & Conclusion

The model presented here could successfully show that an economic and environmental evaluation of a region or a company is practicable with an integrated assessment model based on MFA, LCA and cost analysis. The case study has demonstrated that recycling concrete construction & demolition waste has an impact on the economic performance of a company and a region. We could show that the use of concrete waste in the cement industry not only preserves natural resources, but also reduces CO2-emissions and thus contributes to the mitigation of climate change. In addition, the results provide indications as to where optimisations have the greatest influence in the cement industry's production chain regarding the use of demolition material. The economic evaluation also provides initial indications, that in order to benefit economically from the use of demolition material, cement producers should either expand their business model or enter partnerships with companies.

The results show that it is of crucial relevance to understand the environmental and economic impacts of companies and regions in the context of climate change mitigation and a desired transition towards a sustainable economy. By combining suitable assessment methods, it is possible to indicate the impacts of changing material flows or innovations on the life cycle most relevant for generating value added, causing emissions and consuming natural resources. On a regional level, the results highlight the impact of a specific business-model and show how this effects environmental and economic performance of a regional building materials industry. This provides an improved basis for decision-making for companies in the construction industry to further develop their circular business models and contributes to achieving SDG 12 "Responsible consumption and production" as well as SDG 9 "Industry, innovation and infrastructure".

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Contact Information

Ronny Meglin M.Sc.

University of Applied Sciences
Eastern Switzerland
Institute for Civil and Environmental
Engineering
Oberseestrasse 10
CH-8640 Rapperswil

Tel: +41 55 222 42 57
Email: ronny.meglin@ost.ch
Web: www.ost.ch
LinkedIn

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