The MESSAGE$_{ix}$ 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**,

⇒ using state-of-the-art tools for **data processing**,

⇒ applying best practice of **collaborative research**

Vision:

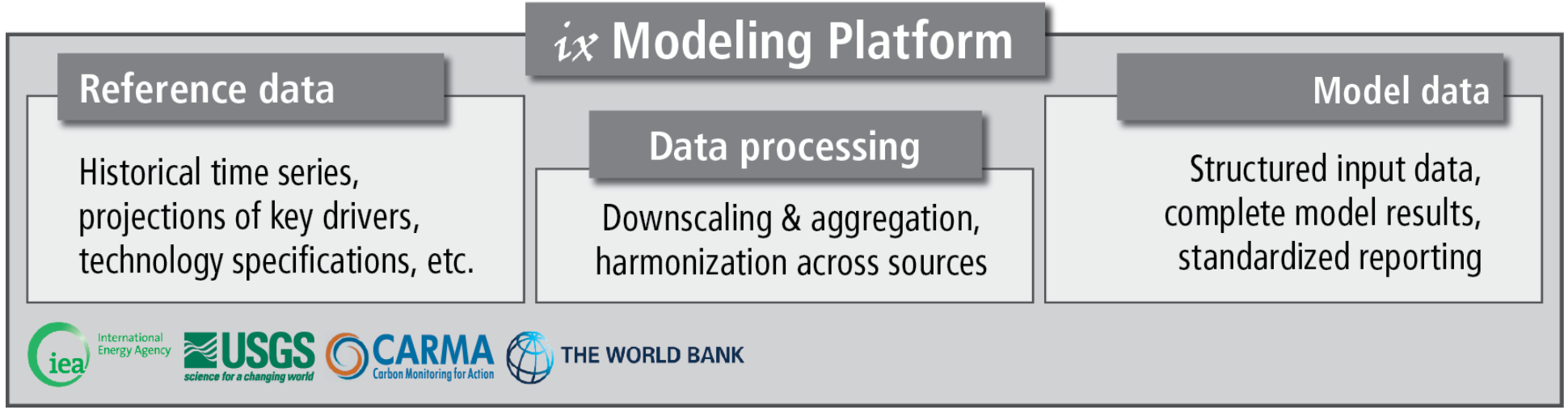
- integration of models & scientific analysis between different disciplines
- highest level of transparency and scientific reproducibility for a wide audience
- flexibility: across **spatial and temporal** levels of disaggregation

The MESSAGE$_{ix}$ modeling framework consists of a variety of different pieces

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

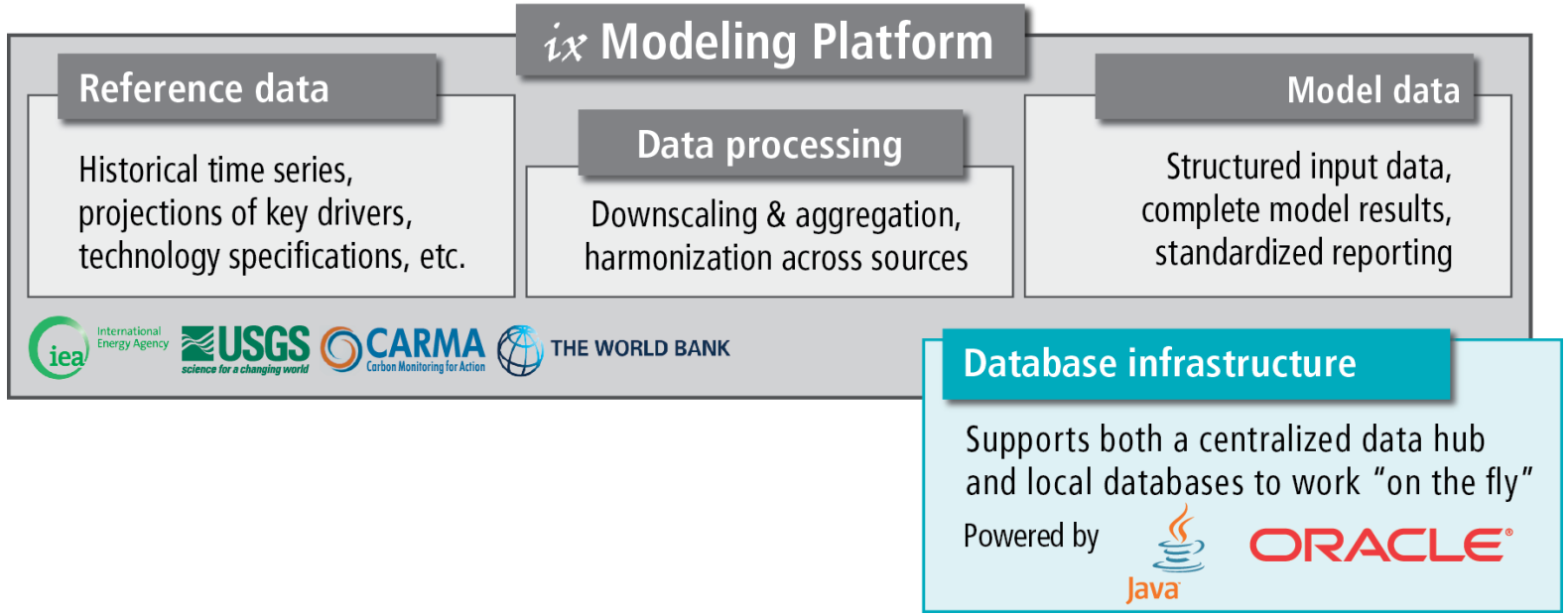
The MESSAGE$_{ix}$ modeling framework: 2. Database backend

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"

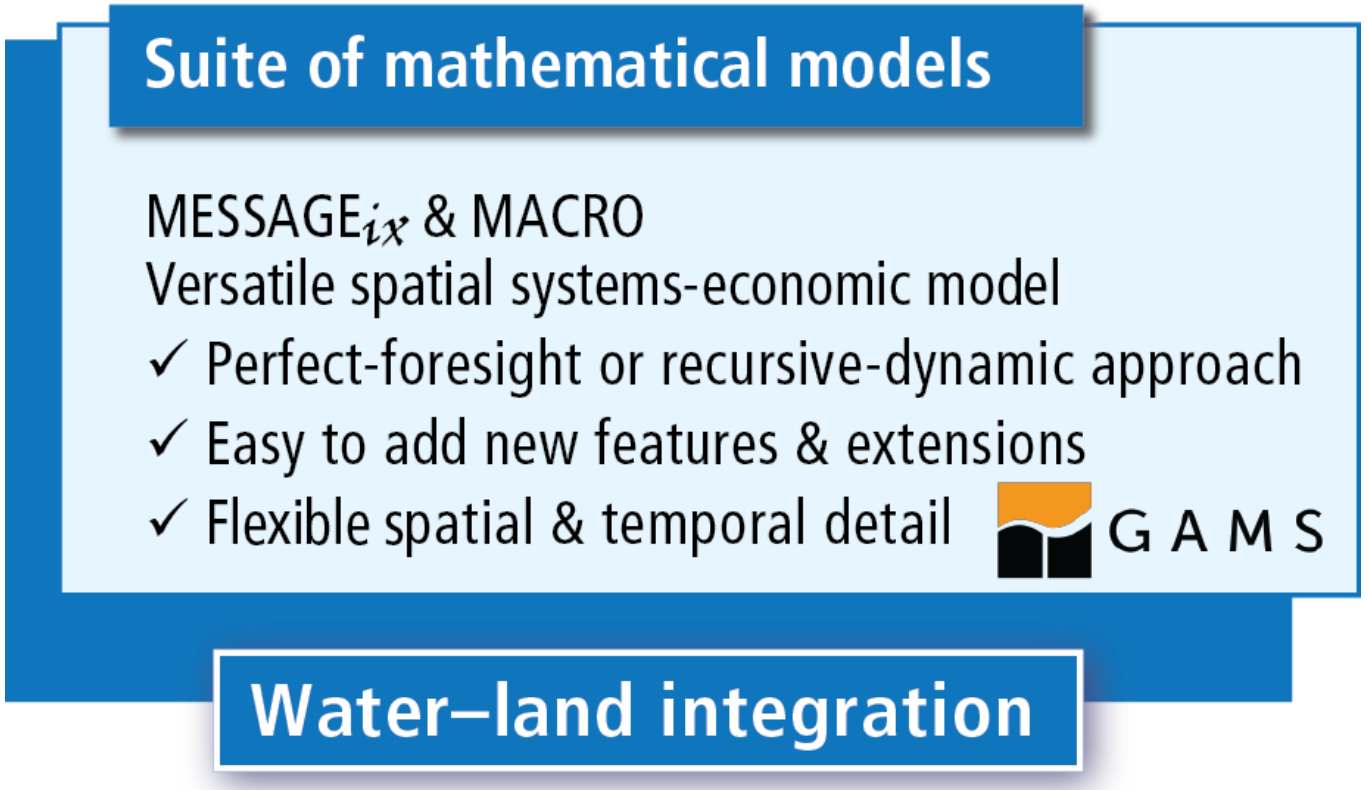


The MESSAGE$_{ix}$ modeling framework: 3. Integration with GAMS

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.

⇒ MESSAGE$_{ix}$ is the first model fully integrated with the *ix* modeling platform (*ixmp*)



The MESSAGE$_{ix}$ modeling framework: 4. Documentation

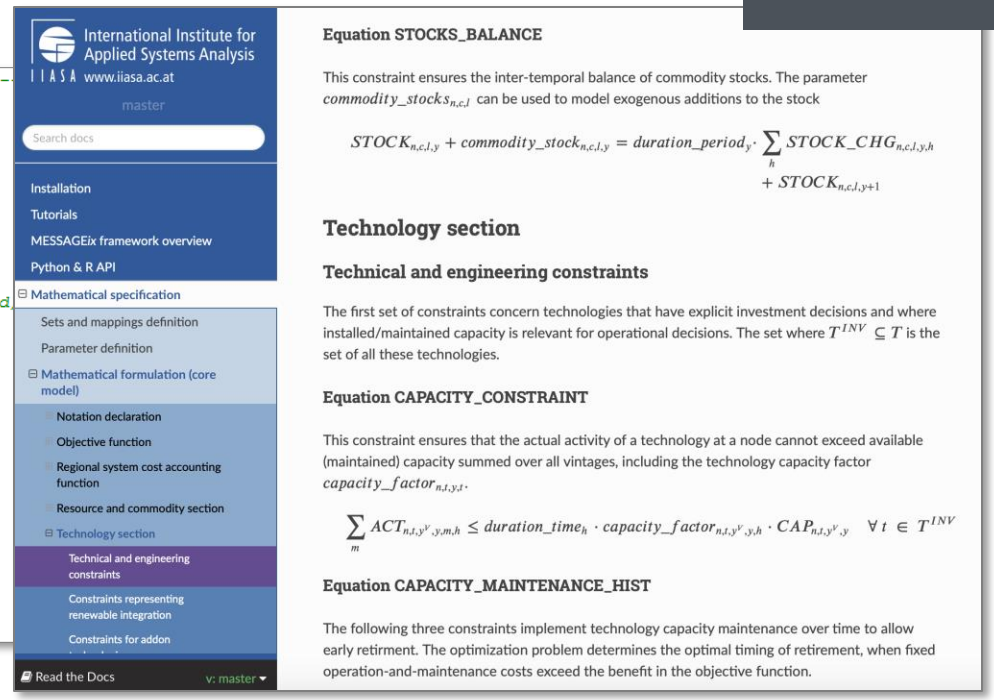
Implementing tools for comprehensive documentation

The framework ensures transparency and intelligibility
through "auto-documentation" of all codes & packages on readthedocs.com

⇒ Documentation of all scientific programming packages using `Sphinx`

⇒ Documentation of the mathematical equations generated automatically from LaTeX mark-up in the GAMS code

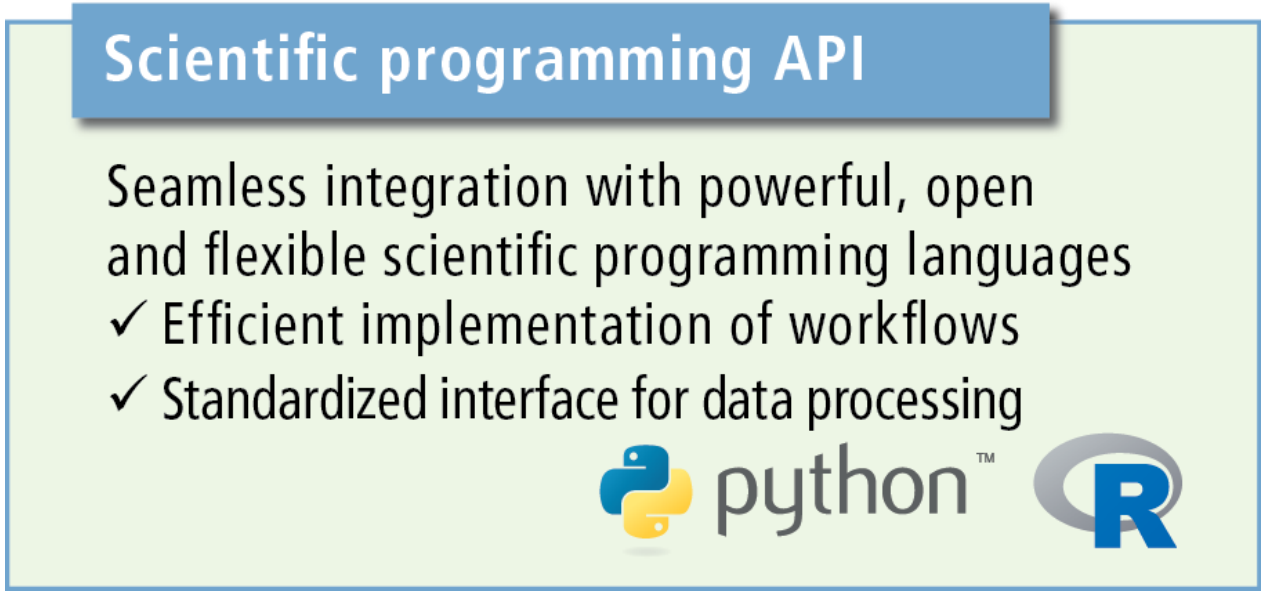
```
*-------------------------------------------------------------------------------------------------------------------
***
* Technology section
* ------------------
*
* Technical and engineering constraints
* ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
*
* Equation CAPACITY_CONSTRAINT
* """"""""""""""""""""""""""""
* This constraint ensures that the actual activity of a technology at a node/time cannot exceed available (maintained)
* capacity summed over all vintages, including the technology capacity factor :math:`capacity\_factor_{n,t,y,t}`.
*
*  .. math::
*     \sum_{m} ACT_{n,t,y^V,y,m,h}
*         \leq duration^H_{h} \cdot capacity\_factor_{n,t,y^V,y,h} \cdot CAP_{n,t,y^V,y}
*         \quad t \ \in \ T^{INV}
*
* where :math:`T^{INV} \subseteq T` is the set of all technologies
* for which investment decisions and capacity constraints are relevant.
***
CAPACITY_CONSTRAINT(node,inv_tec,vintage,year,time)$( map_tec_time(node,inv_tec,year,time)
        AND map_tec_lifetime(node,inv_tec,vintage,year) )..
    sum(mode$( map_tec_act(node,inv_tec,year,mode,time) ), ACT(node,inv_tec,vintage,year,mode,time) )
        =L= duration_time(time) * capacity_factor(node,inv_tec,vintage,year,time) * CAP(node,inv_tec,vintage,year) ;
```



The MESSAGE$_{ix}$ modeling framework: 5. Scientific programming

Interfaces to scientific programming for advanced users

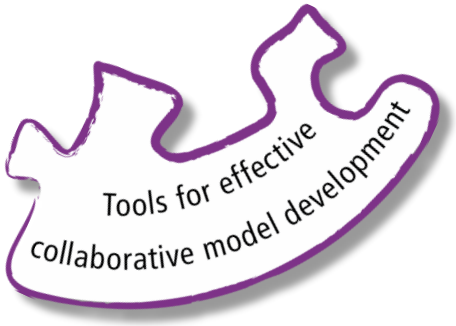
Python and R **Application Programming Interfaces** (APIs)



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.



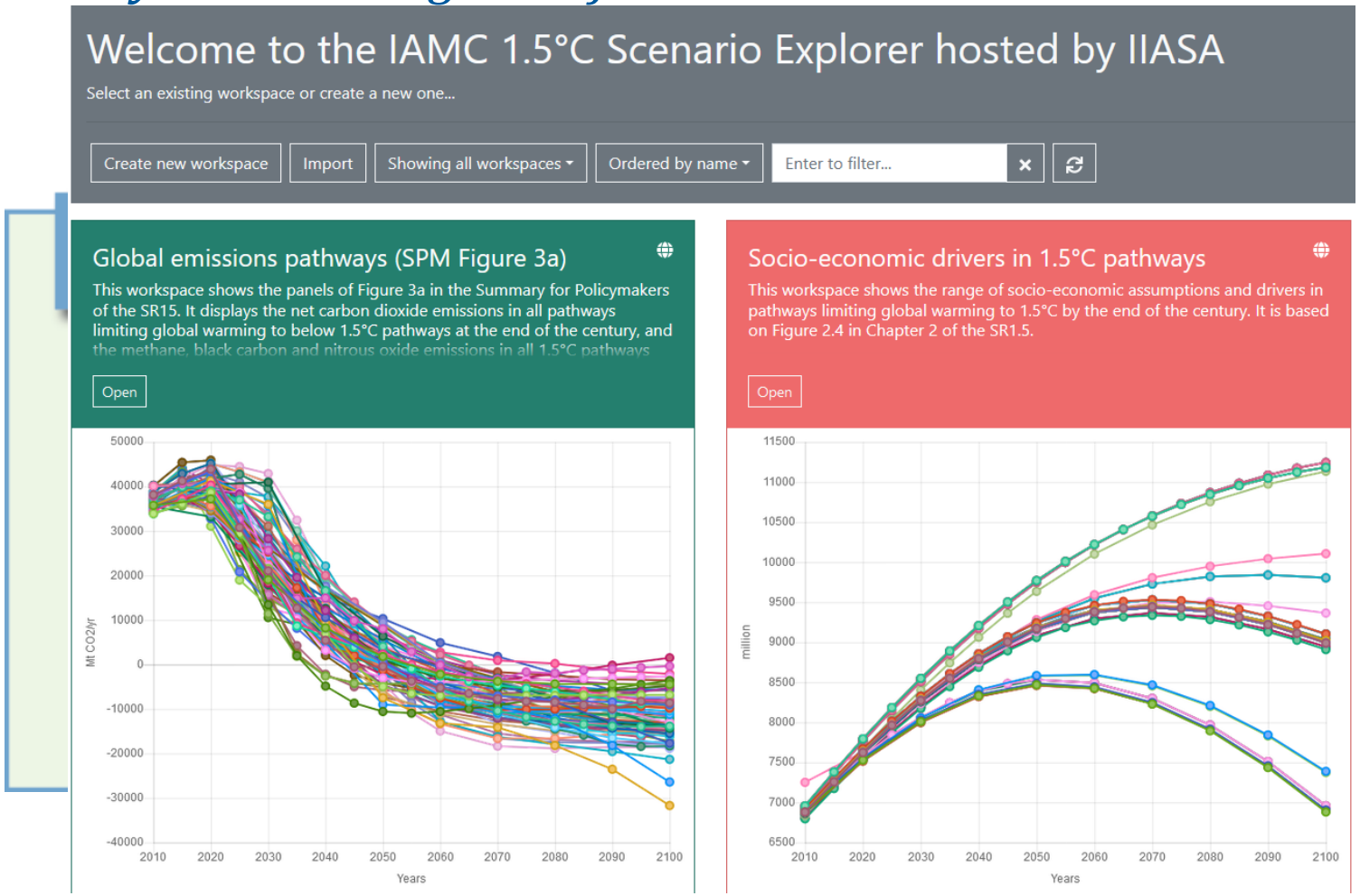
All contents of both MESSAGE$_{ix}$ and *ix*mp are **open-source** and online as GitHub repositories:

- https://github.com/iiasa/message_ix
- https://github.com/iiasa/ixmp/
- https://github.com/iiasa/message-ix-models (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

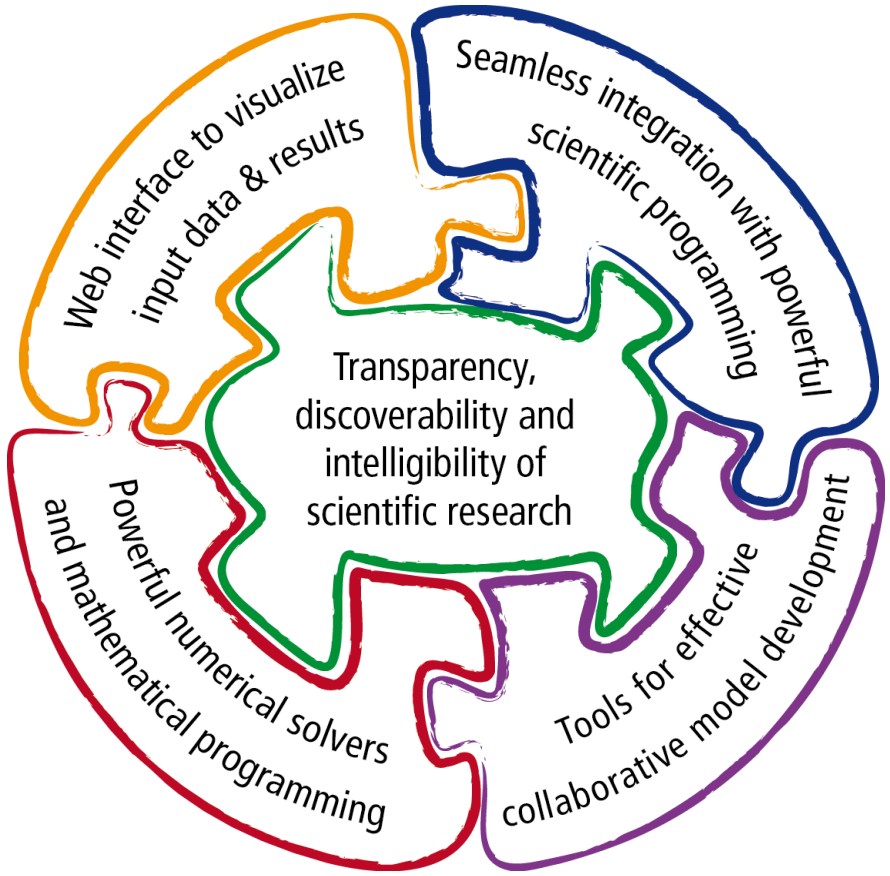
An intuitive gateway to modeling data for researchers and a wider audience

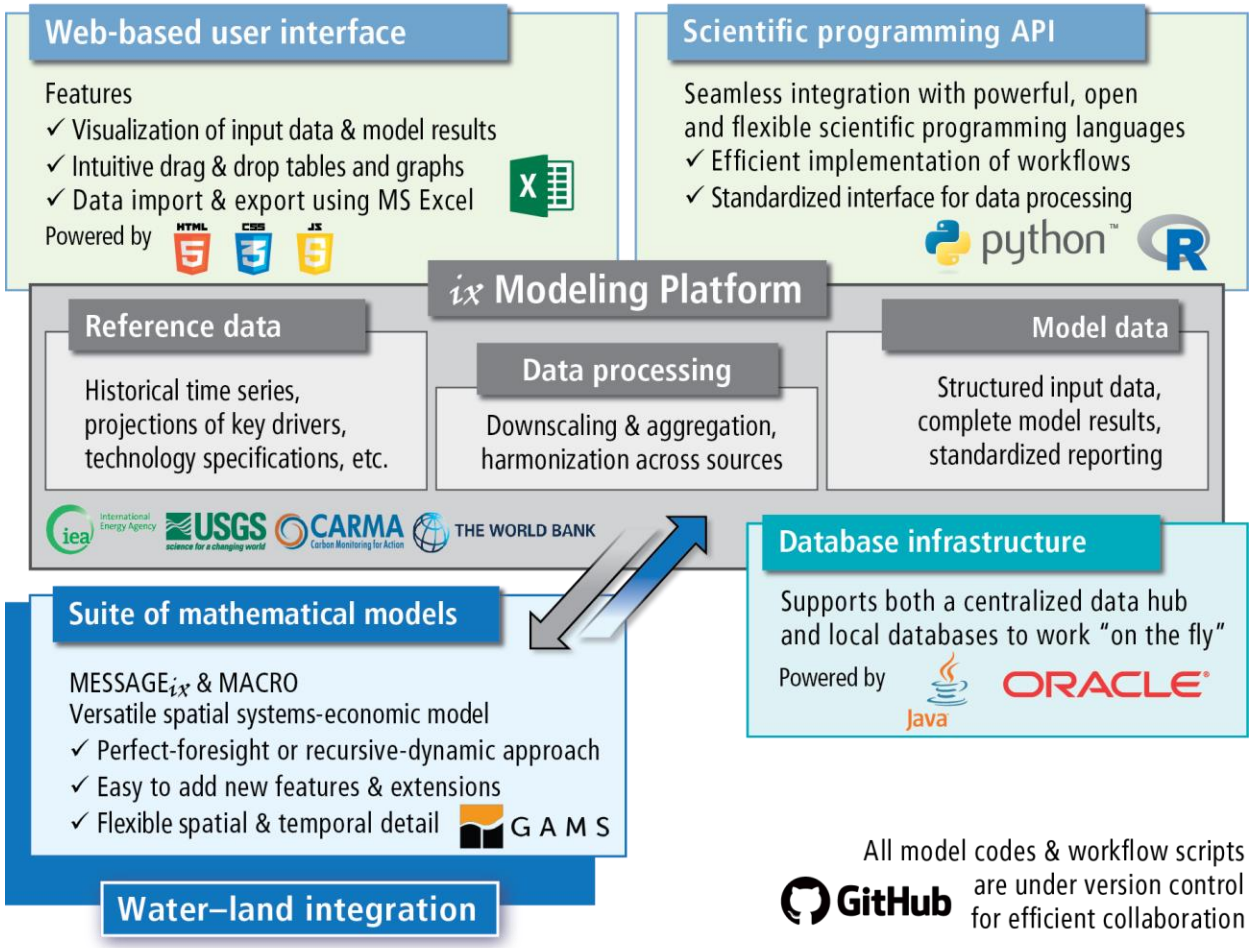


The Scenario Explorer allows for the re-use of scenario data by other research communities

The MESSAGE$_{ix}$ modeling framework: Overview

Facilitating transparency and reproducibility of research





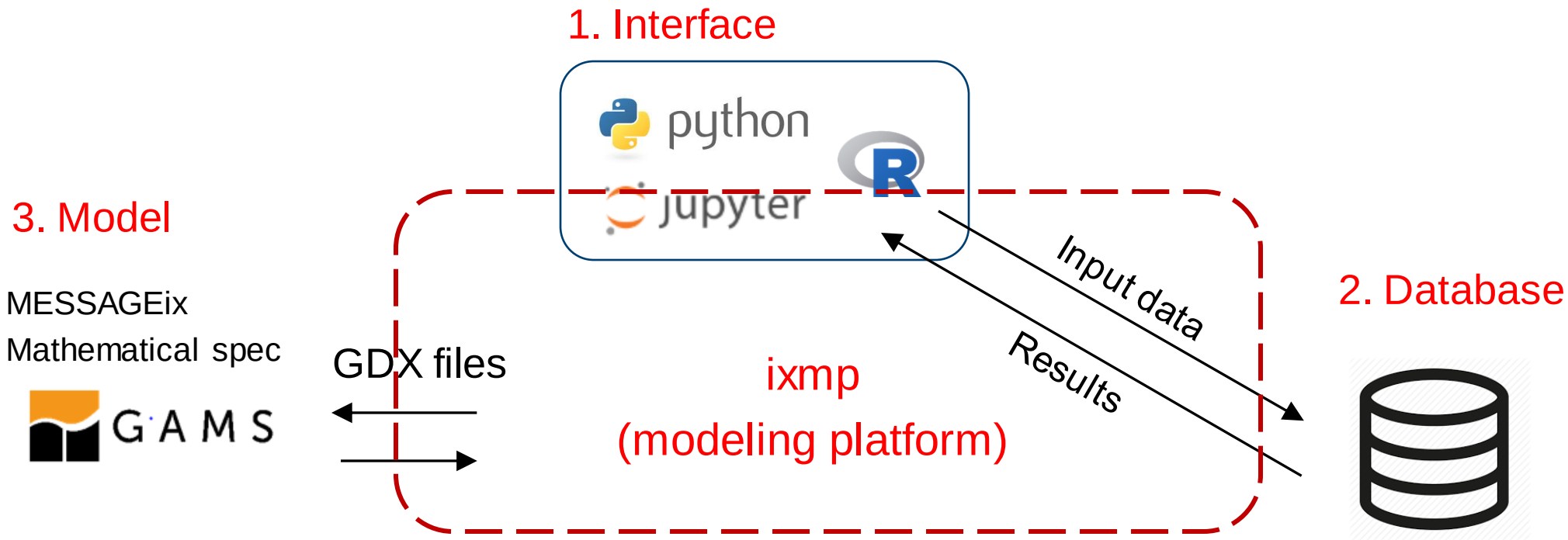
Key features of the *ix* modeling platform (*ixmp*)

(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.

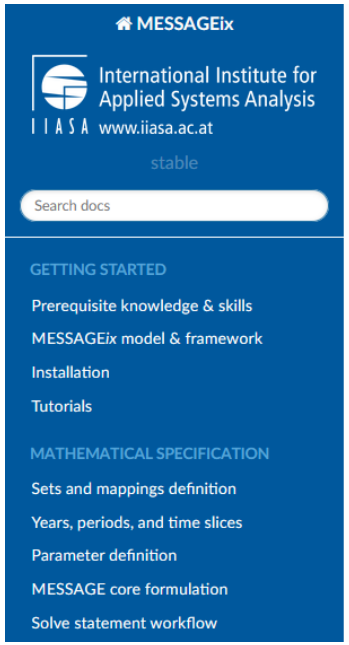


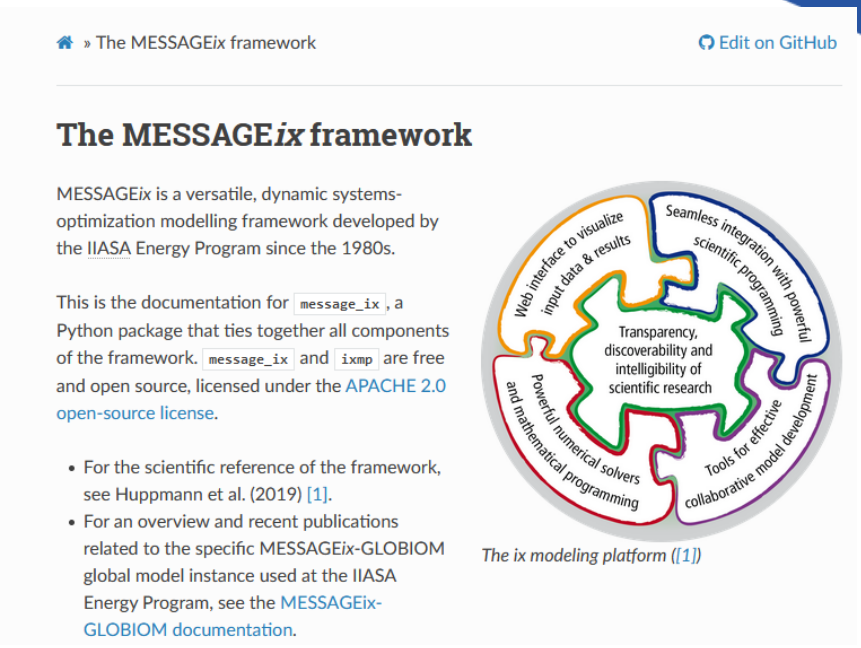
The MESSAGE$_{ix}$ modeling framework: Main sources of information

- Main page in ReadTheDocs:
  ⇒ https://docs.messageix.org/en/stable/

- Open-source GitHub repository:
  ⇒ https://github.com/iiasa/message_ix
  (contribution guide)

- Files for the tutorials can also be found online:
  https://github.com/iiasa/message_ix/tree/master/tutorial





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

For more detailed information on *ix*mp:

ain page in ReadTheDocs:
https://docs.messageix.org/projects/ixmp/en/stable/
en-source GitHub repository:
https://github.com/iiasa/ixmp/

The MESSAGE$_{ix}$ modeling framework: Prerequisites

MESSAGE$_{ix}$ & ixmp, encapsulated as two Python packages

`message_ix`
`ixmp`

python™

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);
  ⇒ 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)
  ⇒ also energy levels and techno-economic parameters

For a complete list, plus links to learning resources, see "Pre-requisite knowledge & skills" 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 (latest version 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.

Basic usage	Advanced usage
Install the released version of `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.

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

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
```

`message_ix` & `message-ix`:
- The actual name of the package installed is message_ix
- `message-ix` is a command-line program used to install and run tasks from message_ix

Video tutorial on the installation

3. Download tutorials (examples for learning the model)

```
$ message-ix dl /path/for/folder_for_tutorials
```

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 latest release 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

193	addon_up	Par	6	6,822
163	aeei	Par	3	726
44	balance_equality	Set	2	0
106	bound_activity_lo	Par	5	8,053
105	bound_activity_up	Par	5	11,845
136	bound_emission	Par	4	0
82	bound_extraction_up	Par	4	88
102	bound_new_capacity_lo	Par	3	150
101	bound_new_capacity_up	Par	3	4,098
104	bound_total_capacity_lo	Par	3	0
103	bound_total_capacity_up	Par	3	0
85	capacity_factor	Par	5	116,559
42	cat_addon	Set	2	29
32	cat_emission	Set	2	16
29	cat_node	Set	2	11
33	cat_relation	Set	2	0

				1990	1995	2000	2005	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110
bio_istig	M1	year	cogeneration_heat					0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
bio_istig_ccs										0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
bio_ppl					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
			scrubber_CO2_bio		0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
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
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
	lignite							0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
coal_adv_ccs	M1								0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	lignite								0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
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
			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
	lignite		cogeneration_heat		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
			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
coal_ppl_u	M1		cogeneration_heat	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15							
	lignite			0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15							

The MESSAGE$_{ix}$ 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 installation video tutorial if you are not sure how to do this)

Thank you very much for your attention!

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