Interaction of Mitigation vs Adaptation Pathways with Environmental Boundaries, Natural Hazards, and Sustainability Objectives Across the Energy, Water and Land Sectors

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Integration of climate impacts in policy analysis

Different approaches:

1. Top-down economic assessments of climate impacts, e.g. damage functions, SCC

2. Sectoral assessment of biophysical impacts: eg, crop yields and food production, power plant capacity and cooling potential, energy poverty due to heat

3. Multi-sectoral approach assessing economic implications and feedbacks across sectors: water, energy, land policy analysis with Integrated Assessment Model (MESSAGEix-GLOBIOM).

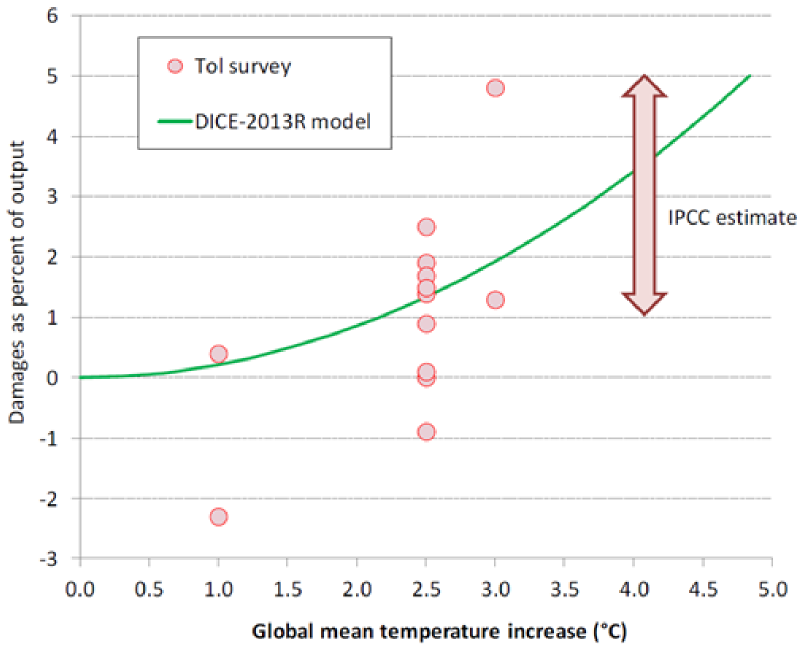

Figure 2. Estimates of the Impact of Climate Change on the Global Economy
This figure shows a compilation of studies of the aggregate impacts or damages of global warming for each level of temperature increase (dots are from Tol 2009). The solid line is the estimate from the DICE-2013R model. The arrow is from the IPCC (2007a). [impacts_survey.xlsx]

Multiple sectors and multiple policy objectives

Climate policy

2.6 W/m² 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 traditional bio, 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.)*

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Climate impacts considered

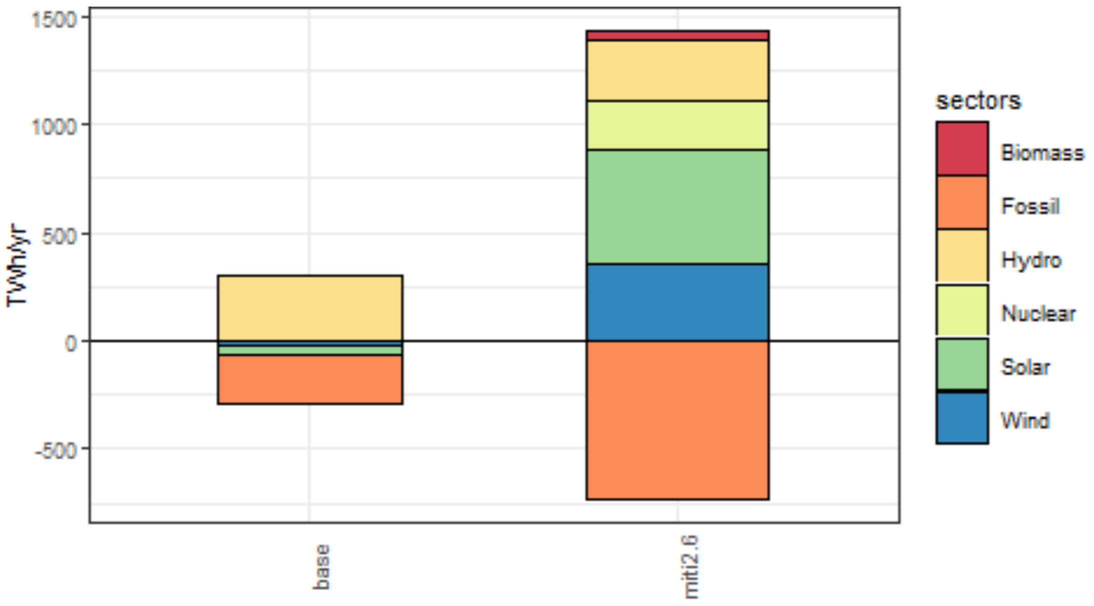
- Hydrology: Precipitation pattern/runoff, groundwater intensity
  (LPJmL, ISIMIP2b)
- Crop Yield changes
  (EPIC model, Jägermeyr et al., 2021)
- Renewable energy potential
  (Gernaat et al., 2021 Nature Climate Change)
- Cooling/heating demand
  (Mastrucci et al., 2021, Climatic Change)
- Power plant cooling capacity
  (van Vliet et al., 2016, Nature Climate Change)

Limitations & challenges:

- **Understanding causalities in complex systems**
- **Spatial and temporal scale**
- **Uncertainty from different sources**

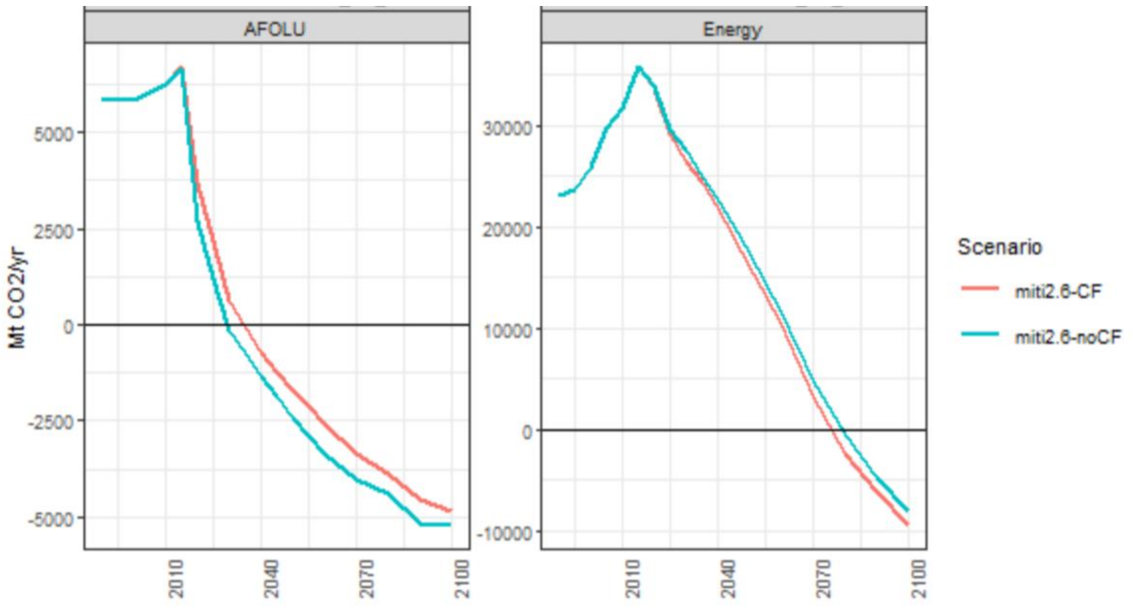
Climate Feedbacks: Electricity mix and CO_2 emissions

Change in electricity generation due to climate feedbacks (avg 2030-2080)



Acceleration of the phase-out of fossil fuels in power generation

CO_2 emissions with and without climate feedbacks



In mitigation pathways:

- Slightly higher CO_2 prices (8%)
- Little impact though on overall CO_2 emissions

Energy poverty: the cooling gap

12 000 estimated annual deaths from heat waves

WHO, 2014

68% world population projected to live in urban areas by 2050

UN-HABITAT, 2020

8% people in hottest world regions possess air-conditioning (AC)

IEA, 2018

~1 billion people living in slums

UN-HABITAT, 2018

Mitig Adapt Strateg Glob Change (2022) 27:59
https://doi.org/10.1007/s11027-022-10032-7

ORIGINAL PAPER

Check for updates

Cooling access and energy requirements for adaptation to heat stress in megacities

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Photo: Alessio Mastrucci

Cooling gaps scenarios

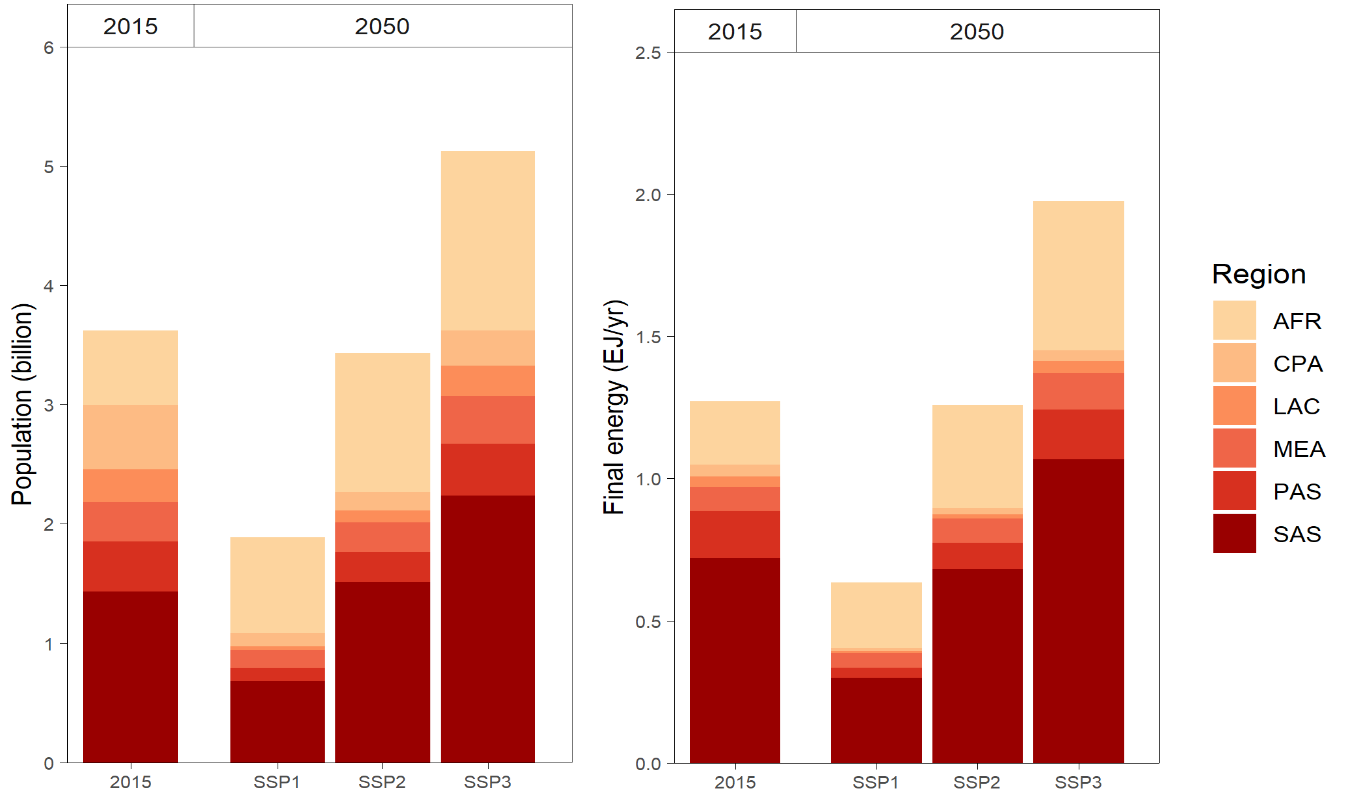
Assess **future cooling gaps** and associated *minimum* energy requirements for megacities in the global South.

Future scenarios:

- Socio-economics: SSP1-3
- Climate futures: 1.5°C, 2.0°C, 3.0°C

Decent living energy thresholds

- Floorspace : $10m^2$/cap (min $30m^2$/household)
- Comfort threshold: 26°C
- AC operation: 4 hours daily



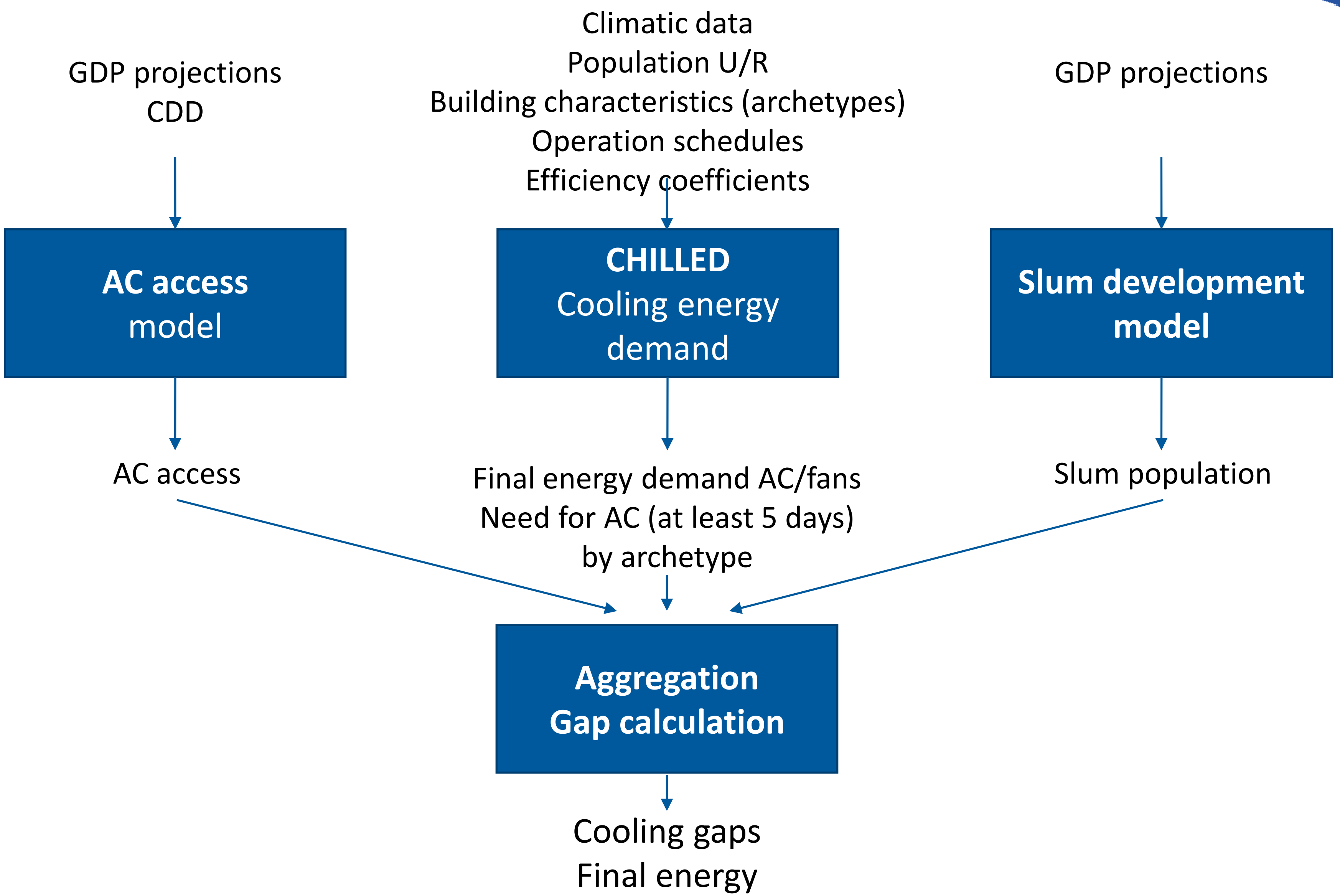
Cooling gaps in 2015 and in 2050 under SSP1-3 in different regions of the global South. Mastrucci et al., 2021

Methods: MESSAGEix-Buildings framework

Climatic data:
EWEMBI – Lange, 2016
Spatially gridded data

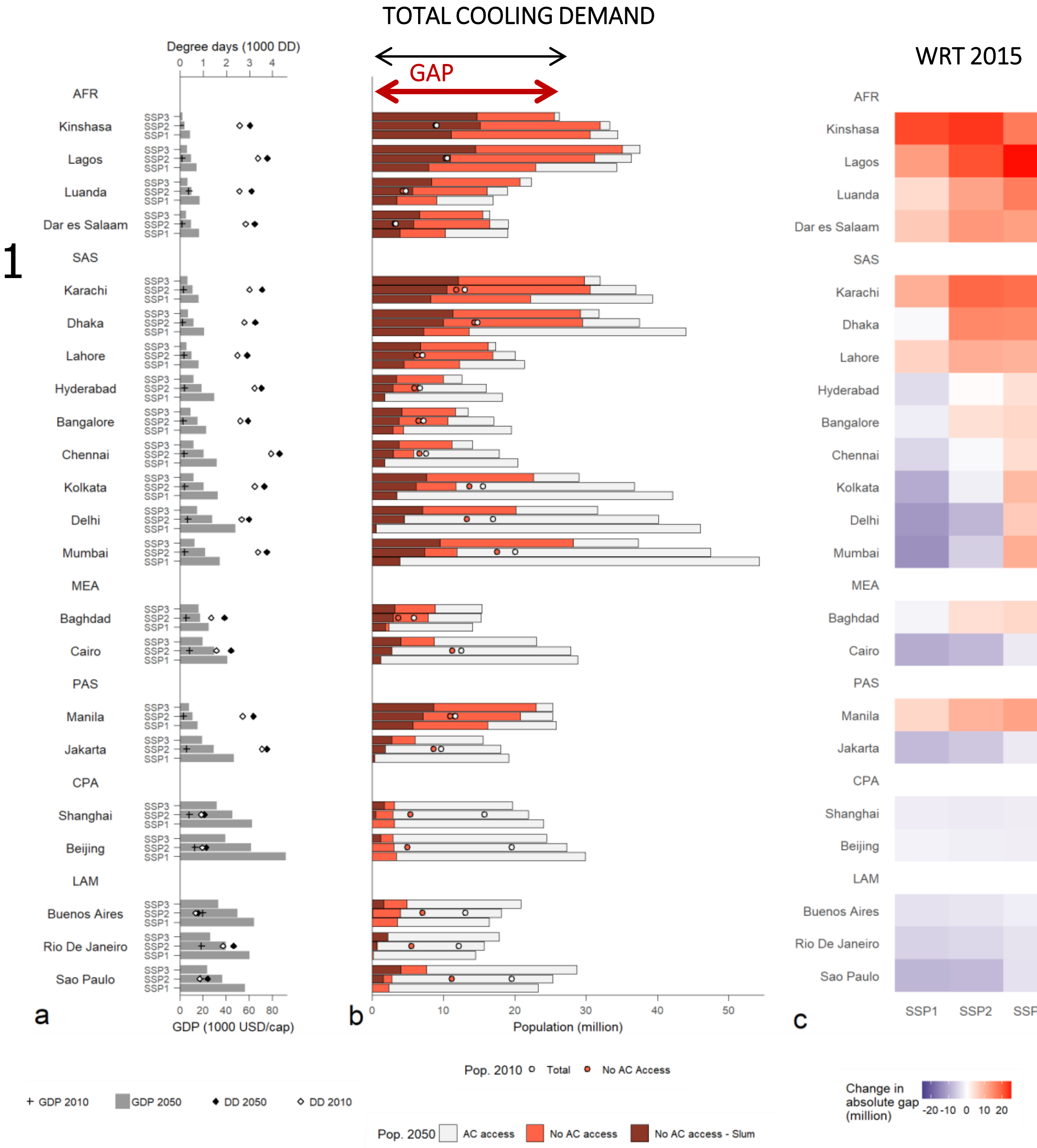
Population data:
Hoornweg & Pope, 2017
City-level projections

GDP data:
Murakami & Yamagata, 2019
Spatially gridded data



Cooling gaps in megacities

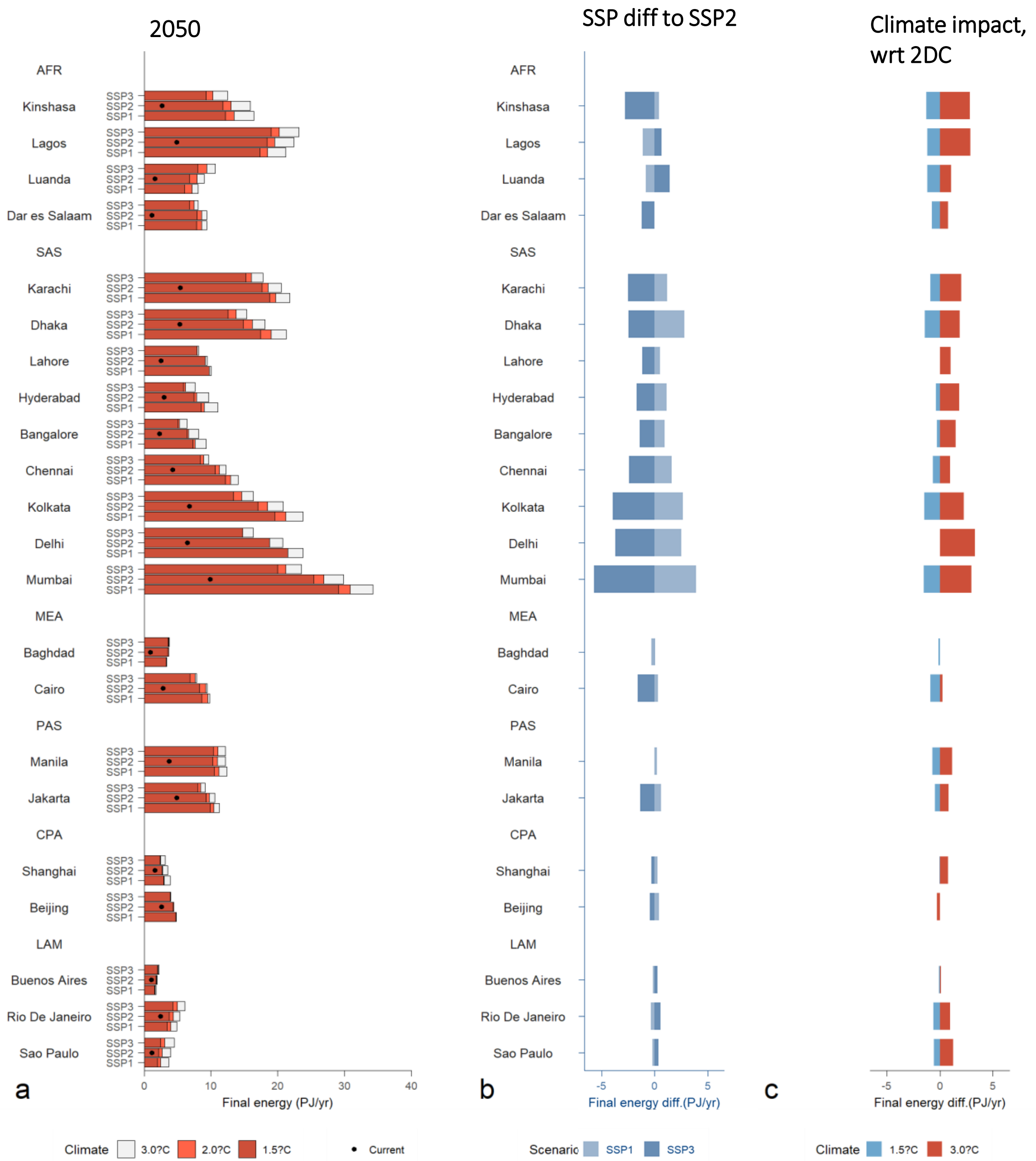
- GDP and Degree-days: drivers of cooling access and gaps
- Demand generally higher in demand in SSP1 (larger urban population) but larger gap in SSP3, especially in AFR and SAS regions
- Three city clusters:
  - AFR and SAS (except India), MEA, PAS: gaps increase in all scenarios
  - SAS (India) changes in gaps strongly depend on different SSPs
  - Other cities: gaps decrease in all scenarios



Energy requirements

Universal AC access

- Most cities will experience increase in energy requirements due to population growth and temperature increase.
- Cities with higher cooling requirements are mostly located in AFR and SAS.
- Different socio-economics will largely impact energy requirements, especially in AFR and SAS, and often to a larger extent than different climate futures.



Conclusions

Cooling gap will persist in 2050, at least 215 (SSP1) to 364 (SSP3) million people (in most exposed megacities)

Energy requirements for universal access to basic cooling will be influenced by socio-economics to a larger extent than climate futures

from 201 PJ/yr (SSP3) to 247 PJ/yr (SSP1) under a 2.0°C scenario.

Two city hotspot archetypes:

- -**Heat stress hotspots**: population growing faster than income growth, with large cooling gaps
- -**Cooling energy hotspots**: income growing rapidly, with stark energy demand growth

Limitations

-Uncertainty analysis

-Costs of cooling systems and interventions

-Behaviour and thermal comfort thresholds

-Urban heat island effect

Thank you!

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Climate Feedback: hydrology, runoff, groundwater

Large hydrological uncertainties with pronounced **regional differences**

Unconventional adaptation options:
- water recycling/treatment,
- Desalination
- deep groundwater (depletion)

Impacts on **SDG 6** (water access) & **SDG 2** (sustainable food production)

Runoff data from LPJmL, ISIMIP2b (gfdl-esm2m, hadgem2-es, ipsl-cm5a-lr climate models)

Climate Feedback: Crop yields

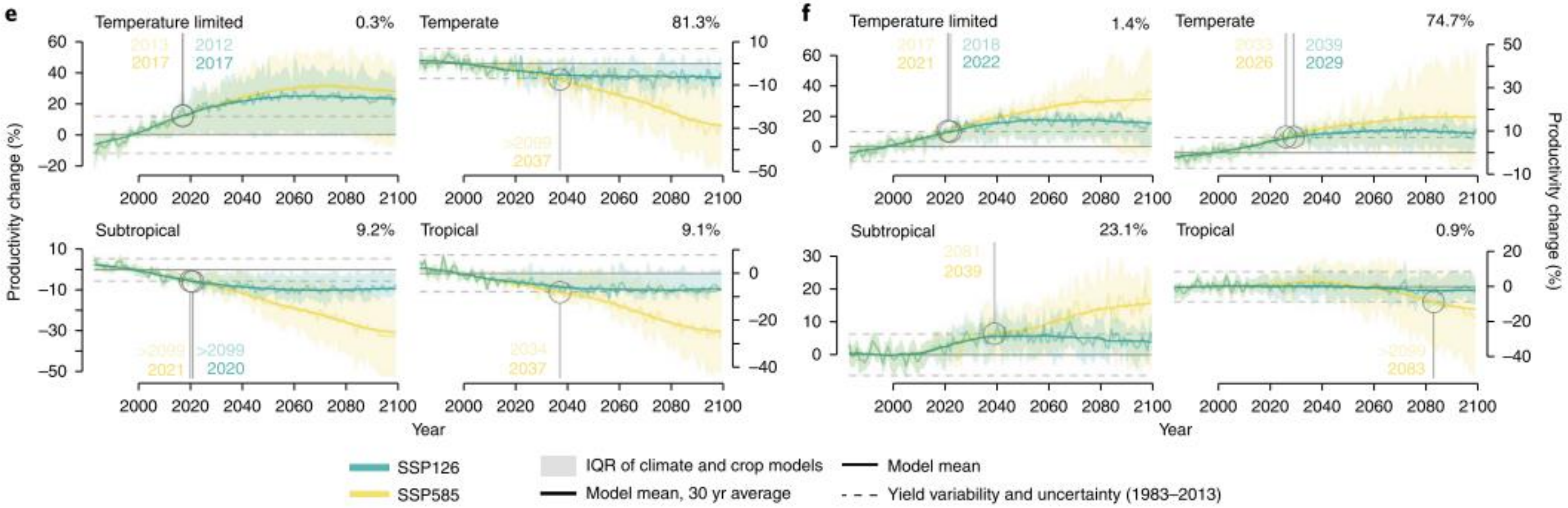
Some regions will gain yield, other will have yield losses.

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

Adaptation options include crop shift, irrigation vs rainfed

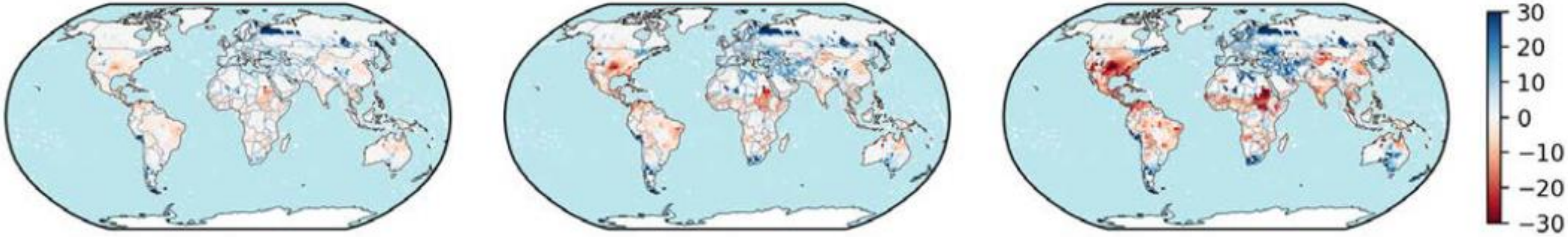
Responses to meet SDG 2 (diet), 15 crop choices and SDG6 (env flow)

Maize **Wheat**



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*

I1: Crop yield change (%)

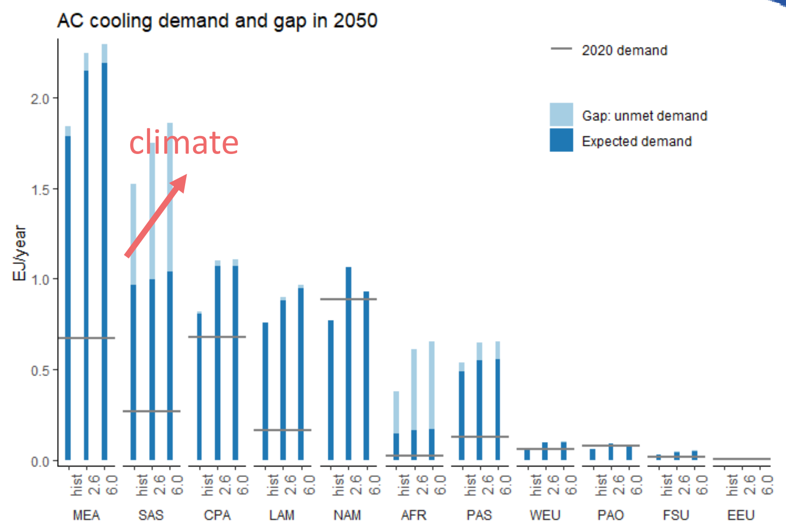


Crop yields change 1.5, 2.0 and 3.0°C GMT change (left to right), from Byers et al. 2018, *ERL*

Climate Feedback: AC cooling demand and gap

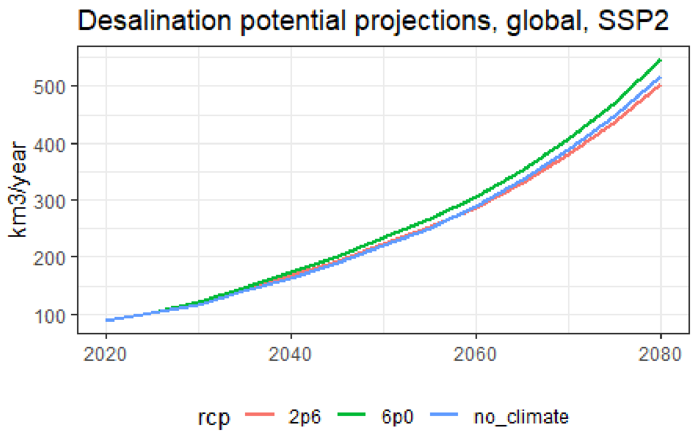
Cooling demand is likely to increase. South Asia and Africa have large % of population with not adequate cooling (Gap: unmet demand). Different climate affects GMT and CDD

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



SSP2 projections from Mastrucci et al. 2021, Climatic Change

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

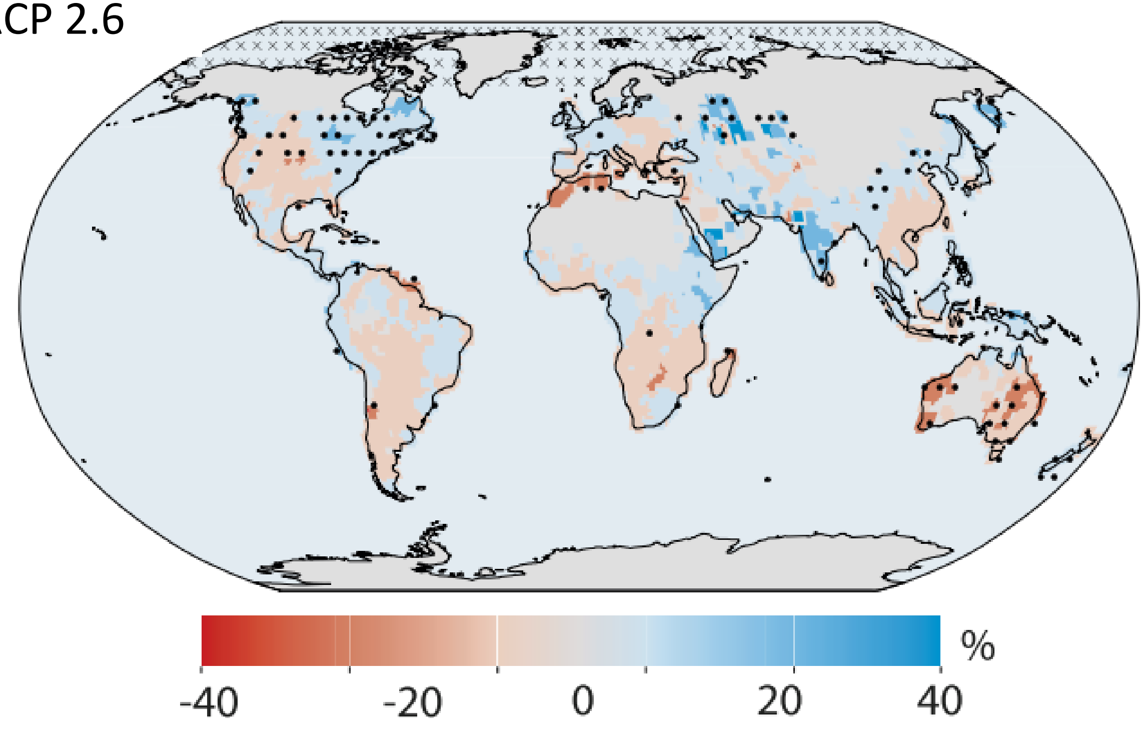
Climate Feedback: Hydropower potential

Some regions benefit, some regions show declining potential

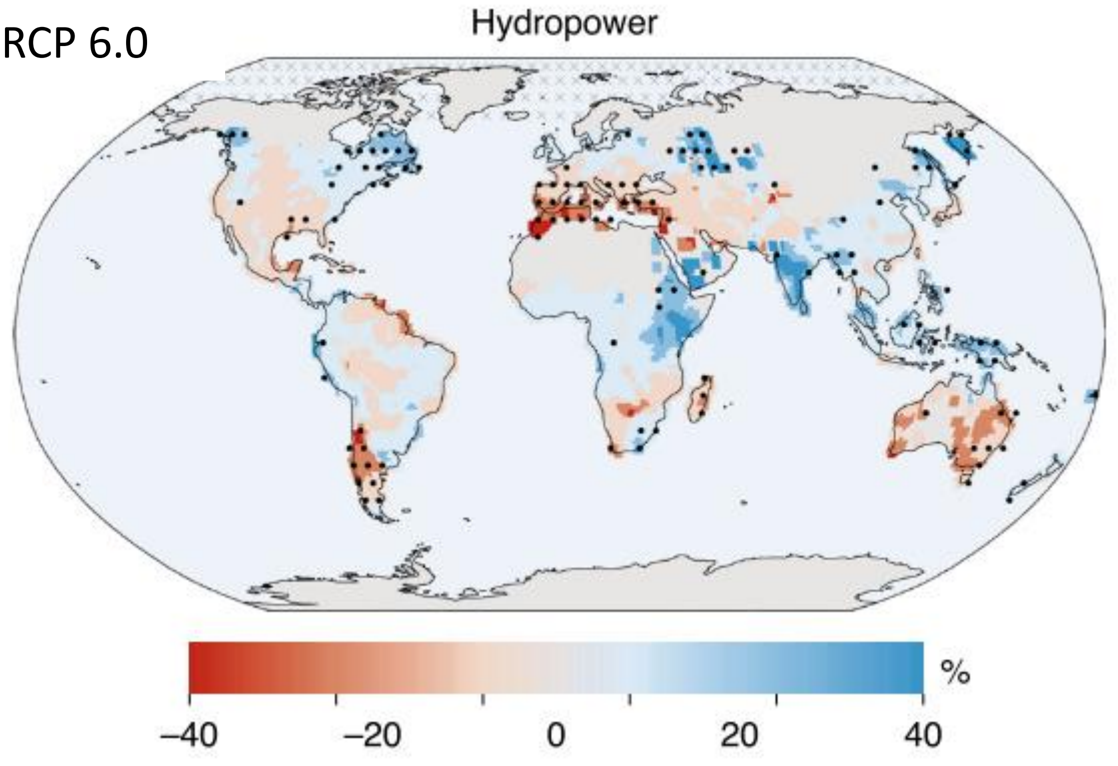
Adaptation→ expand hydro switch to other energy sources

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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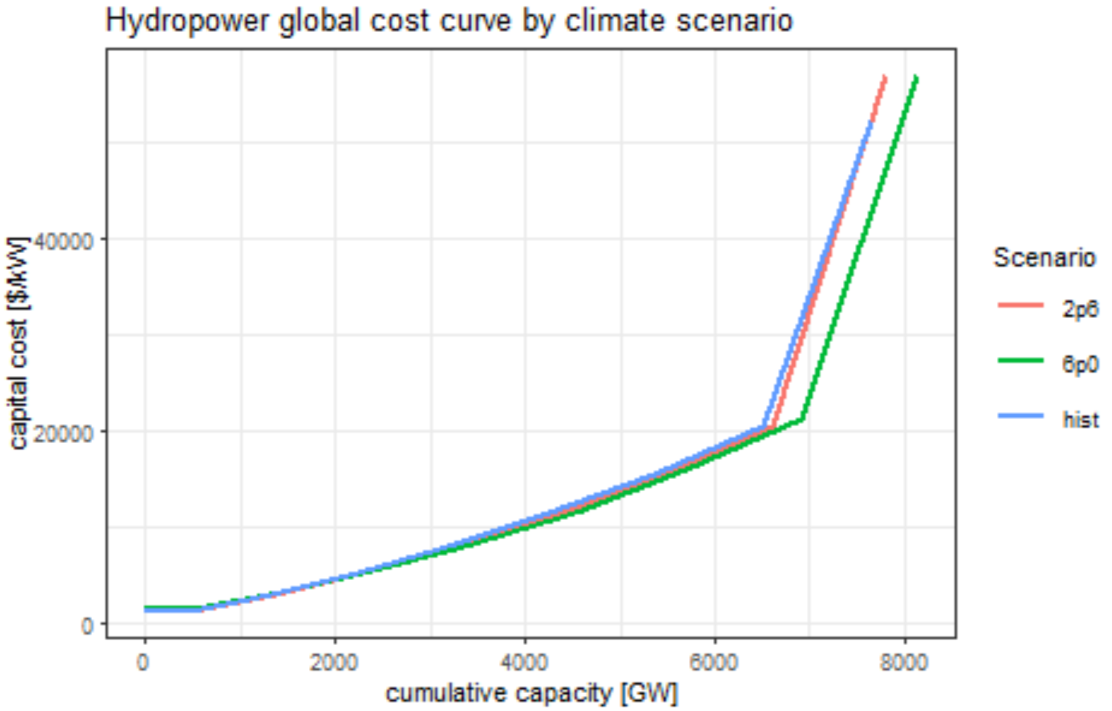

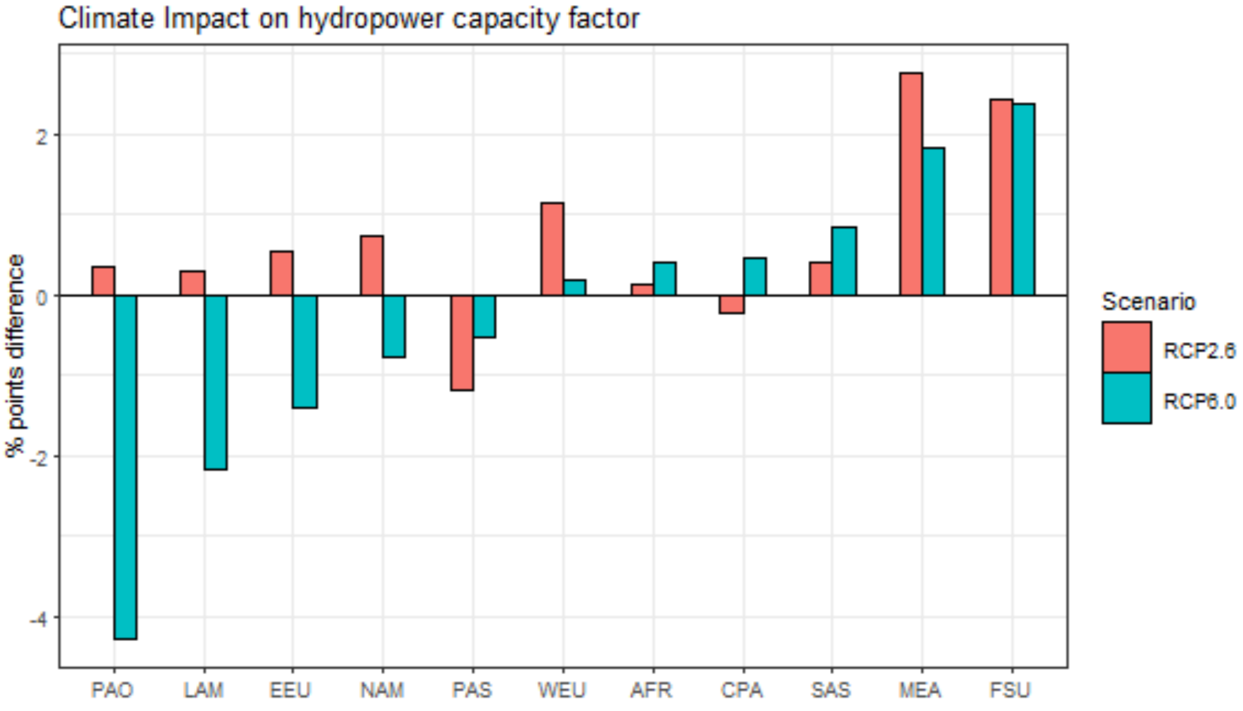

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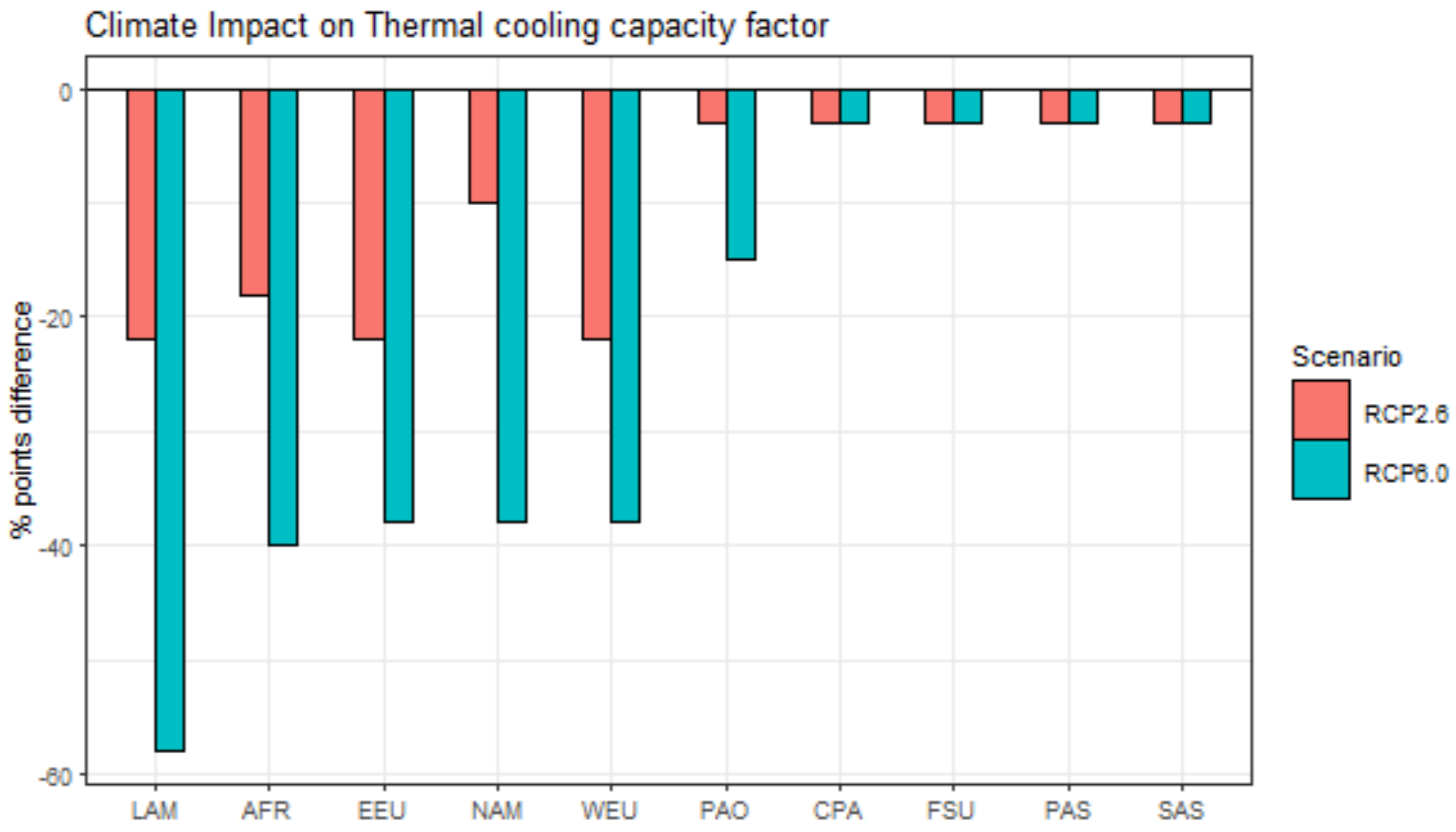
Climate Feedback: Thermal power plant cooling

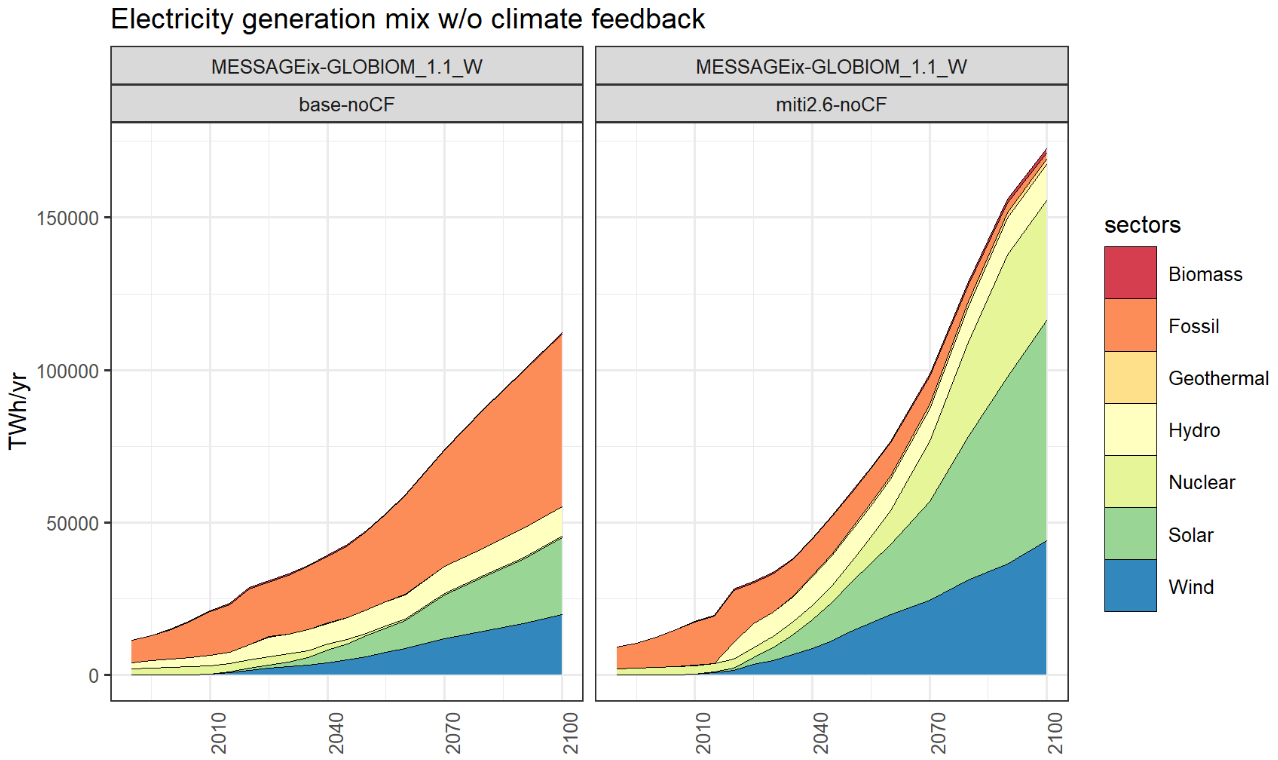
Cooling capacity factor reductions from van Vliet et al. (2021) water availability and thermal pollution

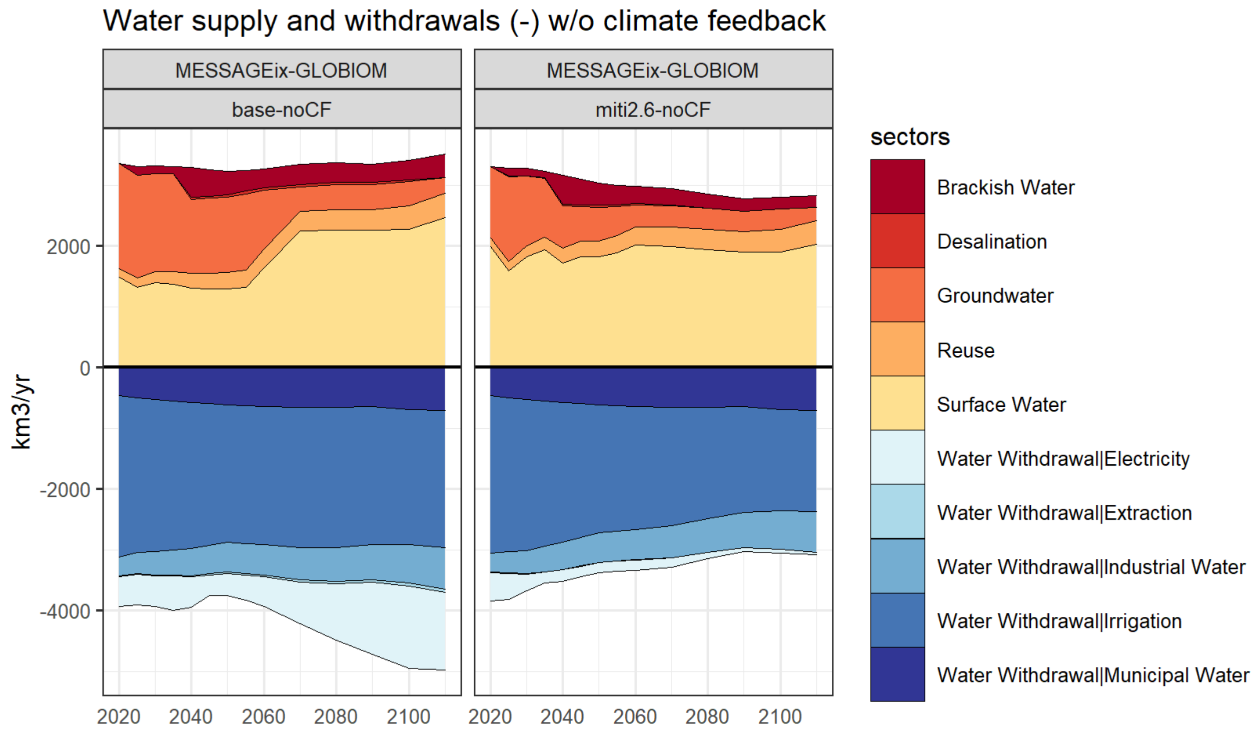
Adaptation→ dry and sea cooling, non-thermal power production

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

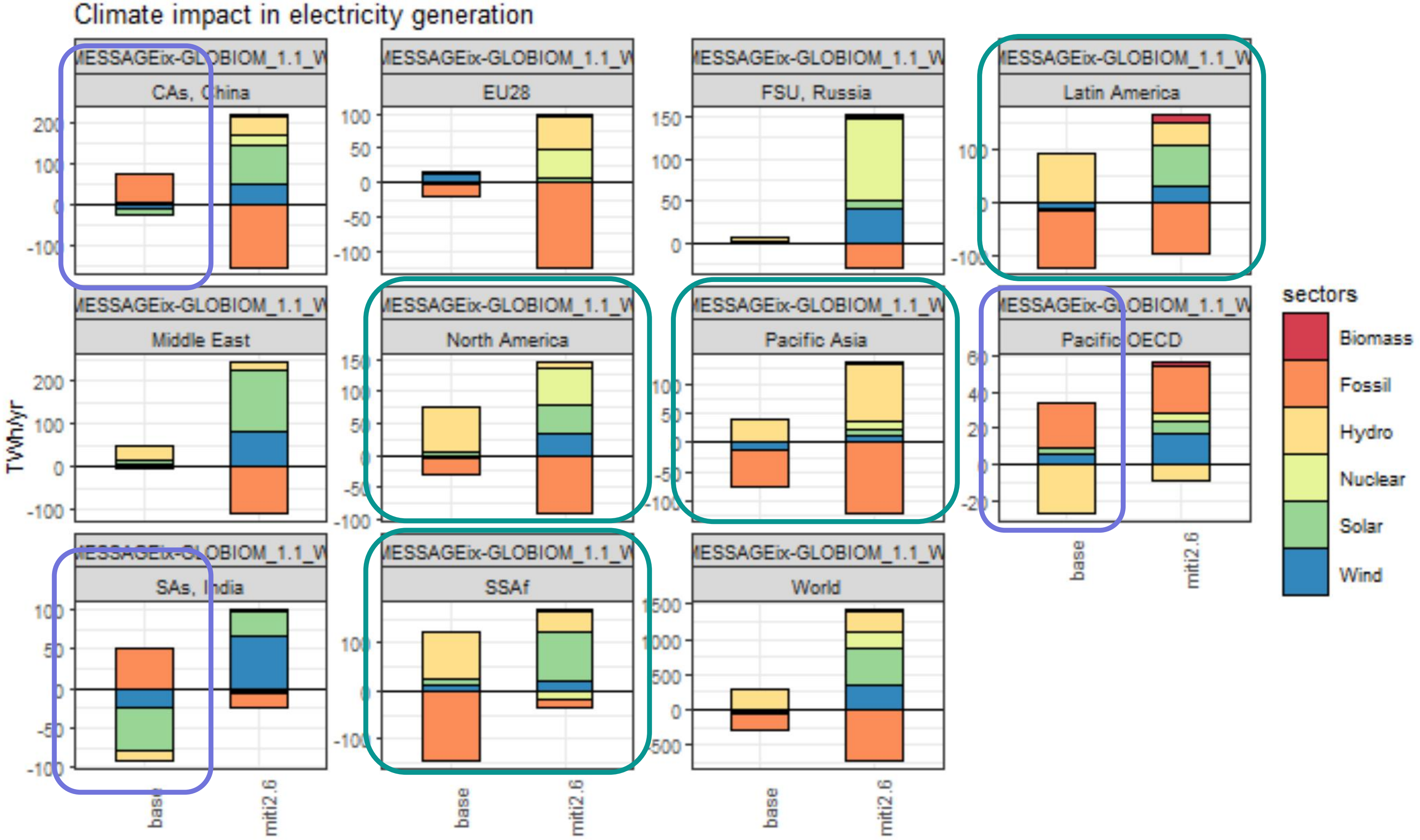


Electricity generation mix and water supply (all sectors)
No climate change impacts or feedbacks





Climate Feedback results: Electricity generation mix



RCP 6.0

Low impacts on thermal cooling and on hydro

Strong impact on thermal cooling and/or hydro increase