Life Cycle Inventories of Different Types of Gold Extraction from Small-Scale Mining in the Amazonian Rainforest in Brazil

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### Overview and Introduction

<table>
<thead>
<tr>
<th>Research of the different types of gold production</th>
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<tbody>
<tr>
<td>Production routes are: Gold mining, refining of copper ores, Artisanal and Small Scale Mining (ASM), Waste Electrical and Electronic Equipment Directive (WEEE), recycling of high-value gold scraps</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Analysis of the LCA-Datasets for the material gold</th>
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<tbody>
<tr>
<td>No data for ASM (publication in progress) and recycling of high-value scraps (publication in review at JCP), very uncertain data for gold mining, refining of copper ores and WEEE (publication submitted)</td>
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<tr>
<th>Collection of primary data for production routes missing in LCA-Databases</th>
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<tr>
<td>Field trip to 11 ASM sites (Garimpos) in Brazilian Amazon Rainforest in September 2018, several factory tours of companies that recycle high-value gold scraps in Pforzheim, Germany</td>
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<th>Preparation of environmental analyses with Umberto for the missing production routes</th>
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<td>For ASM two inventories for Garimpos with and without the use of excavators were developed (publication in progress), for high-value gold scrap recycling a inventory and analysis for energy demand and CO₂-emissions was created (publication in review at JCP)</td>
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<th>Comparison with existing studies on the material gold</th>
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<td>First preliminary results for ASM show that its energy demand and CO₂-emissions are in the same ballpark as industrial mining while recycling of high-value gold scraps is significant better than all outer gold production routes.</td>
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<th>Analysis of technological changes in ASM in Brazil</th>
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<td>Mechanization of ASM processes lead to more deforestation through enhanced productivity. Rudimental cyanidation plants carries risks for Garimpeiros.</td>
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</table>
### Results

- **Gold mining, Process: Cyanidation**
- **Copper mining, Process: Pyrometallurgy**
- **Small scale Mining, Process: Amalgamation**
- **Recycling of jewellery, Process: Only smelting**
- **Recycling of WEEE, Process: Electrolytic refining**

The diagram illustrates the total supply of gold, with contributions from different mining and recycling processes. The processes are categorized as GaBi, ecoinvent v.3.5, and Own estimation. The percentages for each category are:

- **GaBi:**
  - WEEE: 3.0%
  - Copper: 0.2%
  - Small scale Mining: 27.0%

- **ecoinvent v.3.5:**
  - WEEE: 2.4%
  - Copper: 10.1%
  - Small scale Mining: 57.0%

- **Own estimation:**
  - WEEE: 0.7%
  - Copper: 21.5%
  - Small scale Mining: 9.1%

The diagram also notes that the recycling of jewellery involves smelting and aqua regia. Additionally, the recycling of WEEE involves electrolytic refining. The processes are marked with corresponding icons and notes, such as "publication in review at JCP" and "publication in progress."
Results

Clearing without or little mechanization

Removing the surface layer with water jet

Clearing with help of excavators

Removing the top layer with excavators.

Hosing auriferous soil

Cabe

Washing carpets

Retort

Low-value gold scraps

Preparation of scraps for aqua regia

Sweepings

Sweepings preparation

Low-value scrap preparation

High-value gold scraps

Granulation of high-value gold scrap

Case B

Case A

Water

Granulated

Aqua regia dissolving

Preparation

Gold dust

Gold (99.99% pure)

Treatment of waste water

Sweepings

Sweepings preparation

Low-value scrap preparation

Granulation of high-value gold scrap

Granulation of gold dust

Water

Publication in progress
Results

Source: ecoinvent v.3.5
Results

Technological improvements

🌈 Rebound-effect.

Excavators enable more efficient production -> faster gold extraction -> cutting larger areas of rainforest

Better pumps -> higher sedimentation of the rivers -> faster production -> cutting larger areas of rainforest

🌈 Symbiosis

Excavators for gold are used for building roads which are attractive for activities like soy or cattle farming.

Cyanidation in ASM context

🌈 Provisional pits, uncovered from rain and lined with plastic foils serve as tanks for cyanide leaching.

🌈 Mobilization and emissions of heavy metals and cyanide complexes in various process steps.

🌈 Garimpeiros without professional background working with highly lethal chemicals.
Conclusion

No LCA data for recycling of high-value gold scraps (more than 20% of world’s gold production) and ASM (around 10% of world gold production) in LCA databases.

Recycling of high-value gold scraps is significant better than all other gold production routes.

First preliminary results for ASM show that the environmental impact this activity is in the same ballpark as industrial mining.

Technological improvements in the context of ASM vs industrial mines require different consideration.

Outlook

We started to collect primary data in site visits and by distributing questionnaires about how much mercury is lost and recovered through distillation per amount of gold.

First and very preliminary results:

<table>
<thead>
<tr>
<th>Mercury recovered [g]</th>
<th>230</th>
<th>200</th>
<th>240</th>
<th>110</th>
<th>170</th>
<th>110</th>
<th>110</th>
<th>Ø 94 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury lost [g]</td>
<td>16</td>
<td>4</td>
<td>14</td>
<td>8</td>
<td>7</td>
<td>13</td>
<td>7</td>
<td>Ø 6 %</td>
</tr>
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Publications: High-value gold scrap recycling in review at JCP, analysis of gold in LCA datasets submitted, ASM topic in progress.
Sources

