Gaia versus Thanatia: the twilight of the Earth’s mineral resources

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200 people working together for innovation and sustainable development
Gaia versus Thanatia: the twilight of the Earth’s resources

Contents

- Facts
- Questioning the myths surrounding scarcity of mineral resources
- Thanatia as the twilight of the Earth’s mineral resources
- Final reflections
1. KNOWN FACTS...
Exponential consumption trend of minerals

Figura 1: Producción de arrabio (ton.) a lo largo del siglo XX. Datos USGS

Figura 2: Extracción de Aluminio (ton.) a lo largo del siglo XX. Datos USGS

Figura 3: Extracción de Cobre (ton.) a lo largo del siglo XX. Datos USGS

Figura 4: Extracción de Cromo (ton.) a lo largo del siglo XX. Datos USGS.
Exponential consumption trend of minerals

Almost the entire Periodic Table is being used...

Elements used in the production of components for computers

Source: Adapted from different sources
New materials for the Green Economy

- ICT’s ↔ PGM, Au, Sn, Nb, Ta
- Biomass ↔ P
- Wind ↔ permanent magnets: Nd, Dy, Pr, Sm and Co
- Photovoltaics ↔ In, Te, Ga, Ge, As, Gd, Cd
- Compact Fluorescent Lamps & Leds: Y, Eu, Tb In, Sn, Hg, Ga
- Batteries ↔ Ni, Mn, Co, Cd, La, Ce, Li
- High Efficient Turbines (aero & stat) ↔ Co, Nb, V, Re
- Electric Vehicles ↔ La, Ce, permanent magnets,
- SOFC H2 ↔ Pt, Pd
- Catalysts ↔ Pt, La, Ce
- Ce for polishing hard disks.
- Nuclear ↔ In, Hf, Re, Zr, U
Critical metals for the EU

Source: EC (2010). Critical Raw materials for the EU
Example: In and PV

- Today only 0.1% of electricity supply but in 2050 11%. IEA
- Grid parity 1€/kWp
- New PV technologies CdTe, CuInSe$_2$, CuGaSe$_2$, CIGS

**Indium critical**

- Geological 94%
- Ecological 79%
- Economical 56%
- Technical 82%
- Political 59%

*Source: Goessling-Reisemann ISIE 2011*  
*Source: SunShot Vision Study U.S. Department of Energy, 2012*
Yet very little is being recycled...

The case of Aluminium

Source: Gerber (2007): Strategy towards the red list from a business perspective
From availability to accessibility - insights into the results of an expert workshop on "mineral raw material scarcity"
Environmental and social impacts

- Environmental impacts
  - Air
  - Water
  - Landscape
  - Biodiversity
  - Climate change
  - Wastes/Reserves

- Impacts on local communities

<table>
<thead>
<tr>
<th>10 most polluted places in the World (2000)</th>
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<tbody>
<tr>
<td>1. Chernobil (Ucrania)</td>
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<td>2. Dzerzhinsk (Rusia)</td>
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<td>3. Haina (República Dominicana)</td>
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<td>4. Kabwe (Zambia)</td>
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<td>5. La Oroya (Perú)</td>
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<td>6. Linfen (China)</td>
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<td>7. Mailuu-Suu (Kirguistán)</td>
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<td>8. Norilsk (Rusia)</td>
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<td>9. Ranipet (India)</td>
</tr>
<tr>
<td>10. Rudnaya Pristan (Rusia)</td>
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</tbody>
</table>
Environmental and social impacts

La Colosa (Colombia)  
La aldea de Salave (Asturias)
**Facts**

- 3.5 billion tons of metals and industrial minerals in 2008 => at least 6x more waste rock.

- By 2050 Consumption = 5x current consumption => Demand for important ones such as Au, Ag, Cu, Ni, Sn, Zn, Pb and Sb will be greater than reserves (Halada, 2008).

- Yet mining sector only contributes to 0.5% direct employment and 0.9% of gross world product (Sampat, 2003).

- Mining uses between 8-10% of global energy consumption (IEA)

- Responsible for 13% of global SO2 emissions

Sampat, P. State of the World 2003 Scrapping mining dependence World Resources Institute, 2003, 111
Reflections

- Can Gaia absorb all environmental impacts associated with Man’s development?
- Are there enough energy and mineral resources to sustain unlimited growth?
- Will ingenuity through technological development outrun any existing and/or future problems?
- 40 years after “The Limits to Growth” by Meadows et al.
2. QUESTIONING THE MYTHS
SURROUNDING SCARCITY OF MINERAL RESOURCES...
Can Gaia absorb all environmental impacts associated with Man’s development?

- Declining ore grades are forcing higher impacts on environment. The low hanging fruits have already been collected. => A depth of “r” implies an extraction of $1/3\pi r^3$.

- The Nimby effect: Not in my backyard!

- Remote areas, Rain forests, Arctic and the permafrost periglacial cape. Extremely deep mining and oceanic mining.

- Underdeveloped countries
OLYMPIC MOTTO:
CITIUS, ALTIUS, FORTIUS

MINING MOTTO:
Quicker, Deeper, Stronger
Are there enough energy and mineral resources to sustain unlimited growth?

- YES!?, but exponential growth requires exponentially new mines and exponential amounts of energy, water, environmental, social and economic impacts.

- Energy may come from the Sun or from Nuclear fusion in the long term.

- The crust is plenty of minerals: Mass does not disappear BUT disperses.

- Can Man afford to extract critical elements from Barerock? At what cost?
Are there enough energy and mineral resources to sustain unlimited growth?

- A mineral deposit is a rarity in the Earth’s crust.

- Only when a combination of natural processes has worked together to produce an enrichment, is an ore to be found.

- These complex processes operate very slowly compared with the life-span of humans.

All concentrated mineral resources of fuel and non-fuel origin represent only 0.001% of the Earth’s upper continental crust total mass.
Will ingenuity through technological development outrun any existing and/or future problems?

- The role of technology in the minerals industry has allowed to save energy and reach greater depths and more remote sites:
  - Breakthrough in mineral exploration: emergence of geophysics, drilling, remote sensing, bio-prospecting, etc.
  - Increasing mechanisation in underground mining allows to reach greater depths.
  - In open cut mining: increasing truck sizes, safer and cheaper explosives and cheap diesel fuel
  - Refining: flotation, gravity and densemedia separation, carbon-in-pulp and heap leaching solvent extraction, electrowinning...
Will ingenuity through technological development outrun any existing and/or future problems?

- Two effects on the energy consumption associated with mining. Which is winning the race?

  - Declining ore grades
  - Technological development
Will ingenuity through technological development outrun any existing and/or future problems?

Ore grade decline in Australia’s main commodities (Mudd, 2010)

Will ingenuity through technological development outrun any existing and/or future problems?

- According to our studies carried out for gold (Domínguez and Valero, 2013):
  - Although progress in technology has been made, in most cases energy requirements are increasing, because the main variable is the ore grade.
  - Technology cannot in general overcome the rising energy demand for gold mining.

Figure 3.16: Progress ratios for gold mines in United States of America.
Answers in conclusion

- We cannot overcome the limits of the Planet
- We cannot overcome the Second Law of Thermodynamics: Energy degrades and mass disperses
- Urgent tools to rigorously assess the degradation velocity of the Earth’s resources is required: A planetary life cycle assessment
3. THANATIA AS THE TWILIGHT OF THE EARTH’S RESOURCES
Planetary LCA

Cradle

GRAVE
THANATIA as a possible end of the Earth’s resources.

- Thanatia as indicated by the Greek “θάνατος” represents death.

- We can imagine a possible state of the Earth when all commercially exploitable resources have been consumed and dispersed. A possible end to the “anthropocene period”.

- Thanatia, constitutes the starting point for assessing the loss of mineral endowment on Earth.
What is Thanatia?

**THANATIA ATMOSPHERE**
- An atmospheric injection of about 2,000 GtC.
- Carbon dioxide content of 683 ppm, a mean surface temperature of 17 °C (peak carbon dioxide induced warming of 3.7 °C above preindustrial temperatures),
- A pressure of 1.021 bar and a composition, on a volume basis of 78.8% N₂, 20.92% O₂, 0.93% Ar and 0.0015% of trace gases.

**THANATIA HYDROSPHERE**
- Freshwater amounts about 2.5% of global water.
- Freshwater is expected to increase its content of nitrogen, phosphorus, heavy metals, organic substances, sulphates and other components as population grows and climate changes.
- Most of Ice Caps melted
- The changes in freshwater composition should not affect significantly the composition of the ocean. Therefore, the composition of the exhausted hydrosphere can be approximated with high confidence to that of seawater.

**THANATIA CRUST**
- The upper continental crust can be approximated to the average mineralogical composition of the current earth's crust. The resulting crust is composed of 292 common minerals
  - All resources have been extracted and dispersed
  - All fossil fuels have been burned.

# The Crepuscular Continental Crust

<table>
<thead>
<tr>
<th>Name</th>
<th>Abundance, mass %</th>
<th>Name</th>
<th>Abundance, mass %</th>
<th>Name</th>
<th>Abundance, mass %</th>
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</table>

Thanatia as the twilight of the Earth’s mineral resources

By postulating Thanatia we can quantify a thermodynamic limit of the Earth, and thus assess its Mineral Capital and its degradation velocity.
Thanatia as the twilight of the Earth’s mineral resources

From GRAVE to CRADLE

- In order to assess depletion

- Replacement is the key! => What would it cost to replace with current technology the mineral wealth of the planet that Man extracts, uses and finally disperses?
**Cradle to entry gate**
- Man-made stock
- Man-made mining and refining process

**Entry gate to exit gate**
- Useful products

**Grave to cradle**
- Natural stock
- Natural conc. and refining process
- Mineral deposits
- Minerals
- Fuels

**Exit gate to grave**
- Use and dispose of materials
- Recycling of materials
- Landfills
- Materials dispersion and pollution

**Mining and refining costs**
- Avoided costs/mineral bonus

**Reference Environment**
- Zero Exergy

**Exergy/Exergy cost**

 Grave-cradle approach

How much is the loss of the mineral exergy endowment of the Earth?

Grave-cradle approach

- How much is the loss of the mineral exergy endowment of the Earth?

![Pie chart showing the loss of mineral exergy endowment: 36% for non-fuel minerals, 25% for oil, 18% for natural gas, 26% for coal, 6% for smelting and refining, and 1% for mining and concentration. Source: A. Valero and A. Valero (2014). Thanatia: the Destiny of the Earth’s mineral resources. World Scientific Publishing.]
SETEA: New system of environmental accounts

- Would you sell the towers of a cathedral at the price of its constituent bricks?

- GDP and other economic indicators do not take into account the fact that future generations won’t have those “monuments” created by Nature (mineral resources).

- We propose a new system of environmental accounts based on the UN’s SEEA => SETEA (thermoeconomic accounts)
The exergy countdown - Reserves

The exergy countdown - Resources

The exergy countdown - Resources

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Reserves Peak</th>
<th>$R^2$</th>
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<th>$R^2$</th>
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<td>2159</td>
<td>0.31</td>
<td>-</td>
</tr>
<tr>
<td>Potassium</td>
<td>2072</td>
<td>0.91</td>
<td>2272</td>
<td>0.88</td>
<td>-</td>
</tr>
</tbody>
</table>

The exergy countdown - Conclusions

- Most commodities may peak before the end of this century
- Considering world resources instead of reserves shifts the peak 50 years on average
- Some commodities have already peaked!
4. FINAL REFLECTIONS
Final reflections

1) Our planet is headed toward mineral depletion (best ore grades have been extracted and are dispersed in the biosphere)

This is not fatalism but science. It is Thermodynamics
Final reflections

2) This progression is unyielding and the human action is accelerating it.

The way back can only be attained by the Sun’s action and the internal heat of Earth during eons.

Yet technology exhausts mineral resources over human time scales.
Final reflections

3) This progression could be decelerated by an appropriate and global management of our abiotic resources.

Global vision and global decisions are required. Unfortunately these needs are far removed from the current political thinking.
Final reflections

4) Efficiency in the use of materials and their systematic recycling are mostly needed but they are insufficient.

We need to place limits on greed and the plundering of non-renewable materials currently considered as inexhaustible and cheap.
Final reflections

4) “Efficiency and Sufficiency” are both needed, this implies that “Technology and Ethics” are both required.

Technology is never sufficient and in many cases it is more destructive than creative.
5) The Circular Economy is a beautiful myth, but the Second Law of Thermodynamics is unavoidable:

“In each material cycle something is lost because one cannot afford complete and cheap recycling. We can only yearn for a Spiral Economy, with the largest number of turns, but in the end spirals get diluted into Thanatia”

We propose a fractal tree for each chemical element.
Final reflections

6) The continuous declining of ore grades induces an increase in the energy, environmental and social costs of extracting the next tonnage of minerals that irreversibly induce an acceleration of the Planet’s deterioration.

This acceleration can be rigorously calculated in kJ units applying the proposed thermodynamic theory.
Final reflections

7) There is an “Exergy Countdown”, that allows quantifying the degradation rate of our Planet´s mineral endowment in exergy units.

The accounting of this loss and the sense of having a not-so-far expiry date gives maturity to humankind and supports improved management of those remaining resources. This vision could even affect our world´s perception.
Final reflections

- It is the hour for humanity to begin to adequately manage its non-renewable resources with intelligence and order, so that however finite they can be accounted for, as can their loss.

TIME IS RUNNING OUT, LET’S FLIP THE HOUR GLASS!!!
Sustainability is a journey, Thanatia a destiny!

On youtube (Spanish): https://www.youtube.com/watch?v=M6qi4bKRPe0
On youtube (English): https://www.youtube.com/watch?v=76eUJxPaqFU
THANK YOU VERY MUCH FOR YOUR ATTENTION

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