The MESSAGEix IAM and ix modeling platform (ixmp): An open framework for integrated and crosscutting 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.
- Extend features for energy-economic data preparation.
- Exhaustive, automated reporting of IA quantities, using common structure.
- Future implementations to add storage alternatives: PostgreSQL, HDFS, ... – General-purpose ‘reporting’ (post-processing) of model input and output data.

ixmp data/model core

- Reusable command-line interface (CLI).
- Python & R user interfaces.
- Java/JDBC interfaces to Oracle (centralized) and HyperSQL (local, file & in-memory) databases.

Best-practice development

Design: separation of concerns.

- Why so many framework components? \(ightarrow\) atomic, modular parts with small feature sets are easy to...
- understand,
- test individually (unit) and in combination (integration),
- verify, and
- reuse.

Example 1: \text{message\_ix} and MESSAGE-GLOBIOM delegate data I/O to \text{ixmp} \rightarrow fewer chances for user/coding error.

Example 2: \text{ixmp} handles set & parameter data items \rightarrow \text{message\_ix} provides names & dimensionality for IAM-specific items (e.g. ‘technology’) \rightarrow MESSAGE-GLOBIOM populates concrete values (e.g. ‘coal\_ppl’ ∈ ‘technology’).

Continuous integration (CI) testing.

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

MESSAGE-GLOBIOM core containers for LP & CGE models, with accompanying code & extra configuration options.

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

MESSAGE-GLOBIOM core containers for LP & CGE models, with accompanying code & extra configuration options.

Message links to mathematical cores in Julia; other languages.

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 \rightarrow 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.

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], FSU countries, ID...

Soft- or hard-linked modules with sectoral dynamics:

- Transport and mobility [extending nightly, for slow-running tests e.g. large model instances.
- 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.