NTNU

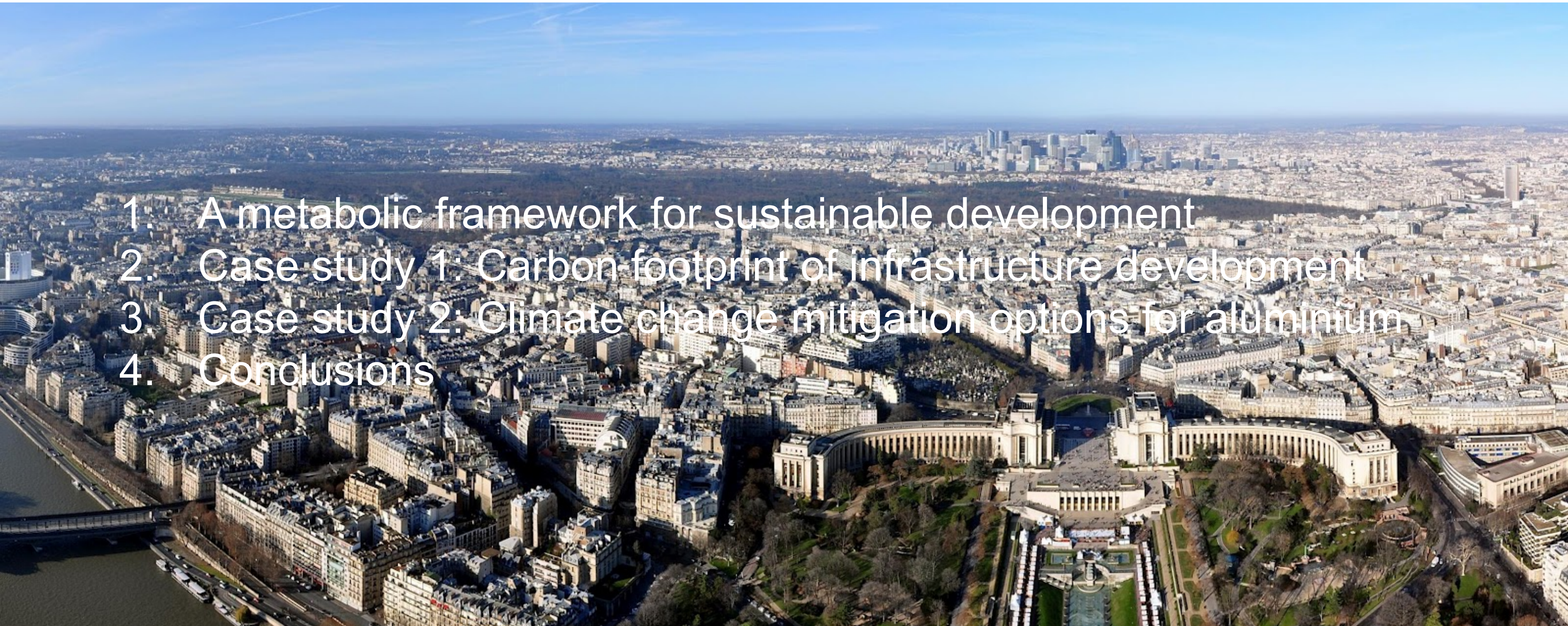
III GSS Open Conference “Unpacking Green Growth”
Brussels, 8-9 October, 2014

IndEcol

Session “Global Flows of Energy, Materials and People”

Infrastructure stocks at the nexus of development, resource efficiency, and climate change mitigation

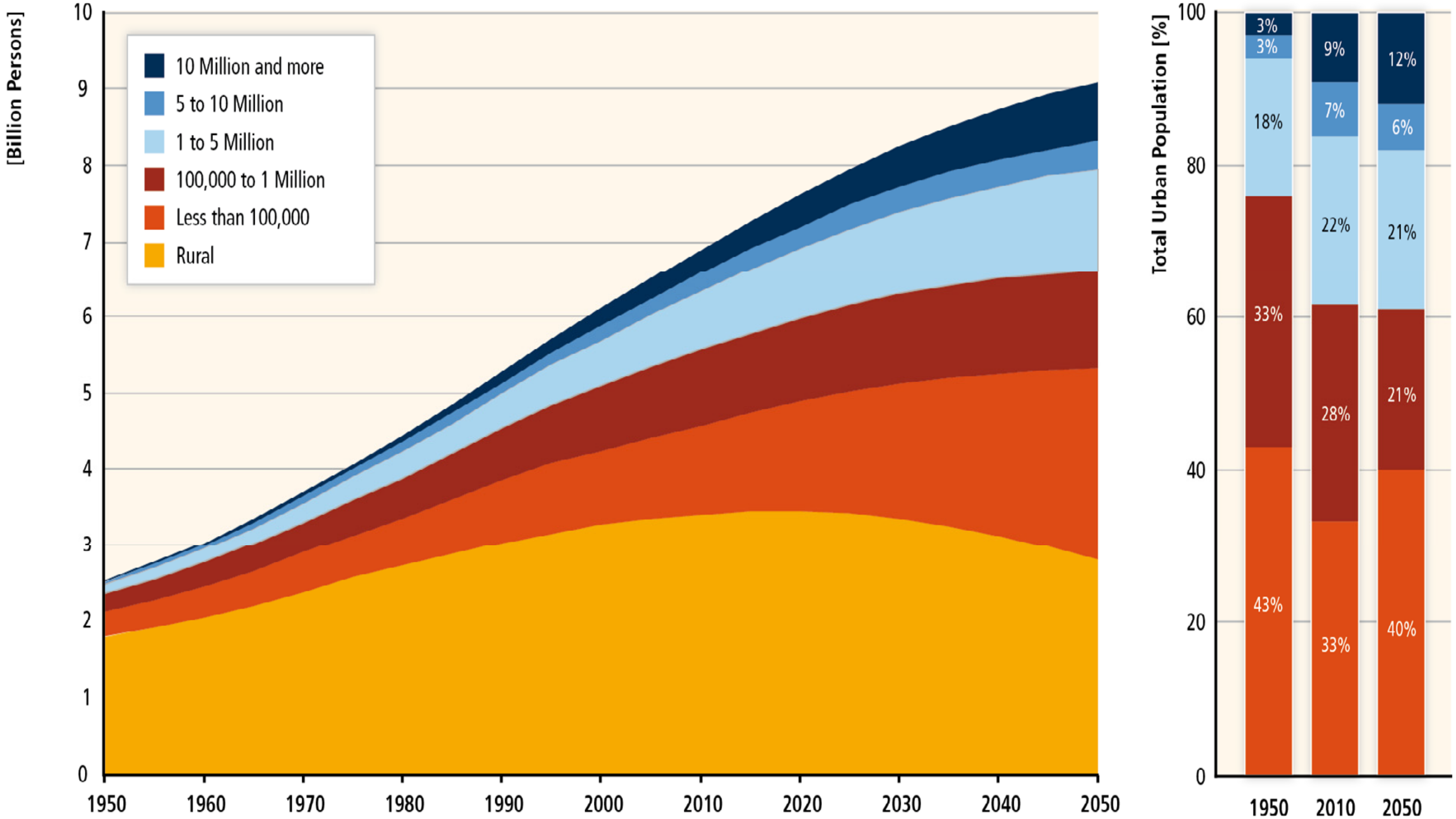
Daniel B. Müller



1. A metabolic framework for sustainable development
2. Case study 1: Carbon footprint of infrastructure development
3. Case study 2: Climate change mitigation options for aluminium
4. Conclusions

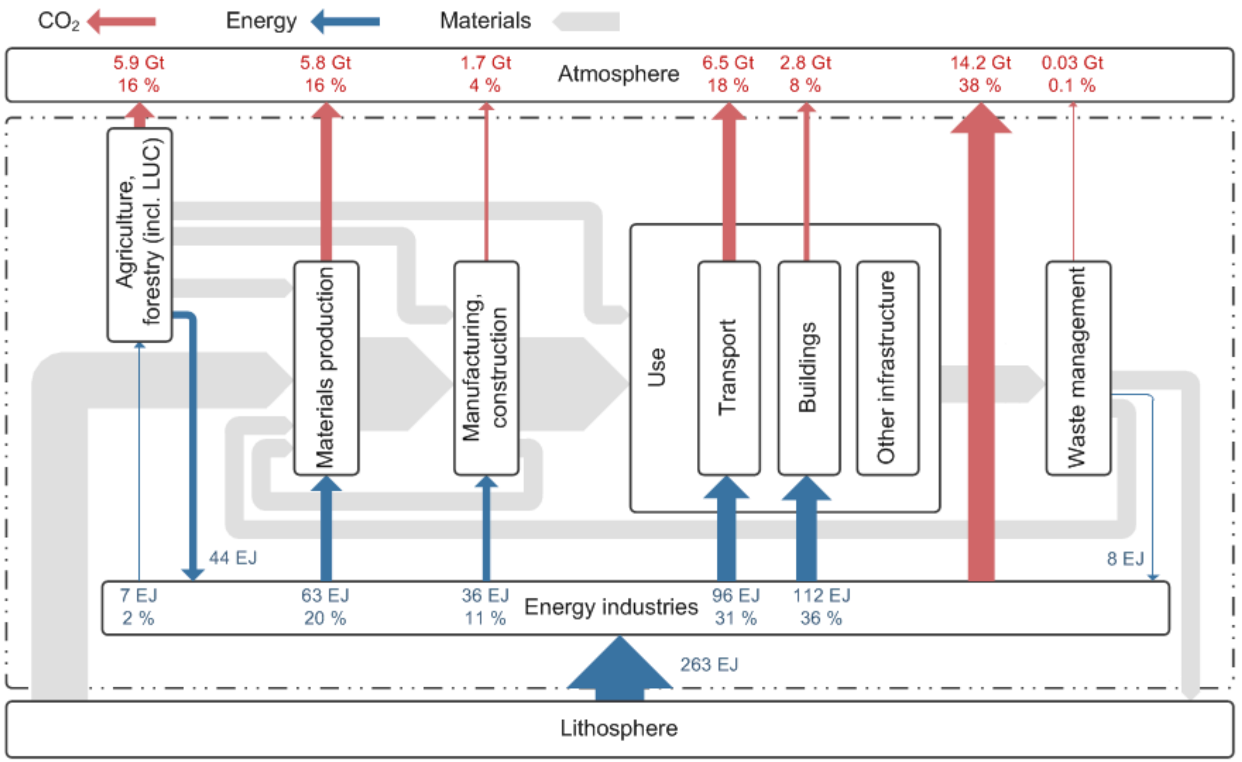
Population growth and urbanization/industrialization – key drivers for flows of materials, energy, and people

Population growth by settlement size



Source: IPCC (2014): AR5, WG3, Fig. 12.1
Data: UN-DESA (2010)

Linkages between materials, energy, and emissions: "socio-economic metabolism"



Müller et al. 2013

Data sources for 2008:
Emissions: EDGAR
Energy: IEA

1. The socio-economic metabolism shapes the quality of our life (services provided by stocks in use and environment)
2. Current socio-economic metabolism is not sustainable:
   - poverty / inequality (lack of access to essential services)
   - resource depletion, limited sinks for pollutants
3. Sustainable development requires transformation of socio-metabolic system
   → from design of processes/products to design of systems

Post-Kyoto climate agreement

- To be developed by 2015 and implemented by 2020

- Needs to include developing countries (DCs) in order to reach necessary goals

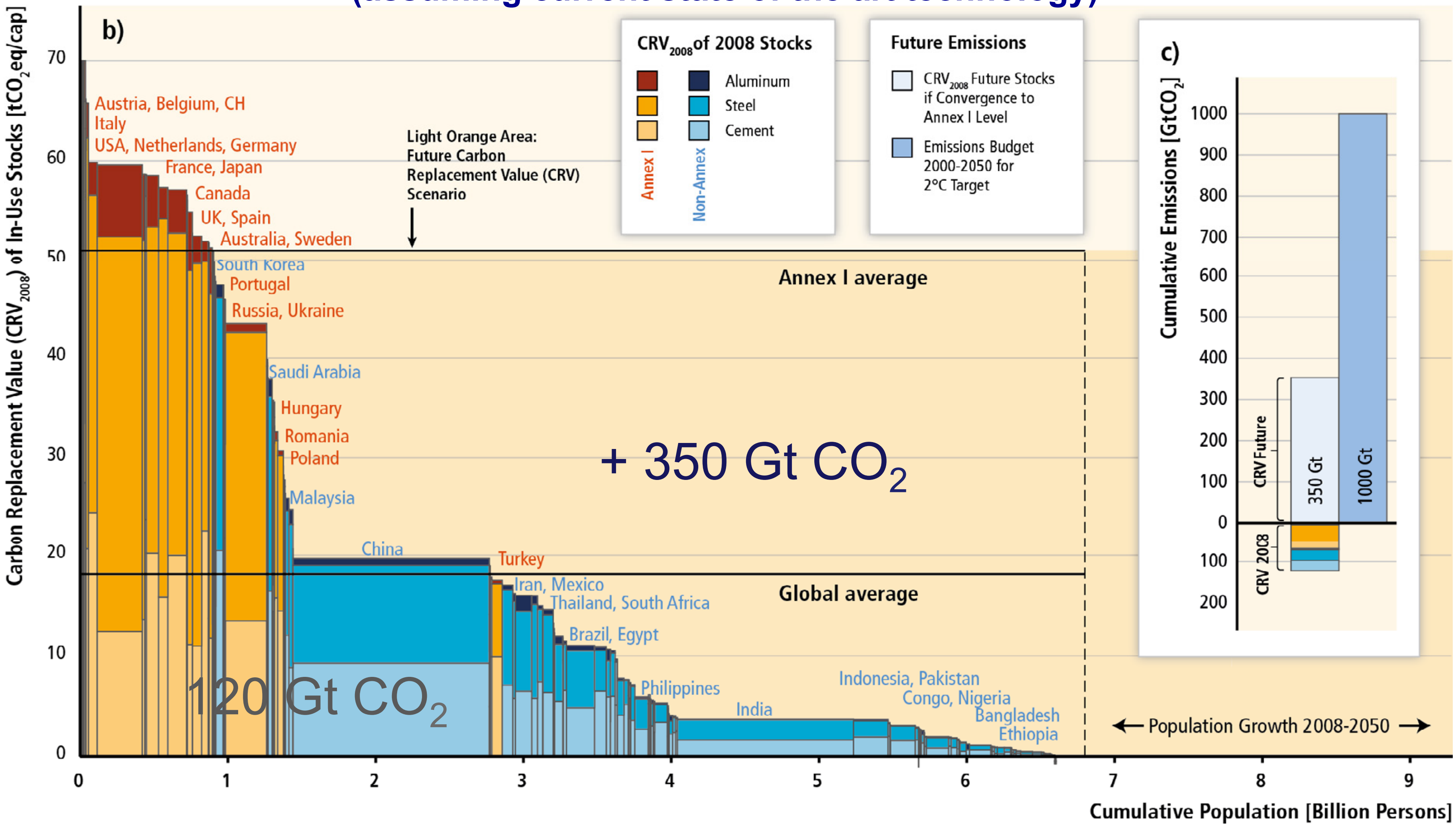
- **Contraction and Convergence (C&C)** framework?
  → Main concern of DCs: want to urbanize and industrialize under fair conditions (ICs industrialized without carbon restrictions)

→ What emissions budget should to be allocated to urbanization and industrialization?

→ Here: **stock approach**
- Industrialization and urbanization = build up of stocks
- Carbon footprint of stocks in ICs → benchmark
- Carbon footprint of stocks in DCs
  → Quantify carbon budget needed to reach current levels in ICs assuming state of the art technologies

Carbon footprint of existing and future infrastructure stocks

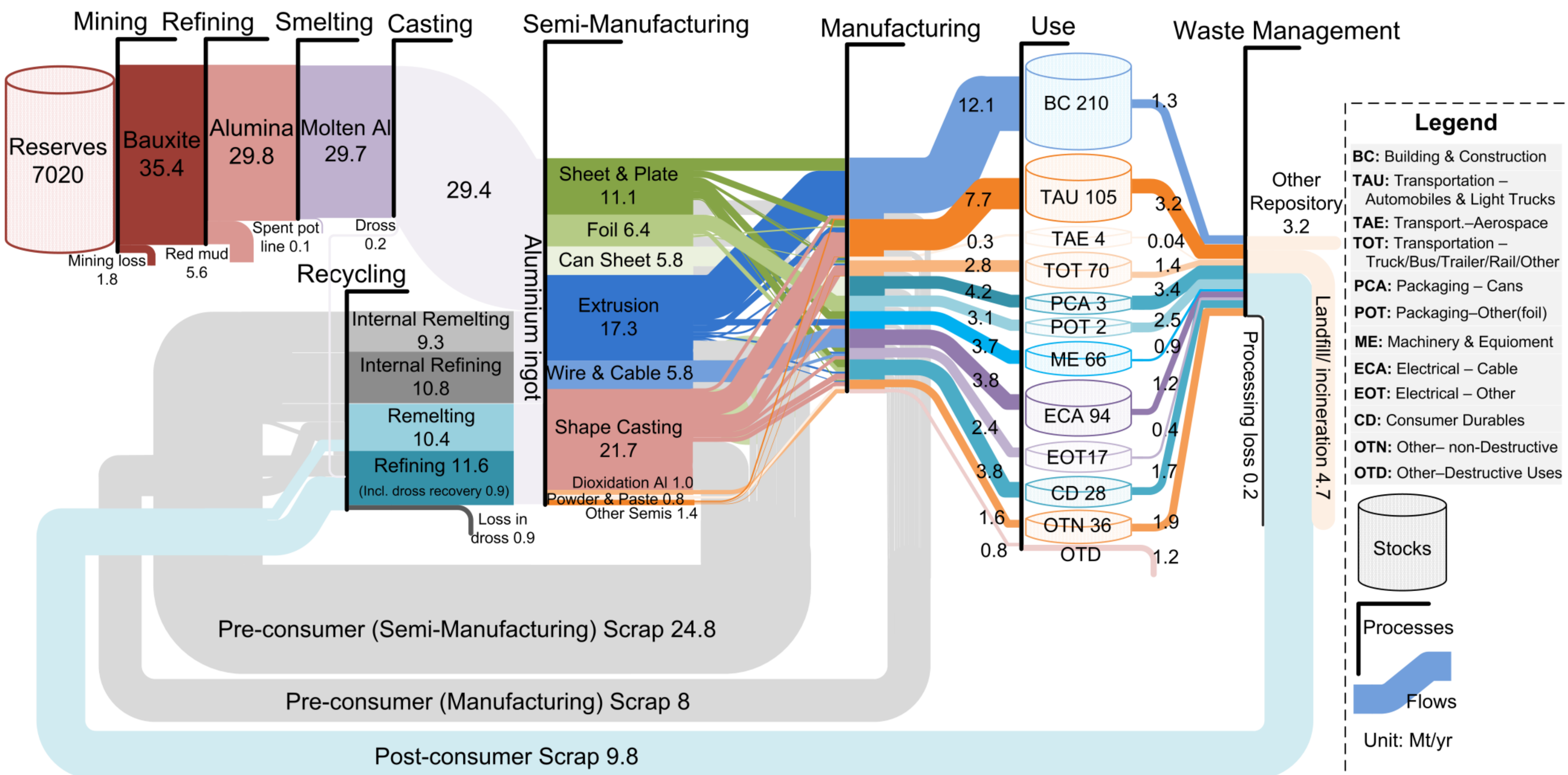
(assuming current state of the art technology)



Source: IPCC (2014): AR5, WG3, Fig. 12.12b; Müller et al. (2013)

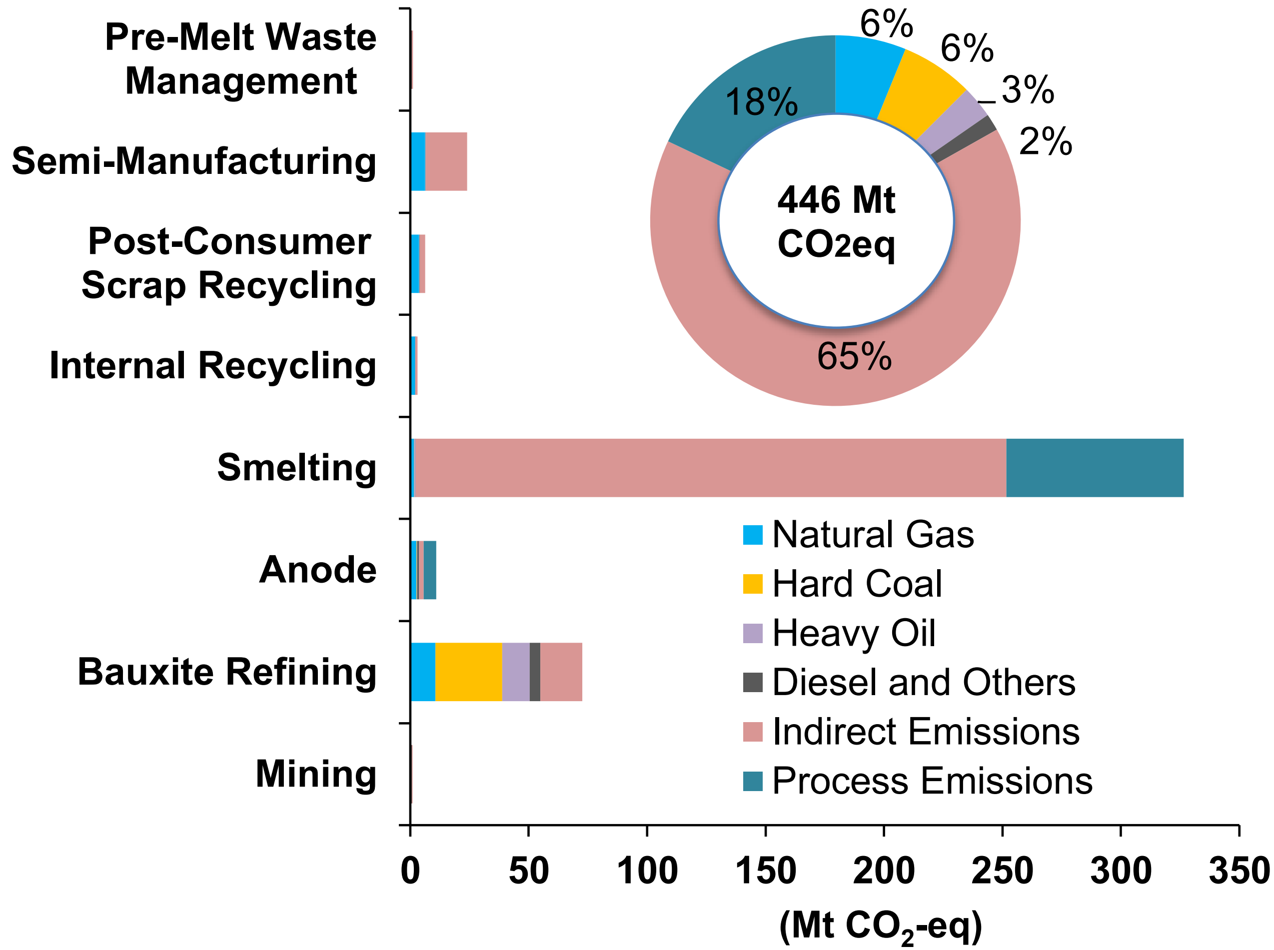
- Carbon footprint of existing stock: large differences rich – poor, but small differences among rich
- A globalization of Western infrastructure stocks could pose a significant challenge for 2° target
  → *Level of urbanization/industrialization should be accounted for in post-Kyoto agreements!*
- Mitigation options: materials production and materials use (urban form → poorly understood)

Global anthropogenic aluminium cycle in 2009



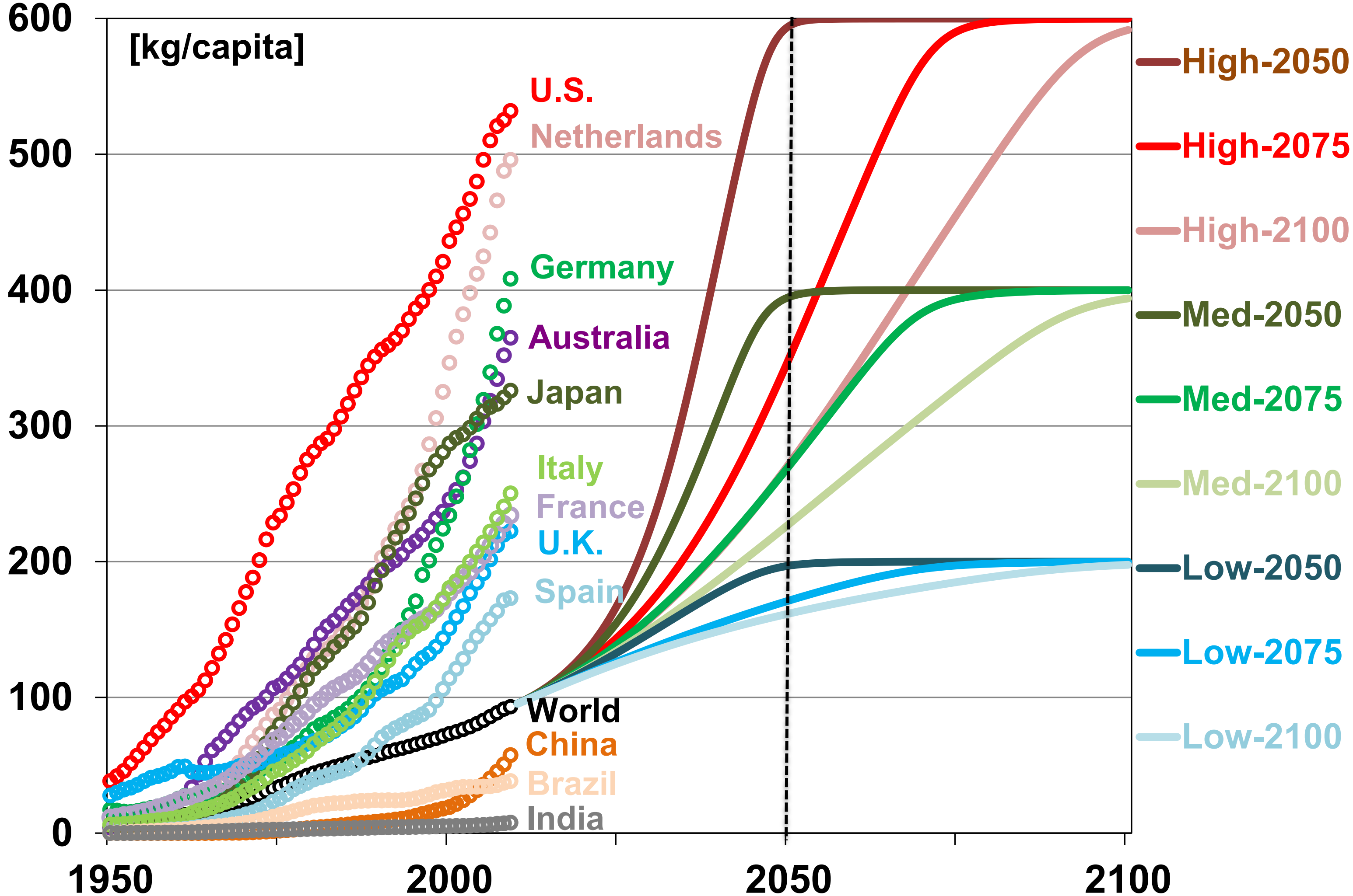
Source: Liu, Bangs, and Müller 2012: Nature Climate Change

GHG emissions of the global aluminium cycle in 2009



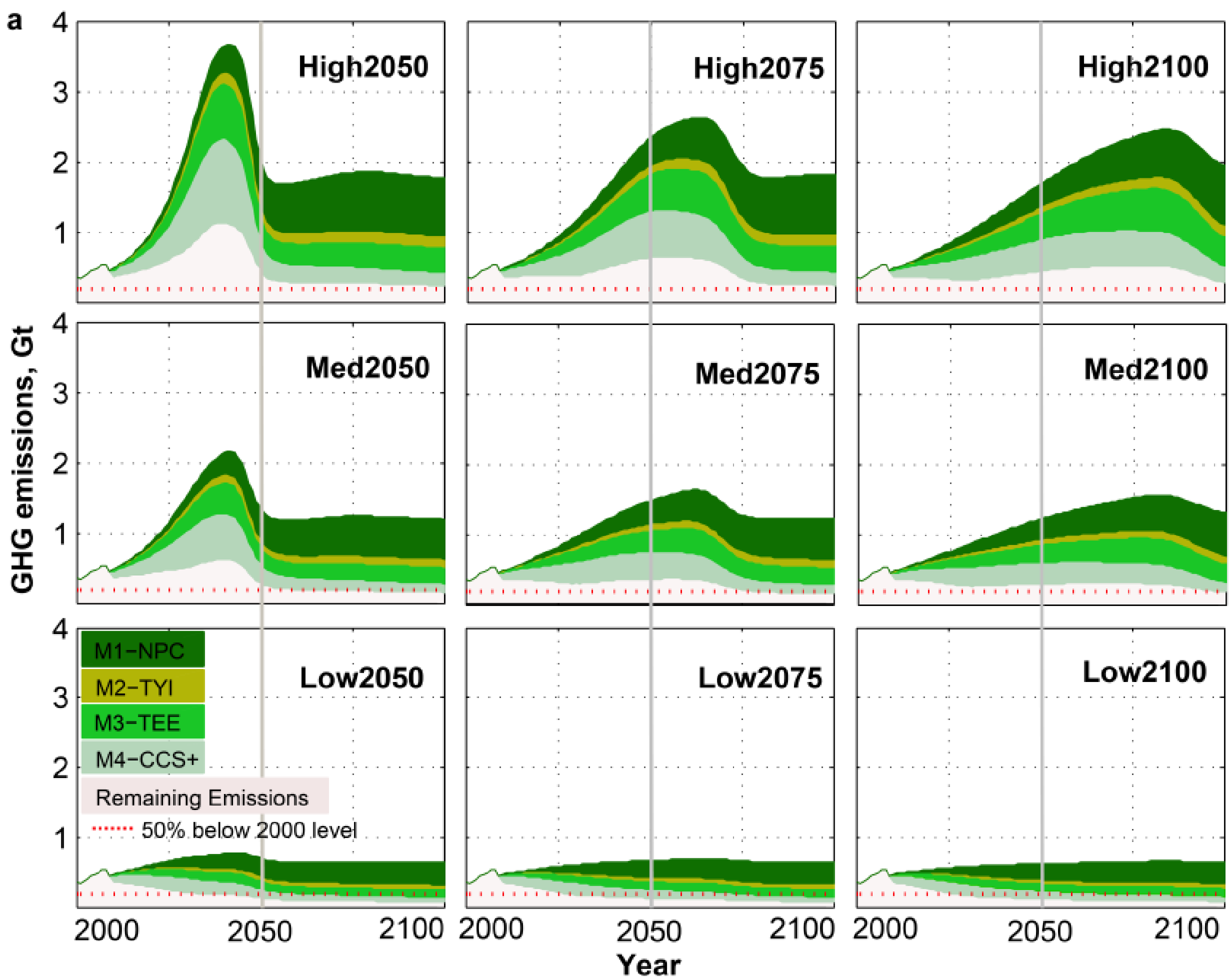
Source: Liu, Bangs, and Müller 2012: Nature Climate Change

Historical country-wise and future global stock patterns (scenarios)



Source: Liu, Bangs, and Müller 2012: Nature Climate Change

GHG emission pathways and mitigation wedges for the nine dynamic stock scenarios



Source: Liu, Bangs, and Müller 2012: Nature Climate Change

M1: Near perfect collection

M2: Technologies for yield improvement

M3: Technologies for energy and emissions efficiency improvement

M4: CCS and electricity decarbonization

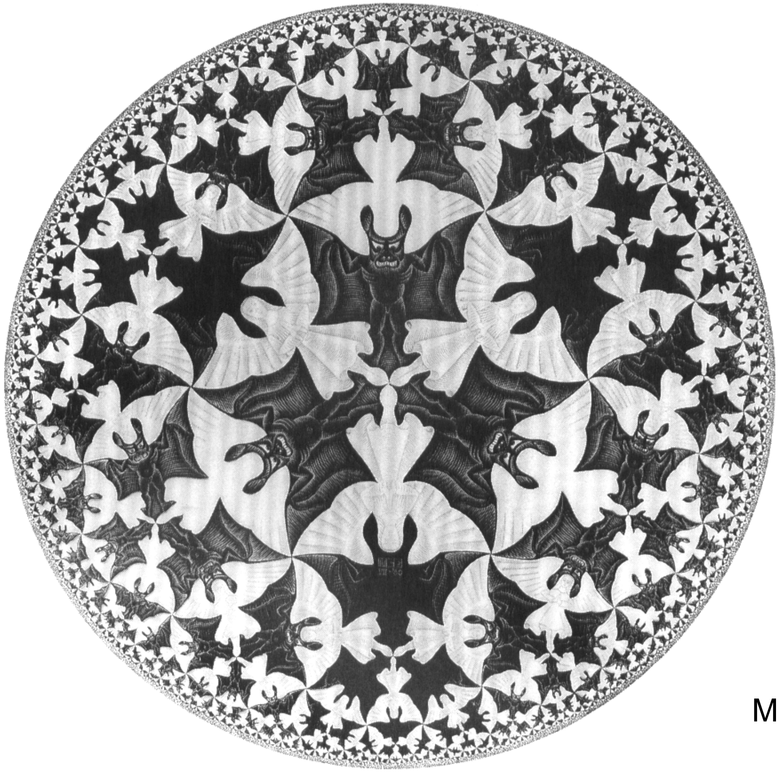
Conclusions

1. **Climate change mitigation is not (only) an energy problem**
   → Processes in energy system are linked through materials / matter (feedbacks and delays)
   → Ignoring the linkages between energy and materials leads to
   - blind spots for climate change mitigation
   - blind spots for synergies with resource efficiency
   - problem shifts

2. **Infrastructure stocks** are at the nexus of development, resource efficiency, and climate change mitigation
   → Key for energy and materials use and emissions
   → Services / human needs (ultimate purpose of economic activity from a consumer perspective)
   → Typically ignored in economic models – poorly understood

3. A **metabolic framework** has the potential to integrate people's needs with available energy and material resources and limited sinks in the environment.
   → Challenge: no simple answers (good or bad depends on context)

Angels or devils? – A question of system boundaries

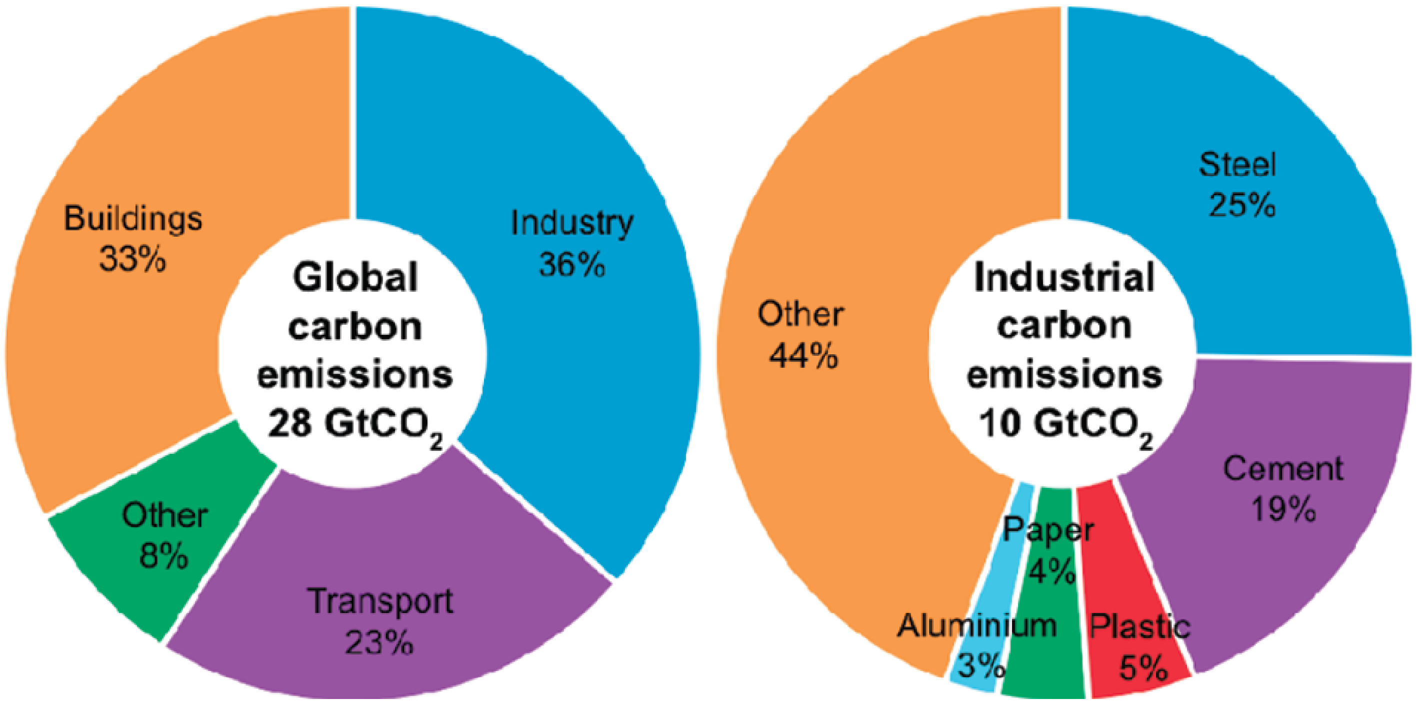


M.C. Escher (1960): Circle Limit IV

Thank you!

daniel.mueller@ntnu.no

Global anthropogenic CO_2 emissions related to energy and industrial processes (2006)



Source: Allwood et al. 2010: Env. Sci & Techn.

Different measures for carbon footprint of built environment stocks

	Prim. or sec. production	Prim. production	Prim. + sec. production
Historical C emissions			
Replacement value of C emissions		CRV_P	

Why replacement value? → Compare ICs and DCs on a fair basis
(all can benefit from technological improvement)
→ Goal: equal service level, not equal emissions

Why primary production? → Stocks cannot grow based on recycling
→ Indicator is limited to net growth of stock

Mitigation options for reducing carbon footprint of infrastructures

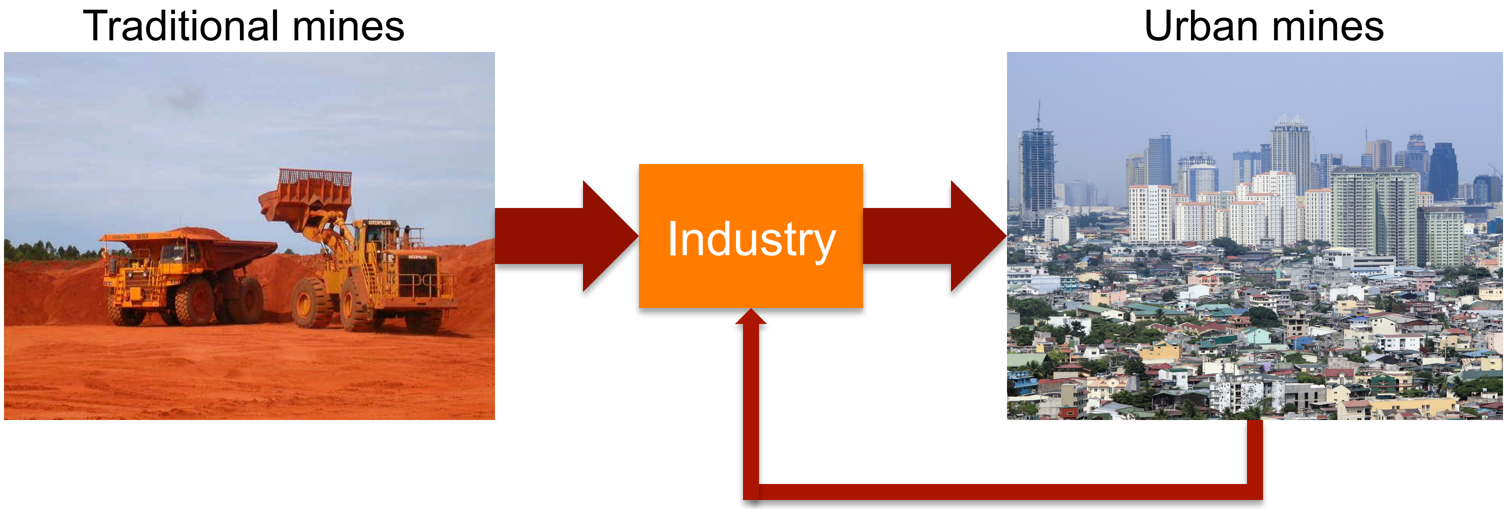
$$F = P * \frac{S}{P} * \frac{M}{S} * \frac{F}{M}$$

Mitigation options

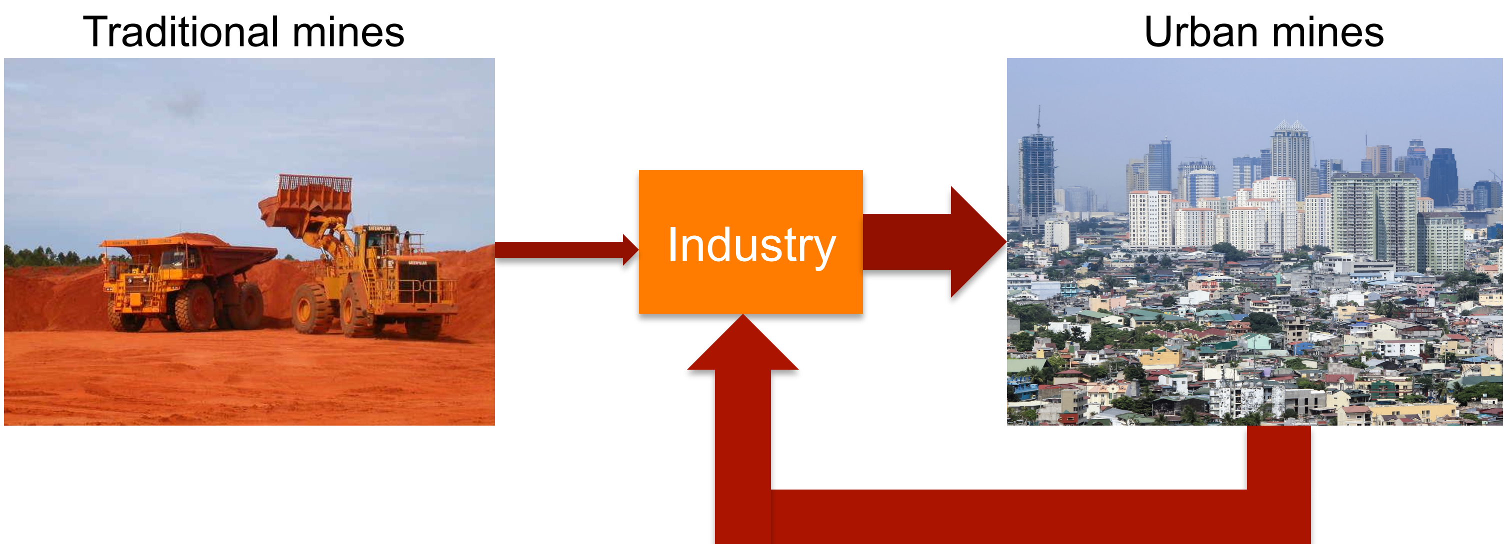
1) Population (**P**)
   → *assumed as a given*
2) Service level per capita (**S/P**)
   → *assumed as a given (C&C framework)*
3) Emissions per material produced (**F/M**)
   → *Has been main focus so far; remaining potential limited*
4) Material use per service (**M/S**)
   → *vastly underexplored option*
   → *potential may be substantial; however, small differences among ICs*
   → *highly fragmented information*
   (no aggregate stock accounting on urban or national scale)

Growing versus mature economies

Growing economies



Mature economies



Mitigation options for the aluminium industry

Twin-challenge

1. Growth in demand expected (factor 3-4)
2. Reduction in GHG emissions required to reach 2°C target (50-85% by 2050)

Emission (E) = Production (P) * emission per ton (e)

E → /2 (-50%)

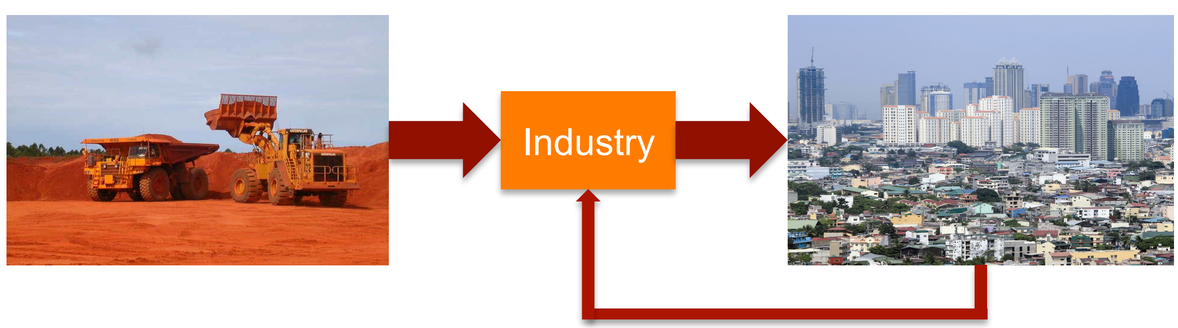
P → *3

e → /6 (-85%)

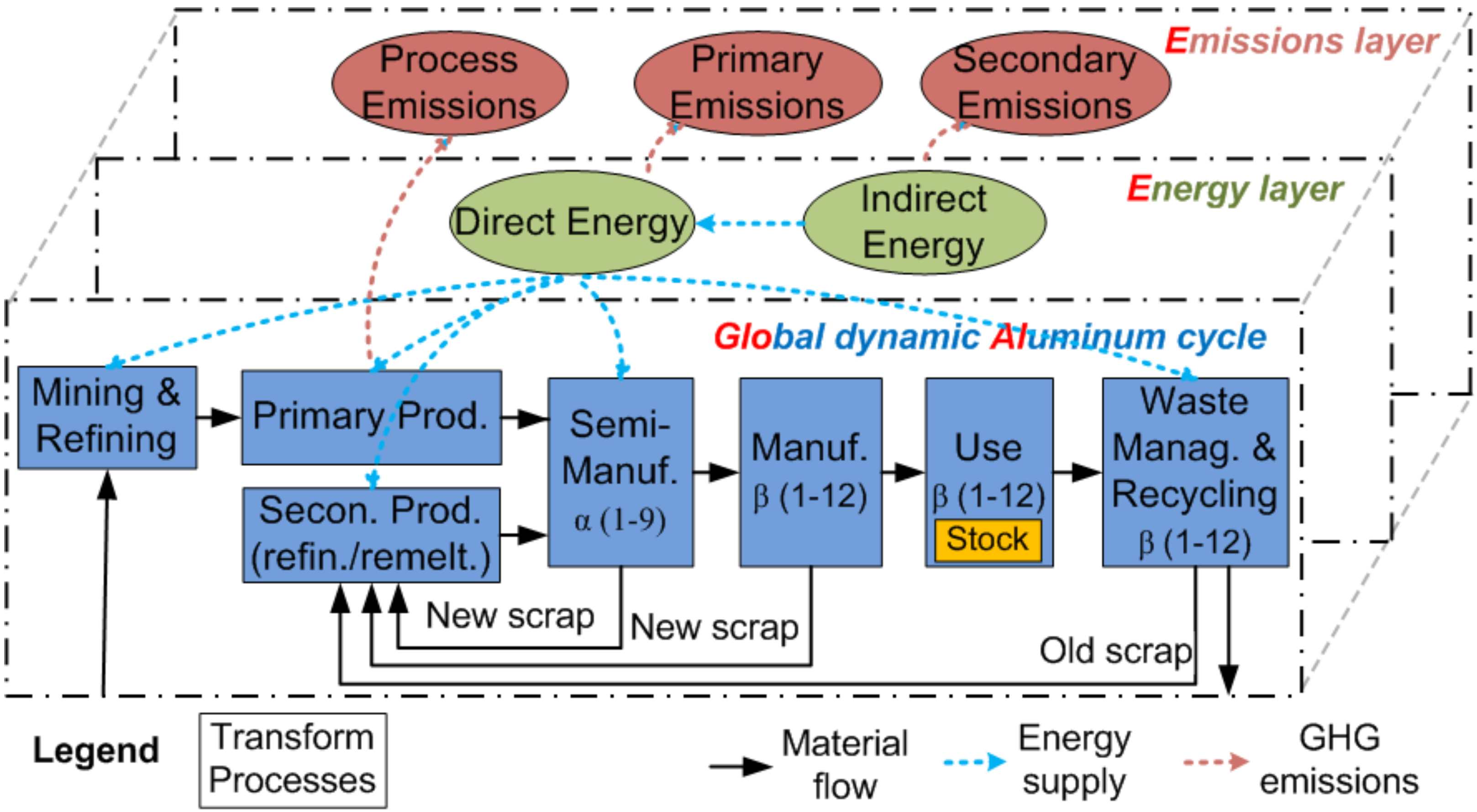
→ Process efficiency in primary production alone: impossible

→ Recycling: reduces energy use by over 90%...

- Al stocks in use approach saturation
- Achieve a 100% recovery of scrap
- Resolve quality challenge (accumulation of alloying elements)

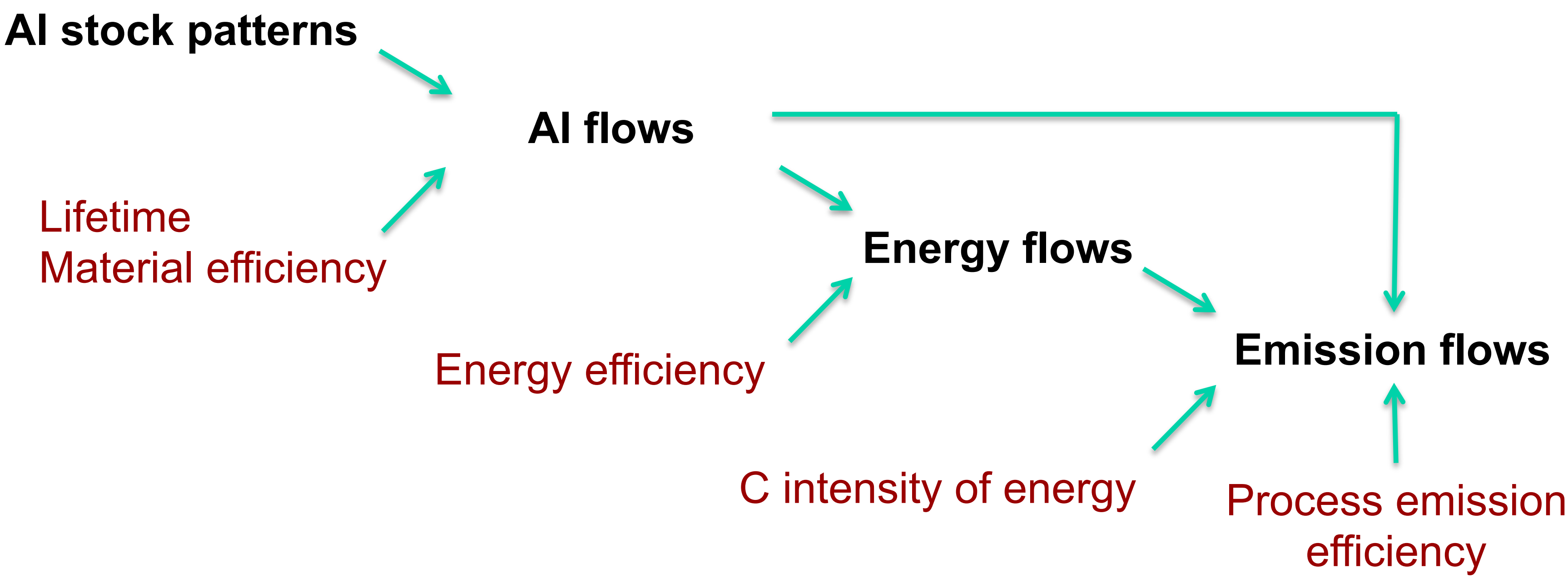


Three layers approach



Source: Liu, Bangs, and Müller (2012): Nature Climate Change

How do we calculate future emissions?

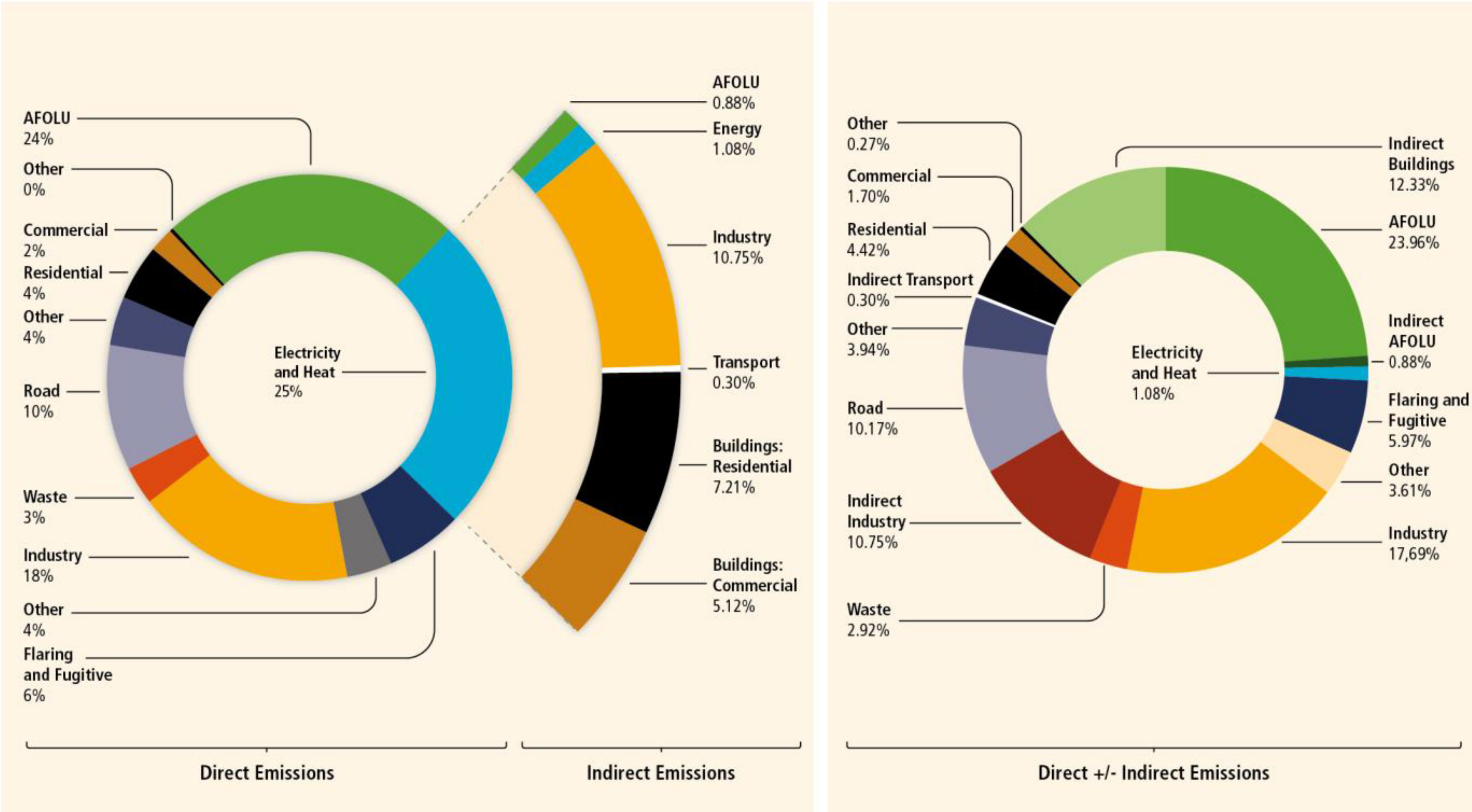


Mitigation wedges and their implementation in the model

Table 1 | Mitigation wedges and their implementation in the model.

Wedge code	Description	Model implementation (details in the Supplementary information)
M1-NPC	Near-perfect collection	Collection rates of BC, TAU, TAE and TOT obsolete products will gradually reach 95% by 2050 Collection rates of all other obsolete products will gradually reach 90% by 2050
M2-TYI	Technologies for yield improvement	Yield ratios (the efficiency of metal to downstream process relative to the sum of all process inputs) of all semi-manufacturing processes will gradually reach 90% by 2050 Yield ratios of all manufacturing processes will gradually reach 95% by 2050
M3-TEE	Technologies for energy and emissions efficiency improvement	Inert anode and wetted cathode: electrolysis energy intensity is projected to reach 13.11 $kWh\ kg^{-1}$ by 2030, and starting then all process emissions from electrolysis are set to zero, whereas anode production emissions increase by a factor of 2.08 (ref. 8) Global average energy intensity of bauxite refining is set to reach today's best-available-technology level (9.5 $GJ\ t^{-1}$) in 2020 (ref. 2) and keep an annual improvement of 0.25% afterwards[14] Energy intensities of all semi-manufacturing processes are reduced by 25%, as demonstrated by continuous strip casting for rolling[8] Oxy-fuel combustion: a 55% reduction is achieved on all natural gas energy use in the model[1]
M4-CCS+	CCS and electricity decarbonization	CCS will be gradually implemented at 85% effectiveness until 2030 (ref. 1) on all coal power supplying electrolysis in the contract mix Decarbonizing the electricity supply in the contract mix by 30% through greater use of renewables, clean coal and others

Greenhouse gas emissions by sector (2010)



Source: IPCC (2014): 5AR-WG3, SPM.3

Emissions benchmarks 2050

Challenge

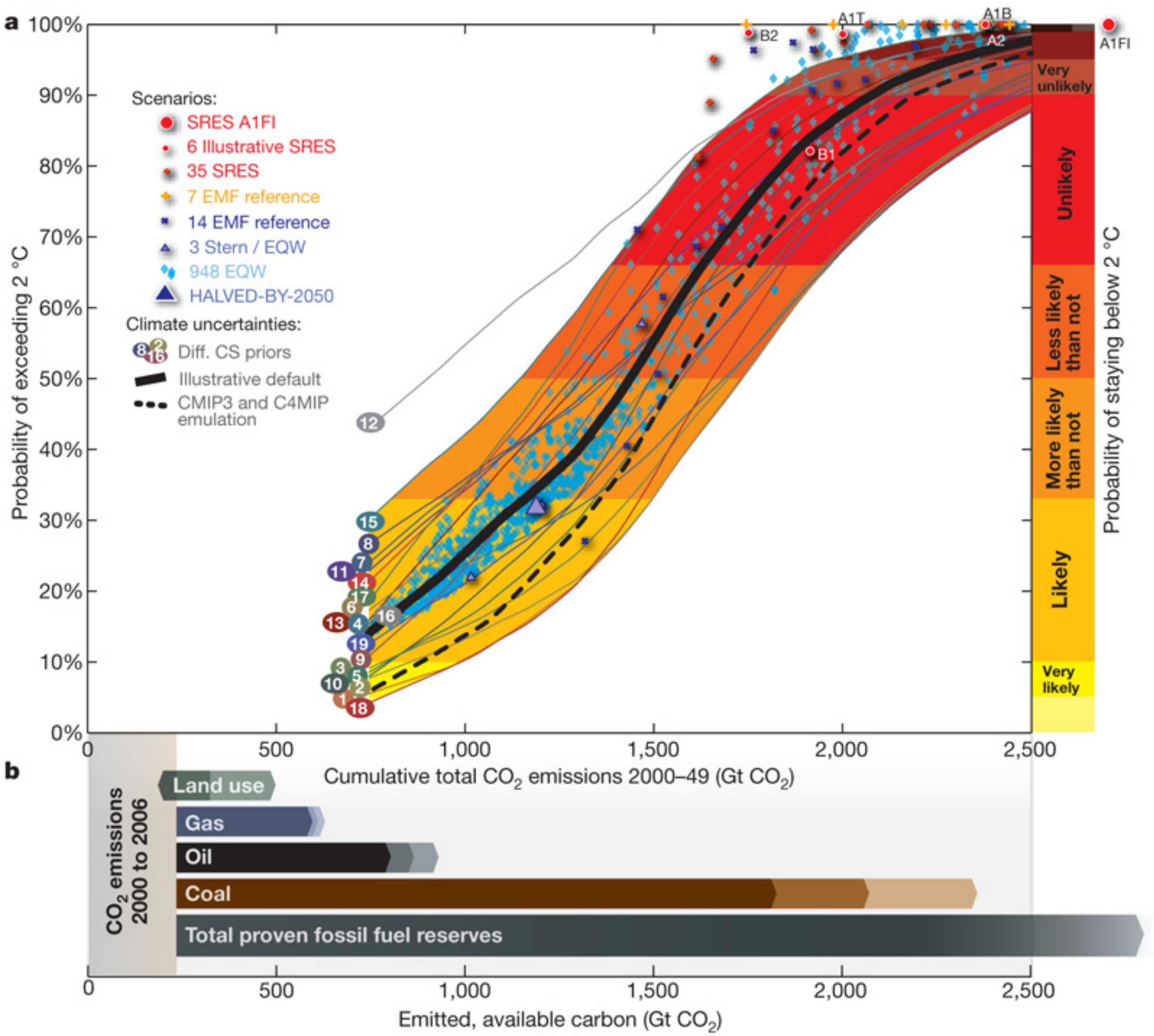
Emissions target global – policies sectorial and/or within countries
→ How to benchmark emissions from individual sectors and countries?

Approach used here

Countries
Equal per-capita emissions in the long-term
→ "Contraction and convergence" (C&C) framework
→ Ignores differences in boundary conditions (geographic, economic…)

Sectors
All sectors need to cut their emissions at the same rate
→ Ignores differences between sectors, structural change, and dependencies between sectors

Probability of exceeding 2 °C warming versus CO_2 emitted in the period 2000-2050



Emissions budget 2000-2050
(25-50% probability):
1000-1500 Gt CO_2

Emitted 2000-2010:
420 Gt CO_2

Emissions budget left
(25-50% probability):
600-1100 Gt CO_2

Meinshausen et al. (2009): *Nature* **458**, 1158-1162