System Dynamics Thinking and its contribution to Geophysical Economics : Modeling long-term trends in Structural Raw Materials Supply, Demand and Pricing

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Growth and Raw Material Consumption

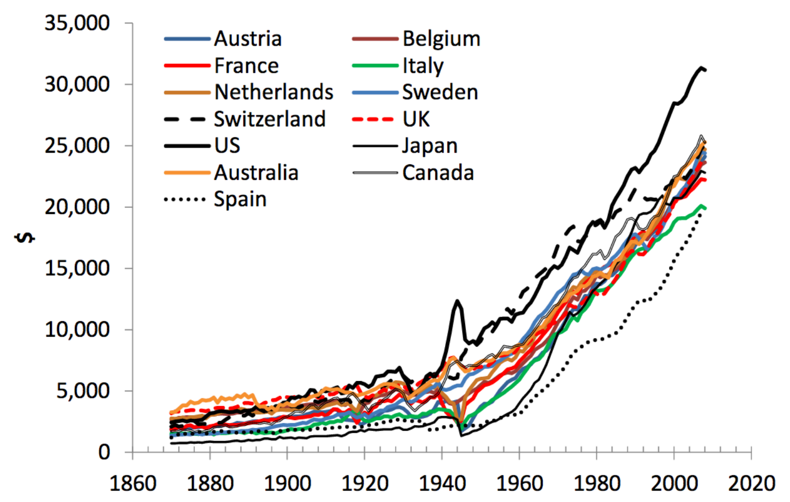
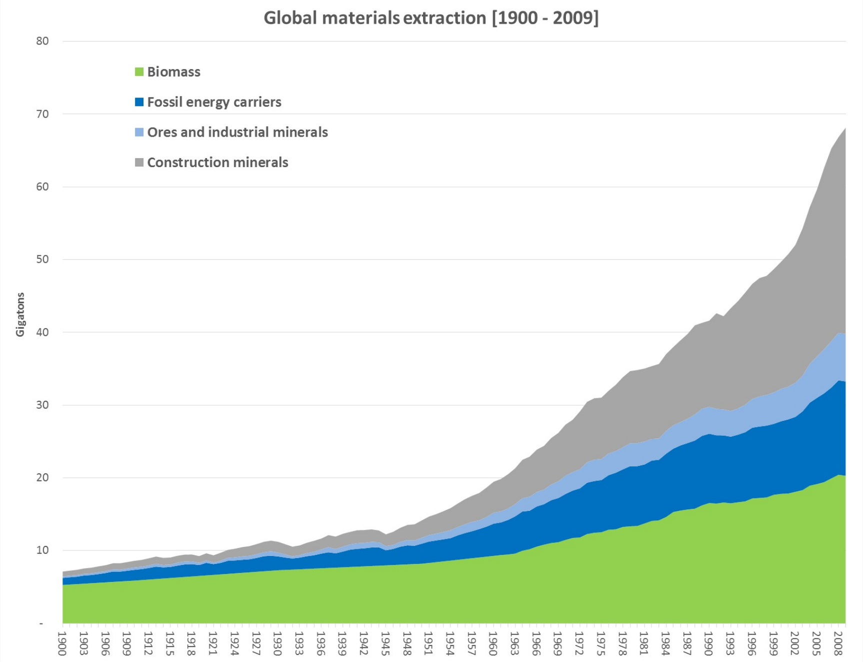


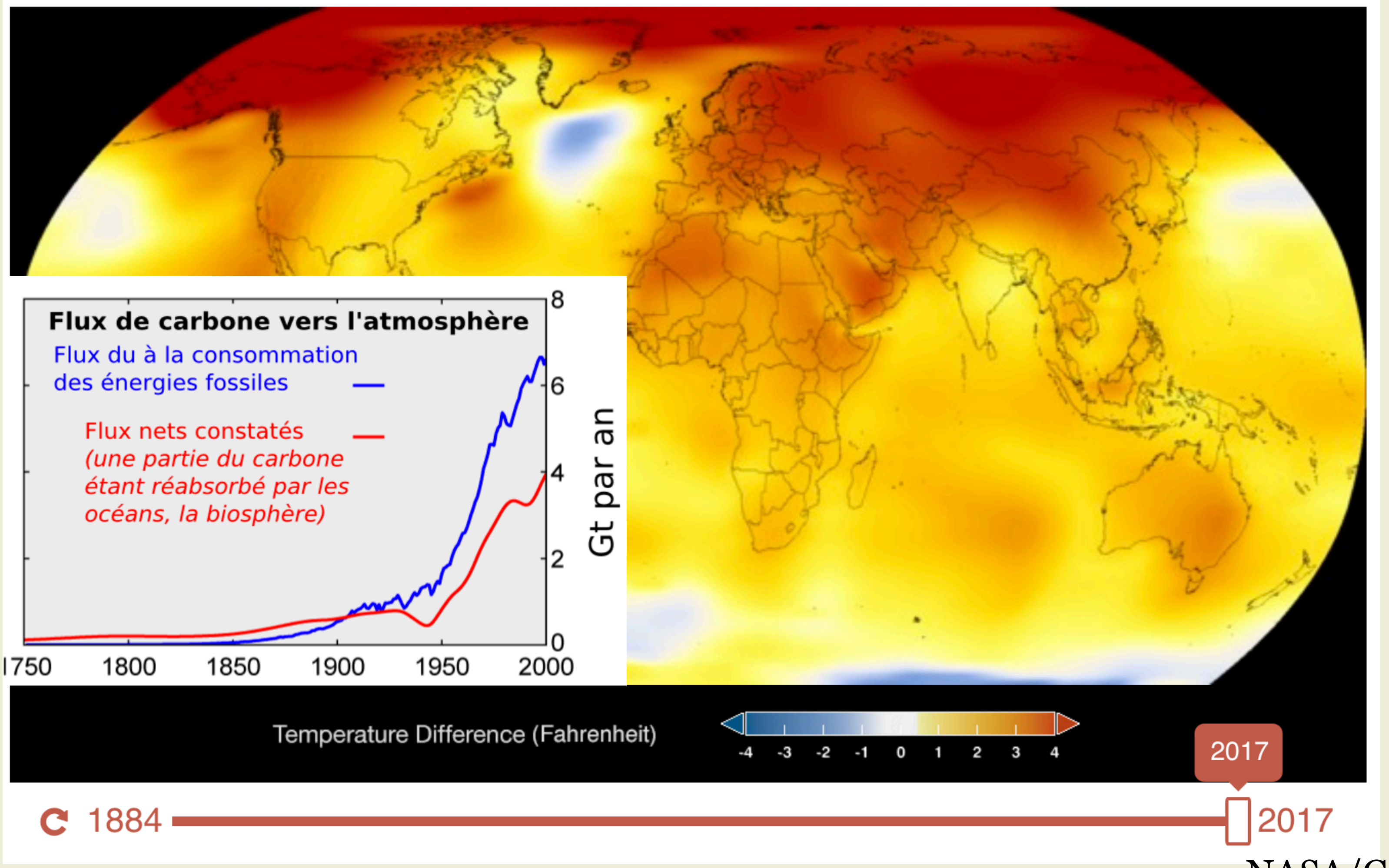
Figure 2. The evolution of real GDP per capita in thirteen developed countries.



GDP/cap in OECD (I. Kitov, 2012)

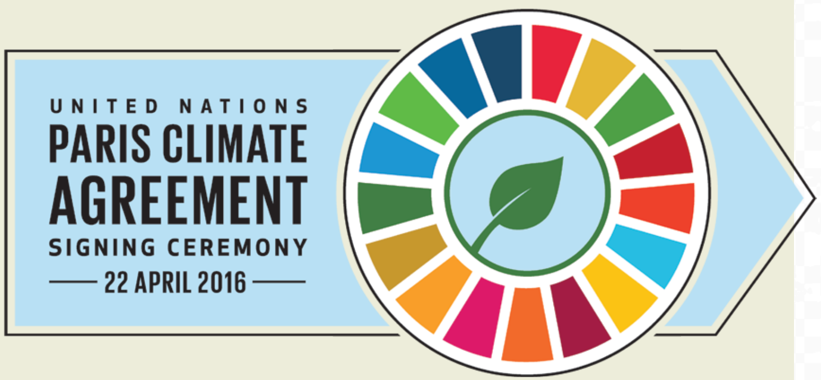
Global materials extraction (Krausmann, 2009)

Climate change



NASA/GISS

Towards a Global Energy Transition?



Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

(a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

(b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and

(c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

2. This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Towards a Global Energy Transition?

Low carbon technologies are more intensive in RM than conventional ones

A new infrastructure has to be built, which has a lower lifetime than conventional ones

« A transition to a low carbon society will require vast amounts of metals and minerals… The world cannot tackle climate change without adequate supply of raw materials to manufacture clean technologies'" (Ali et al. 2017 - Nature) »

The Raw Material Question

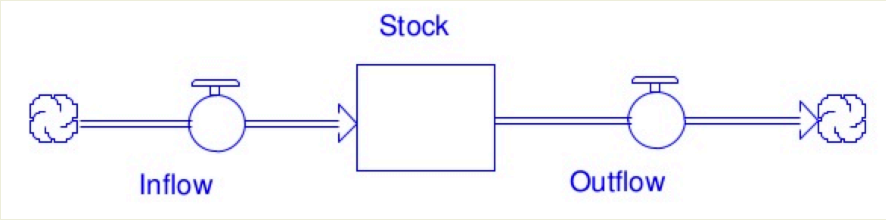
- What are the needs for RM in a context of energy transition?
- Will we be able to extract enough resources ?
- How do we value RM?

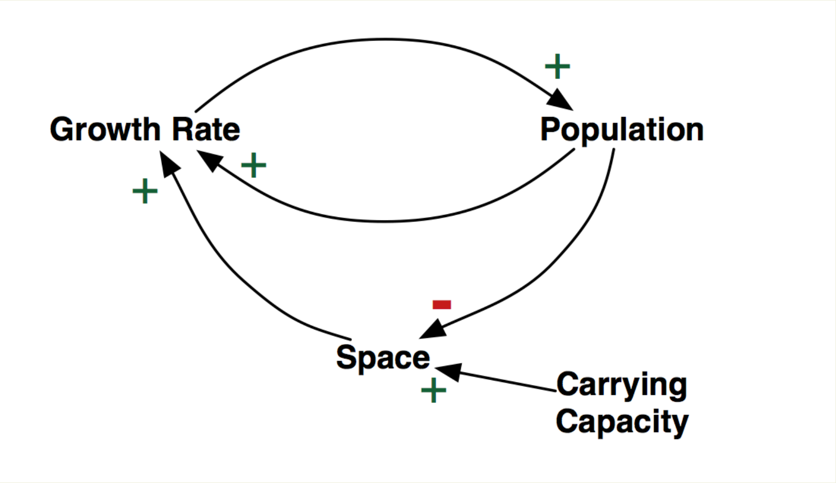
↓

What are the geophysical and economic constraints to prosperity?

System Dynamics

- Numerical approach to understand complex systems behaviour
- Stocks VS Flows
- Retroaction loops
- Delays





The Raw Material Question

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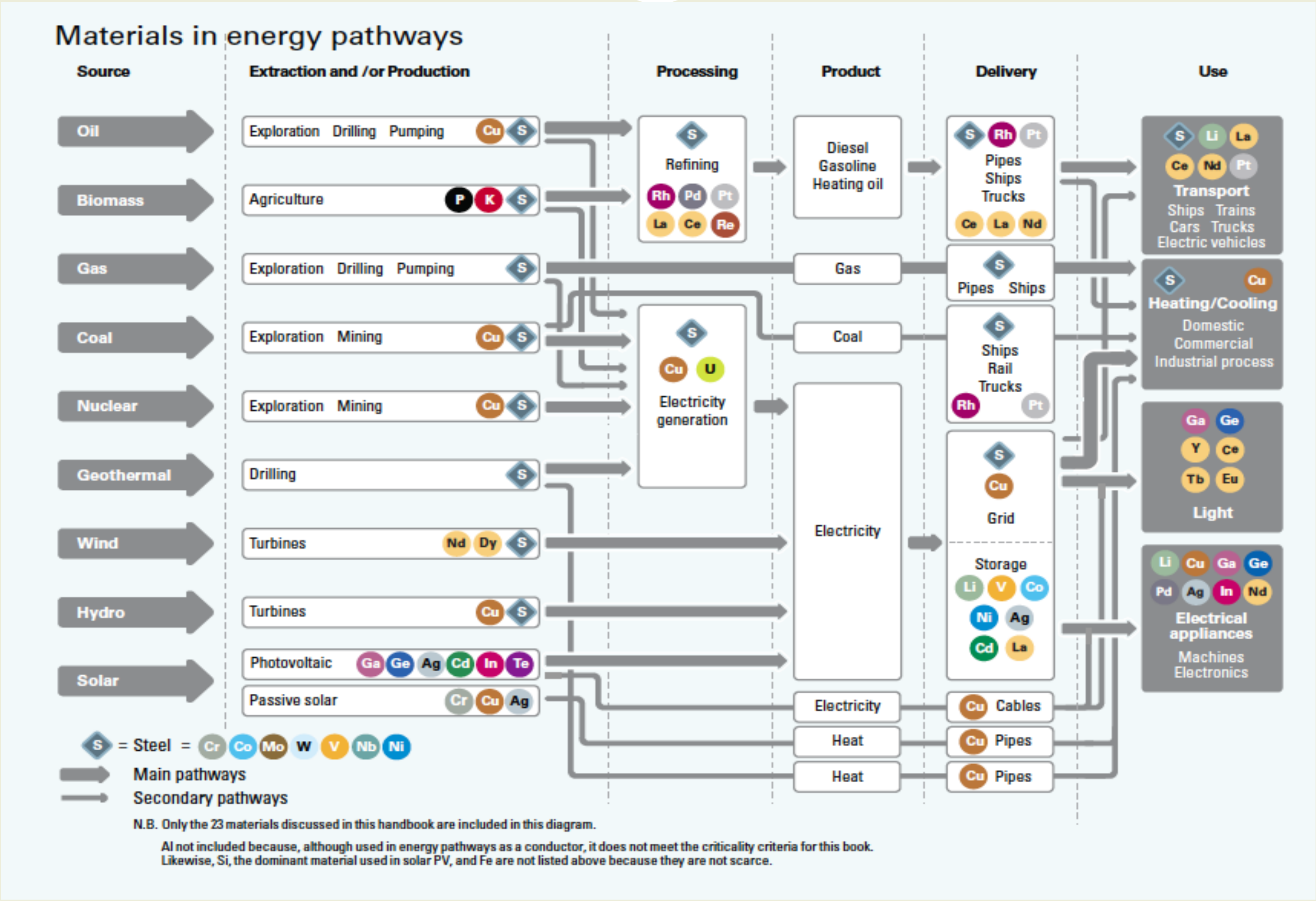
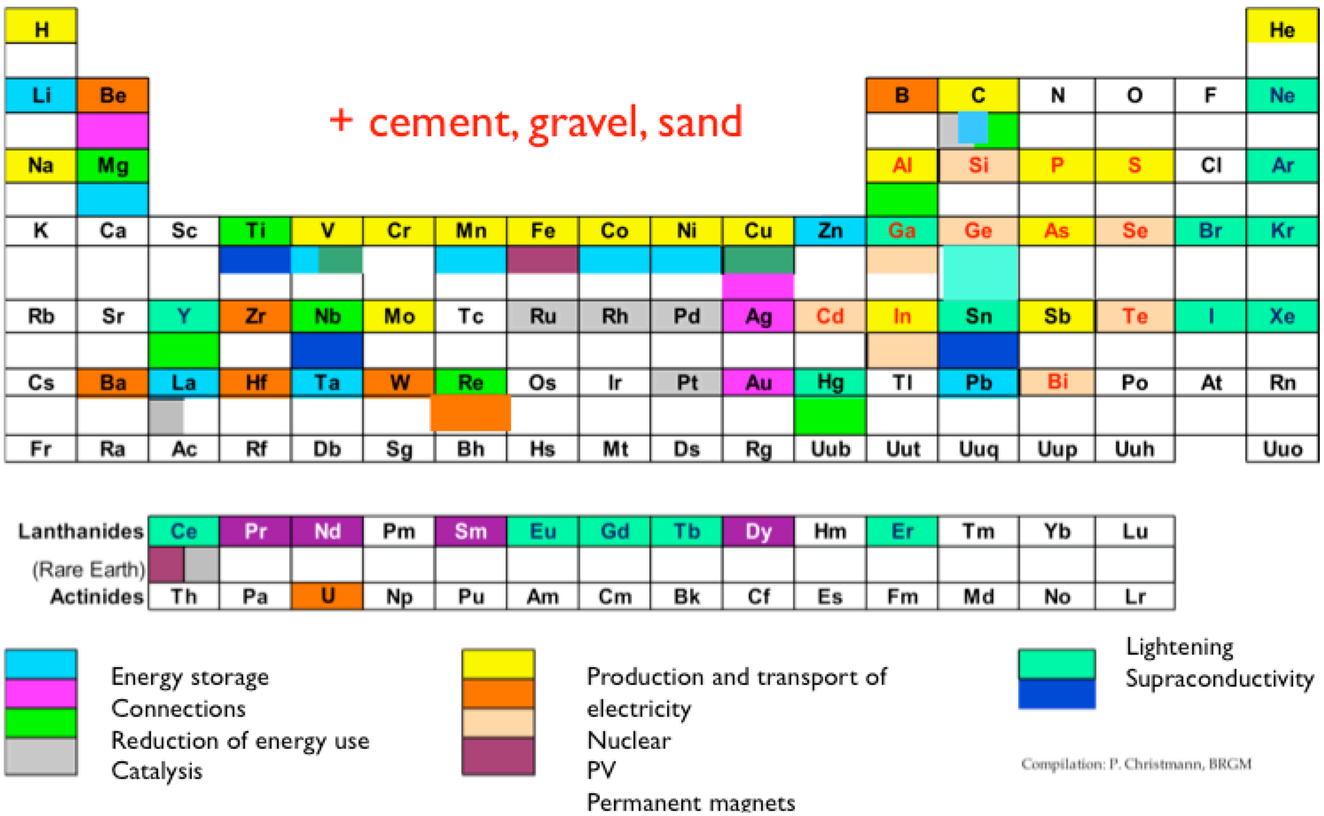
Materials and the Energy Sector

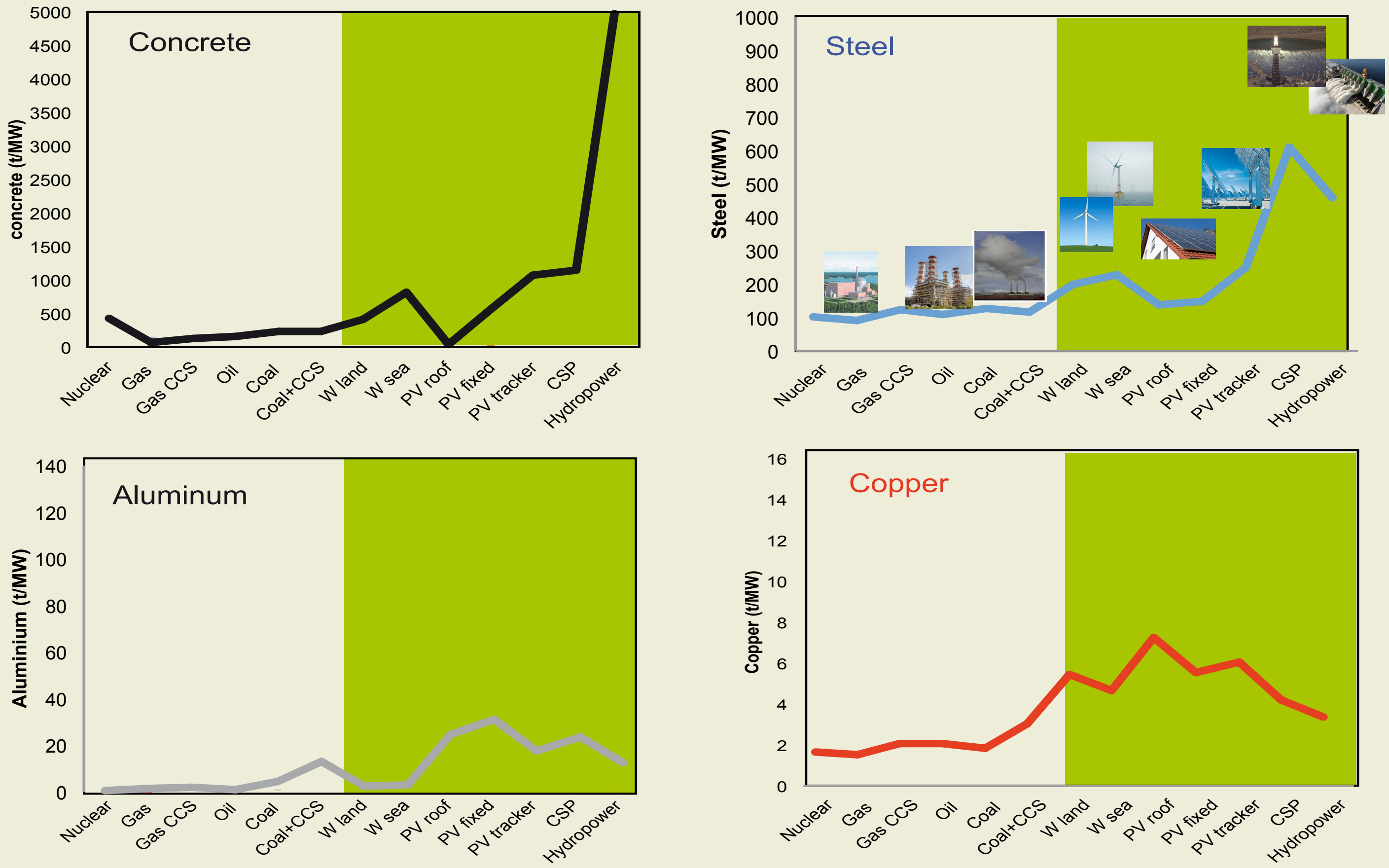


Zepf et al (2014)

Materials and the Energy Sector



Materials Intensity of Energy Technologies

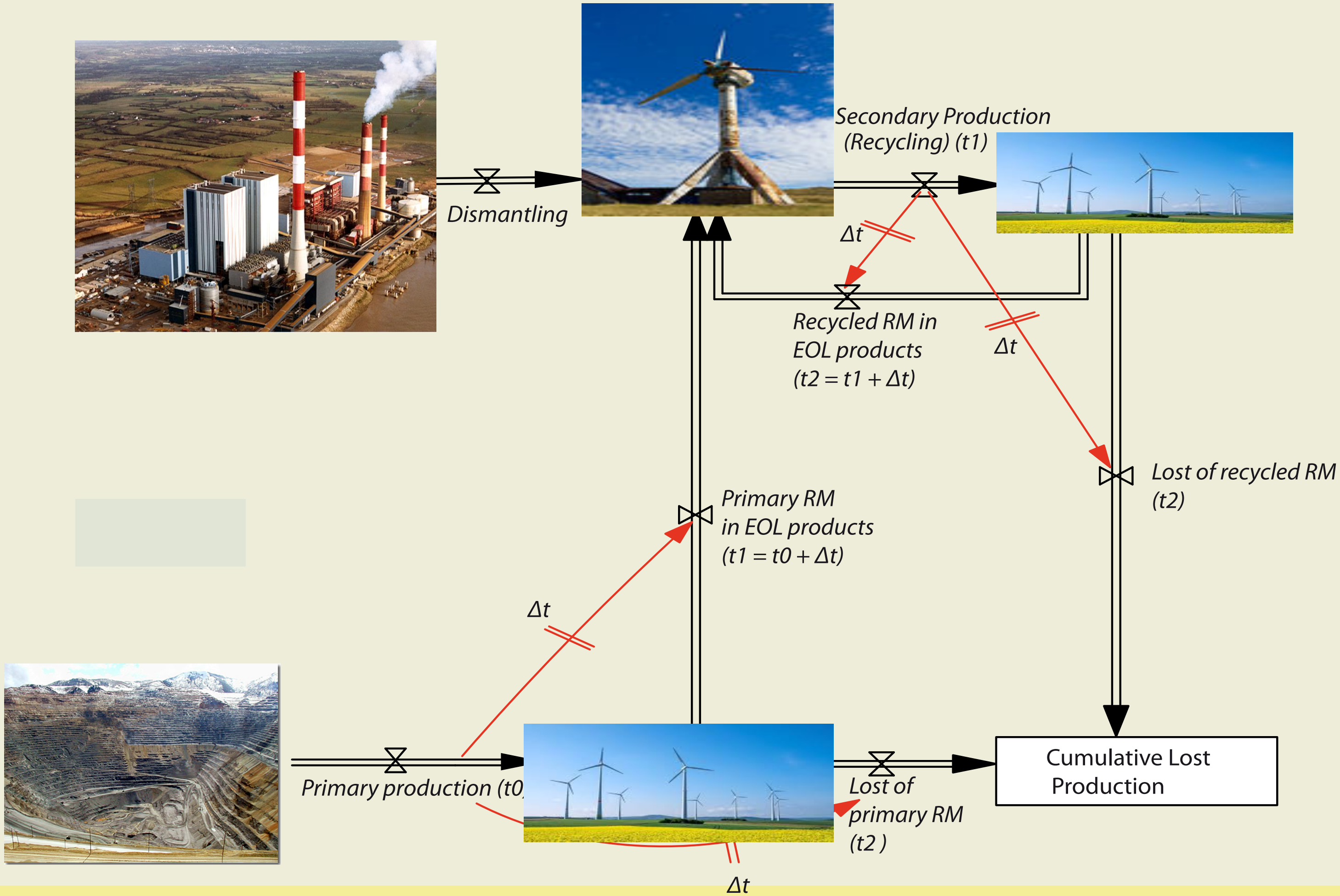


Modeling future mineral demand for transition

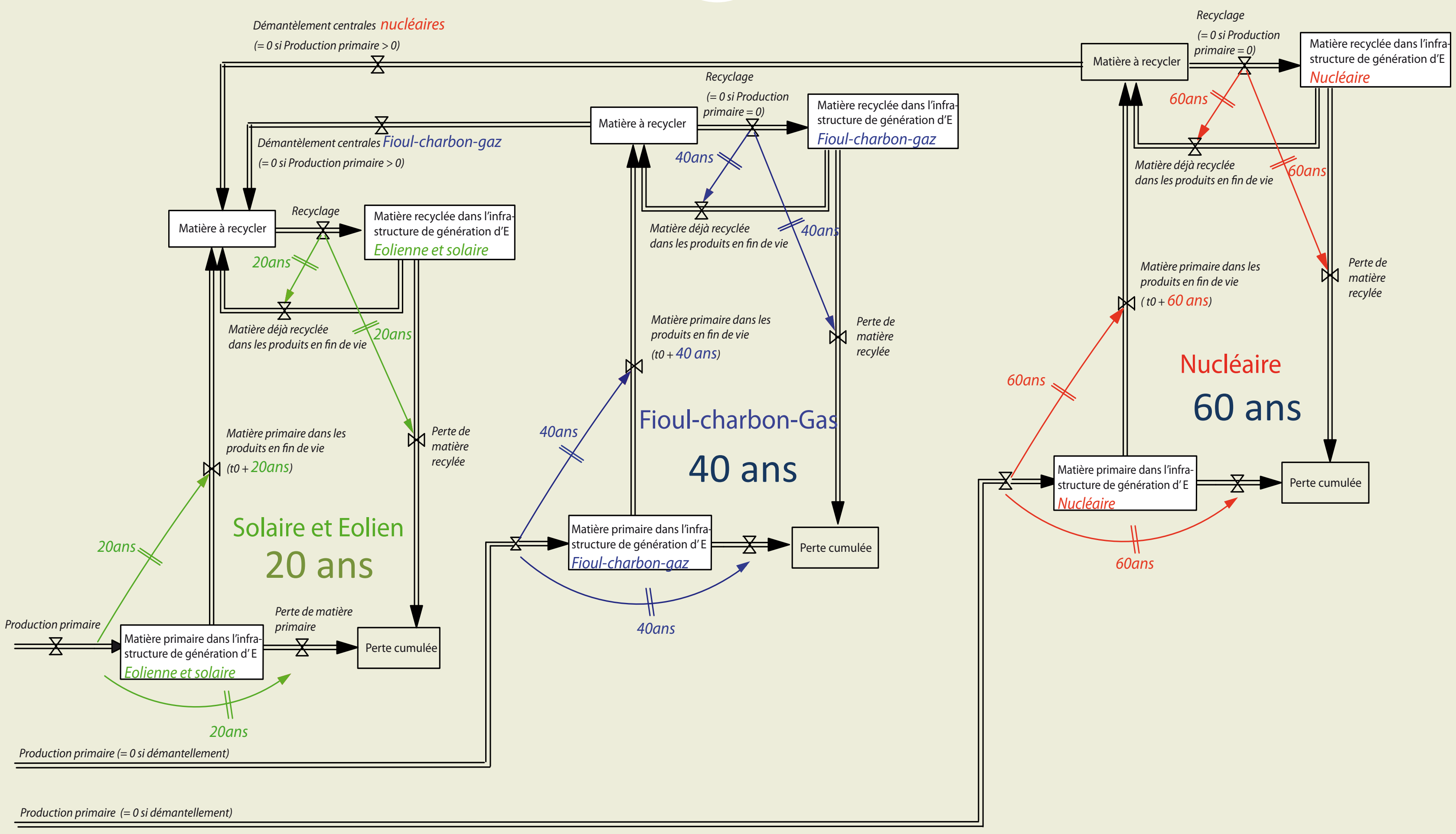
- It depends on the scenario chosen for the energy transition
- Knowing the material intensity of the different technologies available

It is a matter of stocks, flows and delays

Modeling future mineral demand for transition



Modeling future mineral demand for transition

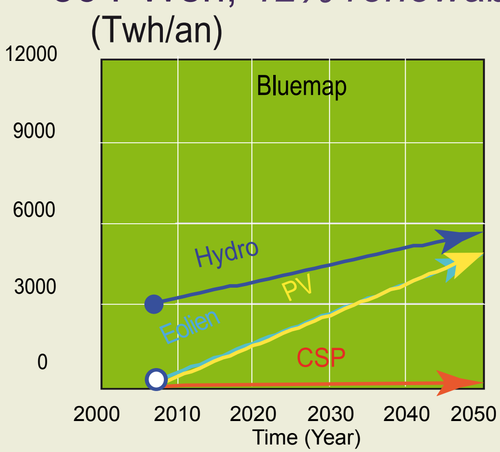


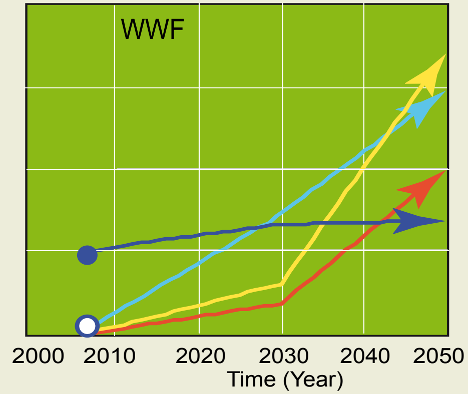
The scenarios

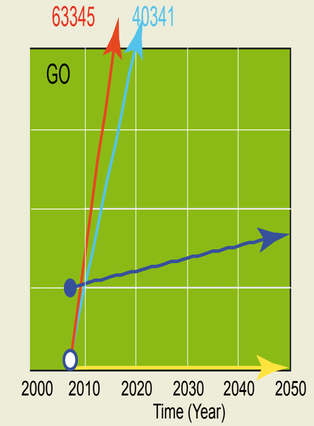
Blue Map IEA (2010)
36 PWeh, *42% renewables*

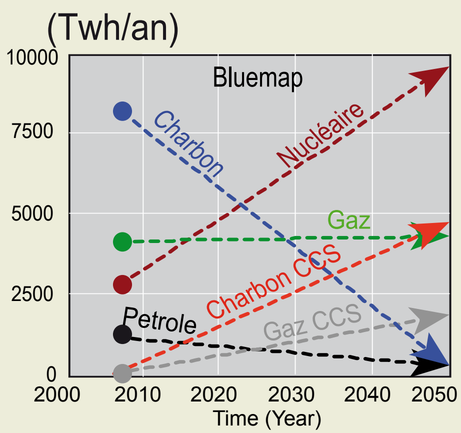
Ecofys-WWF (2012)
29 PWeh, *100% renewable*

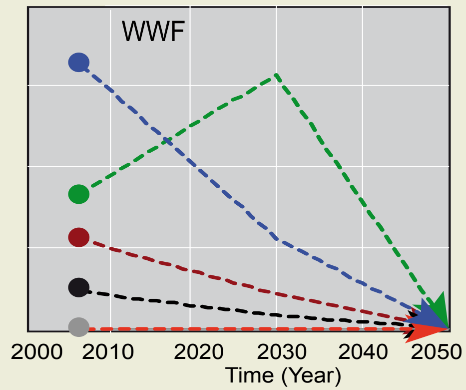
Garcia-Olivares (2013)
109 PWeh, *100% renewable only electricity*

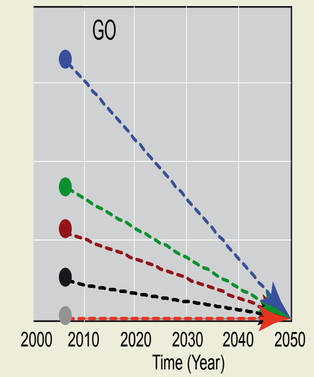




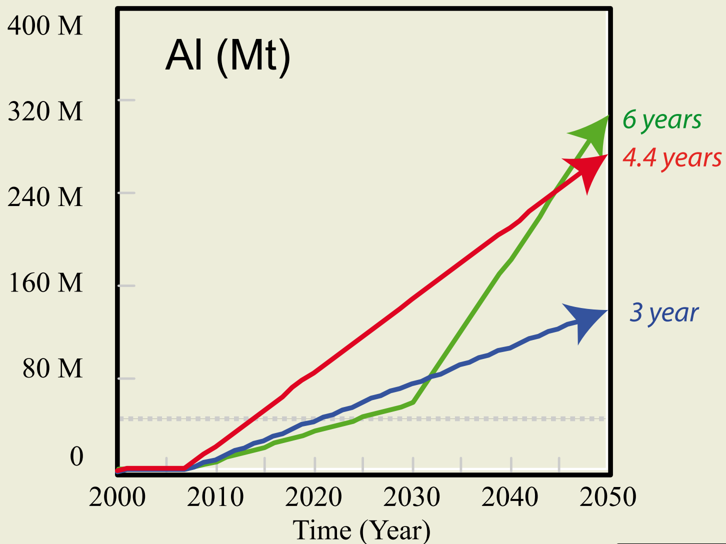


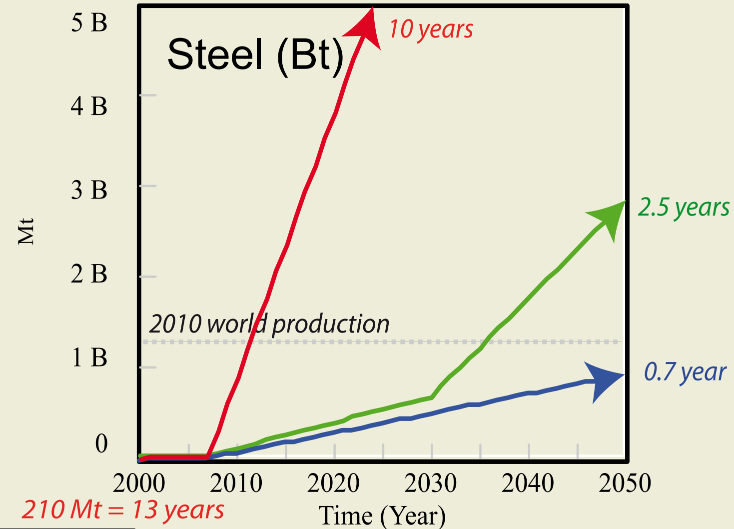


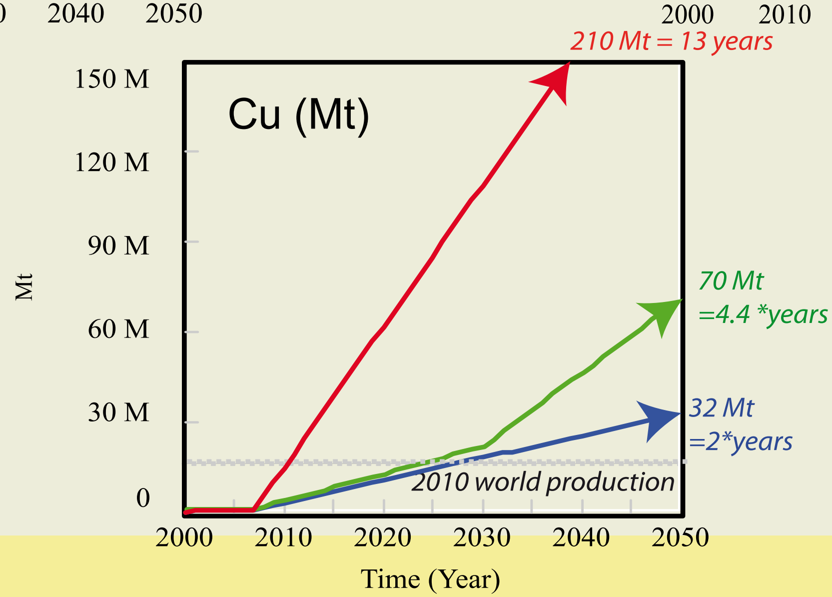




Results in Stocks

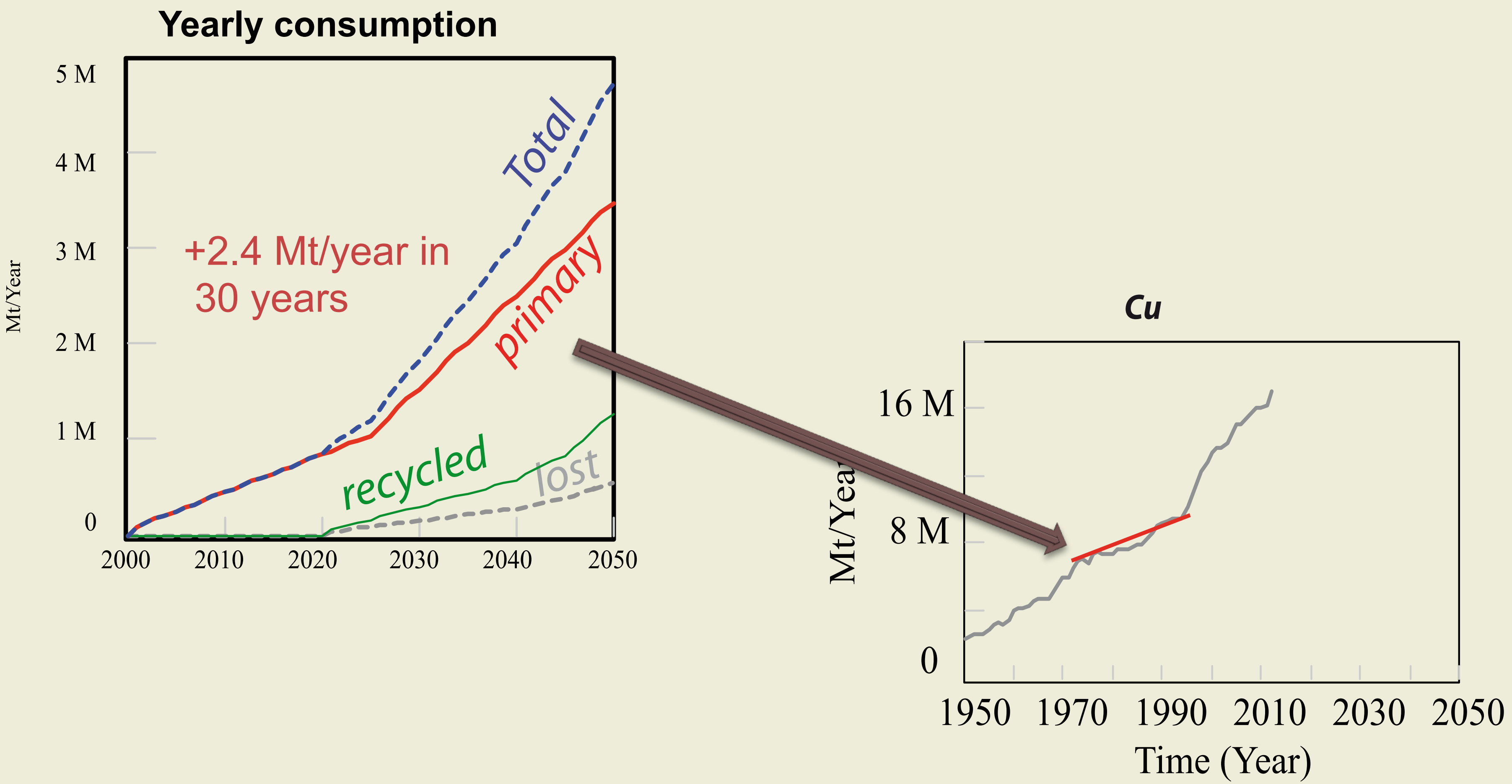






Results in Flows

The case of Copper in Ecofys

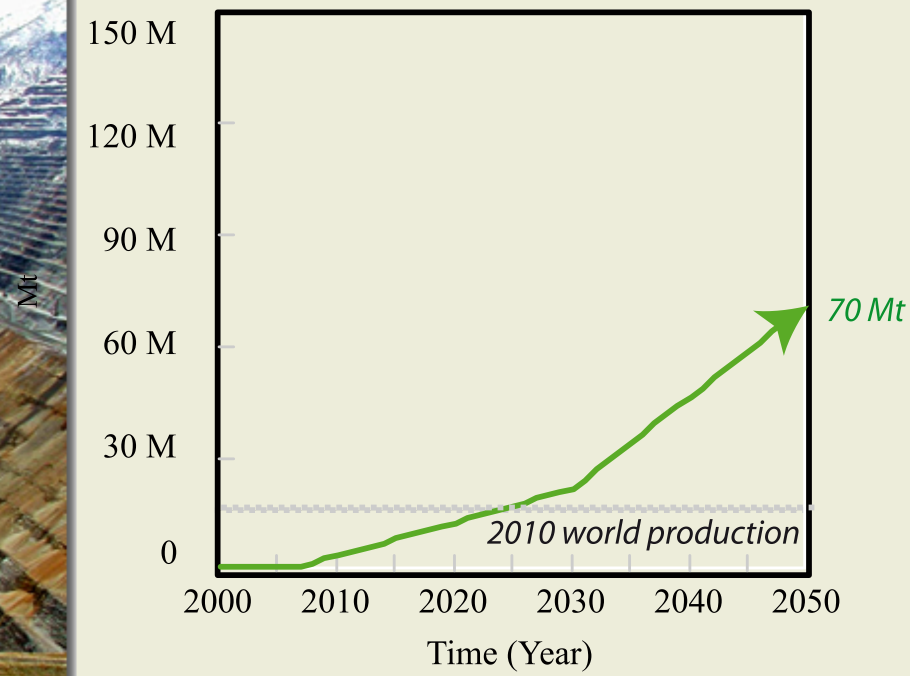


Orders of magnitude

Kennecott Copper Mine (Utah) 3.2 x 1.2 x 1.2 km^3

Since 1906 : 18 Mt

Orders of magnitude



Kennecott Copper Mine (Utah) 3.2 x 1.2 x 1.2 km^3

Since 1906 : 18 Mt

Additional needs

Distribution
3 Mt

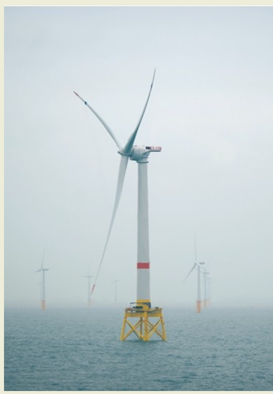
Storage
1Mt

Production
70 Mt

Transportation
40 Mt

Additional needs

on



Production
70 Mt

ation

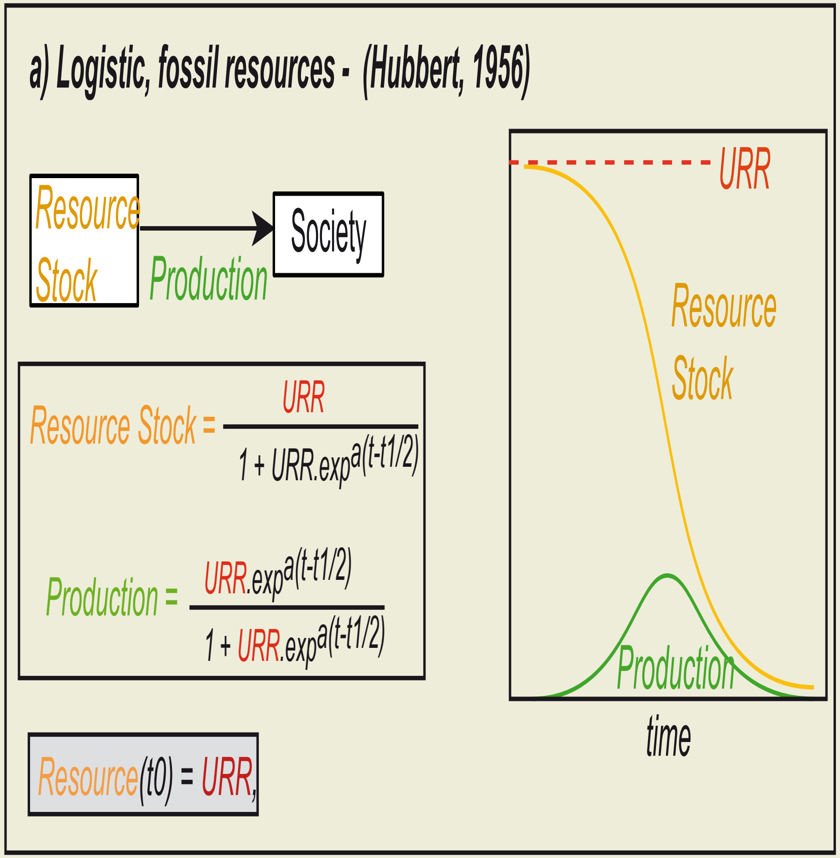
The Raw Material Question

- What are the needs for RM in a context of energy transition?
- Will we be able to extract enough resources ?
- How do we value RM?

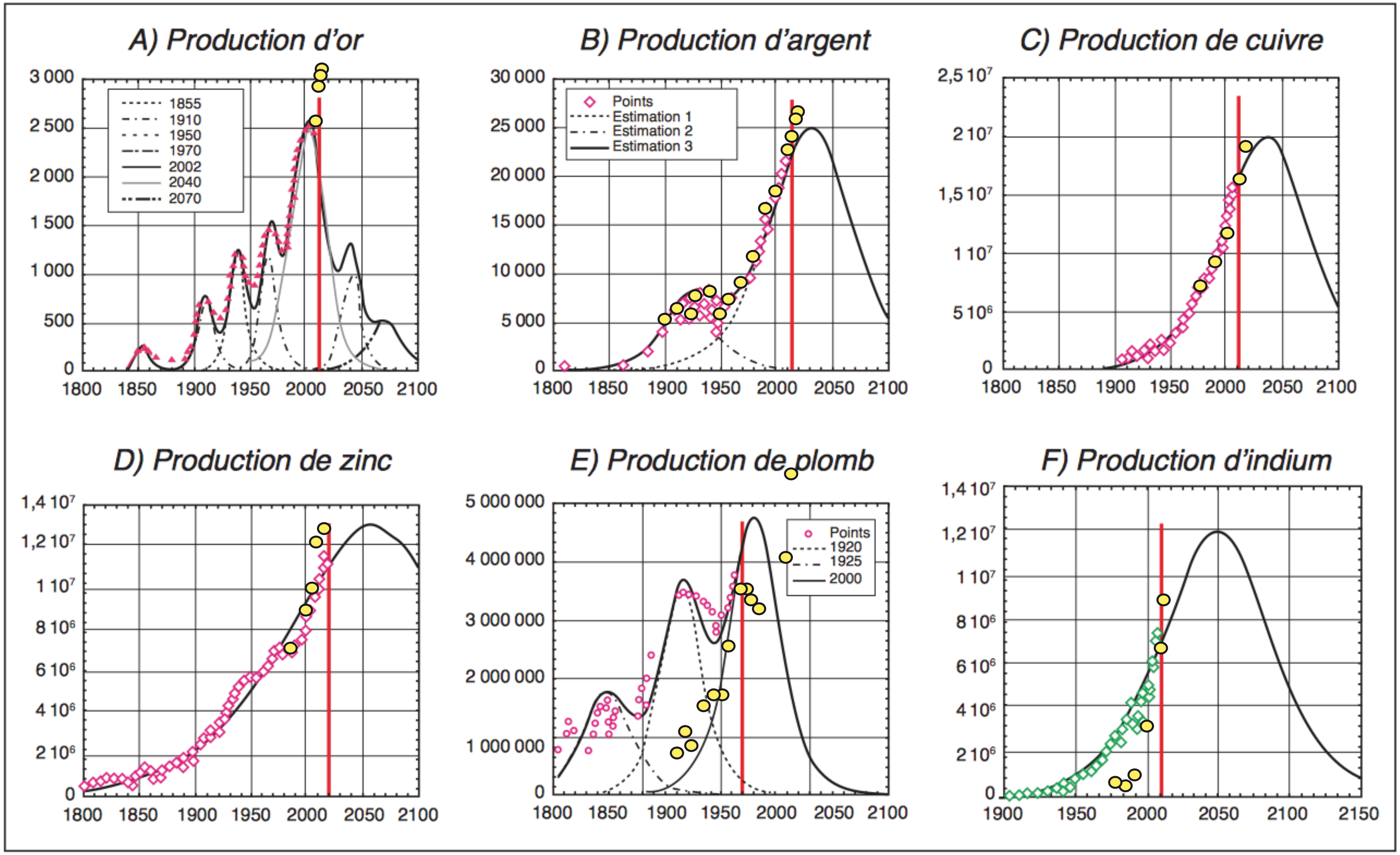
What are the geophysical and economic constraints to prosperity?

Modeling long-term trends of supply

The Hubbert approach

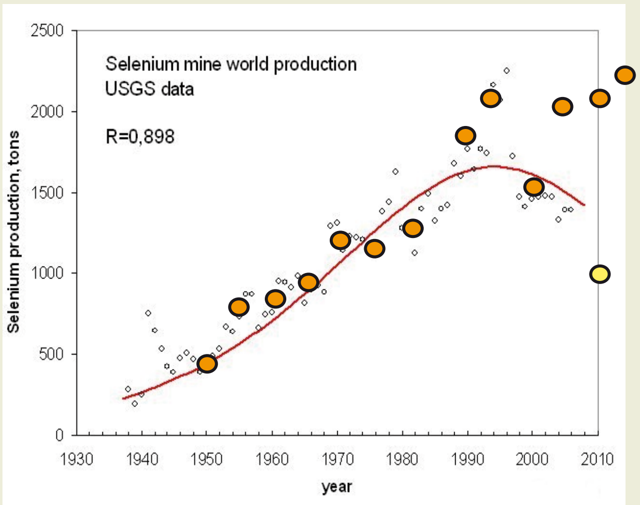


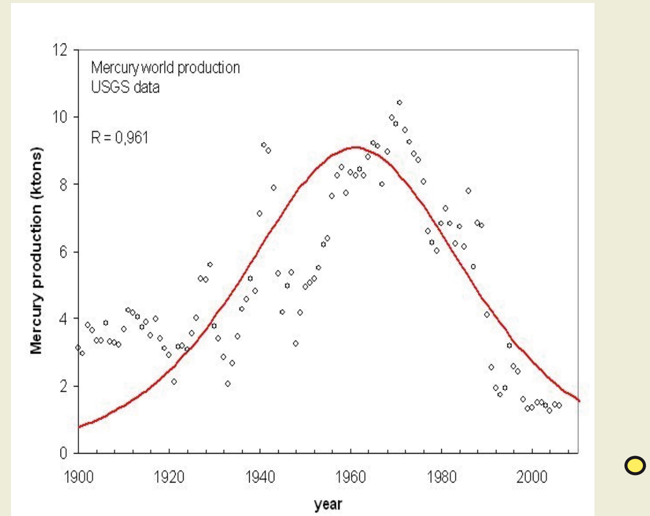
Peak metals

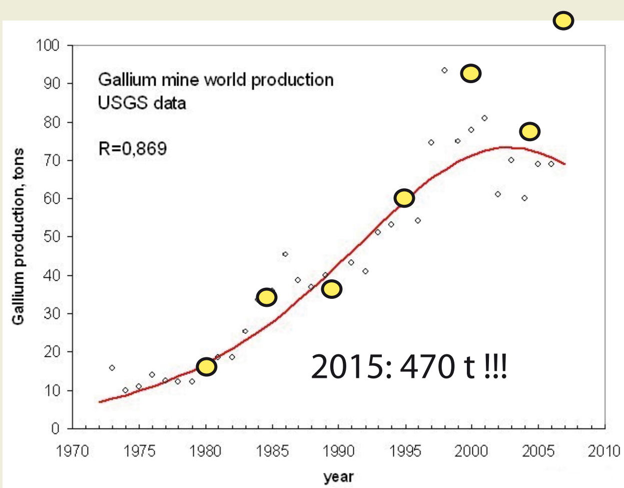


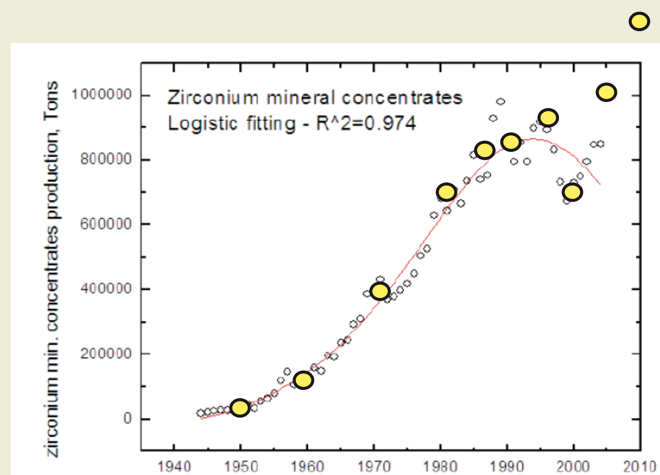
Sverdrup (2012)

Peak metals





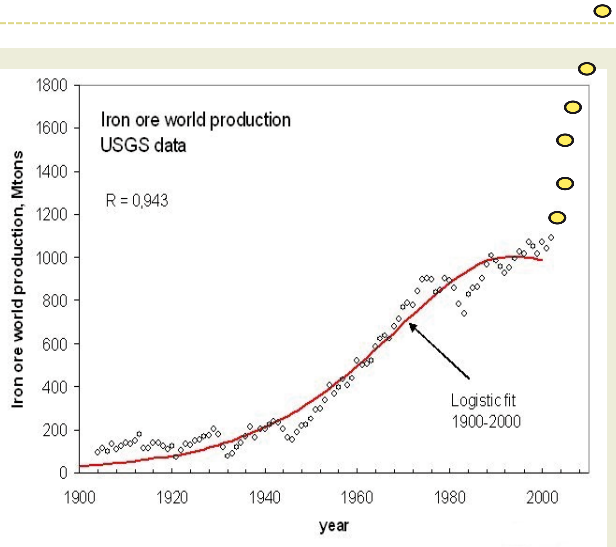


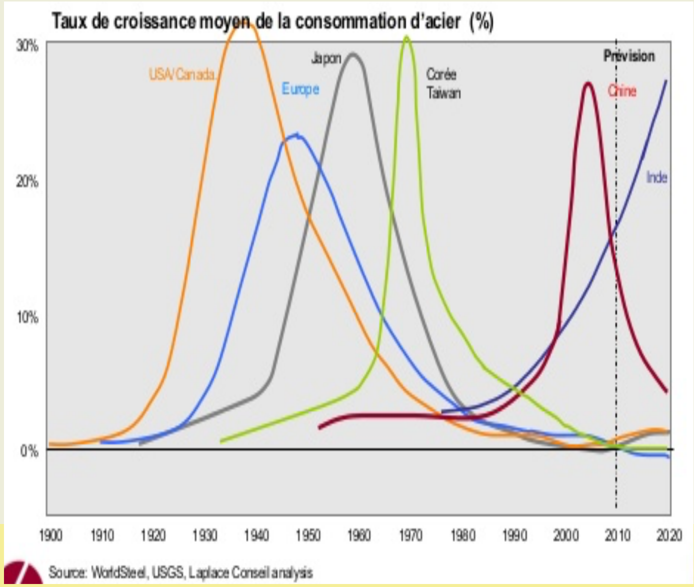


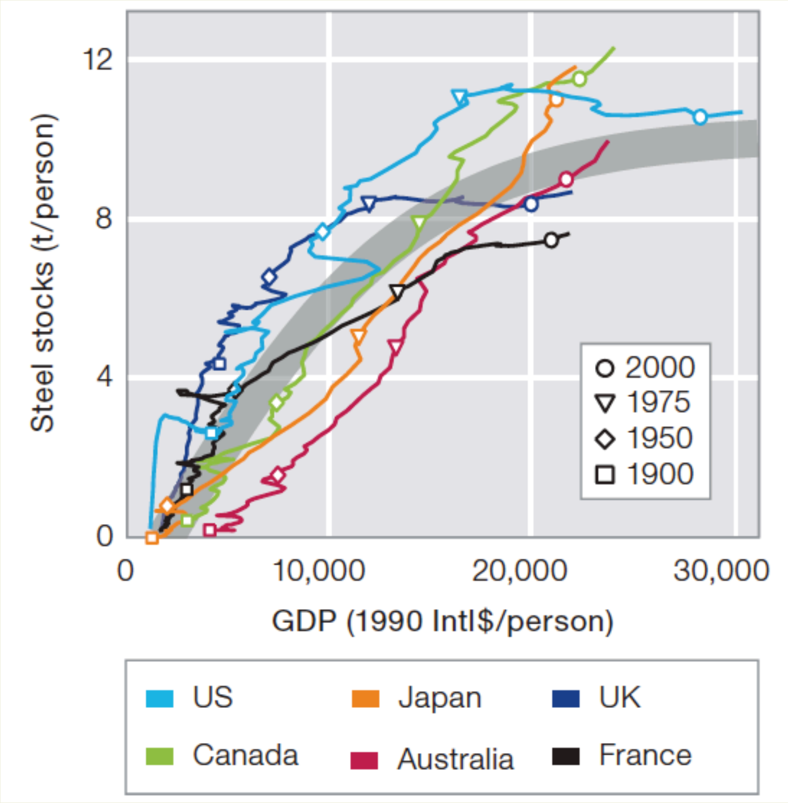
Bardi, U., Pagani, M., ***Peak Minerals***, ĂŠPŌ-Italy and Dipartimento di Chemica dell'Università di Firenze, posted October 15, 2007 at the website The Oil Drum: Europe

Sverdrup (2012)

When demand peaks

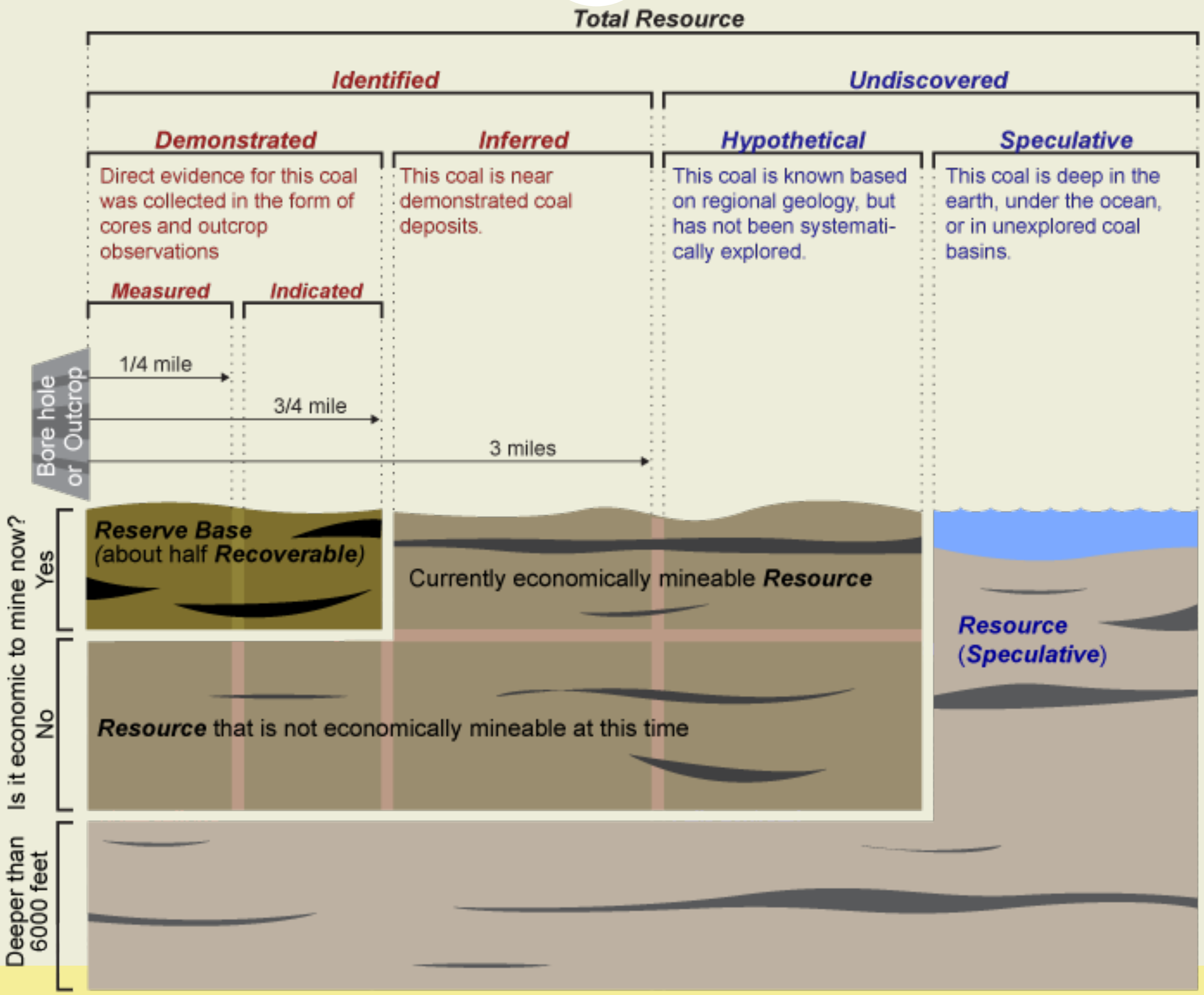




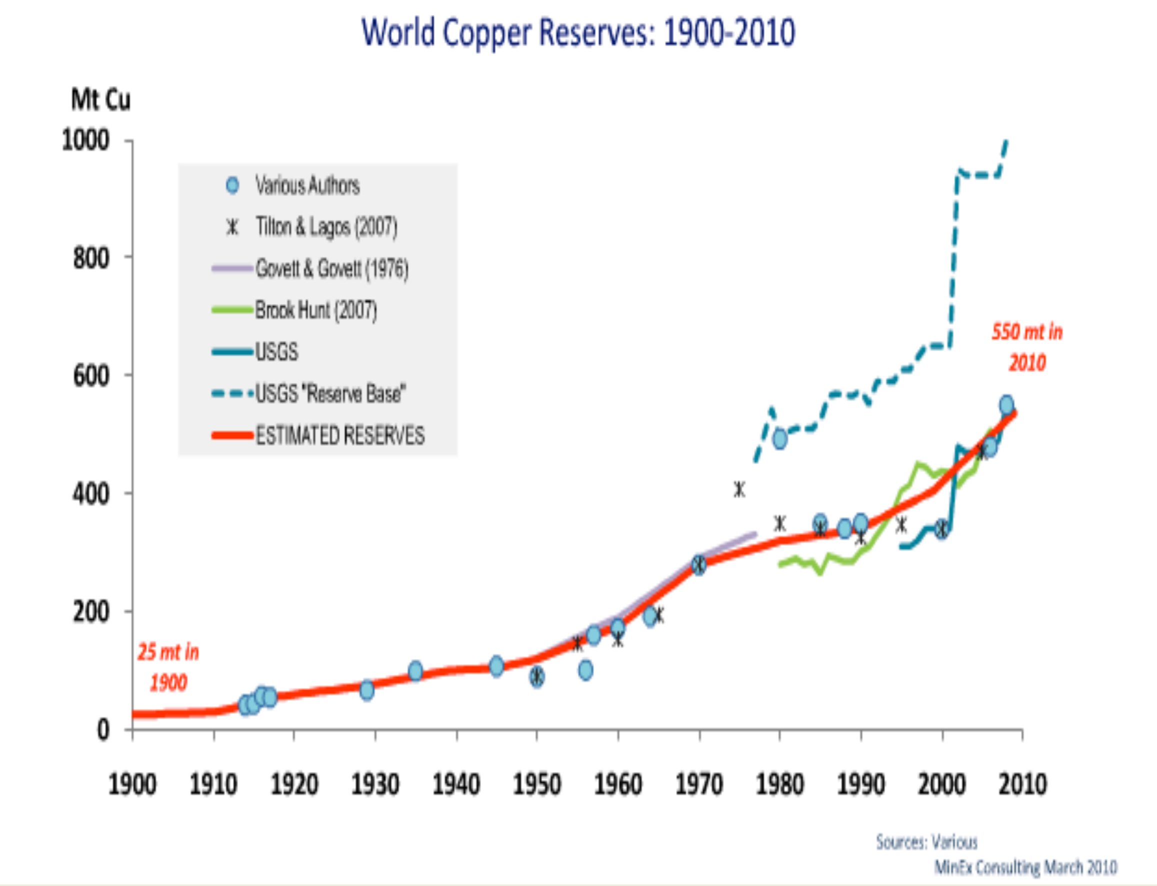


Bleischwitz, 2016)

Resources VS Reserves

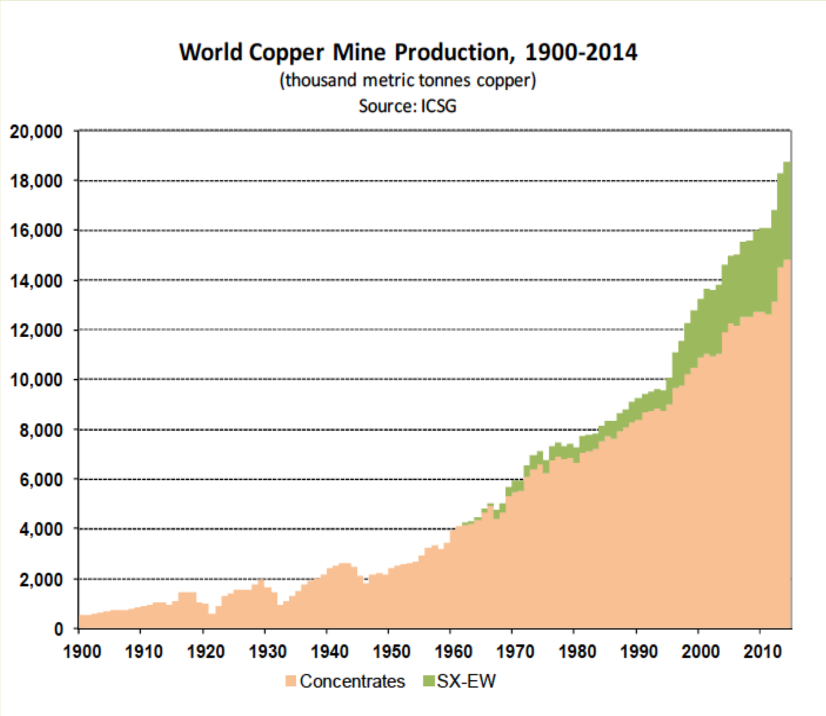


Copper Reserves



The life time of copper is stable since 70 years

Reserves increase



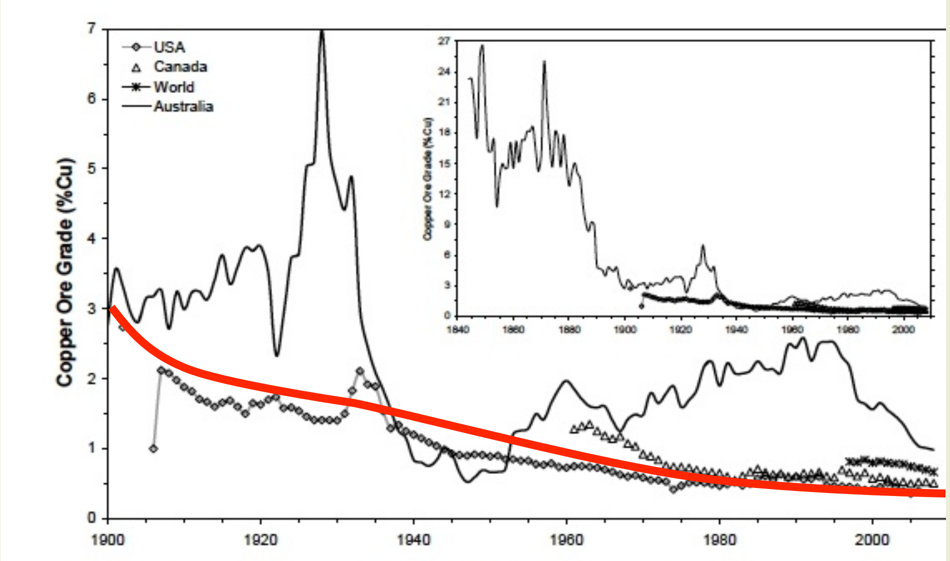
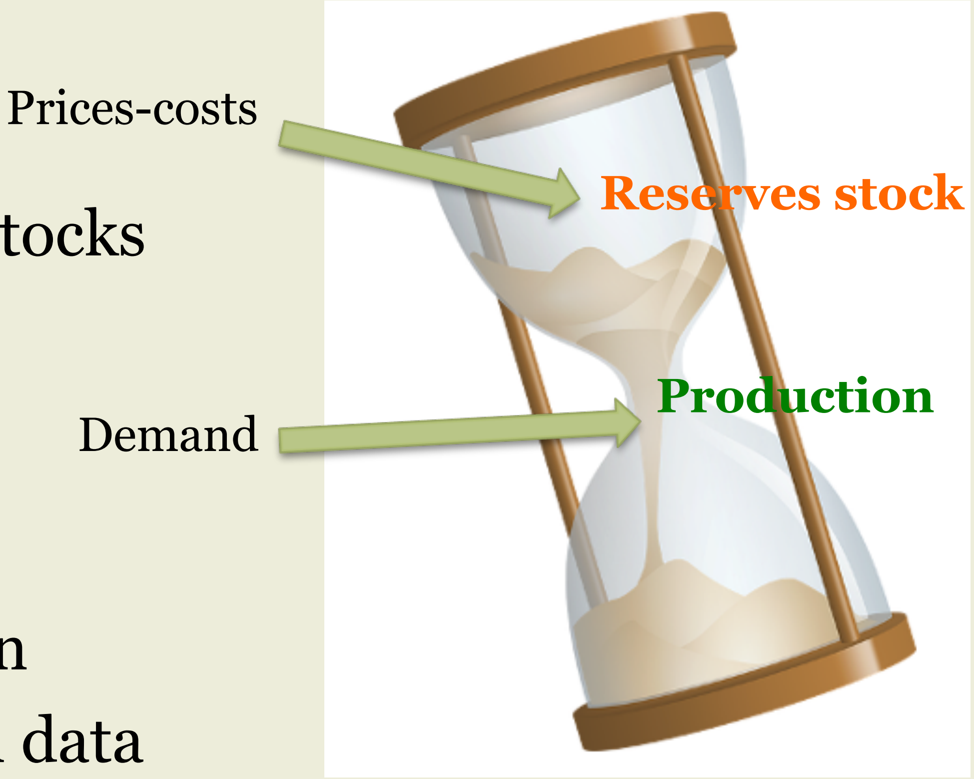


Figure 2 – Copper ore grades over time by country and approximate world average

Modeling long-term trends of supply

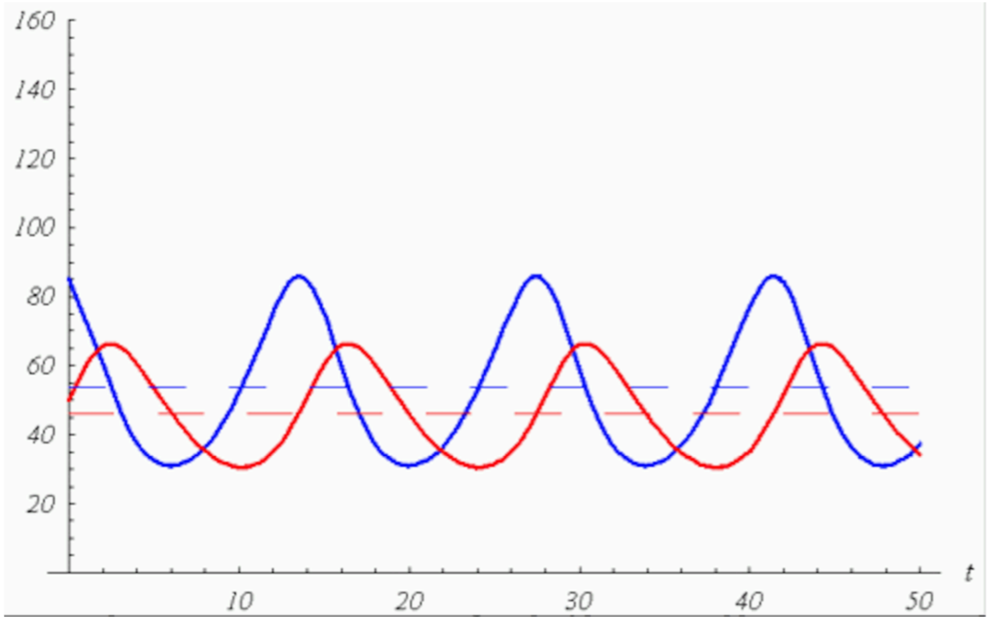
- Mind-sized
- Dynamic description of stocks and flows
- Geological consistency: Resources VS Reserves
- Role of the economic variables in the extraction
- Constrained by historical data



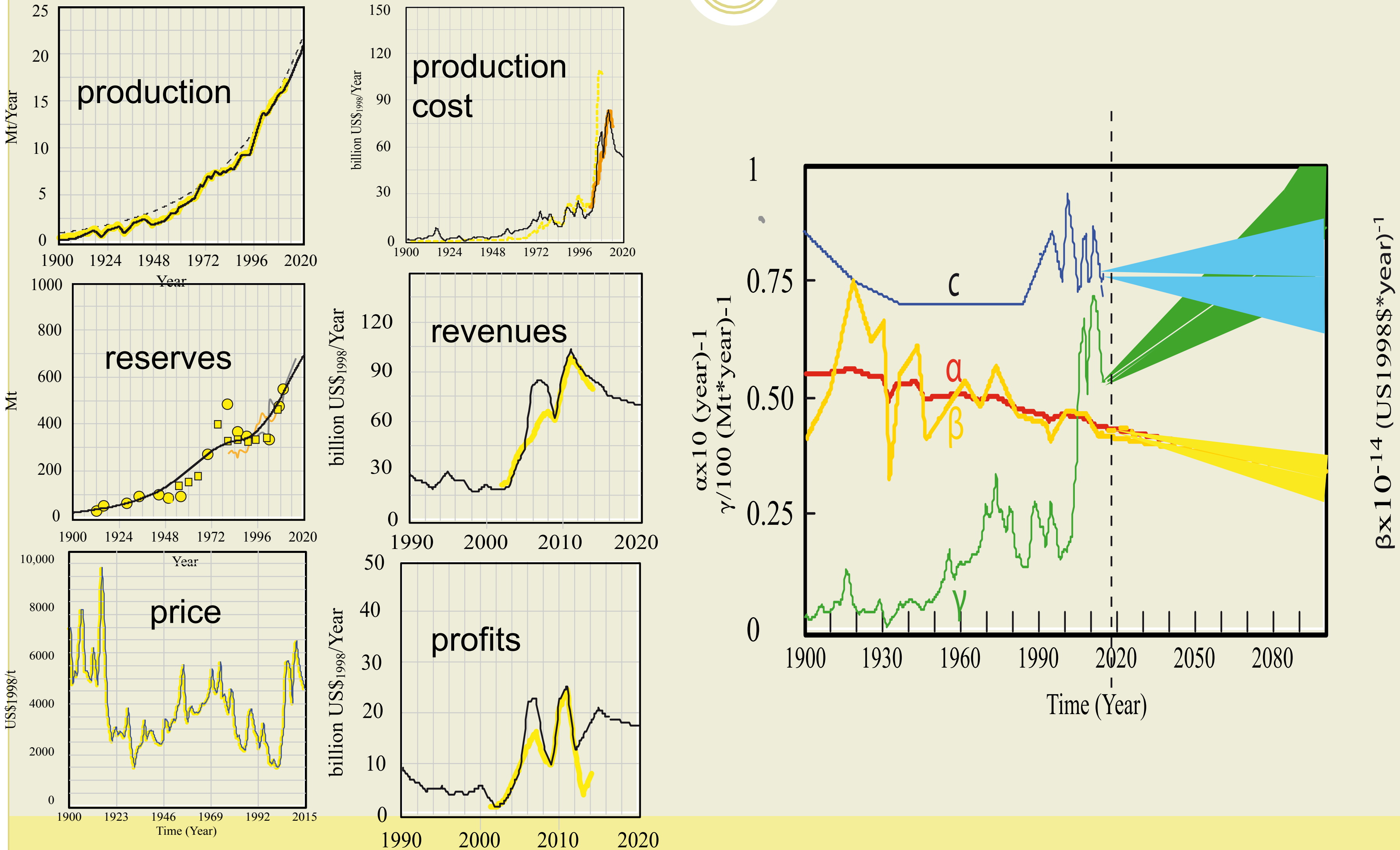
Prey-predator modeling

$$\dot{R} = \alpha R - \beta R W$$

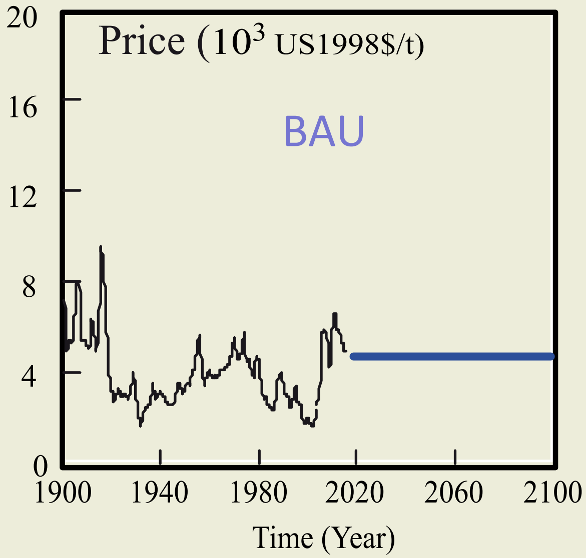
$$\dot{W} = \delta W R - \gamma W$$

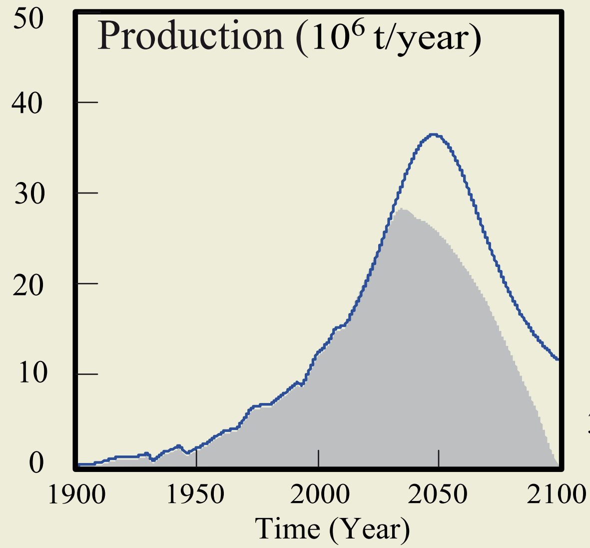


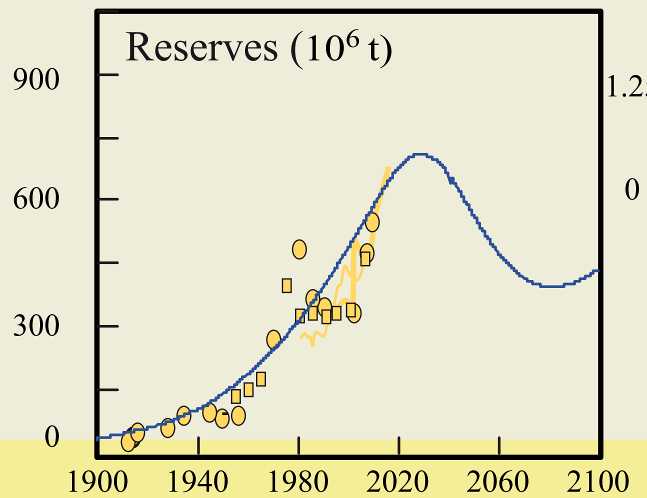
Model Constraints

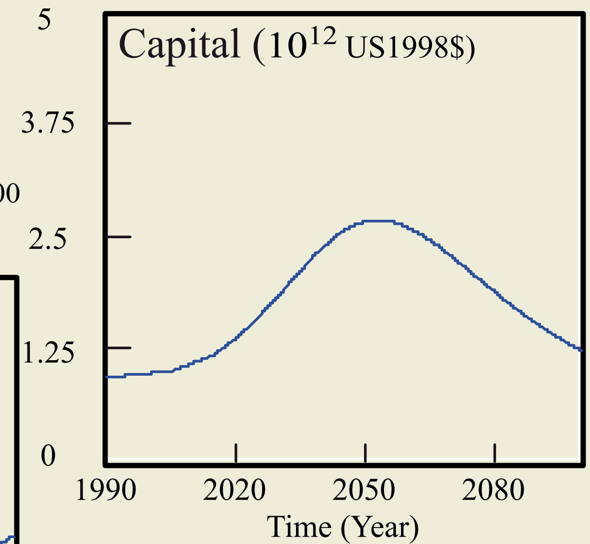


Results



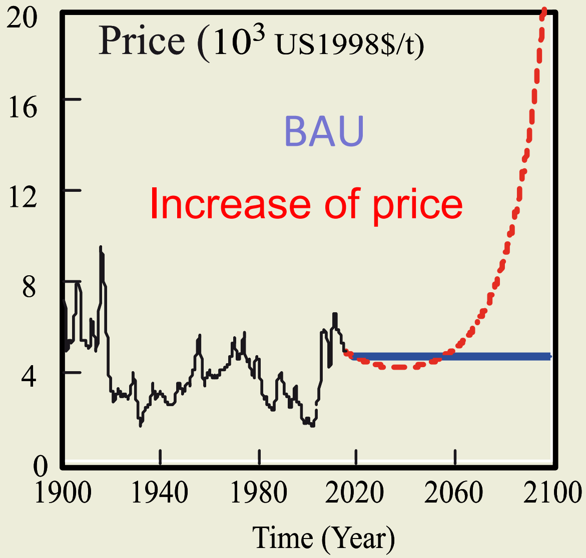


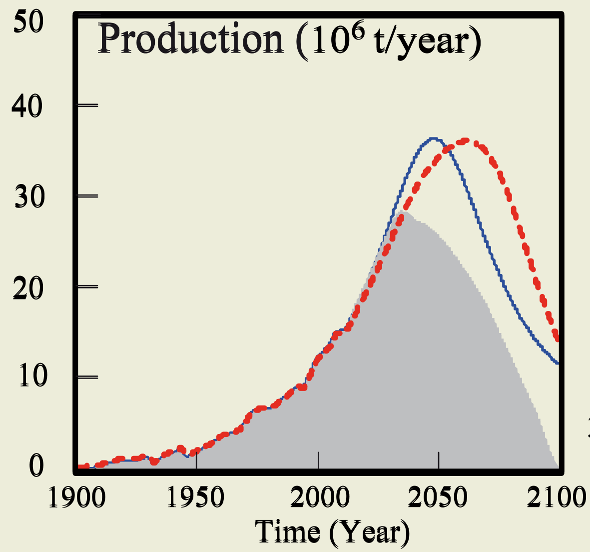


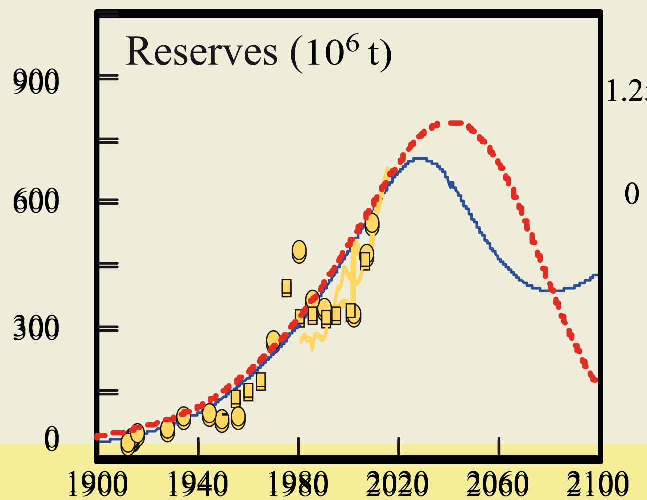


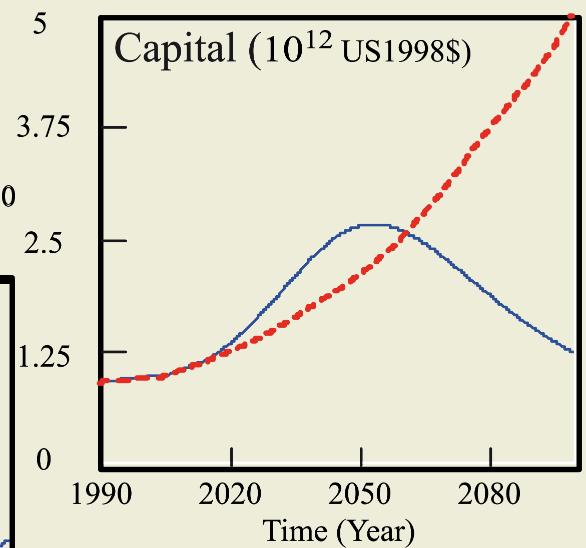
Bankruptcy of the mining sector

Results









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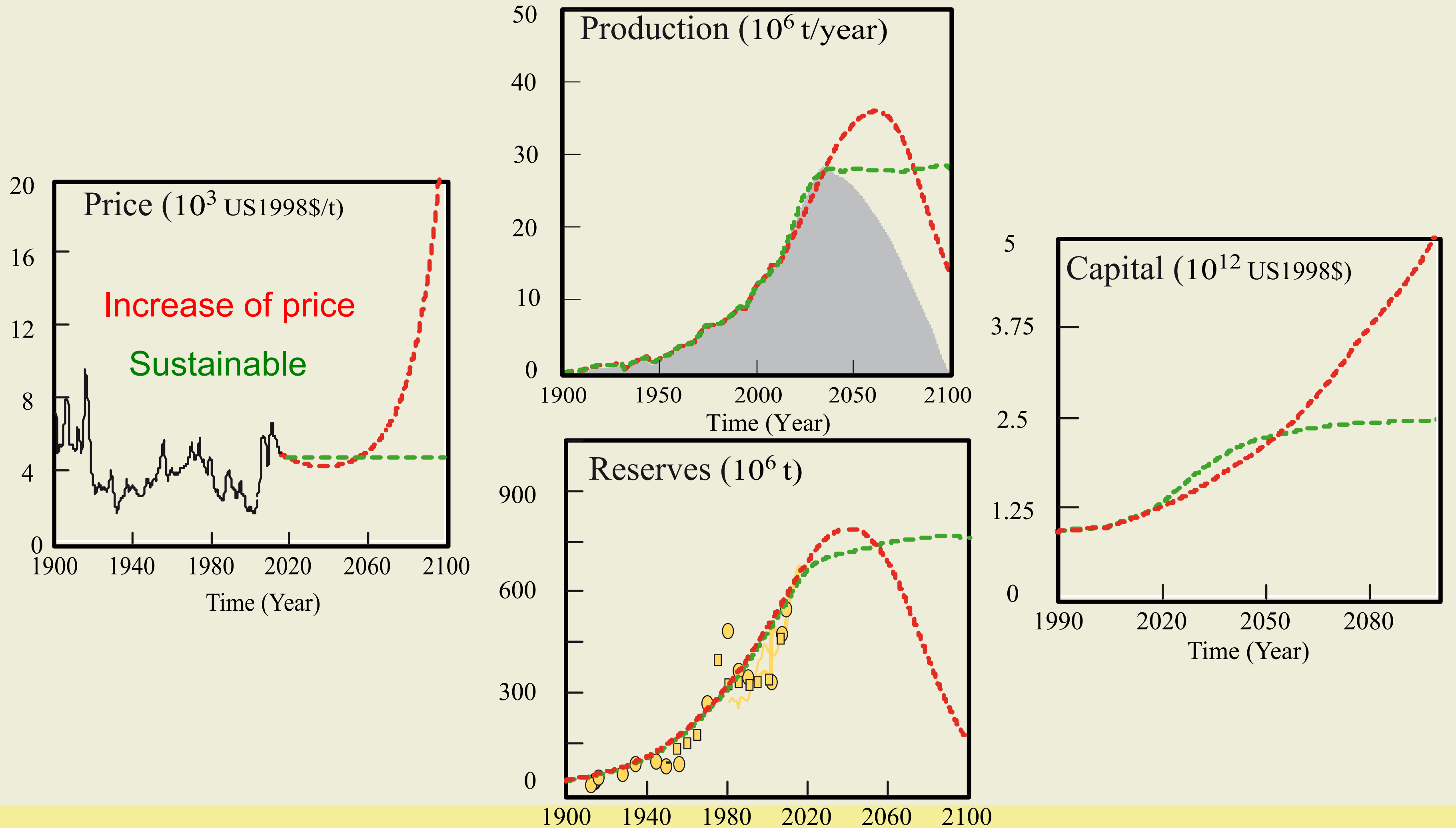
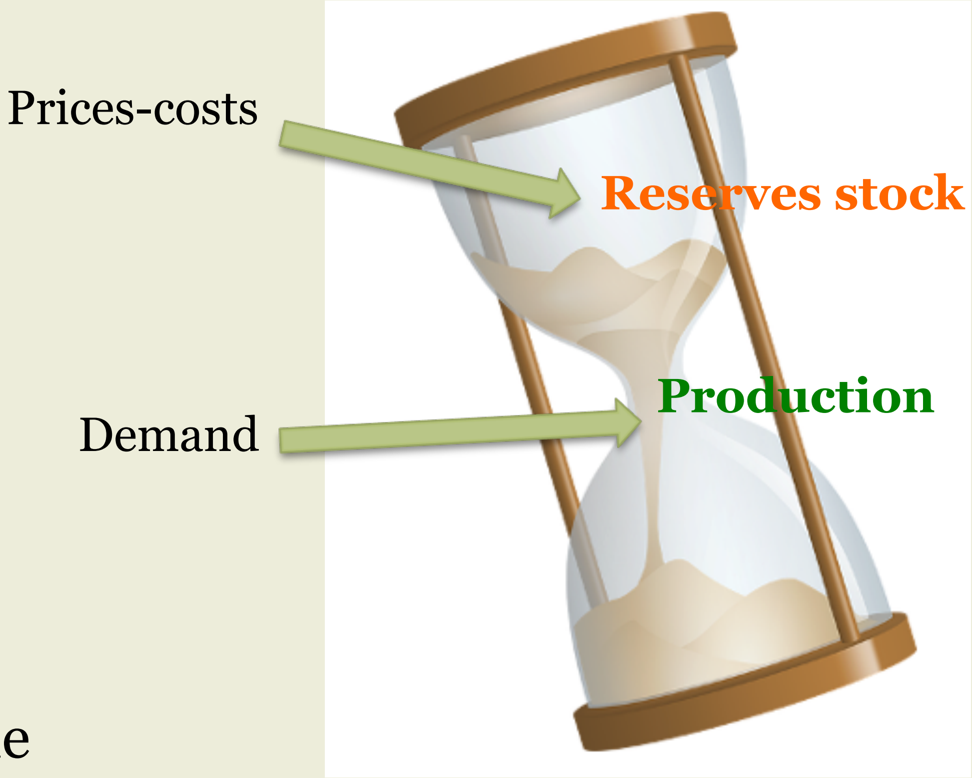


Price (10^3 US1998$/t)
Increase of price
Sustainable
20
16
12
8
4
0
1900
1940
1980
2020
2060
2100
Time (Year)
Production (10^6 t/year)
50
40
30
20
10
0
1900
1950
2000
2050
2100
Time (Year)
Reserves (10^6 t)
900
600
300
0
1900
1940
1980
2020
2060
2100
Capital (10^{12} US1998$)
5
3.75
2.5
1.25
0
1990
2020
2050
2080
Time (Year)

The Economics-Geophysics interface

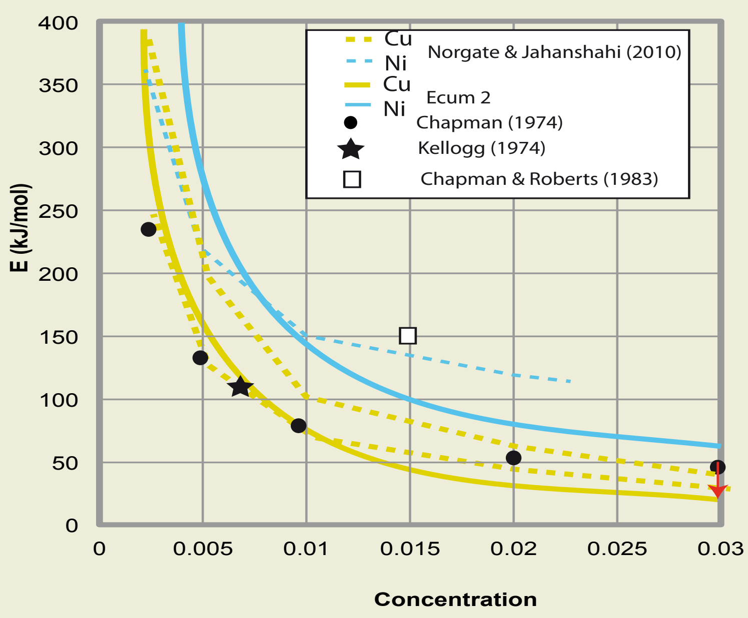
- Our economic system is physically limited
- But the time scale strongly depends on social parameters
- Reserves are a function of prices and innovation
- Extraction is shaped by demand

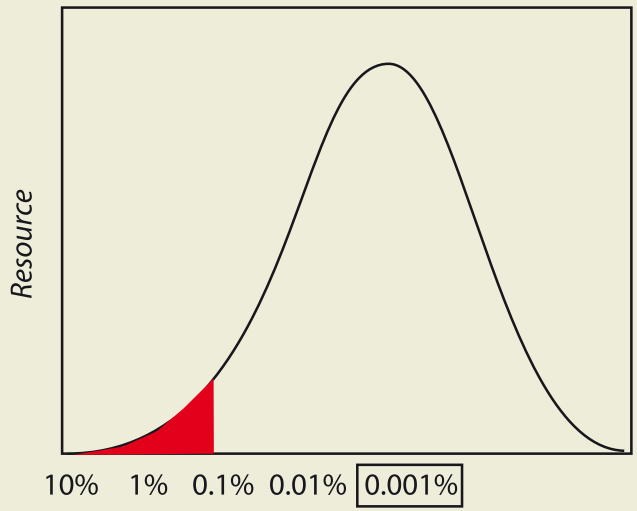


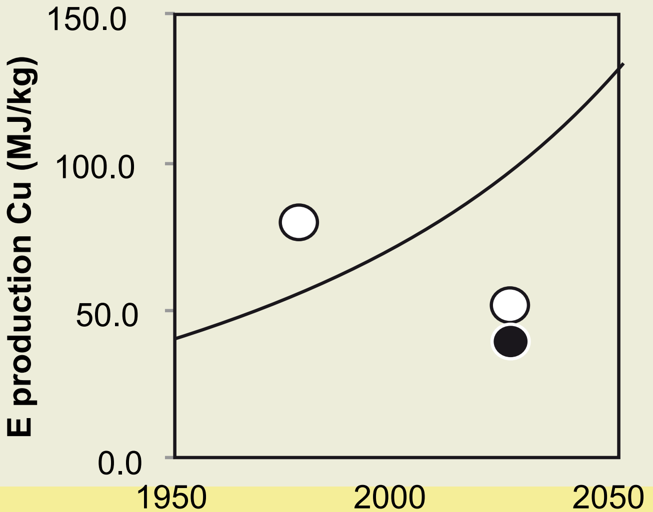
What do we understand of the social system?

Perspectives on prices

Energy, price, cost and technological improvement







Perspectives on Wealth

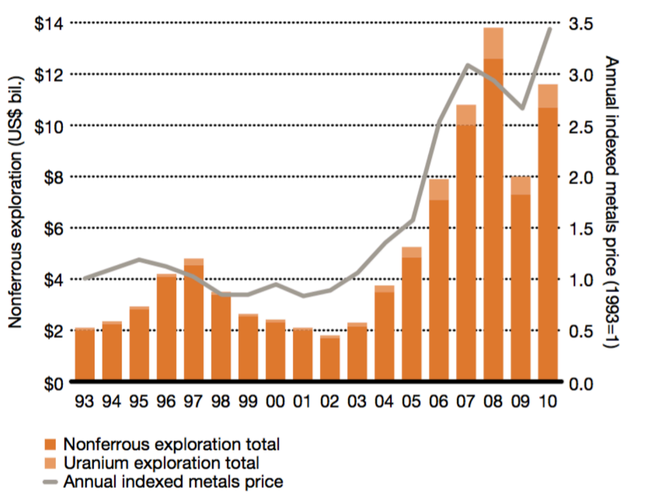
- Capital in a theoretical point of view : the Cambridge Controversy
- What are the behaviors of the mining companies? Going back to the Balance Accounts

$ billion	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
Aggregate market capitalisation	714	494	783	958	1234	1202	1605	1259	563	1481	962
Aggregated income statement											
Revenue	353	354	500	512	525	539	435	325	349	312	249
Operating expenses	-251	-390	-359	-350	-340	-311	-246	-217	-208	-176	-141
EBITDA	102	-36	141	162	185	228	189	108	141	136	108
Amortisation, depreciation and impairment	-63	-101	-63	-97	-86	-42	-34	-31	-57	-19	-12
PBIT	39	-137	78	65	99	186	155	77	84	117	96
Net finance cost	-9	-18	-14	-15	-6	-6	-7	-6	-6	-5	-3
PBT	30	-155	64	50	93	180	148	71	78	112	93
Income tax expense	-15	-5	-22	-30	-25	-48	-38	-22	-21	-32	-27
Net profit	15	-160	42	20	68	132	110	49	57	80	66
Adjusted net profit excl. impairment	30	-1	74	43	111	147	112	60	88	82	66
Year on year increase/ (decrease) in revenue	(0%)	(29%)	(2%)	(2%)	(3%)	24%	34%	(7%)	12%	25%	12%
Year on year increase/ (decrease) in EBITDA	(383%)	(126%)	(13%)	(12%)	(19%)	21%	75%	(23%)	4%	26%	33%
Year on year increase/ (decrease) in net profit	109%	(481%)	110%	(71%)	(48%)	20%	124%	(14%)	(29%)	21%	47%
EBITDA margin	29%	(10%)	28%	32%	35%	42%	43%	33%	40%	44%	43%
Aggregated cash flow statement											
Operating activities	89	96	118	124	137	174	137	83	104	95	77
Investing activities	-40	-83	-87	-125	-169	-142	-79	-74	-102	-126	-67
Financing activities	-44	-18	-27	-3	21	-28	-35	10	14	36	4

Top 40 gearing ratio (%)

Source: PwC Analysis

Exploration expenditure



Source: Metals Economics Group: World Exploration Trends 2011.

Thank you for your attention!

Contact :

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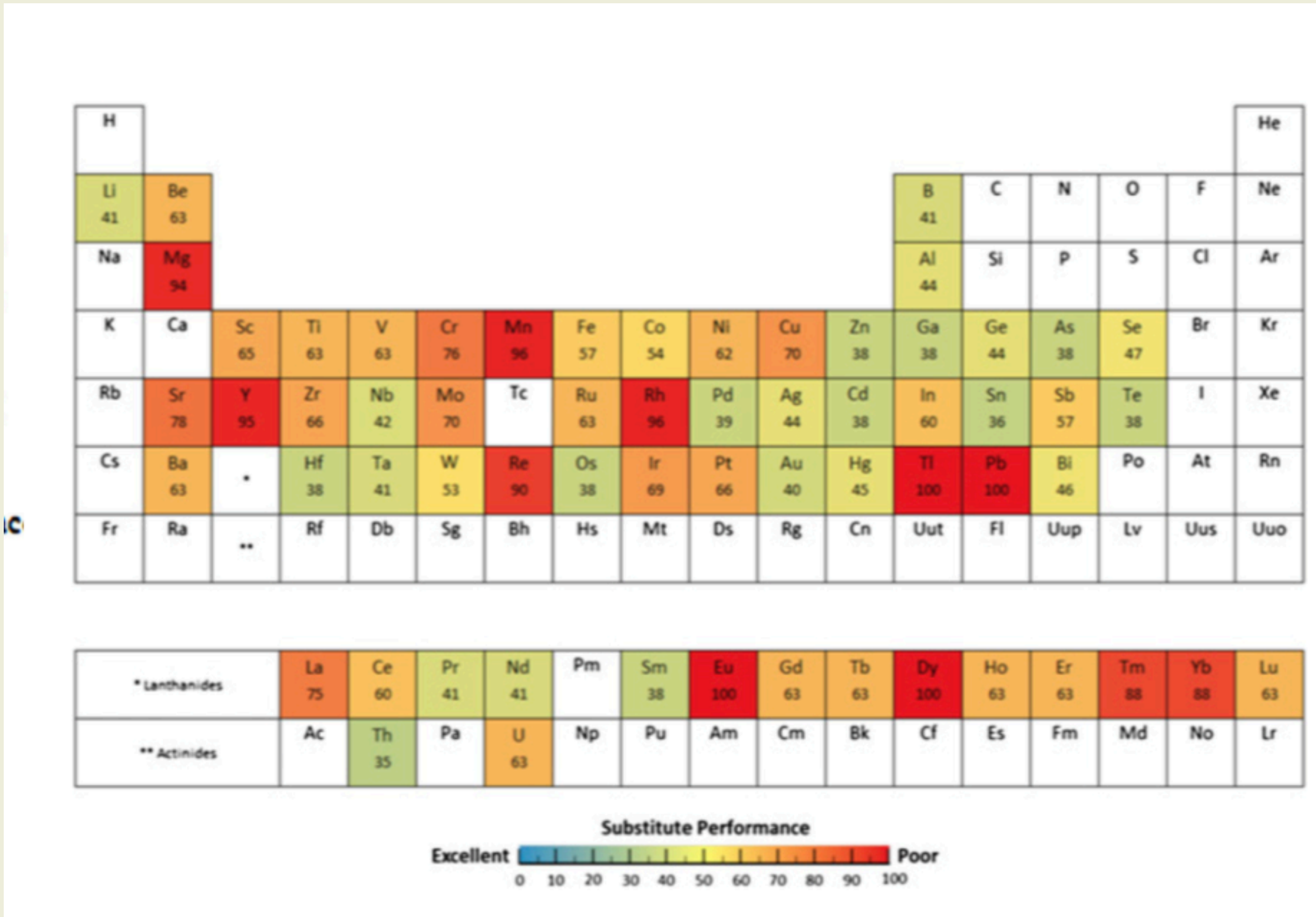
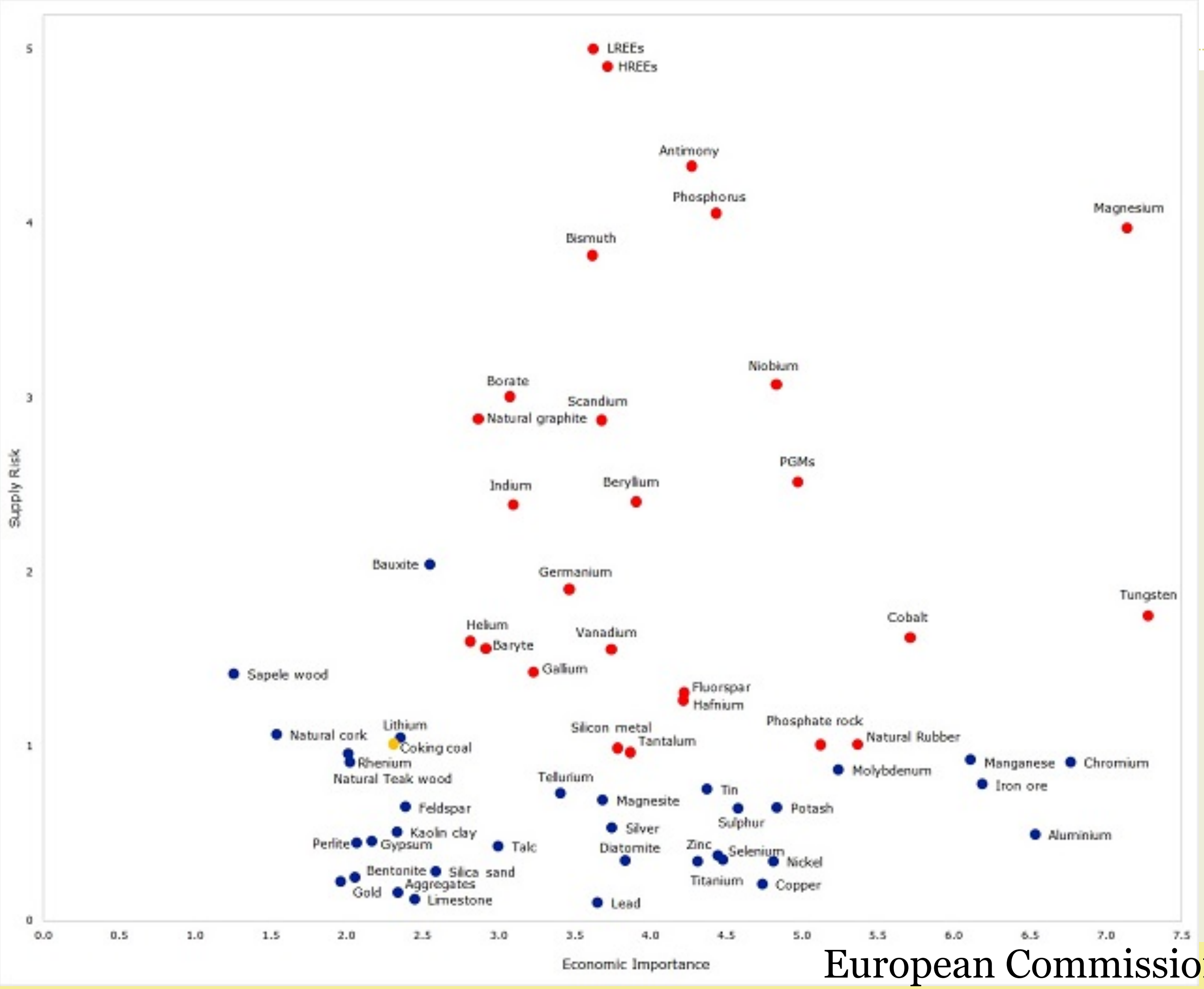
Substitution



Graedel, 2013

Criticality



European Commission, 2017

Recycling rates

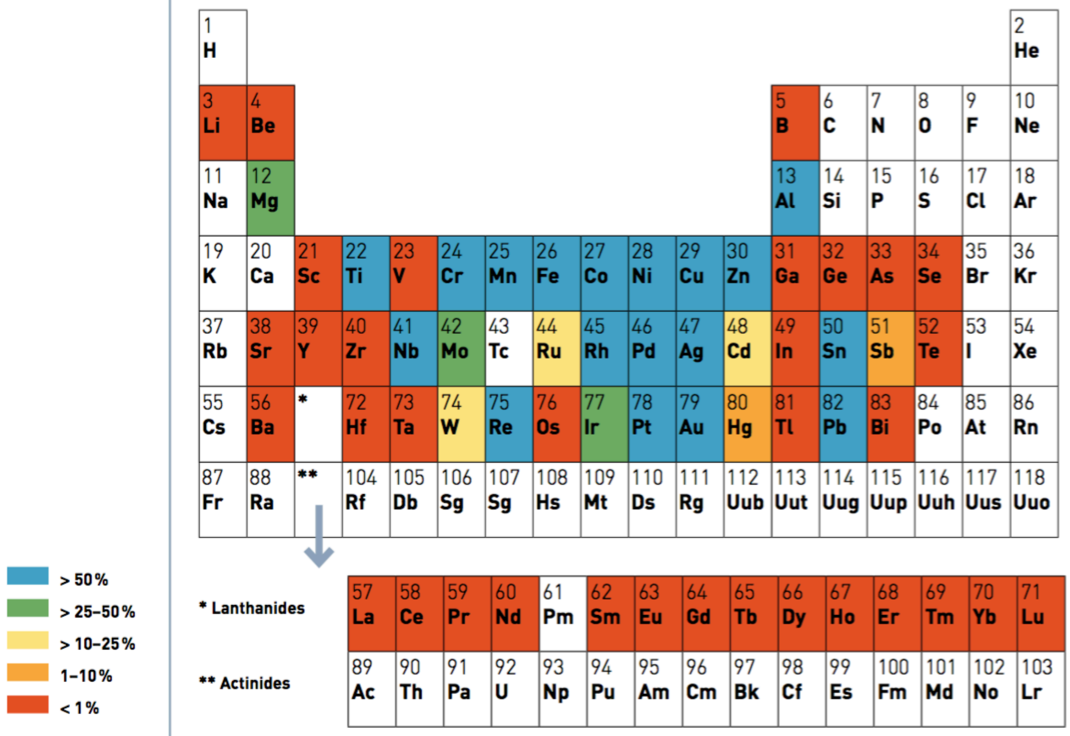


Figure 4. EOL-RR for sixty metals: The periodic table of global average end-of-life (post-consumer) functional recycling (EOL-RR) for sixty metals. Functional recycling is recycling in which the physical and chemical properties that made the material desirable in the first place are retained for subsequent use. Unfilled boxes indicate that no data or estimates are available, or that the element was not addressed as part of this study. These evaluations do not consider metal emissions from coal power plants.

UNEP, 2011