Material Flow Analysis
Fundamentals

Lecture (II): Procedures, Application & Perspectives
Lecture (II): Procedures, applications & perspectives

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3. How to carry out a Material Flow Analysis?
   • General procedure
   • Illustrative case study: Global aluminium cycle

4. Perspectives & conclusions
   • Other types of MFA according to OECD
   • Other sustainability tools
   • Summary of the lecture
Lecture (II): Procedure, Application & Perspectives

3. How to carry out a Material Flow Analysis?
   – General procedure
MFA procedure

1. Define the objectives and parameters to be monitored
2. Limit the balance scope
3. Limit the balance period
4. Identify and define the process steps
5. Draw the flowcharts: material flows – quality
6. Draw up the balances: material flows – quantity
7. Interpret the results and draw conclusions

Source: United Nations Industrial development Organization (UNIDO)
MFA is an iterative process!

Problem definition / Research question

Goal & Scope
- Determination of system boundaries
- Selection of substances
- Determination/selection of goods

Determination of flows and stocks
- Determination of mass flows
- Balancing the goods
- Determination of concentration
- Balancing of substances

Illustration & interpretation

Adjust system
- Redefine problem

1. Refine concentrations
2. Re-determine goods
1. Refine mass flows
2. Refine mass flows
Lecture (II): Procedure, Application & Perspectives

How to carry out a Material Flow Analysis? – Illustrative case study: the global Aluminum cycle

Resources, Conservation and Recycling
Volume 125, October 2017, Pages 48-69

Full length article
A regionally-linked, dynamic material flow modelling tool for rolled, extruded and cast aluminium products


https://doi.org/10.1016/j.resconrec.2017.05.014
Problem definition / Research question

“The purpose of this study is **the quantification of regional stocks and flows** of rolled, extruded and casting alloys across space and over time, giving the industry the ability **to evaluate the potential to recycle aluminium scrap most efficiently.**”

Sources: Asland aluminium, creative commons
Selection of goods & substance

• Targeted substance: Aluminium

• Goods:
  – Primary Aluminium
  – Recycled Aluminium
  – Alumina
  – Bauxite
  – New and old scrap
  – Alloys
  – Semi-finished casting products (ingots)
  – Final products

↘ All flows are expressed in Aluminium mass equivalent value
(for Bauxite & Alumina: mass ratio of Aluminium to other constituents)
## Spatial and Temporal Boundaries

- **Spatial:** Nine regional models representing **Worldwide scale**

<table>
<thead>
<tr>
<th>Region</th>
<th>Countries</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Mainland China</td>
<td>Important ingot producer &amp; consumer of final products</td>
</tr>
<tr>
<td>Europe</td>
<td>EU28+others</td>
<td>Covering regional Europe not only political union</td>
</tr>
<tr>
<td>Japan</td>
<td>Japan</td>
<td>Excellent data quality – High per capita consumer of final products</td>
</tr>
<tr>
<td>North America</td>
<td>Canada, Mexico, USA</td>
<td>Important ingot producer and consumer of final products. Mexico recycles a lot of scrap from USA</td>
</tr>
<tr>
<td>Middle east</td>
<td>Arabic peninsula + Iran</td>
<td>Important primary ingot producer. High per capita consumer of final products</td>
</tr>
<tr>
<td>Other producing countries</td>
<td>Australia, Azerbaijan, Russia, South Africa...</td>
<td>Large bauxite, alumina and primary producing regions</td>
</tr>
<tr>
<td>South America</td>
<td>Argentina, Brazil, Venezuela, etc.</td>
<td>Covering bauxite mine and high income countries in the South America</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>All other countries</td>
<td>No bauxite, alumina or primary aluminium producers. Importer of semis and final products</td>
</tr>
</tbody>
</table>

- **Temporal:** 1950 – 2017 with a particular focus on the year 2014 in the paper

Selection of processes

[Mining & Refining]
- Bauxite mining
- Alumina production

[Aluminium production]
- Primary production
- Recycled production

[Fabrication]
- Semi-fabricated product manufacture (rolling, extrusion, casting, others)

[Manufacturing]
- Production of final products

[Scrap recovery & Trading]
- Management of EOL products
- New scrap

[Use]
- Stock of product in-use

Short exercise:
List several flows & stocks to be quantified in the system
Identification of flows and stocks

- **Flows:**
  - All the flows between the processes (linking the 6 main stages)
  - Inter-regional trade (Import/Export of metal & final non-metal products)
  - Extraction of bauxite in each region
  - Emission of residues & waste (not recycled)

- **Stocks:**
  - P1: Stocks of bauxite and Alumina (Alumina refineries, ports, storage facilities)
  - P3: Aluminium ingot stock (Aluminum production)
  - P6: Final product in use (Anthropogenic stock)
  - P8: Disposal - landfill & incineration (Anthropogenic stock)
  - P9: Bauxite stock change [extraction] (economic reserve is out of the scope)
  - P10: Residue wastes, metal losses during manufacturing
Draw the flowcharts: material flows – quality

Goal & Scope

Other regions

Non-metal flows

Metal flows

• World scale = Σ Regional Scales
Draw up the balances: material flows (Worldwide scale)

- All flows are expressed in Aluminium mass equivalent value (in million tonnes)
- Stock in 2014 equals stock in 2013 plus the stock change in 2014
- Inconsistency in the mass balances
Data reconciliation with STAN software

- Measurements and estimates are subject to errors (e.g. inconsistencies in the law of mass conservation)
- Data reconciliation statistically adjusts the values to resolve contradictions and find the data that fit the model the best

Most probable value (A) with associated uncertainty (b) is calculated: $A \pm b$
Metal-specific recovery rate \( = \frac{27}{(12+19)} = 87\% \)

Recycled content of ingots flow \( = \frac{(27+34)}{(55+1,1+27+34)} = 52\% \)
Comparison between the regions in 2017 (China / Europe / Rest of the world)

http://www.world-aluminium.org/statistics/massflow/
## Comparison of Bauxite & Alumina flows in 2017 (China / Europe)

<table>
<thead>
<tr>
<th></th>
<th>China</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Refining input:</strong></td>
<td>39.9 Mtonnes of Bauxite (67% domestic – 32% import)</td>
<td>4 Mtonnes of Bauxite (4.4% domestic – 95.6% import)</td>
</tr>
<tr>
<td><strong>Output:</strong></td>
<td>35.6 Mtonnes of Alumina (total outputs: 89% Alumina – 9% residue – 2% stocks)</td>
<td>3.28 Mtonnes of Alumina (total outputs: 81% Alumina – 8% residue – 11% stocks)</td>
</tr>
</tbody>
</table>

http://www.world-aluminium.org/statistics/massflow/
### Comparison of Aluminium production in 2017 (China / Europe)

<table>
<thead>
<tr>
<th>China</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production inputs:</strong> 47,2 Mtonnes</td>
<td><strong>Production inputs:</strong> 10,0 Mtonnes</td>
</tr>
<tr>
<td>(77,3% local Aluminia – 20,1% local scrap – 2,6% import scrap)</td>
<td>(50,2% local scrap – 26,2% import Aluminia – 21,5% local Aluminia - others)</td>
</tr>
<tr>
<td><strong>Production output:</strong> 35,9 Mtonnes of primary Aluminium (77,4%)</td>
<td><strong>Production output:</strong> 4,1 Mtonnes of primary Aluminium (46,1%)</td>
</tr>
<tr>
<td>10,5 Mtonnes of Recycled Aluminum (22,6%)</td>
<td>4,8 Mtonnes of Recycled Aluminum (53,9%)</td>
</tr>
<tr>
<td>(93,6% domestic – 1% export – 5,4% stocks &amp; others)</td>
<td>(98,7% domestic – 1,3% export – 2,4% stocks &amp; others)</td>
</tr>
</tbody>
</table>

Ingots per capita: 3,56 kg

Ingots per capita: 3,00 kg

Comparison of in-use stock and flows in 2017 (China / Europe)

<table>
<thead>
<tr>
<th>China</th>
<th>Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use input: 28,7 Million tonnes (96% domestic – 4% import)</td>
<td>Use input: 12,1 Million tonnes (67% domestic – 33% import)</td>
</tr>
<tr>
<td>In-use stock: 235 Million tonnes (cars, building and construction etc.) Per capita: 165,6 kg/capita</td>
<td>In-use stock: 183 Million tonnes Per capita: 269,5 kg/capita</td>
</tr>
<tr>
<td>End-of-life products: 4,6 Mtonnes (75% old scrap recovered)</td>
<td>End-of-life products: 4,8 Mtonnes (79% old scrap recovered)</td>
</tr>
</tbody>
</table>

\( \downarrow \) Trend: The net annual increase in Chinese in-use stocks is currently almost 4 times higher than that of Europe or North America

http://www.world-aluminium.org/statistics/massflow/
Answer to the research question and conclusion (1/2)

“The purpose of this study is the quantification of regional stocks and flows of rolled, extruded and casting alloys across space and over time, giving the industry the ability to evaluate the potential to recycle aluminium scrap most efficiently.”

- 1,1 billions of tonnes of primary Aluminium produced between 1950 & 2014
  - 860 million tonnes (78%) of which are still in-use
  - 80 million tonnes (~7%) are non-recycled products (post-use fate is not known)
  - The remaining part is landfilled, incinerated or dissipated
Answer to the research question and conclusions (2/2)

- **Aluminium Scrap recycling**

  - Europe is net exporter of scrap (surplus scrap in Black)
  - China needs to import 4Mt/yr of scrap to avoid using primary metal (light grey)
  - Globally: recycled scrap reaches 11Mt/yr
  - This leaves a non-supplied recycled demand of 3Mt/year (light grey)
Lecture (II): Procedure, Application & Perspectives

4 Perspectives & conclusions
   – Other types of MFA according to OECD
   – Other sustainability tools
   – Summary of the lecture
MFA: a family of tools

A material flow study can cover any set of materials at various scales and levels of detail and completeness.

Emphasis can be put on:

1. all materials entering and leaving the national economy;
2. the industry level, enterprise level, and product level, from product groups down to specific products;
3. certain materials and substances, from the national down to the local level;
4. a combination of specifications.

OCDE Top-Down Approach

Example: economy-wide monitoring of the biophysical circular economy for Austria.

Fig. 3. The state of the circular economy in Austria in 2014 (aggregated flows). Flows are depicted in Mt/year for a total population of 8.5 Mio. Bar diagrams, show the material composition of flows. Catabolic and oxidation processes are calculated without any balancing water or oxygen from air. Number may not add up due to rounding. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).
Lecture (II): Procedure, Application & Perspectives

 Perspectives & conclusions
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## Environmental Prioritization of Products (I/2)

- **Food, Mobility and Housing dominate (70 % of impacts at 50% expenditure)**

### Table: Environmental Prioritization of Products

<table>
<thead>
<tr>
<th>COICOP</th>
<th>Study</th>
<th>Dall et al.</th>
<th>Kok et al.</th>
<th>Labouze et al.</th>
<th>Nemry et al.</th>
<th>Nijdam and Wilting</th>
<th>CEDA EU25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator</td>
<td>Energy</td>
<td>Energy</td>
<td>GWP</td>
<td>GWP</td>
<td>GWP</td>
<td>GWP</td>
<td>GWP</td>
</tr>
<tr>
<td>Main approach</td>
<td>Bottom-up</td>
<td>Hybrid</td>
<td>Bottom-up</td>
<td>Bottom-up</td>
<td>IO</td>
<td>IO</td>
<td></td>
</tr>
<tr>
<td>CP01-02</td>
<td>Food</td>
<td>26,2%</td>
<td>13,0%</td>
<td>7,0%NA</td>
<td>3,6%NA</td>
<td>22,1%</td>
<td>31,0%</td>
</tr>
<tr>
<td>CP03</td>
<td>Clothing</td>
<td>1,3%</td>
<td>2,2%</td>
<td>3,3%</td>
<td>1,3%</td>
<td>6,5%</td>
<td>2,4%</td>
</tr>
<tr>
<td>CP04-05</td>
<td>Housing</td>
<td>40,8%</td>
<td>54,3%</td>
<td>58,8%</td>
<td>53,5%</td>
<td>33,4%</td>
<td>23,6%</td>
</tr>
<tr>
<td>CP06</td>
<td>Health</td>
<td>1,8%</td>
<td>0,3%</td>
<td>0,3%</td>
<td>1,6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP07</td>
<td>Transport</td>
<td>19,5%</td>
<td>18,3%</td>
<td>29,6%</td>
<td>32,9%</td>
<td>17,3%</td>
<td>18,5%</td>
</tr>
<tr>
<td>CP08</td>
<td>Communication</td>
<td>0,0%</td>
<td>2,9%</td>
<td>0,0%</td>
<td>2,1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP09</td>
<td>Recreation</td>
<td>7,2%</td>
<td>8,1%</td>
<td>0,0%</td>
<td>15,1%</td>
<td>6,0%</td>
<td></td>
</tr>
<tr>
<td>CP10</td>
<td>Education</td>
<td>1,8%</td>
<td>0,7%</td>
<td>0,5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP11</td>
<td>Restaurants</td>
<td>2,8%</td>
<td>9,1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP12</td>
<td>Miscellaneous</td>
<td>5,1%</td>
<td>0,4%</td>
<td>1,3%</td>
<td>5,4%</td>
<td>1,8%</td>
<td>5,2%</td>
</tr>
</tbody>
</table>

**TOTAL** | 100,0% | 100,0% | 100,0% | 100,0% | 100,0% | 100,0% | 100,0% |


• Food, Mobility and Housing dominate (70% of impacts at 50% expenditure)

**Note:**
- Food, Mobility, and Housing are the main contributors to environmental impacts, accounting for 70% of impacts at a 50% expenditure level.
- The table provides a breakdown of impacts across different sectors, with COICOP (Cost of the Impact of Consumption on the Environment) categories used to categorize the data.

**Source:** Journal Indust. Ecology 10:3 (2006)
Environmental Prioritization of Products (2/2)

- surface is a measure for priority
- figure indicates if shift in expenditure makes environm. sense and if ‘rebounds’ are possible

Source: Tukker et al. 2006. Impact of Products (EIPRO)
National level resource accounting: System for Environmental & Economic Accounts (SEEA)

Source: UN System of Integrated Environmental and Economic Accounts (SEEA)
Integration of tools at various levels

Questions at various levels

*Macro*
- **Indicators**
  - GDP, EF, etc.

*Tools available*
- EE Input-Output tables & Env. accounts

*Material Flow analysis*

*Life Cycle Assessment*

*Micro*

*Meso*
- **Material Flow analysis**

Different system analytical tools and a consistent set of indicators are necessary to ensure innovation moves towards a sustainability
Lecture (II): Procedure, Application & Perspectives

4 Perspectives & conclusions
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Examples of potential student projects

1. Cobalt (Co) in the European value chain of electric mobility

2. Machinery tools in the French economy – Focus on the Tungsten

3. Supply of phosphate fertiliser: Potential of recycling from wastewater in Nouvelle Aquitaine region

Source: the Guardian

Source: Vadoudi et al. 2015
Thanks for you attention

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