

JCSS Workshop
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Decision Making for Sustainable Construction

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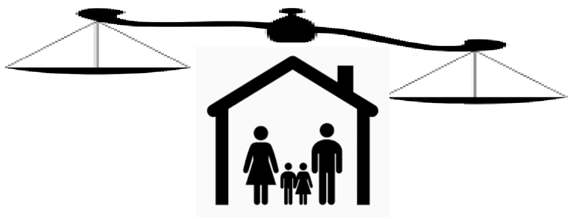
- Considerations on Sustainable Management of Structures
  - Quantifying emissions from design decisions
  - Management of life safety risks
  - Strategy optimization for development of infrastructure
  - Strategy optimization for recycling and minimization of raw material consumption
  - Design optimization of infrastructures projects
  - Design code safety format optimization
- Where to go?

Considerations on Sustainable Management of Structures

- Quantifying effects of design decisions
- Management of life safety risks
- Strategy optimization for development of infrastructure
- Design optimization of infrastructures projects
- Design code safety format optimization

Quantifying Effects of Design Decisions



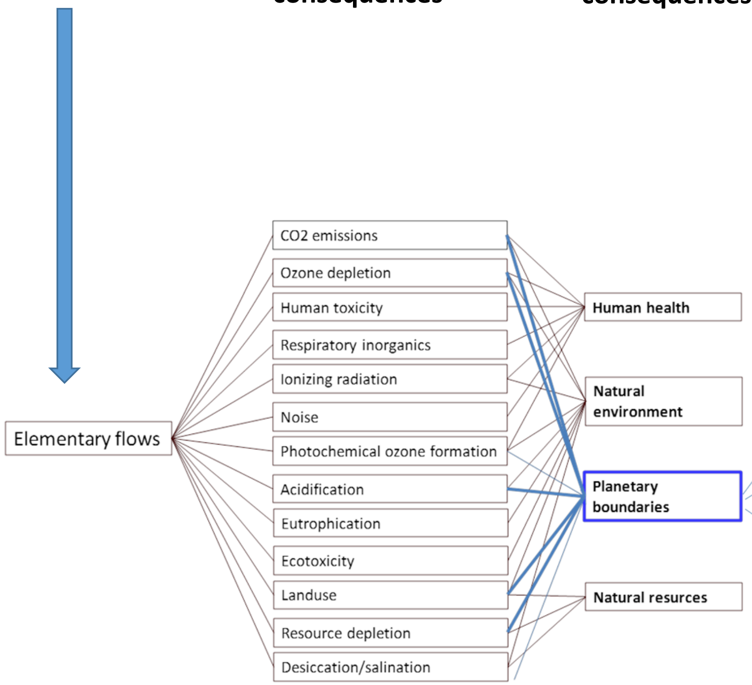
Quantifying safety, resilience and sustainability

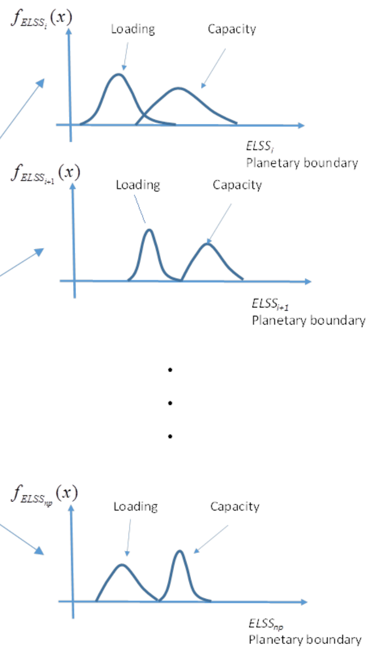
Decision

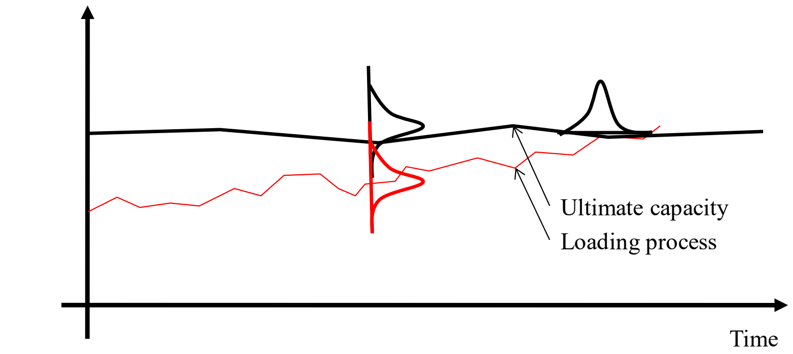
Differentiated consequences

Categorized consequences

Probabilistic model of ELSS capacities and loads





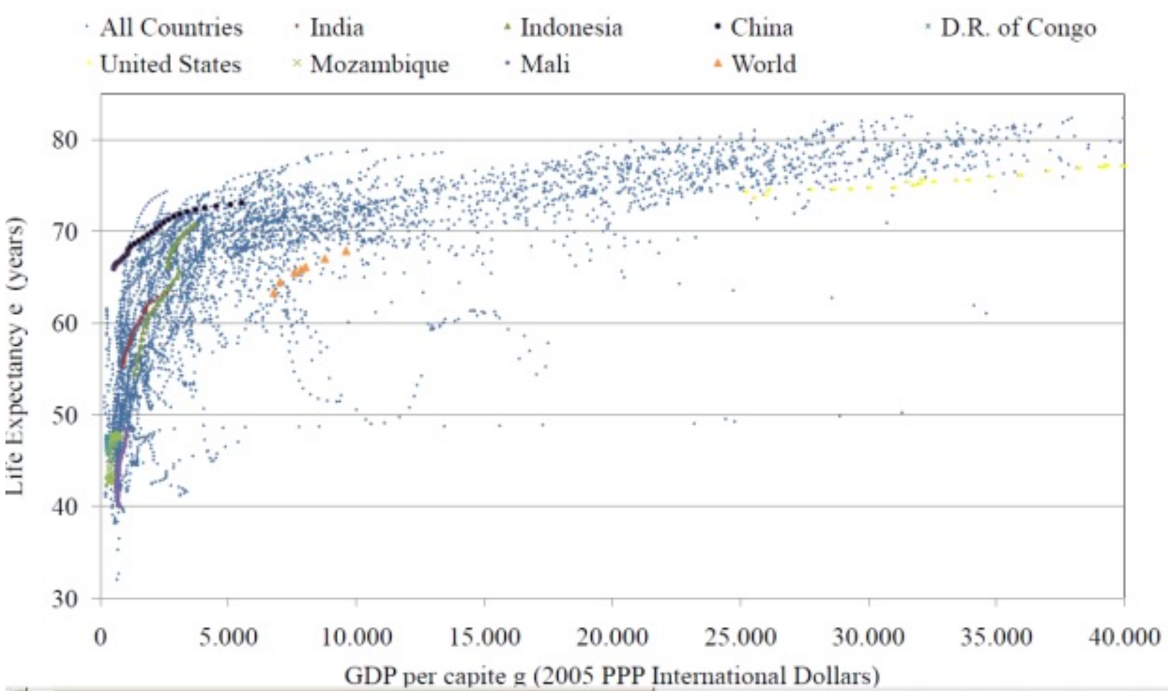


Faber, M. H. (2018). *On sustainability and resilience of engineered systems* (pp. 28-49). Abingdon: Routledge.

Faber, M. H., Qin, J., Miraglia, S., & Thöns, S. (2017). On the probabilistic characterization of robustness and resilience. *Procedia engineering*, *198*, 1070-1083.

Management of Life Safety Risks

Present basis for regulating life safety in construction



Life Quality Index (LQI)

$$L = g^q e$$

$$\frac{dL}{L} = \frac{dg}{g} + \frac{1}{q}\frac{de}{e} \geq 0$$

$$\frac{de}{e} \approx= -C_x dm$$

dm: change in failure rate

C_x: Demographic constant

C_y: Costs of risk reduction

N_{PE}: Number of exposed persons

k_S : Probability of dying given failure

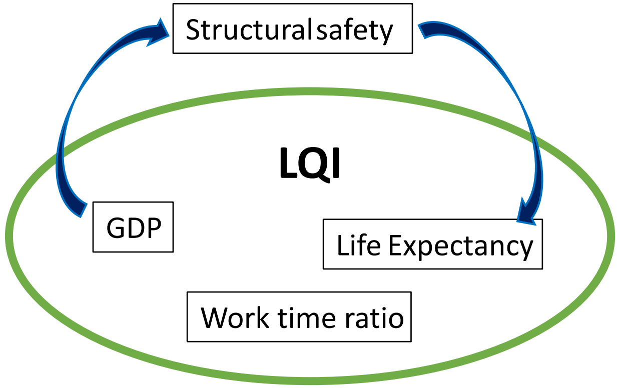
Societal willingness to pay criterion

$$dC_y(p) \geq -\frac{g}{q} C_x N_{PE} k dm(p)$$

Nathwani, J. S., Lind, N. C., & Pandey, M. D. (1997). Affordable Safety by Choice. *Institute for Risk Research, University of Waterloo, Canada*.

Management of Life Safety

ISO 2394: 2015 General Principles on Reliability for Structures



$$dC_y(p) \geq -\frac{g}{q} C_x N_{PE} k dm(p)$$

p: design parameter – increasing *p* increases safety

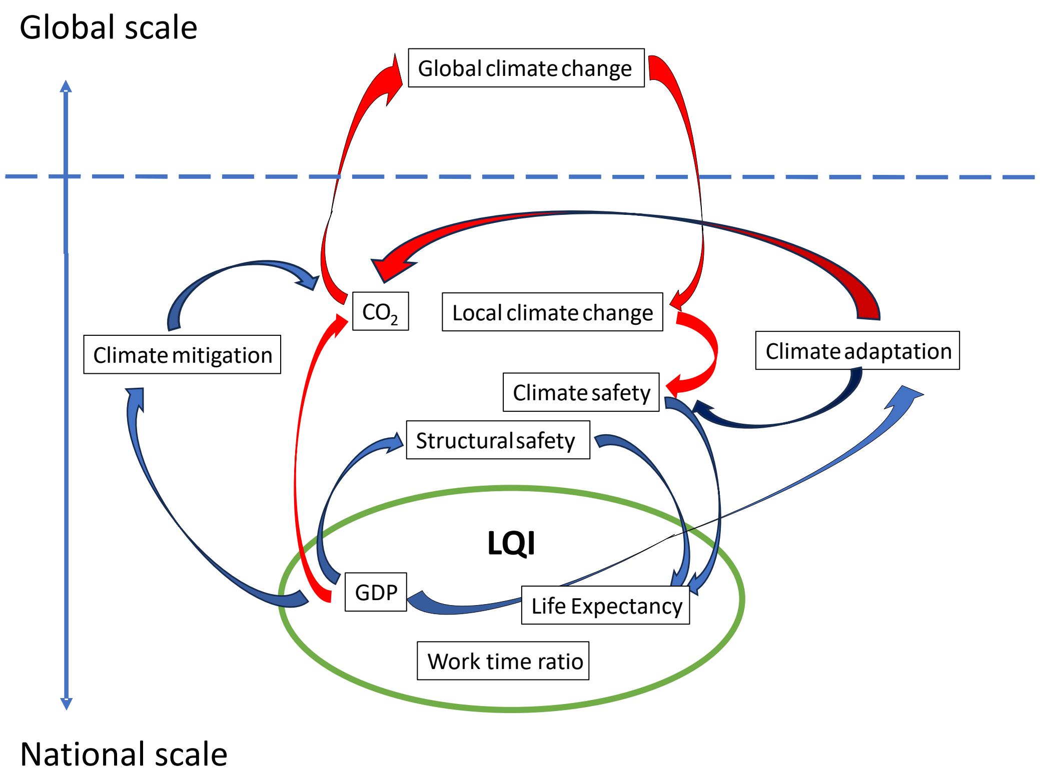
But increasing p also increases emissions and associated loss of lives casused by effects of e.g. global warming

National scale life safety management

- Appreciating that different nations have different capacities for improving life safety
- Different target reliabilities for different nation states

Management of Life Safety

Tradeoffs between welfare, resilience and sustainability



Climate Adjusted Life Quality Index - (CA-LQI)

$$L = g^q e$$

$$\frac{dL}{L} = \frac{dg}{g} + \frac{1}{q}\frac{de}{e} \geq 0$$

$$\frac{de}{e} \approx= -C_x dm$$

$$dm = dm_{\mathrm{f}} + dm_{\mathrm{e}}$$

$$dP_f + \frac{dC_y}{G_x \times k_s \times N_{PE}} - \frac{k_E}{k_s \times N_{PE}} \times dE \geq 0$$

k_E: the change in the mortality associated with a marginal change in carbon emissions

C_y: total safety cost

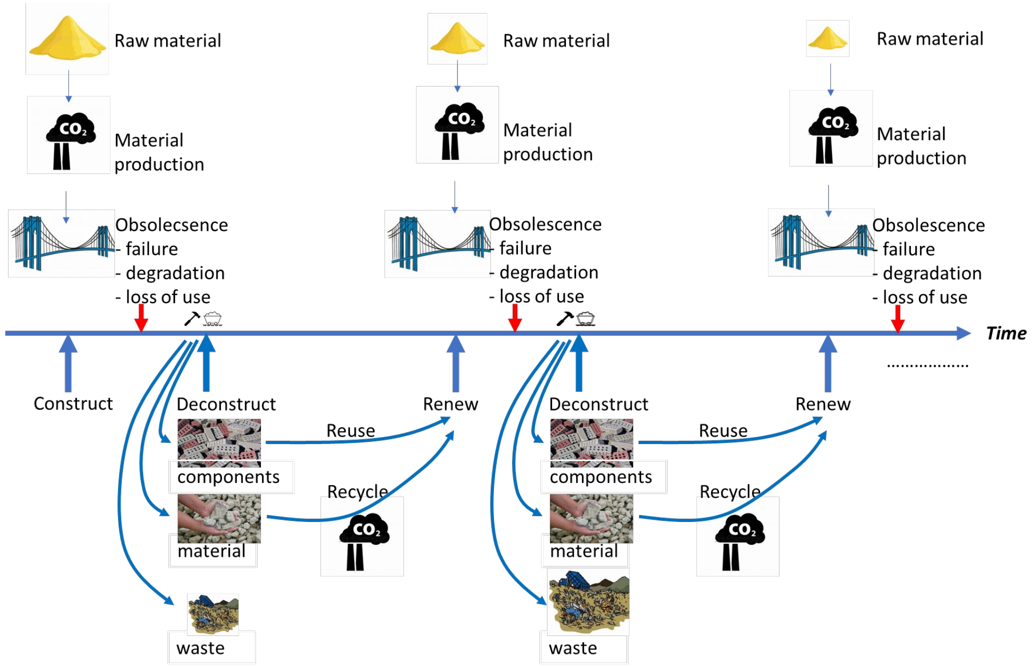
E: emissions

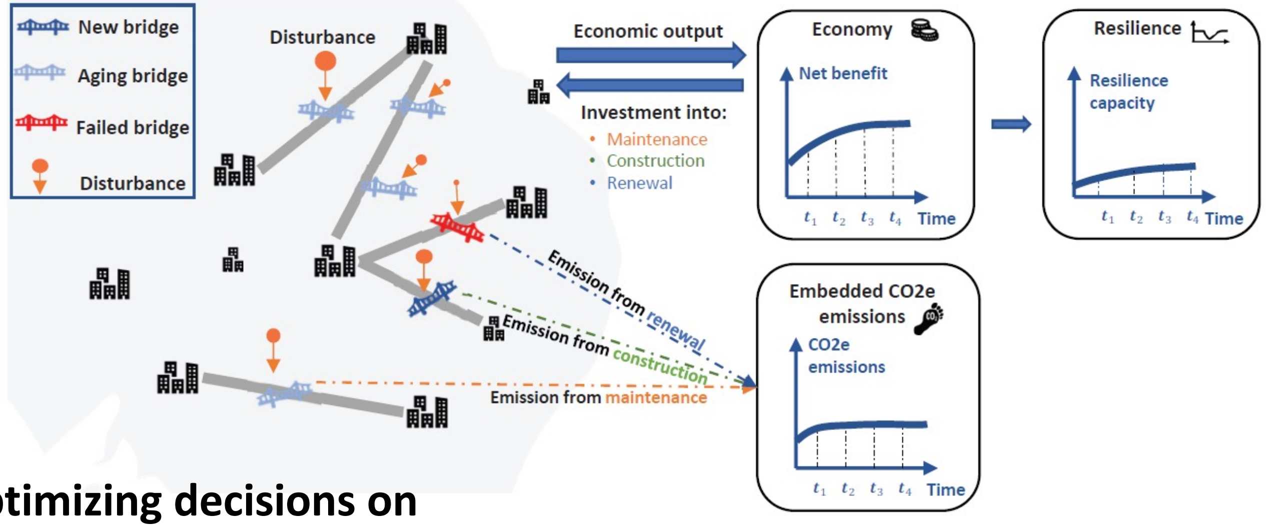
Societal cost equivalent of 1 ton of CO_2 is around 100 – 500 US$

Min Liu, Dagang Lu and Michael Havbro Faber.

Strategy Optimization for Development of Infrastructure

Combining macro-economics, structural reliability, emissions and decision analysis



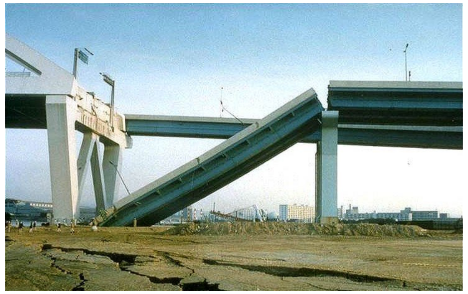


Optimizing decisions on
- **how many new structures**
- **level of safety**
- **durability**
- **maintenance**
- **material recycling/substitution**

Min Liu, Dagang Lu, Michael Havbro Faber (2024)
On CO2 Efficiency and Trade-offs Between Sustainability, Safety, Economy, and Resilience in Infrastructure Developments, Sustainable Cities and Society (in review – accepted)

Min Liu, Buwen Cui, Da-Gang Lu, M. H. Faber (2023), Risk Informed Decision Making for Reducing CO2 Emissions and Resource Consumption in Infrastructure Developments, presented at IFED 2023, Stoos, Switzerland.

Strategy Optimization for Development of Infrastructure



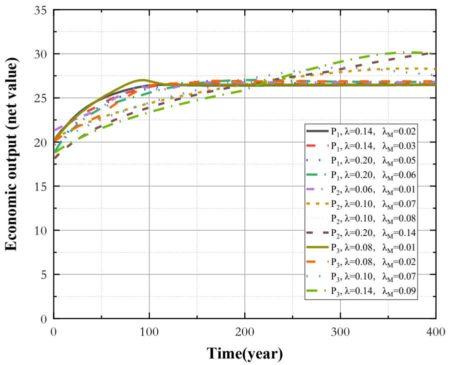

Comparison of embedded CO2e emissions for different strategies resulting in approximately the same expected value of the annual net economic output

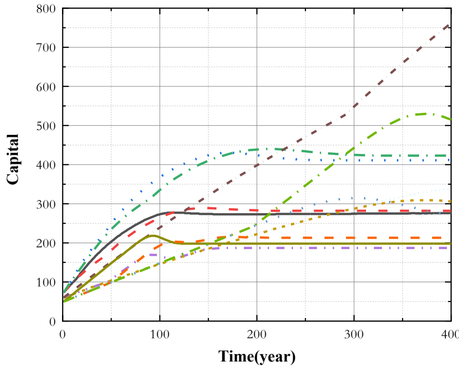
Decision variable 1:
Level of structural safety (Z)

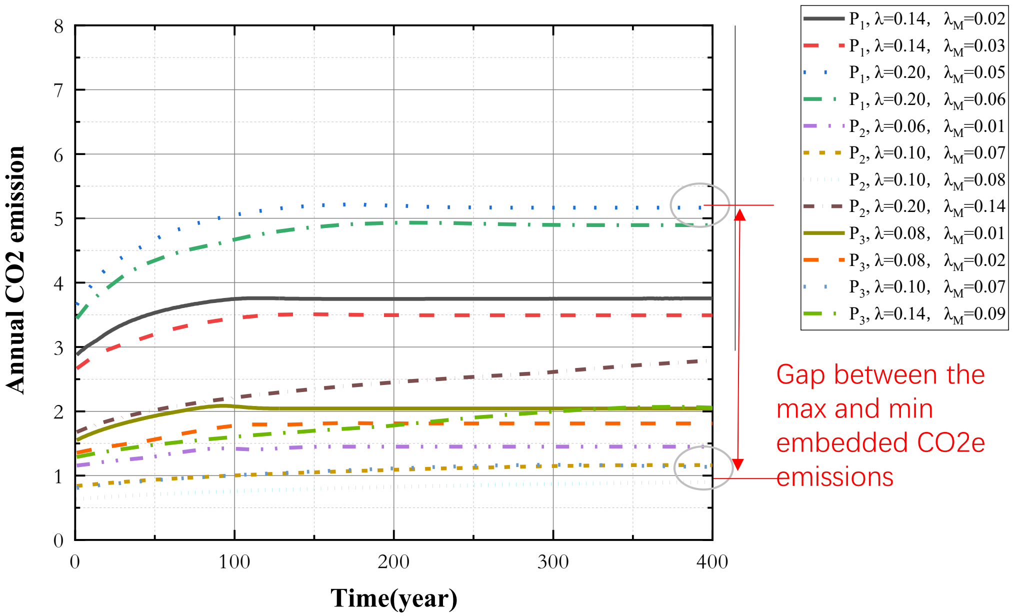
Decision	P_1	P_2	P_3
Annual probability of failure	10^{-2}	10^{-3}	10^{-4}

Decision variable 2:
Maintenance investment ratio ($\lambda_M = 0.02, 0.04, \ldots, \lambda$)

Decision variable 3:
Total investment ratio ($\lambda = 0.02, 0.04, \ldots, 0.20$)

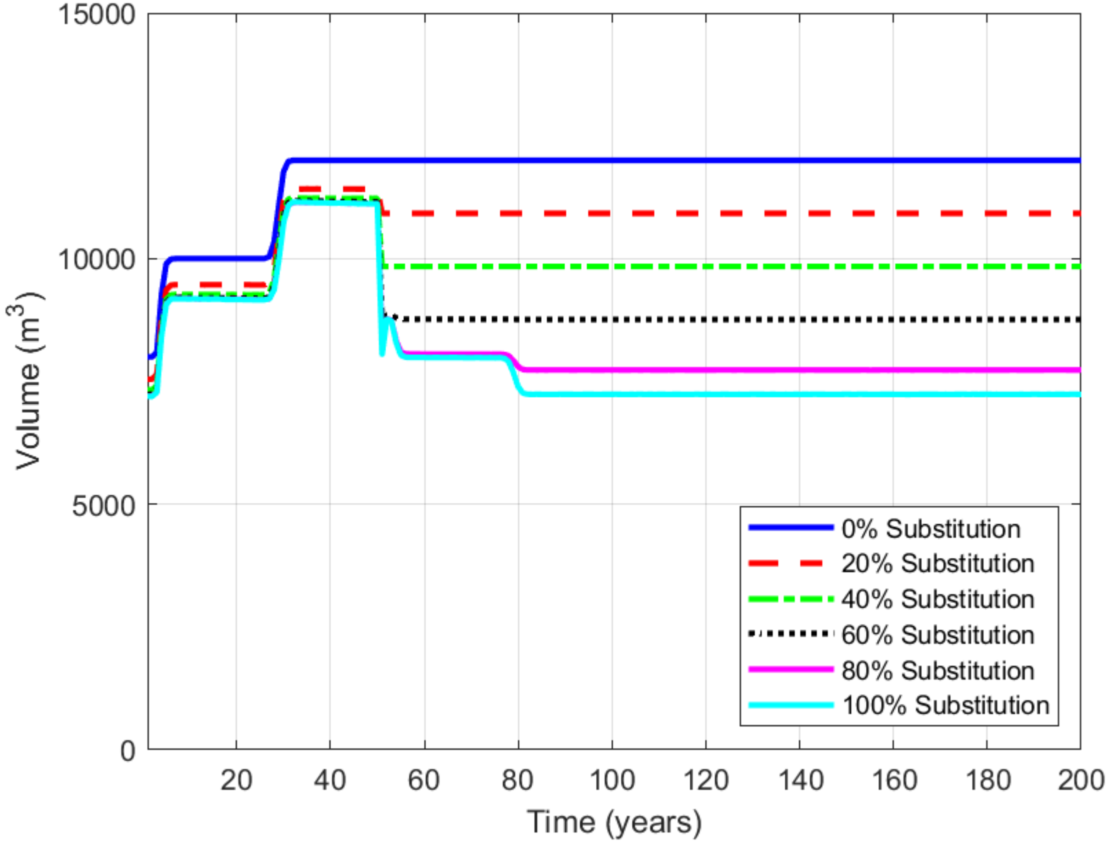






❖ Choices for the development and integrity management indeed may affect embedded CO2e emissions significantly

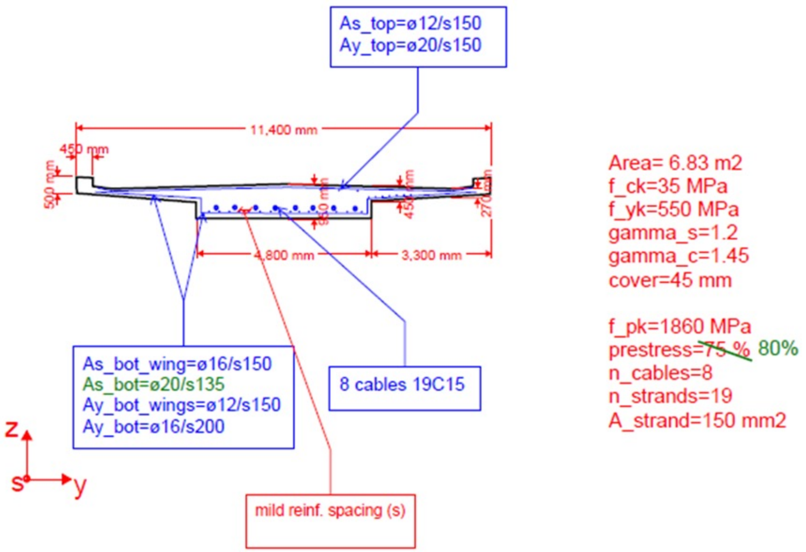
Strategy Optimization for Development of Infrastructure



Comparison of the **annual raw material consumption** for different decisions on substitution ratio

- Despite potential strength reductions, **higher substitution ratios substantially decrease the consumption of raw materials.**

Strategy Optimization of Infrastructure Projects



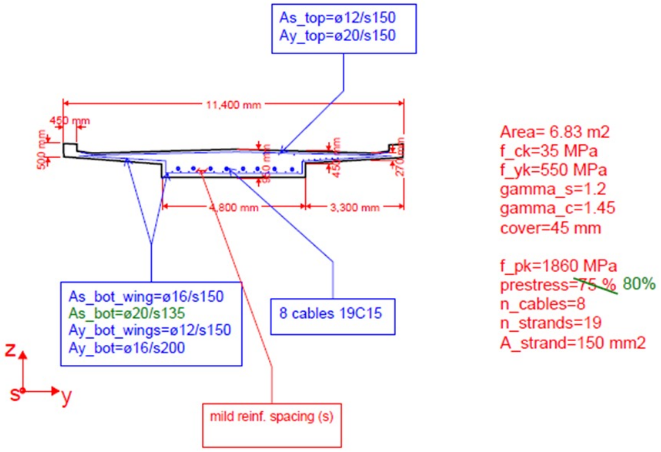
Basic *cross-section of the beam*

$$P_f^T = 10^{-6}$$

- **Normal reliability ($P_f^T = 10^{-6}$)**
  - Futurecem
  - LC3 concrete
  - Cut outs in the cross section
  - Low strength concrete
  - Reused concrete
  - Base case (-10 cm) (+30% mild reinforcement)
  - Base case (-20 cm) (+75% mild reinforcement)
  - Base case (-20 cm) + 700 MPa reinf. (+40% mild reinforcement)

M. Liu, J. Olesen, P. Linneberg, D. G. Lu, M. H. Faber (2024)
On CO2 efficiency and trade-offs between safety and sustainability in concrete bridge management, IABMAS, 2024.

Strategy Optimization of Infrastructure Projects

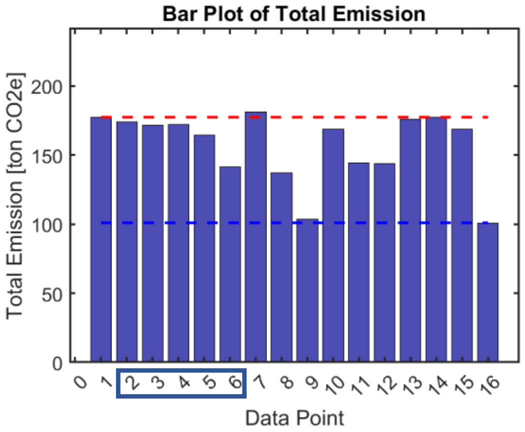


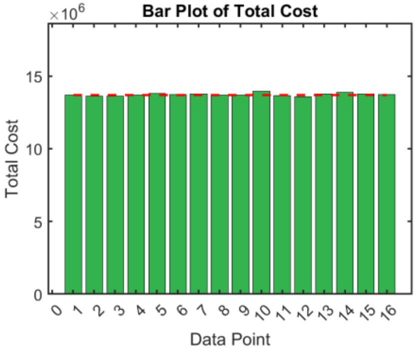
***Basic** cross-section of the beam*

$$P_f^T = 10^{-6}$$

- **Lower reliabilty ($P_f^T = 10^{-5}$)**
  - Reduce the amount of mild reinforcement
  - Using low strength concrete (C30)
  - Reduce the height of the cross section with 10cm
  - Reduce the height of the cross section with 20cm
  - Reduce the height of the cross section with 20cm+ 700 MPa reinf.
  - **LC3 concrete + Reduce the height of the cross section with 20cm** + 700 MPa reinf.
- **Higher reliabilty ($P_f^T = 10^{-7}$)**
  - Increase the amount of mild reinforcement

Strategy Optimization of Infrastructure Projects

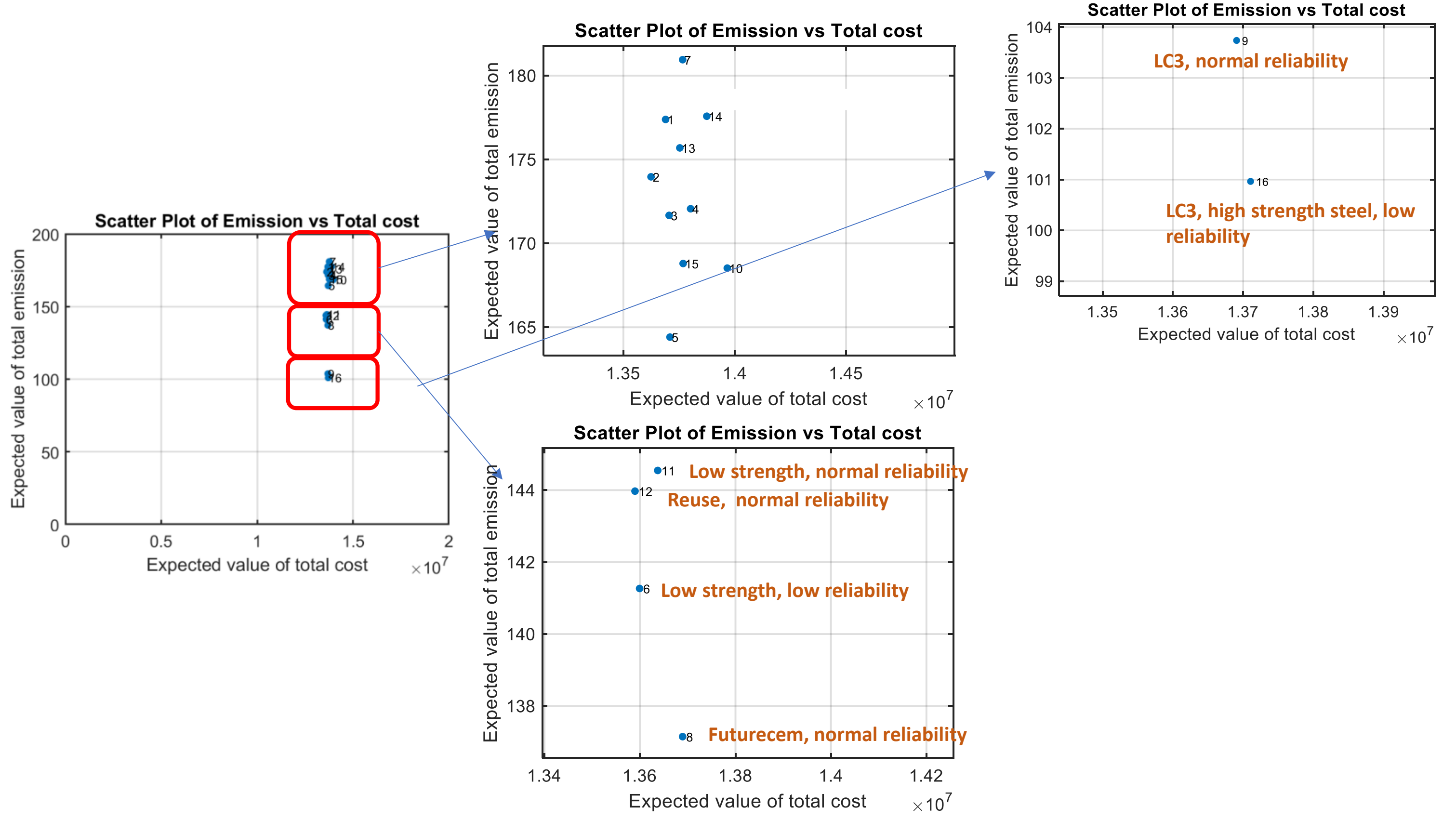




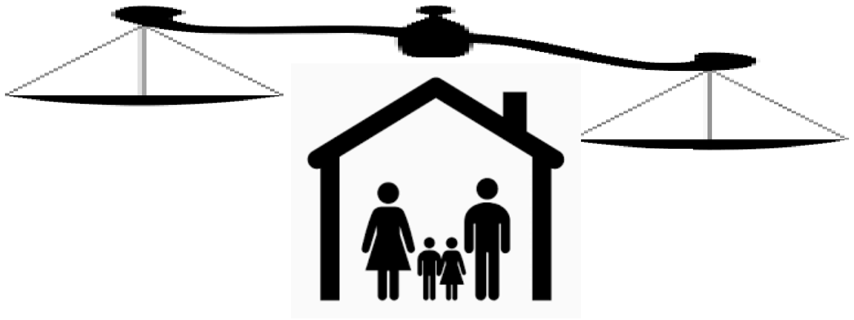
Case	Note	
1	Basic	**Basic ($P_f^T = 10^{-6}$,C35)**
2	Reduce mild reinforcement	**Lower reliability ($P_f^T = 10^{-5}$)**
3	Base case (-10 cm)	
4	Base case (-20 cm)	
5	Base case (-20 cm) + 700 MPa reinf. (+40% mild reinforcement)	
6	Low strength concrete (C30)	
7	Increase mild reinforcement	**Higher reliability ($P_f^T = 10^{-7}$)**
8	Futurecem	**Normal reliability ($P_f^T = 10^{-6}$)**
9	LC3 concrete	
10	Cut outs in (+10% mild reinforcement)	
11	Low strength (+5% mild reinforcement)	
12	Reused	
13	Base case (-10 cm) (+30% mild reinforcement)	
14	Base case (-20 cm) (+75% mild reinforcement)	
15	Base case (-20 cm) + 700 MPa reinf. (+40% mild reinforcement)	
16	Base case (-20 cm) + 700 MPa reinf.+reduce reinforcement+LC3	

Strategy Optimization of Infrastructure Projects

Expected value of total CO_2e emission and cost within 120 years



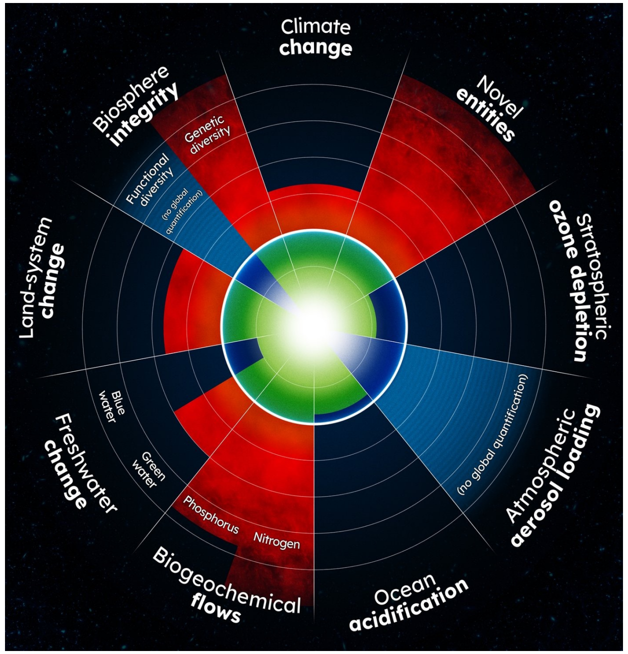
Where to go?



Where to Go?

Budgetting emissions

Global capacities

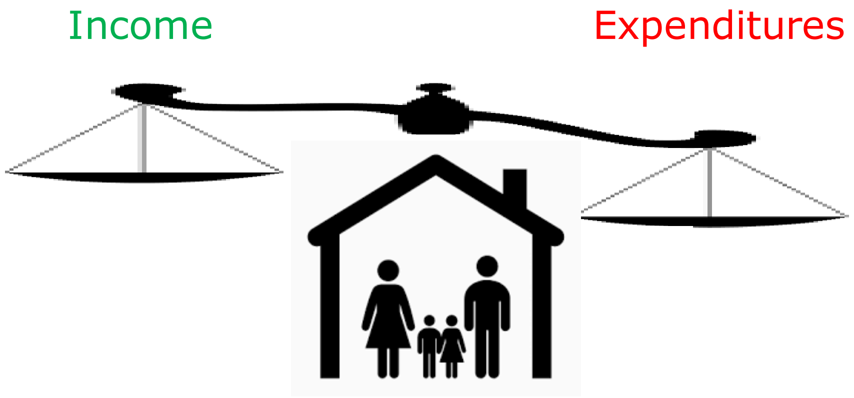


National and sector wise allocation of capacities/emmissions

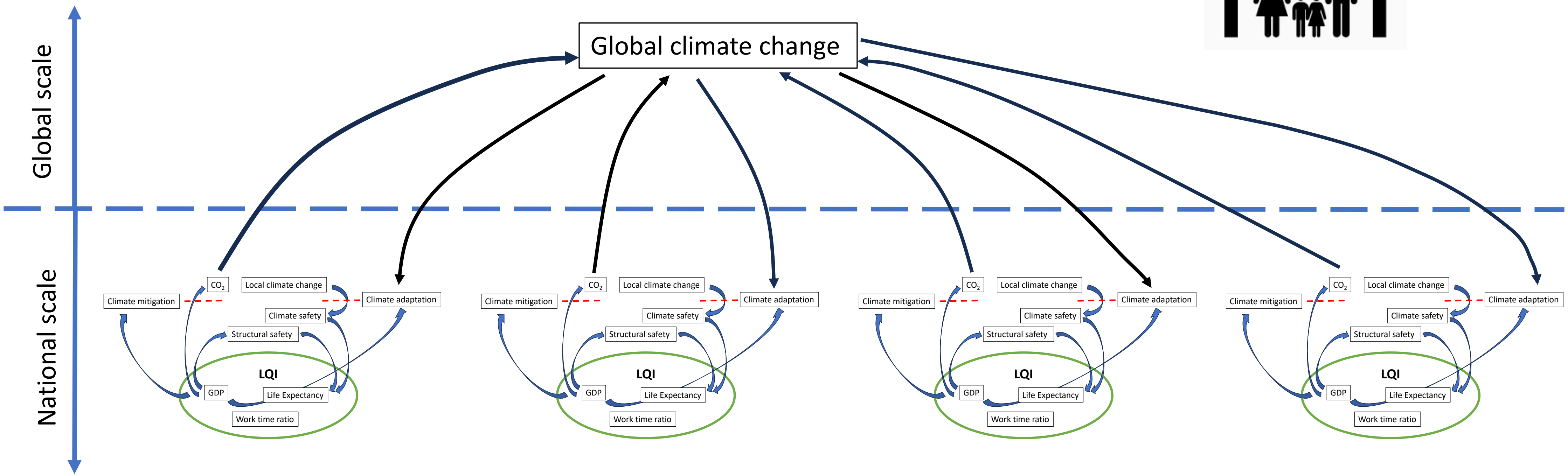
- **Built environment**
- **Energy production and distribution**
- **Food production**
- **Transportation**
- **.....**
- **....**
- **...**
- **..**

Steffen, Will; Richardson, Katherine; Rockström, Johan; Cornell, Sarah E.; Fetzer, Ingo; Bennett, Elena M.; Biggs, Reinette; Carpenter, Stephen R.; de Vries, Wim; de Wit, Cynthia A.; Folke, Carl (2015). "Planetary boundaries: Guiding human development on a changing planet". *Science*. **347** (6223): 1259855.

Where to Go?



Climate justness?



We are facing a very substantial ethical problem that must be resolved
I think it is our responsibility to highlight this and help to inform decisions

Literature Overview

Faber, M. H. (2018). *On sustainability and resilience of engineered systems* (pp. 28-49). Abingdon: Routledge.

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Thomas Bull, Min Liu, Daniel Vig Muff, Paul-Remo Wagner, Wei-Heng Zhang, Matthias Schubert, Michael Havbro Faber, Hans Jørgen Riber (2023). Lifetime extension for offshore wind turbine support structures considering CO2 optimization, presented at IFED 2023, Stoos, Switzerland.

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Thanks for your attention ☺

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