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# An (incomplete) overview of adaptation in global impact models and IAMs

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Utrecht Summer School on Climate Impacts and Equity

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# Content

- Adaptation in:
  - Climate-impact models
  - CB-IAMs
  - Process-based IAMs
- Adaptive capacity measures
- Adaptive capacity in scenarios
- Discussion

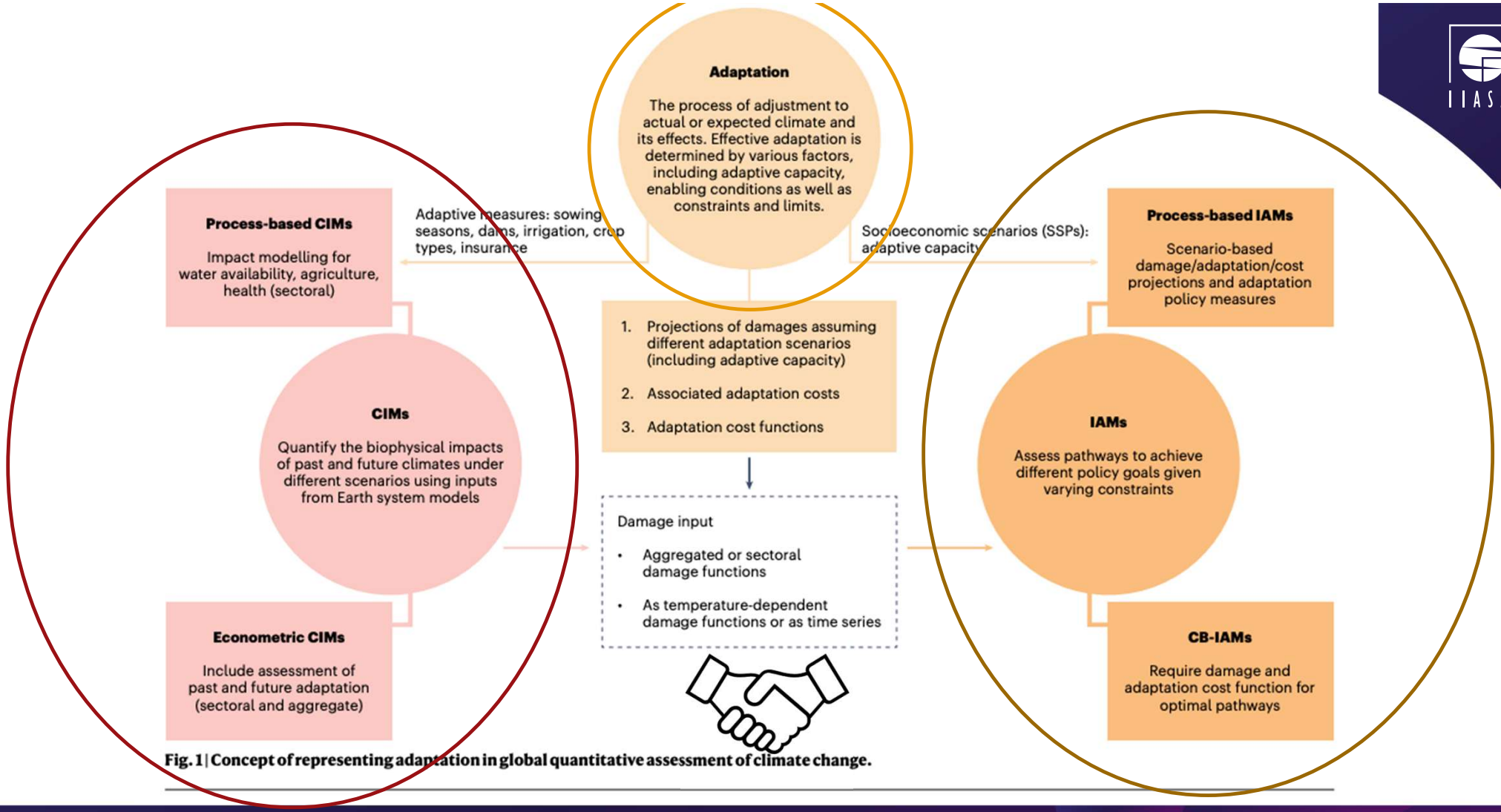


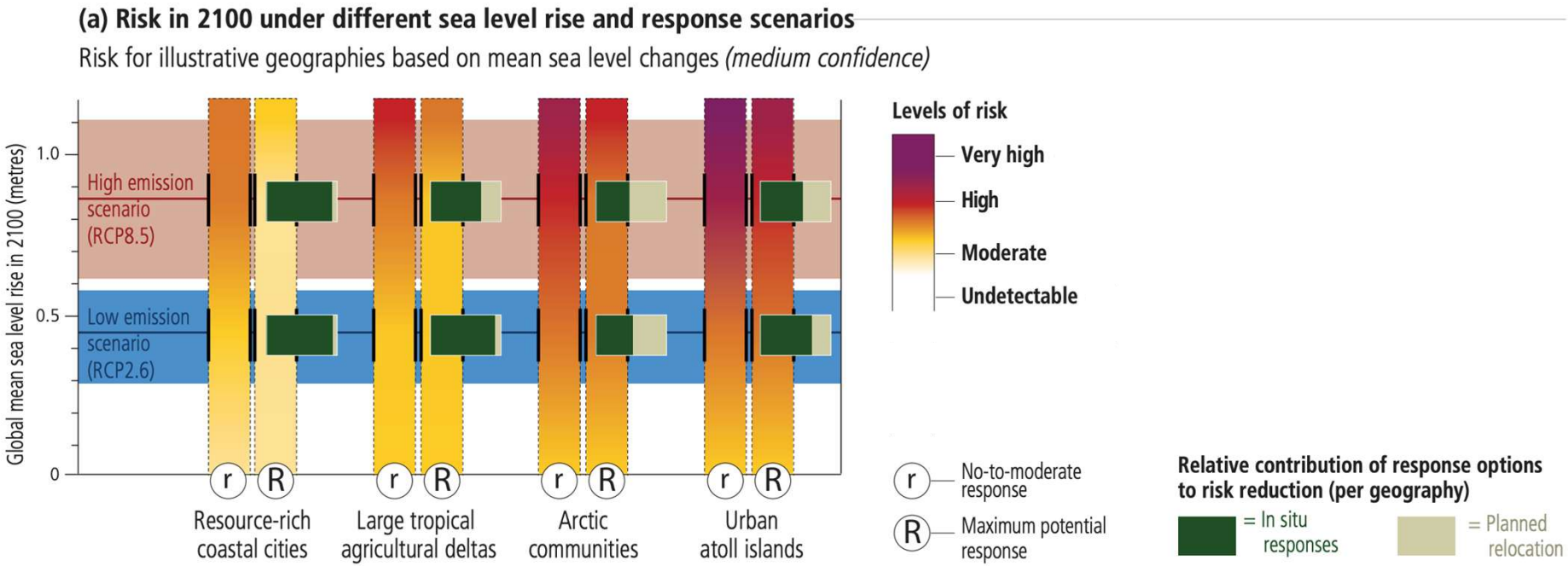

**Fig. 1 | Concept of representing adaptation in global quantitative assessment of climate change.**



van Maanen, N., Lissner, T., Harmsen, M., Piontek, F., Andrijevic, M., & van Vuuren, D. P. (2023). Representation of adaptation in quantitative climate assessments. *Nature Climate Change*, *13*(4), 309-311.

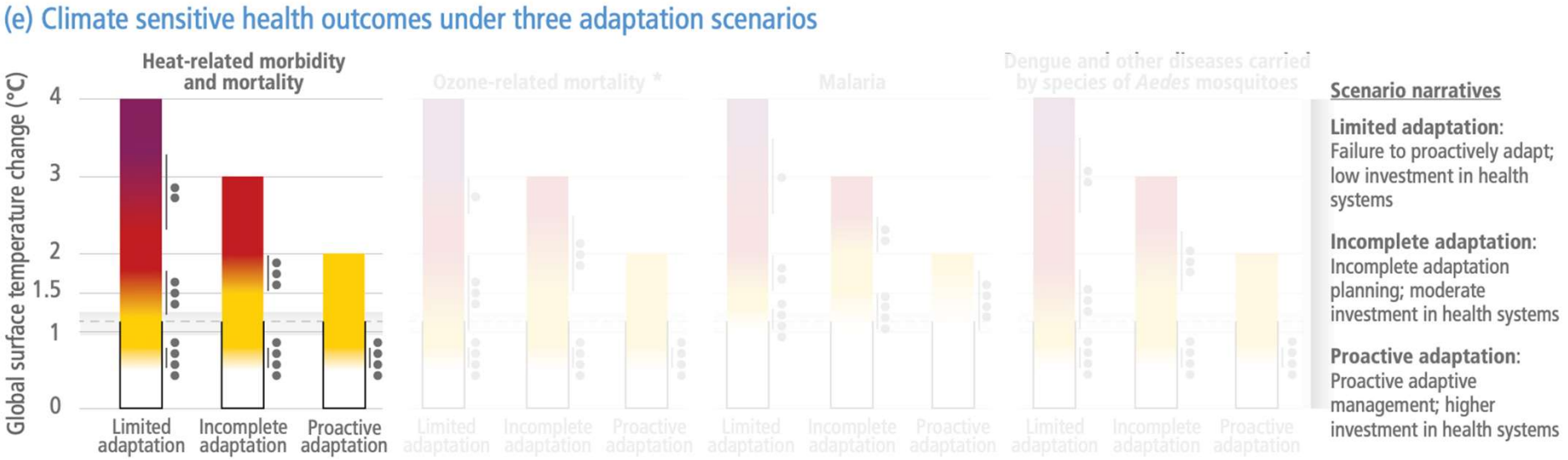
# Climate impact models

# Adaptation to risks of sea level rise




IPCC SROCC Fig. SPM 2 (2019)

# Adaptation in health




IPCC AR6 Fig. SPM 3 (2022)

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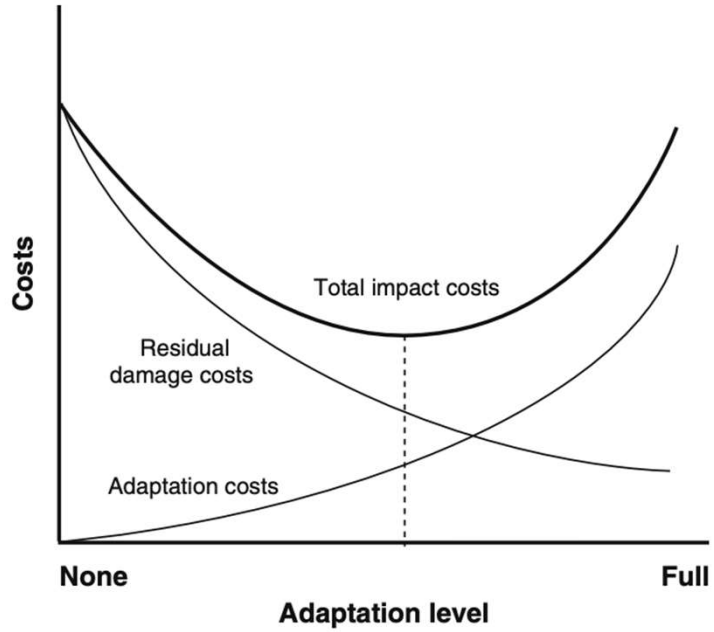
# CB IAMs

# Adaptation in CB IAMs

**IAMs**

Assess pathways to achieve different policy goals given varying constraints

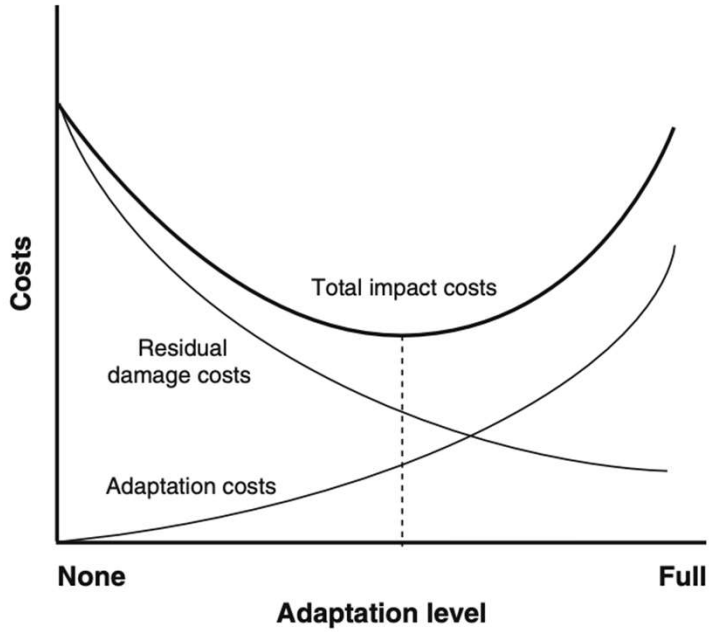


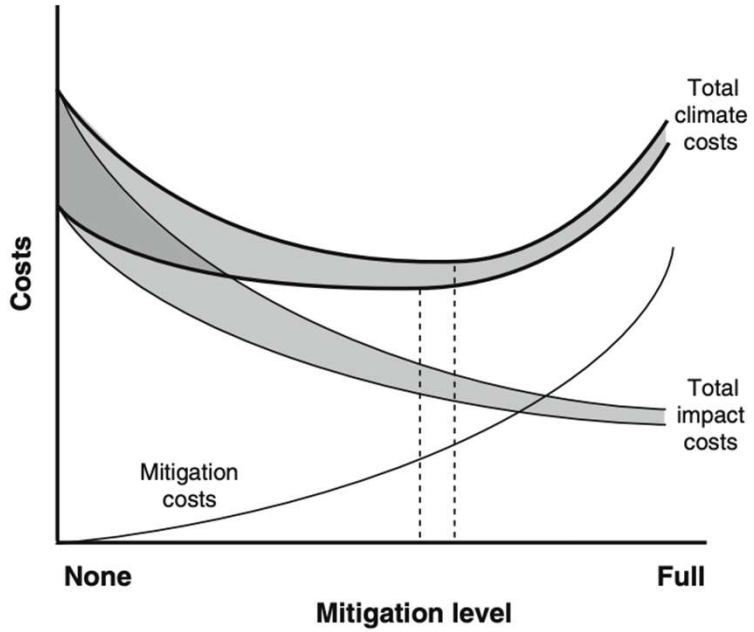

Source: Patt et al. (2010)

# Adaptation in CB IAMs

**IAMs**

Assess pathways to achieve different policy goals given varying constraints




Source: Patt et al. (2010)

# Cost-benefit assessment of adaptation

- FUND model (Tol, 2008): adaptation and mitigation as trade-offs
  - Too high a level of mitigation may take resources away from adaptation and in that way lead to more net damages
- DICE/RICE & AD-DICE/AD-RICE (Nordhaus, 1992; De Bruin et al., 2009): Net damage function is a combination of the optimal mix of adaptation costs and residual damages
  - In DICE: mitigation is set by the marginal damage cost
  - In AD-DICE: mitigation is set by the marginal residual damage + adaptation cost
  - What is optimal adaptation?

# Restrictions on adaptation

Table 1. Description of various restriction levels for each scenario.

| Scenario | Weak restriction | Strong restriction |
|---|---|---|
| Funding | Adaptation costs upper limit is 100% of average optimal level | Adaptation costs upper limit is 50% of average optimal level |
| Quantity | Adaptation upper limit is 100% of average optimal level | Adaptation upper limit is 50% of average optimal level |
| Excess | Residual damage lower limit is 100% of average optimal level | Residual damage lower limit is 50% of average optimal level |
| Delay | Adaptation is not possible in first 30 years | Adaptation is not possible in first 90 years |
| Rigidity | Adaptation cannot vary by more than 10% from one period to the next | Adaptation cannot vary at all from one period to the next |
| Obsolete | Adaptation is ineffective after 7° temperature increase | Adaptation is ineffective after 3° temperature increase |

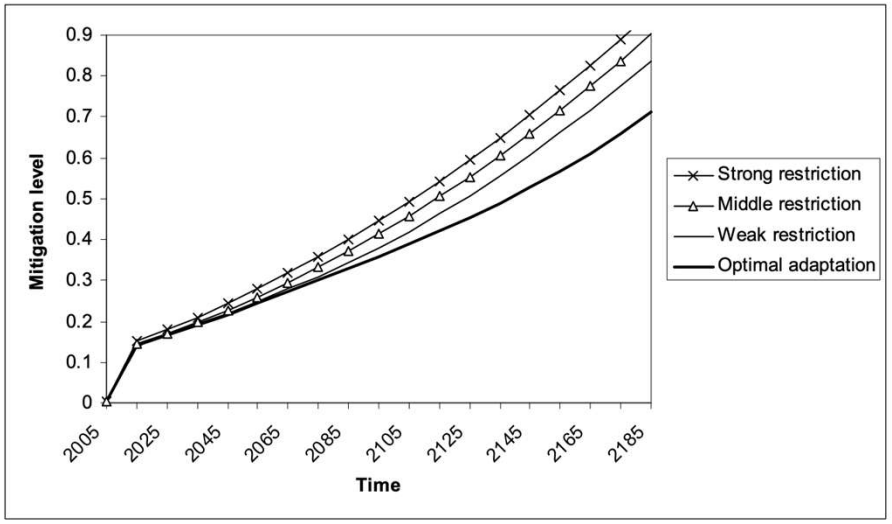



**Figure 12: Optimal mitigation over time for various adaptation upper limit restrictions (scenario A2) and the optimal.**

De Bruin and Dellink (2011)

Universiteit Utrecht

# *RCP–SSP matrix for damage+adaptation costs*

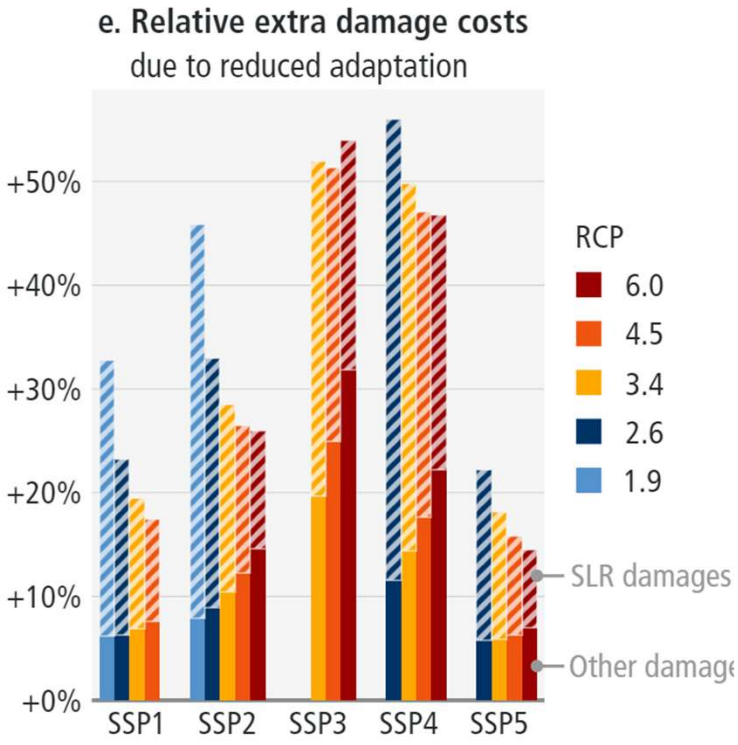
Gross damage function (COACCH p95)

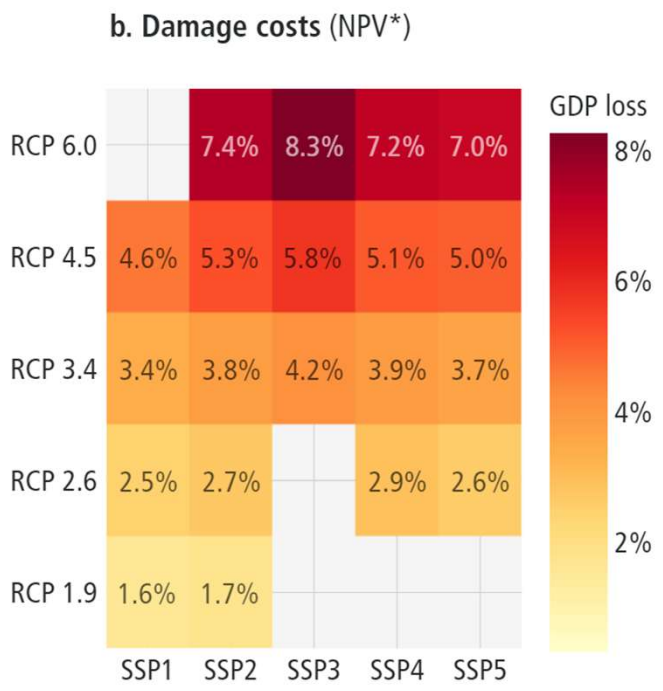
+

Adaptation costs (AD-RICE, 2010) **(update through ACCREU)**

+

Adaptation readiness (Andrijevic et al., 2019)



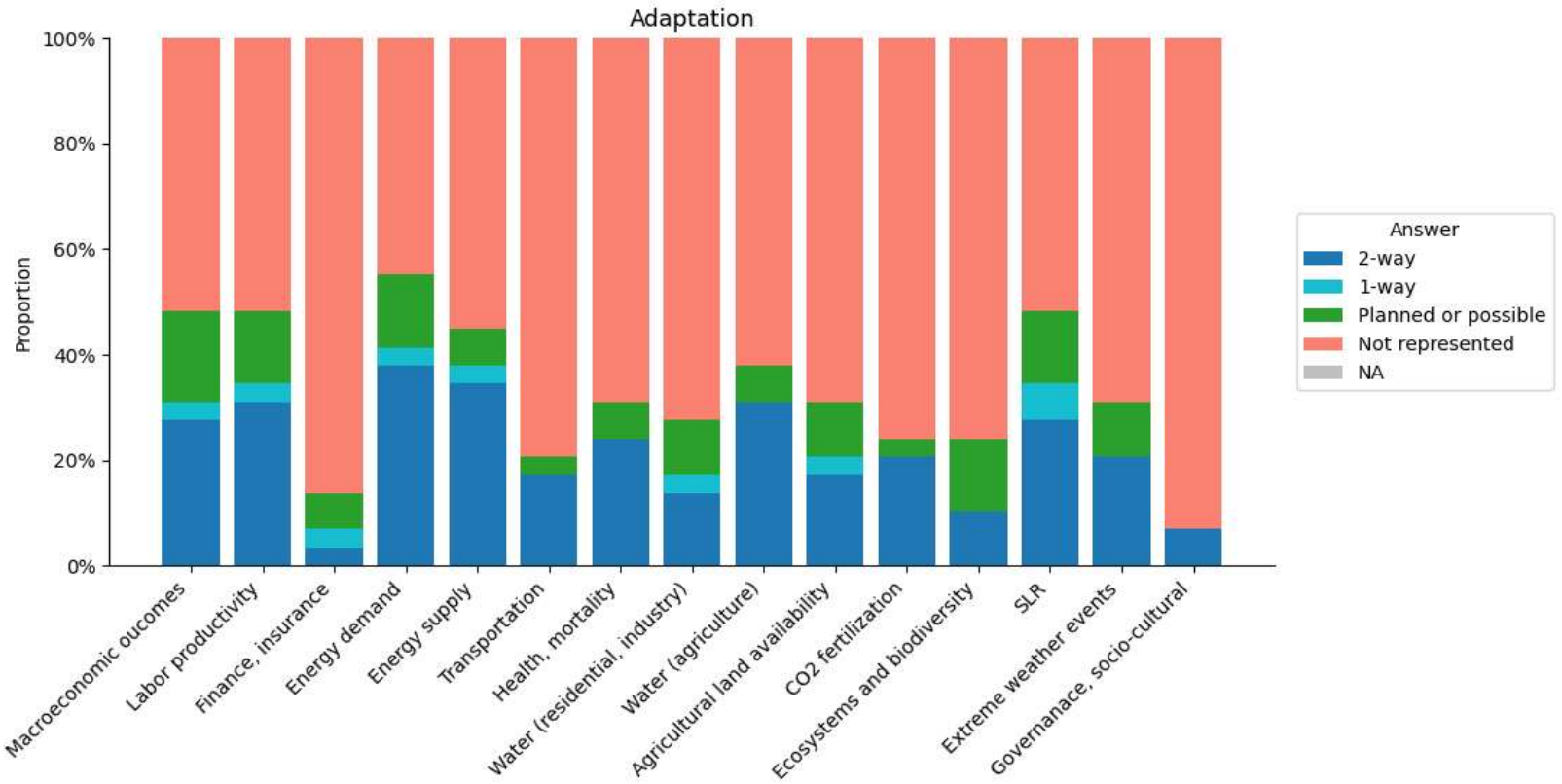

Source: van Wijst et al., (forthcoming)

# Cost-benefit assessment of adaptation

- Efficiency or utilitarian framing of adaptation (see Singh et al., 2021):
  - Adaptation effectiveness is defined though optimization, parsimony or utility maximization
  - Benefits of adaptation can be fully estimated and defined in financial terms
  - If framed only around economic damage reduction, it might favor those with largest assests
- Models rarely account for barriers such as financial, institutional, informational, or behavioral obstacles that limit adaptation in practice

# Process-based IAMs

# Adaptation in process-based IAMs

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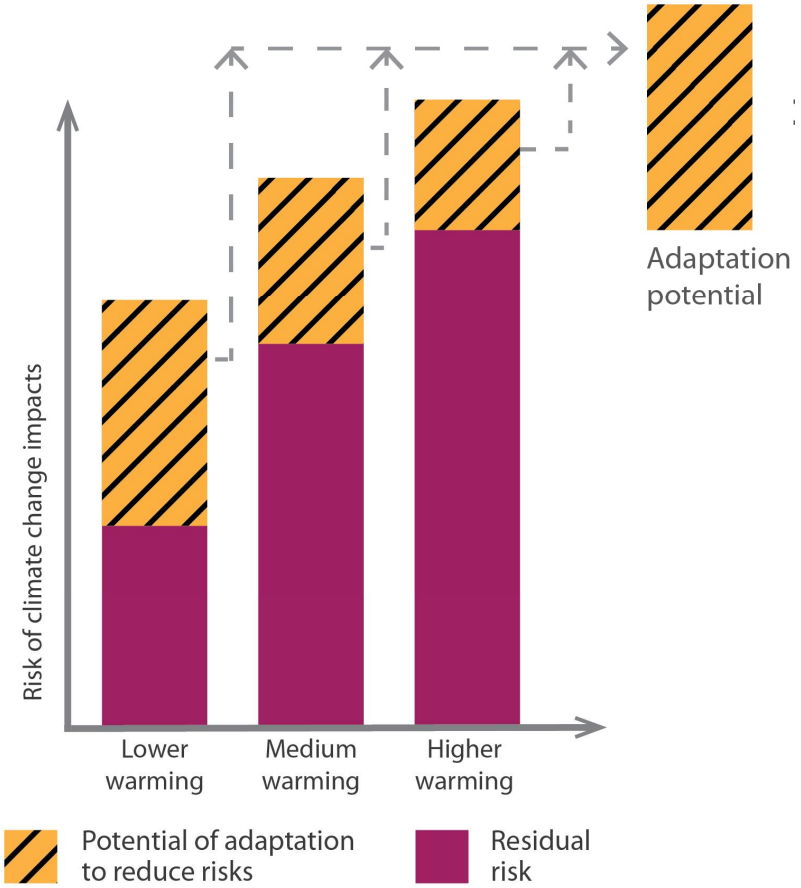
This project has received funding from the European Union's Horizon Europe programme under grant agreement No 101081604.

# Adaptive capacity

# Conventional representation of adaptation

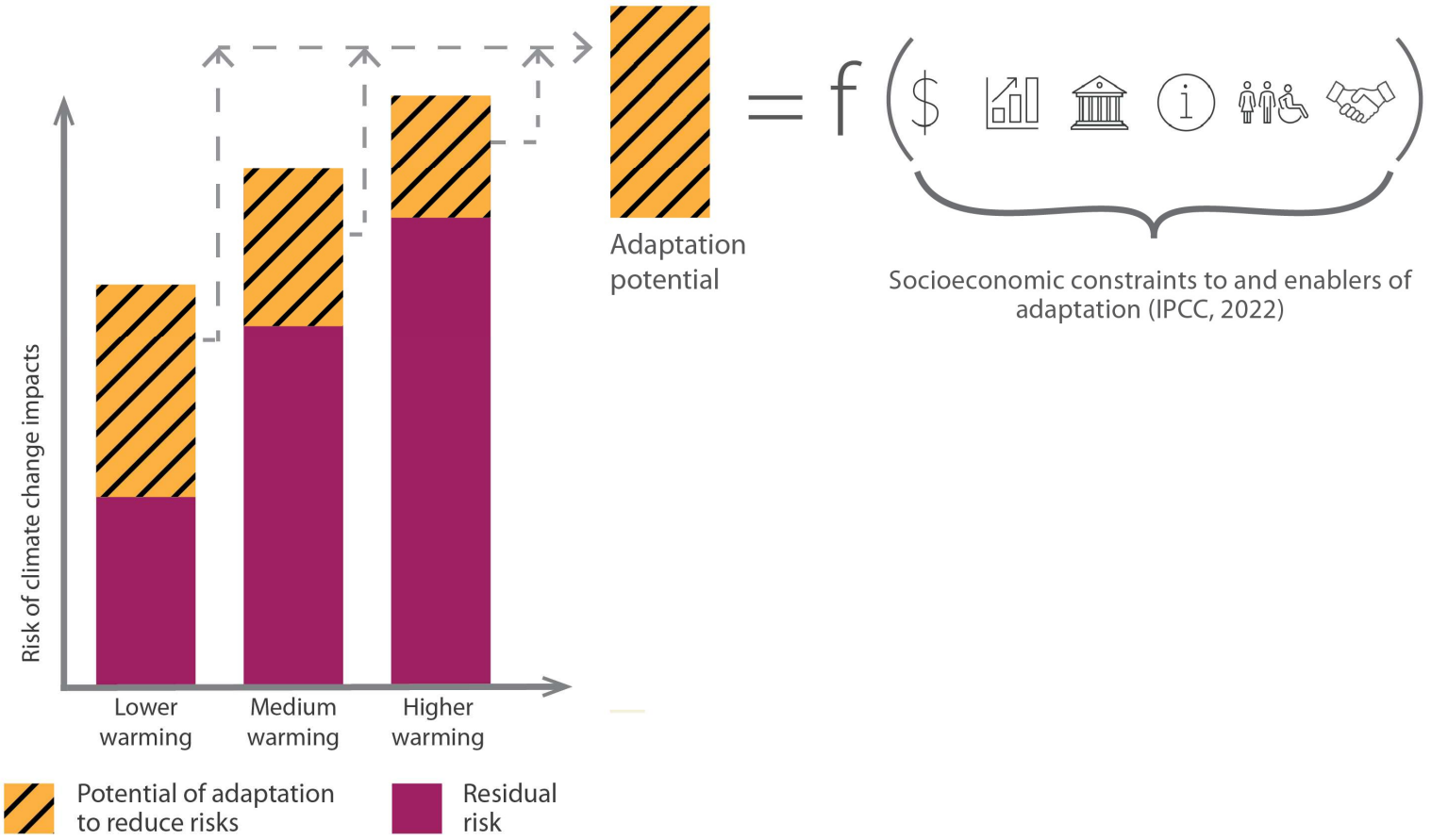



- Adaptation potential reduces at higher levels of warming, because adaptation effectiveness reduces (IPCC, 2022)
- Stylized representations of adaptation typically assume unconstrained/unconditional adaptation



Andrijevic, M., Schleussner, CF., Crespo Cuaresma, J. *et al.* Towards scenario representation of adaptive capacity for global climate change assessments. *Nat. Clim. Chang.* **13**, 778–787 (2023).

# Conventional representation of adaptation



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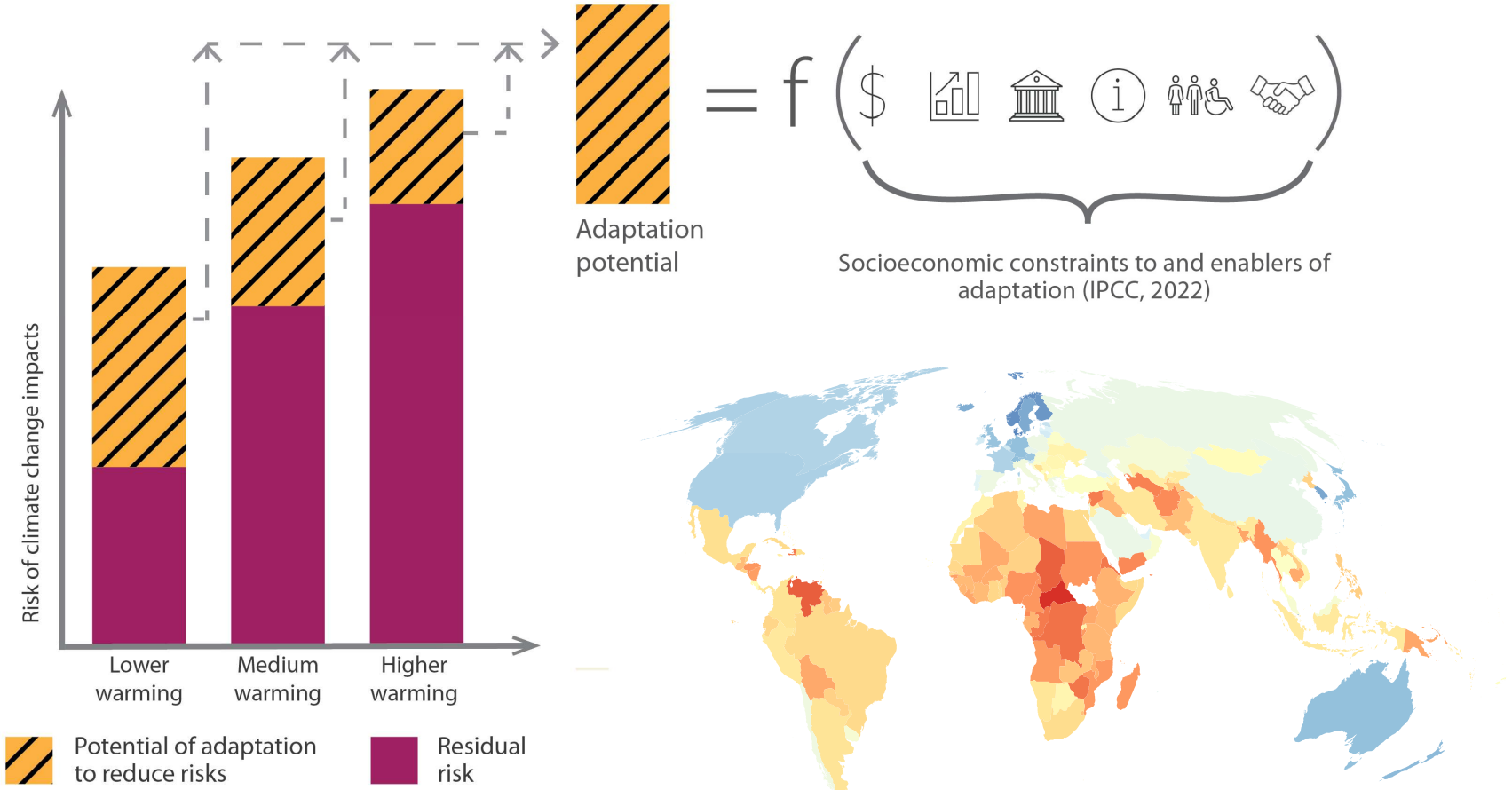




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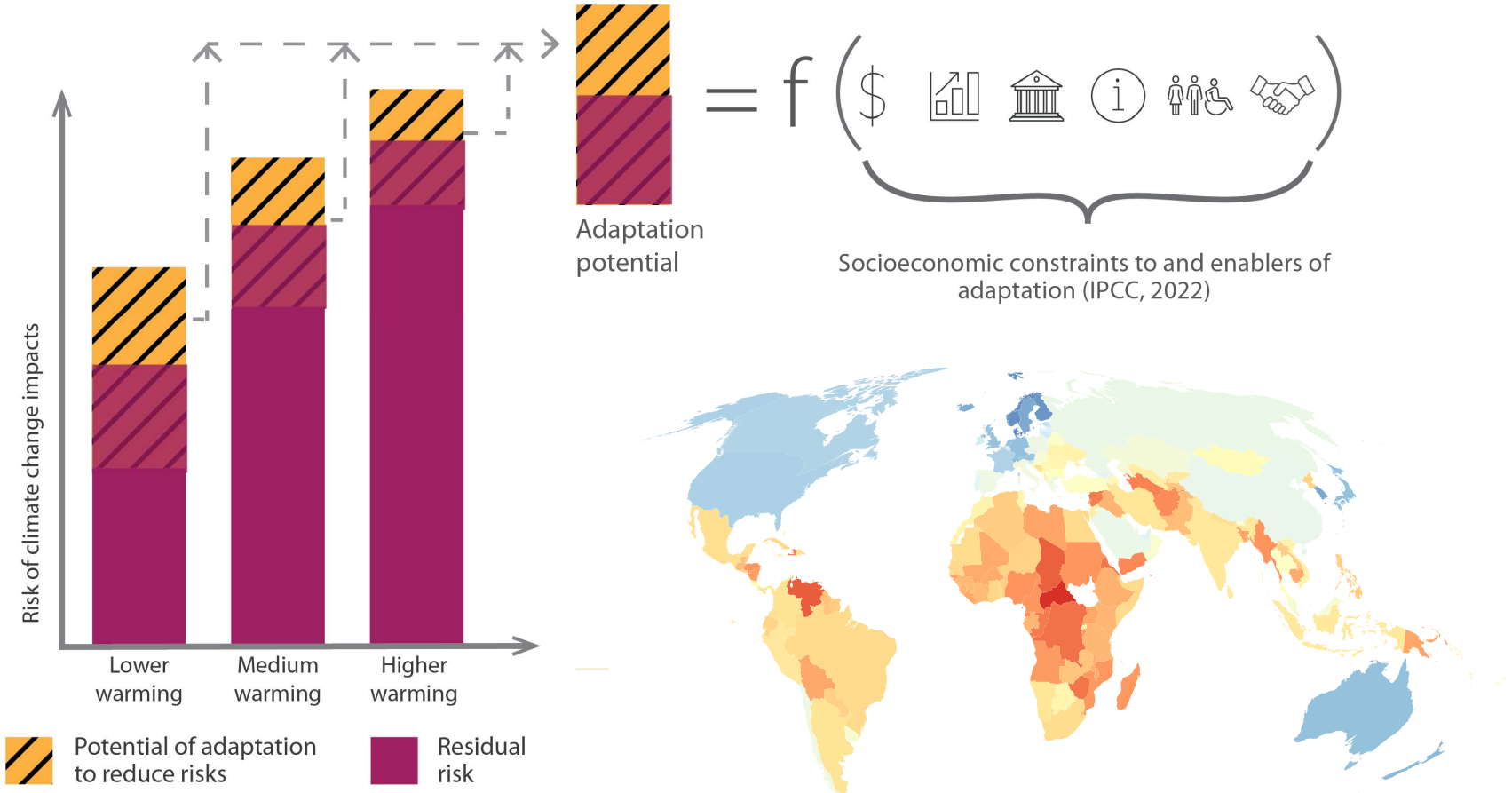




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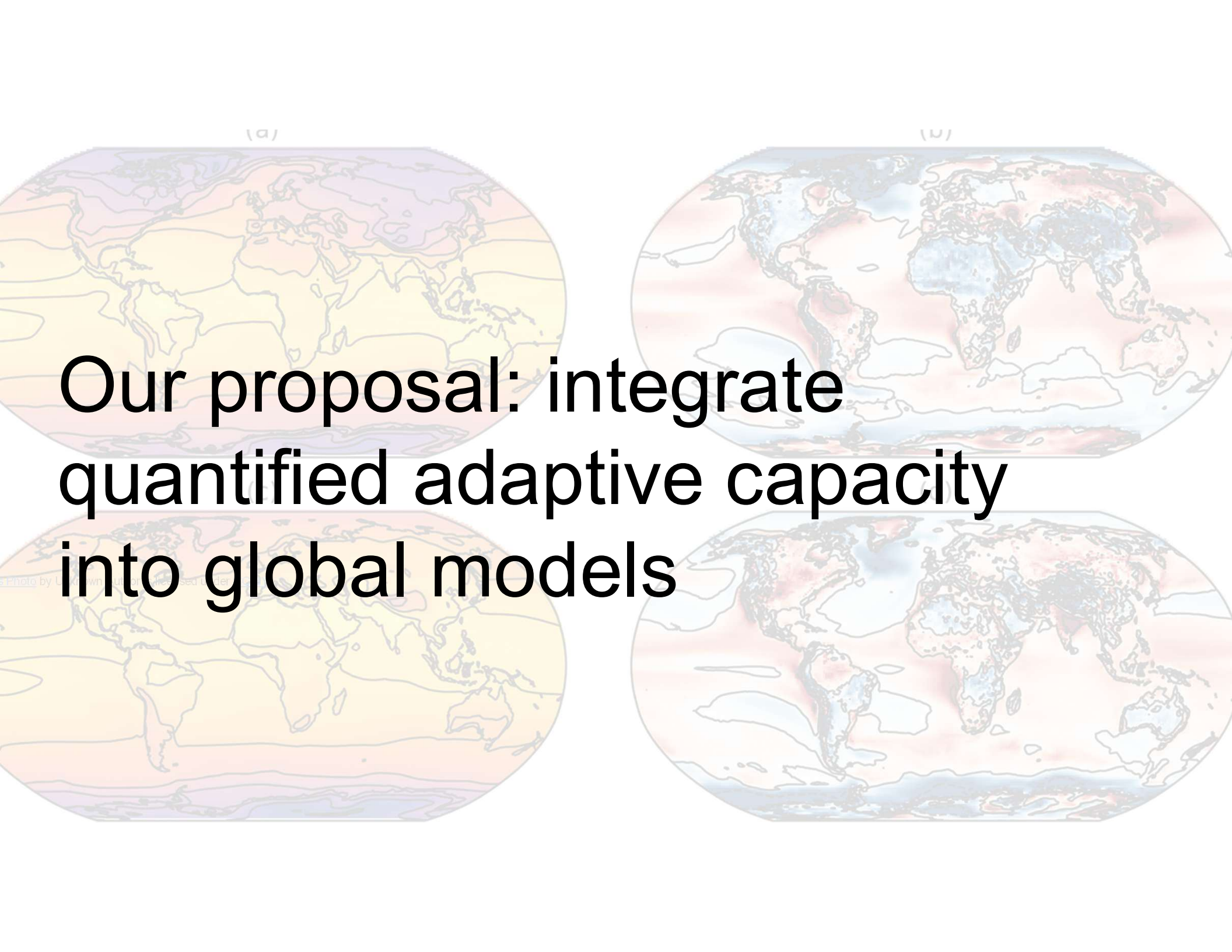
# Bottom line: models do not incorporate the extent to which societies could adapt





# Implications

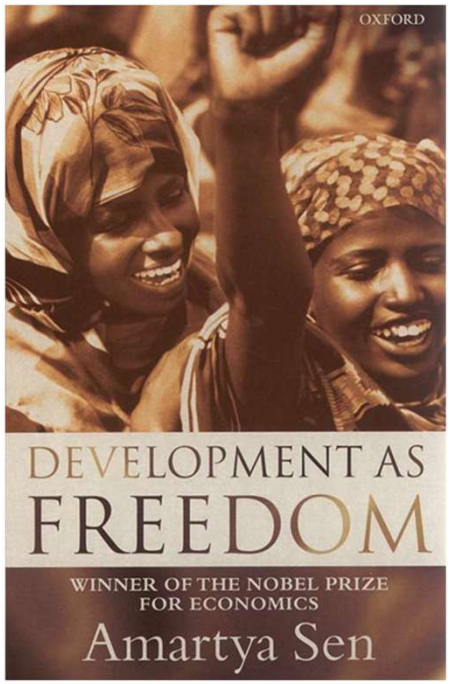
- Unconstrained adaptation is an overly optimistic assumption, not least because adaptive capacity is unequally distributed around the world
- Risks of climate impacts could be underestimated



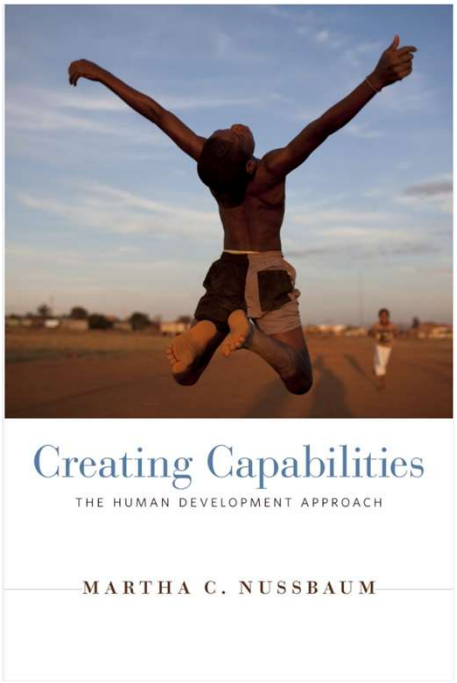
Our proposal: integrate quantified adaptive capacity into global models

# Integrating quantified adaptive capacity into models

- Conceptualization of adaptive capacity similar to **Nussbaum and Sen's understanding of capabilities**: a local actor to pursue (or not) a desired adaptation action
- The socioeconomic factors underlying adaptive capacity can be assessed, described and projected in line with the SSPs




Source: Oxford University Press




Source: Harvard University Press

# What are the dimensions of adaptive capacity?

- Composite indicators of socio-economic and sometimes environmental dimensions
- Existing approaches vary in the scale at which they are applied (local, regional, global)
- Similar in the higher-order dimensions: economic and financial capital, human capital and institutions
- **No global projections to date**

Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity

Gary Yohe [a], Richard S.J. Tol [b]

ND-GAIN
Notre Dame Global Adaptation Initiative

A new composite climate change vulnerability index

H.K. Edmonds, J.E. Lovell, C.A.K. Lovell

Adaptive capacity to climate change: A synthesis of concepts, methods, and findings in a fragmented field

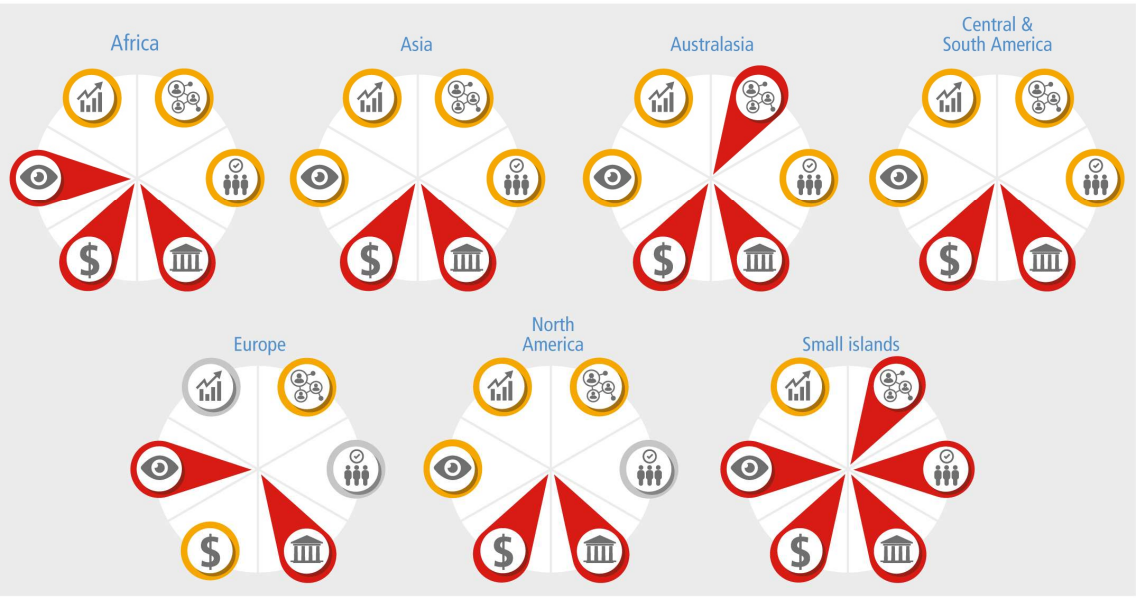
A.R. Siders

How inequitable is the global distribution of responsibility, capability, and vulnerability to climate change: A comprehensive indicator-based assessment

Hans-Martin Füssel

# Integrating quantified adaptive capacity into models

(d) Constraints that make it harder to plan and implement human adaptation




Constraints associated with limits to adaptation for regions across all sectors:



Figure TS.7, WGII IPCC 2022

Indicators consistent with the SSP scenarios

| Dimension | Indicator | Publication(s) |
|---|---|---|
| Economic/ financial | GDP per capita | Refs. 71–74 |
| | Structural change | Ref. 75 |
| | Extreme poverty | Ref. 76 |
| | Income inequality | Ref. 77 |
| | Urbanization | Refs. 78,79 |
| | Remittances | Ref. 80 |
| Governance/ institutions | Governance | Ref. 81 |
| | Government effectiveness | Ref. 81 |
| | Control of corruption | Ref. 81 |
| | Rule of law and civil liberties | Ref. 82 |
| Human capacity / information | Population size | Ref. 83 |
| | Age structure | Ref. 83 |
| | Educational attainment | Ref. 83 |
| | Mean years of schooling | Ref. 83 |
| | Human Development Index | Ref. 84 |
| | Migration flows | Ref. 80 |
| Social/cultural | Gender Inequality Index | Ref. 85 |
| | Gender gap in mean years of schooling | Ref. 83 |

# Integrating quantified adaptive capacity into models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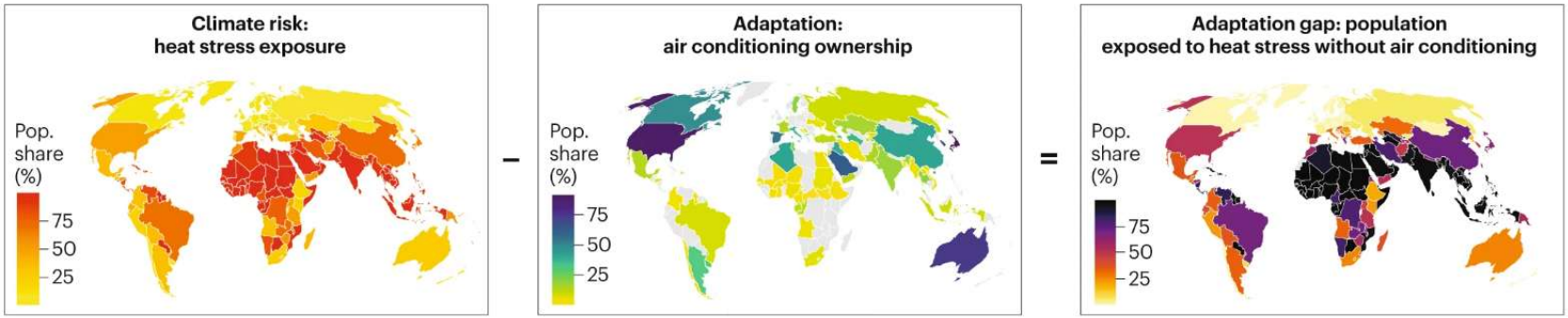
# Cooling gap example

Based on Andrijevic, M., Byers, E., Mastrucci, A., Smits, J., & Fuss, S. (2021). **Future cooling gap in shared socioeconomic pathways.** *Environmental Research Letters*, *16*(9), 094053.

**a Identification of the adaptation gap**

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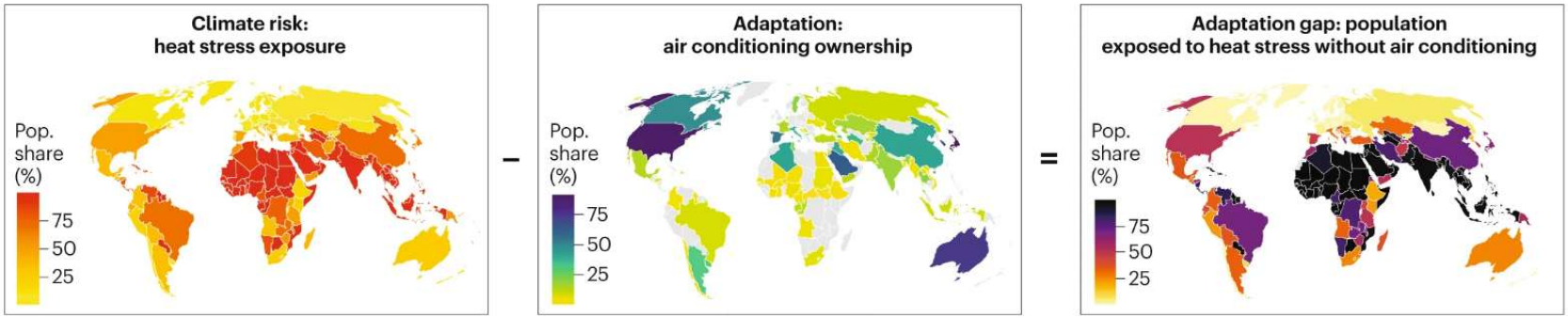
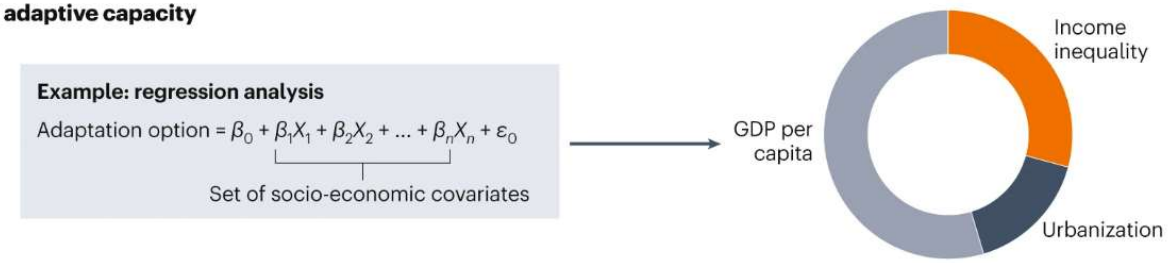



**b** **Identification of adaptive capacity**

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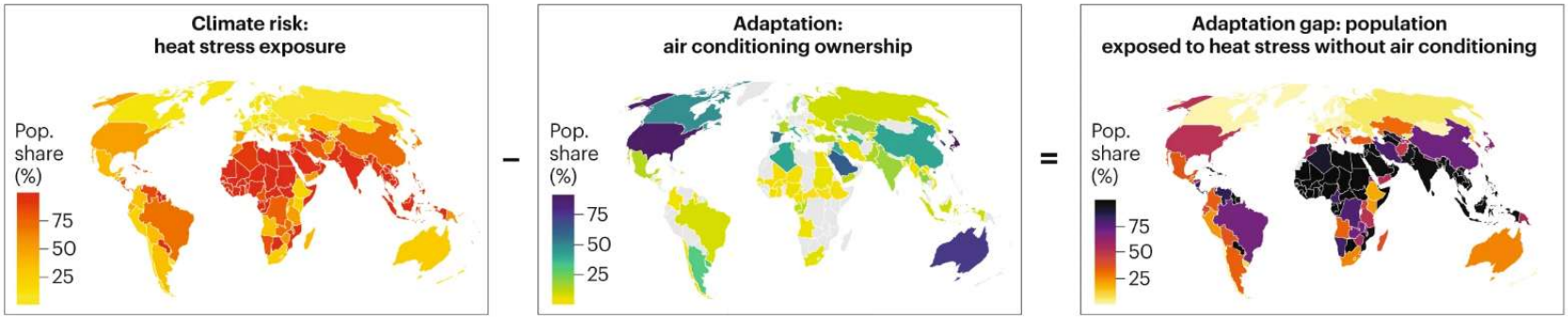
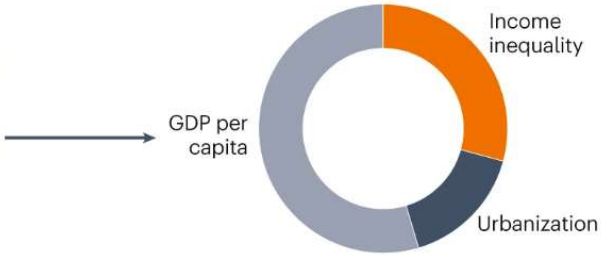



**b** **Identification of adaptive capacity**

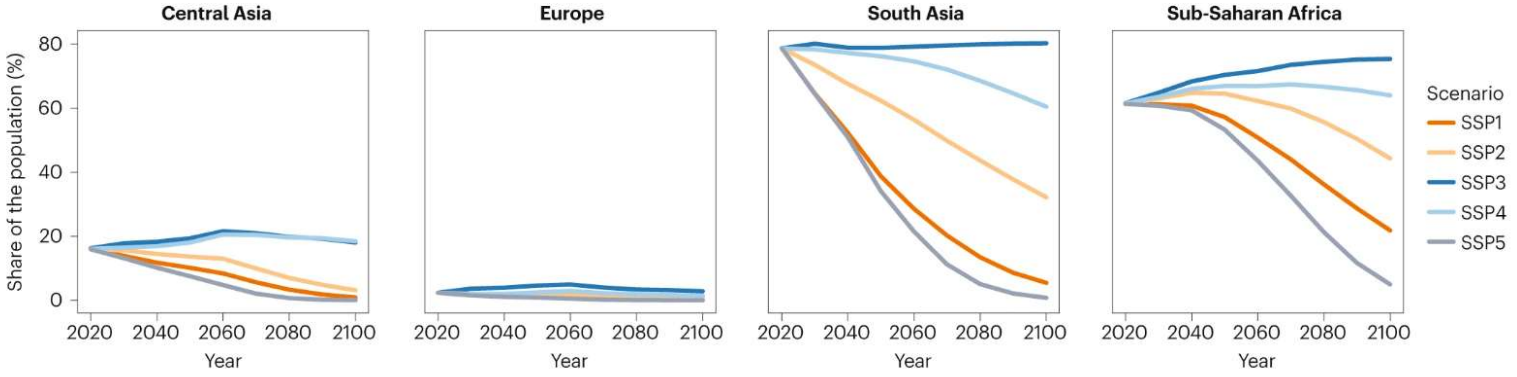
**Example: regression analysis**

Adaptation option = $\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon_0$

Set of socio-economic covariates




**c** **Projections of the adaptation gap (RCP4.5 and five SSPs)**



# Adaptation in the PRISMA project

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This project has received funding from the European Union's Horizon Europe programme under grant agreement No 101081604.

# Water (mal-)adaptation

| Sector/Technology | Main determinants of capacity development | Risk of maladaptation |
|---|---|---|
| Desalination | GDP, governance | Energy, electricity or gas |
| Wastewater treatment/recycling | GDP, climate, institutions | Energy, environmental/health risks |
| Technology use in agriculture | Industrialization, climate, governance | Use of electricity and fertilizers, overuse of water resources |

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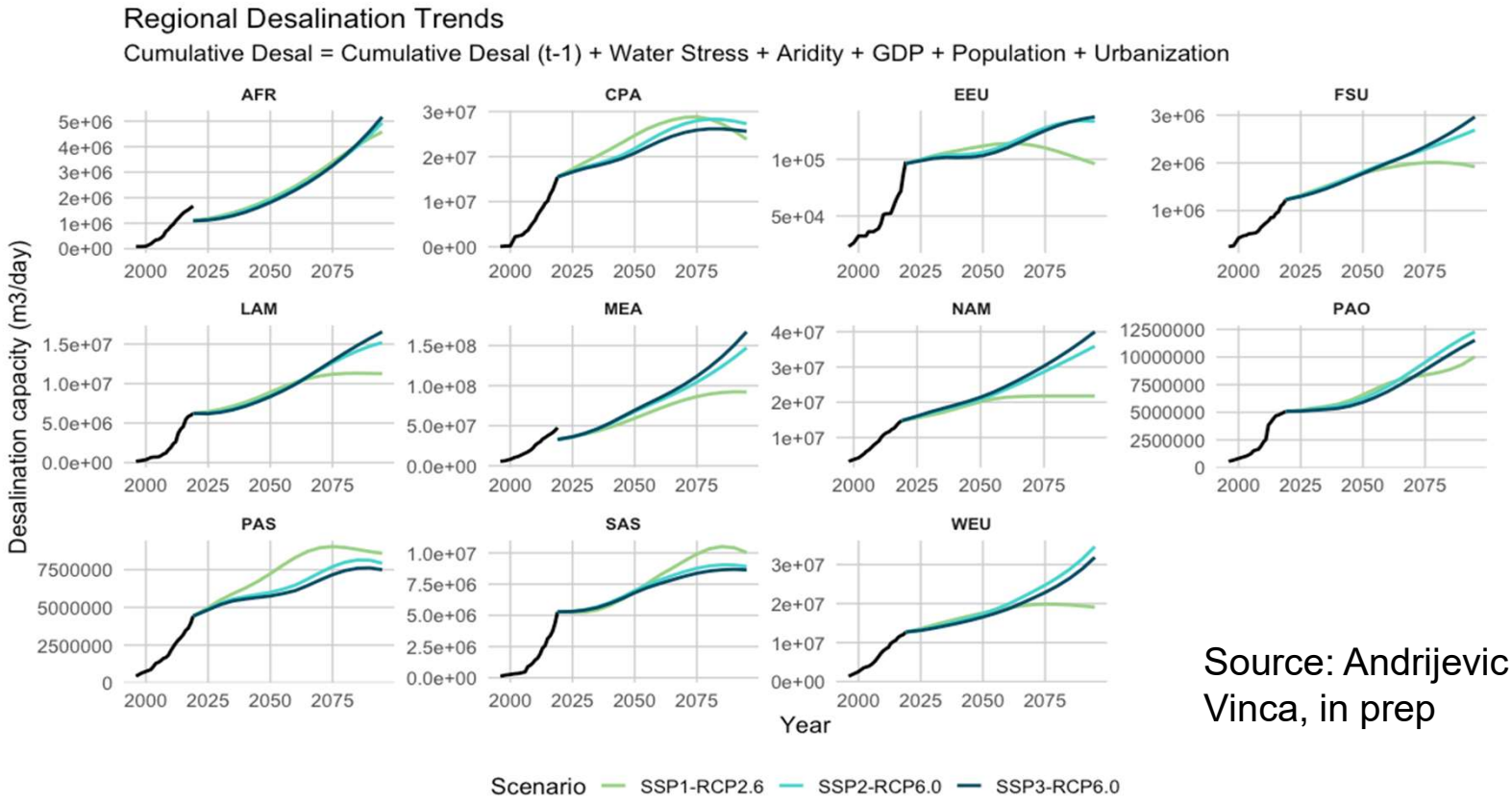


Source: Andrijevic and Vinca, in prep

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# Model integration

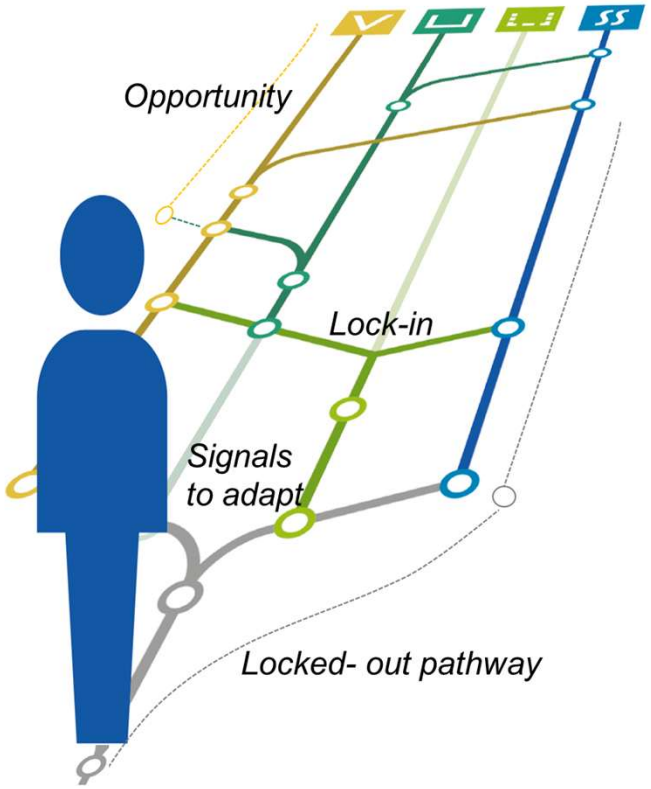
- CIMs can use scenario-specific and time-varying adaptive capacity to parameterize adaptation-relevant inputs
- Example model inputs: technologies to improve crop yields, policies to manage water allocation or finance for building dams
- IAMs can use adaptive capacity as part of the integration of climate impacts into mitigation scenarios

A desalination plant in Dubai, UAE. Richard Allenby-Pratt Getty Images

# Recent advances

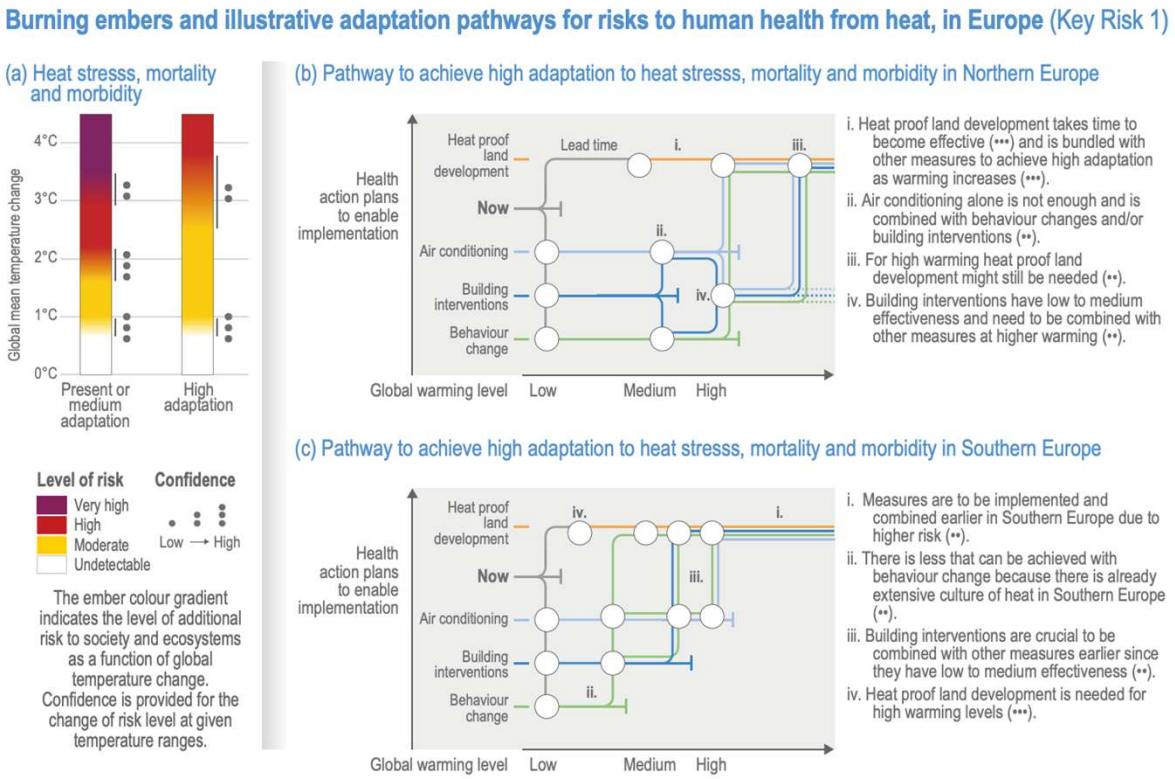
# (Dynamic) adaptation pathways

- A support tool for decision-making under uncertainties
- Effectiveness of adaptation options changes over time, requiring further adaptation actions
- Alternative pathways are possible
- Pathways map shows options and potential transfers if adaptation thresholds and limits are reached



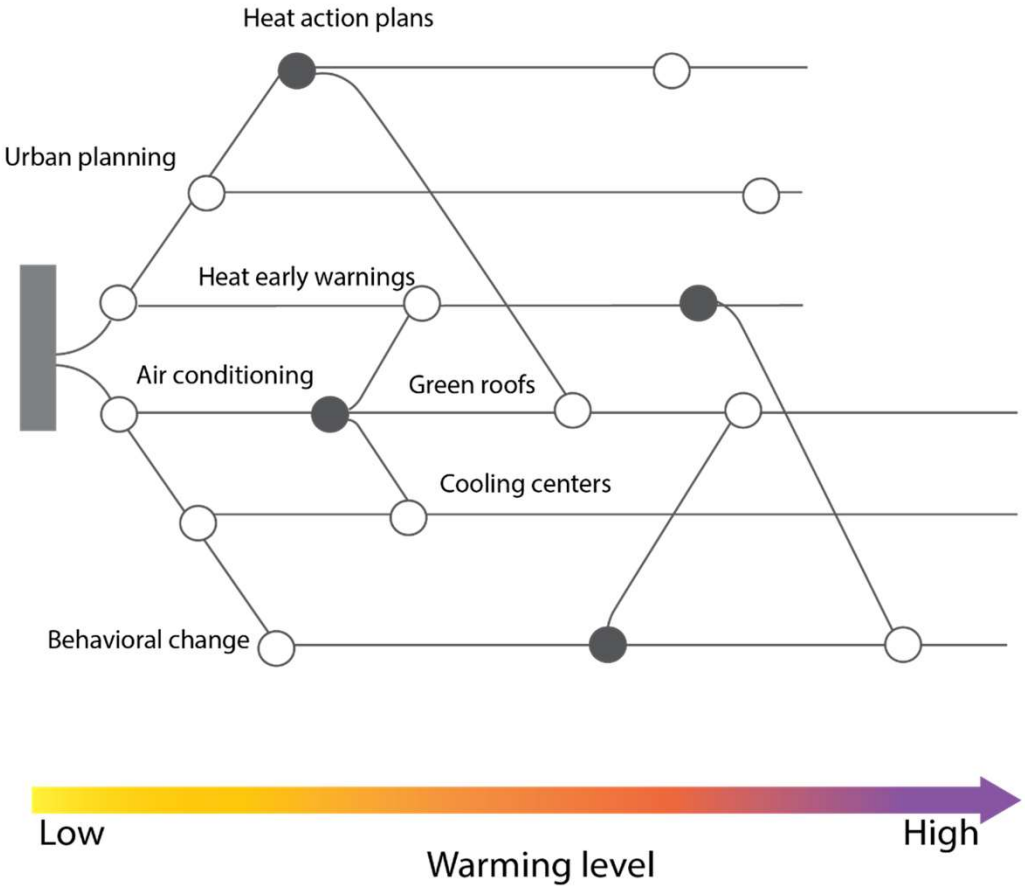

Source: Review of decade of adaptation pathways studies (Haasnoot et al., 2024)

# Adaptation pathways



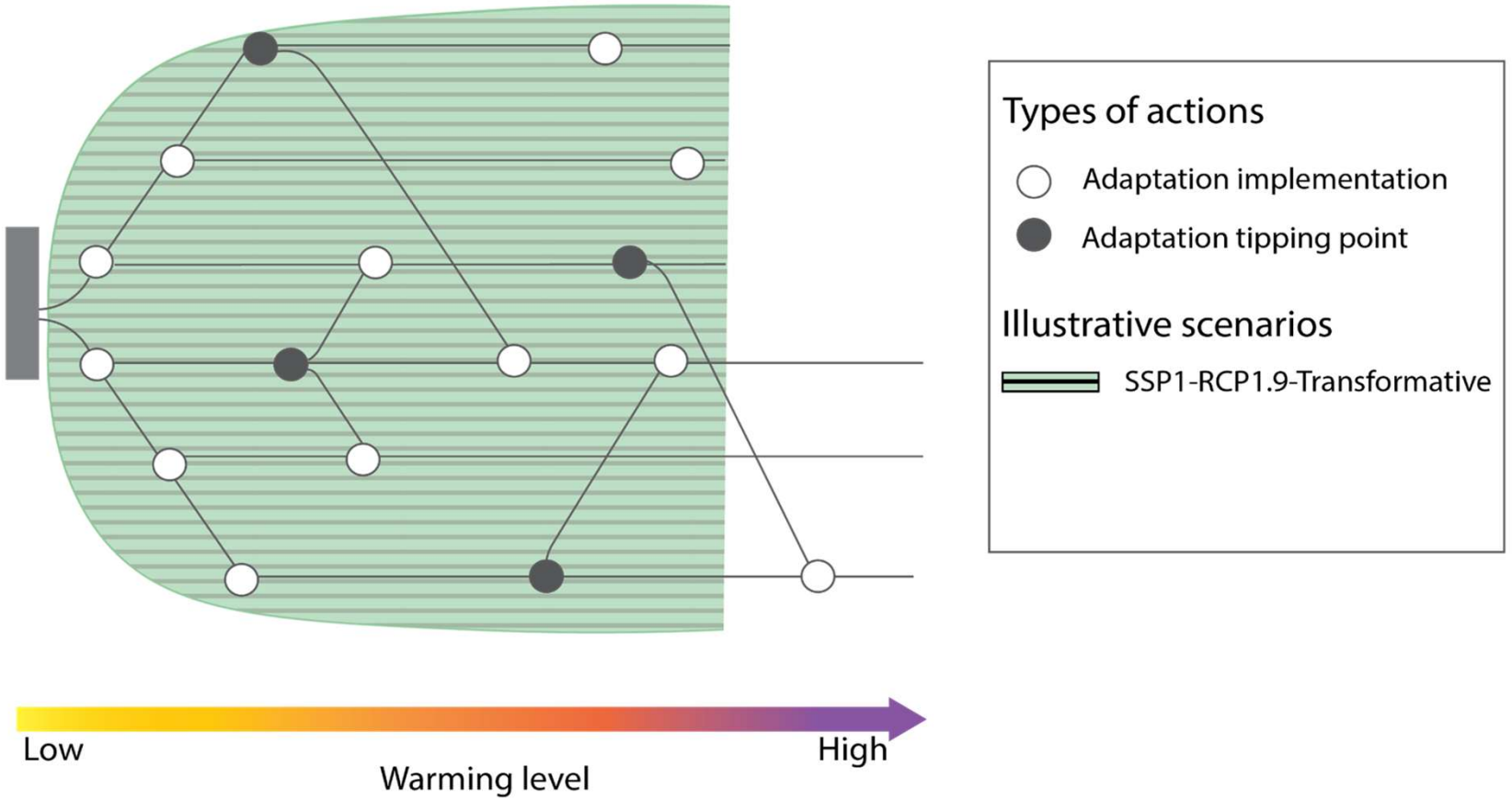


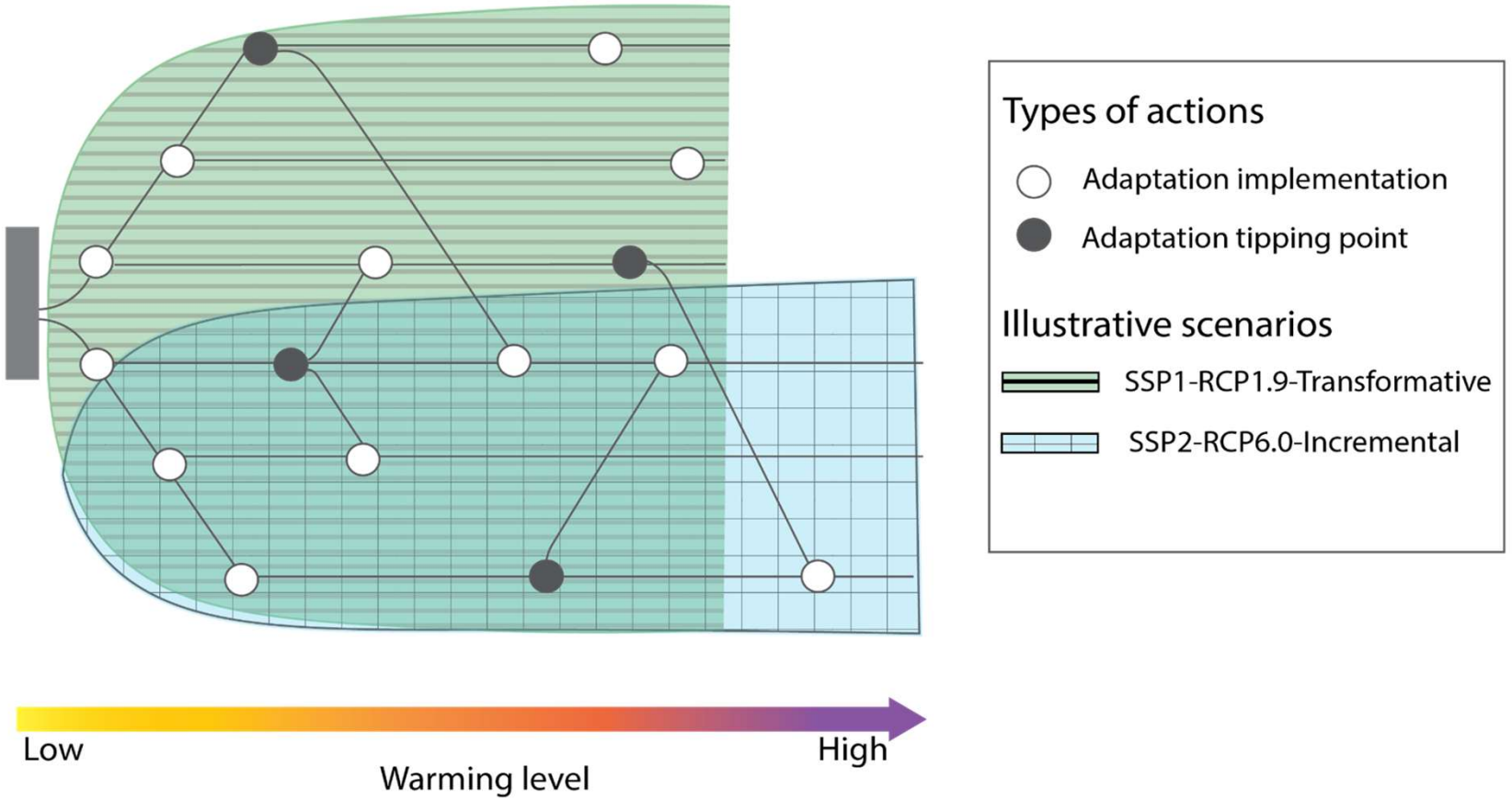

Bednar-Friedl, B., et al., 2022: Europe. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

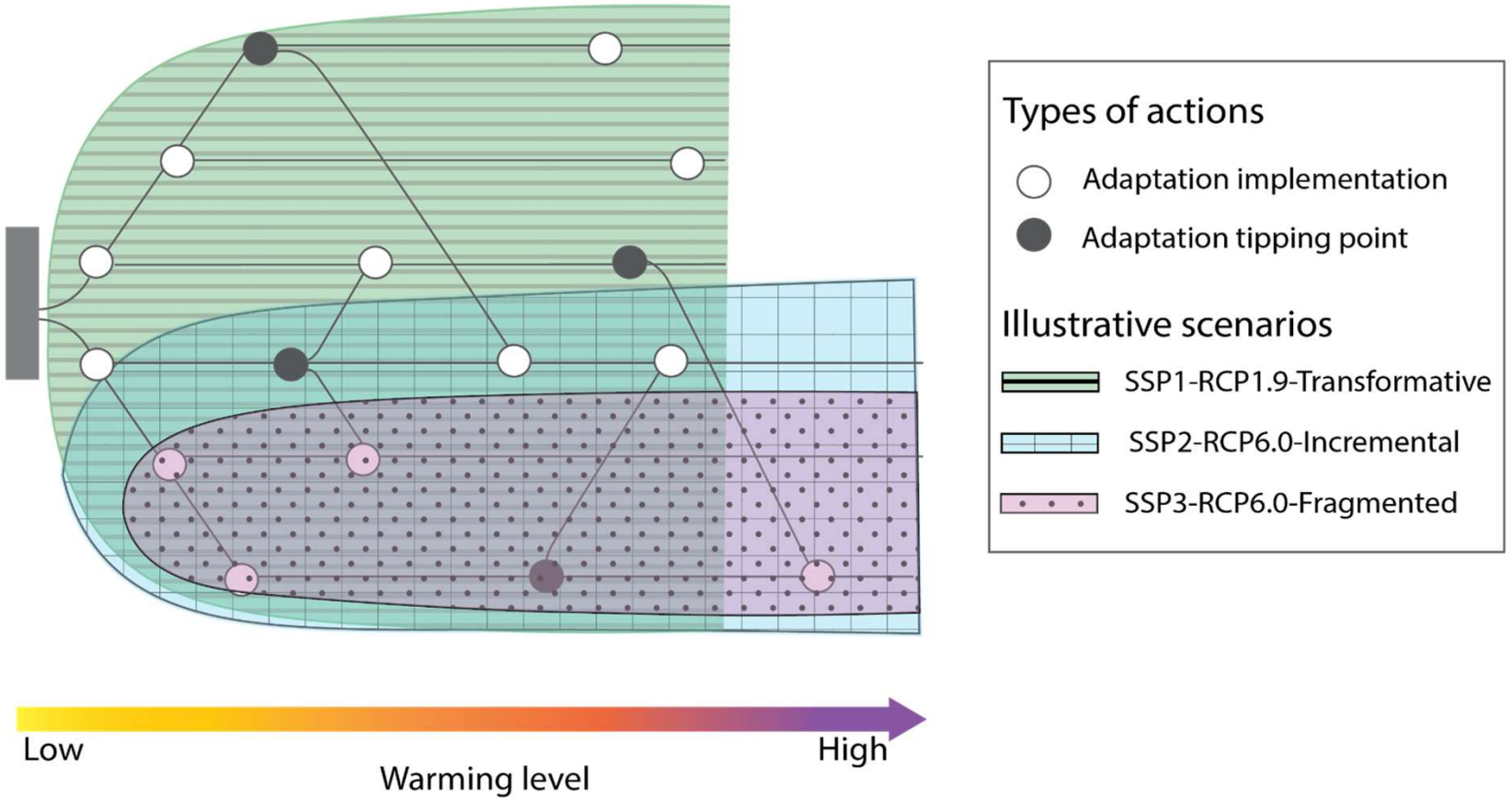



Types of actions

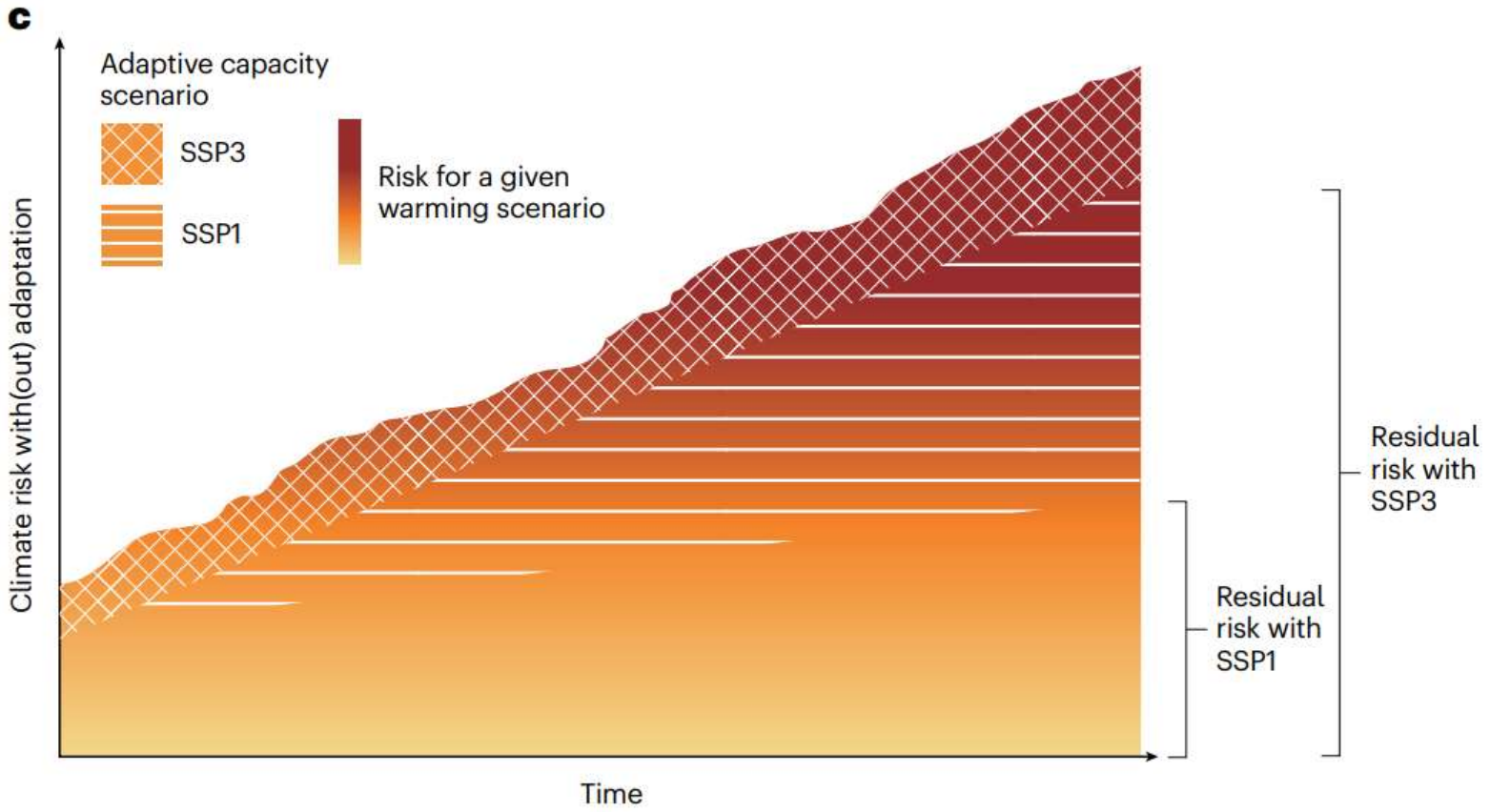
- Adaptation implementation
- Adaptation tipping point


Types of actions
Adaptation implementation
Adaptation tipping point
Illustrative scenarios
SSP1-RCP1.9-Transformative
Low
High
Warming level


Types of actions
Adaptation implementation
Adaptation tipping point
Illustrative scenarios
SSP1-RCP1.9-Transformative
SSP2-RCP6.0-Incremental
Low
High
Warming level


Types of actions
Adaptation implementation
Adaptation tipping point
Illustrative scenarios
SSP1-RCP1.9-Transformative
SSP2-RCP6.0-Incremental
SSP3-RCP6.0-Fragmented
Low
High
Warming level

# How we envisage the result



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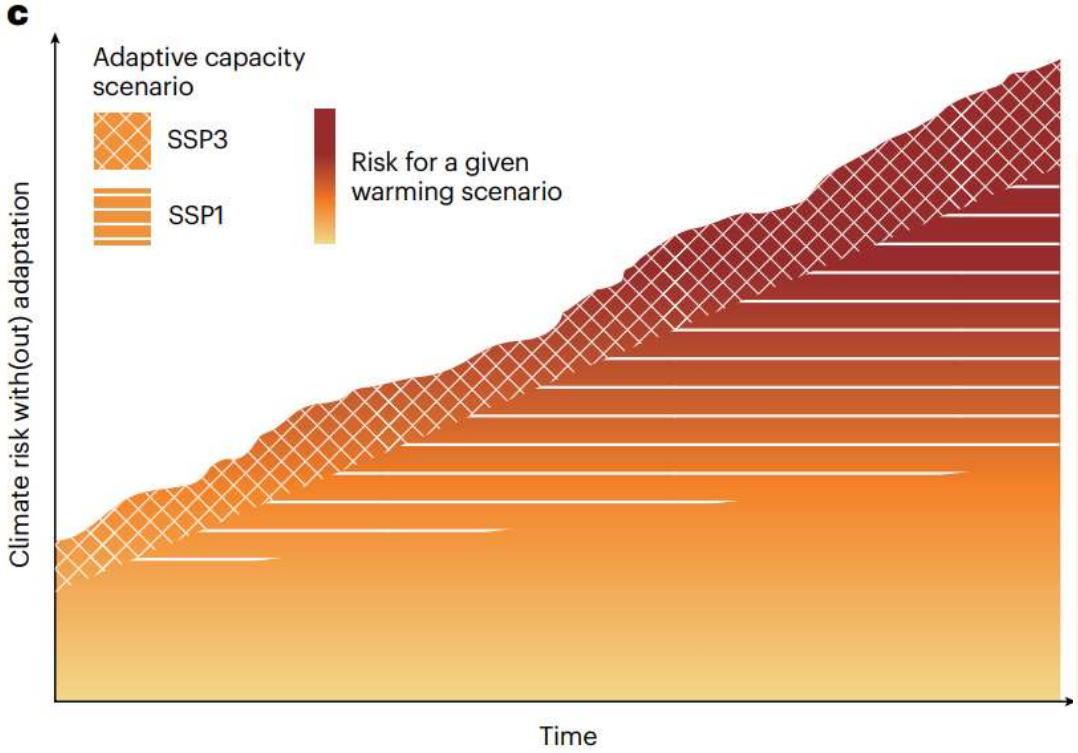
# Implications for loss and damage?




- Could this help to assess loss and damage?
- Can limits to adaptation be established through limited adaptive capacity?



Andrijevic, M., Schleussner, CF., Crespo Cuaresma, J. *et al.* Towards scenario representation of adaptive capacity for global climate change assessments. *Nat. Clim. Chang.* **13**, 778–787 (2023).

# Summary

- In climate impact models (CIMs) and integrated assessment models (IAMs) adaptation tends to be represented in a highly stylized way (e.g., maximum response vs none)
- Difficult, complex, contextual – but also **little out there** that these models could use
- Adaptive capacity can be projected and linked to a portfolio of adaptation options for a more realistic representation
- Further advances in incorporating pathway logic for adaptation needed in CIMs and IAMs

# Equity-relevant research questions

- Level and distribution of:
  - adaptation needs
  - adaptation costs
  - adaptive capacity
- Risks of maladaptation
- Emergence and distribution of limits to adaptation
- Integrated understanding of adaptation, mitigation and residual impacts

# Selection of useful reading


De Bruin, K., Dellink, R., Tol, R., 2009. AD-DICE: an implementation of adaptation in the DICE model. Climatic Change 95, 63–81.

De Bruin, K. C., & Dellink, R. B. (2011). How harmful are restrictions on adapting to climate change?. *Global Environmental Change*, *21*(1), 34-45.

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Füssel, H. M. (2010). Modeling impacts and adaptation in global IAMs. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(2), 288-303.

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# Thanks for listening!

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