Integrating climate change impacts into process-based IAMs

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18 October 2024

NTNU course: Integrated Assessment Modelling (EP8900)

Climate impacts integration: Water-Energy-Land Nexus

Based on material by Adriano Vinca, Muhammad Awais, Edward Byers

Climate impacts & SDGs in MESSAGEix-GLOBIOM

AIM: To improve the representation of the nexus between water, energy, land and climate to identify realistic pathways that can achieve the goal to limit warming to 1.5/2°C and simultaneously other sustainable development goals

- Combination of physical and socioeconomic spatial datasets and models are used to:
  - ⇒ Understand changes in heating & cooling *access, gaps* and *demands* on energy sector (CHILLED+STURM => MESSAGEix-Buildings module)
  - ⇒ Represent changes in resource *potentials* & *availability*, incorporating assumptions about reliability and environmental protection, e.g.
  - ⇒ Water availability for key sectors: Agriculture + irrigation, municipal, industrial, energy, with environmental flow requirements.
    - ⇒ Cooling water availability on thermal power
    - ⇒ Hydro, solar and wind power potentials
    - ⇒ Biomass potentials & crop yields; including protected lands and healthy diets

Not included:
- economic damages

To develop scenarios that

- incorporate mitigation policy, climate impacts and representation of nexus-SDGs, + associated synergies and trade-offs
- Quantify investments required with regional and sectoral granularity

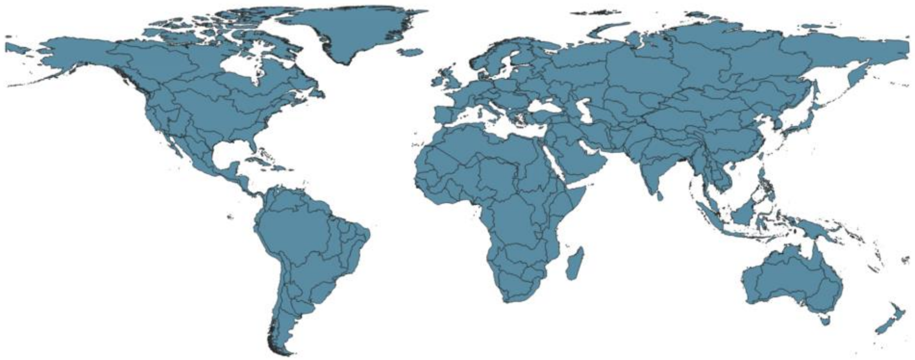
Model Architecture

Water System

- Water availibility
- Sectoral water demands
- Supply & distribution
- Water table depths for GW

Harmonization & upscaling

Water Sector
~202 regions/basins



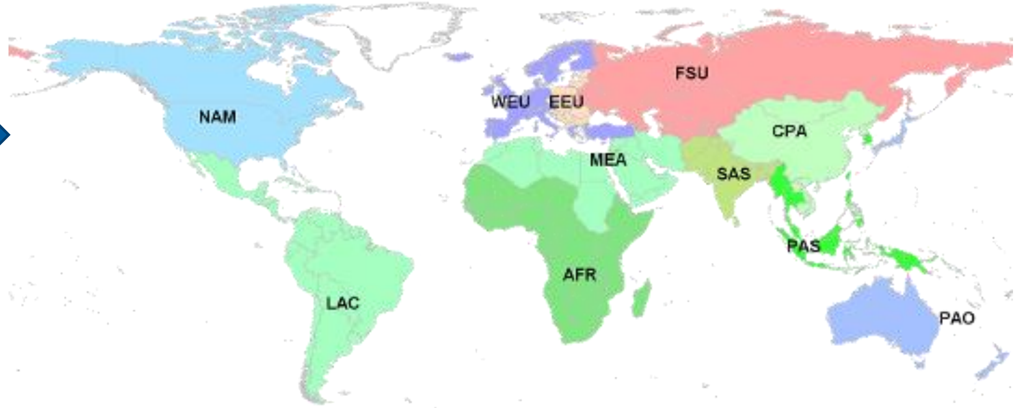
Land System

- Irrigation water
- Crop efficiency
- Crop types
- Biomass trajectories

GLOBIOM emulator

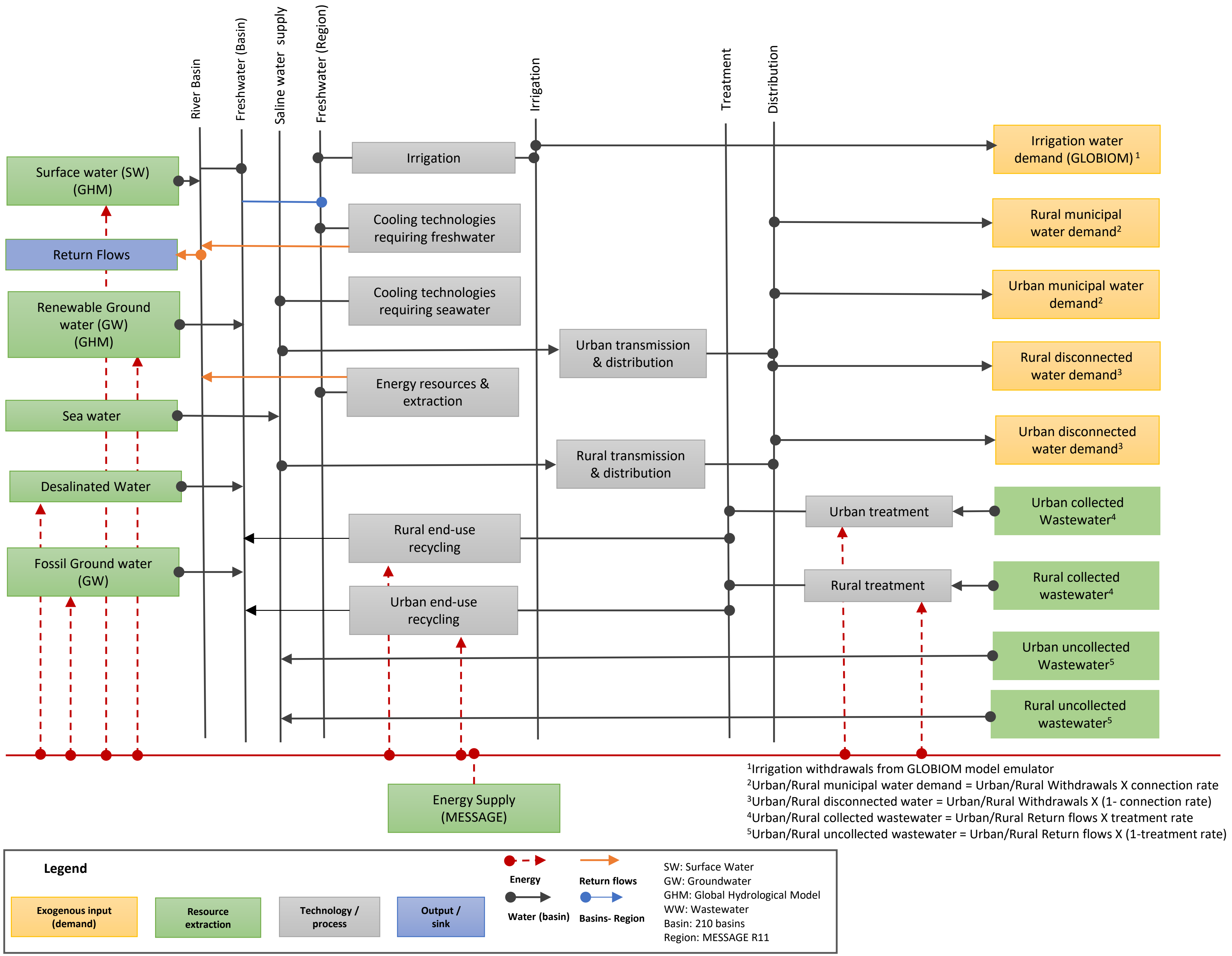
Energy Sector
11 or 12 region

water <->energy, land sector



*ISIMIP Output data from Global Hydrological Models - https://www.isimip.org/
**GLOBIOM – Global Biospehere Management model – https://iiasa.github.io/GLOBIOM/

Reference water system



Approach: MESSAGEix-GLOBIOM IAM

Climate policy

2.6 W/m^2 target

SDG measures

Food	Heathy (EAT-Lancet) diet, reduce food waste
Water	Efficiency improvements, environmental flow constraints, piped water access, wastewater treatment
Energy	Maximized electrification, phase-out trad biomass, cooling gap
Life on land	Protected natural land (>30%)

Based on: Doelman et al. 2022, MESSAGE-ACCESS, Van Vuuren et al., 2019, Parkinson et al., 2019, Frank et al., 2021, Hasegawa et al., 2015, Pastor et al., 2019

Climate impacts

RCP 2.6, 6.0

- Hydrology: Precipitation pattern/runoff, groundwater intensity
- Crop Yield changes
- Renewable energy
- Cooling/heating demand
- Desalination potential
- Power plant cooling capacity

Based on: *ISIMIP 2b (Frieler et al. 2017),Byers et al., 2018, Gernaat et al., 2021 etc.)*

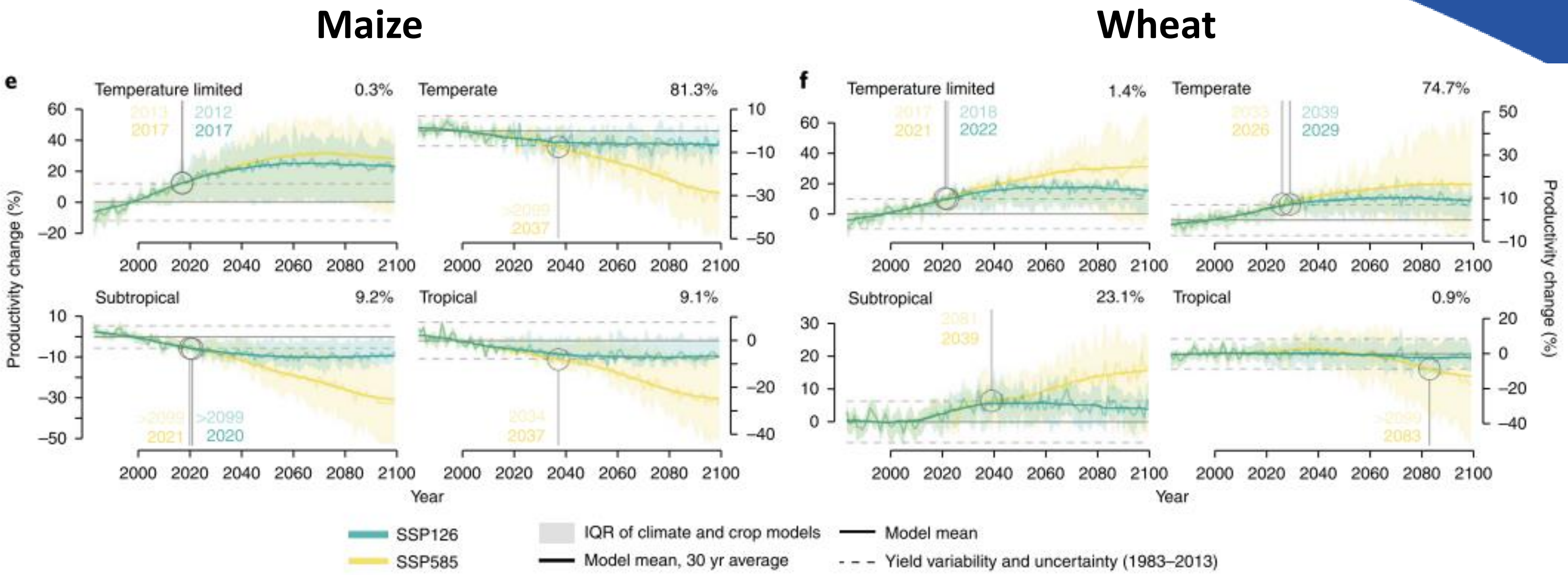
Climate Feedback: Crop yields

Some regions will gain yield, other will have yield losses.

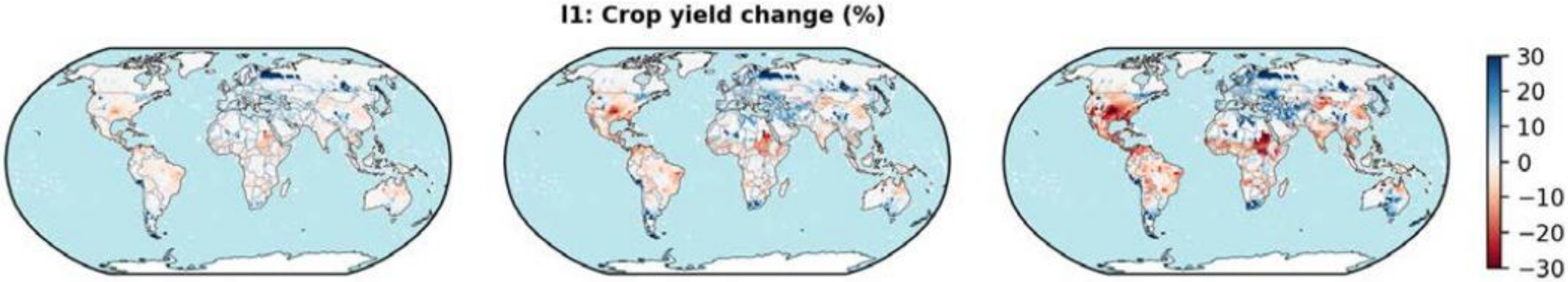
EPIC crop model (ISIMIP, LPJmL input) → MESSAGEix-GLOBIOM

Adaptation options include crop shift, irrigation vs rainfed

Responses to meet SDG 2 (diet), 15 crop choices and SDG6 (env flow)



Regional productivity time series for maize (e) and wheat (f) stratified for the four major Koeppen–Geiger climate zones (temperature limited, temperate/humid, subtropical and tropical). From Jägermeyr et al., 2021, *Nature Food*



Crop yields change 1.5, 2.0 and 3.0°C GMT change (left to right), from Byers et al. 2018, *ERL*

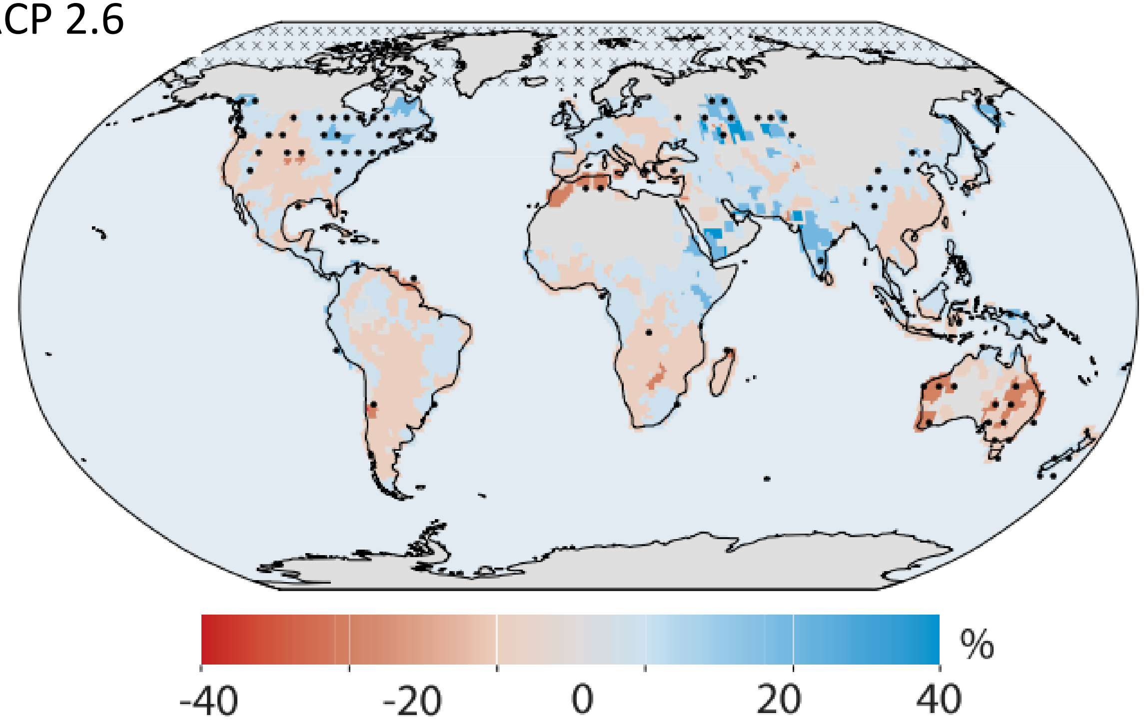
Climate Feedback: Hydropower potential

Some regions benefit, some regions show declining potential

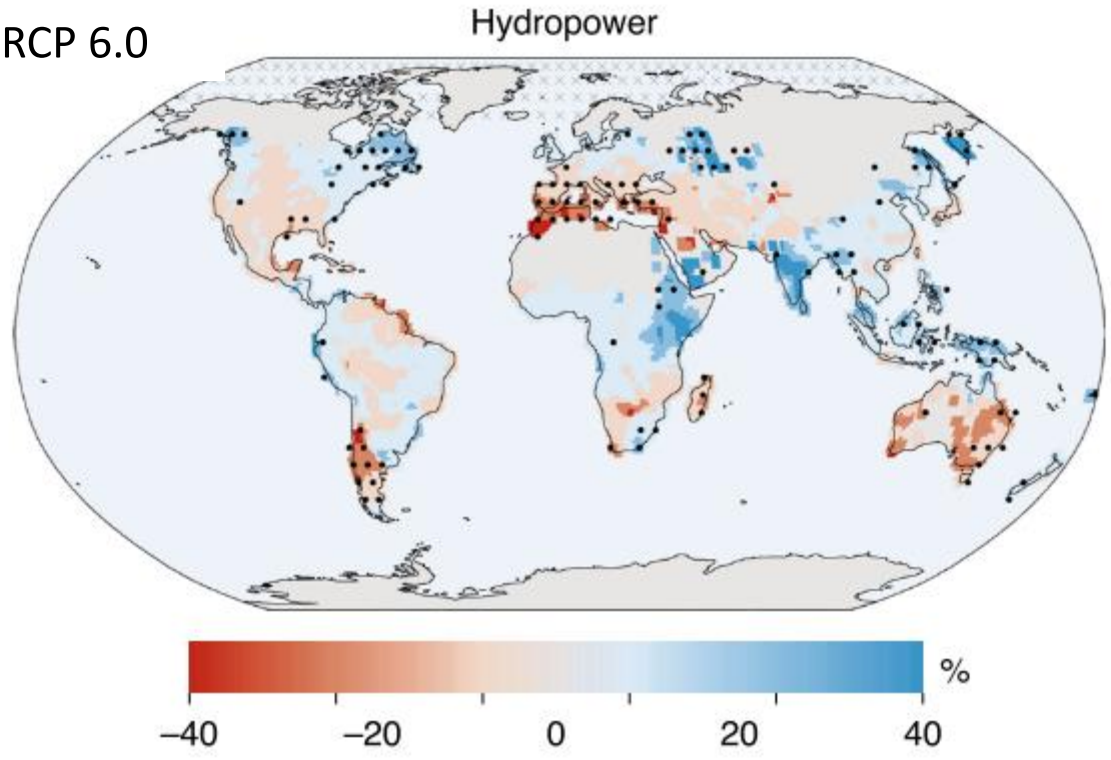
Adaptation→ expand hydro switch to other energy sources

SDG→ Both benefits and trade-off with SDG 7 and SDG 13

RCP 2.6



RCP 6.0



The differences in the multi-model mean (over GCMs GFLD-ESM2M, HadGEM2-ES, IPSL-CM5A-LR and MIROC5) of the historical period (1970–2000) compared with the future period (2070–2100). **Gernaat et al., 2021** ***Nature Climate Change***

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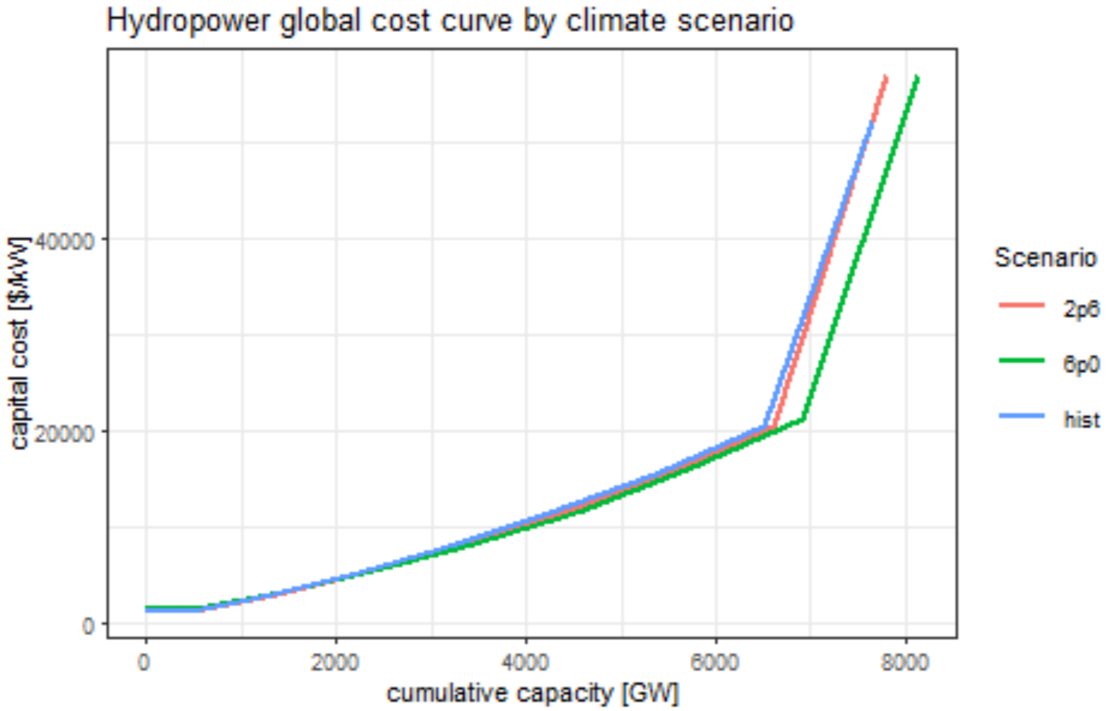

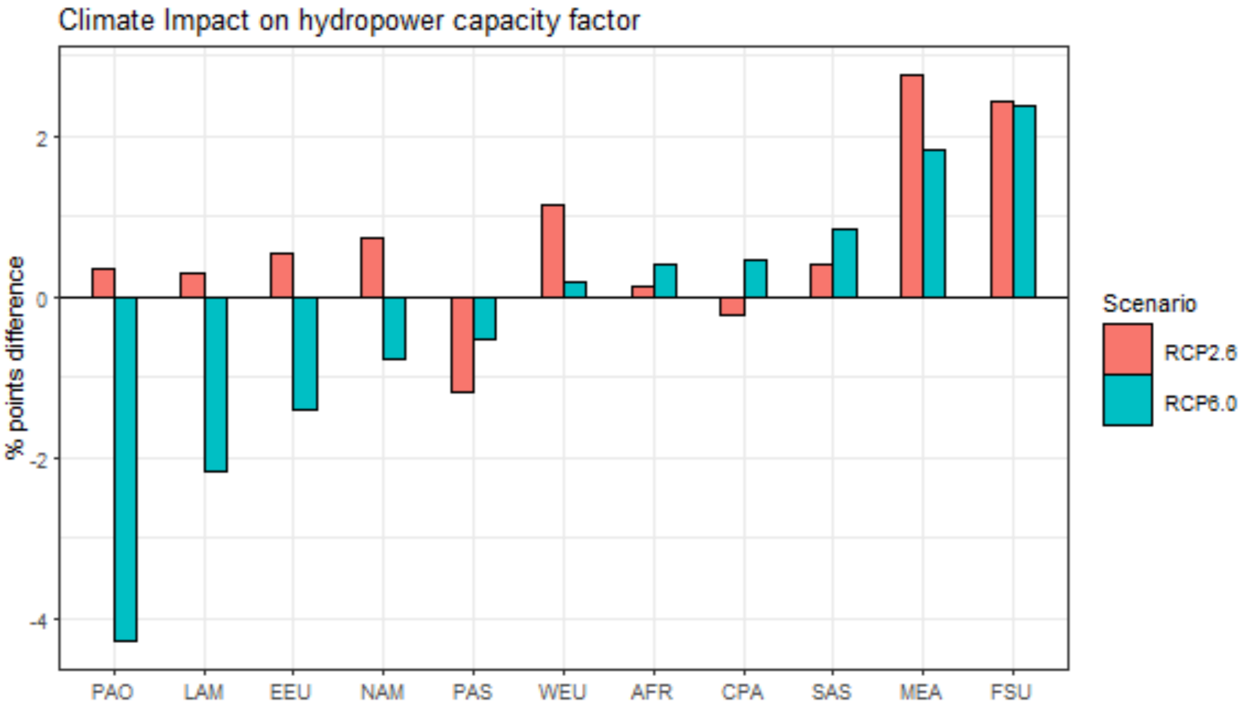

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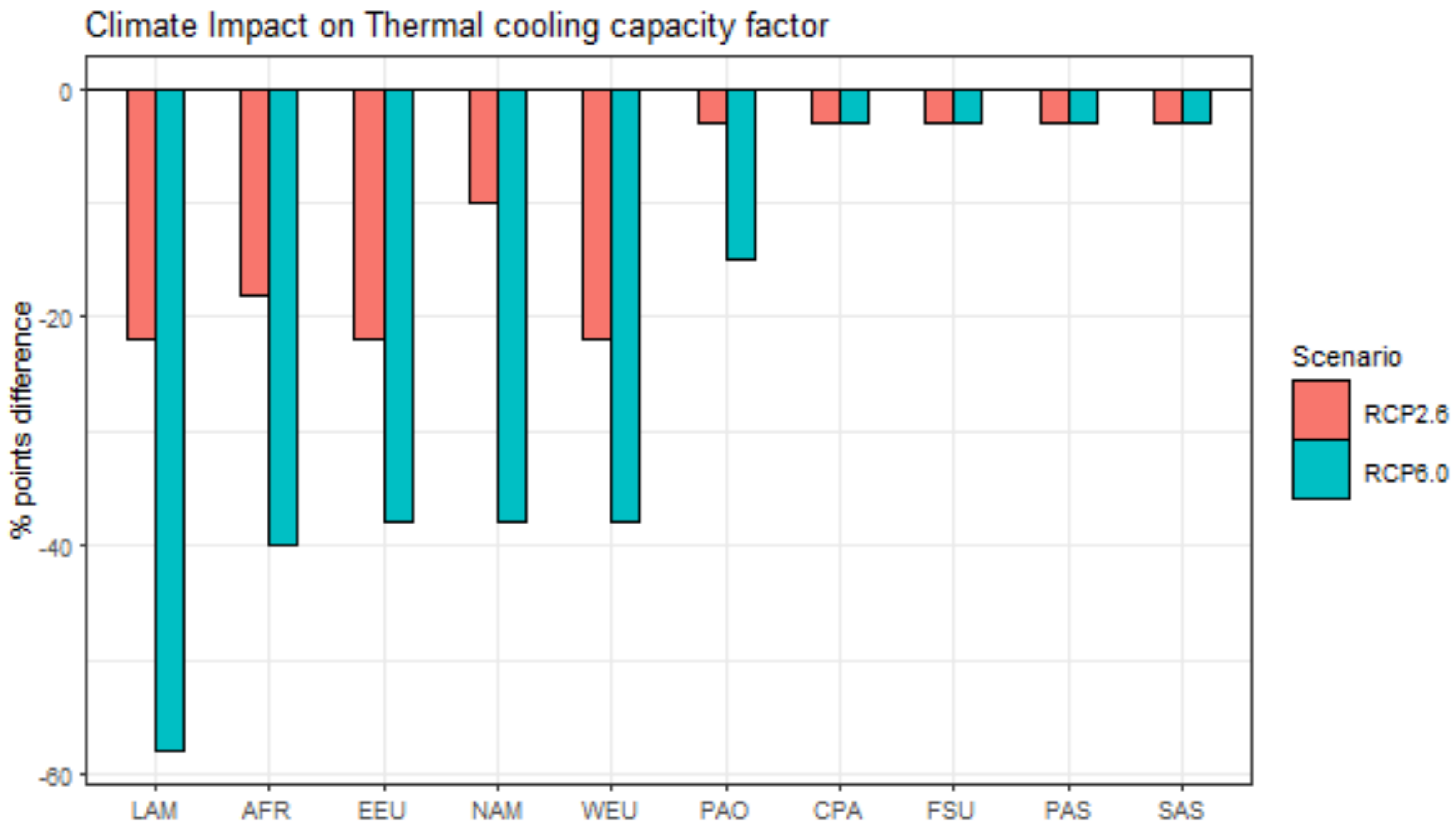
Climate Feedback: Thermal power plant cooling

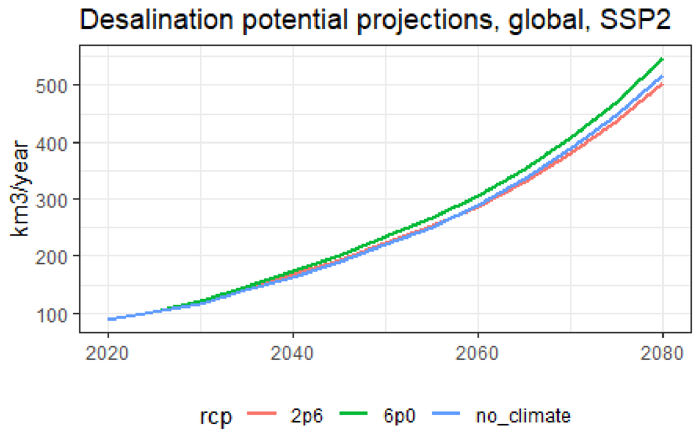
Cooling capacity factor reductions from van Vliet et al. (2021) water availability and thermal pollution

Adaptation→ dry and sea cooling, non-thermal power production

SDG→ Impacts on SDG 6 water withdrawals and SDG 7, 13 Thermal power plants' reliability



Climate Feedback: Desalination potential



Desalination potential depends on governance capacity and water stress

- Regression analysis: log_desal ~ log_gdp + gov + log_wsi + log_coast
- Increased desalination need/potential

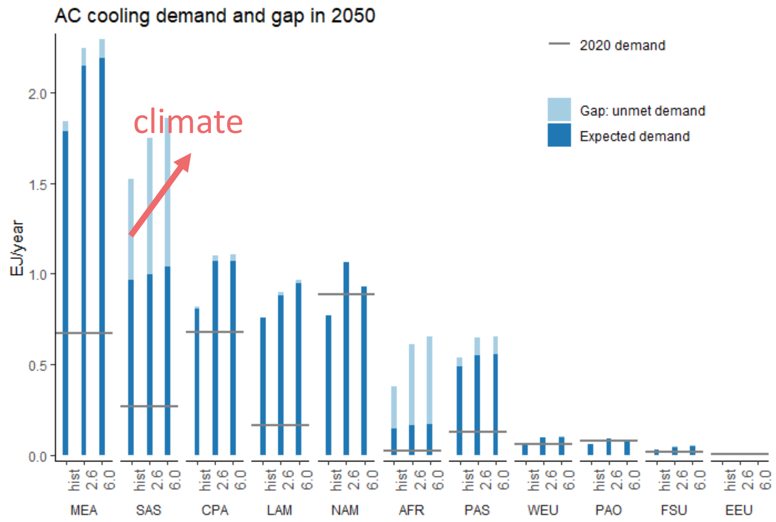
SDG→ Small variations across climate, impacts on SDG 6 costs

Adaptation→ Desalination itself, other water sources

Climate Feedback: AC cooling demand and gap

Cooling demand is likely to increase. South Asia and Africa have large % of population with not adequate cooling (Gap: unmet demand). Different climate affects GMT and CDD

SDG→ interactions with SDG 7, energy access, higher energy requirements for RCP 6.0



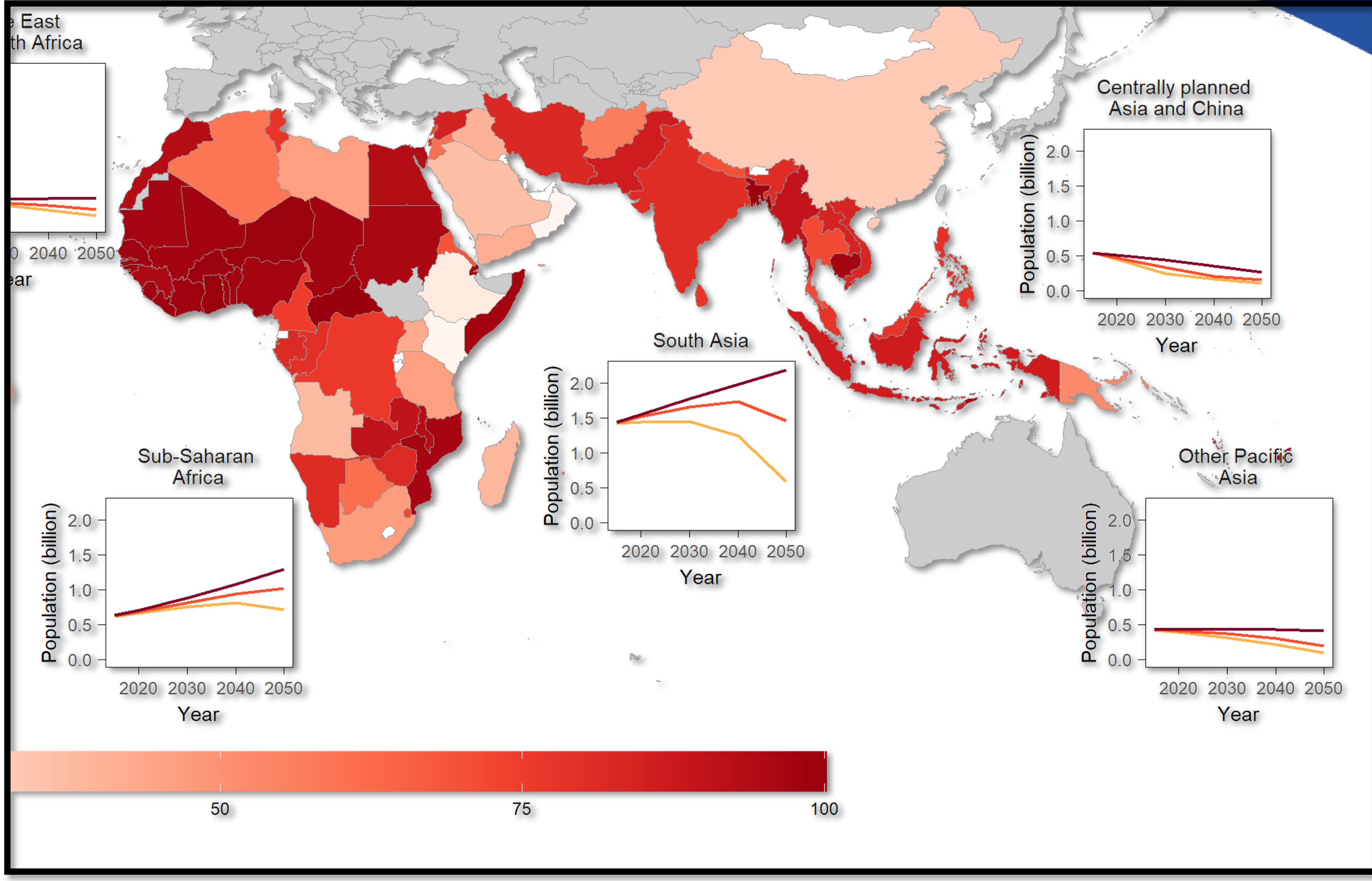
SSP2 projections from Mastrucci et al. 2021, Climatic Change

Drivers of cooling access

- Population growth
- Affluence & electricity connections
- Warming climate

Yet – in South Asia and SSA population may grow faster than affluence

Growing number of people exposed to heat stress, irrespective of climate change



Source: Mastrucci et al. 2022

Flexible emulation of the climate warming cooling feedback to globally assess the maladaptation implications of future air conditioning use

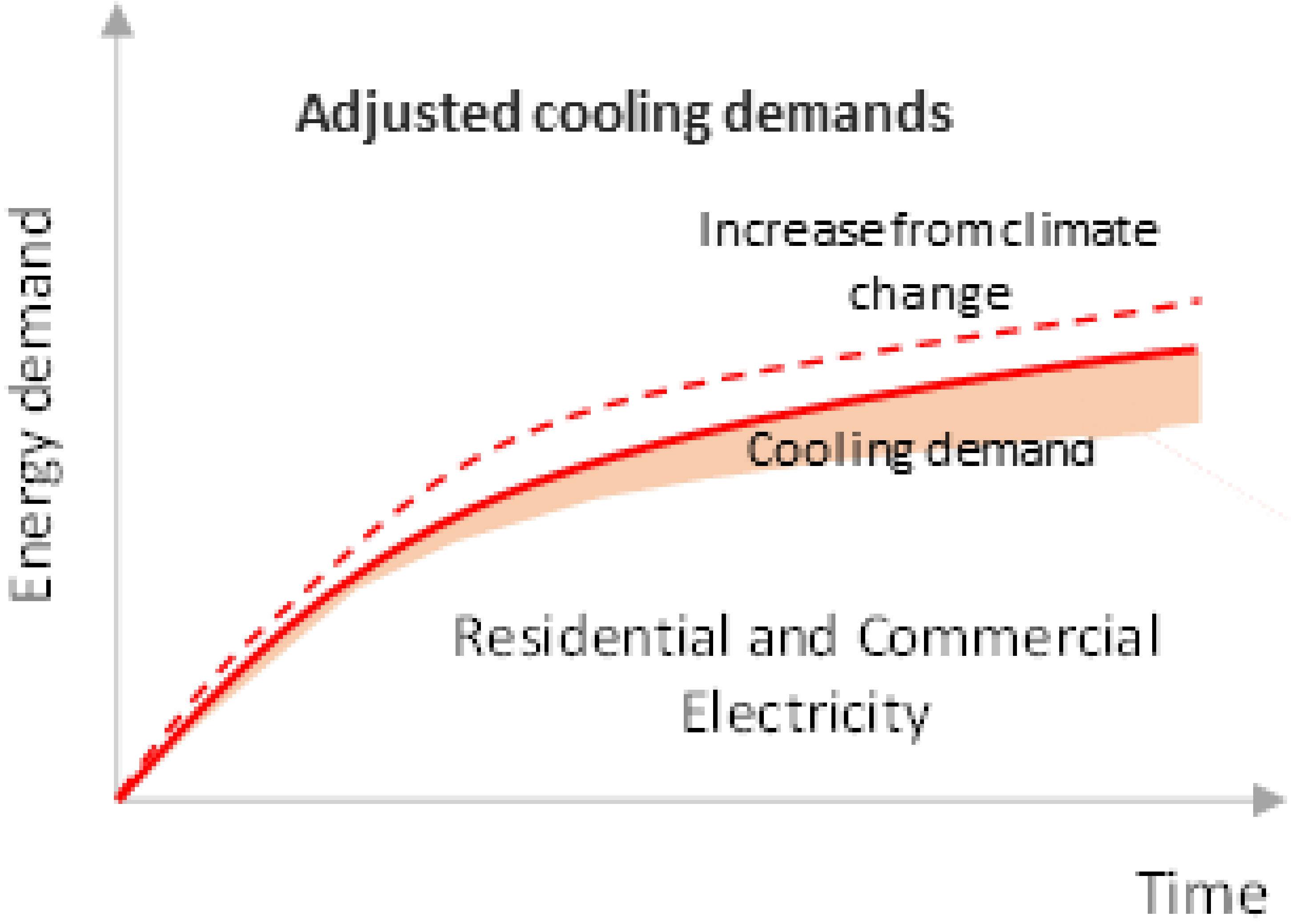
Energy, Climate, and Environment (ECE) Program

Flexible emulation of the climate warming cooling feedback to globally assess the maladaptation implications of future air conditioning use

Based on material by Edward Byers, Measrainsey Meng, Alessio Mastrucci

Byers et al. (2024)

How does cooling demand increase in an IAM scenario?

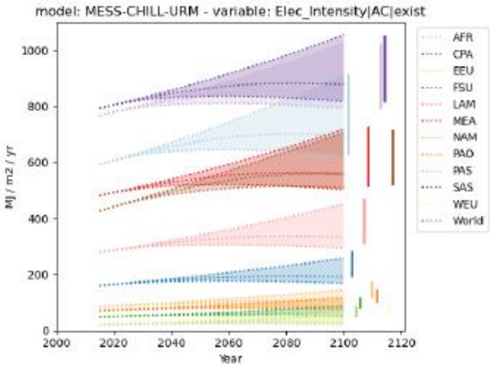


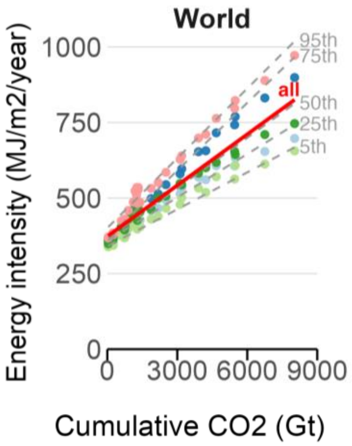
Cooling energy impact model emulation

Applied to **CHILLED-STURM-MESSAGEix**

CHILLED

Global gridded building energy demand model based on Variable Degree Days, and incorporating climate projections



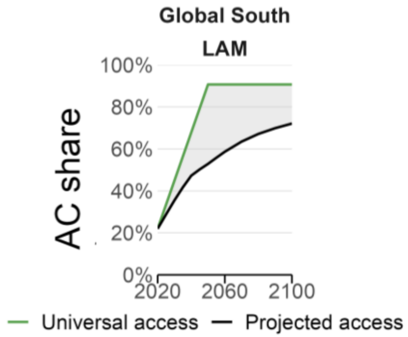


3 SSPs x 5 GCMs
= 15 pathways

+

STURM

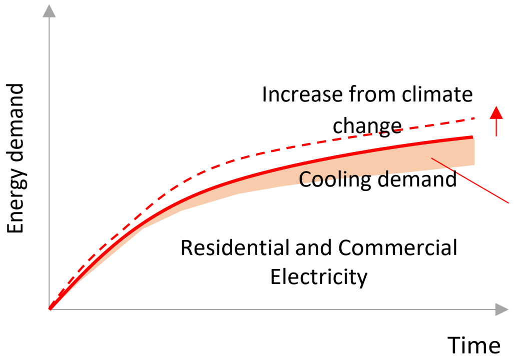
Scenario-specific building stock characteristics, AC access, and behaviour of building occupants



→

MESSAGEix

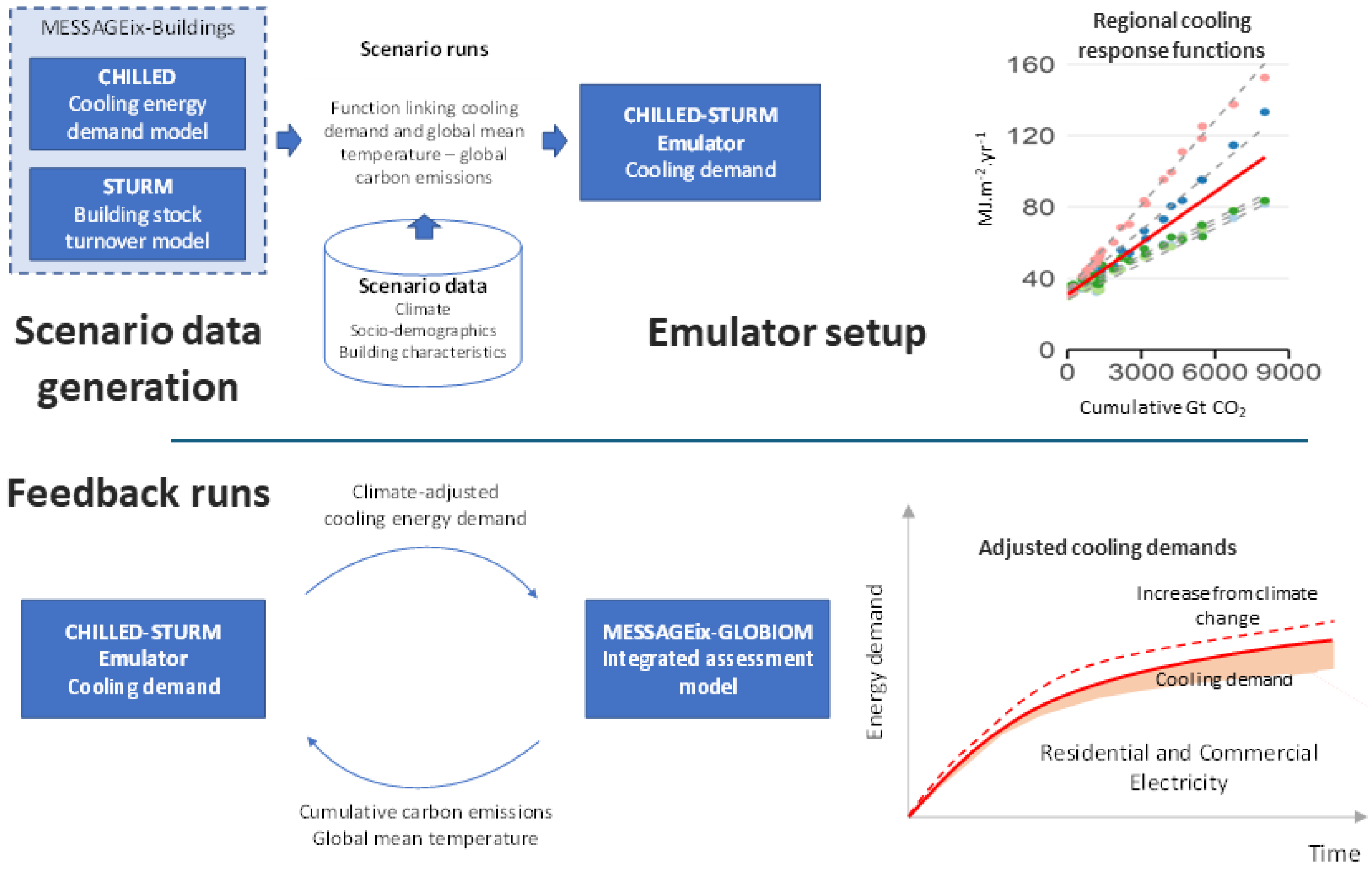
Adjust electricity demand of different carbon mitigation scenarios



Byers et al. (2024)

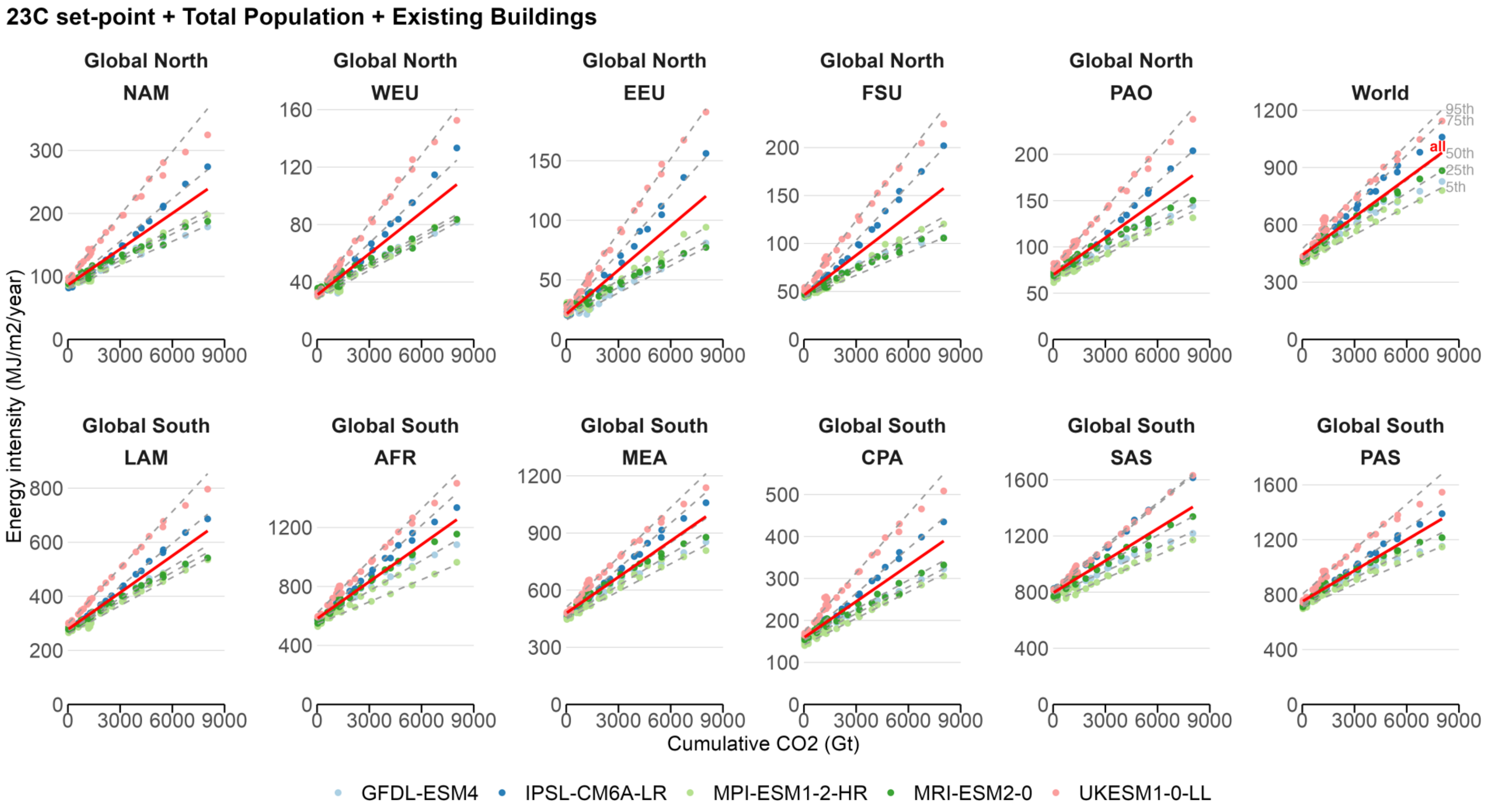
Framework setup

- Modeling framework that links together general circulation models, climate impacts models and integrated assessment models.
- The framework…
  - Uses scenario-specific statistically-derived cooling response functions from **CHILLED** and…
  - Building stock characteristics, AC access, and behaviour of building occupants from **STURM**…
  - To calculate changes in energy demand due to cooling needs, which are used to model energy usage, emissions, carbon prices, and more in **MESSAGEix**.



CHILLED linear response functions

- Ensemble:
- 5 ISIMIP3b GCMs
- 3 CMIP6 SSP-RCP pathways: Baseline + SSP1-26, SSP3-70, SSP5-85

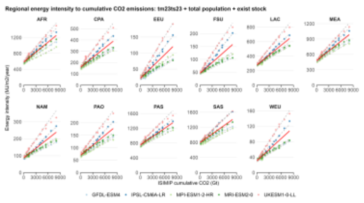


Feedback runs

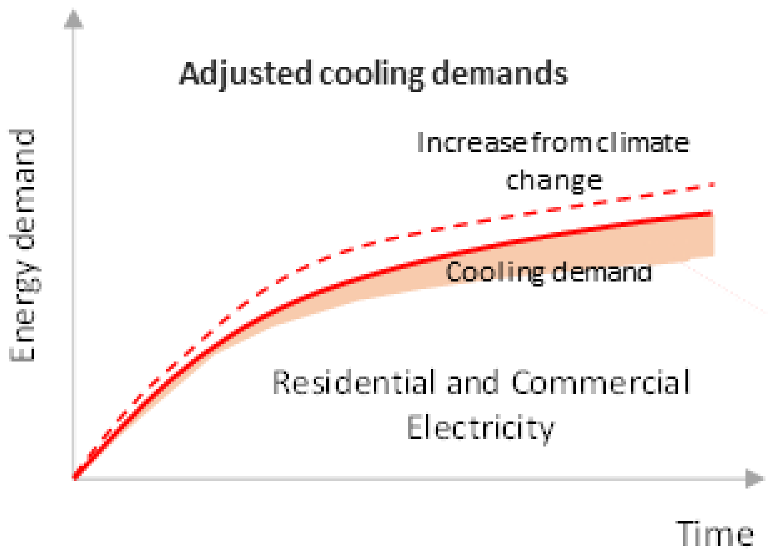
Climate-adjusted cooling energy demand

CHILLED-STURM Emulator Cooling demand

MESSAGEix-GLOBIOM Integrated assessment model



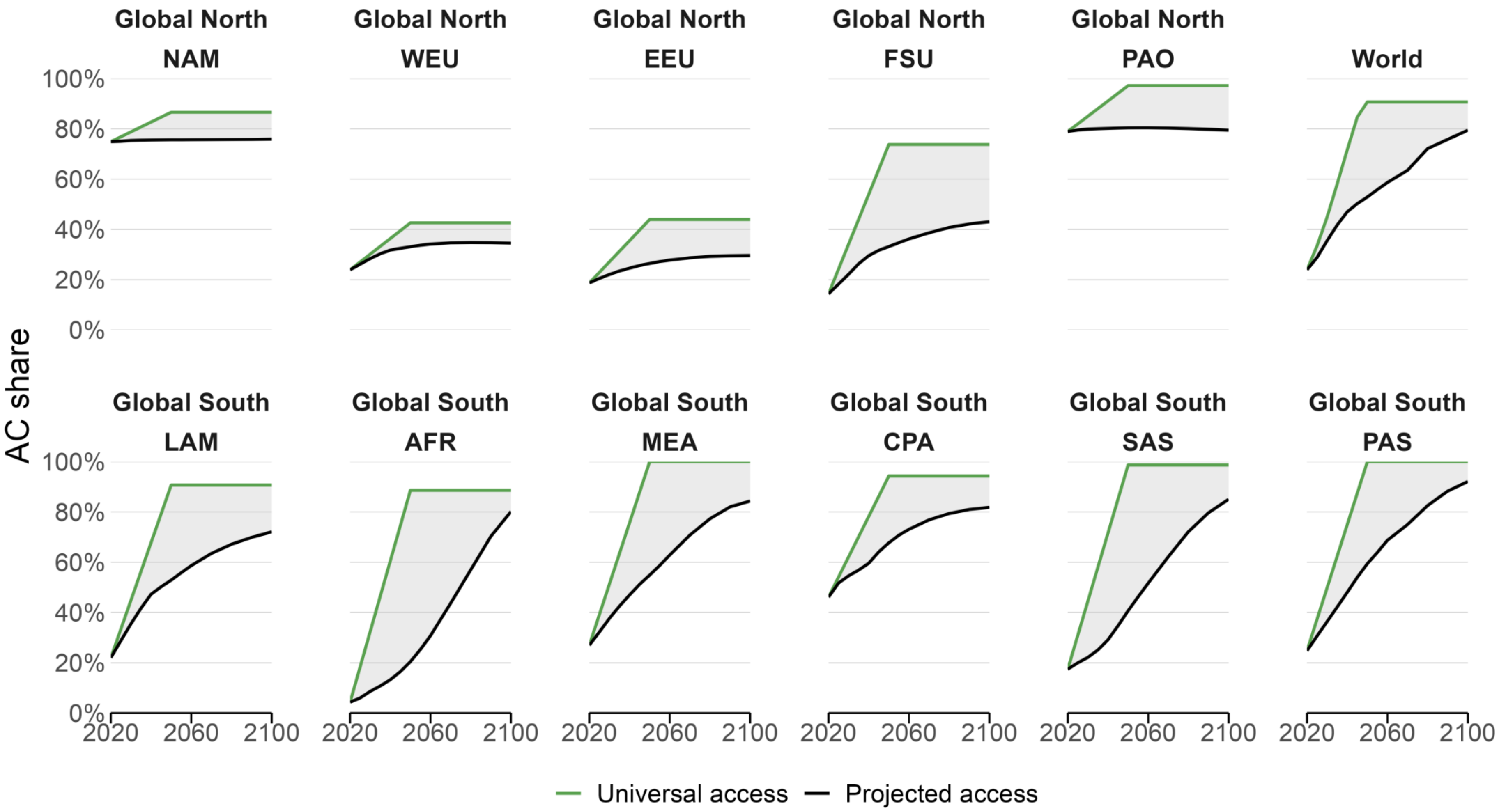
Cumulative carbon emissions
Global mean temperature



Dimension	Scenario	Climate policies	Climate percentile[1]	Set-point temp. [1] (°C)	Level of AC access [2]
Impacts of climate change	Default	NPi, 2 °C, 1.5 °C	50th	23	Projected
	No climate change	NPi, 2 °C, 1.5 °C	N/A	N/A	N/A
	Climate model uncertainty	NPi, 2 °C, 1.5 °C	5th, 95th	23	Projected
Behaviour and Adaptation	High set-point	NPi, 2 °C, 1.5 °C	50th	26	Projected
	Decent living	NPi, 2 °C, 1.5 °C	50th	23	Universal by 2050
	Decent living - High set-point	NPi, 2 °C, 1.5 °C	50th	26	Universal by 2050

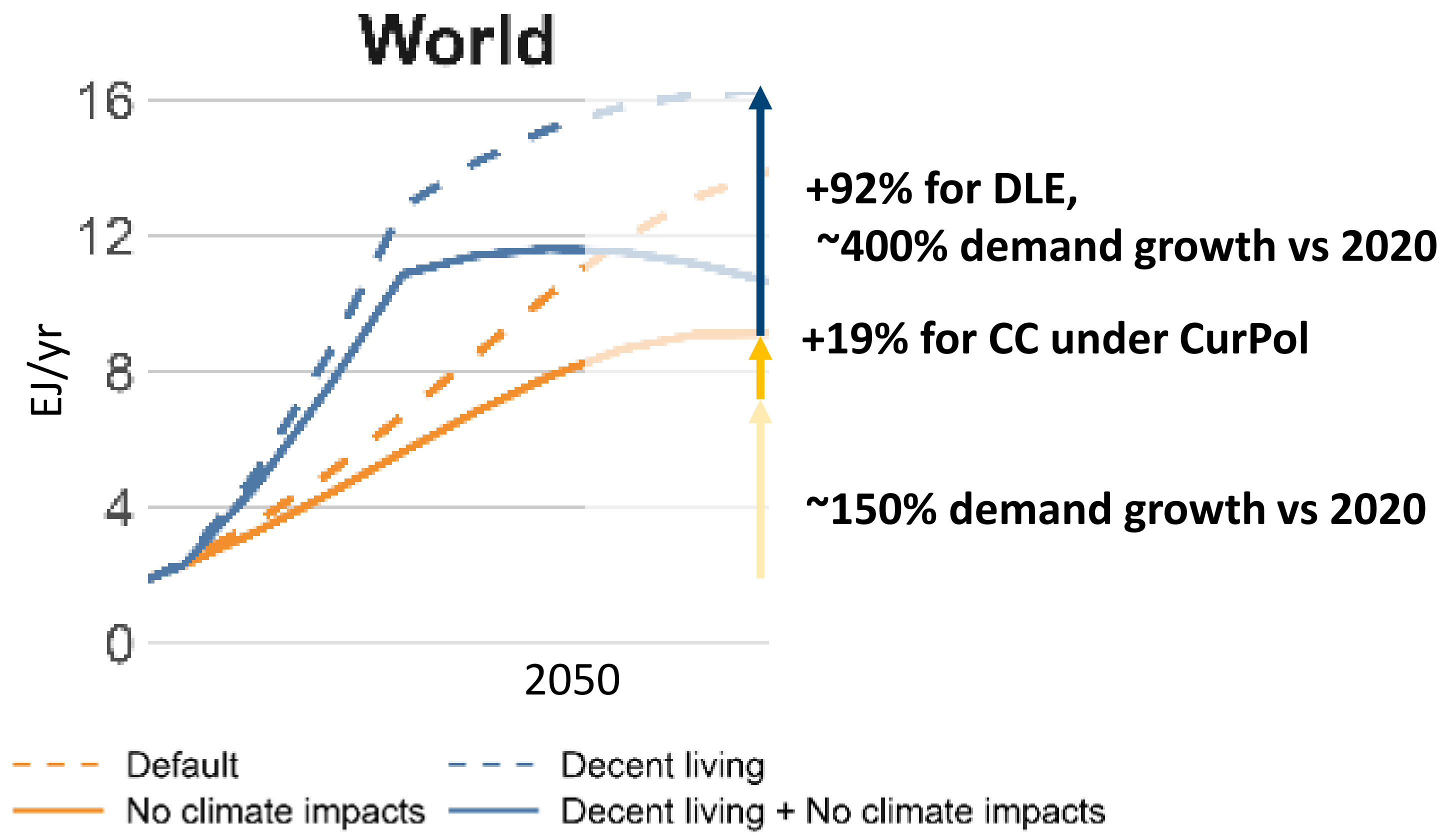
Projected vs. Decent Living AC access

- **Projected access** assumes rising incomes (GDP/cap) increases access and use of AC
- **Decent Living** assumes all those who need AC have access by 2050



World is the median of all regions

Residential AC electricity demand (EJ/yr) in 2050



Compared to 2020

Most demand growth driven by rising incomes, ~+150%

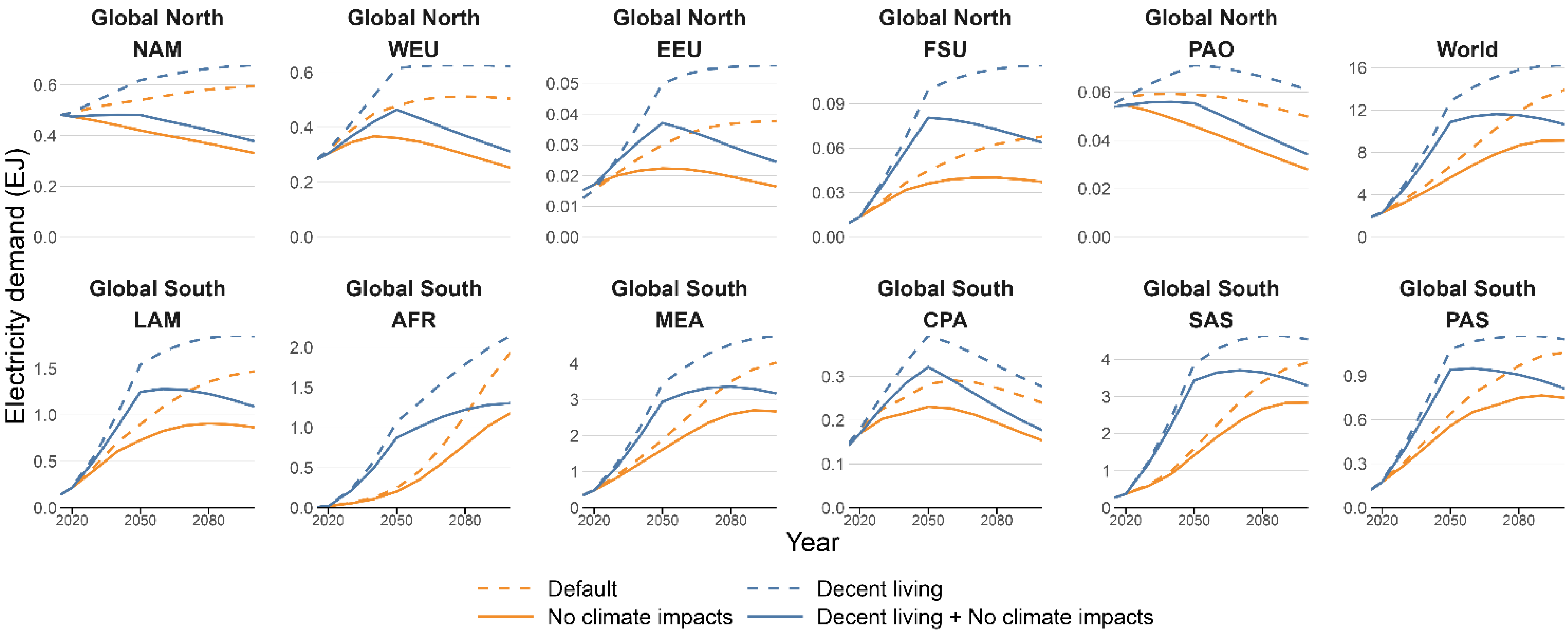
Compared to 2050

Climate change in 2050, adds ~10-20%

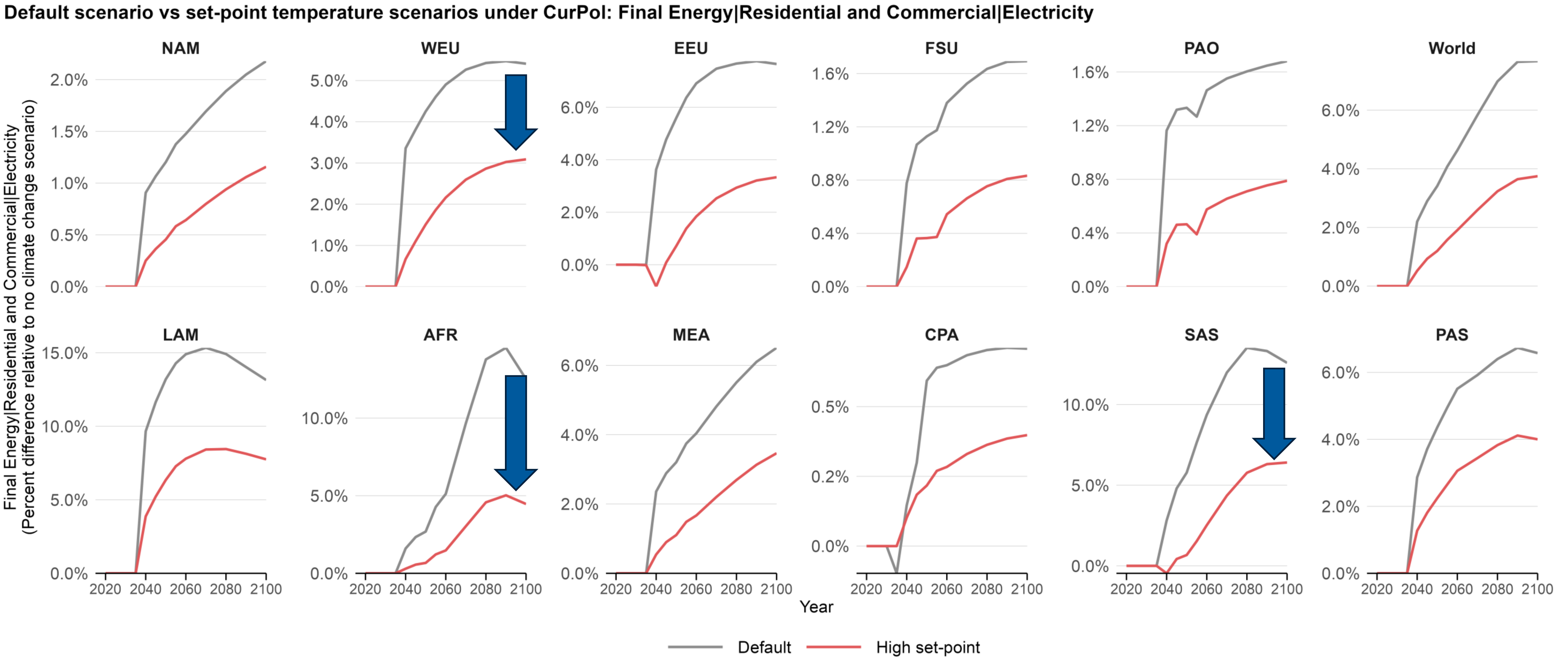
Universal Access (DLE) almost doubles

Residential AC electricity demand

AC electricity demand for the Residential sector under CurPol climate scenario and 23 °C set-point



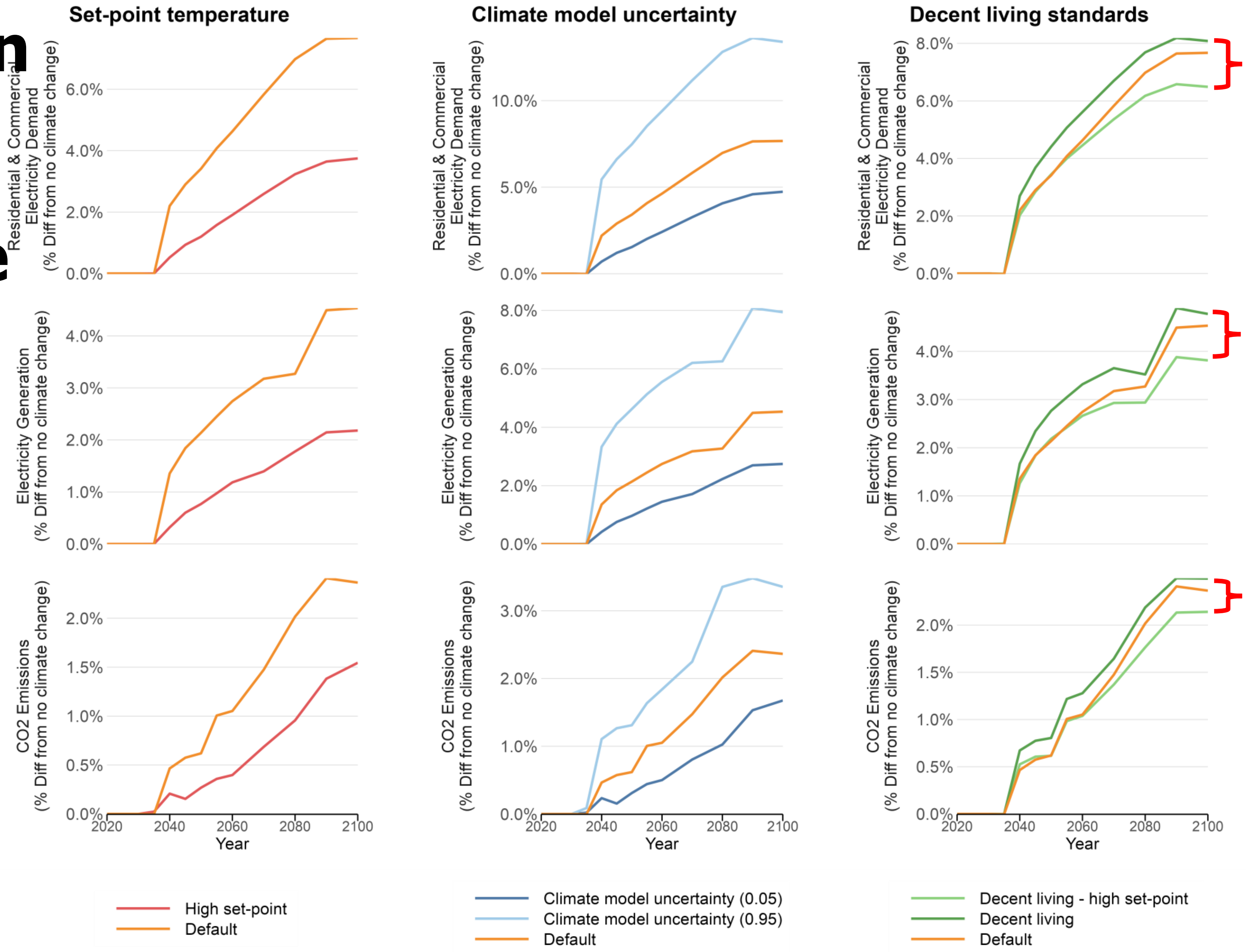
Set-point temperature, 23 vs 26 °C – Res. & Commercial



Increasing set-point from 23 to 26, more than halves the growth in demand (in CurPol). Majority of savings come from Commerical sector.

Dynamics between decent living standards and set point temperature

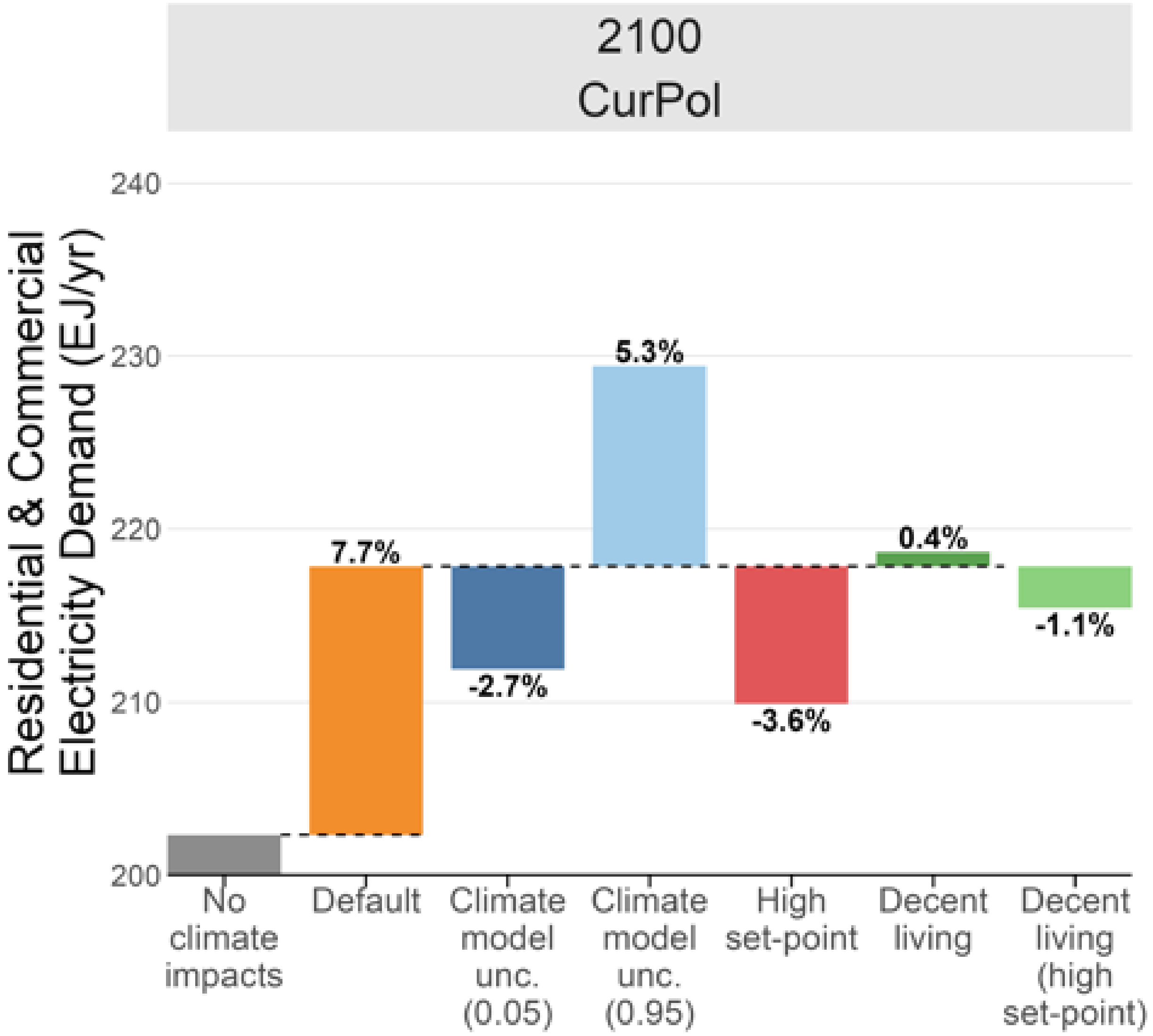
Reductions from higher set-point temperature roughly offset the additional energy required by providing DL access under the current policy scenario.



Global results under Current Policy scenario

Sensitivity in Res & Comm electricity demand

- More change in CurPol scenario
- Mitigation policy is most influential, then climate impacts



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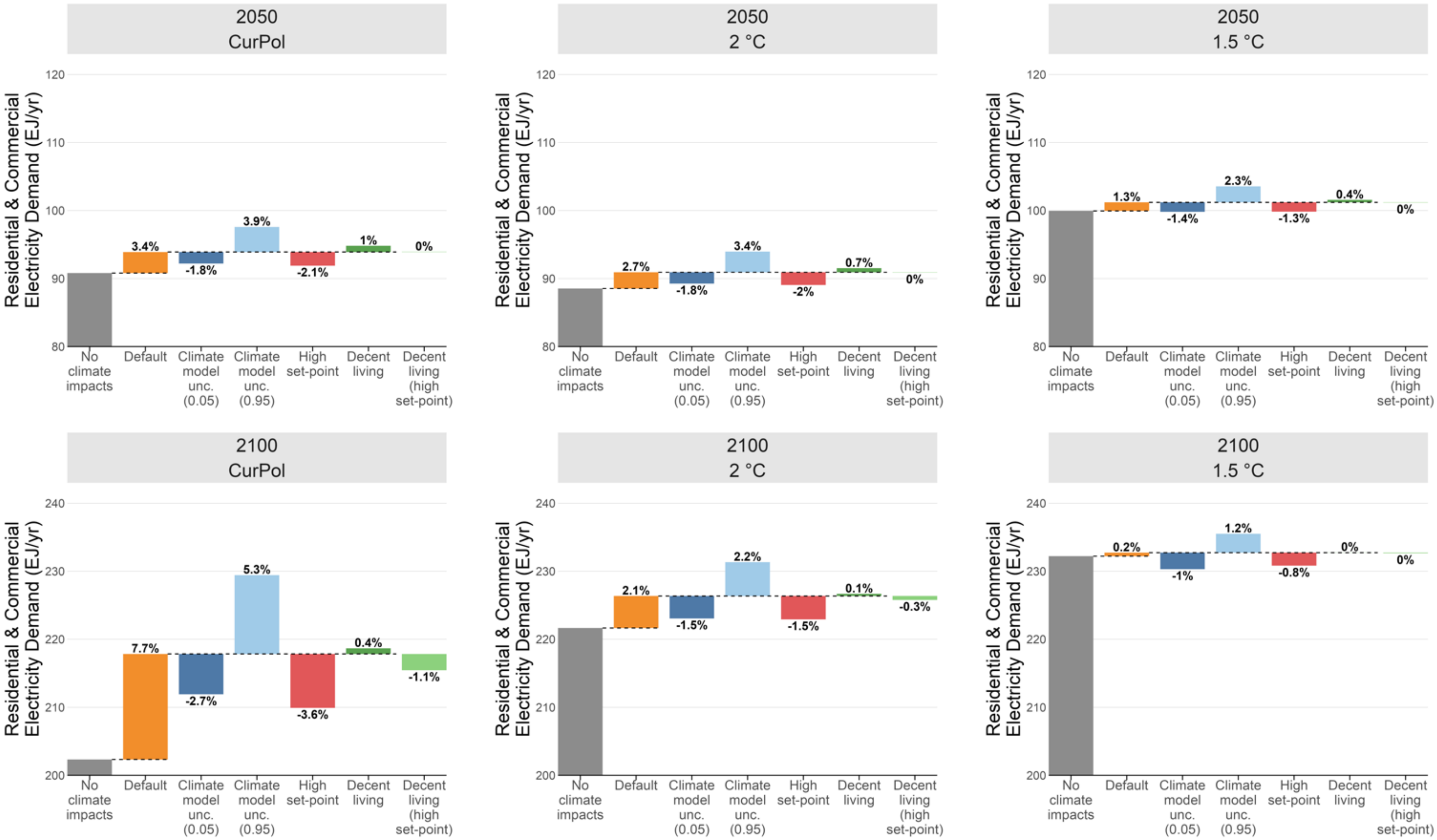

Conclusions

Growing AC access, primarily from rising incomes but also population growth, drive majority of AC energy demand growth

The **climate model uncertainty** has the largest effect on the overall change in electricity demand

Higher set-point temperature offsets the additional energy required by providing DL access

Mitigation policy reduces impact and uncertainty from climate impacts, and reduces the heat-stress burden on most vulnerable

Critical regions

Europe & North America – relatively high changes in temperatures & demand from climate impacts (almost double world average)

South Asia & Africa – huge cooling gap, so largest additional growth in DLE scenario

Thank you very much for your attention!

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