The MESSAGEix IAM and ix modeling platform (ixmp): An open framework for integrated and cross-cutting analysis of energy, climate, the environment, and sustainable development

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MESSAGE-GLOBIOM concrete global model instance

— Reference realizations of SSPs 1–3—validated basis for other scenarios.
— Library of atomic scenario-building tools, e.g. add INDCs; add biomass trade.
— Generic and project-specific protocols for deriving/running sets of scenarios.
— Diagnostics & reporting specific to the features of MESSAGE-GLOBIOM.

`message_ix` generalized integrated assessment model

— GAMS mathematical specification.
— Tutorials and API reference.

`message_ix.Scenario`
`message_ix.Reporter`
`MESSAGE`
`MACRO`
`MESSAGE-MACRO`

Extended features for energy-economic data preparation.

Exhaustive, automated reporting of IA quantities, using common structure.

GAMSModel subclasses for LP & CGE models, with accompanying code & extra configuration options.

`ixmp` data/model core

— Reusable command-line interface (CLI).
— Python & R user interfaces.

`Scenario`: collection of data for a single realization
`Platform`: entry point for storing, running scenarios
`Backend` data storage API: `JDBCBackend` …
`Model` calculation API: `GAMSModel` …
`Reporter`

Java/JDBC interfaces to Oracle (centralized) and HyperSQL (local, file & in-memory) databases.

Future implementations to add storage alternatives: PostgreSQL, HDF, …

Solve optimization problems or perform calculations by GAMS invocation.

Future links to mathematical cores in Julia; other languages.

General-purpose 'reporting' (post-processing) of model input and output data.

Research needs

High-impact studies on capital/investment shifts for meeting climate goals and SDGs [4, SI p.22]; re-imagining potential of low energy demand (LED) [1, p.525].

Pursue higher realism through finer resolution:
- Spatial: 11→14 regions.
- Temporal: 10→5-year periods; sub-annual timesteps.

Prototyping & building single-country model variants: ZA [5], IN [6], IL, FSU countries, ID…

Soft- or hard-linked modules with sectoral dynamics:
- Transport and mobility [extending 3].
- Buildings/residential demand.
- Access to energy in low-income populations.
- Water-energy-land interactions [7, pp.25–29].

Framework development

To serve research needs, MESSAGE contributors:
- Adopt best practices of professional/ non-academic software engineering (→ Box D).
- Iterate software design for modularity, extensibility, and simplicity.
- Pursue reproducibility and validity through testing (→ Box R).
- Continually expand documentation, including of internal interfaces.
- Perform this work in public, on GitHub.

Best-practice development (D)

Design: separation of concerns.

- *Why so many framework components?* → atomic, modular parts with small feature sets are easy to…
  - understand,
  - test individually (unit) and in combination (integration),
  - verify, and
  - reuse.
- Example 1: `message_ix` and MESSAGE-GLOBIOM delegate data I/O to `ixmp` → fewer chances for user/coding error.
- Example 2: `ixmp` handles set & parameter data items → `message_ix` provides names & dimensionality for IAM-specific items (e.g. 'technology') → MESSAGE-GLOBIOM populates concrete values (e.g. 'coal_ppl' ∈ 'technology').

Continuous integration (CI) testing.

- Services/tools in use: Travis, AppVeyor, Stickler, ReadTheDocs, TeamCity, Codecov.
- Checks re-run:
  - manually, by researchers: `$ pytest ixmp`.
  - automatically, on every new commit pushed to GitHub.
  - nightly, for slow-running tests e.g. large model instances.
- Line coverage: ixmp: 93%; message_ix: 78%; message_data: 10%.

Reproducible, valid modeling (R)

Even if models are validated, this validation can be *merely instantaneous*.
- "the model, as of now, is 'good enough to use'".
- Models are continuously developed → this fact quickly becomes stale.

Automated testing and a *culture* of testing (left) help…
- continually and repeatedly **verify** that "the model code still does what it did yesterday, without error."
- provide a basis to *frequently* **validate** that "the model code plus current input data still produce *correct* [perhaps not identical] results."
- draw attention to regressions, to be addressed by researchers.

Testing also *requires* a degree of **reproducibility**:
- CI runs on cloud servers, not a researcher's PC → software environment and model instance are recreated from scratch, *every* time.
- If this can be automated, then the same steps can be performed by another researcher.

Current gap/focus: pipelines for processing primary source data into model input data.

References & applications

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