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# Material Flow Analysis

## Fundamentals

### Lecture (II): Procedures, Application & Perspectives

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# Lecture (II): Procedures, applications & perspectives

## Index




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# Lecture (II): Procedure, Application & Perspectives

## 3 How to carry out a Material Flow Analysis ?

– General procedure

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# 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

Goal & Scope

Quantification

Interpretation

Source: United Nations Industrial development Organization (UNIDO)

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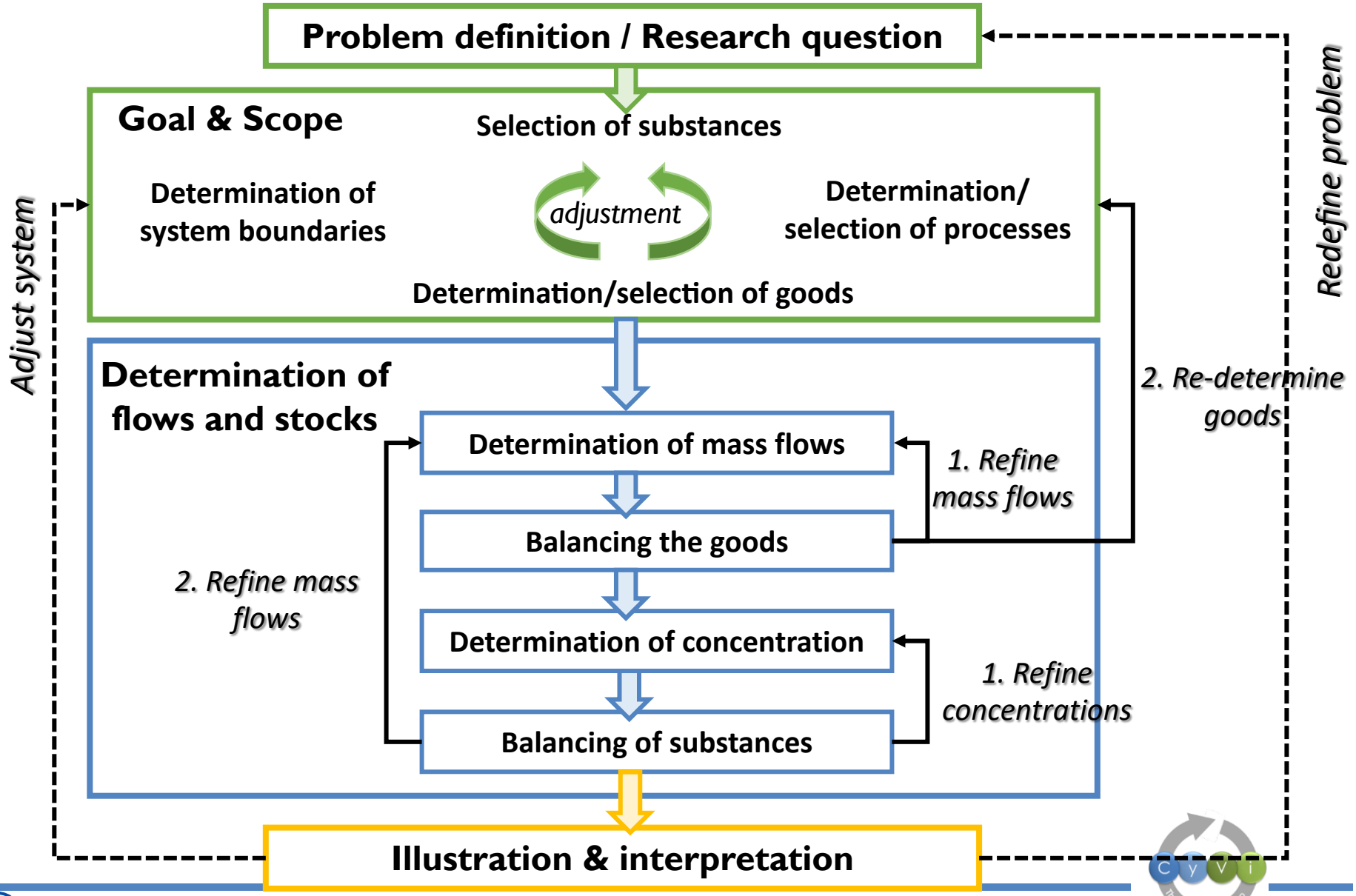
Source: Practical Handbook of Material Flow Analysis, Brunner P.H. & Rechberg H. (2004)

# MFA is an iterative process !

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# Lecture (II): Procedure, Application & Perspectives

## 3 How to carry out a Material Flow Analysis ?

– Illustrative case study: the global Aluminum cycle

WORLD ALUMINIUM


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

M. Bertram [a] ✉, S. Ramkumar [b], H. Rechberger [c], G. Rombach [d], C. Bayliss [a], K.J. Martchek [e], D.B. Müller [b], G. Liu [f]

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https://doi.org/10.1016/j.resconrec.2017.05.014

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# 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

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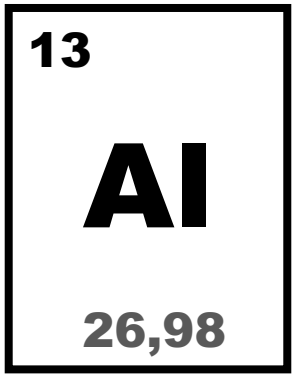
# Selection of goods & substance

- 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)

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# Spatial and Temporal Boundaries

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

| Region | Countries | Comments |
|---|---|---|
| **China** | Mainland China | *Important ingot producer &consumer of final products* |
| **Europe** | EU28+others | *Covering regional Europe not only political union* |
| **Japan** | Japan | *Excellent data quality – High per capite consumer of final products* |
| **North America** | Canada, Mexico, USA | *Important ingot producer and co nsumer of final products. Mexico recycles a lot of scrap from USA* |
| **Middle east** | Arabic peninsula + Iran | *Important primary ingot producer. High per capita consumer of final products* |
| **Other producing countries** | Autralia, Azerbadjan, Russia, South Africa… | *Large bauxite, alumina and primary producing regions* |
| **South America** | Argentina, Brazil, Venezuela, etc. | *Covering bauxite mine and high income countries in the South America* |
| **Rest of the World** | All other countries | *No bauxite, alumina or primary aluminium producers. Importer of semis and final products* |

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

see: http://www.world-aluminium.org/statistics/massflow/

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# 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

**[Use]**

- Stock of product in-use

**[Scrap recovery & Trading]**

- Management of EOL products
- New scrap

Short exercise:

List several flows & stocks to be quantified in the system

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# 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**

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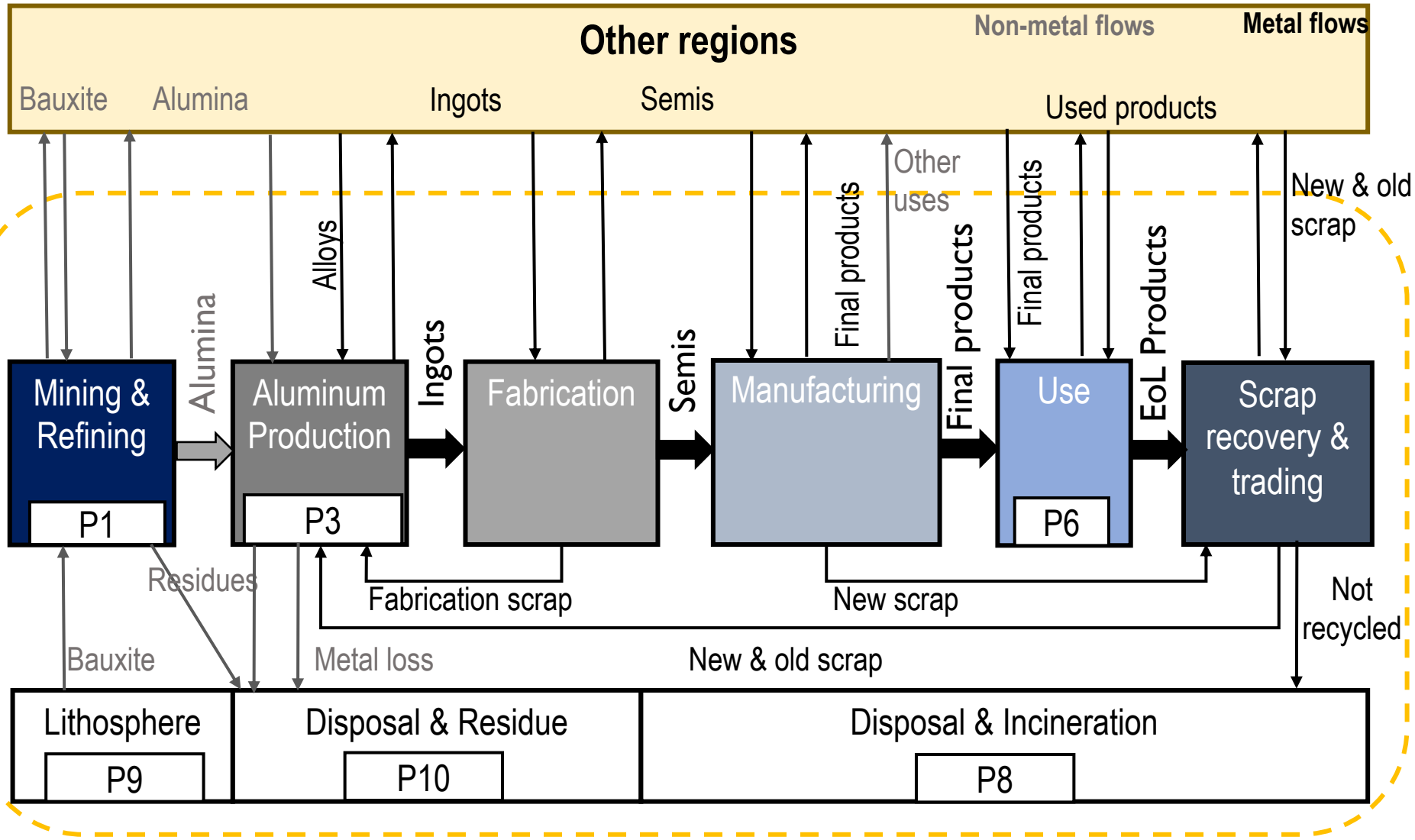
# Draw the flowcharts: material flows – quality

**Goal & Scope**




- **World scale = Σ Regional Scales**

**Region, year**

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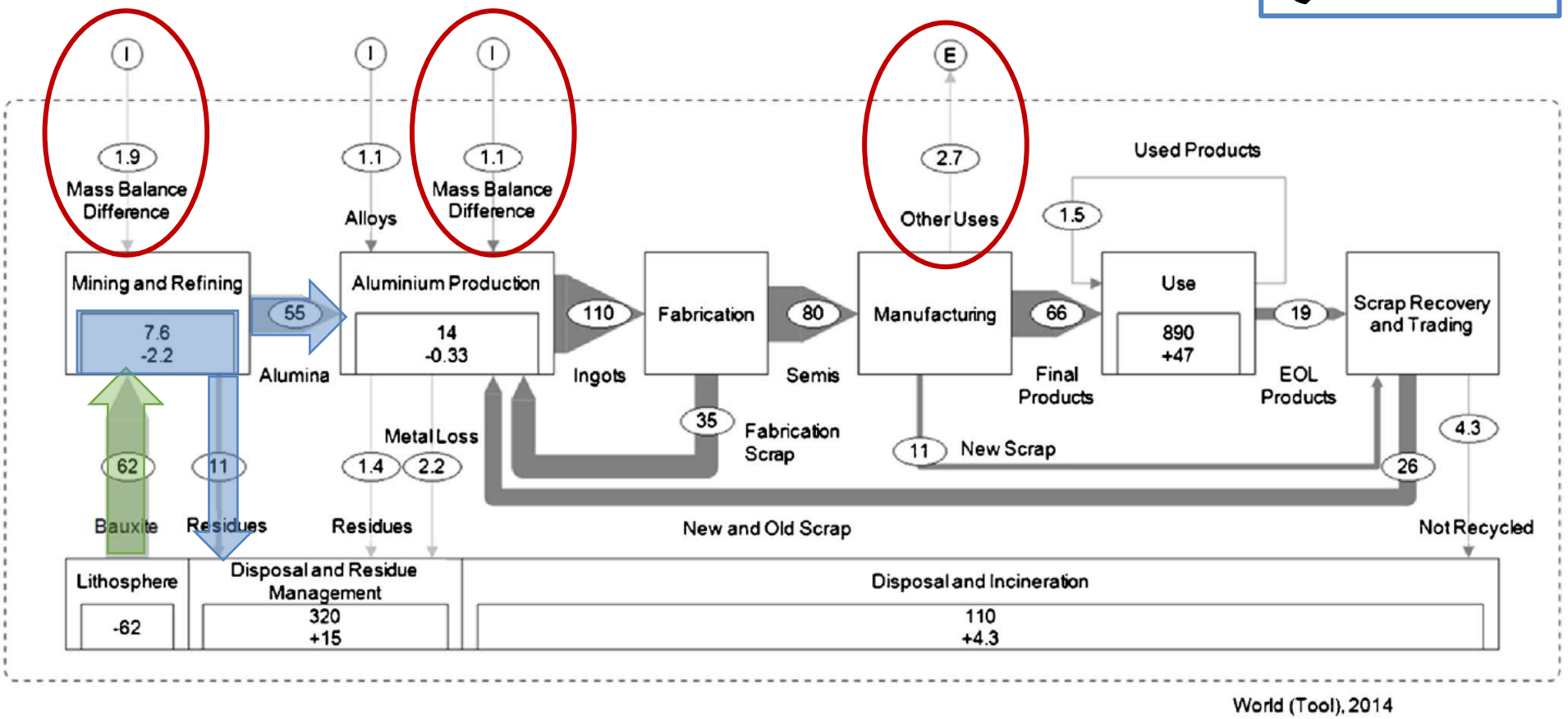
# Draw up the balances: material flows (Worldwide scale)

**Quantification**




World (Tool), 2014

- **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**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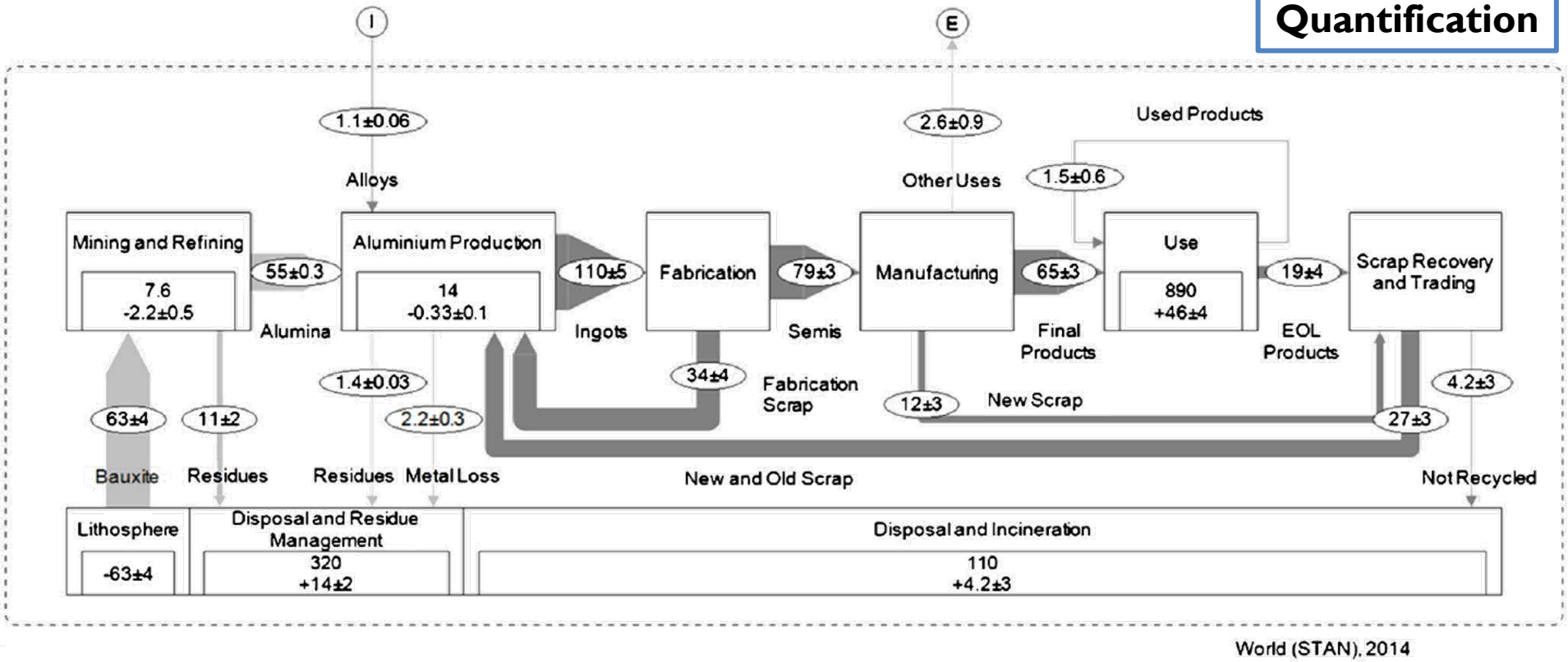
# Data reconciliation with STAN sofware

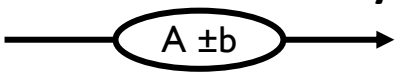
- Measurements and estimates are subject to errors (e.g. inconstancies in the law of mass conservation)
- **Data reconciliation statistically adjusts the values to resolve contradictions and find the data that fit the model the best**

**Quantification**




World (STAN), 2014

- **Most probable value (A) with associated uncertainty (b) is calculated:**

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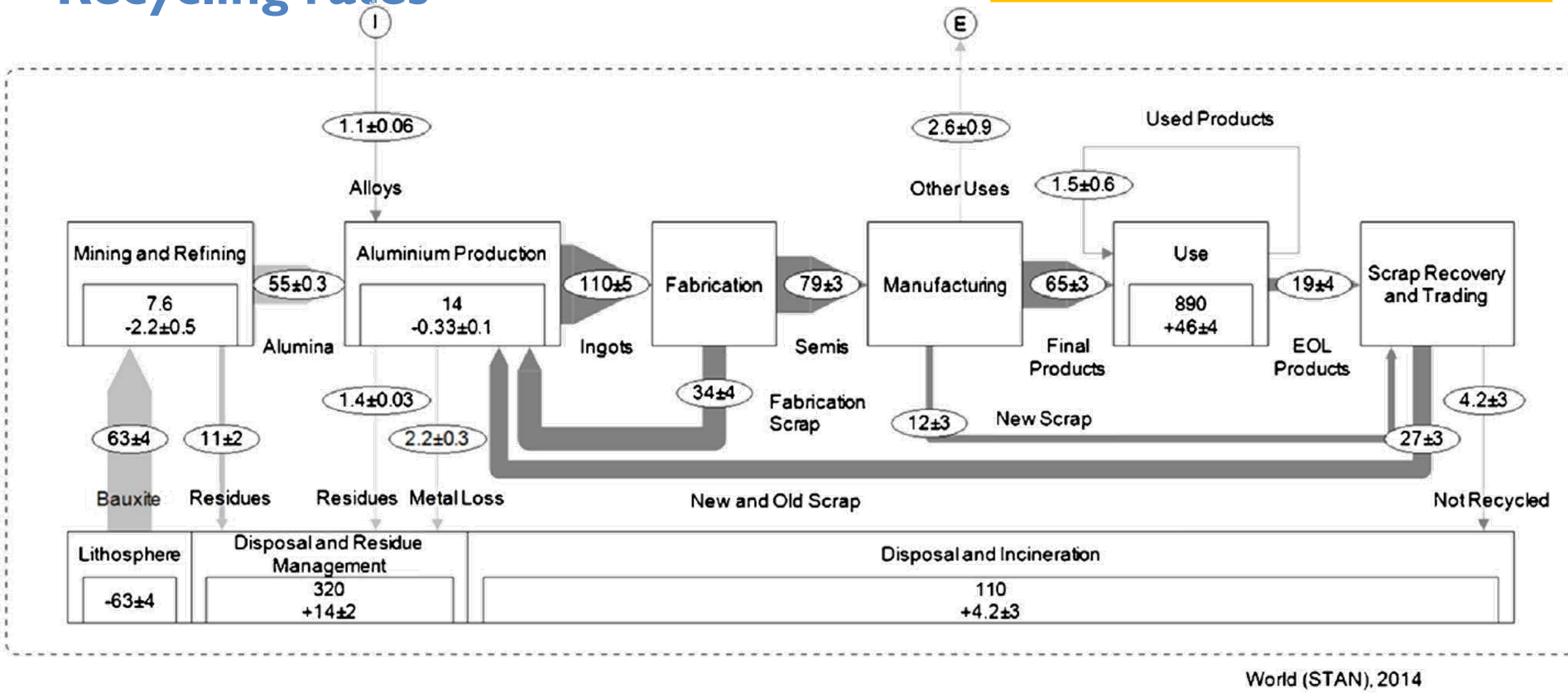
# Recycling rates

**Interpretation**




World (STAN), 2014

**Metal-specific recovery rate** = $^{27}/_{(12+19)} = 87\%$

**Recycled content of ingots flow** = $^{(27+34)}/_{(55+1{,}1+27+34)} = 52\%$

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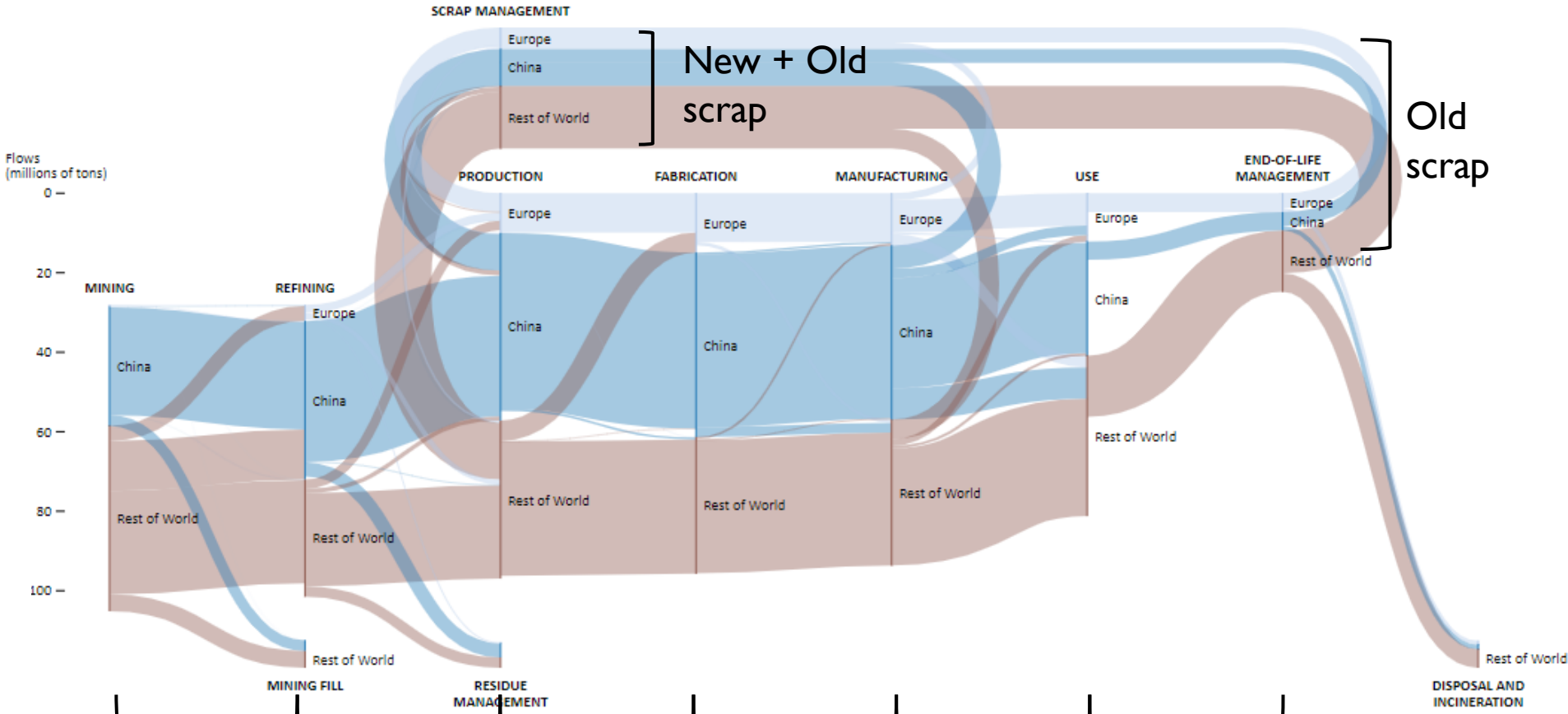
# Comparison between the regions in 2017 (China / Europe / Rest of the world)

**Quantification**




Bauxite | Alumina + scrap | Ingots | Semis | Final Products | EoL Products

http://www.world-aluminium.org/statistics/massflow/

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Quantification

# Comparison of Bauxite & Alumina flows in 2017 (China / Europe)

| China | Europe |
|---|---|
| **Refining input:**<br>**39,9 Mtonnes of Bauxite**<br>(67% domestic – 32% import) | **Refining input:**<br>**4 Mtonnes of Bauxite**<br>(4,4% domestic – 95,6% import) |
| **Output: 35,6 Mtonnes of Alumina**<br>(total ouputs: 89% Alumina – 9% residue – 2% stocks) | **Output: 3,28 Mtonnes of Alumina**<br>(total outputs: 81% Alumina – 8% residue – 11% stocks) |

http://www.world-aluminium.org/statistics/massflow/

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# Comparison of Aluminium production in 2017 (China / Europe)

Quantification

| China | Europe |
|---|---|
| **Production inputs: 47,2 Mtonnes** (77,3% local Aluminia – 20,1% local scrap – 2,6% import scrap) | **Production inputs: 10,0 Mtonnes** (50,2% local scrap – 26,2% import Aluminia – 21,5% local Aluminia - others) |
| **Production output:** 35,9 Mtonnes of primary Aluminium (77,4%) **10,5 Mtonnes of Recycled Aluminum (22,6%)** (93,6% domestic – 1% export – 5,4% stocks & others) | **Production output:** 4,1 Mtonnes of primary Aluminium (46,1%) **4,8 Mtonnes of Recycled Aluminum (53,9%)** (98,7% domestic – 1,3% export – 2,4% stocks & others) |
| Ingots per capita: 3,56 kg | Ingots per capita: 3,00 kg |

http://www.world-aluminium.org/statistics/massflow/

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

Quantification

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

↘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/

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# 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 know)*
  - *The remaining part is landfilled, incinerated or dissipated*

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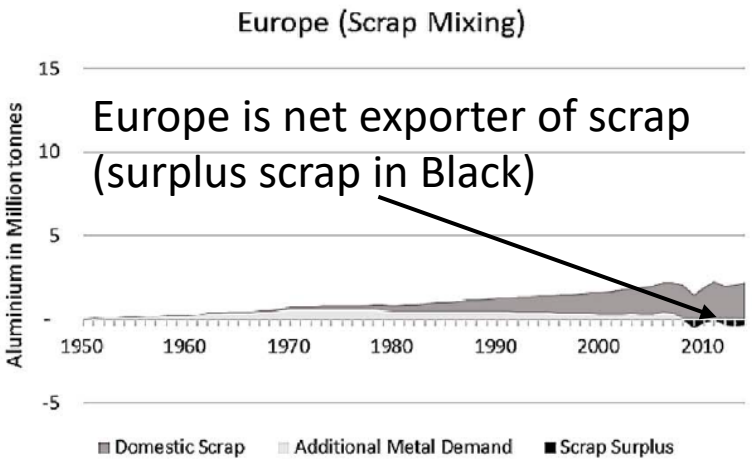
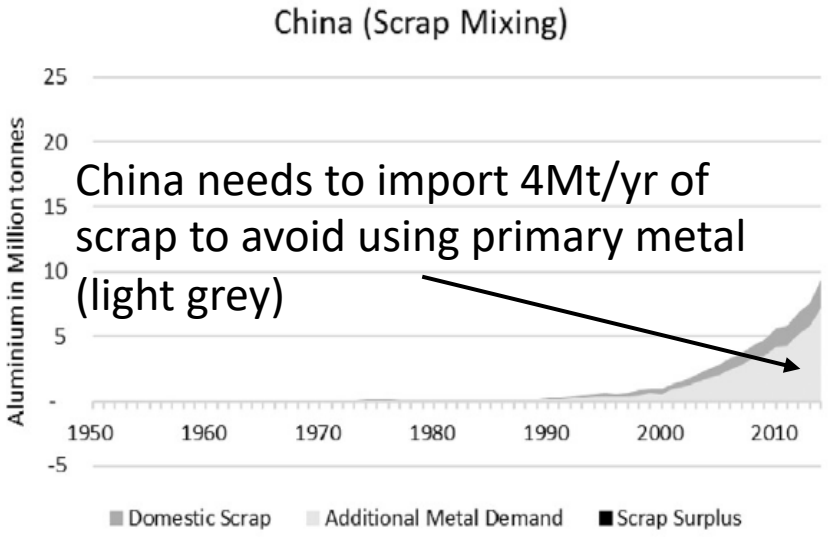
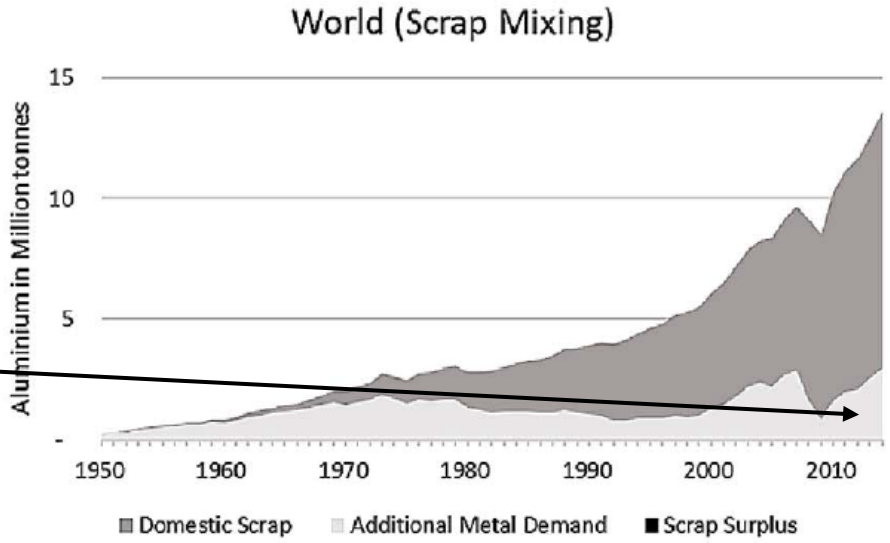
# Answer to the research question and conclusions (2/2)

- **Aluminium Scrap recycling**




Globally: recycled scrap reaches 11Mt/yr
This leaves a non-supplied recycled demand of 3Mt/year (light grey)

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# Lecture (II): Procedure, Application & Perspectives

4 Perspectives & conclusions

- **Other types of MFA according to OECD**
- Other sustainability tools
- Summary of the lecture

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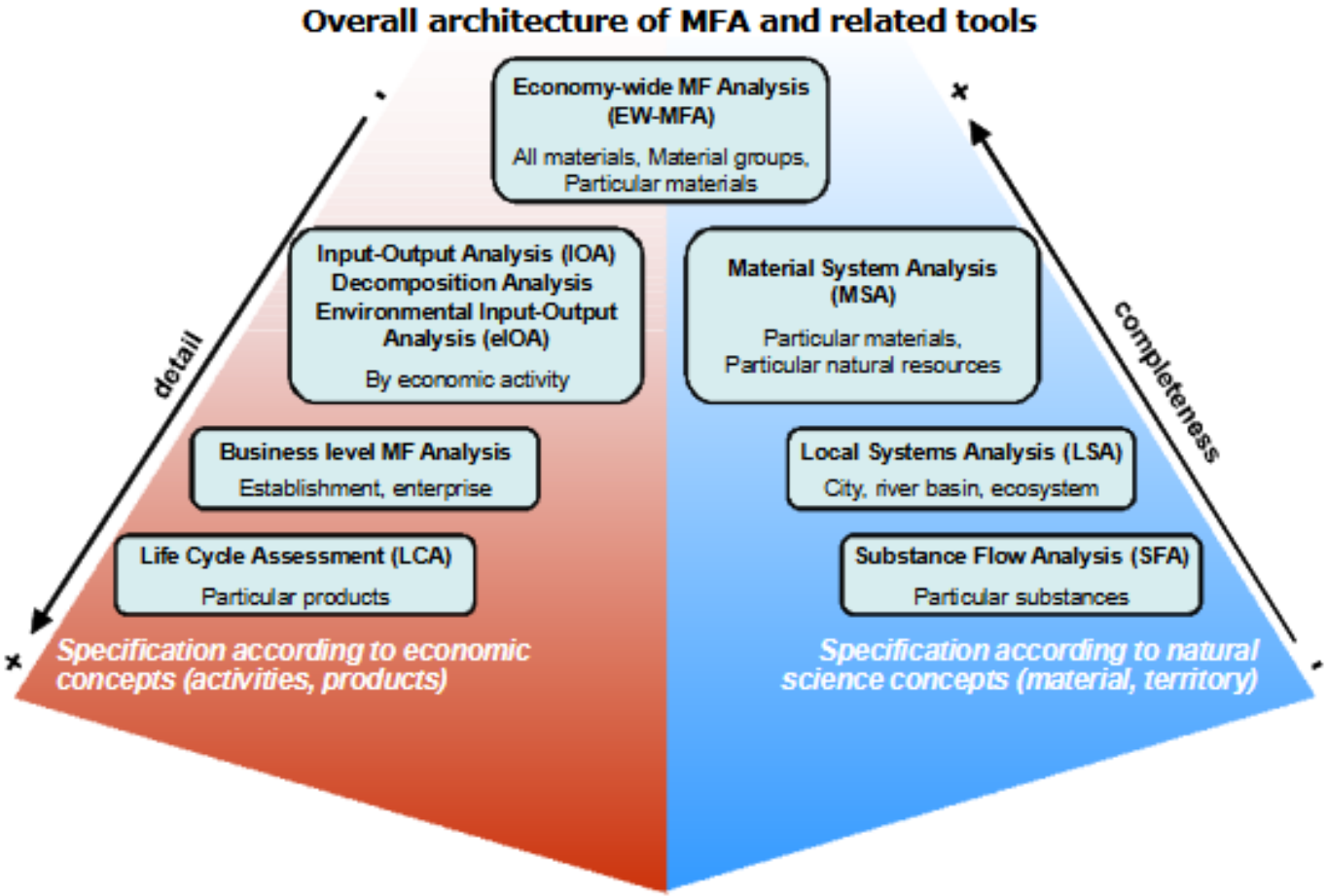
# MFA: a family of tools

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.**




**Types of MF related analyses and associated issues of concern**

Source: Measuring material flows & resource productivity. Volume I. The OECD Guide (2008).

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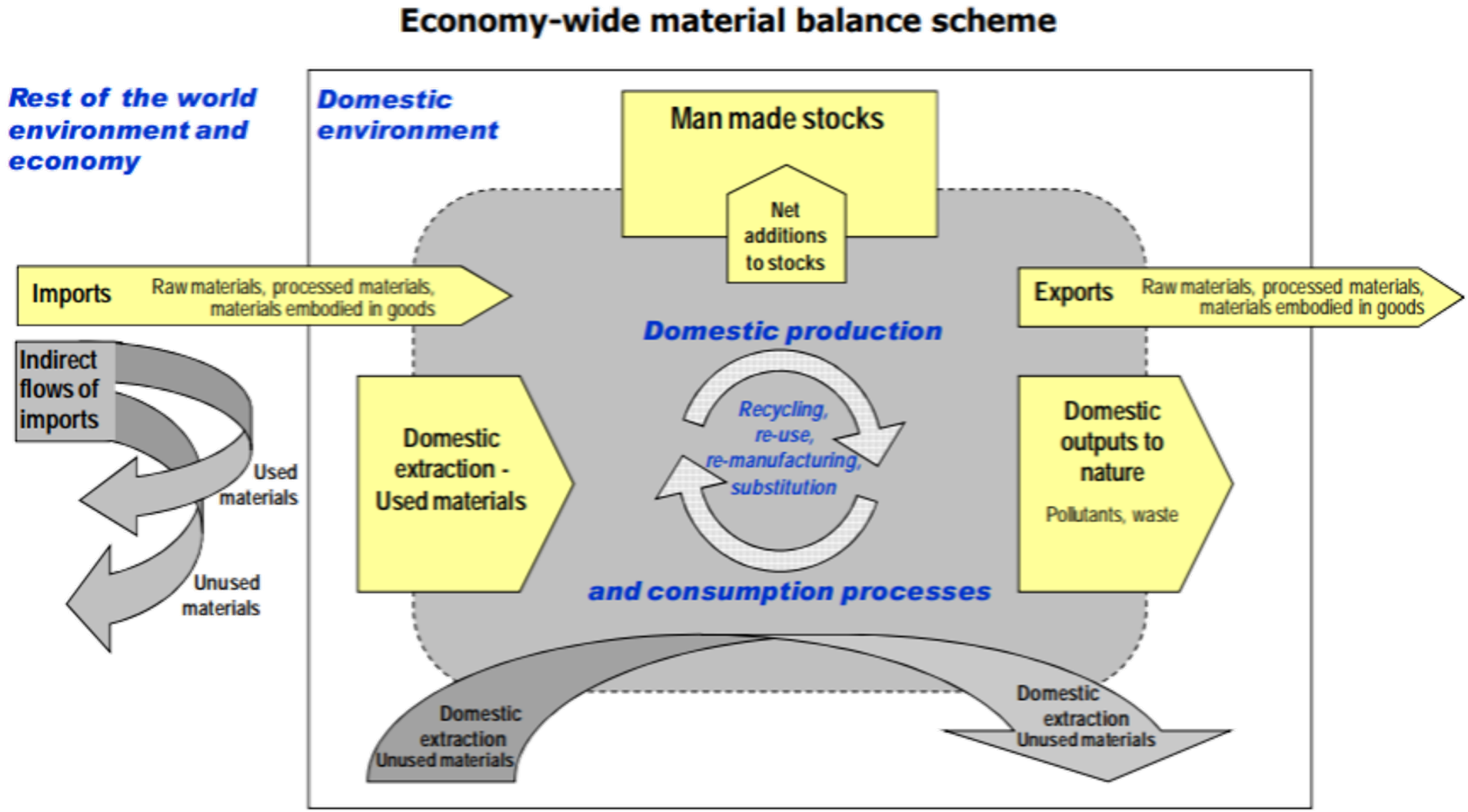
# OCDE Top-Down Approach




Source: Measuring material flows & resource productivity. Volume I. The OECD Guide (2008).

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



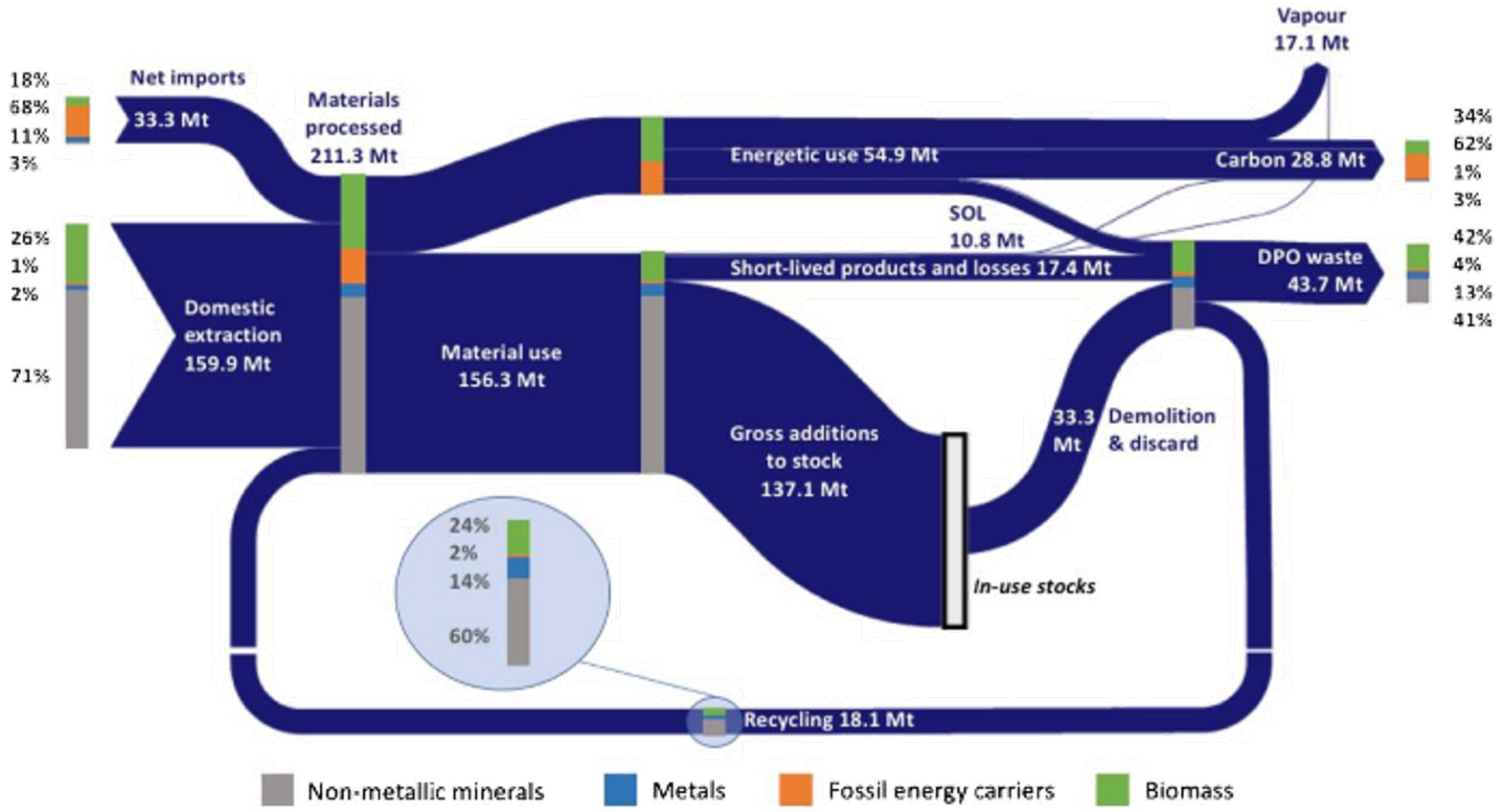


**Fig. 3.** The state of the circular economy in Austria in 2014 (aggregated flows). Flows are depicted in Mt/year for a total population of 8.5 Mio. Bar diagrams, show the material composition of flows. Catabolic and oxidation processes are calculated without any balancing water or oxygen from air. 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).

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# Environmental Prioritization of Products (I/2)

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

*Source: Journal Indust. Ecology 10:3 (2006)*

| COICOP | Study | Dall et al. | Kok et al. | Labouze et al. | Nemry et al. | Nijdam and Wilting | CEDA EU25 |
|---|---|---|---|---|---|---|---|
| | Indicator | Energy | Energy | GWP | GWP | GWP | GWP |
| | Main approach | Bottom-up | Hybrid | Bottom-up | Bottom-up | IO | IO |
| CP01-02 | Food | 26,2% | 13,0% | 7,0%NA | 3,6%NA | 22,1% | 31,0% |
| CP03 | Clothing | 1,3% | 2,2% | 3,3% | 1,3% | 6,5% | 2,4% |
| CP04-05 | Housing | 40,8% | 54,3% | 58,8% | 53,5% | 33,4% | 23,6% |
| CP06 | Health | | 1,8% | | 0,3% | 0,3% | 1,6% |
| CP07 | Transport | 19,5% | 18,3% | 29,6% | 32,9% | 17,3% | 18,5% |
| CP08 | Communication | | | 0,0% | 2,9% | 0,0% | 2,1% |
| CP09 | Recreation | 7,2% | 8,1% | 0,0% | | 15,1% | 6,0% |
| CP10 | Education | | 1,8% | | | 0,7% | 0,5% |
| CP11 | Restaurants | | | | | 2,8% | 9,1% |
| CP12 | Miscellaneous | 5,1% | 0,4% | 1,3% | 5,4% | 1,8% | 5,2% |
| | TOTAL | 100,0% | 100,0% | 100,0% | 100,0% | 100,0% | 100,0% |

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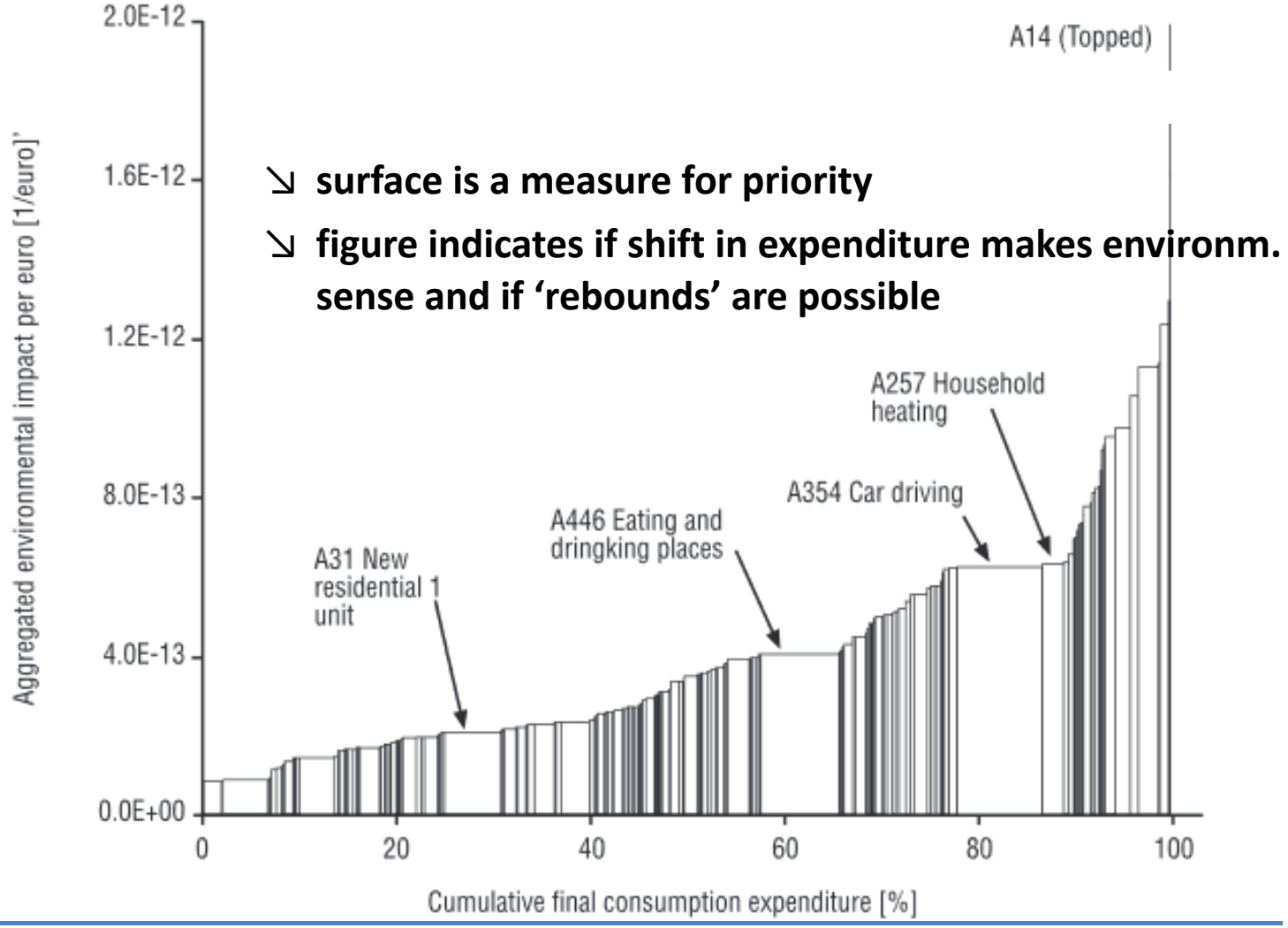
# Environmental Prioritization of Products (2/2)

*Figure 5.4.4: Environmental impact of final consumption, in ascending order of impact per euro: full set of product groupings*




- ↘ 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

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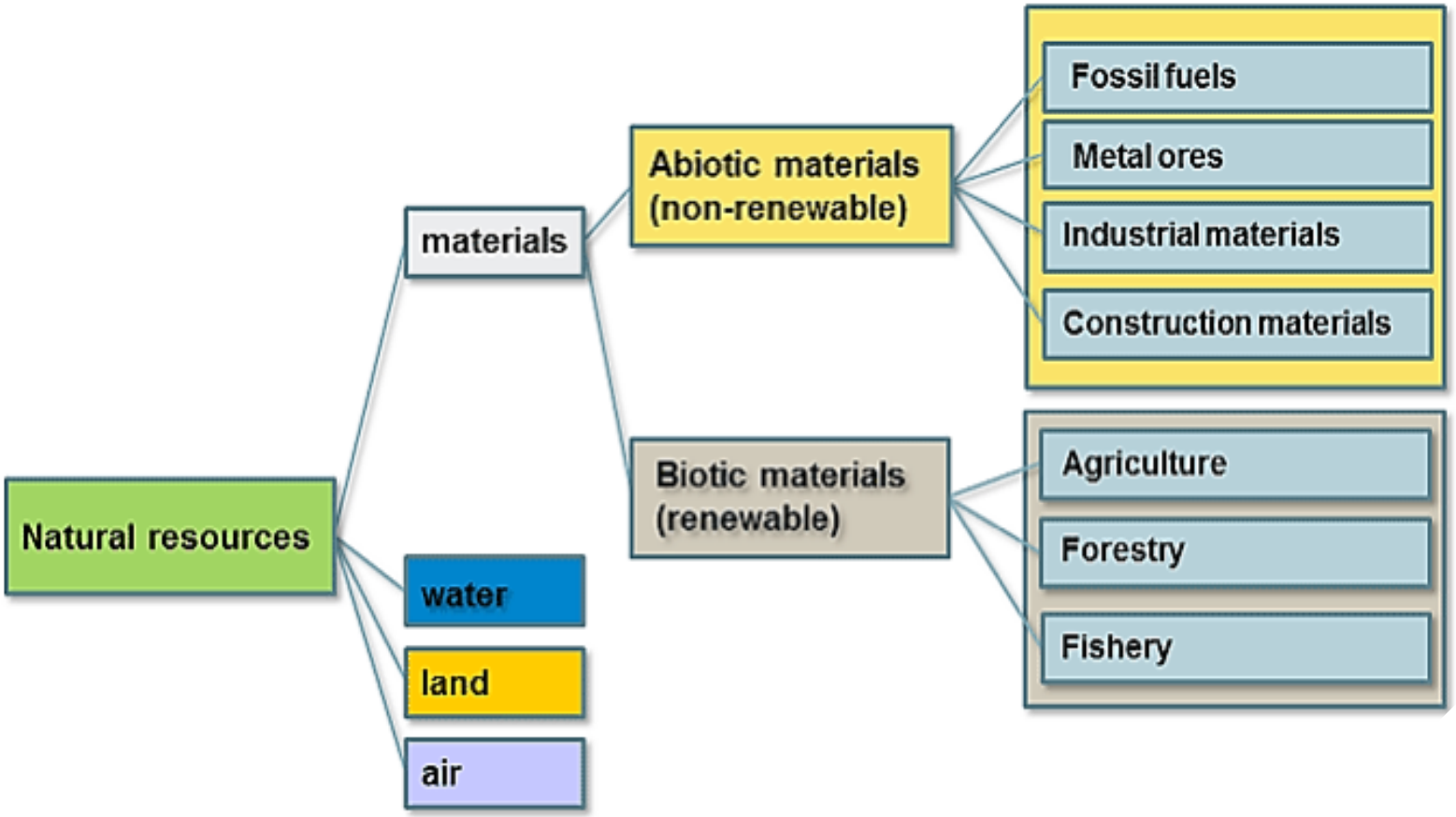
# National level resource accounting: System for Environmental & Economic Accounts (SEEA)




Source: UN System of Integrated Environmental and Economic Accounts (SEEA)

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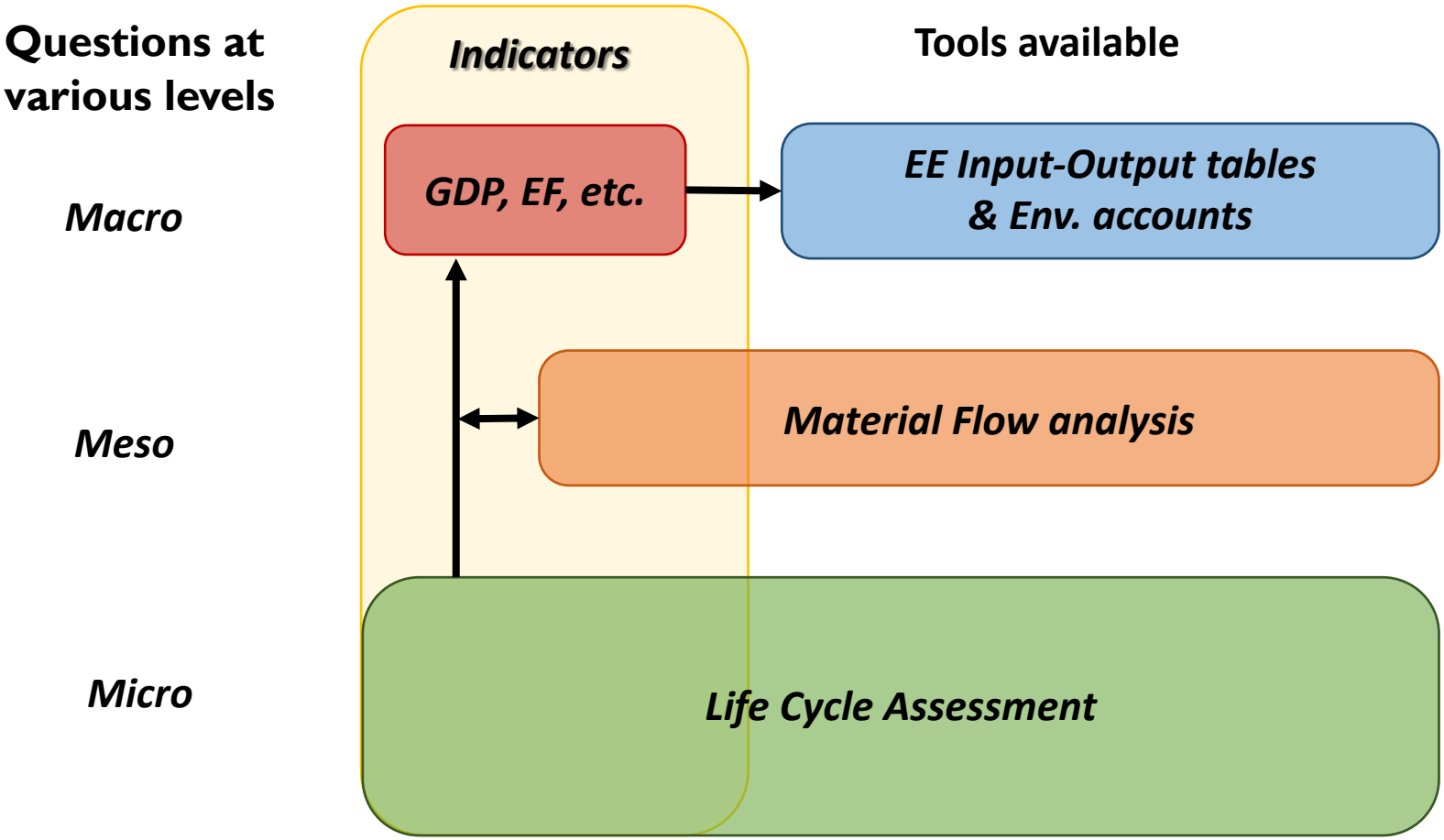
# Integration of tools at various levels




↘ **Different system analytical tools and a consistent set of indicators are necessary to ensure innovation moves towards a sustainability**

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# Lecture (II): Procedure, Application & Perspectives

4 Perspectives & conclusions

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- **Summary of the lecture**

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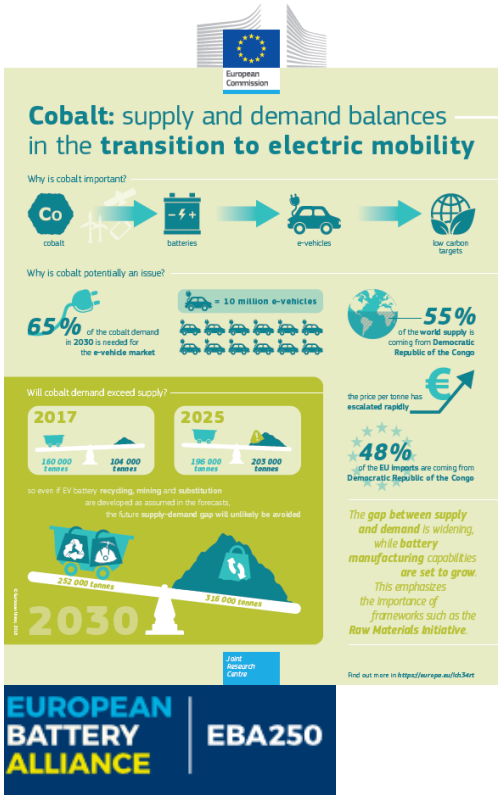
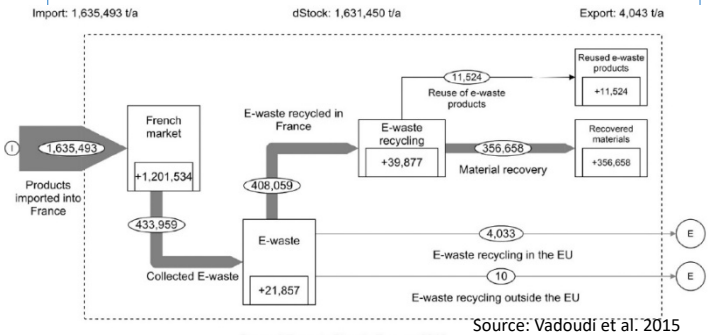
# Examples of potential student projects

## ❶ Cobalt (Co) in the European value chain of electric mobility




## ❷ Machinery tools in the French economy – Focus on the Tungsten




Source: Vadoudi et al. 2015

General E-waste Flow in France, 2010

## ❸ Supply of phosphate fertiliser: Potential of recycling from wastewater in Nouvelle Aquitaine region

**Phosphate fertiliser 'crisis' threatens world food supply**

**Use of essential rock phosphate has soared, but scientists fear it could run out within a few decades**

▲ Untreated phosphate in Western Sahara. Photograph: AFP/Getty Images

Source: the Guardian

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# Thanks for you attention

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