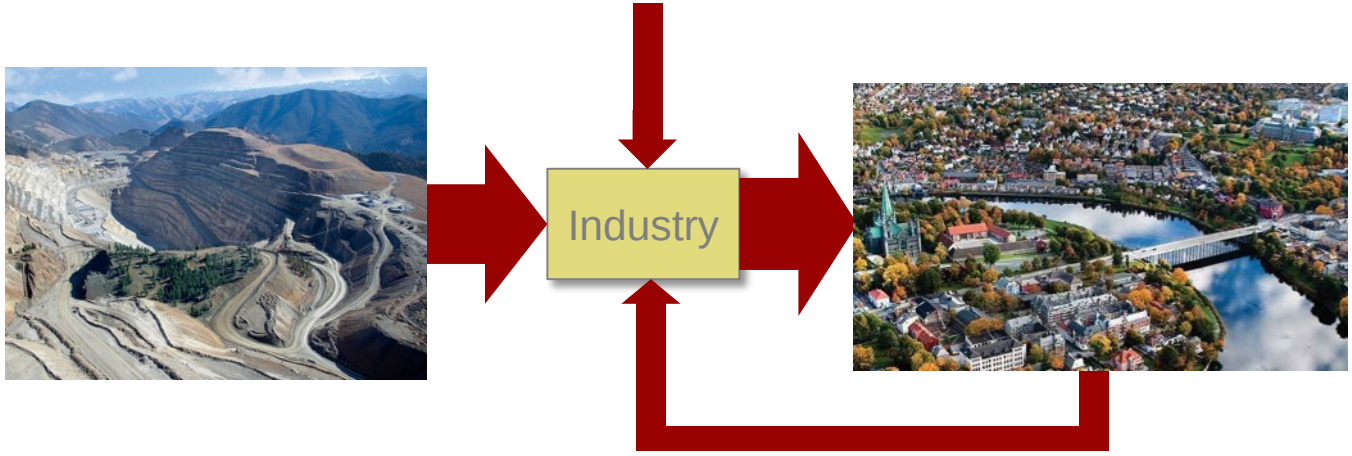
Challenges for anthropogenic resource classification on national level

Daniel B. Müller

1. Motivation
2. Challenges for physical accounting
3. Attempt to integrate UNFC resource classification and MFA
4. Conclusions



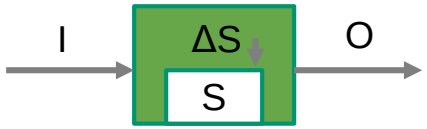
Material Flow Analysis (MFA)

MFA is the systematic assessment of the **flows and stocks** of materials (and energy) in a system defined in **space and time**.

Brunner and Rechberger 2004

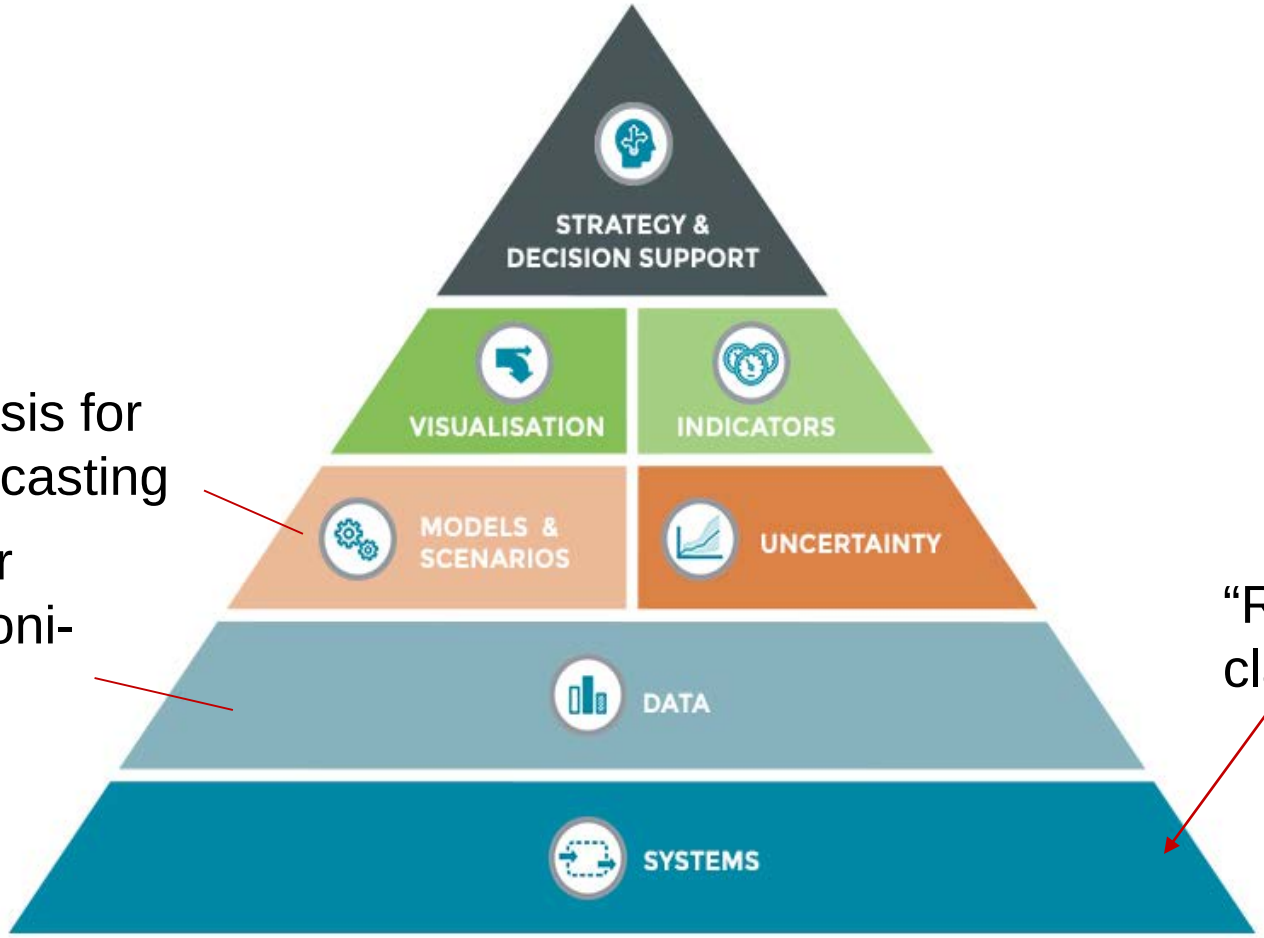
Basic principle: mass (and energy) balance consistency
Mass (and energy) can neither be created nor destroyed.

- Balance equation: $\Delta S = I - O$
- Intrinsic equation: $S_1 = S_0 + \Delta S$



"**Classification**" in MFA = System definition
→ Grouping of processes (stocks) and their connections (flows)

7 hierarchical components of a MFAs

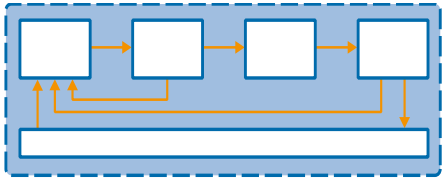


Basis for forecasting

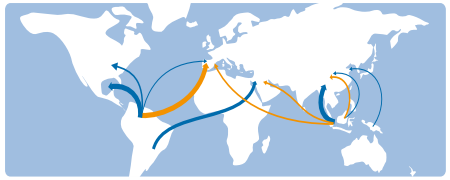
Basis for data harmoni-zation

“Resource classification”

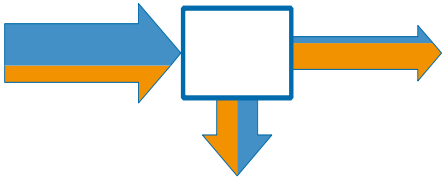
4 dimensions of MFAs



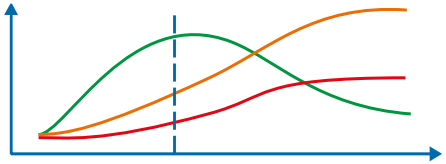
1. **Stages**
   Integrate primary and secondary resources



2. **Trade**
   Integrate trade with production and consumption for analyzing global supply chains



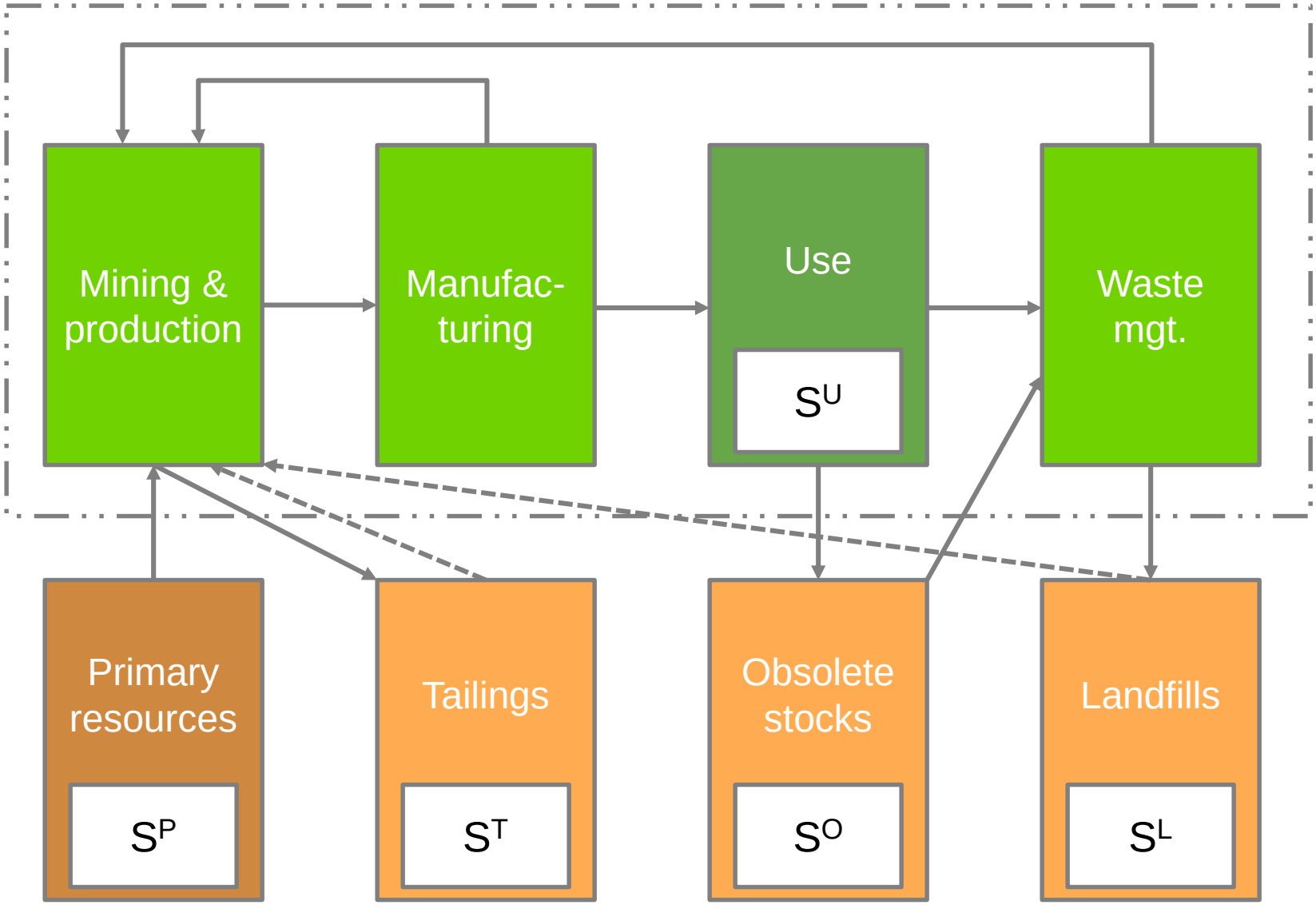
3. **Layers (linkages of materials, energy, value)**
   Capture linkages of materials at all stages



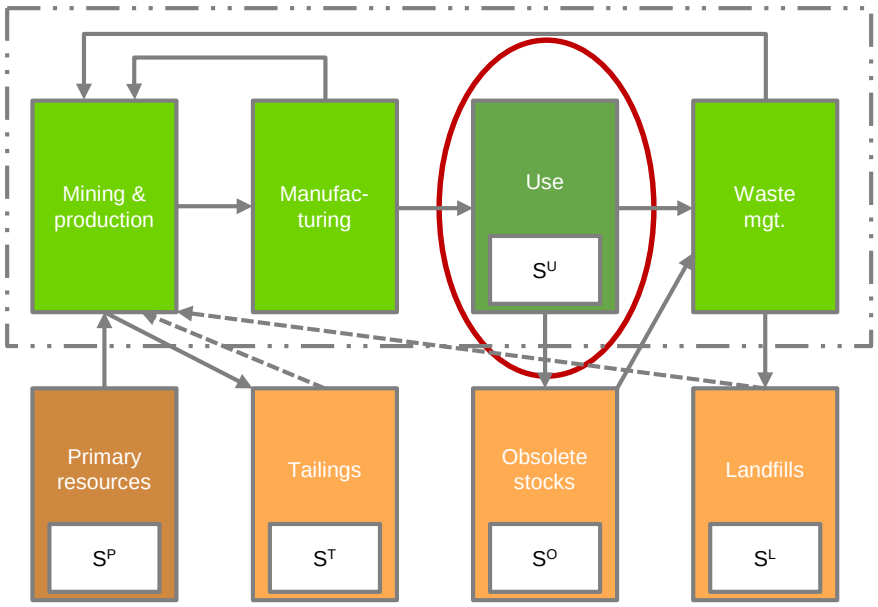
4. **Time**
   Historical development and future scenarios

Simplified material system for a country

(excluding trade flows)



Accounting for material stocks in use



3 approaches for estimation:

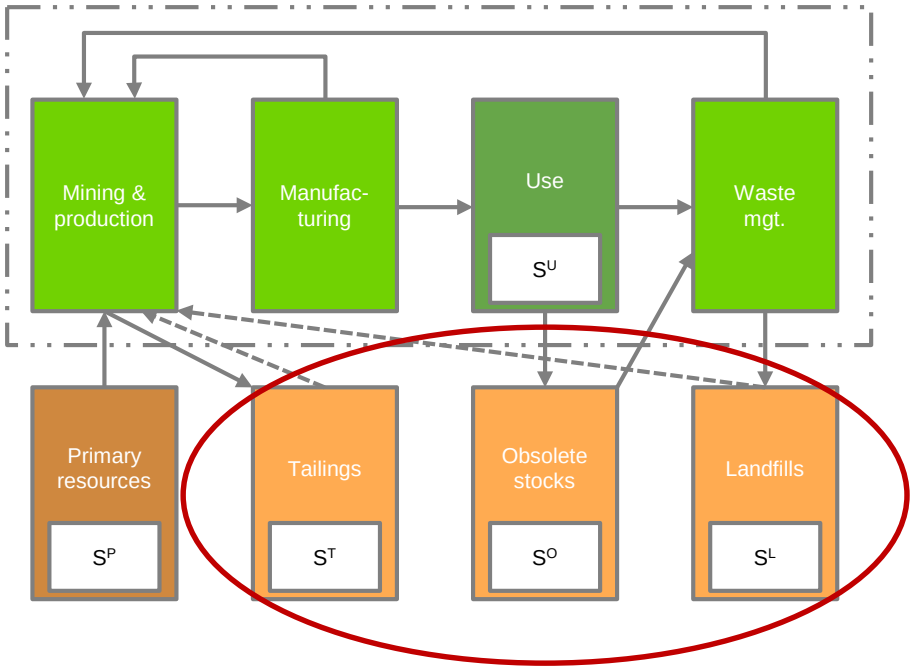
1. Difference approach
   $\Delta S = I - O$
2. Lifetime (or top-down) approach
   Estimation of O based on I and L
3. Bottom-up approach
   Stock is sum of items and their material concentration

→ Combinations (e.g., lifetime appr. on product level)

Mass balance consistent

→ Total inputs, outputs, stocks

Accounting for secondary resource stocks



2 approaches for estimation:

1. Difference approach

   $\Delta S = I - O$

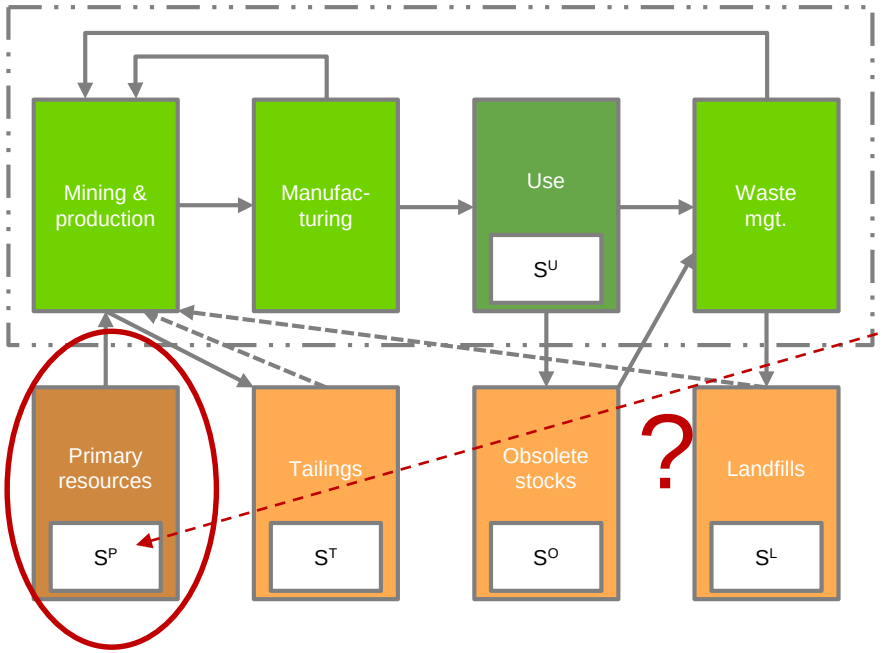
2. Bottom-up approach

   Stock is sum of volumes and their material concentration

Mass balance consistent

→ Total inputs, outputs, stocks

Accounting for primary (mineral) resource stocks



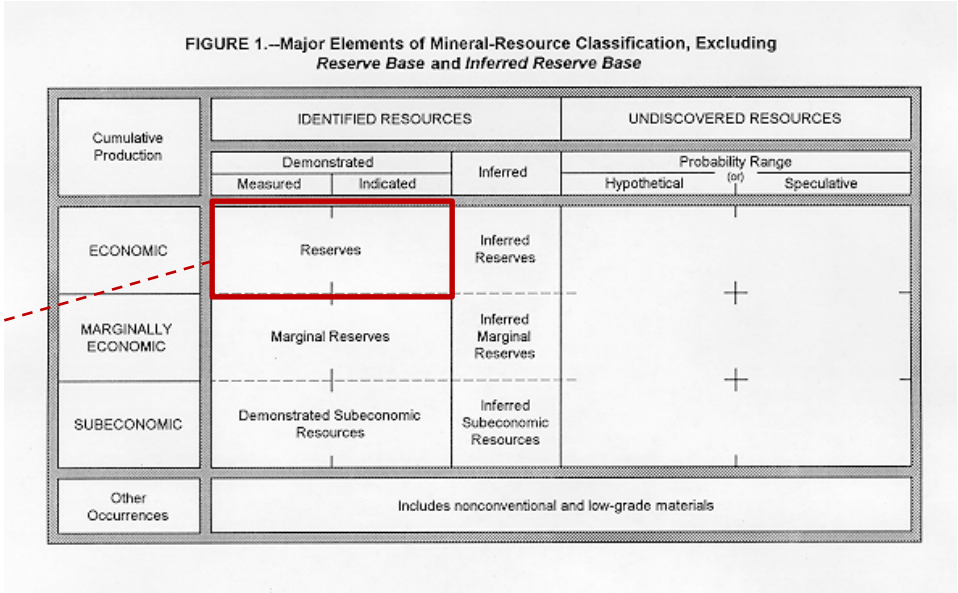


FIGURE 1.--Major Elements of Mineral-Resource Classification, Excluding *Reserve Base* and *Inferred Reserve Base*

Cumulative Production	IDENTIFIED RESOURCES		UNDISCOVERED RESOURCES	
	Demonstrated	Inferred	Probability Range	
	Measured / Indicated		Hypothetical (or)	Speculative
ECONOMIC	Reserves	Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves	Inferred Marginal Reserves		
SUBECONOMIC	Demonstrated Subeconomic Resources	Inferred Subeconomic Resources		
Other Occurrences	Includes nonconventional and low-grade materials			

Source: USGS

Not mass balance consistent!

→ Total output, but

→ only partial stocks

→ stocks measured with changing balance volumes
(system boundary is not defined in space and time, but economically)

Example: economic definition of balance volumes

Reserves 1.1.2017: 25
Reserves 1.1.2018: 22

Mining in 2017: 2

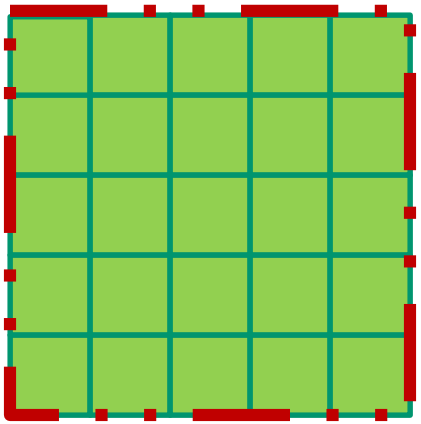
} What happened to the reserves?

Matter seems to be magically appearing and disappearing

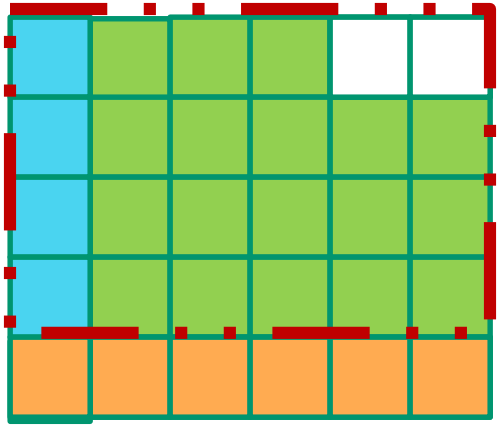
Accounting of reserves is **not mass balance consistent**, because
- reserves represent a small fraction of the resources
- the location of the balance volume is changing

Example: spatial definition of balance volumes

Reserves
1.1.2017



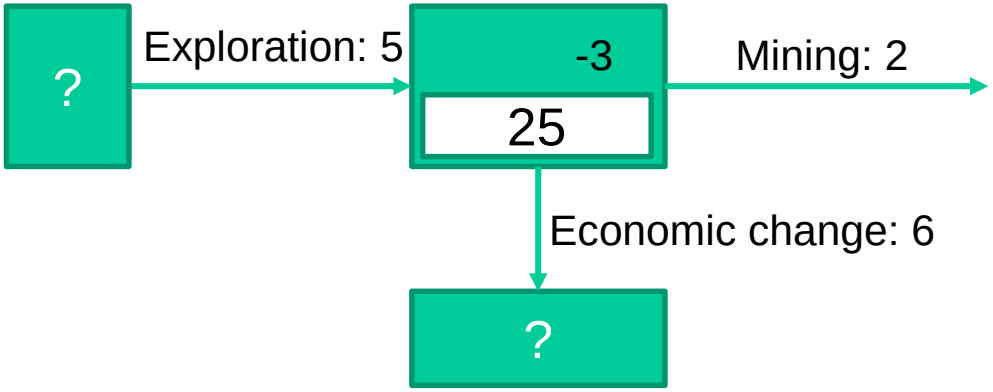
Reserves
1.1.2018



Mined

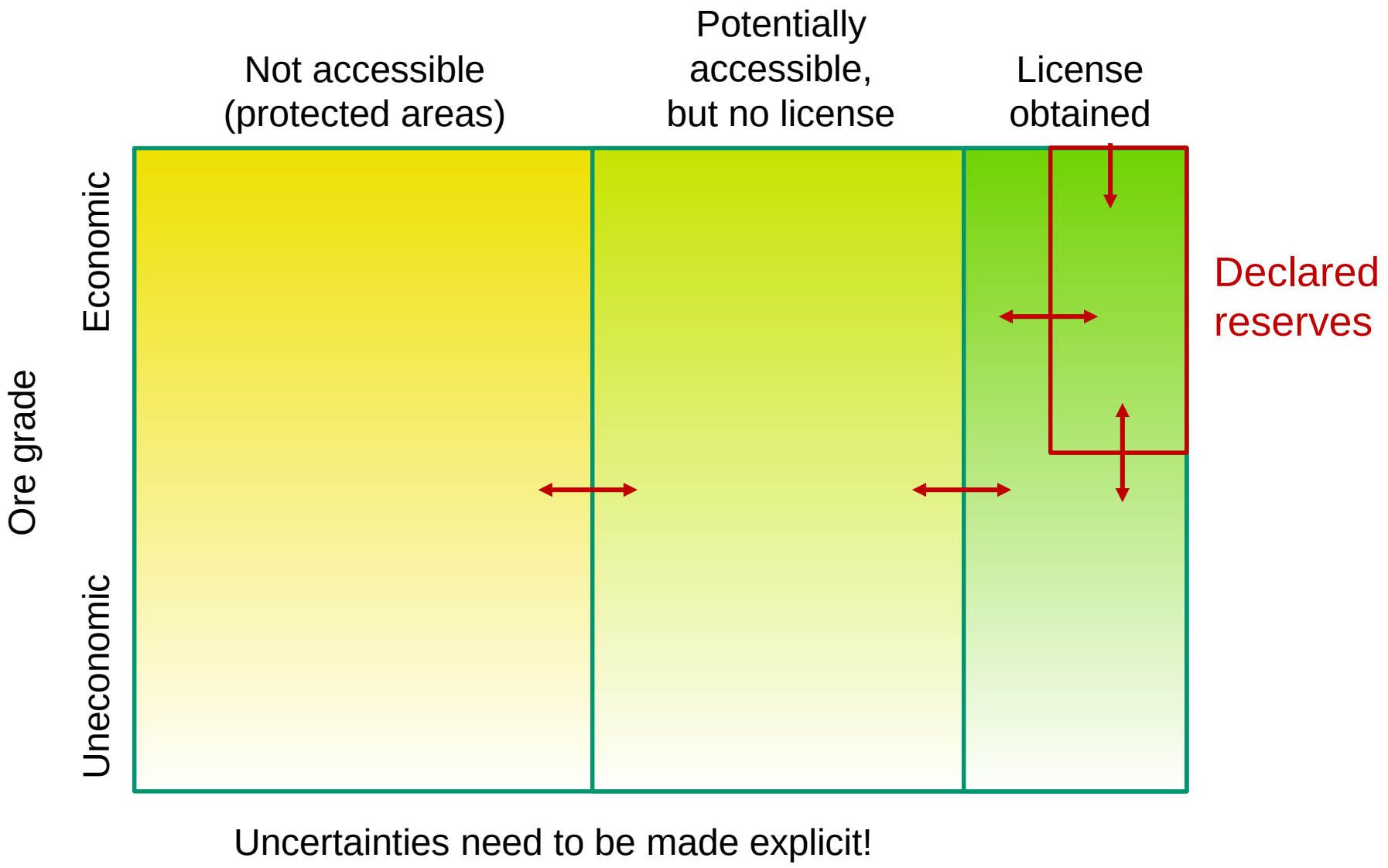
Economic change

Exploration

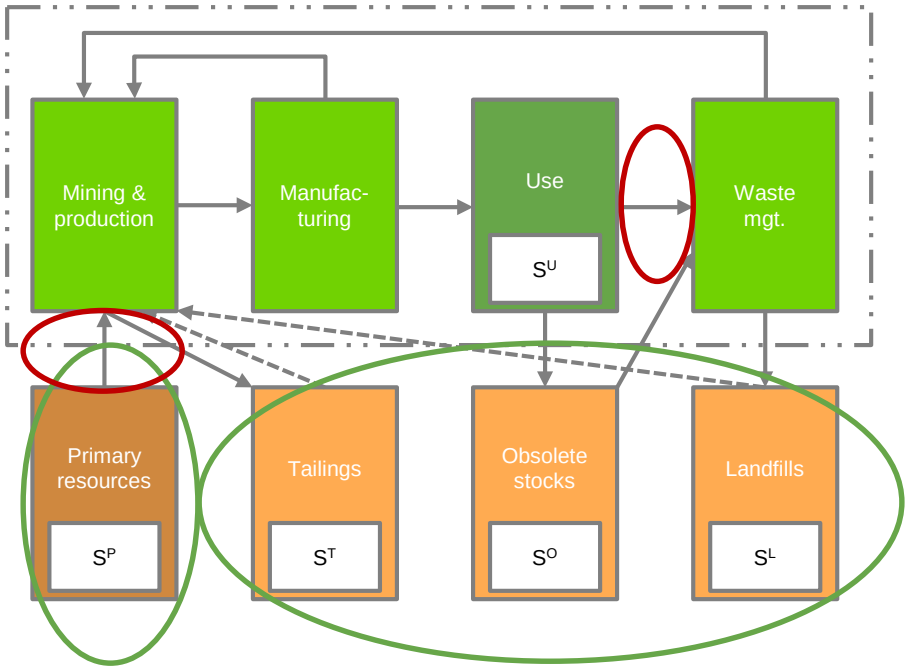


- **Balance volumes** (boxes) are defined spatially
- **Physical properties** of boxes (e.g., ore grade) are constant attributes
- **Economic properties** of boxes (e.g., exploration, economic change) are changing attributes

Conceptual design of a mass balance consistent classification of primary mineral resources



“Mining of stocks” versus “mining of flows”



Mining of stocks:

- Primary resources
- Tailings, obsolete stocks, landfills

→ Mining directly on the stocks

→ Availability limited by stocks

Mining of flows:

- Discards
- Extraction of by-products

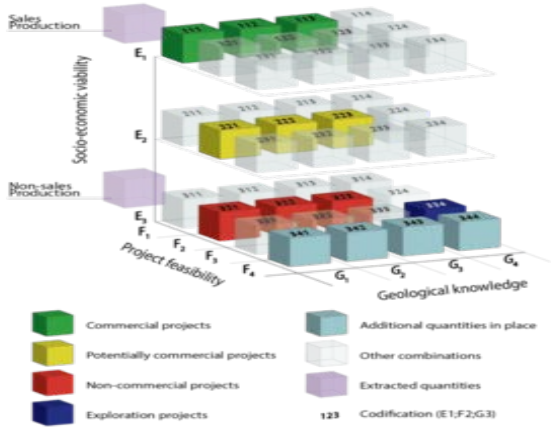
→ Mining of available material flow

→ Availability limited by discards or host material

→ Reserve numbers are less useful

UNFC resource classification versus MFA classification

UNFC



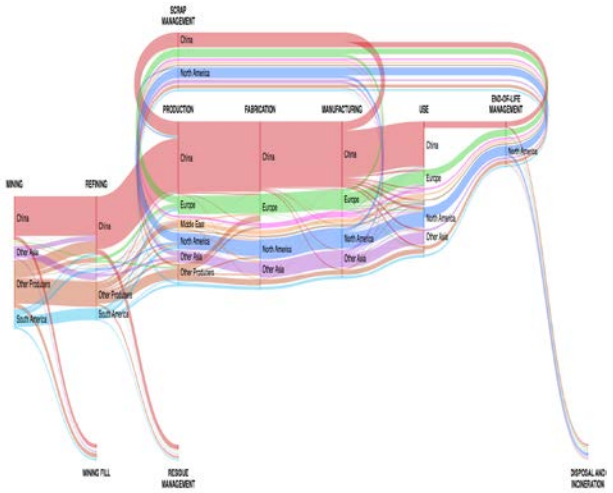
A) Scale: Project (expand to region?)

B) Dimensions (physical and others):

- E: Socio-economic viability
- F: Project feasibility
- G: Geological knowledge

C) Focus: Stocks (or flows)

MFA



A) Scale: Region of any scale

B) Dimensions (exclusively physical):

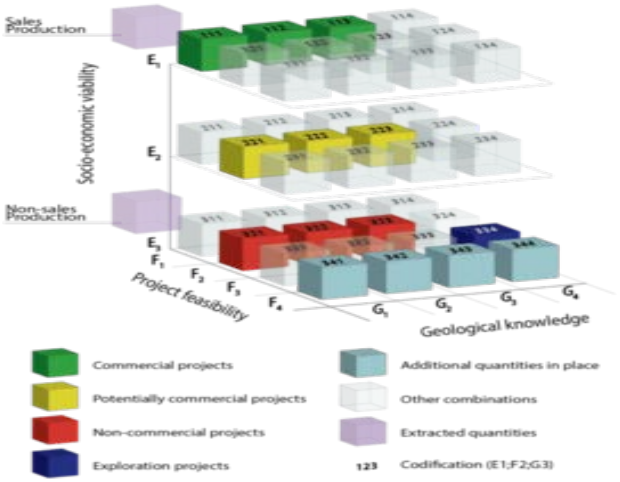
- Supply chain
- Trade
- Layers
- Time

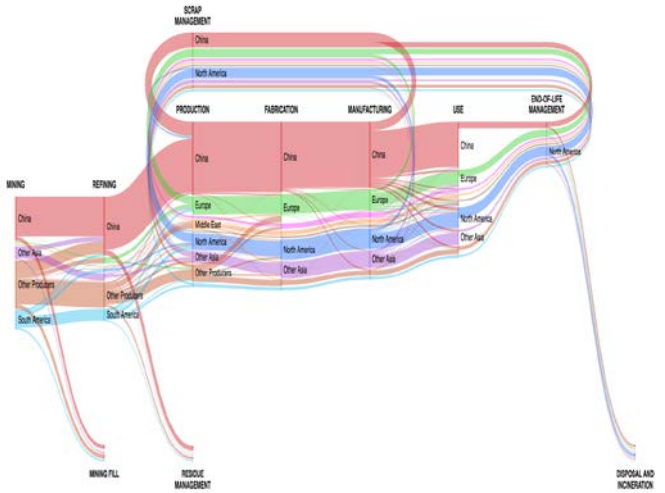
C) Focus: Stocks and flows (systems)

UNFC includes more dimensions
MFA ensures mass balance consistency

} Integration possible?

First attempt for integrating UNFC resource classification and MFA





4 conditions for integration:

1. Boxes are defined spatially and are fix
   → G axis: constant attributes of boxes (unless inputs and outputs)
2. E and F axes: changing attributes of boxes
   → No moving boxes (unless removed), but changing attributes
3. Differentiate mining of stocks versus mining of flows
   → Use MFA as basis
4. Define boxes beyond project level
   → Boxes for entire region

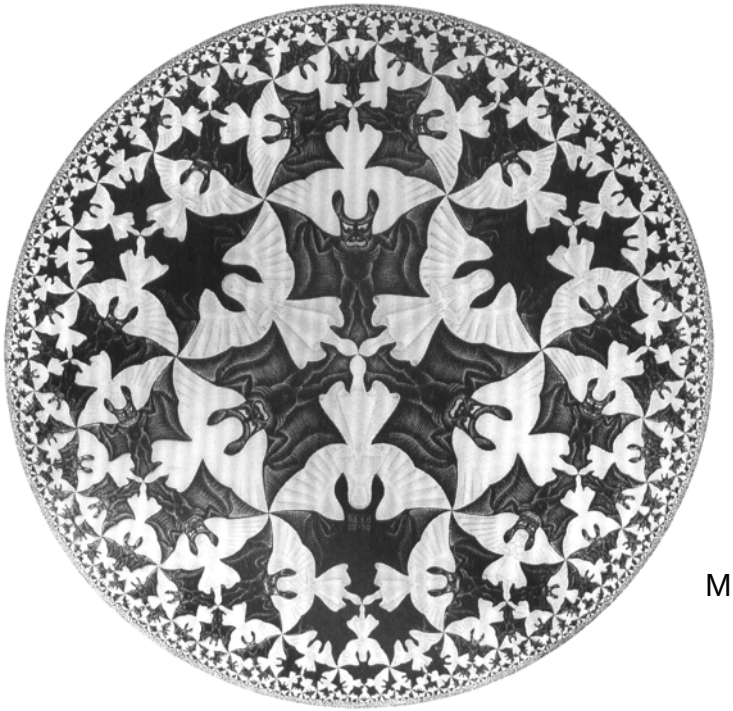
Conclusions

1. We need to move from a monitoring of isolated stocks and flows to a **monitoring of systems** (stocks and flows).
   → Material flow analysis (MFA) allows for a mass balance consistent accounting of stocks and flows in 4 dimensions

2. "MFA classifications" differentiate "mining of stocks" from "mining of flows".
   → **Urban mining is a mining of flows**, similar to by-product extraction

3. **Current geological resource (reserve) estimates are not mass balance consistent.**
   → Cannot be integrated properly into a common framework
   → Two reasons: (i) reserves reflect only a fraction of the resources
   → project scale, not national scale
   (ii) balance volumes unclear and changing
   → economic system definition, not spatial

Angels or devils?
It depends on the system definition

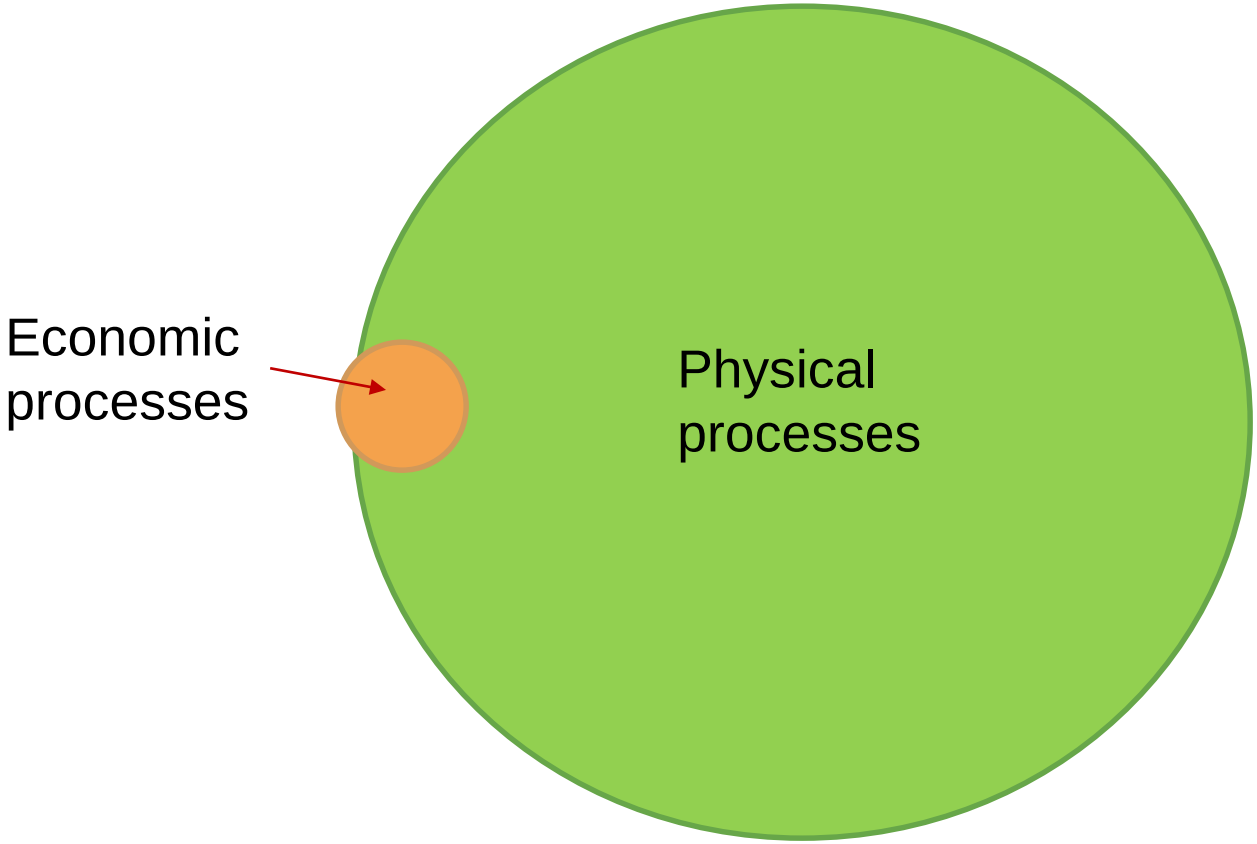


M.C. Escher (1960): Circle Limit IV

Thank you!

daniel.mueller@ntnu.no

How to integrate physical and economic accounting?



Physical accounting can serve as a basis for most economic transactions.
Economic accounting can serve as a basis for a few physical transactions.