Closing data gaps in LCI based on environmental IOA: a case study for German building products

Bodo Müller[1,*], **Liselotte Schebek**[1, 2]

[1]KIT, Institute for Technology Assessment and Systems Analysis, Department of Technology-Induced Material Flow, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany.

[2]TU Darmstadt, Institute IWAR, Chair of Industrial Material Cycles, Petersenstrasse 13, 64287 Darmstadt, Germany

[*]bodomueller@web.de

Abstract In the case of building-LCA, available data sets do not cover sufficiently the required spectrum of building products manufactured in Germany. Closing data gaps the application of environmental IOA in software tools is refused as the underlying data does not represent adequately German conditions. So we developed a German input-output-based approach to derive IO-LCI-datasets for German building products. It is based on the German National Accounting Matrix [1] on the German Environmental Accounts [2] which provides sector specific direct emissions on seven airborne substances. The emissions were characterized using characterization factors and opposed to the specifications of German database Ökobau.dat [5]. As the data for CO_2 and CH_4-emissions showed minor uncertainties in validation it is recommended to use the generated IO-LCI-datasets especially for calculating carbon footprints of buildings.

1 Introduction

In recent years, buildings are increasingly supposed to comply with ecological criteria set by labels or standards from diverse organizations to foster sustainable development. In Germany, the Code of practice for sustainable building [3] is applied for buildings commissioned from state or other public authorities. As ecological assessment is based on a life cycle approach (chapter 4 in [3]), demand for Life Cycle Assessment of buildings comprehending all relevant materials and components has increased as well.

For reliable results of a building-LCA, the underlying database has to be as comprehensive as possible. In a research project commissioned by the German

Federal Ministry of Transport, Building and Urban Development a list of altogether 423 products and processes has been identified as relevant for building-LCA [4]. In a first effort to establish a publicly open database (“Start-Datenbank”) realized in database Ökobau.dat [5] it was found, that out of the 423 products and processed no data were available for 178 building products. Moreover, it is expected that these data will not become available in the near future due to cost intensive data collection and / or reluctance of industry to provide data. In the absence of “bottom-up” generated process based Life Cycle Inventory (LCI); the so called input-output-based life cycle inventory (IO-based LCI) is an adequate approach to provide data sets in building-LCA [6, 7]. It is based on environmental input-output-analysis using economic input-output models bearing on statistical data. An additional advantage is that data can be generated fast and at low costs. IO-based LCI seems to be a promising possibility to fill data gaps also in the case of the German building sector. Methods and results of this approach are described in the following sections.

2 Prerequisites for application of input-output-based LCI for the German building sector

In the last years software tools were developed in which the method of IO-based LCI is integrated like EIO-LCA-model [9] or Missing Inventory Tool (MIET) that is part of the LCA-software SimaPro [10]. Both tools were evaluated as to the suitability of their statistical data base for use for the German building sector. Building materials are often regionally produced so especially for the building sector statistical data with other geographical system boundaries should not be used.

MIET includes no statistical data from Germany at all but is based on other national statistical data with structures of economy e.g. the US different to Germany. The EIO-LCA-model includes rather old German statistical data from the year 1995 for 58 sectors representing the situation of the economy shortly after the German reunification that was affected by closing of companies and a dramatically reduction of airborne emissions. Moreover, the best available technology developed considerably since 1995. Moreover, using EIO-LCA for generating IO-LCI-datasets valid for Germany is not reasonable due to a lower number of sectors (presently in German statistics the economy is subdivided in 71 sectors).

Using system processes, i.e. all emissions of upstream chains are already cumulated in a process-based LCI dataset, and IO-LCI-datasets together in building-LCA, IO-LCI-datasets should be adjusted to the system boundaries of process-based LCI. So there should be a feasibility to modify the statistical datasets (e.g. exclude emissions from intermediate inputs of certain sectors that are generally not considered in LCI like services) that is not possible in the existing tools. In addition this modification allows validating the generated IO-LCI-datasets by comparison with existing system processes. Summing up reasons, neither EIO-LCA nor MIET seemed suitable to generate IO-LCI-datasets for German building products. Therefore we developed an IO-based approach adapted to current statistical information from Germany and allowing the calculation of up-to-date cumulated emissions for German building products.

3 Method of Calculation of IO-LCI-datasets

Generating IO-LCI-datasets for German building products needs to take several steps. First the building products have to be allocated to the corresponding registration numbers ("Meldenummern") in German census of production [11]. With the registration numbers it is possible to determine, in which sector a product is manufactured. In census of production the revenues and produced amount of products (pieces, mass, etc.) within certain sectors are given over the period of a year. In a next step sales prices averaged over a year are calculated by dividing revenues by produced amounts for selected products.

To calculate the cumulated emissions of a product, the sales price of a product from sector *k* is entered as coefficient y^k in equation (1) taken from [12]. In this equation certain sectors (e.g. service sectors) and their environmental contributions are excluded from the calculation in IO-based LCI in order to comply with the system boundaries of LCI:

$$\mathbf{z}_x^k = \mathbf{B}_x \cdot ((\mathbf{I} - \mathbf{A})^{-1} .* \mathbf{R}) \cdot \begin{pmatrix} 0 \\ \vdots \\ y^k \\ \vdots \\ 0 \end{pmatrix} \tag{1}$$

$\mathbf{z}_x^k$: Cumulated emission of airborne substance *x* (for *x*: CO_2, CH_4, etc.) for a product from sector *k* without consideration of emissions from sectors to be eliminated

A: Direct requirements coefficients matrix

$\mathbf{B}_x$: Environmental intervention matrix [emissions of airborne substance *x* in mass / € output]

I: Identity matrix

R: Matrix that consists only of 1s except in rows and columns corresponding to the commodities and industry sectors to eliminate, which are set to 0

y^k: coefficient of final demand vector **y**

.*: Element by element multiplication

The matrixes **B** and **A** are published in [1, 2], the list of sectors to be excluded leading to **R** is taken from [12] and converted to German Classification system. All statistical data refer to the same base year 2003.

For each building product the calculated $\mathbf{z}_x^k$ values for the seven airborne emissions are compiled to an IO-LCI-dataset. Tab. 1 shows some examples of the generated list of IO-LCI-datasets. #

Tab.1: Examples of generated IO-LCI-datasets

building product	**unit**	**emissions**						
		CO_2	CH_4	N_2O	NH_3	SO_2	NO_x	NMVOC
		[g]	[g]	[g]	[g]	[g]	[g]	[g]
tile adhesive	kg	55	0,06	-	-	0,03	0,03	0,02
bituminous concrete	kg	15	0,02	-	-	0,01	0,01	0,01
foam of melamine resin	kg	650	2,59	0,27	0,20	1,30	1,04	5,46
foam of natural rubber	kg	399	1,59	0,17	0,12	0,80	0,64	3,35
jointing band silicone	kg	768	3,06	0,32	0,23	1,54	1,22	768
jointing band polyurethane	kg	576	2,29	0,24	0,18	1,15	0,92	576

4 Validation

For validation of the emission values in IO-LCI-datasets generated according to equation (1), a comparison with the corresponding system processes of 106 building materials from the ecoinvent-database was performed [13]. Validation is carried out by calculating the relative deviations of values for airborne substances of IO-LCI-datasets from those of system processes taken as a reference. The corresponding quotients q_x were calculated for each building product and particular airborne substances *x* according to equation (2):

$$q_x = \frac{z_x^k}{p_x} \tag{2}$$

p_x : emissions of airborne substance *x* from system process

For more substantial information and the detailed discussion and interpretation of results it is referred to [13]. In summary a huge spread of relative deviations was observed where the spread was rather low for CO_2- and CH_4-emissions. The emissions of NH_3, SO_2 and NO_x were mostly underestimated; N_2O-emissions were overestimated in the majority of cases [13].

5 Characterization

Characterization factors are needed to weight the environmental effects of certain emissions in life cycle impact assessment (LCIA). The seven airborne emissions in the IO-LCI-datasets have been be characterized according to the structure of datasets in Ökobau.dat [5]. These characterization factors are taken from [14] and multiplied with the emissions given in Tab.1 resulting in characterized IO-LCI-datasets (Tab.2.).

Tab.2: Examples of characterized IO-LCI-datasets

building product	unit	category indicators			
		global warming potential	acidification potential	eutrophication potential	photochemical ozone creation potential
		[g CO_2 eq.]	[g SO_2 eq.]	[g PO_4^{3-} eq.]	[g C_2H_4 eq.]
tile adhesive	kg	57	0,04	-	0,03
bituminous concrete	kg	16	0,01	-	0,01
foam of melamine resin	kg	791	2,40	0,20	5,54
foam of natural rubber	kg	485	1,47	0,13	3,4
jointing band silicone	kg	6,45	933	2,83	0,24
jointing band polyurethane	kg	4,83	700	2,12	0,18

6 Results

From the 178 building products where data is missing, IO-LCI-datasets could be generated for 139 building products (78 % of the identified data gaps from [4]). As to the still missing building products IO-LCI-datasets could not be generated due to data gaps in census of production or it was not possible to classify a product clearly to a corresponding registration number.
Using the data of seven airborne emissions in the IO-LCI-datasets four out of six output-indicators given in Ökobau.dat could be calculated (s. Tab.3). Abiotic depletion potential and ozone depletion potential could not be calculated as well as data for inputs (primary energy, derived fuels, use of water) due to limited information in German environmental accounting.

Tab.3: Comparison of inputs and outputs of datasets in Ökobau.dat and of generated IO-LCI-datasets

	Ökobau.dat	**IO-LCI-datasets**
inputs		
primary energy of non renewable resources	x	-
primary energy of renewable resources	x	-
derived fuels	x	-
use of water	x	-
outputs		
sedimentation/deposition	x	-
municipal waste	x	-
hazardous and nuclear waste	x	-
category indicators		
abiotic depletion potential	x	-
ozone depletion potential	x	-
acidification potential	x	x
eutrophication potential	x	x
photochemical ozone creation potential	x	x
global warming potential	x	x

7 Conclusions

Generation of IO-LCI-datasets has been successfully applied to close data gaps in building-LCA as to most products contained in the German list of relevant building products. However it should be noted, that IO-LCI datasets of course cannot to be used for comparing single products but represent generic information to be used for an estimate of an average product and for background processes. Validation of IO-LCI data sets against system processes taken from ecoinvent database showed that rather large deviations may occur as to specific airborne substances due to uncertainties in the primary statistical data. Therefore it is strongly recommended to carry out a sensitivity check if the calculated emissions in IO-LCI-datasets are relevant for the result of an LCA. For LCIA the environmental data from German Environmental Accountings is not sufficient to calculate values for all category indicators. More elementary flows should be integrated in Environmental Accounting leading to a more complete assessment of environmental impacts of buildings. A further data source could be German PRTR (Pollutant Release and Transfer Register) containing data of industrial emissions in air, water and soil for altogether 91 substances [16]. As most reliable data for specific compounds in IO-LCI the major climate-relevant gases CO_2 and CH_4 have been identified. Consequently, the category indicator global warming potential is best represented by corresponding airborne emissions in IO-LCI-datasets and the German IO-based approach may be predominantly suited for modeling carbon footprints of buildings.

8 Outlook

Using IO-based LCI is a low-budget, fast and feasible possibility to create data sets to be implemented in building-LCA (respectively carbon footprint of buildings). Reliability of data compared to process-based LCI varies dependant from the species of airborne emission, being the best for CO_2 and CH_4. Even if uncertainty of data may be rather high in some cases, in general the use of IO-LCI is proposed in order to avoid data gaps leading to underestimated figures for environmental effects of buildings.

Equation (1) is principally valid for all products respectively sectors. It should not be used for calculating cumulated emissions of goods exclusively manufactured abroad. Thus the developed method of IO-based LCI for Germany is not constricted to the building sector and can also be used for other purposes e.g. carrying out a screening LCA.

9 References

[1] Statistisches Bundesamt (Ed.): *Volkswirtschaftliche Gesamtrechnungen - Input-Output Rechnung 2003*. Fachserie 18 / Reihe 2. Wiesbaden: Statistisches Bundesamt, 2007

[2] Statistisches Bundesamt (Ed.): *Umweltnutzung und Wirtschaft – Tabellen zu den Umweltökonomischen Gesamtrechnungen 2007*, Wiesbaden: Statistisches Bundesamt, 2007

[3] Bundesministerium für Verkehr, Bau und Stadtentwicklung (Hrsg.): Leitfaden Nachhaltiges Bauen. Online-Information. URL: http://www.nachhaltigesbauen.de/leitfaeden-und-arbeitshilfen/leitfaden-nachhaltiges-bauen/oekologische-bewertung.html (accessed 8 february 2011)

[4] Kreissig, J., Binder, M.: Aktualisieren, Fortschreiben und Harmonisieren von Basisdaten für das Nachhaltige Bauen. Leinfelden-Echterdingen: PE International, 2007

[5] Bundesministerium für Verkehr, Bau und Stadtentwicklung (Hrsg.): Ökobau.dat. Online-Information. URL: http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html (Accessed 8 february 2011)

[6] Hendrickson, C.T., Lave, L.B., Matthews, H.S.: *Environmental Life Cycle Assessment of Goods and Services*, Washington, DC: Resources for the Future, 2006

[7] Suh, S., Huppes, G.: Methods for Life Cycle Inventory of a product. In: *Journal of Cleaner Production* 13 (2005) no. 7, pp. 687-697

[8] Strogies, M., Gniffke, P: *Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2010 - National Inventory Report for the German Greenhouse Gas Inventory 1990 - 2008*. URL: http://www.umweltbundesamt.de/uba-info-medien/mysql_medien.php?anfrage=Kennummer&Suchwort=3958 (Accessed 8 february 2011)

[9] Carnegie Mellon: Available EIO-LCA Models. Online-Information. URL: http://www.eiolca.net/Models/index.html (accessed 8 february 2011)

[10] Weidema, B.P., Nielsen, A.M., Christiansen, K., Norris, G., Notten, P., Suh, S., Madsen, J.: Prioritisation within the Integrated Product Policy, Danish Ministry of the Environment, Environmental Protection Agency, 2005

[11] Statistisches Bundesamt (Ed.): *Produzierendes Gewerbe – Produktion im Produzierenden Gewerbe 2004*. Fachserie 4 / Reihe 3.1, Wiesbaden: Statistisches Bundesamt, 2005

[12] Rebitzer, G.: *Enhancing the application efficiency of life cycle assessment for industrial use*. Dissertation. Ecole polytechnique fédérale de Lausanne. Lausanne, 2005

[13] Müller, B: Weiterentwicklung und Validierung der Methode der Input-Output basierten Sachbilanz für deutsche Gebäudeökobilanzen. Dissertation. Technische Universität Darmstadt. Darmstadt, submitted 2011

[14] Guinée, J. B. (Hrsg.), Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Sleeswijk, A. W., Suh, S., de Haas, H. A. U., de Buijn, H., van Diun, R., Huijbregts, M. A.J.: Life cycle assessment – An operational guide to the ISO standards – Part 2b Operational annex. Final report, Leiden University. Leiden, 2001

[15] Umweltbundesamt 2011: Schadstofffreisetzungs- und –verbringungsregister http://www.prtr.bund.de/frames/index.php?PHPSESSID=93e7afebd3562bb4b7a7cc37b1bed4ed&gui_id=PRTR (accessed 8 february 2011)