# Fossil and mineral resource scarcity

Course materials

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# Research objective and approach

## Objective

To develop an operational impact assessment method for addressing abiotic resource scarcity and corresponding characterization and normalisation factors

## Approach

1. Stakeholder consultation
2. Cause-effect chain
3. Characterization factors
4. Normalization factors

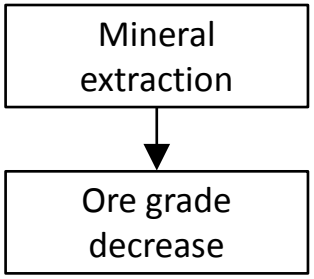
# Stakeholder consultation

- To bring **clarity on issue of concern** regarding the use of abiotic resources
- 20 participants in total representing policy, industry and experts

- Identification of issue of concern for different time frames:
  - ✓ **short term** (< 5 years): availability of resources constrained by geopolitical factors
  - ✓ **midterm** (5-20 years): increase in extraction efforts
  - ✓ **long term:** overall availability/depletion

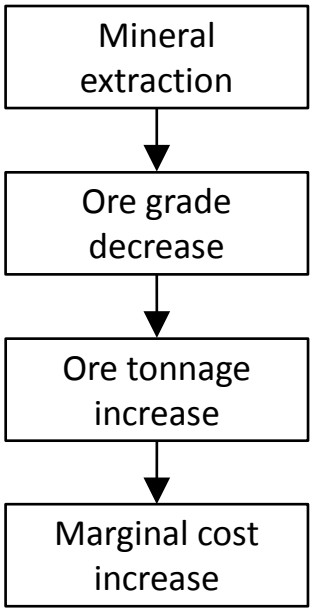
**Publication:** Vieira M, Storm P, Goedkoop M. 2011. Stakeholder Consultation: What do Decision Makers in Public Policy and Industry Want to Know Regarding Abiotic Resource Use? In M. Finkbeiner, *Towards Life Cycle Management* (pp. 27-34). Springer Science+Business Media B.V.

# Mineral resources



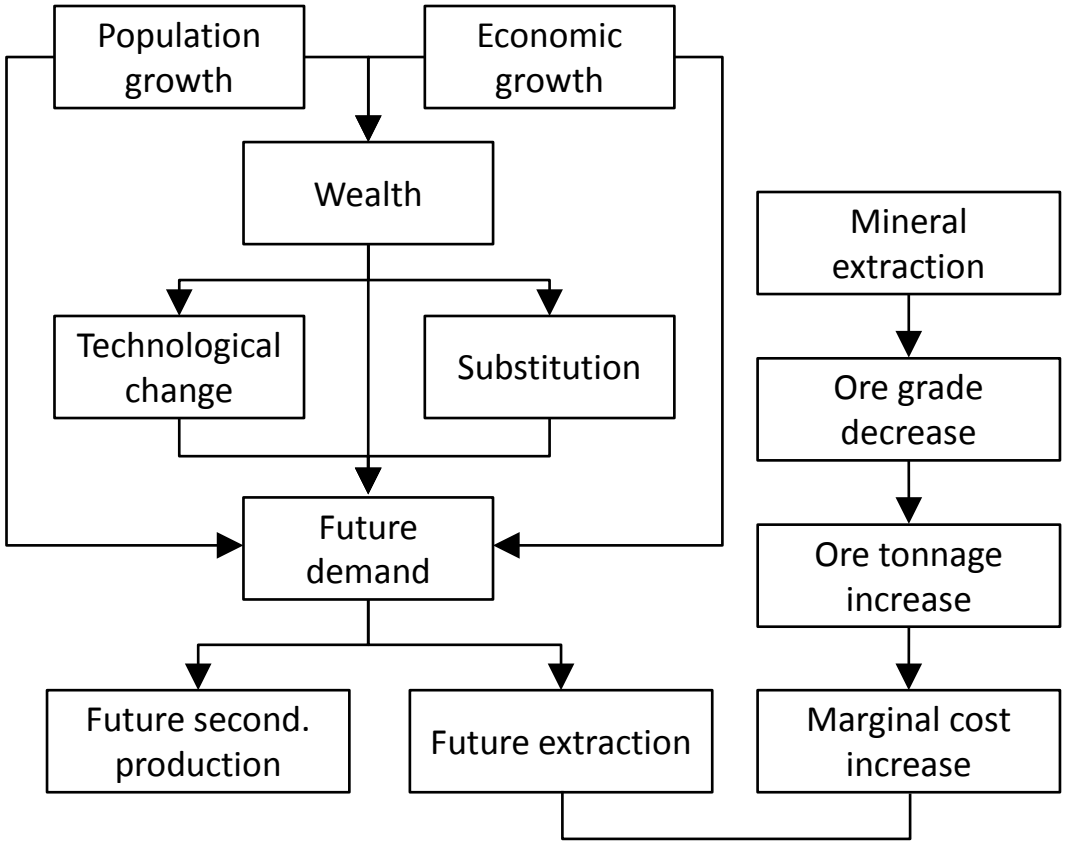

The concentration of a mineral resource element within an ore, defined as ore grade, is a quality property of a mineral resource. Assuming that mines with higher grades are explored first, when a mineral resource is extracted, its average ore grade worldwide decreases.

# Mineral resources



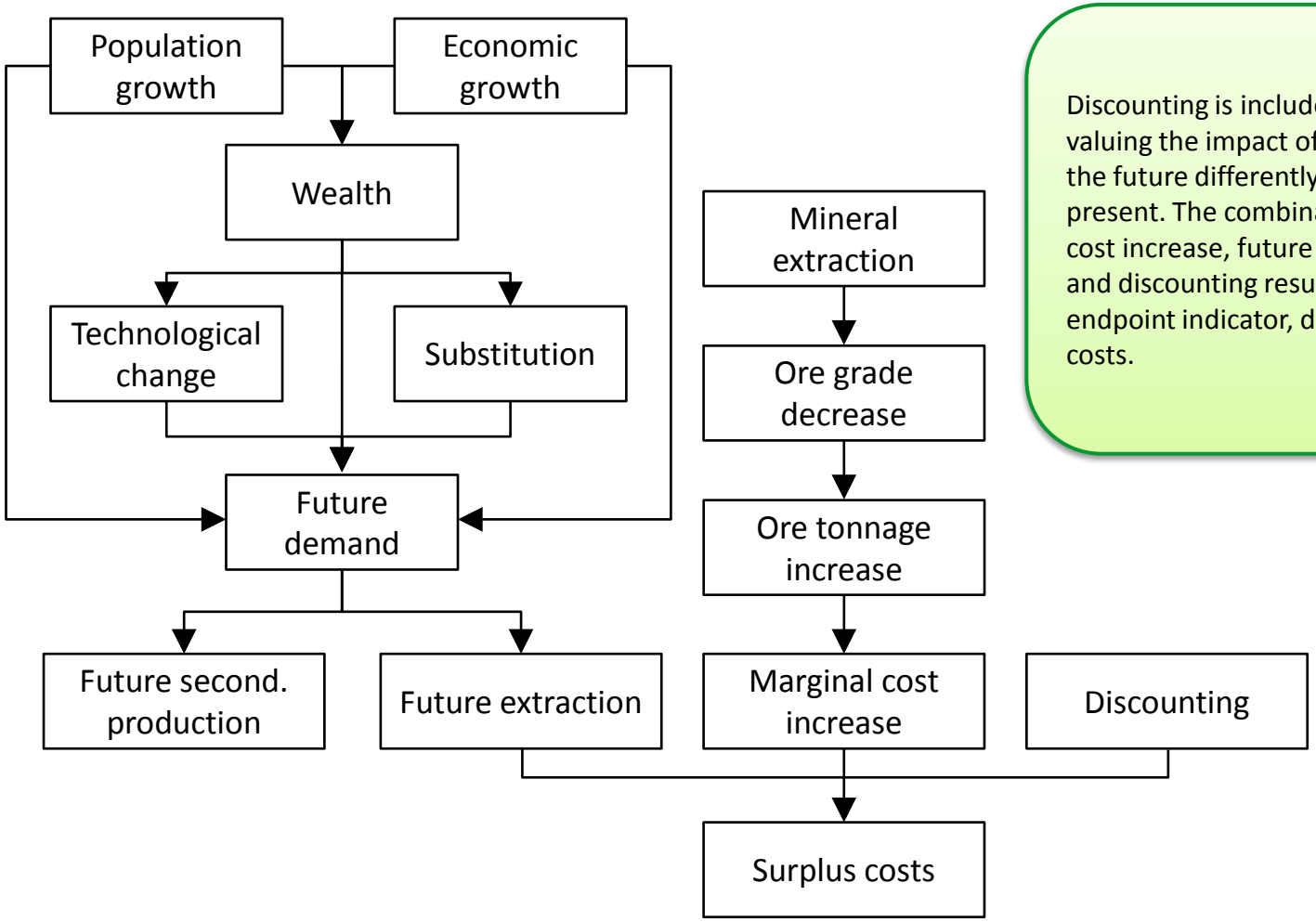

The higher the grade of a mineral in a deposit, the larger the volume of mineral extracted per ore mined. Consequently, if the ore grade decreases, in order to extract the same amount of mineral resource, more ore needs to be mined. Because more ore is mined, the extracting costs per mineral extracted also increase.

# Mineral resources




The significance of marginal cost increase is connected with the future resource to be extracted. Future mineral demand is influenced by a region's economic development and population size, the consumption trends (technologies expected), and by resource substitution. The fraction of mineral demand remaining after taking into account secondary production must come from extraction.

# Mineral resources

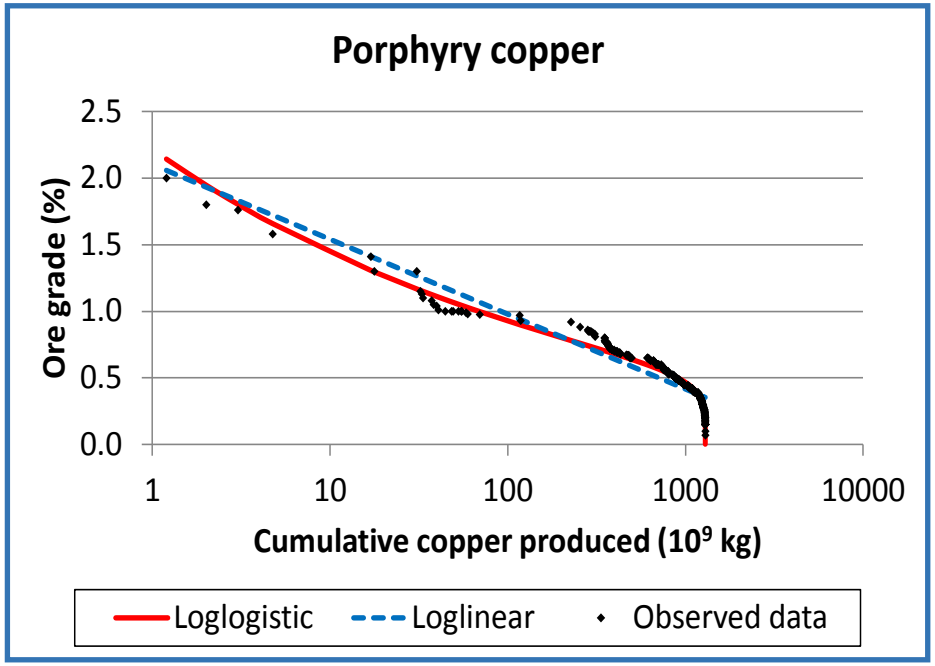



Discounting is included to account for valuing the impact of cost increase in the future differently than in the present. The combination of marginal cost increase, future mineral extraction, and discounting results in the proposed endpoint indicator, defined as surplus costs.

# Mineral resources

## Midpoint indicator – Ore grade decrease

- Use of cumulative grade-tonnage relationships per deposit type
  - Marginal modeling
  - Loglinear regression
- Characterization factor calculated as symmetric of the derivative of these relationships
- Data source: U.S. Geological Survey



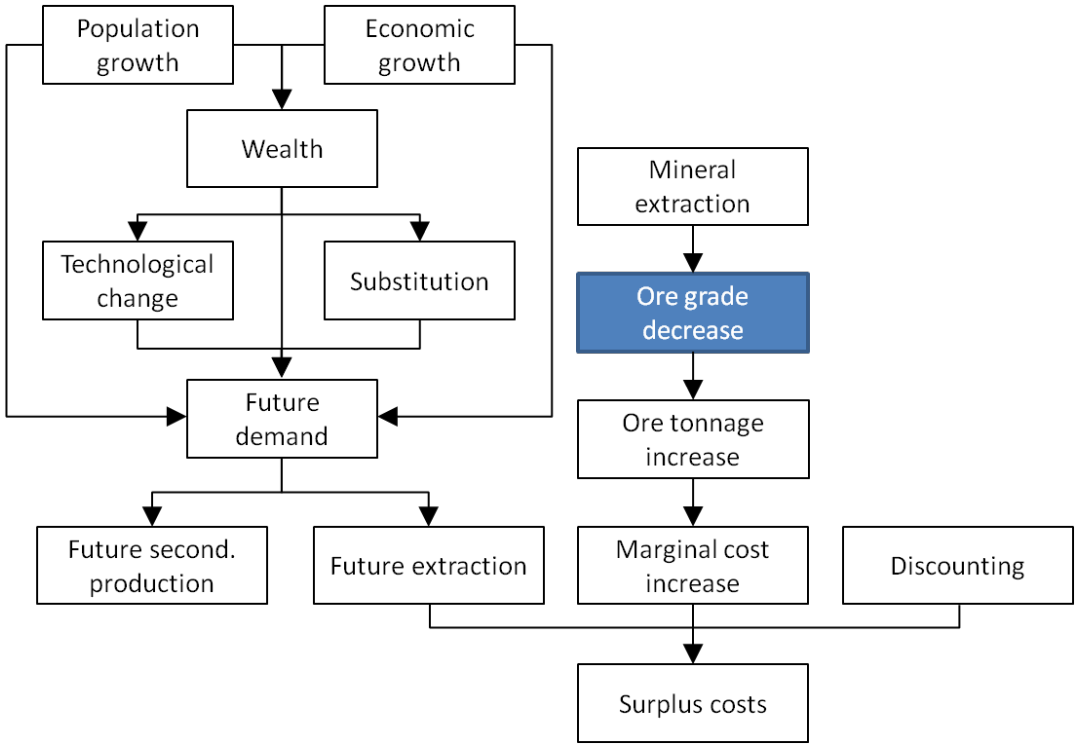
# Mineral resources

## Midpoint indicator – Ore grade decrease

**Midpoint characterization factor:**

$$CF_{mid,x} = \frac{\partial g_x}{\partial CMT_x}$$

in %/kg where $g_x$ is the grade of a specific resource $x$ and $CMT_x$ is the cumulative mineral $x$ extracted.




**Publication:** Vieira MDM, Goedkoop MJ, Storm P, Huijbregts MAJ. 2012. *Ore Grade Decrease As Life Cycle Impact Indicator for Metal Scarcity: The Case of Copper*. Environ. Sci. Technol. 46(23): 12772-12778.

# Mineral resources

## Endpoint indicator – Surplus cost

Surplus cost modelled according to three perspectives following the Cultural Theory

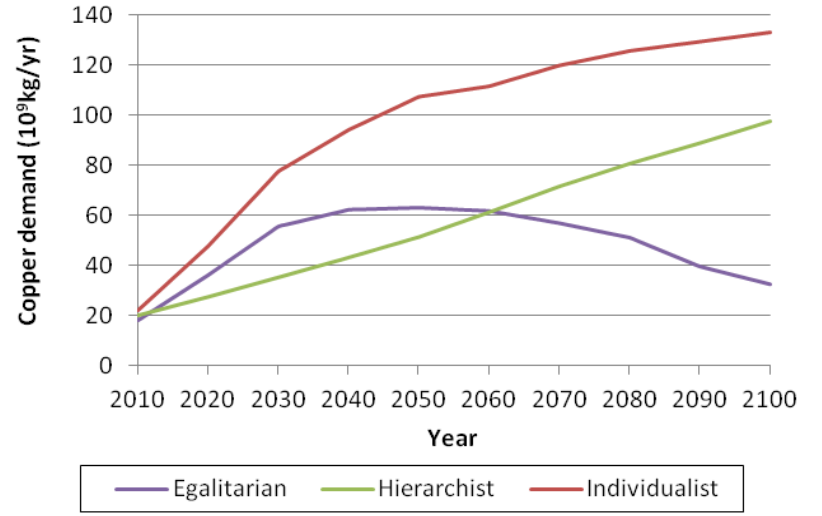
**Discounting**

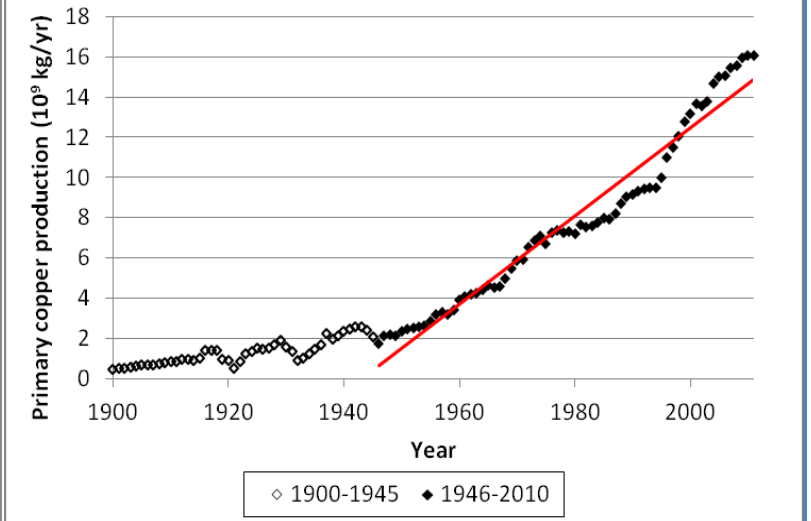
- Individualist (I) 15%
- Hierarchist (H) 3%
- Egalitarian (E) 0%

**Future demand scenarios** can be estimated using two approaches:

- Bottom-up: from demand per sector
- Top-down: using the intensity of use hypothesis

**Future production estimates** can also be derived using historical trends.



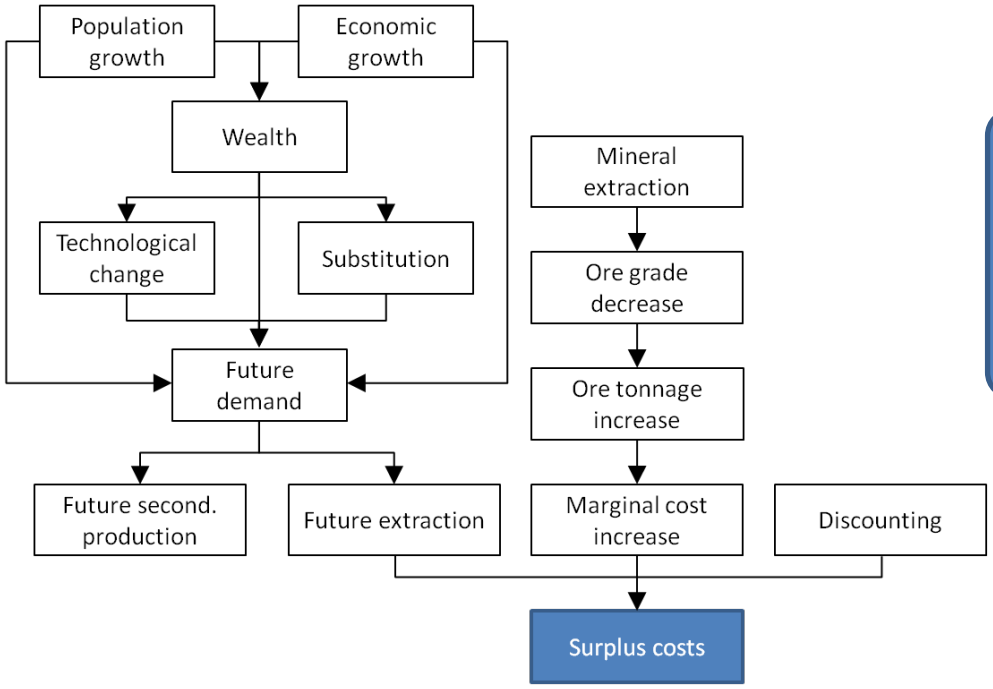
# Mineral resources

## Endpoint indicator – Surplus cost

### Endpoint characterization factor:

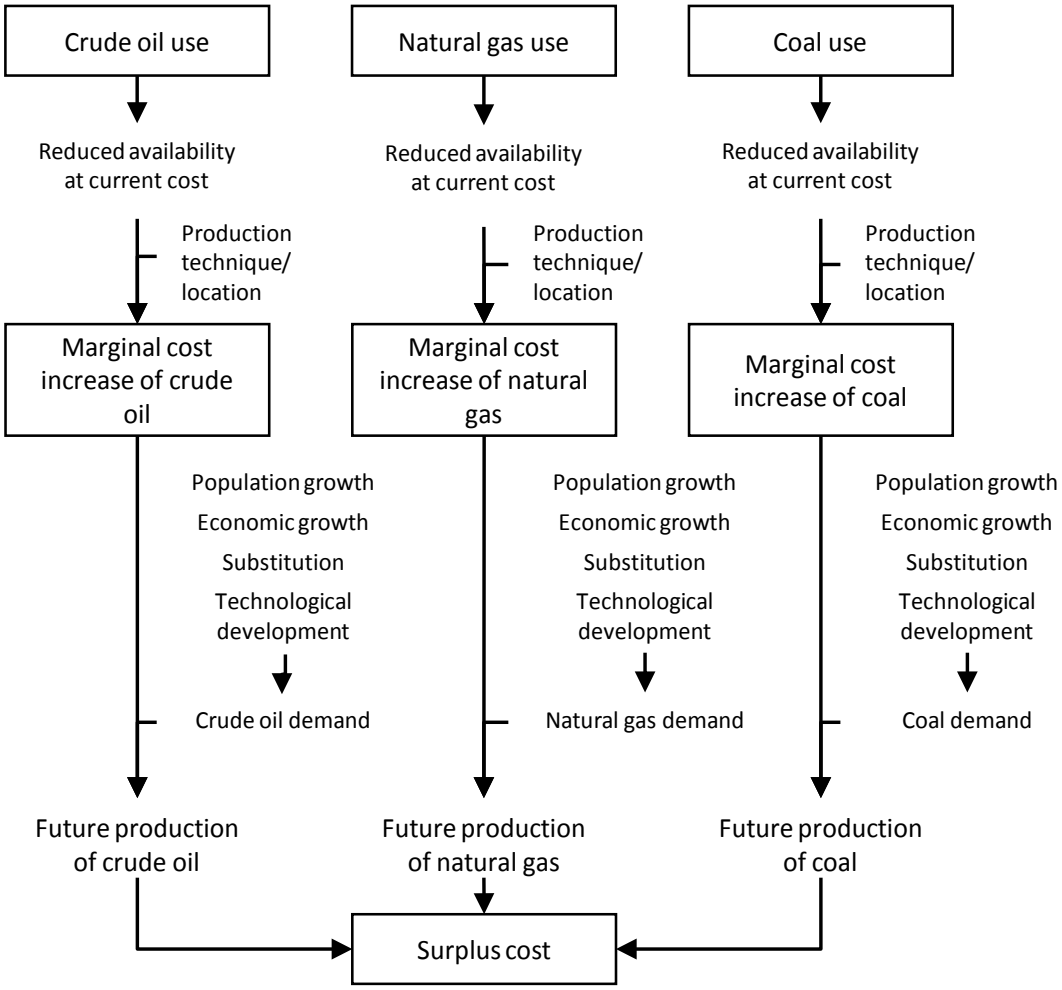
$$CF_x = \sum_{t=0}^{\infty} \left( \frac{\partial OT_x}{\partial CMT_x} \times \frac{\partial Cx}{\partial O_{Tx}} \times MT_{x,t} \times \frac{1}{(1+d)^t} \right)$$

in US$/kg where $OT_x$ is the ore extracted per mineral $x$ extracted, $C_x$ are the operating costs per ore mined, $MT_{x,t}$ is the annual primary production of mineral $x$ in year $t$, and $d$ is the discount rate.



# Fossil resources

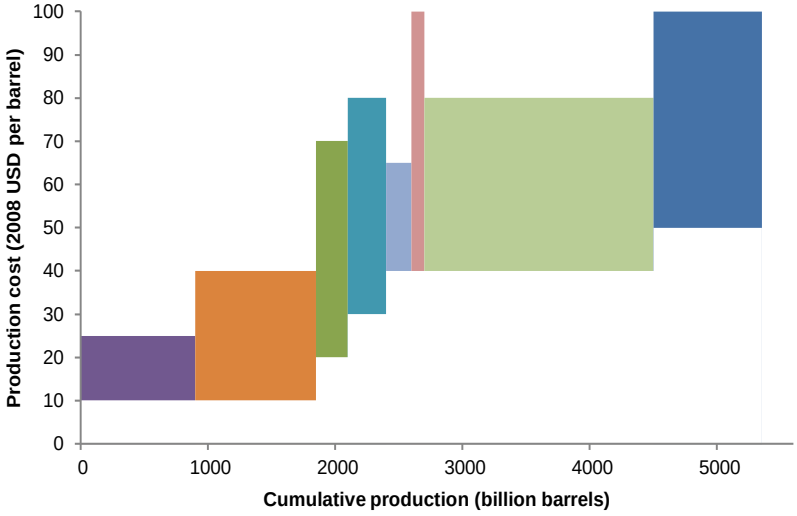
When all conventional oil is depleted, alternative techniques, such as enhanced oil recovery, will be applied or oil will be produced in alternative geographical locations, e.g. in the arctic. The additional production cost resulting from the change in production technique or location is defined as the marginal cost increase. The pathway between marginal cost increase and surplus cost is similar to that of mineral resources, namely by including future production of the fossil resource and discounting.

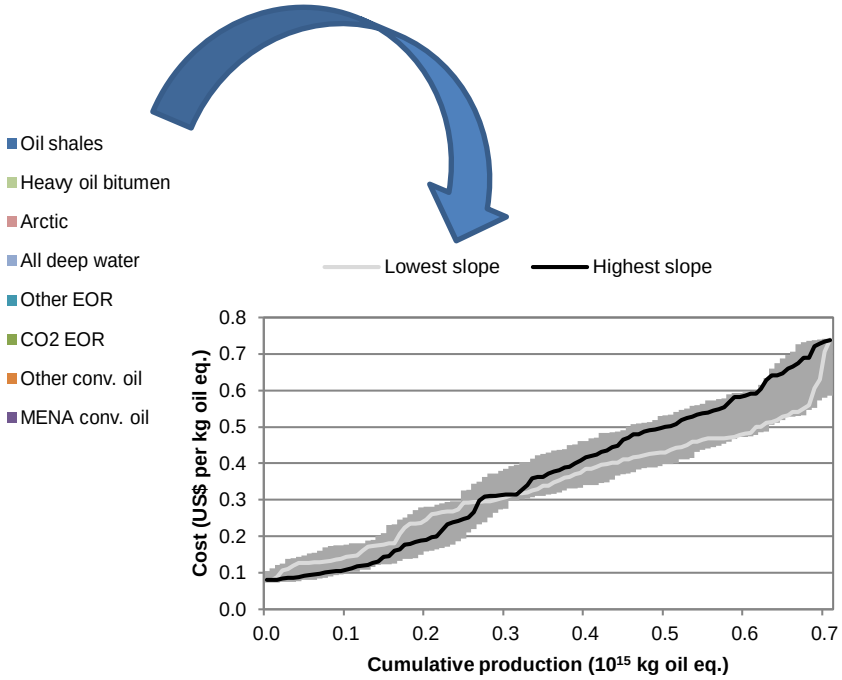


# Fossil resources

## Endpoint indicator – Surplus cost

- Relationships between production costs and cumulative fossil resource used to determine marginal cost increase of each fossil resource
- Data source: International Energy Agency

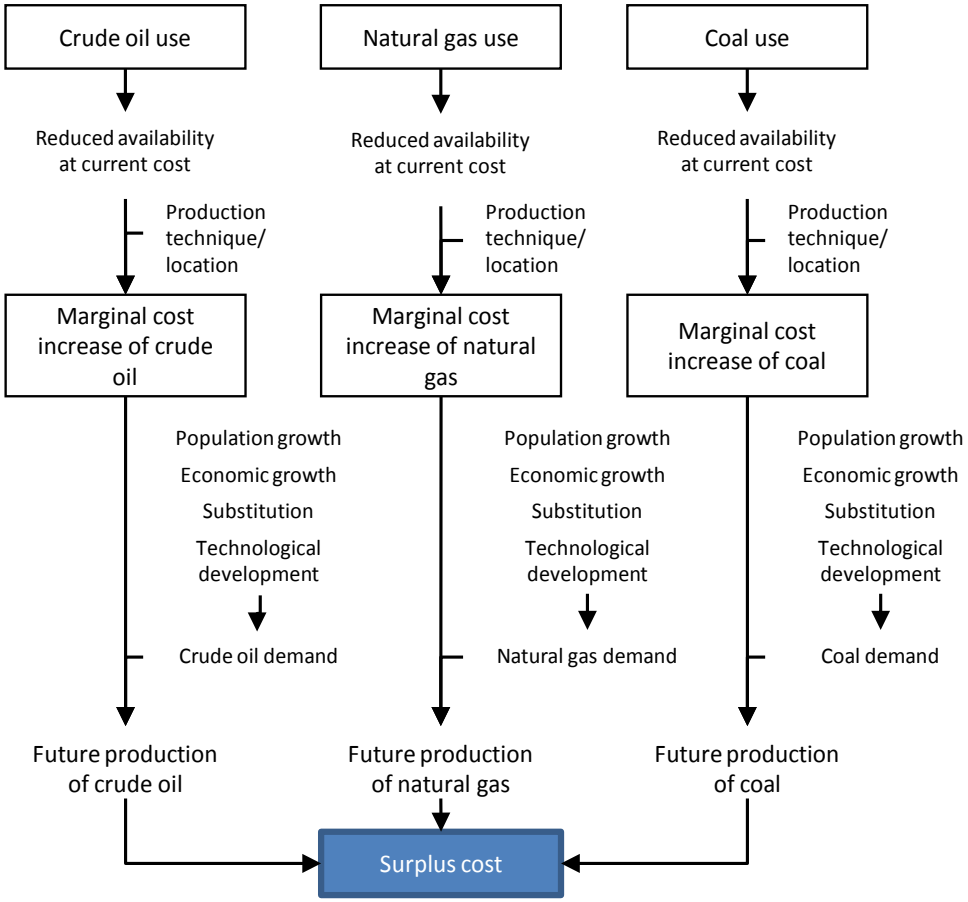



- Future production for three perspectives retrieved from the IPCC Special Report on Emissions Scenarios (2000)
- Discounting rules are the same as for mineral resources

# Fossil resources

## Endpoint indicator – Surplus cost



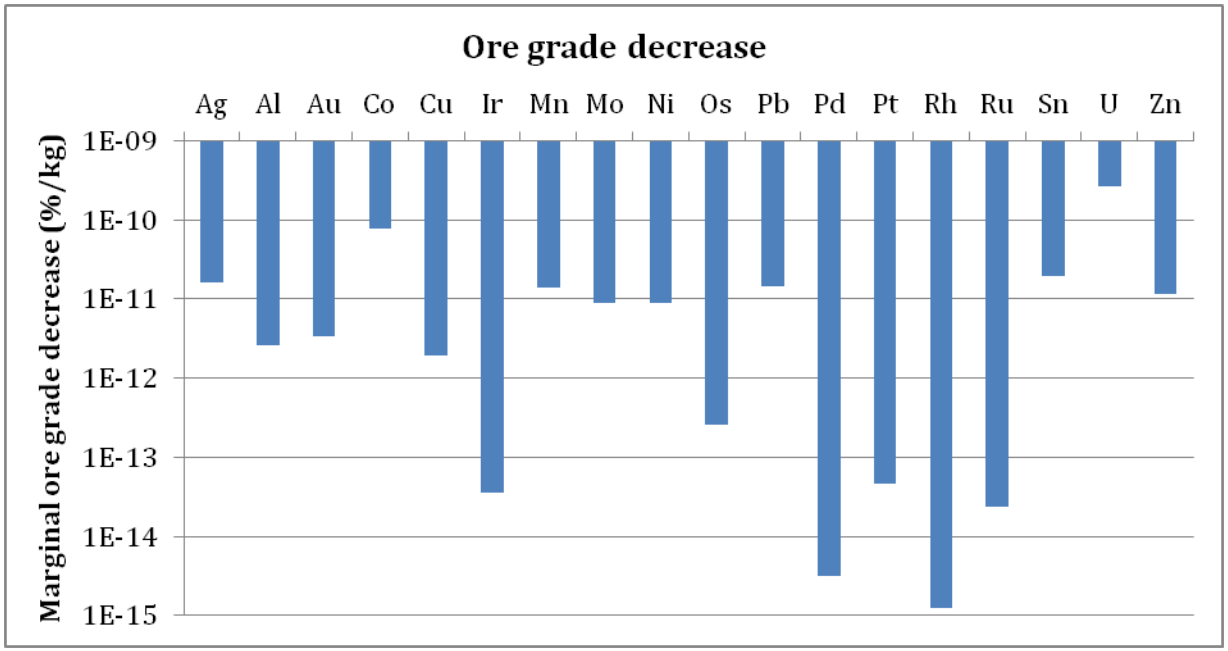

### Endpoint characterization factor:

$$CF_x = \sum_{t=1}^{\infty} \left( MCI_x \times P_{x,t} \times \frac{1}{(1+d)^t} \right)$$

in US$/kg or US$/m$^3$ where $MCI_x$ is defined as the extra cost resulting from the production of one additional kg or m$^3$ of fossil fuel, $P_{x,t}$ is the annual production of resource $x$ in year $t$, and $d$ is the discount rate.

# Characterization factors

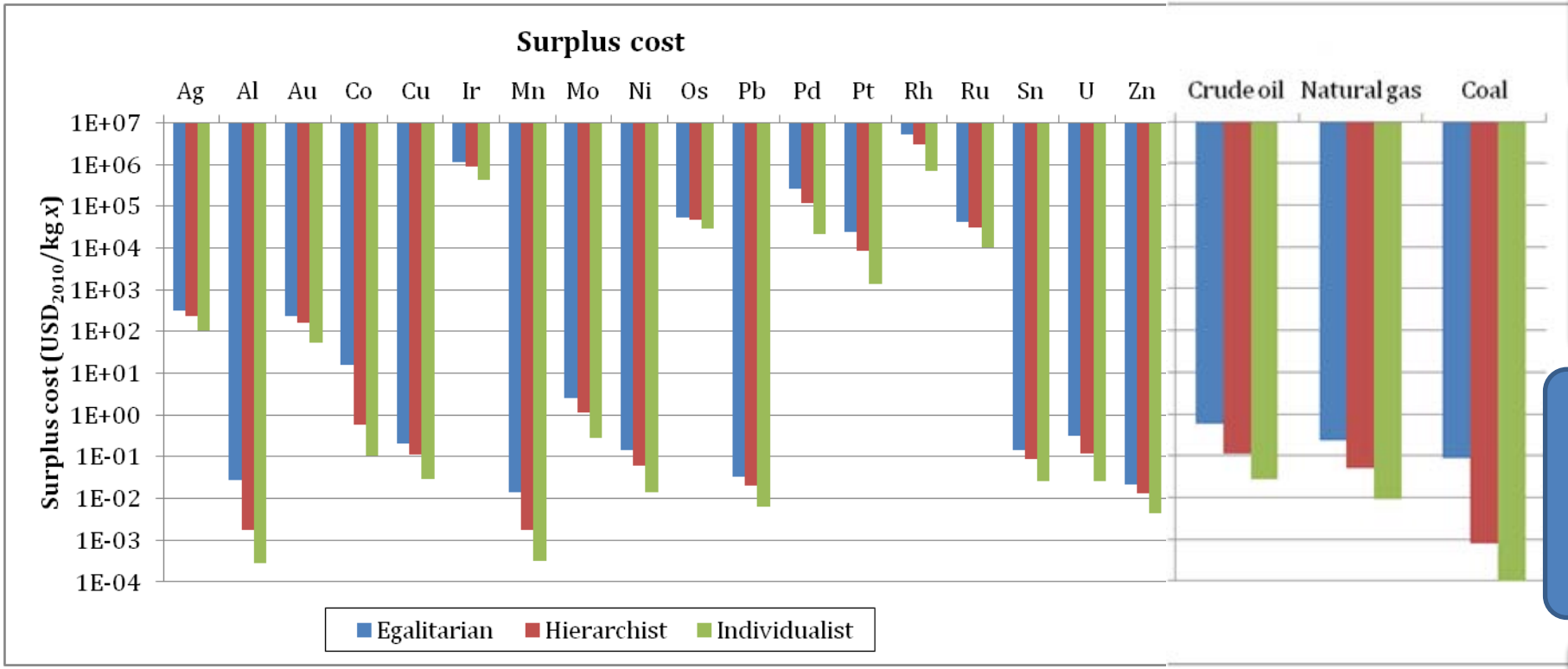
## Mineral midpoint indicator – Ore grade decrease




- 18 metal commodities covered
- 5-6 orders of magnitude difference between the midpoint CFs obtained
- Platinum-group metals have the lowest CF and uranium the largest

# Characterization factors

## Endpoint indicator – Surplus cost




- 18 metal and 3 fossil resource commodities covered
- Endpoint CFs derived for 3 human perspectives
- 11 orders of magnitude difference between the endpoint CFs obtained
- CFs obtained for fossil fuels similar to those obtained for main industrial metals

# Normalization factors

- 2 regions covered:
  - ✓ EU27 – 27 EU member countries
  - ✓ World
- In year 2010

**Normalization factor:**

$$NF_{i,r,z} = \frac{\sum_x CF_{x,i} \times M_{x,r,z}}{P_{r,z}}$$

in the impact category *i*, reference region *r* and year *z* ($USD_{2010}$/person·year), *where* $CF_x$ is the characterization factor of resource flow *x*, *M* is the amount of resource flow, and *P* is the population size.

| | | E | H | I | E | H | I |
|---|---|---|---|---|---|---|---|
| Indicator / Region | Ore grade decrease | Surplus cost - Minerals | | | Surplus cost – Fossil fuels | | |
| EU27 | $4.59 \cdot 10^{-11}$ | 2.0 | 1.1 | 0.4 | 210 | 22.4 | 5.5 |
| World | $8.68 \cdot 10^{-11}$ | 14.7 | 7.8 | 2.1 | 574 | 95.9 | 21.7 |

# Discussion

- Data on ore grade and cumulative metal production only available for 18 mineral commodities -> more data needed for method completeness
- Future mineral/metal production was calculated based on historical trends -> future forecasts based on scenario analysis are preferable
- Better estimates for mining costs are needed
- The role of extraction technological development to cost reduction is excluded
- Supply restrictions due to geopolitical trade barriers are excluded

Research in this topic must continue!

# Acknowledgments and Contact info

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