

The MESSAGE_{*i*x} modeling framework for *i*ntegrated and *x*-cutting analysis

Part II

7 Jun 2021

Energy, Climate, and Environment (ECE) Program International Institute for Applied Systems Analysis (IIASA), Austria

The MESSAGE_{ix} modeling framework: Goals and Vision

Aim and vision of the framework as a whole

Goal: Developing a platform for streamlined modeling

- ⇒ building versatile & powerful mathematical models,
- \Rightarrow using state-of-the-art tools for **data processing**,
- \Rightarrow applying best practice of **collaborative research**

Vision:

- integration of models & scientific analysis between different disciplines
- highest level of transparency and scientific reproducibility for a wide audience
- flexibility: across spatial and temporal levels of disaggregation

The MESSAGE_{ix} modeling framework: 1. Data management in *ix*mp



A central data management system (the *ix* modeling platform)

• An **open** platform for *i*ntegrated and *x*-cutting analysis of energy, climate, the environment, and sustainable development.

	ix Modeling Platform	
Reference data Historical time series, projections of key drivers, technology specifications, etc.	Data processing Downscaling & aggregation, harmonization across sources	Model data Structured input data, complete model results, standardized reporting
International Energy Agency Science for a changing world	THE WORLD BANK	

ixmp, ix modeling platform or simply "*platform*" will be used interchangeably

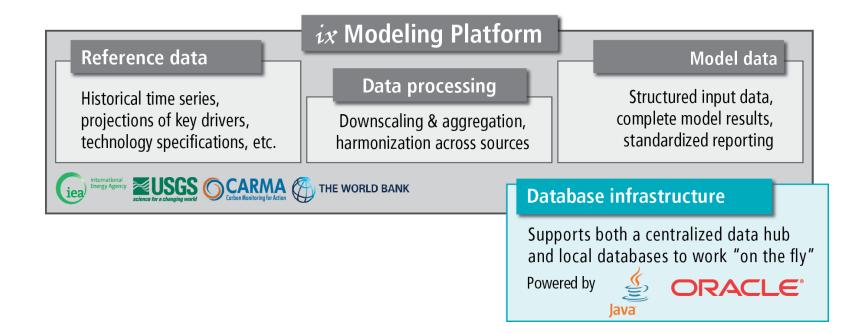
The MESSAGE_{ix} modeling framework: 2. Database backend



Supported by a high-performance database architecture

The platform (*ix*mp)...

- ... is based on a Java interface as gateway to the data
- ... supports both an ORACLE database backend for high-performance, collaborative modeling and local, file-based databases for getting started or working "on the fly"



The MESSAGE_{ix} modeling framework: 3. Integration with GAMS



Connected to high-performance numerical programming

MESSAGE_{ix} in an **Integrated Assessment Model** (IAM). Its mathematical formulation is in GAMS, a versatile software for mathematical programming & optimization.

 \Rightarrow MESSAGE_{*ix*} is the first model fully integrated with the *ix* modeling platform (*ixmp*)

Suite of mathematical models

MESSAGE_{ix} & MACRO Versatile spatial systems-economic model

- ✓ Perfect-foresight or recursive-dynamic approach
- \checkmark Easy to add new features & extensions

 \checkmark Flexible spatial & temporal detail

Water-land integration

The MESSAGE_{*i*x} modeling framework: 4. Documentation

Implementing tools for comprehensive documentation

The framework ensures transparency and intelligibility

through "auto-documentation" of all codes & packages on <u>readthedocs.com</u>

- ⇒ Documentation of all scientific programming packages using Sphinx
- ⇒ Documentation of the mathematical equations generated automatically from $\boxed{\text{IAT}_{E}X}$ mark-up in the GAMS code

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Equation STOCKS_BALANCE

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integration

This constraint ensures the inter-temporal balance of commodity stocks. The parameter $commodity_stocks_{n,c,l}$ can be used to model exogenous additions to the stock

$$\begin{split} STOCK_{n,c,l,y} + commodity_stock_{n,c,l,y} = duration_period_y \cdot \sum_{h} STOCK_CHG_{n,c,l,y,h} \\ &+ STOCK_{n,c,l,y+1} \end{split}$$

Technology section

Technical and engineering constraints

The first set of constraints concern technologies that have explicit investment decisions and where installed/maintained capacity is relevant for operational decisions. The set where $T^{INV} \subseteq T$ is the set of all these technologies.

Equation CAPACITY_CONSTRAINT

This constraint ensures that the actual activity of a technology at a node cannot exceed available (maintained) capacity summed over all vintages, including the technology capacity factor capacity_factor_ $n_{s,y,t}$.

$$\sum_{m} ACT_{n,t,y^{\nu},y,m,h} \leq duration_time_{h} \cdot capacity_factor_{n,t,y^{\nu},y,h} \cdot CAP_{n,t,y^{\nu},y} \quad \forall t \in T^{INV}$$

Equation CAPACITY_MAINTENANCE_HIST

The following three constraints implement technology capacity maintenance over time to allow early retirment. The optimization problem determines the optimal timing of retirement, when fixed operation-and-maintenance costs exceed the benefit in the objective function.



The MESSAGE_{ix} modeling framework: 5. Scientific programming

Interfaces to scientific programming for advanced users

Python and R Application Programming Interfaces (APIs)

Scientific programming API

Seamless integration with powerful, open and flexible scientific programming languages
✓ Efficient implementation of workflows
✓ Standardized interface for data processing



26 July 2021

The MESSAGE_{ix} modeling framework: 6. Collaborative research

Geared towards best-practice in collaborative research

The modeling framework facilitates collaborative model development through comprehensive **version control** of data, model codes and scripts.

All contents of both MESSAGE $_{ix}$ and ixmp are **open-source** and online as GitHub repositories:

- https://github.com/iiasa/message_ix
- https://github.com/iiasa/ixmp/

<u>https://github.com/iiasa/message-ix-models</u> (package that provides tools for research using the MESSAGE_{ix} - GLOBIOM family of models)

In the last session of this workshop (Session IV) there will be more explanation on how to collaborate through GitHub.



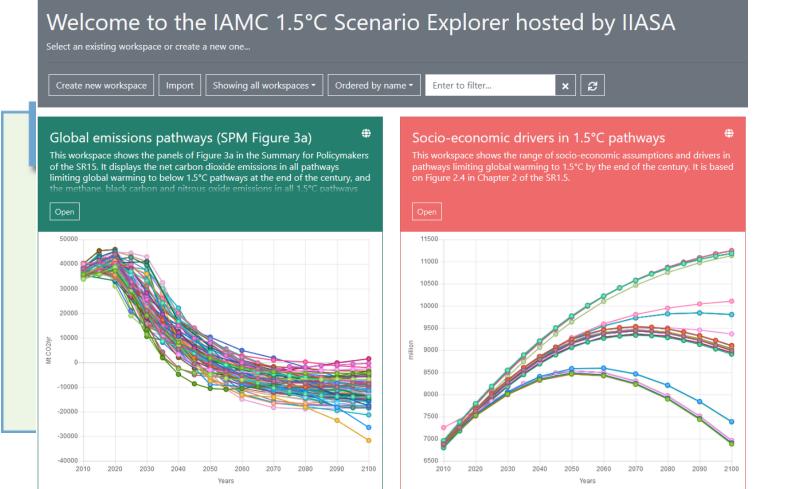




The MESSAGE_{ix} modeling framework: 7. Interactive web user interface



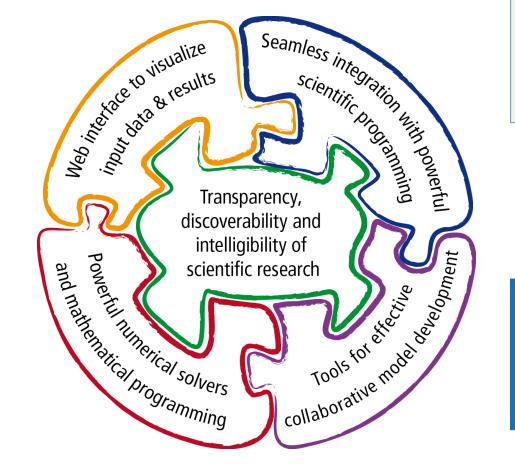
An intuitive gateway to modeling data for researchers and a wider audience

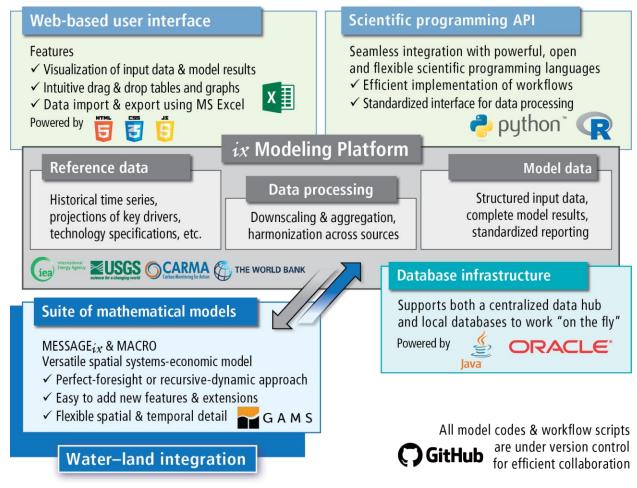


The Scenario Explorer allows for the re-use of scenario data by other research communities

The MESSAGE_{ix} modeling framework: Overview

Facilitating transparency and reproducibility of research



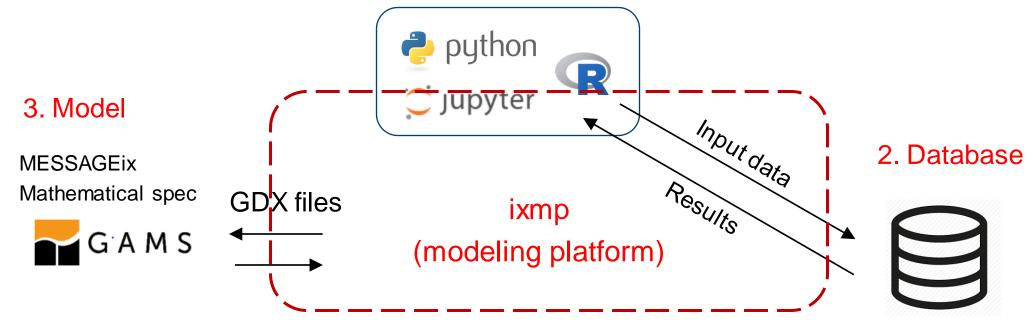


Key features of the *ix* modeling platform (*ixmp*)

(Huppmann et al. 2019)

The MESSAGE_{*ix*} modeling framework: Simplistic workflow of modeling *Flexible and high-performance processes*

- Interface a *central place* for creating, loading, or working with a scenario
- Data can be modified through the interface or other input files (e.g., Excel)
- Model data and results: loaded from database, model GDX files, etc.



1. Interface

The MESSAGE_{ix} modeling framework: Main sources of information

- Main page in ReadTheDocs:
 - ⇒ <u>https://docs.messageix.org/en/stable/</u>
- Open-source GitHub repository:
 - ⇒ <u>https://github.com/iiasa/message_ix</u> (contribution guide)
- Files for the tutorials can also be found online:
 <u>https://github.com/iiasa/message_ix/tree/master/tutorial</u>
- # MESSAGEix

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 stable

 Search docs

 GETTING STARTED

 Prerequisite knowledge & skills

 MESSAGEix model & framework

 Installation

 Tutorials

 MATHEMATICAL SPECIFICATION

 Sets and mappings definition

 Years, periods, and time slices

 Parameter definition

 MESSAGE core formulation

 Solve statement workflow

* » The MESSAGEix framework

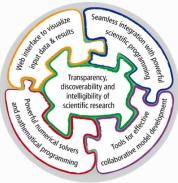
O Edit on GitHub

The MESSAGE ix framework

MESSAGEix is a versatile, dynamic systemsoptimization modelling framework developed by the <u>IIASA</u> Energy Program since the 1980s.

This is the documentation for message_ix, a Python package that ties together all components of the framework. message_ix and ixmp are free and open source, licensed under the APACHE 2.0 open-source license.

- For the scientific reference of the framework, see Huppmann et al. (2019) [1].
- For an overview and recent publications related to the specific MESSAGEix-GLOBIOM global model instance used at the IIASA Energy Program, see the MESSAGEix-GLOBIOM documentation.



The	ix	mode	eling	platform	([1])
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 For more detailed information on ixmp:

 message-ix-models (only relevant for MESSAGE_{ix}-GLOBIOM):

 • Main page in ReadTheDocs:

 → https://docs.messageix.org/projects/models2/en/latest/

 • Open-source GitHub repository:

 → https://github.com/iiasa/message-ix-models



ixmp

The MESSAGE_{*ix*} modeling framework: Prerequisites

 $MESSAGE_{ix} \& ixmp$, encapsulated as two Python packages

The workshop is designed to be accessible for participants with different backgrounds and levels of experience with the modeling. However, there are some pre-requisite knowledge and skills, including:

- Elementary computer programming (preferably in the Python or R language);
 - \Rightarrow especially, basic knowledge of **pandas**, a Python package for data analysis (**pandas** tutorials)
- Fundamental concepts of mathematical modeling, optimization, and linear programming;
- Energy systems (e.g., energy supply, energy conversion technologies, and demand sectors and their linkages)
 - \Rightarrow also energy levels and techno-economic parameters

For a complete list, plus links to learning resources, see "<u>Pre-requisite knowledge & skills</u>" in the documentation

The MESSAGE_{ix} modeling framework: Installation

Two types of installation

- 1. Install MESSAGE $_{ix}$ through Anaconda
 - You only want to use the public release (<u>latest version</u> is v3.3.0; ~every 6 months).
 - You don't aim to contribute to the code on GitHub.
 - Still possible to develop code and a model specific to your research needs.

2. Install through the source (advanced users, developers)

- You want to test and review the latest features (i.e., since the latest public release).
- You want to contribute to the code.
- You want to (learn to) participate in collaborative code development.

Link to installation page in ReadTheDocs: <u>https://docs.messageix.org/en/stable/install.html</u>

Basic usage	Advanced usage							
Install the released version of $\ensuremath{\mathtt{message_ix}}$.	Install the development version (source code).							
Use a laptop/desktop computer.	Use cloud computing/HPC servers.							
Store data on your local machine.	Store data in a shared database.							
Run/modify the tutorial notebooks.	Build large models from scratch.							
	Collaborate on MESSAGEix-GLOBIOM.							
Use the mathematical formulation as-is.	Modify the MESSAGE equations.							
Use the message_ix Python/R code.	Contribute or request new features.							

The MESSAGE_{ix} modeling framework: Installation (2)

Installation through Anaconda. A checklist

- 1. Install the required software
 - Anaconda (add to PATH environment variable)
 - GAMS (add to PATH environment variable)

2. Install MESSAGE_{ix}

- Open Anaconda Prompt window, and type:
 - \$ conda config --prepend channels conda-forge
 - \$ conda create -n my-env
 - \$ conda activate my-env
 - \$ conda install message-ix

\$ python -m ipykernel install --user --name=my-env or

- \$ conda install nb conda
- 3. Download tutorials (examples for learning the model)
 - \$ message-ix dl /path/for/folder_for_tutorials

message_ix & message-ix:

- The actual name of the package installed is <u>message ix</u>
- message-ix is a command-line program used to install and run tasks from message ix

Video tutorial on the installation



The MESSAGE_{ix} modeling framework: After installation

Check installation. What is where?

- 1. Check that installation was successful
- Verify that the version installed corresponds to the <u>latest release</u> by running the following commands on the command line:
 - \$ message-ix show-versions
- If an error occurs, this may mean that an older version has been installed and should be updated
 \$ conda list message-ix

2.ixmp & message_ix Python packages

- Locate your Anaconda (python) library and navigate to site-packages (good to pin this path)
 - You can open windows command line and type:

\$ where conda

- Then, navigate to *site-packages* (C:\...\Anaconda3\envs\my-env\Lib\site-packages)
- You should be able to see two packages **ixmp** and **message_ix**

3. Mathematical model folder

- Model/folder is by default under message_ix/folder
- **Model/**folder can be changed to a new folder (optional) Open an *Anaconda Prompt* window, and type:
 - \$ message-ix copy-model /path/for/GAMS/files

The MESSAGE_{ix} modeling framework: Mathematical formulation



A deeper view into the GAMS workflow

Looking into the GAMS files

- Locate your "model" folder (for example, C:\...\message_ix\message_ix\model)
- Create a GAMS project there to work with the files more easily (optional)
- **MESSAGE formulation** in (*C*:\...*model**MESSAGE*): for example look at **model_core.gms**
- Input data in (C:\...\model\data): GDX files
- **Output results** in (*C*:\...\model\output): GDX files

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136 bound emission	Par	4	0	cement_CO2			scrubber_CO2_cement	0.28	0.28	0.28	0.25	0.23	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
82 bound extraction up	Par	4	88	coal_adv			cogeneration_heat					0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
102 bound_new_capacity_lo	Par	3	150		lignite							0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
101 bound_new_capacity_up	Par	3	4,098	coal_adv_ccs	M1								0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
104 bound total capacity lo	Par	3	0		lignite								0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
103 bound total capacity up	Par	3	0	coal_ppl	M1				0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
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32 cat emission	Set	2	16				scrubber_CO2_coal		0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
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The MESSAGE_{*i*x} modeling framework

Homework I (to be done before the next Workshop session)

1. What is **ixmp** and how MESSAGEix is related to that?

2. How can a user test that if the MESSAGEix installation is correct? (see the documentation of MESSAGEix for finding the solution). Can you locate where MESSAGEix is installed in your machine? (consult with the slides of the first session)

3. Try to open a Jupyter Notebook within the Conda environment that you have installed MESSAGEix. (please see the <u>installation video tutorial</u> if you are not sure how to do this)



Thank you very much for your attention!

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