Methods for the assessment of air pollution health damages

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Basque Centre for Climate Change

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Outline

Scientific evidence: Why does climate change affect our health and economy?

Outdoor air pollution in numbers

According to IHME database (IHME (2019)), in 2019...

4.505 (95% CI 3.625-5.364) million deaths

124.21 (95% CI 398.89-147.63) disability-adjusted life years (DALYs)

Pollutants origin

$PM_{2.5}$

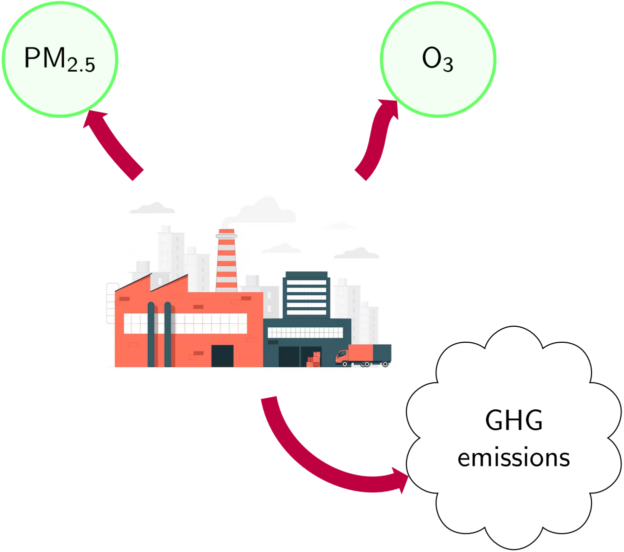
O_3

Pollutants origin

$PM_{2.5}$

O_3

Pollutants origin



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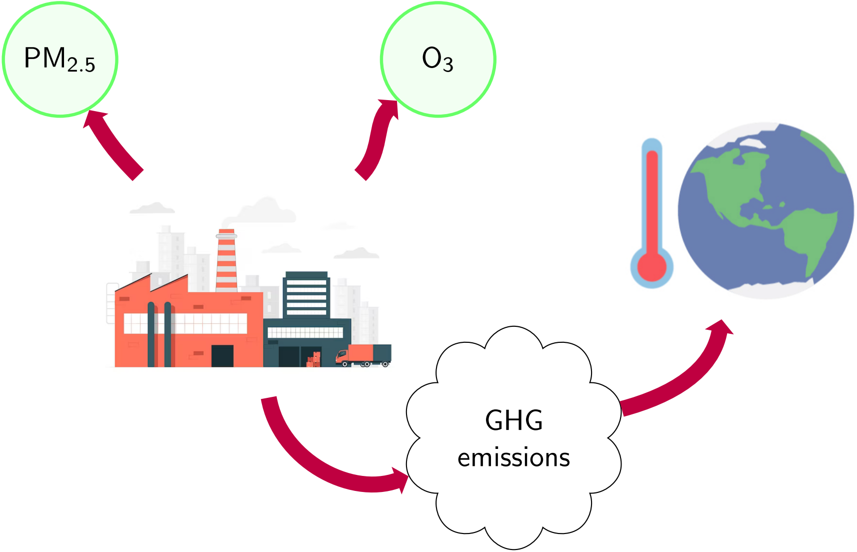

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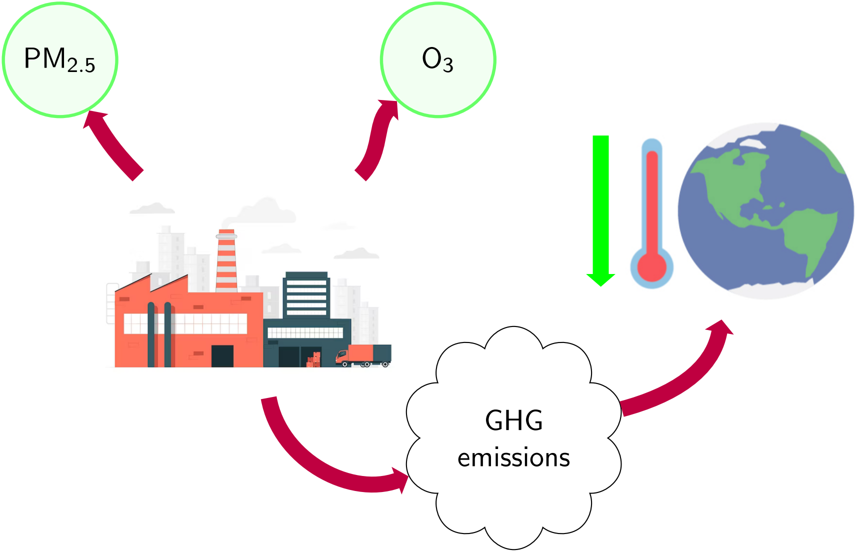

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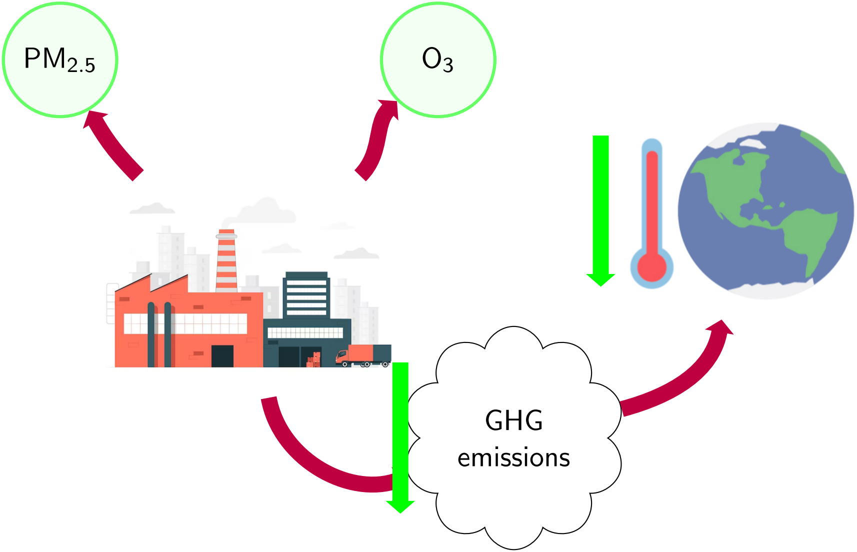

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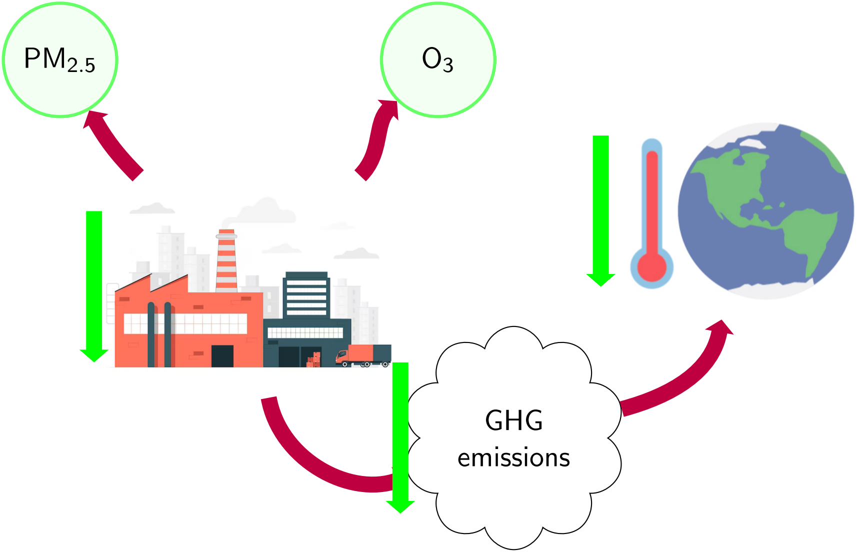

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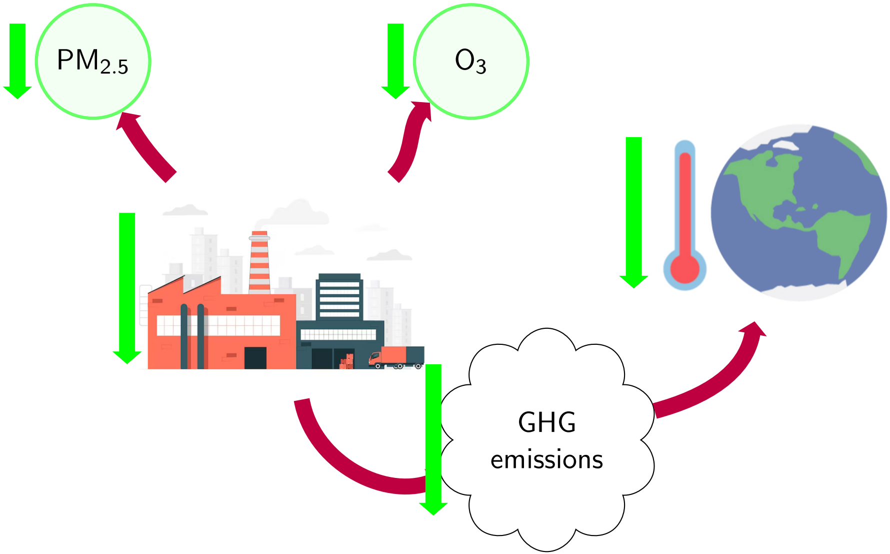
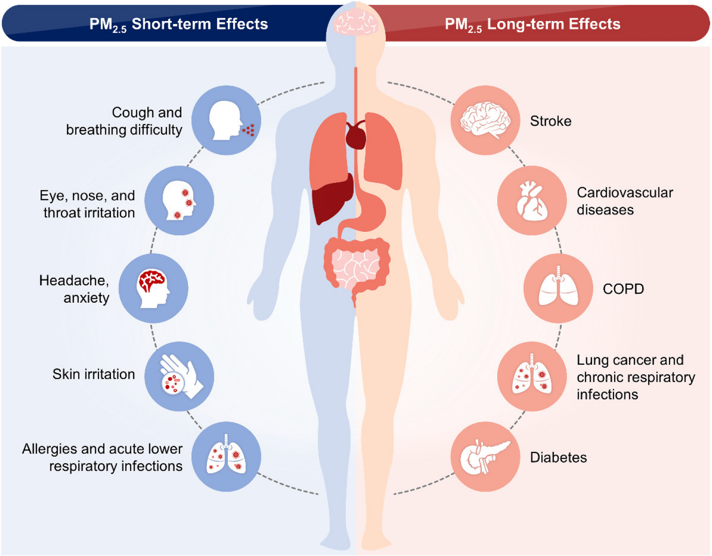


$PM_{2.5}$ map (https://www.iqair.com/earth)

Health impact of $PM_{2.5}$



Basith et al. (2022)

IHME database (https://vizhub.healthdata.org/gbd-compare/)

Air pollution health and economic implications

- Premature deaths
- Years of Life Lost (YLLs)
- Disability Adjusted Life Years (DALYs)
- ...

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$$\Downarrow$$

- Economy growth
- Human Capital Lost (HCL)
- Value of Statistical Life (VSL)
- ...

Brief overview of climate policies

Climate policies overview

Paris Agreement main objective (2015) (Current Policies (CP))

To limit warming well below 2°C and pursue limiting it to 1.5°C

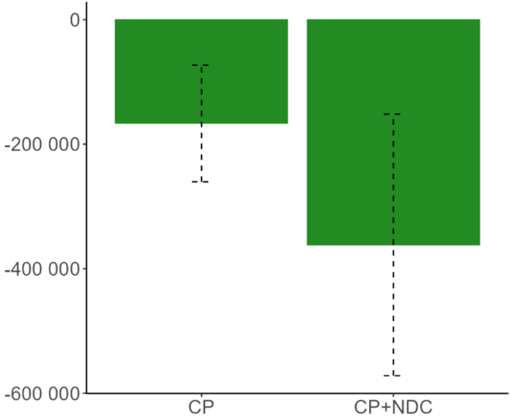
Climate policies overview

Paris Agreement main objective (2015) (Current Policies (CP))

To limit warming well below 2°C and pursue limiting it to 1.5°C

Post-Glasglow Contributions (2021) (Nationally Determined Contributions (NDC))

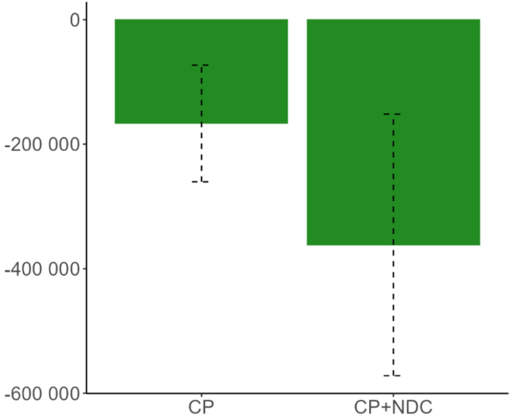
To revisit and strengthen the countries 2030 emissions reduction targets



By 2030, 166623 (72789 - 260347 95% CI) annual avoided premature deaths due to the CP, and 361744 (151698 - 571779 95% CI) avoided premature deaths due to the NDC

Sampedro et al. (2023)

Climate policies pathways



By 2030, 166623 (72789 - 260347 95% CI) annual avoided premature deaths due to the CP, and 361744 (151698 - 571779 95% CI) avoided premature deaths due to the NDC

To apply the NDC over the CP, avoids 195121 premature deaths

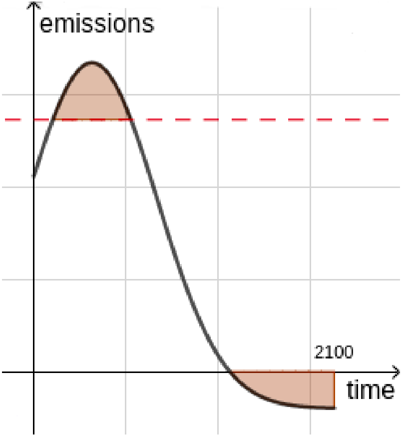
Sampedro et al. (2023)

Climate policies pathways

Temperature increase	Carbon budgets ($GtCO_2$)
Range around 1.5°C	200, 300, 400, 500, 600, 700, 800, 900
Range around 1.5-2°C	1000, 1200, 1400, 1600, 1800, 2000
Higher budgets	2500, 3000

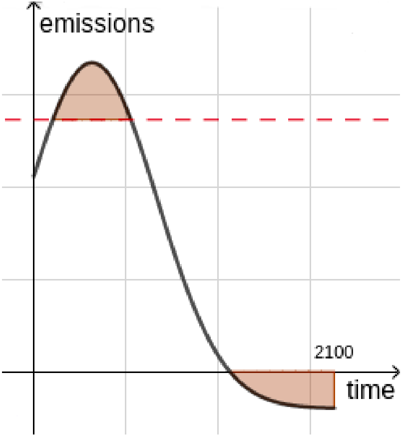
Table 1: Source: Riahi et al. (2021)

Climate policies pathways



Overshooting climate policy

end-of-century



Overshooting climate policy
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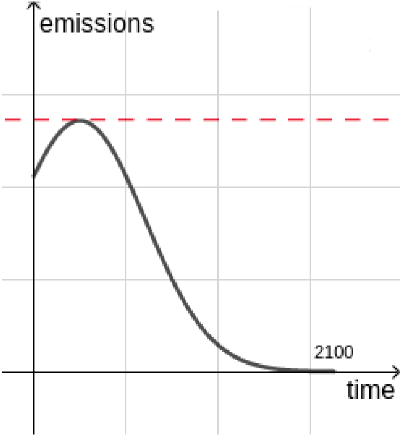
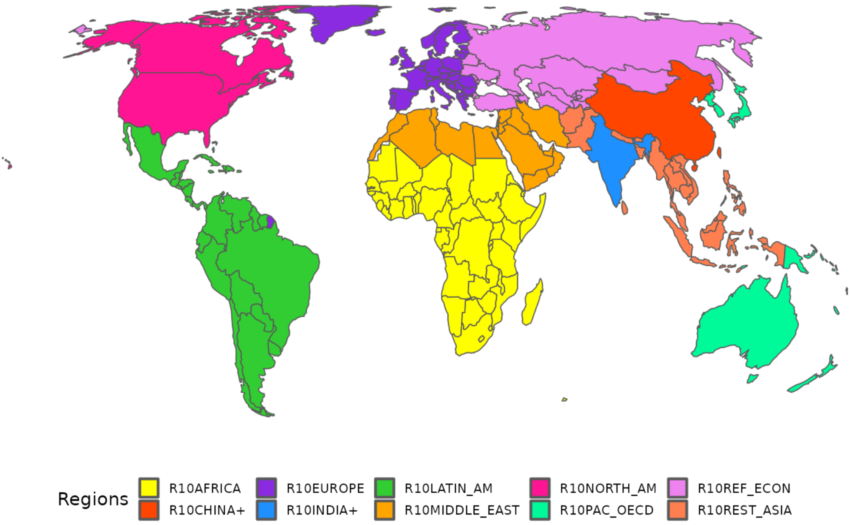


Non-overshooting climate policy
net-zero

How can we compute the air pollution damage?

Computational Flow

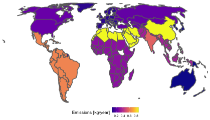


Computational Flow

Detailed database

Detailed database

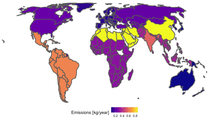
Estimated emissions



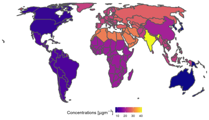
Detailed database

Chemical model

Estimated emissions



Computed concentrations



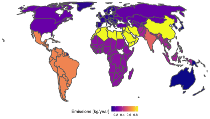
Computational Flow

Detailed database

Chemical model

Impact functions

Estimated emissions



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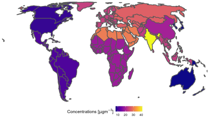
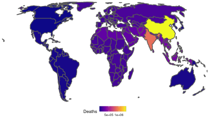
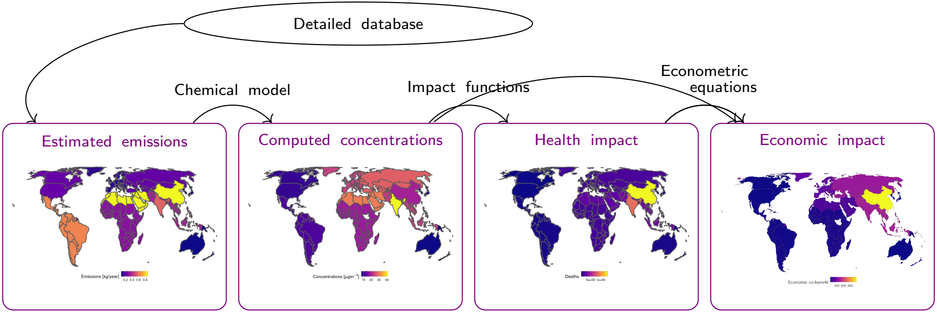
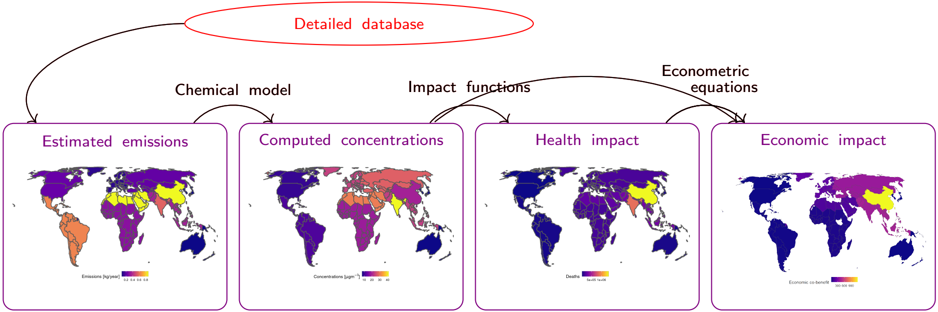


Health impact




Detailed database
Chemical model
Impact functions
Econometric equations
Estimated emissions
Computed concentrations
Health impact
Economic impact
Emissions [kg/year]
Concentrations
Deaths
Economic co-benefit

Computational Flow



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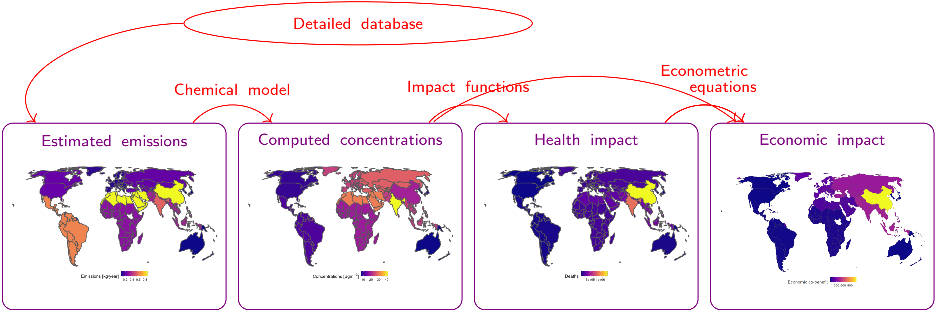

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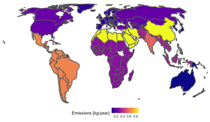

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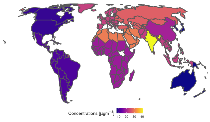

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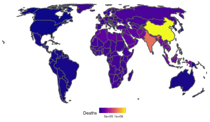
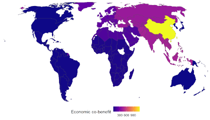
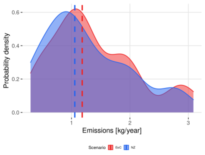
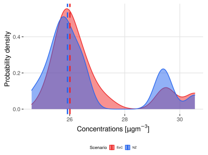
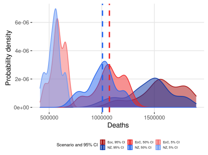


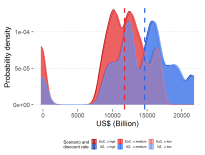
Economic impact











Four methods to compute the air pollution health damage

Value of Statistical Life (VSL)

$$VSL_{i,t} = VSL_{R10EUROPE,2005} \cdot \left(\frac{GDPpc_{i,t}}{GDPpc_{R10EUROPE,2005}} \right)^{\alpha}, \quad \alpha \in \{0.8, 1, 1.2\}$$

$$i \in \{\text{region}\}$$

$$t \in \{\text{year}\}$$

OECD (2012); Roy et al. (2015); Reis et al. (2022)

Value of Statistical Life (VSL)

$$VSL_{i,t} = VSL_{R10EUROPE,2005} \cdot \left(\frac{\overset{\text{GDP per capita}}{GDPpc_{i,t}}}{GDPpc_{R10EUROPE,2005}} \right)^{\overset{\text{elasticity}}{\alpha}}, \quad \alpha \in \{0.8, 1, 1.2\}$$

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OECD (2012); Roy et al. (2015); Reis et al. (2022)

Value of Statistical Life (VSL)

region	year	GDP [billion US$2010/yr]	population [nº people]
R10AFRICA	2030	6690.474	1690667000
R10CHINA+	2030	38588.497	1416996000
R10EUROPE	2030	21838.421	500700000
R10INDIA+	2030	14680.280	1593797000
R10LATIN_AM	2030	13126.332	693664000
R10MIDDLE_EAST NZ	2030	9314.170	576311000
R10NORTH_AM	2030	24351.917	424540000
R10PAC_OECD	2030	7567.581	210367000
R10REF_ECON	2030	6518.265	320831000
R10REST_ASIA	2030	13674.476	1411653000
R10EUROPE	2005	16598.317	512050000

$$VSL_{R10EUROPE,2005} = 0.00342$$

Value of Statistical Life (VSL)

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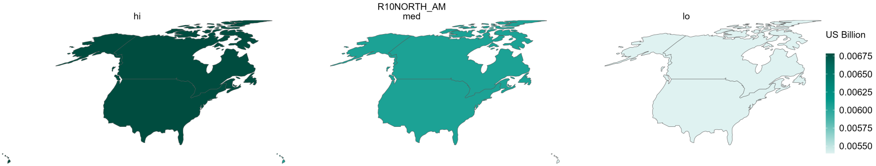

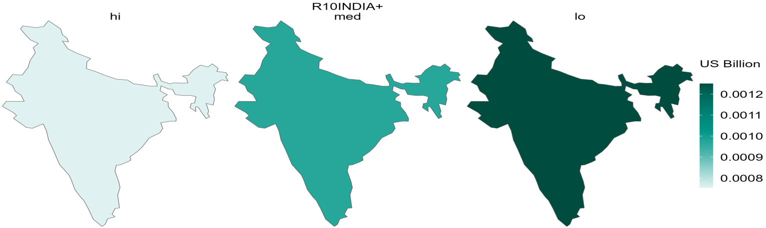

Value of Statistical Life (VSL)

$$AvoidedDamage_{i,t,p} = (VSL_{i,t,p} \cdot \Delta Mort_{i,t,p}) - (VSL_{i,t,REF} \cdot \Delta Mort_{i,t,REF})$$

$$i \in \{\text{region}\}, t \in \{\text{year}\}, p \in \{\text{policy}\}$$

Value of Statistical Life (VSL)

Premature Mortality
due to $PM_{2.5}$ & O_3

$$AvoidedDamage_{i,t,p} = (VSL_{i,t,p} \cdot \Delta Mort_{i,t,p}) - (VSL_{i,t,REF} \cdot \Delta Mort_{i,t,REF})$$

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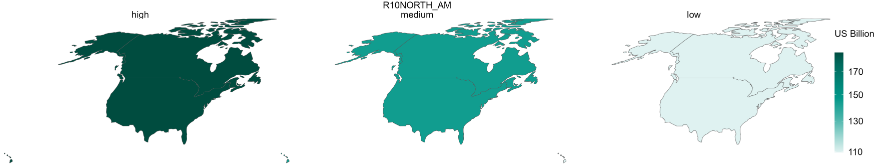

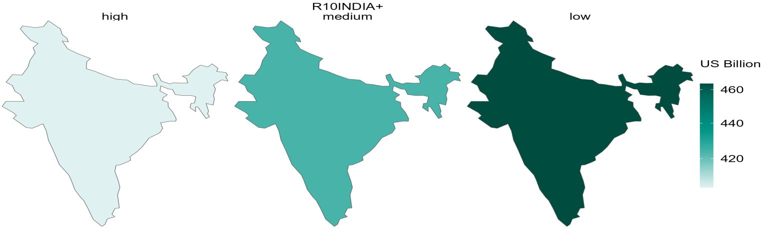

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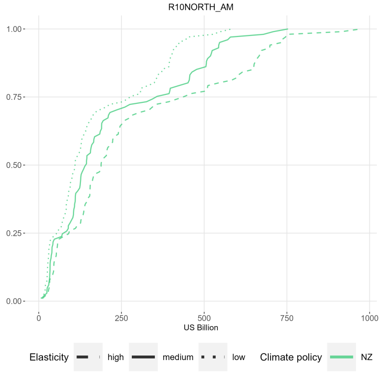

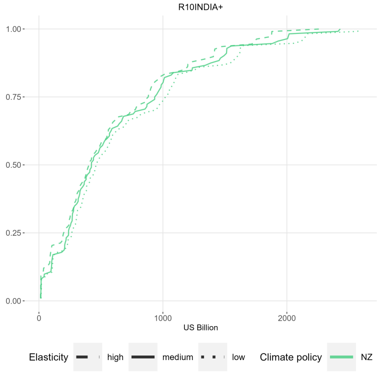

Human Capital Loss (HCL)

$$HCL_{i,t} = HC_{i,t} \cdot \Delta Mort_{i,t}$$

Liu et al. (2011); Zhao et al. (2022)

Human Capital Loss (HCL)

$$\overset{\text{Human Capital}}{\downarrow} \qquad \overset{\text{Premature Mortality due to PM}_{2.5}\text{, adults}}{\downarrow}$$

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Human Capital Loss (HCL)

$$HCL_{i,t} = \underbrace{HC_{i,t}}_{\text{Human Capital}} \cdot \underbrace{\Delta Mort_{i,t}}_{\text{Premature Mortality due to } PM_{2.5}\text{, adults}}$$

where,

$$HC_{i,t} = \sum_{i=1}^{t} GDP_{i,t} \cdot \left(\frac{1+\gamma}{1+\alpha}\right), \quad \alpha \in \{0.6, 0.8, 1\}$$

$$i \in \{\text{region}\}$$

$$t \in \{\text{year}\}$$

Liu et al. (2011); Zhao et al. (2022)

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Human Capital

Premature Mortality due to $PM_{2.5}$, adults

$$HCL_{i,t} = HC_{i,t} \cdot \Delta Mort_{i,t}$$

where,

GDP annual growth

$$HC_{i,t} = \sum_{i=1}^{t} GDP_{i,t} \cdot \left(\frac{1+\gamma}{1+\alpha}\right), \quad \alpha \in \{0.6, 0.8, 1\}$$

Human Capital

elasticity

$i \in \{\text{region}\}$

$t \in \{\text{year}\}$

Liu et al. (2011); Zhao et al. (2022)

Human Capital Loss (HCL)

$$AvoidedDamage_{i,t,p} = (GDP_{i,t,REF} - HCL_{i,t,REF}) - (GDP_{i,t,p} - HCL_{i,t,p})$$

$$i \in \{\text{region}\}, t \in \{\text{year}\}, p \in \{\text{policy}\}$$

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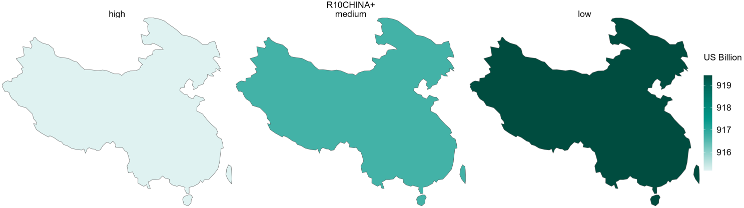

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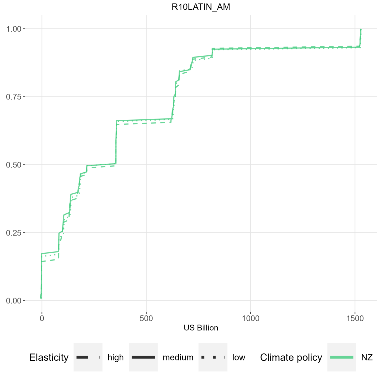

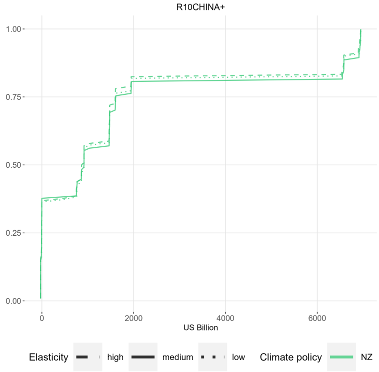

Dechezleprêtre et al. 2019

$$\Delta lnGDPi,t = \gamma_1 \Delta AP_{i,t} + \gamma_2 \Delta f(W_{i,t}) + \Delta\nu_{i,t} + \Delta\varepsilon_{i,t}$$

$$i \in \{\text{region}\}$$
$$t \in \{\text{year}\}$$

Dechezleprêtre et al. 2019

GDP per capita

flexible function

random disturbance term

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$PM_{2.5}$ concentration

fixed region-year effects

$i \in \{\text{region}\}$

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Dechezleprêtre et al. 2019

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$PM_{2.5}$ concentration

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$$\Delta lnGDP_{i,t} = \gamma_{i,t} \Delta AP_{i,t}$$

Dechezleprêtre et al. (2019)

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fixed region-year effects

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Taylor aproximation

$$\Delta lnGDP_{i,t} = lnGDP_{i,t,p1} - lnGDP_{i,t,p2} \approx \frac{lnGDP_{i,t,p1} - lnGDP_{i,t,p2}}{lnGDP_{i,t,p2}}$$

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$PM_{2.5}$ concentration

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$PM_{2.5}$ concentration

fixed region-year effects

$i \in$ region, $t \in \{\text{year}\}$

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elasticity

$$\gamma_{i,t} = \gamma_{R10EUROPE,2015} \cdot \left(\frac{GDPpc_{i,t}}{GDPpc_{R10EUROPE,2015}} \right)^{\alpha}, \quad \alpha \in \{0.8, 1, 1.2\}$$

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R10INDIA+	2030	14680.280	1593797000
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R10MIDDLE_EAST NZ	2030	9314.170	576311000
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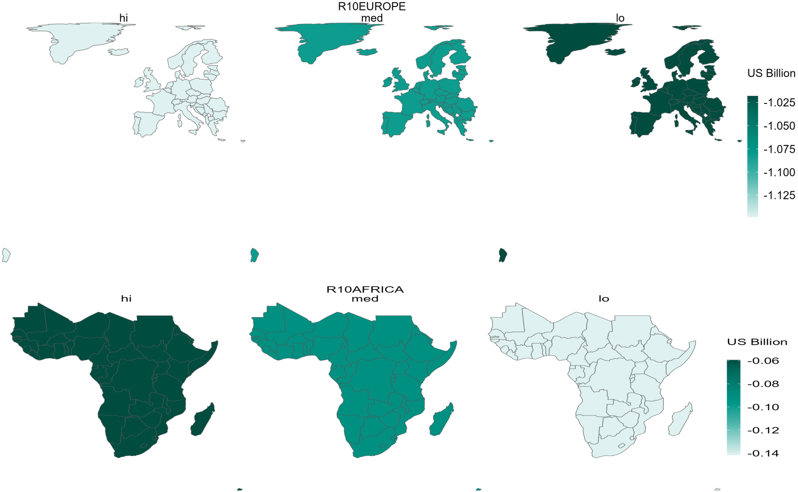
R10PAC_OECD	2030	7567.581	210367000
R10REF_ECON	2030	6518.265	320831000
R10REST_ASIA	2030	13674.476	1411653000
R10EUROPE	2015	18804.280	512822000

$$\gamma_{R10EUROPE,2015} = -0.8$$

Dechezleprêtre et al. 2019

$$\gamma_{i,t} = \gamma_{R10EUROPE,2015} \cdot \left(\frac{GDPpc_{i,t}}{GDPpc_{R10EUROPE,2015}} \right)^{\alpha}$$

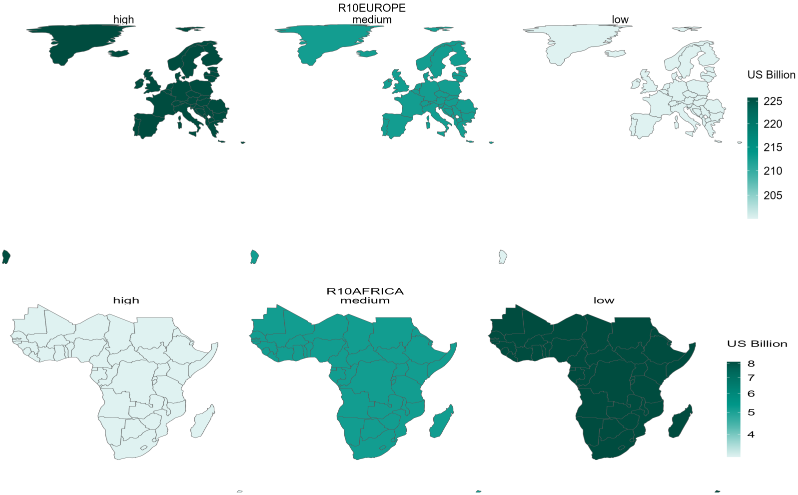


$$AvoidedDamage_{i,t,p} = GDP_{i,t,REF} \cdot \gamma_{t,i} \cdot (AP_{i,t,p} - AP_{i,t,REF})$$

$$i \in \{\text{region}\}, t \in \{\text{year}\}, p \in \{\text{policy}\}$$

Dechezleprêtre et al. 2019

$$\Delta lnGDP i, t = \gamma_{i,t} \Delta AP_{i,t}, \ \gamma_{i,t} = \gamma_{R10EUROPE,2015} \cdot \left(\frac{GDPpc_{i,t}}{GDPpc_{R10EUROPE,2015}} \right)^{\alpha}$$



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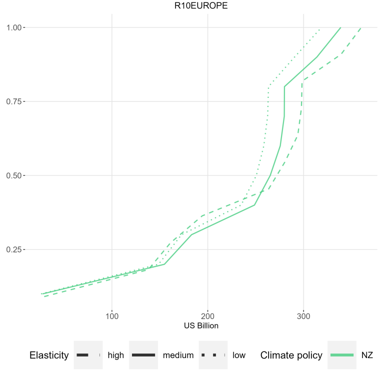

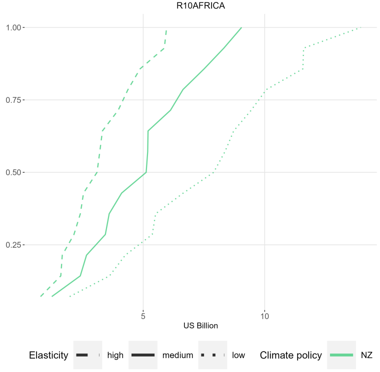

Dong et al. 2021

$$GDPgrowth_{i,t} = \beta_1 AP_{i,t} + \beta_2 s_i + \beta_3 \nu_t + \varepsilon_{i,t}$$

$i \in \{\text{region}\}$

$t \in \{\text{year}\}$

Dong et al. (2021)

Dong et al. 2021

$$\underbrace{GDPgrowth_{i,t} = \beta_1 \overset{\text{PM}_{2.5}\text{ concentration}}{AP_{i,t}} + \beta_2 \underset{\text{fixed regional effects}}{s_i} + \beta_3 \overset{\text{fixed time effects}}{\nu_t} + \underset{\text{random disturbance term}}{\varepsilon_{i,t}}}$$

$i \in \{\text{region}\}$

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Dong et al. (2021)

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PM$_{2.5}$ concentration

fixed time effects

fixed regional effects

random disturbance term

$i \in$ region, $t \in \{\text{year}\}$

$$GDPgrowthNEW_{i,t} = GDPgrowthBASE_{i,t} + \beta_{i,t} AP_{i,t}$$

Dong et al. (2021)

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Dong et al. (2021)

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elasticity

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Dong et al. (2021)

Dong et al. 2021

region	year	GDP [billion US$2010/yr]	population [nº people]
R10AFRICA	2030	6690.474	1690667000
R10CHINA+	2030	38588.497	1416996000
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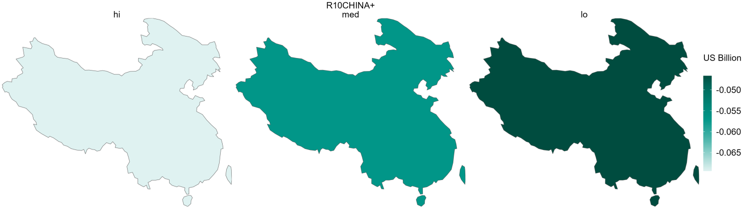
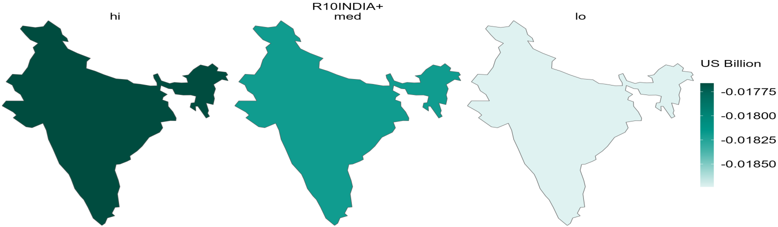
R10REST_ASIA	2030	13674.476	1411653000
R10CHINA	2015	18548.173	1433079780

$$\beta_{R10CHINA,2015} = -0.02108$$

Dong et al. 2021

$$\beta_{i,t} = \beta_{R10CHINA,2015} \cdot \left(\frac{GDPpc_{i,t}}{GDPpc_{R10CHINA,2015}} \right)^{\alpha}$$





$$GDPnew_{i,t} = GDPbase_{i,t} \cdot (1 + GDPgrowthNEW_{i,t})$$

$$AvoidedDamage_{i,t,p} = GDPnew_{i,t,p} - GDPnew_{i,t,REF}$$

$$i \in \{\text{region}\}, t \in \{\text{year}\}, p \in \{\text{policy}\}$$

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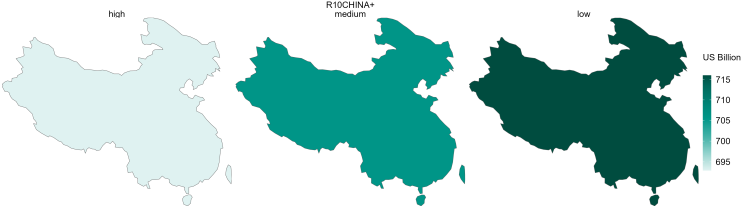

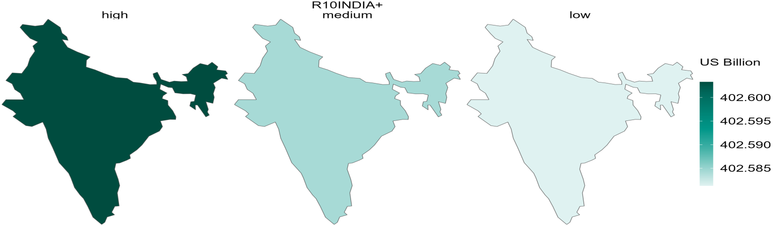

Dong et al. 2021

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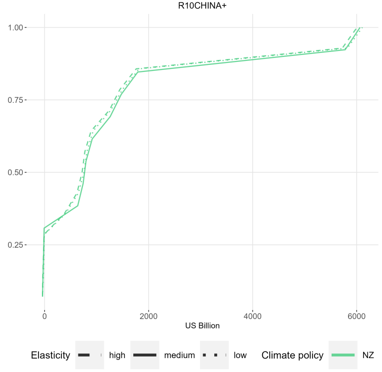

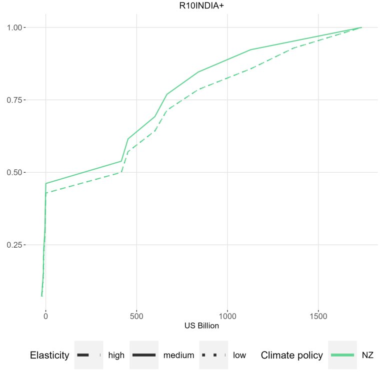

Recap

Detailed database

↓

Estimated emissions

↓

Computed $PM_{2.5}$ and O_3 concentrations

↓

Premature deaths

↓

Economic damages

Dechezleprêtre et al.

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Dong et al.

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VSL

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HCL

$$HCL_{i,t} = HC_{i,t} \cdot \Delta Mort_{i,t}$$

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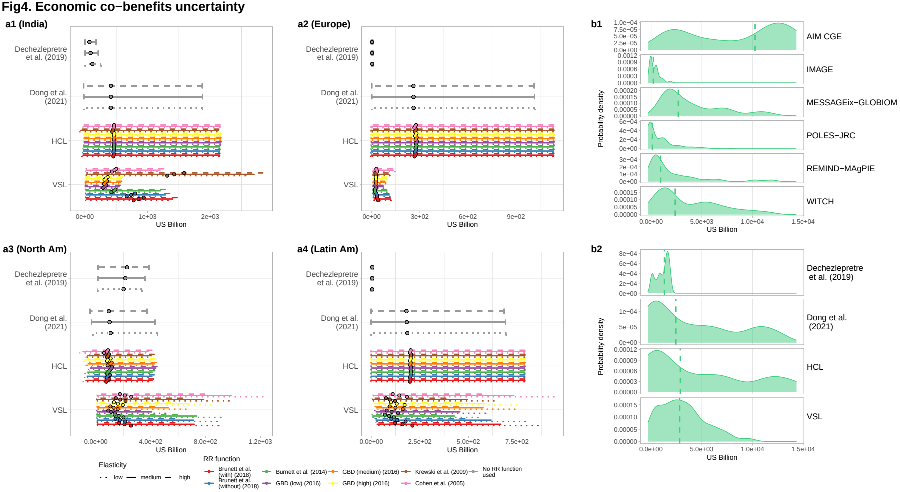
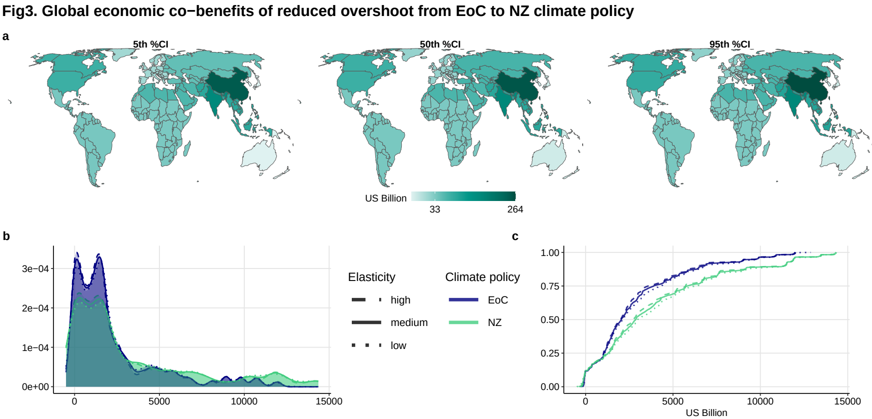
Four Statistical methods to analyze the results

Sensitivity analysis

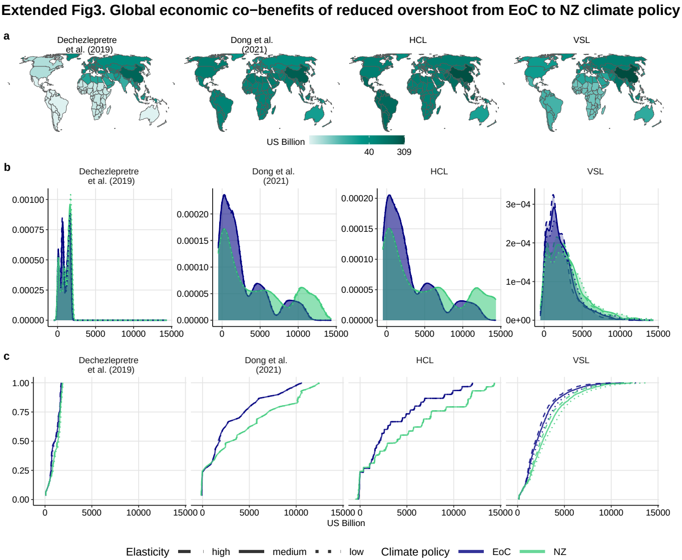


Rodés-Bachs et al. (2023)

Probability distribution & Cummulative frequency graphs



Rodés-Bachs et al. (2023)



Rodés-Bachs et al. (2023)

Binomial distribution

Our random variable

Num trials

Probability of success on each trial

$$X \sim \mathrm{Bin}(n, p)$$

Is distributed as a

Binomial

With these parameters

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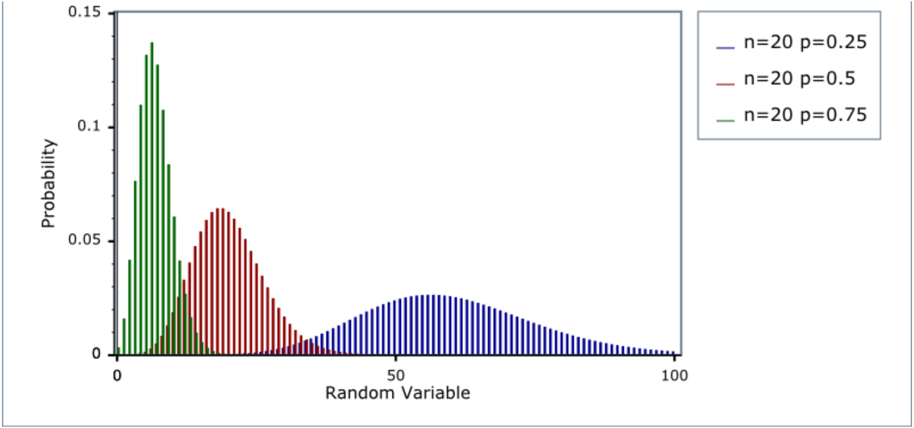

Definition: heavy-tailed probability distribution, Foss et al. (2013)

A probability distribution $F(x)$ is heavy-tailed if and only if

$$\int_{\mathbb{R}} e^{\lambda x} F(x) dx = \infty, \ \forall \lambda > 0.$$

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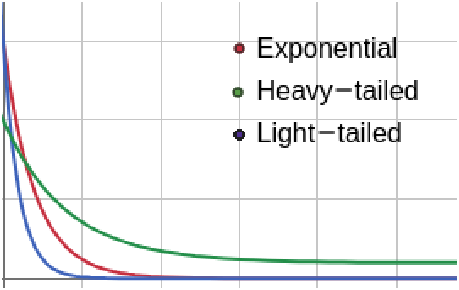
Intuitively:



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We can relay on a finite sample argument relative to the binomial random behavior of threshold exceedances.

Consider the sequence of economic damage for a given region and year:

$$X_t^1, X_t^2, X_t^3, ..., X_t^n,\ \ t \in \{2020, 2030...\}$$

Outliers analysis

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Consider a *high* thereshold h given by the 90^{th} percentile of the economic damages of that region

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Consider the probability of exceeding the thereshold value h:

$$p = P(X_t^i > h) \, \forall i \in \{1, ..., n\}$$

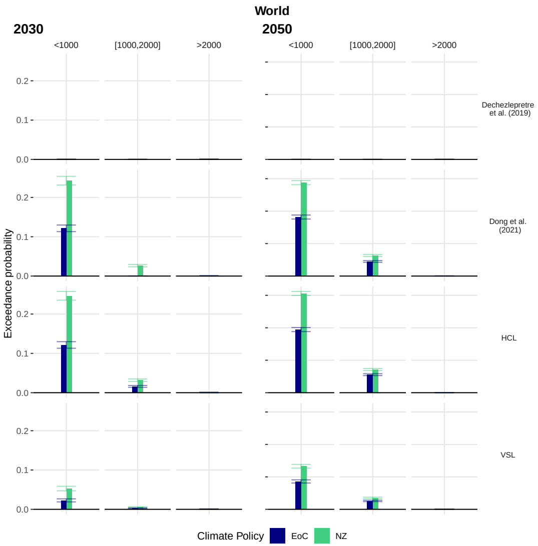
Assume that this are observations from independent random variables.

Thus,

$$\sum_{i=1}^{n} \mathbb{1} \left(X_t^{(i)} > h \right) \sim \mathrm{Bin}(n, p)$$

i.e., the number of exceedances on n trials follows a binomial distribution with success probability p.

Outliers analysis



Rodés-Bachs et al. (2023)

Kolmogorov-Smirnov test

Consider two distribution functions.

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In a more formal way:

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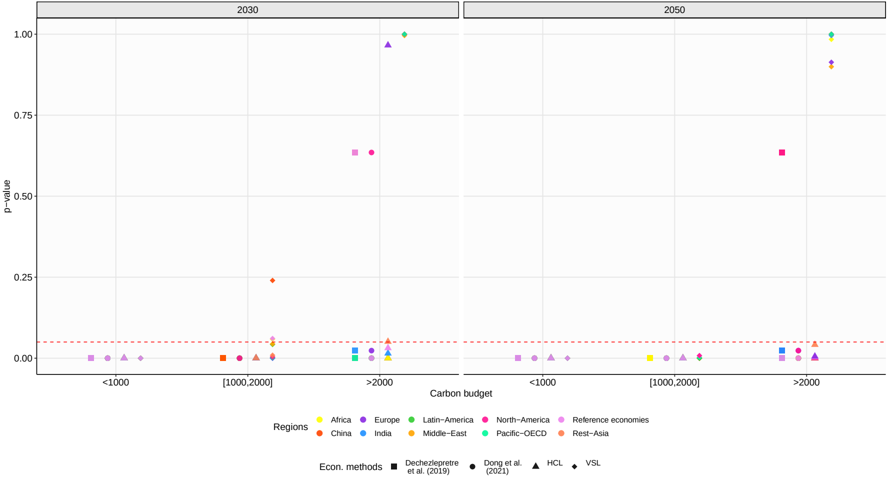
which is equivalent to

$$\begin{cases} H_0: & \text{NZ and EoC climate policies have the } \textbf{same} \text{ distribution function,} \\ H_1: & \text{NZ and EoC climate policies have the } \textbf{different} \text{ distribution function} \end{cases}$$

Kolmogorov-Smirnov test



Rodés-Bachs et al. (2023)

Summary & Discussion

- Does *net-zero* climate policy have significantly more co-benefits for air pollution damages outcomes?

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Summary & Discussion

- ⋆ Does *net-zero* climate policy have significantly more co-benefits for air pollution damages outcomes?
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- ⋆ What contributes more to the uncertainty in air pollution economic outcomes: emissions uncertainty, impact functions uncertainty, econometric equations, or the elasticity choice?
- ⋆ How does the *net-zero* climate policy affect the tails' heaviness?
- ⋆ Which regions will benefit the most from the *net-zero* climate policy? And when will these benefits be more tangible, in the near term or in the mid-century?

Master Thesis Proposal

IHME database (https://vizhub.healthdata.org/gbd-compare/)

Analysis of health impacts attributable to household air pollution associated with alternative futures

The **objective** of this internship is to develop an **econometric model** to calculate future household air pollution and its subsequent impacts.

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Prerequisites:

- Advanced experience in econometrics and econometric-software (ideally R)
- Panel data analysis
- Data processing, curation, and visualization (large databases)
- Spanish knowledge

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If you are interested, see the full proposal here and write at `jon.sampedro@bc3research.org` and `inaki.arto@bc3research.org`

Thank you for your attention!!

Questions?

claudia.rodes@bc3research.org

Basith, S., Manavalan, B., Shin, T. H., Park, C. B., Lee, W.-S., Kim, J., and Lee, G. (2022). The impact of fine particulate matter 2.5 on the cardiovascular system: A review of the invisible killer. *Nanomaterials*, 12(15):2656. Publisher: MDPI.

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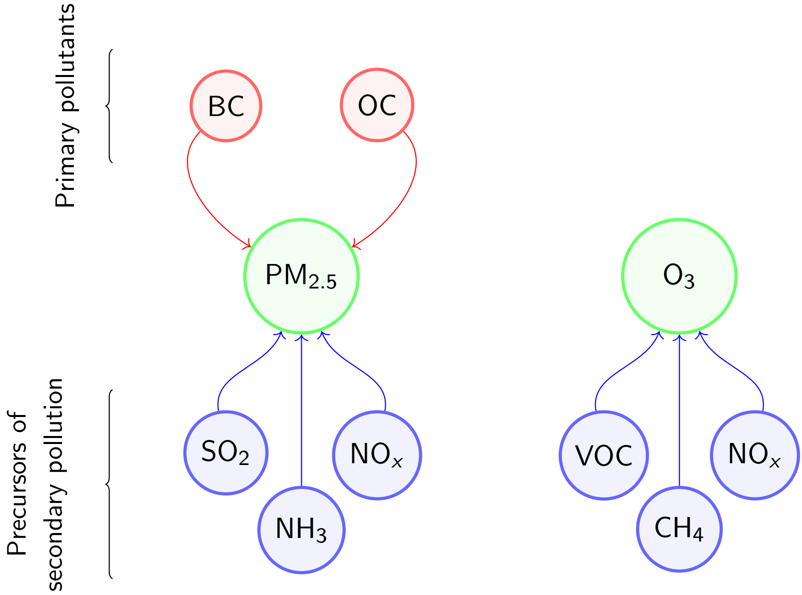
Extra Slides

Pollutants main precursors



Health impacts (mortality) equations

$$\Delta Mort = y_0 \cdot PAF \cdot pop$$
$$PAF = \frac{RR-1}{RR}$$

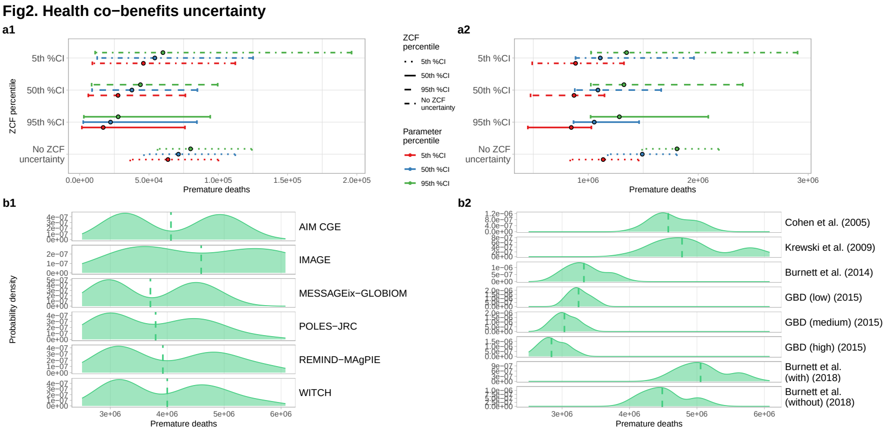
$$GEMM(X) = \exp\left\{\frac{\theta \log\left(\frac{z}{\alpha+1}\right)}{1+\exp\{-\frac{z-\mu}{\nu}\}}\right\},$$
$$z = X - \min(X)$$

$$LL(X) = \exp\{\beta(X - X_0)\}$$

time

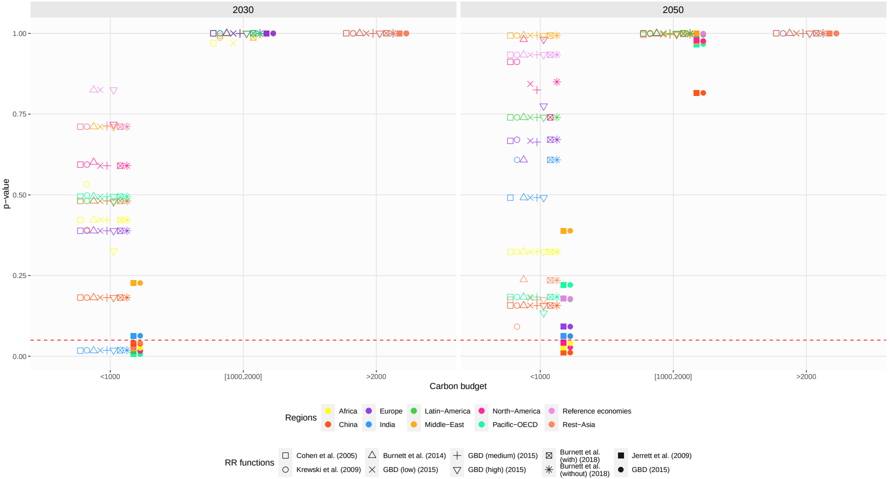
$$IER(X) = 1 - \nu(1 - \exp\{-\omega z^{\delta}\}),$$
$$z = \max(0, X - X_0)$$

Health impacts uncertinaty



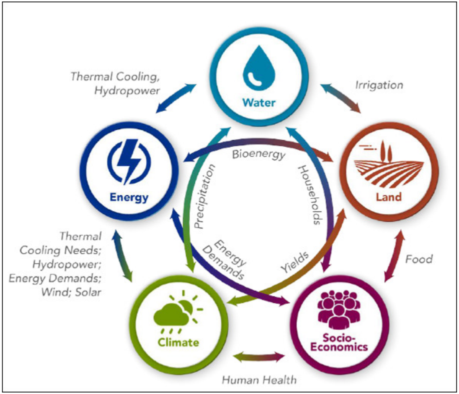
Rodés-Bachs et al. (2023)

Health impacts Kolmogorov-Smirnov test



Rodés-Bachs et al. (2023)

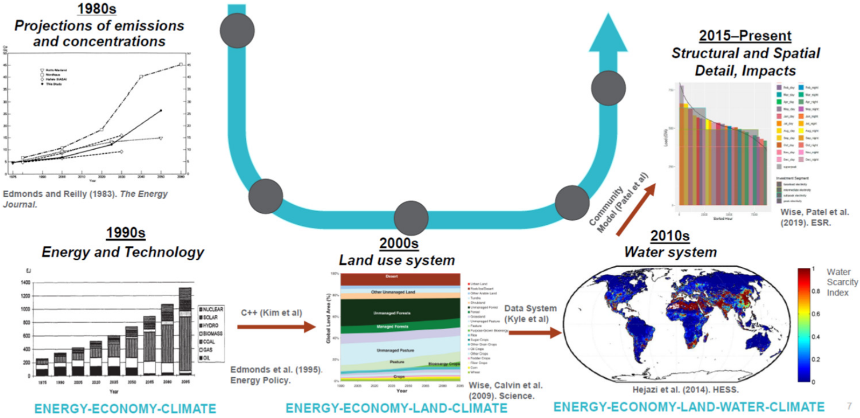
The Global Change Analysis Model (GCAM) in a figure:



Source: `https://github.com/JGCRI/gcam-doc`

- The Global Change Analysis Model (GCAM) is an open-source community model developed by Joint Global Change Research Institute (JGCRI) (University of Maryland, MA, USA)
- It is a partial-equilibrium, multisector, integrated assessment model designed to explore human and Earth-system dynamics
- GCAM analyses the interdependencies between global energy, AFOLU, water, emissions, and climate systems within a single computational platform from now to 2100
- The model has been widely used for IPCC scenarios, SSP pathways, and several multisector multiscale studies and reports

GCAM evolution



Source: `https://github.com/JGCRI/gcam-doc`

GCAM inputs and outputs

KEY ASSUMPTIONS

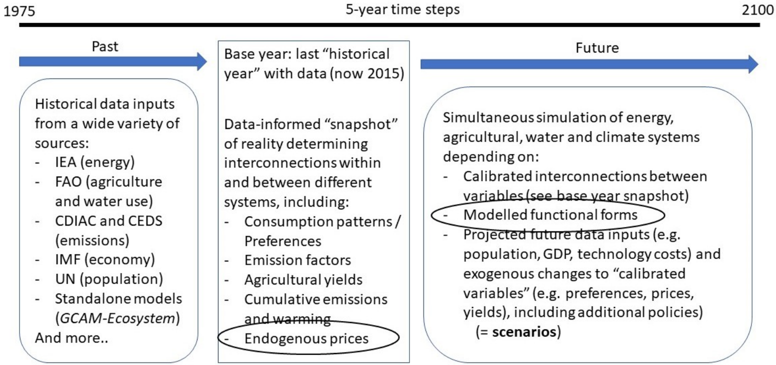
- Socieconomics:
  - Population
  - GDP growth
- Costs / efficiencies for energy technologies
- Agricultural/land costs, crop yields, profitability, water/fertilizer requirements and carbon contents
- Water runoff/availability
- Depletable and renewable resource supply curves
- Policies in place:
  - Emission constraints
  - Temperature limits
  - Renewables / efficiency targets
  - Land constraints / afforestation targets

OUTCOMES

- ENERGY SYSTEM:
  - Demand and flows
  - Technology mix by sector
  - Energy prices
- AFOLU:
  - Land allocation
  - Forest and agricultural production by crop
  - Commodity prices
  - Food/Feed balances
- WATER:
  - Water withdrawals/consumption by region for all uses (e.g. irrigation or municipal)
- EMISSIONS:
  - GHG and air pollutant emissions by region/sector/tech (24 species)
- CLIMATE:
  - Radiative forcing / temperature increase
  - CO_2 concentrations
  - +Land/Ocean metrics (HECTOR)
- ECONOMY
  - Policy Costs
  - Carbon prices

Source: `https://github.com/JGCRI/gcam-doc`

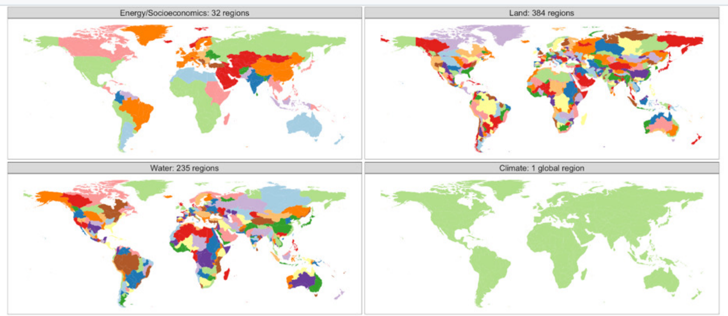
GCAM temporal scale and strucutre



Source: `https://github.com/JGCRI/gcam-doc`

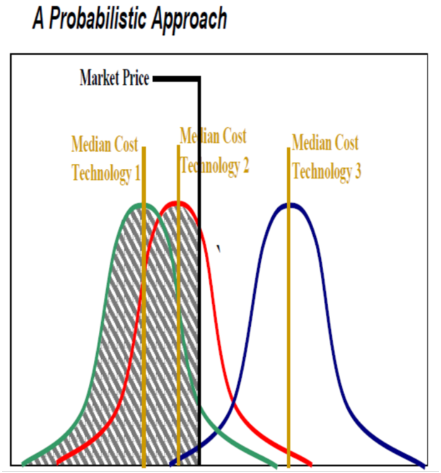
GCAM spatial layers

- The core version of GCAM divides the entire World in 32 geopolitical regions and 235 water basins
- The land regions (384) are the intersection between regions and water basins
- There is a single global region for climate system impacts



Source: `https://github.com/JGCRI/gcam-doc`

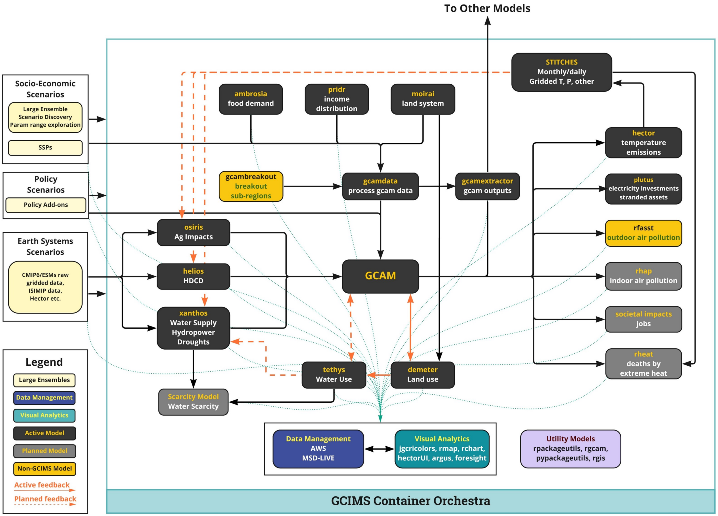
GCAM prices, competition, and funcional forms



- Calibrated logit approach assumes a distribution of realized costs due to heterogeneous conditions
- Market share based on probability that a technology has the least cost for an application, avoiding a "winner take all" result
- Historical calibration influences future competition through the "share-weight"

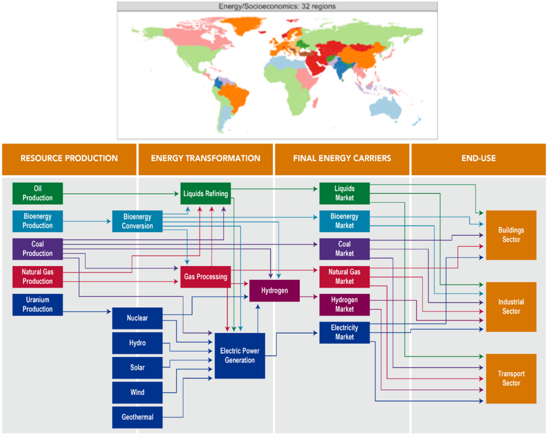
Source: `https://github.com/JGCRI/gcam-doc`

GCAM ecosystem



Source: `https://github.com/JGCRI/gcam-doc`

GCAM Energy system



Source: `https://github.com/JGCRI/gcam-doc`

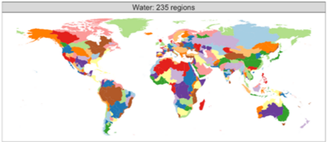
- ⋆ Regional Energy production, transformation, and end-use demand are based on economic functions of resources, technologies, prices, population, and income
- ⋆ Energy transformation and end-use consumption are represented by specific, bottom-up technologies in most sectors

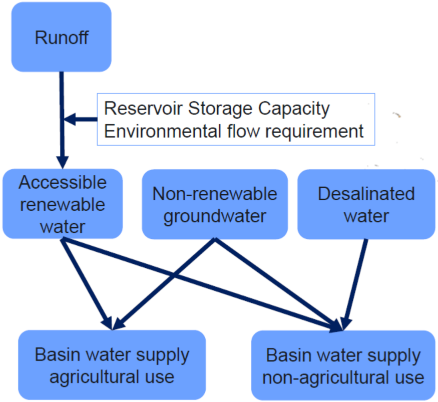
GCAM Land system

Source: `https://github.com/JGCRI/gcam-doc`

- ⋆ All land cover and use, including all commercial land uses as well as non-commercial natural lands, are represented in GCAM
- ⋆ These land categories are represented in each of the 384 land regions (where applicable) and calibrated to match a historical base year
- ⋆ Economics drive future changes in cropland, pasture, forest, and other land uses

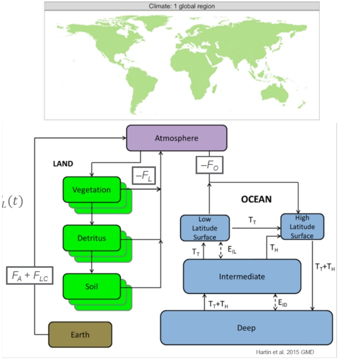
GCAM Water system

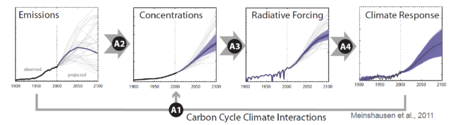




Source: `https://github.com/JGCRI/gcam-doc`

- ⋆ Runoff from Xanthos model with global climate data
- ⋆ Non-renewable groundwater/depletable resource curves
- ⋆ Water supply and demand are economically-balanced in each river basin





Source: `https://github.com/JGCRI/gcam-doc`

- GCAM passes emissions to Hector:
  - Fossil CO_2 (FA)
  - Land-Use CO_2 (FLC)
  - CH_4
  - N_2O
  - 26 halo-carbons
  - Pollutants: SO_2, CO, NO_x, $NMVOC$s, BC, OC
- Hector computes atmospheric CO_2 concentrations, radiative forcing (direct and indirect), temperature change, air-land/sea fluxes, ocean heat flux