Ressources Minérales pour les ENergies Renouvelables

Olivier Vidal, CNRS, Isterre
olivier.vidal@ujf-grenoble.fr

MI 24/03/2015
Population

Energy

Population growth and energy consumption over time.

Global warming and carbon emissions.
The available global energy scenarios rely on a strong increase in the share of solar and wind energy.
Solar and wind sources are diluted and require large facilities.

Latest wind turbine generation:
6 Mw, basement at 60 m depth, rotor > 150 m, >1500 t of steel

800 of such wind turbines are necessary to produce the same energy (Wh) as a 1300 MW nuclear plan.

Steel intensity (t/MW capacity):
- Wind: 250 t/MW
- Nuclear: 60 t/MW
- Hydro: 20 t/MW
In 2050, the cumulative amount of concrete, steel, Al, Cu and glass sequestered in wind and solar facilities will be 2 to 8 times the 2010 world production.
Population

Energy

Base metals
The energy-raw materials nexus

Need of metals to produce energy

Need of energy to produce metals

- “21% of the global energy consumed by the industry in 2011 was used for the production of steel + cement” (International Energy Outlook 2013)

- “Energy consumption and intensity in mining and mineral processing is rising at around 6% per annum” (Australian Bureau of Agricultural and Resource Economics - 2010)

- “1 tCO₂ is generated for 1t of produced concrete” (Natesan et al., 2003) and about 2 t CO₂ are generated for 1 t of produced steel.
Objectifs du projet ReMinER (focalisé sur les énergies renouvelables):

- Quelle **intensité matérielle** pour produire l’énergie, stocker et transporter l’énergie ? Spécialistes des technos actuellement en développement, ingénierie et processus.

- Quelle **intensité énergétique** pour produire les métaux ? Spécialistes de l’industrie extractive.

- Quels impacts **économiques et sociaux** ? Economistes et sociologues/géopolitique.

- Quelles **réserves et ressources primaires et secondaires** ? Sciences de la terre.

- Quels sont les **flux de matière** ?

- Compilation et intégration des données: création d’une **base** de format Wiki. Compétence en gestion de bases de données.

- Intégration dans un **modèle dynamique** et contraint par des données historiques, pour modéliser les tendances futures. Compétences en modélisation dynamique.
1) Material intensity of fossil and renewable energy production facilities
1) Material intensity of fossil and renewable energy production facilities

Impact of new technologies
1) Material intensity of production facilities

Systèmes et composants…

Falconer 2009 (HV connection)

Connected wind turbine farm

Wind turbine component

Material intensity of production facilities

Hydropower, Nuclear, Gas, Coal, W land, W sea, PV roof, PV fixed, PV tracker, CSP
1) Material intensity of other energy sectors
1) Material intensity of storage and transport. Cu example

- For a storage capacity = 10% of the production capacity -> 0.5 to 2 Mt Cu

- 45000 km of new HV network until 2030 -> 0.5 to 2 Mt Cu (Ten Year Network Development Plan)

- 100 millions hybrid and electric vehicles in 2035, (60 kg/vehicle) -> 6 Mt Cu
  => 175 kt Nd

Sum: 10-20 Mt Cu (2050) to be added to the 50 Mt estimated previously.
  4 ans de production I annuelle mondiale
2) Energy intensity of metal production

Ore grade vs time

Energy vs ore grade

Figure 2 – Copper ore grades over time by country and approximate world average
2) Energy intensity of metal production

Improvement of technology and energy efficiency + secondary production
3) Enjeux géopolitiques, économiques & sociaux

1) l’organisation des filières en Europe & France,
2) les évolutions de la demande et la géographie de l’offre,
3) l’anticipation d’éventuels conflits locaux associés à l’exploitation minière.

Cu, Fe, Li, Ga

Social and industrial development — Demand — Price

Investment and production cost

Resources and reserves — Debt
4) Modelling the whole value chain: In contrast to oil & gas, metals can be recycled (secondary reserves)

- Extraction
- Concentration
- Purification
- Recycling
- EOL
- Use

Resources (réserve)
Integration of data: Dynamic Modelling (prey-predator model)

\[
\frac{ds_{\text{sheep}}}{dt} = \text{sheep}(t) \times (\text{birth rate} - \text{wolves}(t) \times \text{predation rate})
\]

\[
\frac{dw_{\text{wolves}}}{dt} = \text{wolves}(t) \times (\text{sheep}(t) \times \text{delta} - \text{death rate})
\]

**Number**

**Time**
Prey-predator modelling

Increase of reserves (I) due to lowering ore grade \( R(t) = R_{1900} \exp(\tau t) \), equivalent to the regeneration of renewable resources.

Resource

« Wealth »
(Capital, labour, infrastructure, energy, etc)

Demand

\[
\frac{dR}{dt} = R(t)\tau - C(t)\beta(t)
\]

\[
\frac{dW}{dt} = W(t)(R(t)\delta - \gamma)
\]

\[
\frac{dD}{dt} = D(t)\tau
\]

Efficiency of wealth to extract the resource.

Erosion of capital
Integration of data: Dynamic Modeling (prey-predator)

Recycling

Wealth II

EOL

Delay (life time)

Products made of II

Lost

Ore grade

Reserves I

Products made of I

Wealth I

Primary extraction

Energy I

Technology

Demand

Energy II

Technology

Demand

Integration of data: Dynamic Modeling (prey-predator)
The copper example: reserves (primary) and ore grade

The model fits the historical reserves

The model fits the historical data of production

Ore grade

secondary production
primary production
Total production

Note: Rise in ore grade in Australia from 1972 onwards resulted from the startup of the high-grade Olympic Dam mine.

The copper example: secondary flows and stocks

Data from Glöser et al. (2014)
Long term trends (flow)

Demand > supply?

Recycled Cu in products
EOL

Primary Cu in products

Not recycled

Long term trends (stocks)

The model fits evolution of production predicted by Northey et al. (2013)

Mohr model, which aggregates detailed logistic data from each copper producing country to form planet-wide trends

https://lasttechage.wordpress.com/2014/02/26/is-copper-entering-crisis-mode/
The model predicts variations of « Wealth » equal to the variations of world real GDP and realistic production costs.

Correlation Wealth (I) - GDP variations Between 1970 and 2010
Postponing the shift towards renewable energy costs energy!
The evolution of raw material prices following a possible decline of production in a context of rising demand would have a dramatic effect on our capacity to achieve the energy transition.

Postponing the shift towards renewable energy costs energy!

Waiting longer makes little sense because if demand continues to rise, the primary metal required to build the infrastructure might become difficult to find, and it is likely to become expensive (copper is hardly substitutable).
2015

• Première version de la base de données Wiki en ligne - NoSQL database pour gérer les LCI-LCIA et les intensités en ressource des secteurs de production d’E:

Les bases existantes (e.g. Ecoinvent, ELCD, GaBi, NEEDS) ont des formats différents (ecospold1, ecospold2, ILCD, SimaPro CSV, etc.) et sont difficiles à désagréger. Structuration en une base unique avec représentation ontologique, meilleure adéquation requêtes - besoins.

• Economie: Modèle économique type Goodwin Keen avec matrices d’I/O qui sera incorporé au modèle dynamique + approche indépendante en Equilibre Général Calculable.

• Géopolitique/Socio : organisation des filières en Europe & France, évolutions de la demande et la géographie de l’offre, anticipation d’éventuels conflits locaux associés à l’exploitation minière: Cu, Li

• Modélisation dynamique: Intégration du module économique et application en régional, extension aux petits métaux. Lien réserves - prix – Energie - coûts de production
The evolution of raw material prices following a possible decline of production in a context of rising demand would have a dramatic effect on our capacity to achieve the energy transition.

Postponing the shift towards renewable energy costs energy!

Waiting longer makes little sense because if demand continues to rise, the primary metal required to build the infrastructure might become difficult to find, and it is likely to become VERY expensive (copper is hardly substitutable).
Total Energy

Energie production II : Current
Energie production I : Current
"Energie production I + II" : Current

Postponing the shift towards renewable energy costs energy!

Waiting longer makes little sense because if demand continues to rise, the primary metal required to build the infrastructure might become difficult to find, and it is likely to become expensive (copper is hardly substitutable)
Energy production: 0.15 – 1% increase of the present raw materials production each of the next 40 years...

In addition to base metals there a need of «scarce metals» in increasing quantities.

Between 2010 and 2030, the yearly global demand in Ga, In, Se, Te, Dy, Nd, Pr et Tb for solar and wind facilities could be boosted to 10 to 230% of the 2010 world supply.
Prey-predator modelling

\[
\text{dsheep}/\text{dt} = \text{sheep}(t) \times (\text{birth rate} - \text{wolves}(t) \times \text{predation rate})
\]

\[
\text{dwolves}/\text{dt} = \text{wolves}(t) \times (\text{sheep}(t) \times \text{delta} - \text{death rate})
\]

Increase of reserves (I) due to lowering ore grade \(R(t) = R_{1900}\exp(\text{taux}\times t)\), equivalent to the regeneration of renewable resources.

\[
\text{dR}/\text{dt} = R(t) \times (\text{taux} - C(t) \times \beta(t))
\]

\[
\text{dC}/\text{dt} = C(t) \times (R(t) \times \text{delta} - \gamma)
\]

Efficiency of wealth to extract the resource.

\[
\text{dD}/\text{dt} = D(t) \times \tau
\]

Erosion of capital

Resource

« Wealth »

(Capital, labour, infrastructure, energy, etc)

Demand
Can we make it ? and where ?
Recycling will be fed by EOL products. We should keep them at home instead of exporting them abroad!

In the US, it is estimated that 50-80 percent of the waste collected for recycling is being exported to India, Africa and China.
China import of scrap and waste Cu: about 4 Mt/a (global EOL flow = 10 Mt/a)

Chinese refinery devoted to the extraction of copper from e-waste.


it is cheaper to export e-waste to developing countries than it is to locally recycle (yet).
- In 2005, inspections of 18 European seaports found that approximately 47% of exported waste was illegal
- 75% of the exported e-waste are working machines

http://shanghaiscrap.com/2013/09/page/2