Environmental Impact Indicators and Mining Method

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Background: Increasing attention onto mining environmental impacts

**Resource Efficiency & Sustainable Resource Use/Management?**

So many people have interests in mining’s environmental impact. Then, we’d better be equipped with the idea of how to measure it and communicate with non mining related people? If there is any indicator, which can summarize the impacts, it would be useful.

![Graph showing Resource Decoupling and Impact Decoupling](image)

*UNEP International Resource Panel Decoupling Report*
Comparison of multiple case for same mining method is relatively easy. But how about comparing open-pit mines against block-caving mines?
Objective of this study

**<Motivation & Research Questions>**

- Difference between two mining methods
  - \(\text{CO}_2\) emission: Different sources, need to be analyzed
  - AMD, vibration, noises: More site specific
  - Waste Rocks & Land-use change: Obviously "\text{OP}>\text{UG}\"
- But really large scale underground mining is more environmental friendly mining method?
  - Honestly, I don’t know.

**<Objective>**

- Explore whether there is any good *indicator, to measure the mining environmental impacts* reflecting the different *mining methods and site specific environment*.
  - Case study: Open-pit vs Block Caving
  - Indicators: TMR, \(\text{CO}_2\) emission, Ecological Footprint (and land use change)
## METHODS & RESULTS

<table>
<thead>
<tr>
<th>Copper Mines</th>
<th>Environment</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>Forestry</td>
<td>Open Pit</td>
</tr>
<tr>
<td>Mine B</td>
<td>No Green</td>
<td>Open Pit</td>
</tr>
<tr>
<td>Mine C</td>
<td>No Green</td>
<td>Block Caving</td>
</tr>
</tbody>
</table>
Indicators: TMR (Total Material Requirement)

Not every material-flow-based indicator measures environmental pressure. A precondition is that it always addresses physical interaction between the environment and the human sphere. In other words, it is a matter of system-boundary definition. (Bringezu et al. 2008)

\[
\text{TMR} = \text{DMI (Direct Material Input)} + \text{Hidden Flows}
\]

In the case of mining, not only ores but also waste rocks are included. In short, TMR is the weight of everything we excavate.

TMR in mine site can measure the size of our activities in the sense of the intervention onto environment by us, while at least this gives some ideas on the amount of waste rocks.
Indicators: $\text{CO}_2$ emission

Of course, $\text{CO}_2$ emission is not an indicator but just an inventory. However, this is one important inventory item, which we don’t know how much it is going to be changed by mining method therefore analyzed here.

**Source of the $\text{CO}_2$ emission at mine site**

- Surface mine
- Block Caving
  - Truck & other Haulage
  - Crushing (Mill)
  - Underground Haulage (i.e.) LHD
  - Crushing (Mill)

$\text{CO}_2$ emission tool for mine site: **MLED**

Land Use Change

✔ Method: Satellite Image Analysis
✔ In the case of mine A, which is located in a forestry area, bare land was detected using data from the red spectral band. Boundaries between bare and vegetated land were delineated by density slicing (Yamano et al., 2006) using threshold values determined by the Threshold Selection Method from Gray-Level Histograms of Otsu (1979).
✔ For mine A and B, the boundaries are defined manually by authors.
✔ Enclosed boundary lines, extracted based on these threshold values, were converted to polygons. The polygon areas were then calculated using ArcGIS version 10 (ESRI, Redlands, USA).
✔ Data: Landsat imagery (cloud-free)

In open-pit mining, the largest Built-up land is the one for the “pit.”

Even in the case of block-caving, we also need to evaluate the area of related facilities, which will be counted as Built-up land.
Indicators: Ecological Footprint

• EF analyzes our footprints in the following six land use categories
  – Built-up land
  – Forest land
  – Fishing Ground
  – Grazing Land
  – Cropland
  – Carbon Footprint

• Our objective is to analyze the footprint of the mining activity. Therefore we limited our analysis to built-up land only.

• Built-up lands for mining activities may be a good indicator of mining’s impacts onto local ecosystem.
Where
✓ A: the demanded area for the concerned activity for the land use type L
✓ EQF: equivalence factor, which is weighting factor between the land types.
✓ YF: yield factor, which is another weighting factor for country N to adjust the difference between countries.

Problems in EF with existing factors.
✓ EQF prepared by GFN (Global Footprint Network) assumes Built-up Land is located in an area, which previously was cropland.
✓ However, mine sites may locate various types of lands.
✓ Also, GFN’s land use consists of 6 and are not sufficient to reflect the local environment well.

We re-estimate EQF with NPP following Venetoulis and Talberth (2008).
✓ We assumed mine sites’ EQFs are equal to nearest land types’.
✓ 6 is not sufficient!; 13 land use types are prepared.
Result: Land Use Change and EF (Built-up land)

Land Use Change

A@ 2014 is 3 times larger than B @ 2013

EF (Built-up Land)

A@ 2014 is 20 times larger than B @ 2013
Result: CO₂ emission and TMR

<table>
<thead>
<tr>
<th></th>
<th>CO₂ emission</th>
<th>TMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>2.32 [CO₂ –kg/Cu-kg]</td>
<td>N/A</td>
</tr>
<tr>
<td>Mine B</td>
<td>1.38 [CO₂ –kg/Cu-kg]</td>
<td>348.98 [kg-TMR/kg-Cu]</td>
</tr>
<tr>
<td>Mine C</td>
<td>1.16 [CO₂ –kg/Cu-kg]</td>
<td>139.85 [kg-TMR/kg-Cu]</td>
</tr>
</tbody>
</table>

Even though all inputs’ rucksacks are accounted for TMR estimation, almost all of them are waste rocks, which were governed by grade and waste/ore ratio.

Regarding CO₂, mine A is located in a more mountainous area, which may force more energy consumption therefore more emission.

Mine B and C show similar values, though the details are different.
Conclusions

### CO₂ emissions
- Reflecting some details of operation

### TMR
- Works as pressure indicator to the environment and also reflecting volumes (3D)

### Land Use Change
- Area indicator (2D). Nice counterpart for TMR?

### EF (Build up land)
- Area indicator, considering local environment.

<table>
<thead>
<tr>
<th></th>
<th>Mining Method</th>
<th>Local Environment</th>
<th>AMD</th>
<th>Dynamic (not-static)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>○: OK</td>
<td>Δ: Reflect some?</td>
<td>×: No</td>
<td>×: No</td>
</tr>
<tr>
<td>TMR</td>
<td>○: OK</td>
<td>×: No</td>
<td>Δ: Possible?</td>
<td>×: No</td>
</tr>
<tr>
<td>Land Use</td>
<td>×: not suitable UG</td>
<td>×: No</td>
<td>×: No</td>
<td>○: Yes</td>
</tr>
<tr>
<td>EF (BUL)</td>
<td>Δ: not suitable UG</td>
<td>○: Yes</td>
<td>×: No</td>
<td>○: Yes</td>
</tr>
</tbody>
</table>
Conclusions

**CO₂ emissions**
- Reflecting some details of operation

**TMR**
- Works as pressure indicator to the environment and also reflecting volumes (3D)

**Land Use Change**
- Area indicator (2D). Nice counterpart for TMR?

**EF (Build up land)**
- Area indicator, considering local environment.

- EF (Built-up land) showed some potential. Though, the factors prepared by GFN are not useful for this kind of microscopic analysis, therefore we need some adjustment.
- TMR could be nice complement for EF (Built-up Land) because of its 3D nature.
- CO₂ emissions give you some idea on operation.
- Dynamic aspects of mining are not well reflected in most indicator. (EF does.)
THAT’S ALL. THANKS FOR LISTNING.
SUPPLEMENTARY SLIDES
Sustainable Resource Use/Management

Reducing Resource Use as much as possible

If use, as green as possible

More Interest in mining impact
From many researchers and others...

Human Well-Being

Economic Growth

Resource Decoupling
(dematerialization: 脫物質化)

Resource Use

Impact Decoupling

Associated Environmental Impact

Time

Impact Decoupling

UNEP International Resource Panel Decoupling Report
Validation:
EF with Global Footprint Network factors vs this study

**EF with GFN**

- **EF-NPP**

- **A**
- **B**
- **C**
鉱山Aのポリゴン作成手順
鉱山B、鉱山Cの面積測定

鉱山B、Cでは周辺環境に植生が存在しておらずしきい値の設定が困難であった。そのため面積の過大評価とならぬように注意しながら目視によりポリゴンを作成した。
鉱山Aの緑化面積の測定

① 各年の画像を古いものを下にして重ね合わせた。
② 目視で確認した緑化箇所と一致したことを確認した
③ 各年の緑化箇所を切り取った

ある年では裸地の部分が2014年には植生が回復していることが確認出来る。この面積を緑化面積とした。
鉱山Aの緑化箇所の確認

緑化箇所を目視による確認を行った