Material Flow Analysis (MFA)
Witold-Roger Poganietz
Outline

1. From LCA to MFA
2. MFA
3. Process-based MFA
4. MFA & LCA
5. Discussion
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From LCA to MFA

Agriculture

Food processing

Fermenter

Power plant

Refinery

Demand food

Demand power & heat

Demand fuels

Emissions

LCA

MFA
From LCA to MFA

Beware:
- Generally LCA comprises **all** materials of a product system
- Generally MFA focuses only on **one** material
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MFA

• Material flow analysis: aim is to provide a comprehensive assessment of the flows of one material within a chosen system and between the system and its environment

• Methodological foundation: law of the conservation of matter

• Conceptual steps:
  • Systems definition
  • Analysis of processes
  • Modeling
  • Interpretation of results
Example: Global lithium flows

- Chemical element:
  - silvery-white light metal
  - density about half that of water
  - most negative redox potential of all elements

- Applications:
  - chemical and pharmaceutical products
  - glass, ceramics, aluminum, and lubricant production processes
  - lithium-based rechargeable batteries
  - E-Mobility!
Systems definition and analysis of processes

Brines
  Spodumene
  Lepidolithe
  Petalite

Production
  Li-carbonate
  Li-min.conc.
  Li-hydroxide
  Butyl-Li
  Li-Metal
  Li-chloride
  Other Li-deriv.
Systems definition and analysis of processes

Extraction / Production

Pegmantit ore Processed to

- lithium hydroxide
- butyl lithium
- lithium metal
- lithium chloride and
- other lithium derivatives
Systems definition and analysis of processes

- Brines
- Spodumene
- Lepidolithe
- Petalite

Production:
- Li-carbonate
- Li-min.conc.
- Li-hydroxide
- Butyl-Li
- Li-Metal
- Li-chloride
- Other Li-deriv.

Manufacture:
- Batteries
- Glass & Ceramics
- Air Conditioning
- Aluminium Production
- Chemicals
- Unknown
- Alloys & Other Uses
- Lubricants
- Pharmaceuticals

Use:
- Recycling & Waste Management

Lithium-Recycling:
- Lithium-Recycling

Environment:
- Other Uses

Ores:


lithium flows in metric tons of lithium content per year

very little

dissipative applications

assumptions
Modeling and interpretation of results


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CarboMoG ~ Carbon Flow Model of Germany is a dynamic process-based carbon-carrier energy and material flow model

- currently about 361 (mainly) carbon-related processes are modeled
- comparative-static but also dynamic scenarios can be calculated
- since primary and secondary material flows are included analysis of interdependent life cycle process chains is possible („cradle to grave“)

- Reference year: 2005
- Reference region: Germany
Concept (I)

- Methodological foundation: linear input-output functions (comparable to Life Cycle Inventory (LCI) or IOT)
- Differentiation between
  - extraction,
  - cultivation,
  - production,
  - waste treatment,
  - service and
  - consumption processes

Extraction process crude oil
## Distribution of the processes along sectors

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture and forestry</td>
<td>60</td>
<td>o/w 10 forestry processes; 4 auxiliary processes (power proc.)</td>
</tr>
<tr>
<td>Mining</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>142</td>
<td>o/w 5 food industry processes, 14 wood and paper industry proc., 49 chemical industry processes; 12 auxiliary processes (proc. heat)</td>
</tr>
<tr>
<td>Electricity and heat</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Private consumption</td>
<td>97</td>
<td>Includes individual transport and private generation of heat</td>
</tr>
<tr>
<td>Traffic and transport</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Waste treatment</td>
<td>21</td>
<td>Mainly treatment of biogenic by-products, waste and residuals</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>361</strong></td>
<td></td>
</tr>
</tbody>
</table>
Concept (II)

Connecting of individual processes via market relations
## Resources, intermediate and final products

<table>
<thead>
<tr>
<th>Resources, intermediate and final products</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural products</td>
<td>25</td>
</tr>
<tr>
<td>Livestock</td>
<td>19</td>
</tr>
<tr>
<td>Forest</td>
<td>10</td>
</tr>
<tr>
<td>Mining and rocks</td>
<td>8</td>
</tr>
<tr>
<td>Processed products incl. food and wood</td>
<td>131</td>
</tr>
<tr>
<td>o/w food</td>
<td>15</td>
</tr>
<tr>
<td>o/w wood and paper</td>
<td>16</td>
</tr>
<tr>
<td>Energy carriers</td>
<td>26</td>
</tr>
<tr>
<td>Transport services</td>
<td>17</td>
</tr>
<tr>
<td>(Mainly biogenic) By-products, waste and residuals</td>
<td>47</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>314</strong></td>
</tr>
</tbody>
</table>

Additionally: CO$_2$, CH$_4$, N$_2$O, SO$_2$, CO, NO$_x$, NMHC and dust
Solution algorithm

Parameter
- Final demand (e.g. food)
- Production coefficients
- Land constraints

Solving algorithm
- Iteration
- Auxiliary constraints
- Material balance
- Non negative constraints

Model output
- Resource requirements (e.g. land)
- Intermediate demand
- Emissions
Solution algorithm

Primary material flow

Inputs (Materials, Energy) - Primary output - Additional supply (By-products) - Domestic demand, exogenous - Trade balance

Secondary material flow

Data sources

- Process data
  - Life Cycle Inventory (LCI) data (ecoinvent or GEMIS)
  - LCI from different studies
  - Questionnaires

- Sectorial data
  - Statistics
  - Sectorial information of industrial associations
  - EU Project “Forwast”

- Data sources: about 50
Load flexible non-conventional power plants

- Aim: to quantify the contribution of load flexible power plants demanding coal, biomass and RDF as inputs in 2050.

Change of GWP of selected energy carriers, only by the technology induced

<table>
<thead>
<tr>
<th>Energy Carrier</th>
<th>Variant I</th>
<th>Variant II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard coal</td>
<td>+24.5 %</td>
<td>+ 33.1 %</td>
</tr>
<tr>
<td>Gas</td>
<td>- 6.8 %</td>
<td>- 6.8 %</td>
</tr>
<tr>
<td>Oil (heavy)</td>
<td>- 11.4 %</td>
<td>- 11.4 %</td>
</tr>
</tbody>
</table>

Change of GWP 100yr., compared to 2005
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Process-based MFA ~ Wood

Production processes in „Holzbearbeitung“
- Wood panel technology
- Sawmilling and planing technology
- Paper technology

Production processes in „Holzverarbeitung“
- Building components:
  - Außenwände
  - Fenster/ Fassaden
  - Innentüren
  - Leinwände

- Buildings:
  - Bautenschal- Zimmermannware
  - Ein- und Zweifamilienhäuser
  - and. Gebäuden, Betriebsgebäude (Dachstühle)

- Wooden goods:
  - Baukastenspielzeug
  - Betonschalungsware
  - Holzrahmen
  - Säge
  - Werkzeuggriffe, steile
  - Zapfen
  - zur Verwendung bei Tisch/ in der Küche

- Interiors:
  - Fußbodenbeläge
  - - Parkett und Dielen
  - - Saunakabinen
  - - Stühle
  - - Kinderzimmer
  - - Tische

- Furniture:
  - Badezimmermöbel
  - - Küchenmöbel
  - - Schrankzimmernmöbel

- Package:
  - - Boxpalett
  - - Flachpalett

- Energy conversion technology

Other sectors:
- - Infrastruktur
- - Maschinen

Recycling processes:
- - Recycling industry:
  - - Waste wood
  - - Sawmilling side products
  - - Waste paper

Energy conversion technology
- - industrial
- - privat

Resources
- - Energy use and pre-processes

Products of processing level 1: semi-finished goods

Products of processing level 2: final goods

Natural environment
- - Technosphere

Resource use and pre-processes
- - Chemical Industry:
  - - Adhesive, glue
  - - Varnish
  - - Binder
  - - Oil, lipid, wax

- - Energy supply:
  - - Heat
  - - Electricity

- - Logistic/ Transport:
  - - by ship
  - - by train
  - - by truck 32 t
  - - by truck 16 t

- - Forest industry:
  - - Stem hardwood
  - - Industrial hardwood
  - - Stem softwood
  - - Industrial softwood
  - - Woodfuel
  - - Tropical hardwood

- - other sectors:
  - - Infrastruktur
  - - Maschinen

Resources
- - Production processes
- - Emissions

- - Recycling industry:
  - - Waste wood
  - - Sawmilling side products
  - - Waste paper

Energy conversion technology
- - industrial
- - privat

Waste wood
Process-based MFA – details

Up-stream processes

Resource use and pre-processes

Natural environment

Technosphere

Chemical Industry:
- Adhesive, glue
- Varnish
- Binder
- Oil, lipid, wax

Energy supply:
- Heat
- Electricity

Logistic/ Transport:
- by ship
- by train
- by truck 32 t
- by truck 16 t

Production processes in „Holzverarbeitung“
(e.g. Processes in the furniture industry)

Building components:
- Auflagen
- Fenster/ Fassaden
- Innenräume
- Leimbauteile

Buildings:
- Baumschulmaterial
- Betonschalungsmaterial
- Holzrahmen
- Säge
- Werkzeuggriffe, -stiele
- Ziergegenstände
- zur Verwendung bei Tisch/ in der Küche

Wooden goods:
- Fußbodenbeläge (Parkett und Dielen)
- Saunakabinen
- Truhen
- Wandelemente

Interiors:
- Badzimmernmöbel
- Büromöbel
- Gartenmöbel
- Küchenmöbel
- Ladeneinrichtung
- Schlafzimmernmöbel
- Sitz-, Polstermöbel
- Wohn-, Esszimmernmöbel

Furniture:
- Boxpalettte
- Flachpalette
- Kabeltrummel
- Kisten für ein Holz
- Kisten aus anderem Holz

Package:

Energy conversion technology

Waste wood
Process-based MFA – details

1st Product level

12 Intermediate products
Process-based MFA – details

2nd Product level

Grouping and amounts based of production statistics of consumer goods

38 Final products
Process-based MFA – driver

Main driver: final demand
Example

Objective:

Identification and quantification of the environmental impacts of using lightweight boards in the German forest-based industry

Conventional chip board

Lightweight board

Source: www.glunz.de

Quelle: Siempelkamp
Example

Methods:
- Process-based material-flow model
- LCIA method such as Impact 2002+
- Scenario technique

Approach:
- Defining of the systems boundaries: by domestic demand for forest-based products induced production in Germany
- Modeling of all production processes and demand pattern
- Estimation of future pattern of final demand (target years: 2015, 2025)
- Evaluation of the system:
  - Requirements of raw materials
  - Environmental impacts of the whole industry
Reference system – status quo in 2005

- Depiction of the forest-based industry considering:
  - Products
  - Material and energy flows
  - Production quantities

- Data sources
  - Process data: ecoinvent data base, various studies, interviews with experts
  - Output data: production statistics of consumer goods
  - Future demand in 2015 and 2025: extrapolation of production statistics
## Overview of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2005</th>
<th>2015</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference system</td>
<td>Base year</td>
<td>Extrapolation of production stats</td>
<td>Extrapolation of production stats</td>
</tr>
<tr>
<td>Lightweight boards</td>
<td>Base year</td>
<td><strong>Additionally:</strong> processing of lightweight boards</td>
<td><strong>Additionally:</strong> processing of lightweight boards</td>
</tr>
</tbody>
</table>

**Development of the production of furniture**
- 2015: - 55% to + 15% (compared to 2005)
- 2025: - 80% to + 27% (compared to 2005)

**Proportion of the lightweight board as share of the production volume of chipboard**
- 2005: 0,0%
- 2015: 13,5%
- 2025: 27,0%
Example of extrapolation: Kitchen corpus

<table>
<thead>
<tr>
<th>Güterproduktionsstatistik Meldenr.</th>
<th>3613 10 500</th>
<th>Kücheneinbauelemente (Korpusse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jahr</td>
<td>Produktion Möbelstücke [1.000 Stück]</td>
<td>Zuwachsrate [%]</td>
</tr>
<tr>
<td>1996</td>
<td>23.012</td>
<td>0,543%</td>
</tr>
<tr>
<td>1997</td>
<td>23.137</td>
<td>3,540%</td>
</tr>
<tr>
<td>1998</td>
<td>23.956</td>
<td>2,734%</td>
</tr>
<tr>
<td>1999</td>
<td>24.611</td>
<td>-0,532%</td>
</tr>
<tr>
<td>2000</td>
<td>24.480</td>
<td>0,768%</td>
</tr>
<tr>
<td>2001</td>
<td>24.668</td>
<td>-2,663%</td>
</tr>
<tr>
<td>2002</td>
<td>24.011</td>
<td>-2,028%</td>
</tr>
<tr>
<td>2003</td>
<td>23.524</td>
<td>5,463%</td>
</tr>
<tr>
<td>2004</td>
<td>24.809</td>
<td>3,297%</td>
</tr>
<tr>
<td>2005</td>
<td>25.627</td>
<td>6,587%</td>
</tr>
<tr>
<td>2006</td>
<td>27.315</td>
<td>-0,626%</td>
</tr>
<tr>
<td>2007</td>
<td>27.144</td>
<td>-0,910%</td>
</tr>
<tr>
<td>2008</td>
<td>26.897</td>
<td>1,348%</td>
</tr>
<tr>
<td>2009</td>
<td>..</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
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<tr>
<td>2011</td>
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<tr>
<td>2012</td>
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<td>2013</td>
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<tr>
<td>2014</td>
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</tr>
<tr>
<td>2015</td>
<td></td>
<td>28.809.673</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Reference data:** production in the years 1996 – 2007
- **Calculation of mean average of growth (degrowth)**
- **Extrapolation of the production for the years 2015 and 2025**
Lightweight boards in the system
Results of the reference system: development of the overall environmental impacts

Impact 2002+-points

- Global warming potential
- Non-renew. energy resources
- Occupation of land
- Human toxicity
Results of the lightweight boards scenario: development of the overall environmental impacts

Impact 2002+-points

- Global warming potential
- Non-renew. energy resources
- Occupation of land
- Human toxicity
Results Reference vs. Lightweight – Global warming potential

Impact 2002+-points

<table>
<thead>
<tr>
<th>Year</th>
<th>Reference System</th>
<th>Lightweight Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>6.522</td>
<td>6.522</td>
</tr>
<tr>
<td>2015</td>
<td>11.326</td>
<td>11.386</td>
</tr>
<tr>
<td>2025</td>
<td>17.203</td>
<td>17.273</td>
</tr>
</tbody>
</table>

- Reference system
- Lightweight scenario
Results Reference vs. Lightweight – Occupation of land

Impact 2002+-points

Conclusions

- Process-based MFA ~ extended LCI
- Continuous increase of total impacts from 2005 until to 2025 with linear behavior
- Environmental performance of sector is getting worse due to an overall increase of production
- Environmental impacts by using lightweight boards in the forest-based industry is barely recognizable, i.e.
  - no significant environmental benefits
  - but also no significant disadvantages
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