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# MESSAGEix-Transport/-GLOBIOM

## and the 2024 ScenarioMIP/SSP update

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# Outline

MESSAGEix-Transport

- Open source, finally
- About the model: purpose, requirements
- Development and calibration; `genno`
- Ongoing work & future directions

Shared Socioeconomic Pathways (SSPs) 2024 & ScenarioMIP

- Linked scenario processes
- ScenarioMIP, CMIP7, IPCC AR7
- SSP 2024 update
- Interpretation in MESSAGEix-GLOBIOM and -Transport

# MESSAGEix-Transport

# MESSAGEix-Transport code & data

## Open source—finally!

Docs: docs.messageix.org/models

Code & data: github.com/iiasa/message-ix-models

Issues and pull requests: (link)

# MESSAGEix-GLOBIOM model family I

Linear optimization (LP)-based integrated assessment models (IAMs):

- 'Integrative' of the full global energy-economic system.
- For 'assessment' of future scenarios (incl. climate policy) and their effects on global total emissions.
- Linked to MACRO (CGE), GLOBIOM (land use, via emulator).
- Spatial resolution: 12 regions.
- Temporal scope & resolution: 5- and 10-year periods to 2110.

A family because:

- Many model variants with similar but different structure: spatial scope/res.; sets of technologies; constraints.
- e.g. MESSAGEix-Nexus, MESSAGEix-Materials, MESSAGEix-Buildings.

# MESSAGEix-GLOBIOM model family II

`message-ix-models` —a Python package for code to build (set up structure + add data) → solve → report (postprocess) MESSAGEix-GLOBIOM scenarios.

- Free and open source since 2021.
- 14,000+ lines of Python code; submodules for model variants.
- Documentation, changelog, test suite, automated quality control (QC) and validation.
- Not *all* MESSAGEix-GLOBIOM applications and code (some still private), but a growing share.
- >1 'snapshot' of the base/global MESSAGEix-GLOBIOM available on Zenodo (docs).

# MESSAGEix-Transport: a variant in the family

MESSAGEix-GLOBIOM transport structure is aggregated/low resolution.

- Technologies like `t=elec_trp` = sum total of all transport modes, vehicle types, powertrains that input commodity `c=electr`.
- Input in [GW·y] of (final) energy; output in [GW·a] of 'useful energy'.
- Exogenous[1] `demand` projection for this useful energy.

MESSAGEix-Transport structure is (slightly) higher resolution.

- Transport `demand` expressed in PDT [km] or freight volume [t·km], projected using outside calculation, data sources, and models.
- Intermediate VDT [km] for 5 passenger and 2 freight modes.
- 1-10 technologies for each (service, mode) combo $\rightarrow$ distinct costs, efficiencies, constraints. `CAP`-acity variable measures vehicle stock [#]; `ACT`-ivity measures VDT.

[1] Aggregate price elasticity via MACRO.

# MESSAGEix-Transport

## Purpose and applications

These are most importantly varied—this is a tool meant to be used for multiple purposes—but include:

- Add transport sector detail to scenarios & reported/output data while retain the detail of MESSAGEix-GLOBIOM's scope & representation of energy supply, land use, other sectors.
- Provide aggregate outputs to calibrate the 'base' (`t=elec_trp`) representation.[2]
- Enable connections to transport literature and data:
  - Higher-resolution (if not "bottom-up") models, e.g. ITF-OECD 'PASTA'.
  - Data on stocks; techno-economics of technologies; mode share; etc. that is recognizable to iTEM participants.



[2] As in ScenarioMIP / SSP (2024)—second half of this talk.

# Development and calibration

- Initial data and structure from McCollum et al. (2017).
- New system for build and report portions of workflows.
- Workflow automation and testing.

These serve some process and usability goals:

1. Provide flexibility for the varied applications (above),
2. Enable repeatable, reproducible workflows.
3. Reduce development/maintenance burden and facilitate collaboration. (Only <2 FTE working on this implementation).

# Implementation detail: input data workflows

Often in model-building we need to set values of some parameter $C$ derived from other quantities like:

$$C_{s,t,n,y} = A \times B$$

- with dimensions like ‘s’cenario, ‘t’echnology, ‘n’ode (geo), ‘y’ear/period…
- e.g. total VDT [km/a] = vehicle stock [1] × average driving distance per vehicle per year [km/a]

What are the dimensions of $A$, $B$?

- Often we don’t have data at the desired resolution, e.g. only $A_{n,y}$ for a subset of all $y$.
- Or, we may apply assumptions to produce $B_s = k_{s,n,y}(...) \times B_{n,t}$.
- We may want to change these choices over time.

# genno: a library for *N*-D data workflows I

Describe calculations as atomic operations in either *dimension-agnostic* or dimensionally precise manner.

Generic:

```
c = genno.Computer()
c.eval("""
    Z = - (0.5 / (X ** 3))
    A = X ** 3 + Z
    B = A + A
    D = assign_units(B, "km")
    """)
```

Dimensionality and units of derived quantities are inferred automatically.

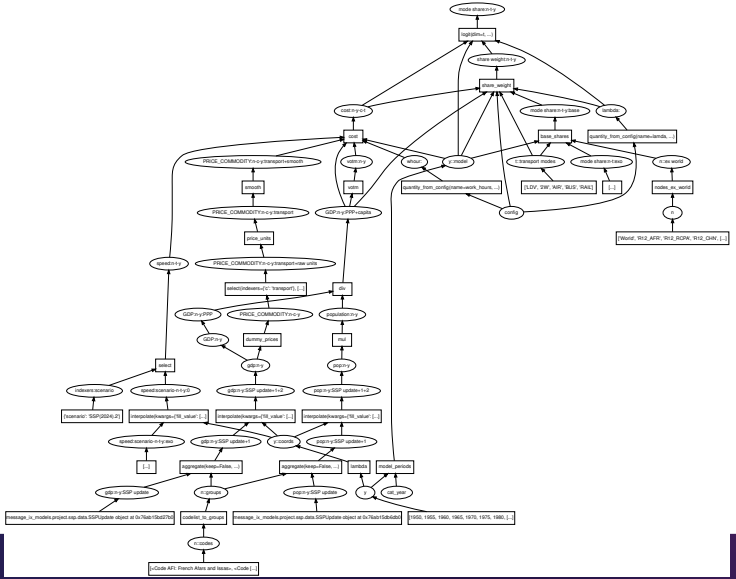
# genno: a library for *N*-D data workflows II

In MESSAGEix-Transport, this allows to compose calibration and input data workflows using small functions/steps: `logit`, `mul`, `factor_pdt`

```
# Mode shares
c.add(ms, "logit", cost, sw, "lambda:", y), dict(dim="t")
# Total PDT (n, t, y), with modes for the 't' dimension
c.add(pdt_nyt + "0", "mul", pdt_ny, ms)
# Scenario-specific adjustment factors
c.add("pdt factor:n-y-t", "factor_pdt", n, y, t_modes, "config")
```

Because small, these are reusable, testable, easy to document/read (transparent), etc.

# genno: a library for *N*-D data workflows III




`genno` makes it simple to set up & manipulate potentially very complicated chains of these atomic steps.

At execution, it caches and re-uses values (e.g. GDP) that flow into multiple computations, and uses `pandas` etc. for good performance.

# “Isn’t this overkill? The methods are simple.”

Often “simple methods” end up embedded 1000+-line ‘scripts’. Then, changing a *conceptually simple* aspect of the script (e.g. add a dimension) can require an *extensive rewrite*.

Because all intermediates are labelled in `genno`, we can simply:

1. Identify a quantity to be changed or replaced.
2. Pick the desired key, e.g. `<cost:n-y-c-t>@`.
3. `"Prune" off the sub-graph of tasks that yields these values.`
4. `Define some other operations (load a file, do other methods) to produce a value for the same key (measure & dimensionality).`

# Ongoing work & future directions

1. “Demand-side changes” (EDITS project) —replace default activity projection (based on modified logic per Schäfer et al. (2009)) with transformed data directly from PASTA.
2. Direct integration with MESSAGEix-Materials.
   - Growth of vehicle `CAP` $\rightarrow$ inflows of materials used in vehicles.
   - Growth of mode `ACT` $\rightarrow$ inflows of materials used in infrastructures.
3. Trip-based activity projection.
4. Links to other, detailed models of water freight & air transport.

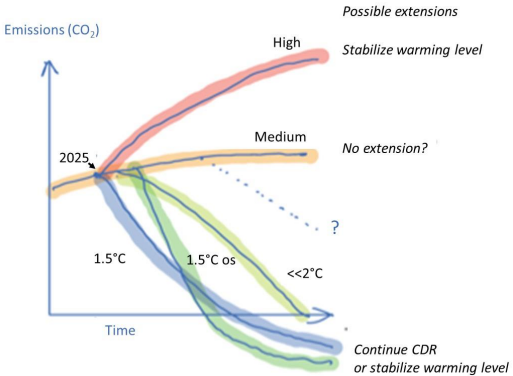
# Shared Socioeconomic Pathways (SSPs) 2024 & ScenarioMIP

# Linked scenario processes: ScenarioMIP

For IPCC AR7 (ca. 2028), many earth system models will run as part of Coupled Model Intercomparison Project 7.

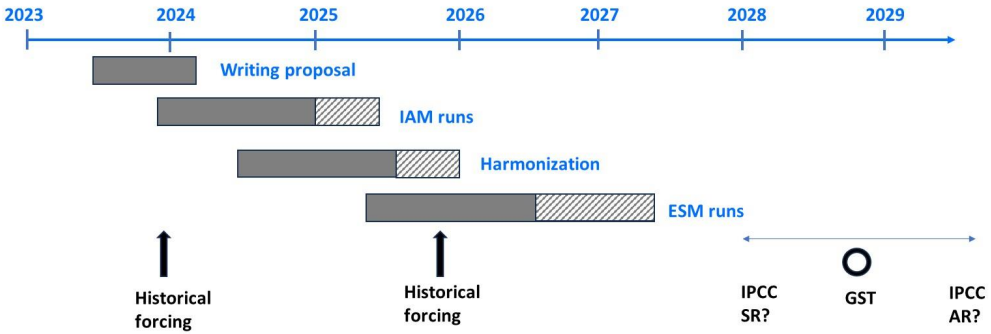
- Same inputs to each CM: emissions of GHGs and non-GHGs in 5–6 scenarios (right).
- Distinct outputs from each CM → info about uncertainty etc.

ScenarioMIP = IAMs' output compared and selected for CMIP7 inputs.




DOI: 10.5281/zenodo.818611, Fig. 1
wcrp-cmip.org/mips/scenariomip

# ScenarioMIP/CMIP7 timeline




DOI: 10.5281/zenodo.818611, Fig. 3

# SSP 2023–2024 update I

The original Shared Socioeconomic Pathways (SSPs) were published in 2016–2017 (Riahi et al. (2017) = overview paper).

These are narratives describing 5 possible future worlds in which:

- Challenges to climate change *mitigation* are either small or large.
- Challenges to climate change *adaptation* are either small or large.

…and include details about socio-economics (incl. inequality), technology, etc.

These narratives were realised/quantified through:

- Common demographic *inputs* to IAMs: population, GDP.
- Several IAMs *interpretation* of the narratives' meaning w.r.t. their input data and assumptions.

# SSP 2023–2024 update II

In 2023, a process started to update the SSP quantifications.

- **No change** to the narratives.
- Updated common socioeconomics.
- Updated interpretation by same IAMs, possibly more.

These new SSP realizations are *also* used as basis for ScenarioMIP submissions:

- “High” ScenarioMIP scenario may be based on an IAM’s SSP5 or SSP3.
- “Medium” ScenarioMIP scenario may be based on SSP2.
- etc.

# Further details

The ScenarioMIP emissions are not the same as an (expected) AR7 Scenario Database (likely to be similar to the AR6 Scenario Database).

- Such a database will accept many more scenarios, hopefully from a broader range of models, implementing narratives that may be different from the SSP narratives.
- ScenarioMIP emissions are needed because CMIP7 ESMs are big, complex, take time to run; this work must start if results are to be ready for AR7.

IAM teams have thus been working on 2 tasks:

1. Update common GDP/pop + all other inputs/assumptions, for each SSP.
2. Select from their 5 SSP realizations or derive further scenarios + submit to ScenarioMIP.

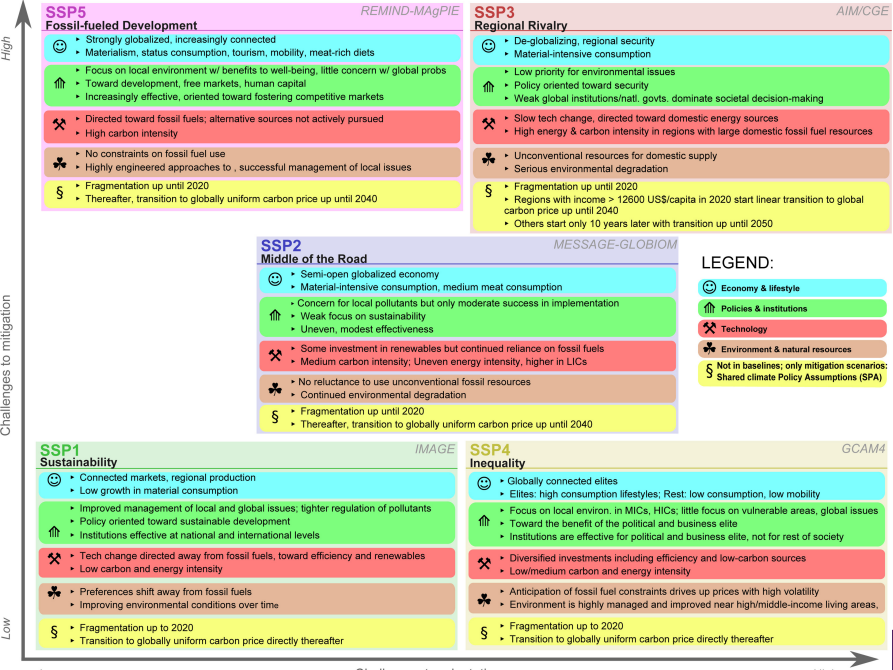
# MESSAGEix-GLOBIOM SSP update

An updated ‘base’ version of MESSAGEix-GLOBIOM is used for SSP 2024/ ScenarioMIP.

MESSAGEix-Transport and some other detailed variants are not used directly.

Rather:

1. MESSAGEix-Transport & co. implement the SSP narratives *within* their respective sector/input data.
2. Outputs from these detailed variants are aggregated and used to parametrize MESSAGEix-GLOBIOM.




Narrative details for the energy sector in the 5 SSPs (Bauer et al. 2017, fig. 1)

# MESSAGEix-Transport implementation of SSPs

## Some challenges

- SSP narratives are high level → there are multiple possible/consistent interpretations of how transport (sub)system(s) will change.
- No coordination was planned → each modeling teams' choices will be different.
- SSPs are fundamentally outcome-based → transport system changes are not represented based on epistemic/measurement uncertainty in input parameters (e.g. lowest vs. highest plausible values) but by selecting values *such that* the projected outcome matches the SSP narrative.
- Many input parameters with high resolution → many values to set or adjust for each SSP.

## SSP5: Fossil-fueled Development

- Higher PDT due to high GDP growth
- Standard GDP-PDT r/s
- Higher share of LDV and AIR, with improvements in these mode shares
- Current pace of energy intensity improvements in LDVs
- Current patterns of vehicle occupancy with LMICs converging to HICs values

## SSP1: Sustainability

- Lower PDT demanded at the same level of GDP due to better demand management
- Higher share of sustainable modes

Low energy intensity of LDVs with
- quicker adoption of EVs, and
- improvements in fuel efficiency of LDVS

High occupancy for vehicles

## SSP2: Middle of the road

- Standard GDP growth & GDP-PDT r/s
- Transport modes follow current patterns with regions converging to their corresponding ~~sets~~
- Current pace of energy intensity improvements in LDVs
- Current patterns of vehicle occupancy

| Indicator |
| --- |
| PDT |
| Mode Share |
| Technological improvements |
| Vehicle usage |

## SSP3: Regional Rivalry

- Low PDT due to very low GDP growth
- Lower PDT demanded at the same level of GDP due to lower inter-regional travel
- Improvements in some RAIL and BUS. More barriers to (international) *AIR* travel
- Current pace of energy intensity improvements in *LDVs*
- Vehicle occupancy of *LDVs* for LMICs (HICs) stays at the current high (low) level, converging to HICs values

## SSP4: Inequality

- Lower PDT demanded at the same level of GDP due to lower demand by LMICs and low-income groups
- Transport modes follow current patterns with regions
- Growth in AIR and LDV drive by global elite
- Current pace of energy intensity improvements in LDVs
- Current patterns of vehicle occupancy

## SSP5: Fossil-fueled Development


Speed **LDV (improv.)** → **70** km/hr in **2100**


Speed **2W (default)**


Speed **AIR (high improv.)** → **330 km/h in 2100**


Speed **Bus (default.)** → **19** *km/h* in **2100**


Speed **RAIL (default.)** → **35** *km/h* in **2100**

## SSP2: Middle of the road


Speed **LDV (improv.)** → **70** km/hr in **2100**


Speed **2W (default)**


Speed **AIR (improv)** → **300 km/h** in **2100**


Speed **Bus (improv.)** → **32** *km/h* in **2100**


Speed **RAIL (improv.)** → **58** *km/h* in **2100**

## SSP3: Regional rivalry


Speed **LDV (improv.)** → **70** km/hr in **2100**


Speed **2W (default)**


Speed **AIR (low)** → **200 km/h** in **2100**


Speed **Bus (improv.)** → **32** *km/h* in **2100**


Speed **RAIL (improv.)** → **58** *km/h* in **2100**

## SSP1: Sustainability


Speed **LDV (improv.)** → **70** km/hr in **2100**


Speed **2W (default)**


Speed **AIR (low)** → **200 km/h** in **2100**


Speed **Bus (high improv.)** → **42** *km/h* in **2100**


Speed **RAIL (high improv.)** → **81** *km/h* in **2100**

## SSP4: Inequality


Speed **LDV (improv.)** → **70** km/hr in **2100**


Speed **2W (default)**


Speed **AIR (improv)** → **300 km/h** in **2100**


Speed **Bus (improv.)** → **32** *km/h* in **2100**


Speed **RAIL (improv.)** → **58** *km/h* in **2100**

# Following the SSP/ScenarioMIP processes

Be critical and careful consumers of these scenarios.

- Scenarios are constructed for the specific purposes described above.
- They have sufficient quality from this perspective.
- Some value as common points for derived work that can be comparable.
- May not be the right starting point for exploring narratives that don't align with the SSP narratives.

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# Thank you!

# References I


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