Resources and Raw Materials: Measurement of the Efficient Use and the Benefits of Closing the Loops

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&
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1. Background  
2. Resource efficiency  
3. Exergy as a base to quantify Resource efficiency  
4. Natural Resources versus Raw Materials  
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1. Background
FOCUS ON RESOURCES
LIFE CYCLE THINKING
THERMODYNAMIC PRINCIPLES
The mission of the IES is to provide scientific-technical support to the European Union's policies for the protection and sustainable development of the European and global environment.

Sustainability Assessment Unit:
- fosters sustainability principles in EU policies
- hosts the European Platform on Life Cycle Assessment (EPLCA).
EU “Raw Materials Initiative”:

- **Aim:** securing sustainable supply of raw materials
- **Launched in 2008, consolidated in 2011**
- **Non-energy, non-agricultural raw materials**
- **Connecting EU external and internal policies**
- **Integrated strategy (3 pillars)**
- **Introduced list of Critical Raw Materials (CRMs) in 2011 and 2014**

Ensure level playing field in access to resource in third countries

Foster sustainable supply from European sources

Boost resource efficiency and recycling
2. Resource efficiency
Resource efficiency = ______________________

Inputs/Burden/Impact

Benefits:
- Benefits: €? Kg? MJ?
- Inputs/Burden/Impact: What? From where?
A framework for Resource efficiency metrics:

<table>
<thead>
<tr>
<th>Fields of study: environmental science and engineering versus environmental policy</th>
<th>Level 1</th>
<th>Level 2 (Eco-efficiency)</th>
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<tbody>
<tr>
<td></td>
<td>Resource efficiency at flow level (RE-FL)</td>
<td>Resource efficiency at impact level (RE-IMP)</td>
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<tr>
<td>Benefits over resource flows (natural, waste or industrial)</td>
<td>Benefits over emission flows (often the reciprocal is used)</td>
<td>Benefits over impacts derived from the resource flows</td>
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<td>Benefits over impacts derived from the emission flows</td>
<td>Benefits over impacts from both resource and emission flows</td>
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<th>Micro-scale</th>
<th>Gate-to-gate perspective</th>
<th>Level 2 (Eco-efficiency)</th>
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<tr>
<td>Perspective</td>
<td>benefits over (kg) resources</td>
<td>benefits over (ADP) impact</td>
</tr>
<tr>
<td></td>
<td>benefits over (kg) emissions</td>
<td>benefits over (GWP) impact</td>
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<td></td>
<td>benefits over (kg) resources in life cycle</td>
<td>benefits over single score impact</td>
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<td>benefits over (kg) emissions in life cycle</td>
<td>benefits over single score impact in life cycle</td>
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<td>GDP over (kg) domestic extracted resources</td>
<td>GDP over domestic (ADP) impact</td>
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<td>GDP over (kg) global extracted resources</td>
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Only 2 universal units that are able to capture energy and mass:
- Economic sciences: €
- Natural Sciences : MJ_{exergy}

Source: Huysman et al., RCR, 2015a
3. Exergy as a base to quantify Resource Efficiency
What if our world were an infinite hazy desert? The sand and air are warm, an ocean of energy – energy everywhere. But if you try to use it, it doesn’t work. A landscape of uniformity, nothing concentrated, nothing unique.
Mankind uses these resources and brings them to the reference environment e.g. oil to CO₂, water from high to low, steam to water, ... (conservation of energy?)
**exergy** is a measure of work potential or disequilibrium from the environment.

While **exergy** can be destroyed, **energy** cannot.

**exergy** is the useful portion of **energy**.

**exergy** is what most mean when they say **energy**.
Efficiency analysis using exergy

2nd law of thermodynamics:
‘all real processes generate entropy’
‘all real processes generate loss of work potential’

Source: Dewulf et al. ES&T, 2008
Exergy analysis features: at process, gate-to-gate and cradle-to-gate level
Micro-level:
Product/process: gate-to-gate and life-cycle level

Approach:
- Industrial collaborations
- Micro-level
- Process based life cycle
- Exergy-based quantification

Overall resource efficiency:
Cumulative Degree of Perfection
Macro-level: Coupling EE-IO Databases with Exergy Accounting of Resources

Source: Huysman et al. ES&T, 2014
4. Natural Resources versus Raw Materials
Natural Environment: Asset of Natural Resources

Natural Resources

Primary Production

Raw Materials and Primary energy Carriers

Manufacturing

Products and Services

End-use

Waste

End-of-Life: energy and/or material recovery or disposal

Natural Resources:

Heterogeneous definitions:
- OECD:
  - asset in nature,
  - starting point econ. production
- EC 2005:
  - Source and sink functions (incl. ecosystem services)

Consequences of definition on:
→ ‘Resource’ efficiency
→ ‘Natural Resources’ as AoP in LCA

Natural Resource assets:
- Abiotic resources (stocks)
- Abiotic resources (flows)
- Air and water bodies
- Natural biomass
- Land and water surface

Sources: Dewulf et al., J. Ind. Ecol., 2015; Dewulf et al., ES&T, 2015
Raw Materials:

Heterogeneous definitions:

- As they occur in the natural environment, next to flow resources (EC 2005)

- Partially processed natural resources (e.g., chemical, high-tech raw materials), also even processed waste (e.g., scrap: so-called secondary raw materials) (EC 2008)

→ Need for common understanding

Sources: Dewulf et al., J. Ind. Ecol., 2015; Dewulf et al., ES&T, 2015
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Proposed definitions:

Primary:
- Raw Materials are result from primary production processes:
  - Mining
  - Growing
  - Harvesting
  - Refining
- Raw Materials are typical first market commodities
- Depending on future applications:
  - [Primary] [nonenergy] Raw Mat.
  - Primary energy carriers

Secondary: Waste:
- Source of secondary materials or of energy
- Enters operations like:
  - Recycling/Downcycling
  - Incineration

Sources: Dewulf et al., J. Ind. Ecol., 2015; Dewulf et al., ES&T, 2015
### Classification of primary raw materials:

- **85 raw materials (7 subgroups)**
- **30 primary energy carriers (5 subgroups)**

<table>
<thead>
<tr>
<th>ORIGIN OF RAW MATERIALS</th>
<th>RAW MATERIAL GROUP</th>
<th>#</th>
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</thead>
<tbody>
<tr>
<td>Terrestrial biomass (for material applications)</td>
<td>Agricultural raw materials</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Forestry raw materials</td>
<td>12</td>
</tr>
<tr>
<td>Aquatic biomass for food and material applications</td>
<td>Aquaculture raw materials</td>
<td>2</td>
</tr>
<tr>
<td>Water (components)</td>
<td>Freshwater raw materials</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Raw materials from seawater</td>
<td>3</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Raw Materials from atmosphere</td>
<td>3</td>
</tr>
<tr>
<td>Fossil fuels (for material applications)</td>
<td>Petroleum raw materials</td>
<td>5</td>
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<tr>
<td></td>
<td>Raw Materials from natural gas</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Raw materials from non-conventional fossil fuels (shale gas, oil sands, methane hydrates, coal bed methane ...)</td>
<td>3</td>
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<tr>
<td>Metal ores</td>
<td>Ferrous metals raw materials</td>
<td>8</td>
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<tr>
<td></td>
<td>Non-Ferrous bulk/traditional metal raw materials</td>
<td>6</td>
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<tr>
<td></td>
<td>Non-Ferrous rare metal raw materials</td>
<td>5</td>
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<tr>
<td></td>
<td>Non-ferrous precious/high tech metal raw materials</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Alkali metal raw materials</td>
<td>3</td>
</tr>
<tr>
<td>Natural deposits of industrial minerals and construction materials</td>
<td>Construction minerals and mineral materials</td>
<td>4</td>
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<tr>
<td></td>
<td>Industrial minerals and mineral materials</td>
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<tr>
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<td>Other</td>
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<table>
<thead>
<tr>
<th>ORIGIN OF PRIMARY ENERGY CARRIERS</th>
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<tr>
<td>Terrestrial biomass (for energy applications)</td>
<td>Energy crops</td>
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<tr>
<td></td>
<td>Forestry products (for energy)</td>
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<tr>
<td></td>
<td>Soil products</td>
<td>1</td>
</tr>
<tr>
<td>Aquatic biomass (for energy applications)</td>
<td>Aquaculture energy products</td>
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</tr>
<tr>
<td>Flow resources (solar, water, wind and geothermal)</td>
<td>Solar based energy carriers</td>
<td>3</td>
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<td>Hydropower based energy carriers</td>
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<td>Wind energy based energy carriers</td>
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<td>Tidal energy based energy carriers</td>
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<tr>
<td></td>
<td>Geothermal based energy carriers</td>
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<tr>
<td>Fossils for energy applications</td>
<td>Coal and lignite energy carriers</td>
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<tr>
<td></td>
<td>Petroleum based energy carriers</td>
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<tr>
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<td>Natural gas based energy carriers</td>
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<tr>
<td></td>
<td>Non-conventional fossil based energy carriers (shale gas)</td>
<td>1</td>
</tr>
<tr>
<td>Nuclear energy metal ores</td>
<td>Nuclear energy based energy carriers</td>
<td>2</td>
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Source: Dewulf et al., J. Ind. Ecol., 2015
5. Quantification of benefits of open and closed loop recycling
Context:
EU policy on Single Market for Green Products
Flemish Policy Support Centre: SUMMA

Goal:
Development and application of a framework for resource efficiency indicators of (plastic) waste stream recovery
Method relies on two principles:

- **Benefit rates (Ardente & Mathieieux, 2014):**

\[
R'_{\text{cyc,n}} = \frac{\sum_{i=1}^{P} \sum_{j=1}^{N} m_{\text{recycl},i,j} \cdot RCR_{i,j} \cdot D_{n,i,j} + \sum_{i=1}^{P} \sum_{j=1}^{N} m_{\text{recycl},i,j} \cdot RCR_{i,j} \cdot (V_{n,i,j} - R_{n,i,j})}{\sum_{j=1}^{P} \sum_{i=1}^{N} m_{i,j} \cdot V_{n,i,j} + M_n + U_n + \sum_{j=1}^{P} \sum_{i=1}^{N} m_{i,j} \cdot D_{n,i,j}} \cdot 100
\]

- Avoided Impact due to recycling
- Impact due to production of virgin material

Initially developed for product, here tailored for waste streams

- **Resource consumption quantified in MJ_{ex}**
Method defines different scenarios:
Case 1: Ekol: plastics in household waste
(±13000 ton per year processed, with PE/PP focus)

Benefit rates of recycling:
- 72.9%
- 1.28-1.64 kg oil equivalent per kg of pellets recycled

Sources: Huysman et al., RCR, 2015b; Van Eygen et al., RCR, submitted
Applications of pellets

Recycled PE/PP
Virgin PET
Concrete
Recycled PE/PP
Iron
Wood
Recycled PE/PP
Wood

Sources: Huysman et al., RCR, 2015b; Van Eygen et al., RCR, submitted
Case 2: Galloo: plastics in e-waste

(± 20000 ton per year)

Benefit rates of recycling of PS:
- 78.2%
- 1.32-1.84 kg oil equivalent per kg of pellets recycled
6. Conclusions

- Need for common understanding of:
  - *Natural Resources*
  - *Raw Materials*
  - *Resource Efficiency*

- Physical Resource Efficiency: role of exergy

- Importance of closing loops for resource efficient society, with need of metrics
Thank you for your attention!

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