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An integrated assessment of provincial economic damages from climate change in China

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joint work with Fang Chen[2], Tianpeng Wang[1], Da Zhang[1], Yixiong Lu[3], Xiaoye Zhang[3], Xiliang Zhang[1]

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3, Chinese Academy of Meteorological Sciences

Motivation

- China’s provinces face **heterogeneous potential climate damages** under climate change
  → support appropriate mitigation and adaptation efforts by region
- Direct loss caused by climate change may propagate across different regions and economic sectors, potentially resulting in **equilibrium impacts**.

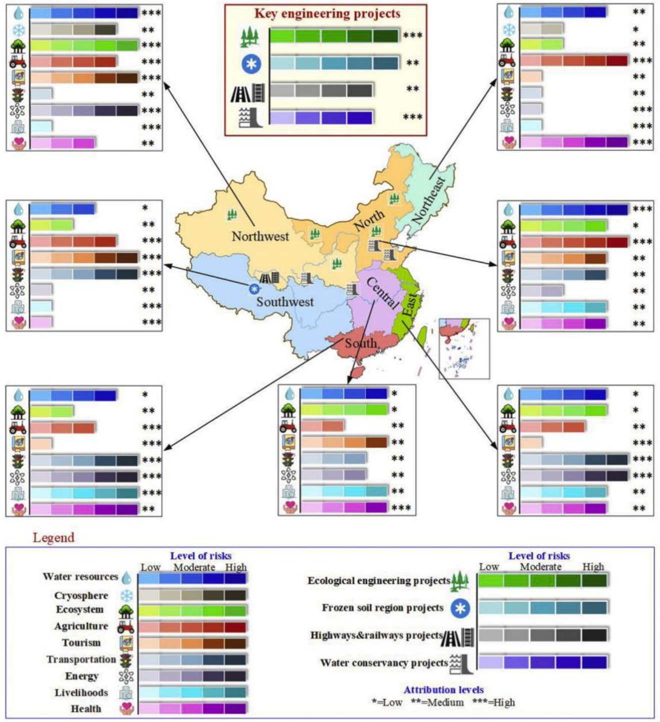
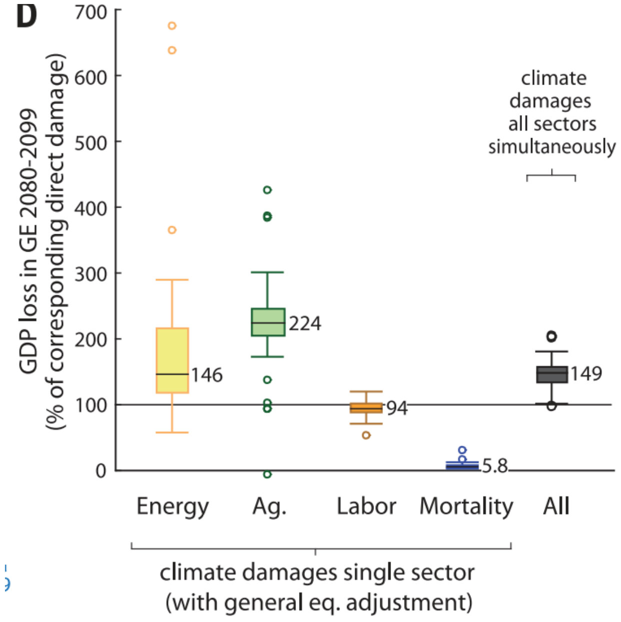


Fig. 1. The pattern map of climate change risk showed the risk levels and attribution levels in water resources, cryosphere, ecosystem, agriculture, tourism, transportation, energy, livelihoods, and health in each geographical region of China.



Feng, A., & Chao, Q. (2020). An overview of assessment methods and analysis for climate change risk in China. *Physics and Chemistry of the Earth*, *117*(February), 102861.

Hsiang, S., et al. (2017). Estimating economic damage from climate change in the United States. *Science*, *356*(6345), 1362–1369.

Literature review

- **Physical risk (direct damage) in China’ s provinces**
  - Direct losses from certain extreme events (Wu et al., 2017; Wu et al., 2019)

Climate change simulation

- **Aggregate damage functions and IAM**
  - Apply the same damage function to China’ s provinces (Wang et al., 2022)

Economic loss estimates

- **Adaptive multiregional input-output model (AMRIO)**
  - For China’ s seven regions (Liu et al., 2020; Huang et al., 2021; Liu et al., 2021)

Consider sectoral and regional detail

- **CGE-IAM studies**
  - Study at global scale (Piontek et al., 2021), country scale (Kompas et al., 2018; T. Wang et al., 2020), or sub-national scales (Ciscar et al., 2011; Hsiang et al., 2017)
  - Limited research about China’ s provinces (Zhao et al., 2024)

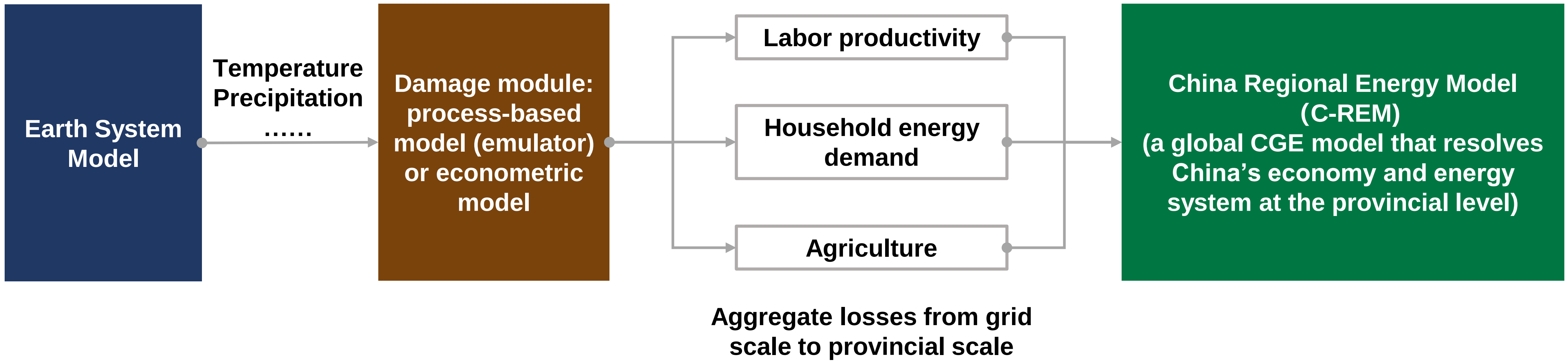
Simulate market adaptation; cost-benefit analysis

Research questions

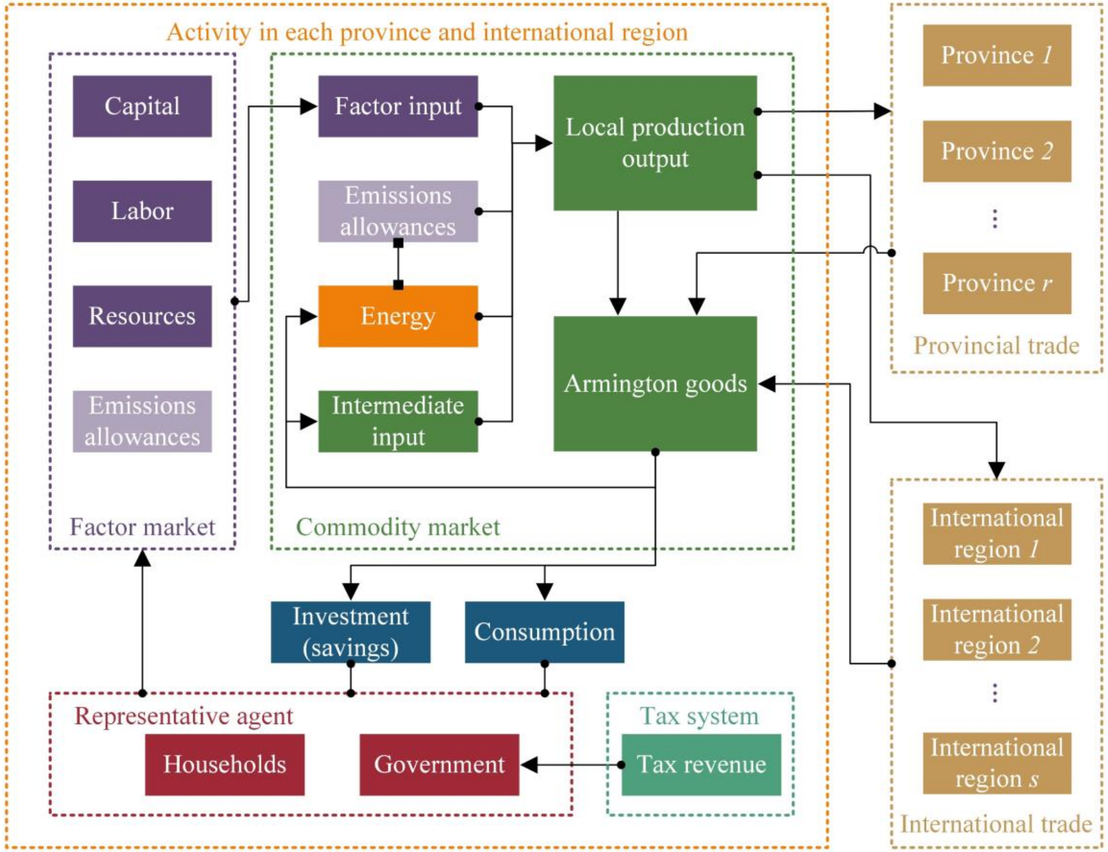
- How do the economic impacts of climate change vary across provinces?
- How do the direct and equilibrium impacts differ across damage channels?
- Will the cost of reducing emissions be offset by avoiding damages from climate change?

Methods

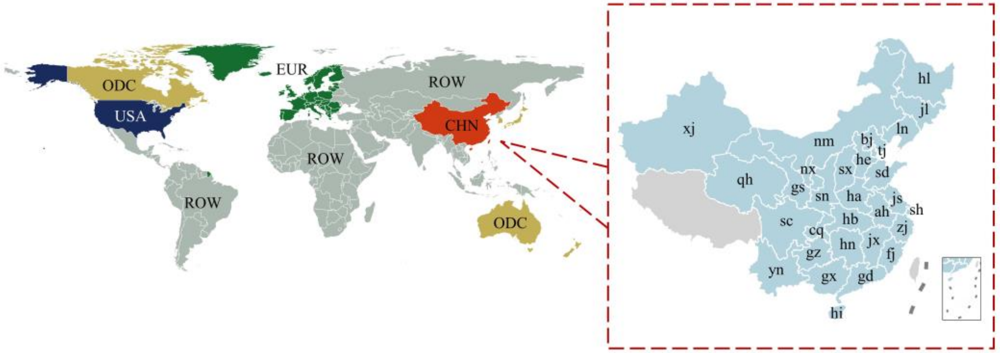
An integrated modeling framework linking a CGE model and earth system models by damage modules.



China Regional Energy Model （C-REM 4.0）

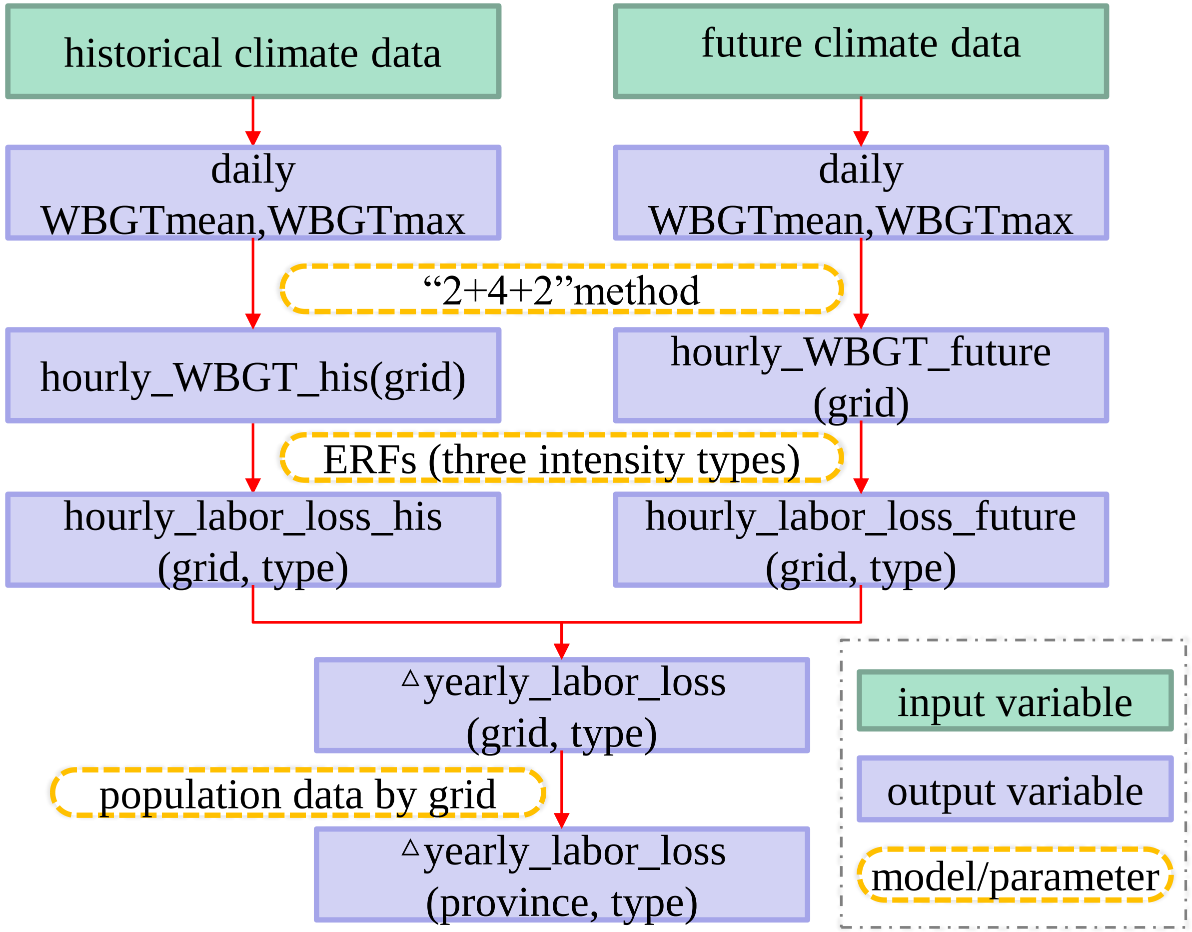


- Recursive-dynamic CGE model
  - Resolves China’s economy and energy system at the provincial level
  - Updated with GTAP11 and 2017 provincial I-O data
  - 20 production sectors and 2 consumption sectors
  - Include renewable electricity production and carbon capture and storage technologies



Peng, et al., (2024). The C-REM 4.0 model: A CGE model for provincial analysis of China’s carbon neutrality target. Energy and Climate Management.

Labor productivity change : From heat stress to productivity loss



$$Productivity\ loss = 0.5\left[1 + erf\left(\frac{WBGT - \mu}{\sigma\sqrt{2}}\right)\right]$$

$$erf(x) = \frac{2}{\sqrt{\pi}}\int_0^x exp(t^2)dt$$

Function parameters for the Chinese ERF

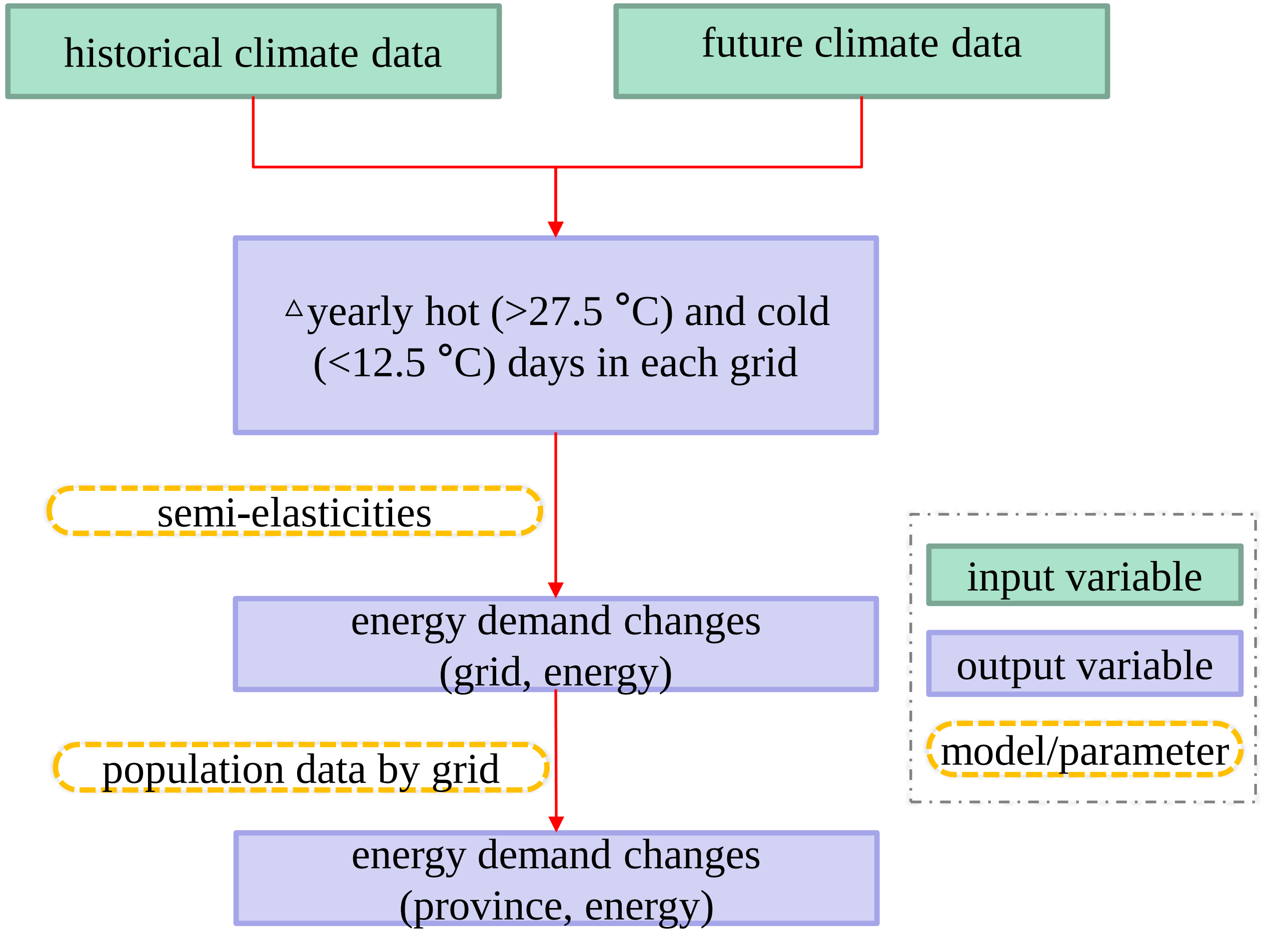
Work intensity type	μ	σ
200W	35.129	3.503
300W	33.492	3.948
400W	32.492	3.948

adopted from Cheng et al. (2023)

Kjellstrom, et al.,(2018). Estimating population heat exposure and impacts on working people in conjunction with climate change. *International journal of biometeorology*, *62*(3), 291-306.

Cheng, L., et al., (2023). Projecting future labor losses due to heat stress in China under climate change scenarios. Science Bulletin

Household energy demand:
From hot and cold days to demand changes



$$\Delta Energy\_Consumption_{ijst} = \beta_{ijst} \times \Delta Day_{it}$$

Semi-elasticities for energy demand change

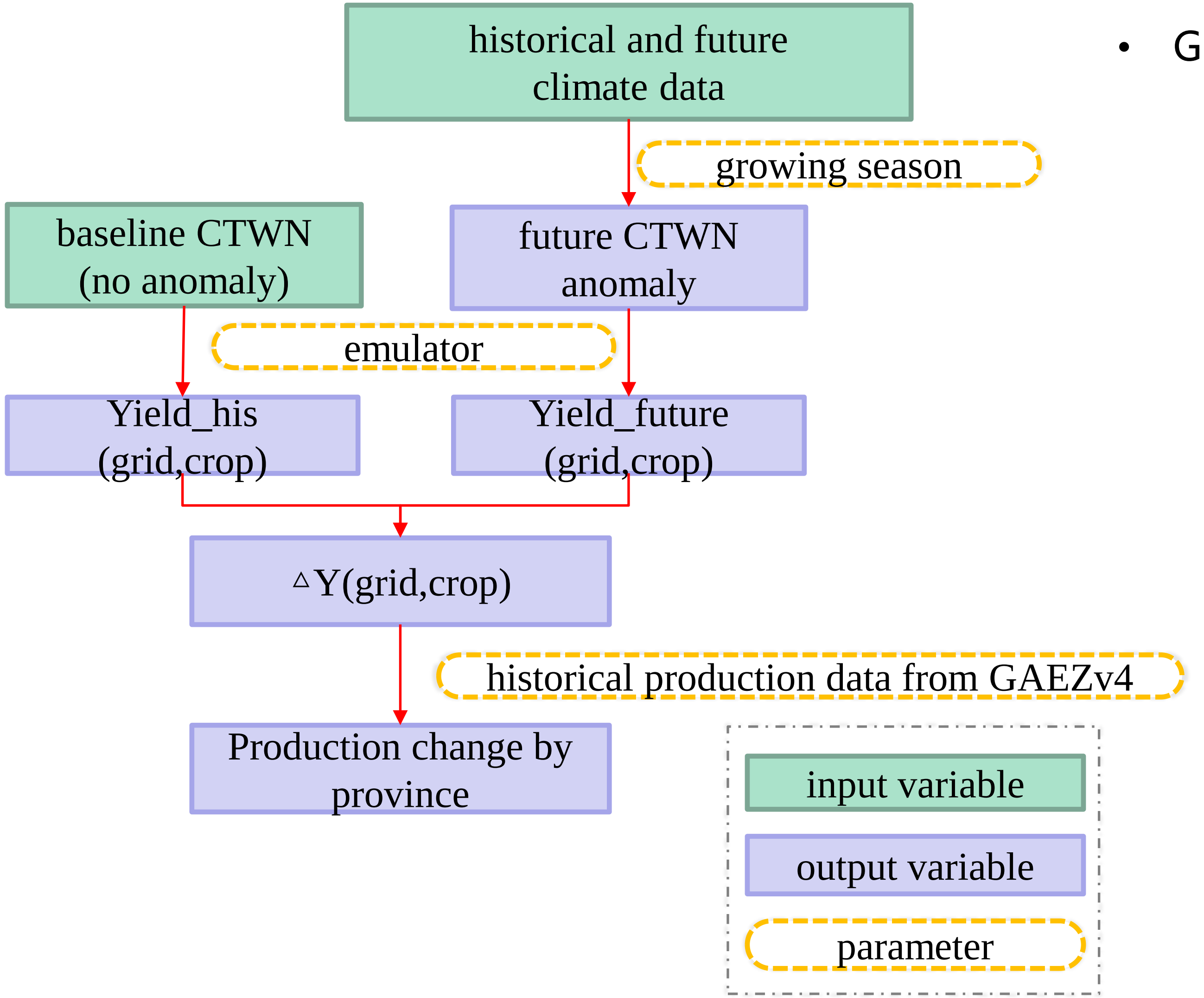
Energy	**cold days**	**hot days**
Electricity		0.015
Natural gas	0.023	
Petroleum	0.021	

adopted from De Cian and Sue Wing (2019)

De Cian, E., & Sue Wing, I. (2019). Global Energy Consumption in a Warming Climate. Environmental and Resource Economics, 72(2), 365–410.

van Ruijven, B. J., De Cian, E., & Sue Wing, I. (2019). Amplification of future energy demand growth due to climate change. Nature Communications, 10(1), 1–12.

Agriculture loss:
From temperature and precipitation to yield change



- GGCMI Phase 2 emulators (Franke et al., 2020)
  - Trained by experiments **from process-based crop models**
  - Crop yield change from the anomaly of CO_2, temperature, water supply, and nitrogen application (CTWN)
  - **0.5◦ latitude and longitude resolution**
  - Include: maize, rice, soybean, and spring and winter wheat

$$
\begin{aligned}
Y = & K_1 \\
& + K_2 C + K_3 T + K_4 W + K_5 N + K_6 C^2 \\
& + K_7 CT + K_8 CW + K_9 CN + K_{10} T^2 + K_{11} TW \\
& + K_{12} TN + K_{13} W^2 + K_{14} WN + K_{15} N^2 \\
& + K_{16} C^3 + K_{17} C^2 T + K_{18} C^2 W + K_{19} C^2 N \\
& + K_{20} CT^2 + K_{21} CTW + K_{22} CTN + K_{23} CW^2 \\
& + K_{24} CWN + K_{25} CN^2 + K_{26} T^3 + K_{27} T^2 W \\
& + K_{28} T^2 N + K_{29} TW^2 + K_{30} TWN + K_{31} TN^2 \\
& + K_{32} W^3 + K_{33} W^2 N + K_{34} WN^2 + \cancel{K_{35} N^3} \qquad (1)
\end{aligned}
$$

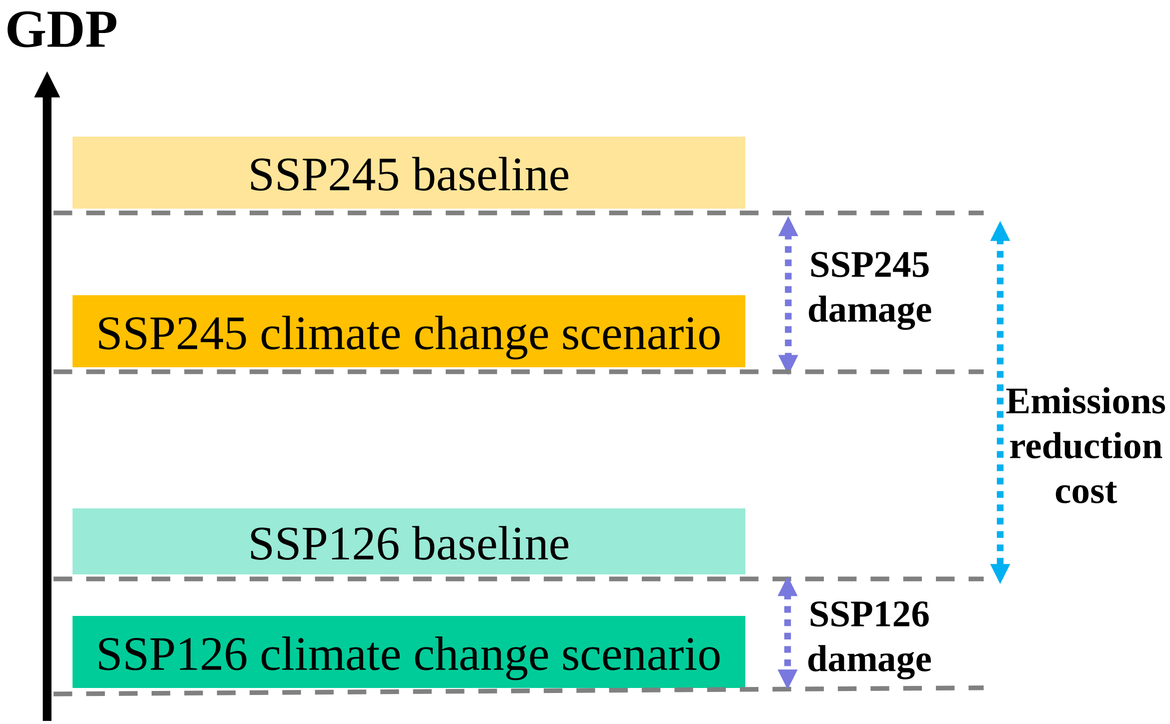
Franke, J. et al. (2020). The GGCMI Phase 2 emulators: Global gridded crop model responses to changes in CO2, temperature, water, and nitrogen (version 1.0). Geoscientific Model Development, 13(9), 3995–4018.

Direct damages and shocks to the CGE parameters

Damage channel	Direct damage	Shock to CGE parameters
Labor productivity	loss rate $\times$ labor income	increase labor input per unit of output
Household energy demand	change rate $\times$ household expenditure on energy consumption	change energy consumption per unit of utility
Agriculture	change rate $\times$ output of the agriculture sector	Reduce output per unit total input

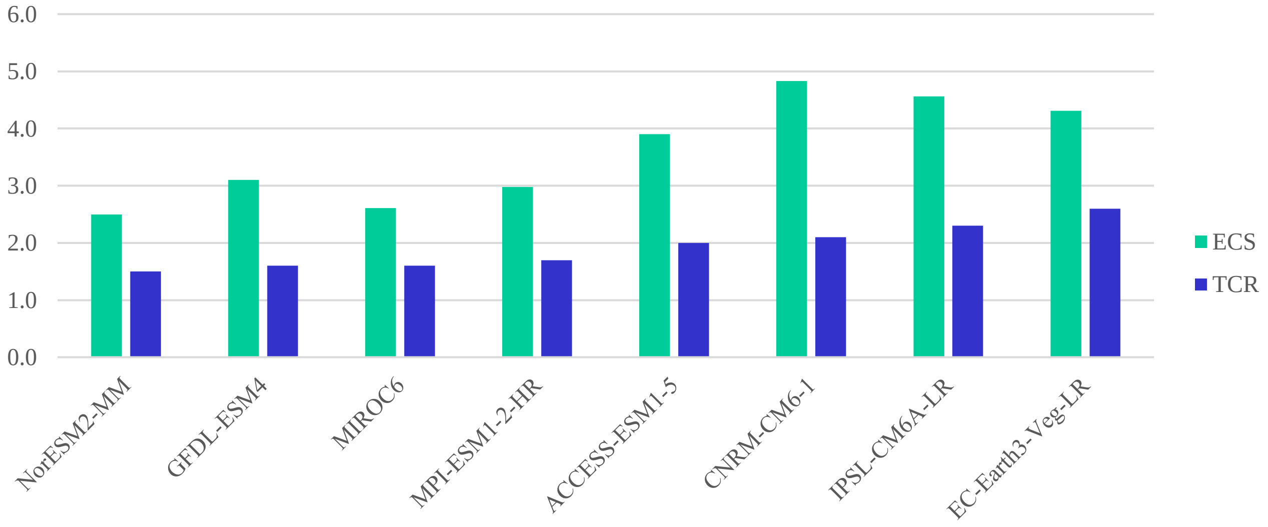
Scenario and climate data

- Shared Socioeconomic Pathway (SSP) 126 and SSP245 from CMIP6
    - **SSP126**: low emissions pathway; China 2060 carbon neutrality target; 1.8 ℃
    - **SSP245**: medium-to-high emissions pathway; reference mitigation efforts; 2.7 ℃
- Baseline and climate change scenario
    - Baseline: impose CO_2 emissions constraints aligned with SSPs; without climate change shock
    - Climate change scenario:
        - use 2050-2080 climate data to derive climate shock
        - Shock to the 2060 economy in the CGE model



Scenario and climate data

- Earth system models (ESMs) data
  - NASA Earth Exchange Global Daily Downscaled Projections
    - 0.25-degree horizontal resolution
  - 8 ESMs to reflect uncertainties in ESMs
    - equilibrium climate sensitivity (ECS): 2.5-4.8
    - transient climate response (TCR): 1.5-2.6



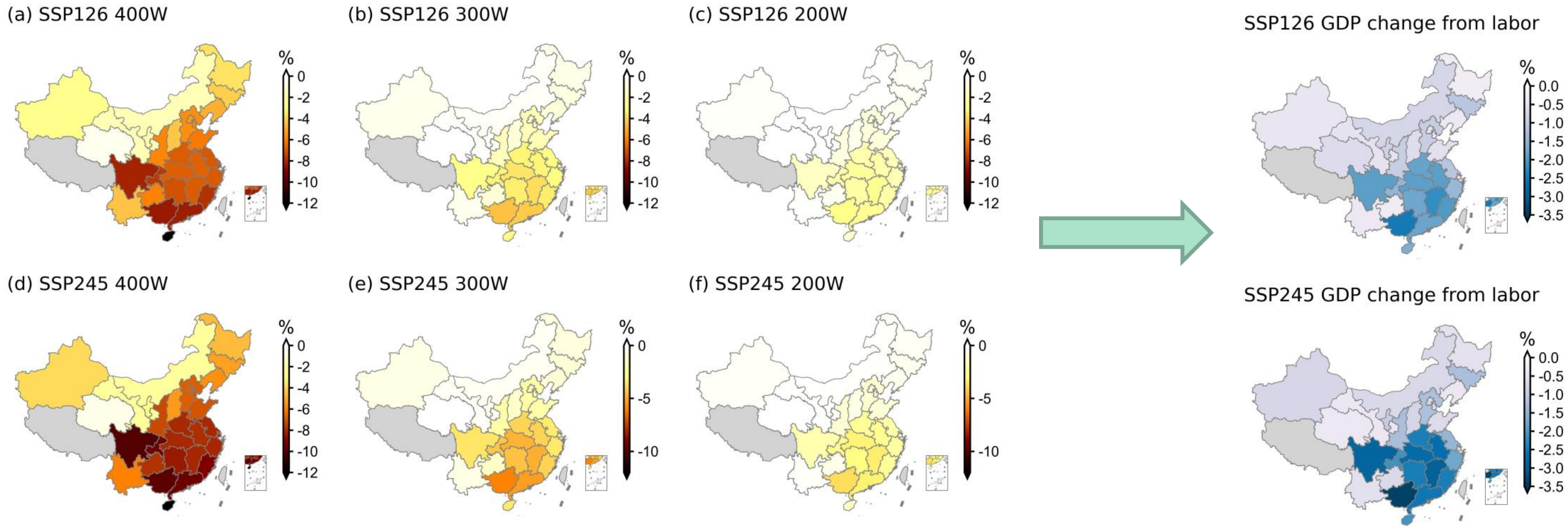
Thrasher, B., et al. (2022). NASA Global Daily Downscaled Projections, CMIP6. Scientific Data, 9(1), 1–6.

Results 1.1: Labor productivity loss

- Labor productivity loss
  - National: 6.9% (400W), 2.6%(300W), 1.5%(200W) under SSP245; 20% smaller under SSP126
  - **Regional: North-south divide**; 0.54%~13.7% (400W) under SSP245
- Induced GDP change
  - National: -1.3% under SSP126, -1.8% under SSP245
  - Regional: Guangxi -2.5%, Heilongjiang -0.3% under SSP126

SSP126

SSP245

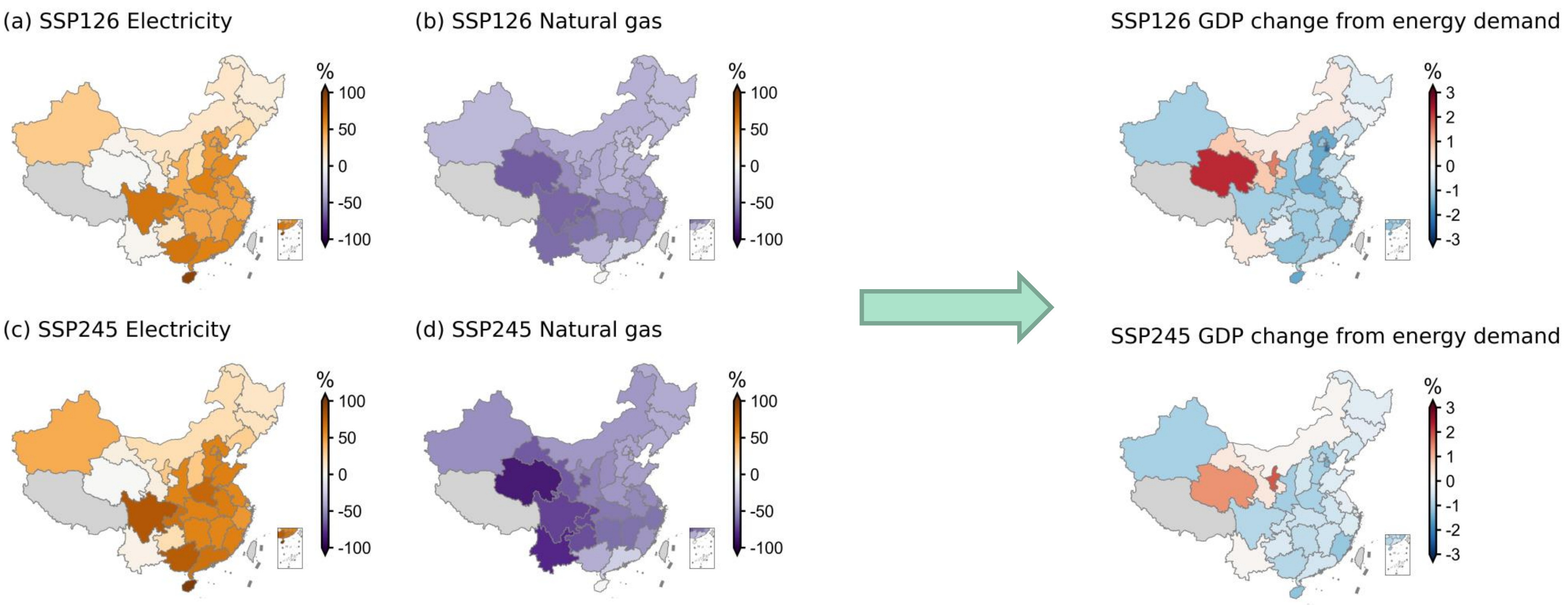


Results 1.2: Household energy demand change

- Demand change:
  - More electricity (average +48%), less natural gas (average -51%) under SSP245
  - Larger increase in electricity demand **in North, South, and Central areas**
- Induced GDP change：
  - National: -0.8% under SSP126, -0.6% under SSP245
  - Regional: negative impact in North, South, and Central areas, positive impact in Northwest area

SSP126

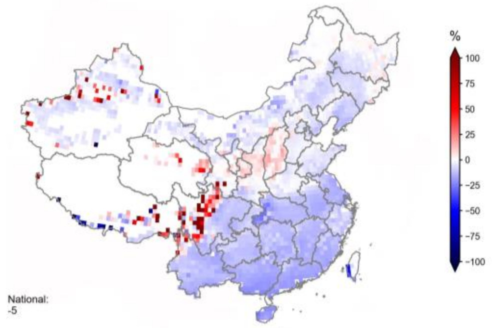
SSP245



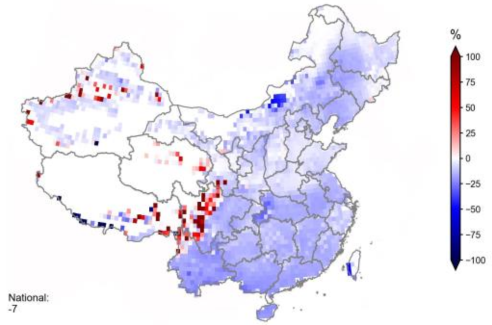
Results 1.3: Agricultural production change

- Yield change
  - Yield of four major crops generally decreased, **but wheat yield may increase (Qinghai, Shanxi)**
  - Large yield reduction of rice in South and Central area
- Induced GDP change：
  - National: -1.5% under SSP126, -2.1% under SSP245
  - Regional: notable loss in Hubei

SSP126



SSP245



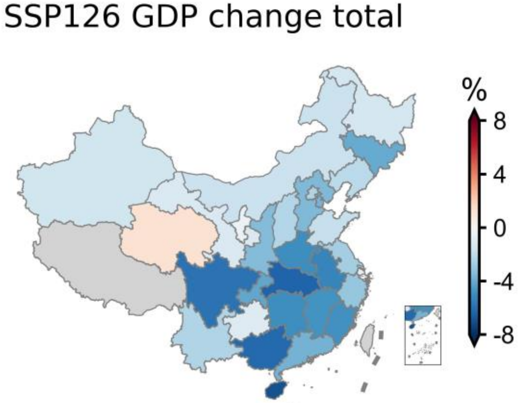
e.g. Production change rate estimated using GFDL-ESM4 data and LPJmL emulator

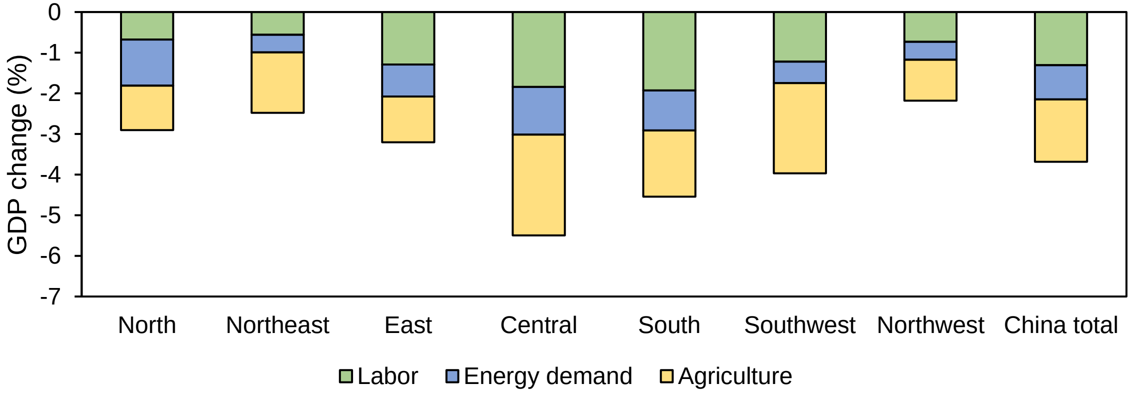
SSP126 GDP change from agriculture

SSP245 GDP change from agriculture

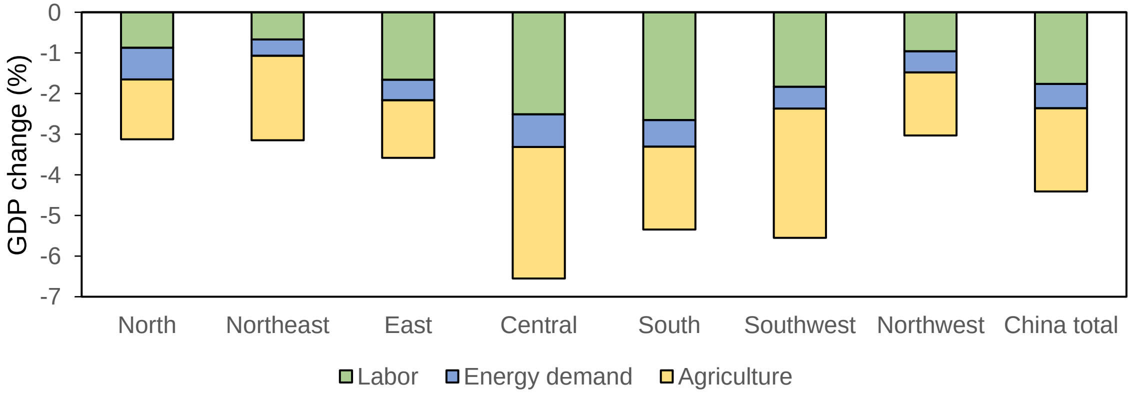
Results 1.4: Total GDP change

- National: -3.6% under SSP126, -4.4% under SSP245
- Regional:
  - Larger loss in Central, South, and Southwest area
  - Main loss channel: Northeast and Northwest - Agriculture, South – Labor productivity





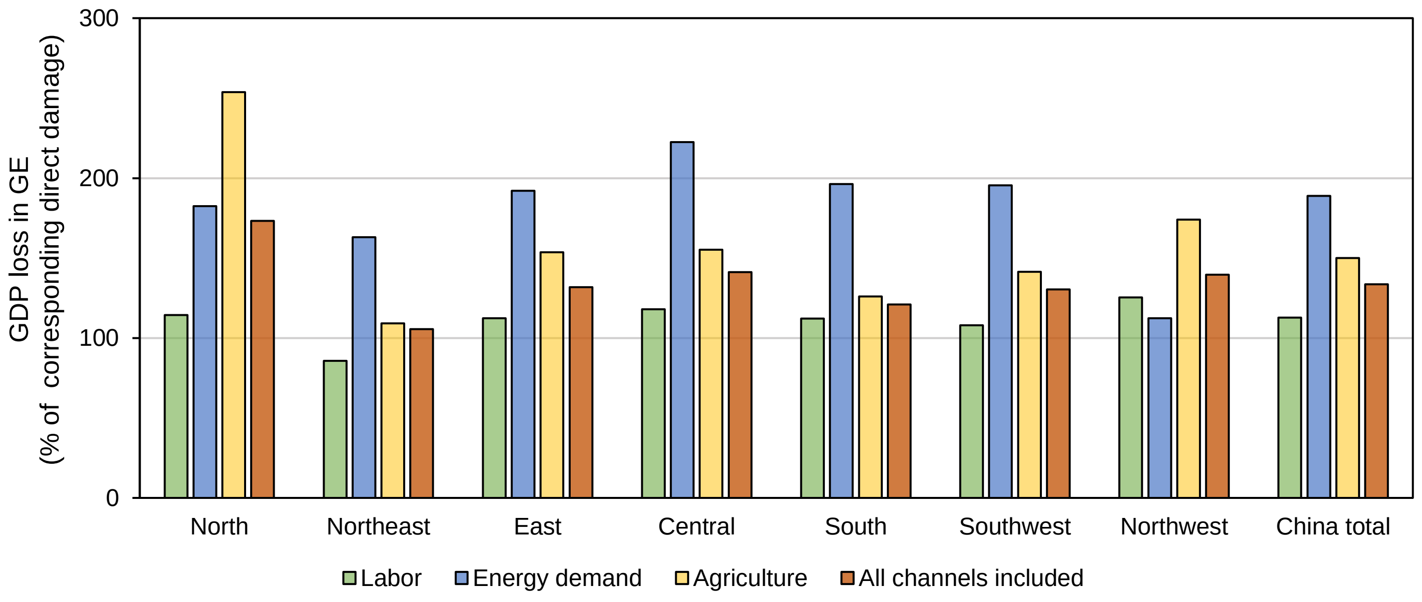
SSP126



SSP245

Results 2: Direct and general equilibrium impact

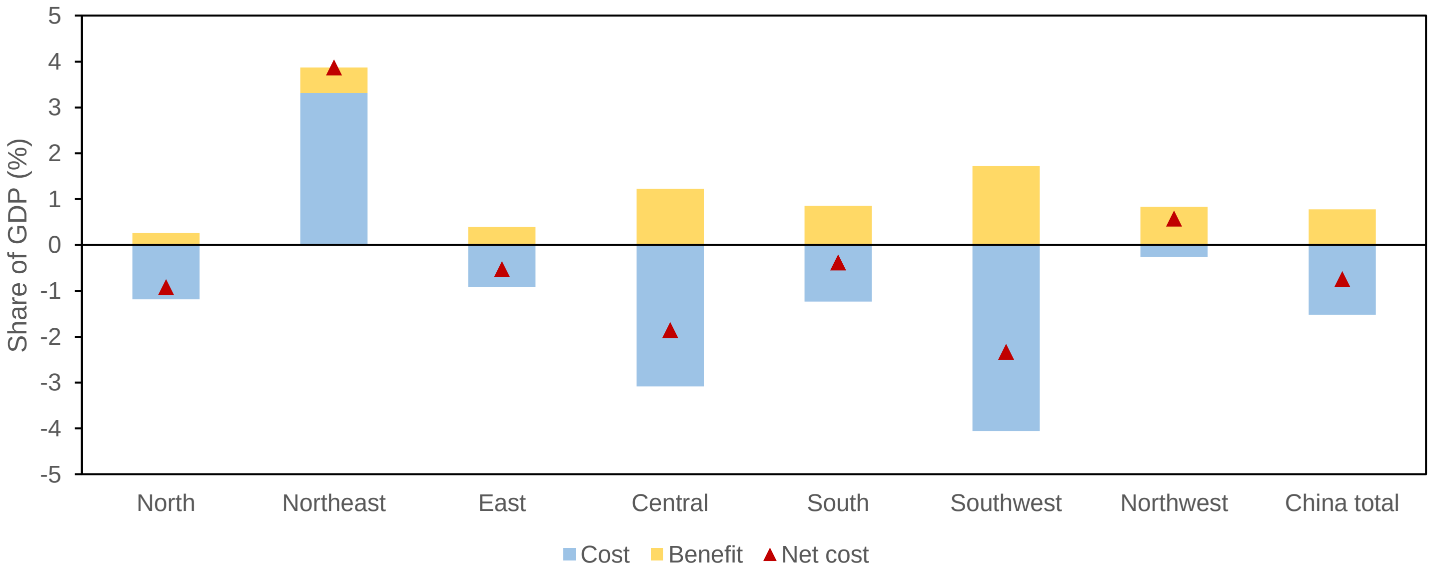
- National: amplification effect
  - All channels included: GE loss tends to be larger than direct impact by 34%
  - energy demand channel ＞ agriculture channel ＞labor productivity channel
- Regional:
  - Adaptation effect in the labor productivity channel in the Northeast regions
  - Notable amplification effect in the agriculture channel in the North regions



General equilibrium GDP loss compared with direct loss under SSP245

Result 3: Cost-benefit analysis

- National:
  - The benefits (avoided climate damages) could cover about 50% of the mitigation costs
- Regional: may reduce inter-regional inequalities
  - Net GDP increase in Northeast (+3.9%) and Northwest (+0.6%) areas
    - Small (or even negative) mitigation costs due to high-quality renewable resources and CO_2 storage potential
  - Stronger net negative impact in Central and Southwest areas than the national average



Conclusions

- China’ s national damage from climate change in 2060 GDP: **-3.6% (SSP126), -4.4% (SSP 245)**
- Clear **north-south divide**: stronger negative impacts in southern provinces
- Difference in main damage channel of different regions → **Priority for adaptation**
- Notable **indirect impact** of household energy demand change
- Benefits from avoided climate damages could **cover around 50% of the mitigation costs** at the national scale; net positive impact in Northeast and Northwest areas.

Limitations and future work

- Dynamic modeling of the damages (from 2020 to 2060)
- Coverage of impacts (health, sea level rise …)
- Uncertainty in impacts (involve more crop models, considering CO_2 fertilization…)
- Adaptation modeling

Thank you!

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