Towards a better representation of inequality and sustainable development in IAMs

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+ the REMIND & MAgPIE teams

ENGAGE Final Workshop 2019
Global distribution of income

Absolute poverty line: $1.25 / day (2005 PPP)

Approx. 10% of the global population in absolute poverty.

Both inequality between and within countries matters.

Inequality in IAMs

Layers of inequality & current modelling status:
• between generations (discounting)
• within generations, between countries (country groups)
• within generations, within countries (income distribution)

Steps towards representing inequality:

1) Ex-post analysis (today):
   - distributional effects of mitigation costs / damages
   - connection to SDGs

2) Represent income distribution in IAMs (“work in progress”)

3) Energy + food demand scenarios by income group
Climate change, inequality & sustainable development

IPCC 1.5°C Special Report

Four illustrative model pathways

In pathways limiting global warming to 1.5°C with no or limited overshoot as well as in pathways with a high overshoot, CO₂ emissions are reduced to net zero globally around 2050.

Global total net CO₂ emissions

Billions of CO₂/yr

IPCC 1.5°C Special Report

Global inequality in different scenarios

Year

Gini index

SSP1 - SSP2 - SSP3 - SSP4 - SSP5

2020 2030 2040 2050

Carbon price vs. energy access

Climate impacts & bioenergy vs. food prices

mitigation costs & climate impacts as poverty trap

Sustainable Development Pathways?

7. Affordable and clean energy

2. No hunger

1. No poverty

+ many more
Mitigation pathways & sustainable development

Mitigation pathways

- Economic growth
- Energy and food prices → regressive
- Carbon price revenue → progressive

Income distribution

Change in distribution of real income, i.e. after increased energy/food expenditures and revenue recycling

SDG indicators

Income/cap & Gini are key drivers for:
- poverty rates
- energy access
- food security
- ...

Global total net CO₂ emissions

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Four illustrative model pathways

Income distribution

SDG indicators

Income/cap & Gini
REMIND/MAgPIE modelling framework

REMIND

- Welfare
  - Macro-economic Module
    - Energy System Module
      - Energy System Costs
        - Fuel Costs
        - Investments
        - O&M Costs
      - Energy Transformation Technologies
        - Resource and Potential Constraints
        - Emissions
          - GHG and aerosol concentrations; Temperature
          - agriculture and forestry bioenergy supply
  - Output
    - Trade
      - Capital
      - Labor
      - Final Energy
      - Exogenous Data
        - Labor Efficiency
        - Energy Efficiency

(MAGPIE) Bioenergy price, CO₂ price, bioenergy demand

(MAGPIE) Bioenergy price

(REMIND) Bioenergy price, CO₂ price, bioenergy demand

(Dietrich et al. 2018)

(e.g. Luderer et al. 2015)
Example scenario: SSP2 1.5°C

NB: Here for a globally uniform carbon price. Results will depend on burden sharing regime.
Distributional effects – “real income” approach

Increased energy/food expenditures reduce real income; effect stronger for low-income groups.

- Food / energy expenditures:
  \[ \text{exp.} \propto y^\alpha \]
  - income elasticity \( \alpha \) here: \( \alpha = 0.8 \) for energy,
    \( \alpha = 0.5 \) for food
  
- Recycling of carbon price revenue
  
- Compute “real income” Gini from distribution of \((y - \text{exp.} + \text{rev.rec.})\)
Linking income and Gini to SDG objectives

Logistic regression model for SDG objectives ($x = \text{GDP/cap.}, \ G = \text{Gini}$):

$$\log \frac{p_{it}}{1 - p_{it}} = \beta_0 + \beta_1 \log x_{it} + \beta_2 G_{it} + \beta_3 \log x_{it} \times G_{it} + \mu_i + \epsilon_{it}$$

Example: poverty threshold of $1.90/day

$\rightarrow p_{it} =$ fraction above poverty line

$R^2 = 0.93$
Projections for SDG 1 (SSP Baselines)

SDG 1 not even reached in SSP1 & SSP5 baselines.

Baseline SSP Gini scenarios: Rao et al. 2018
Projections for SDG 1: Mitigation scenario (SSP2 – 1.5°C)

Number of people in absolute poverty (global):

Without progressive use of carbon price revenue

Reduced rate of poverty reduction (+ 95 million people in 2030)
Effect mostly compensated from domestic revenues.
Projections for SDG 1: different SSPs – 1.5°C

**SSP1:** low baseline poverty, low mitigation pressure

**SSP2:** middle of the road scenario

**SSP5:** lowest baseline poverty, high mitigation pressure

SDG “side-effect” of mitigation depends on socioeconomic baseline
More research questions for this framework

- other SDG dimensions: energy access, food security, ...

- Co-benefits & trade-offs of different mitigation options (e.g. BECCS limit, demand-side, …)

- How to design burden sharing schemes (differentiated carbon prices + transfers) to minimize negative side-effects?

- Which other policies are required to go from a mitigation pathway to a sustainable development pathway?

- SDG side-effects of impacts vs. mitigation
Outlook: integrating inequality into IAMs

So far most IAMs include temporal and regional inequality, but not inequality within countries/regions.

Representing inequality:

→ assume lognormal income distribution ($\sigma \leftrightarrow \text{Gini}$)

→ standard isoelastic utility function (inequality aversion $\eta$)

→ analytically calculate social welfare function with inequality

→ effects of impacts/mitigation through moments of distribution (instead of quantiles)
Summary

- A better modelling of inequality is required both on the impacts and mitigation side.

- Distributional questions are at the core of many SDG objectives.

- First step: Ex-post analysis of mitigation pathways → effects on income distribution → connection to other SDG objectives → Example: SDG 1 – zero poverty → mitigation pathway vs. sustainable development pathway.

- Next levels: impacts and inequality, endogenously model income distribution within IAMs.
Scenarios for socio-economic drivers

Cannot predict socio-economic drivers (population, GDP,...) reliably until 2100 → work with **scenarios** (narratives, not predictions!)

Shared socio-economic pathways (SSPs):

- **SSP 1**: (Low Challenges) Sustainability
  - Taking the Green Road

- **SSP 4**: (Adapt. Challenges Dominate) Inequality
  - A Road Divided

- **SSP 2**: (Intermediate Challenges) Middle of the Road

- **SSP 3**: (High Challenges) Regional Rivalry
  - A Rocky Road

- **SSP 5**: (Mil. Challenges Dominate)
  - Fossil-fueled Development
  - Taking the Highway

O’Neill, Kriegler et al., 2017
Shared Socioeconomic Pathways

NB: SSPs are a valuable data set for global change studies beyond climate change.
Inequality under the SSPs: global Gini coefficient

Based on country-level Gini scenarios by Rao et al., 2018
Linking income and Gini to SDG objectives

Fraction of population above the poverty line

absolute poverty threshold: $ 1.90/day

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year
Linking income and Gini to SDG objectives

Logistic regression for fraction of population above the poverty line:

Coefficients:

|                      | Estimate  | Std Error | t value  | Pr(>|t|)    |
|----------------------|-----------|-----------|----------|-------------|
| (Intercept)          | -27.543020 | 1.916208  | -14.374  | < 2e-16     *** |
| log(gdppcap)         | 3.946146   | 0.229753  | 17.176   | < 2e-16     *** |
| Gini                 | 20.095888  | 4.509789  | 4.456    | 9.37e-06    *** |
| log(gdppcap):Gini    | -3.510272  | 0.562928  | -6.236   | 6.83e-10    *** |

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5583 on 924 degrees of freedom
Multiple R-squared: 0.94, Adjusted R-squared: 0.9312
F-statistic: 107.2 on 135 and 924 DF, p-value: < 2.2e-16
Example: SDG2 – zero hunger

![Graph showing the malnourished (BMI < 18.5) population over years for different scenarios and regions.]
REMIND energy sector

(Graphic: Jessica Strefler, PIK)
Example scenario: SSP2 – 1.5°C

CO₂ emissions

Primary Energy

BECCS
Example scenario: SSP2 – 1.5°C
Distributional effects – “real income” Gini

At country-level (assuming equal GDP/capita loss within region):

Without lump-sum transfer of tax revenues

Baseline: SSP
Gini scenarios
(Rao et al. 2018)
Distributional effects – “real income” Gini

At country-level (assuming equal GDP/capita loss within region):

With lump-sum transfer of full tax revenues

Baseline: SSP Gini scenarios (Rao et al. 2018)
Projections with mitigation effect included (SSP2 – 1.5°C)
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Distributional effects – “real income” approach

Increased energy/food expenditures reduce real income; effect stronger for low-income groups.

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Toy model for distributional effects

Total damage = 10% of GDP, damage ~ income$^\alpha$
Toy model for distributional effects

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