

# The MESSAGE<sub>ix</sub> IAM and the “*ix* modeling platform” for *i*ntegrated and *x*-cutting analysis

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# The MESSAGE model at IIASA

## What we talk about when we talk about MESSAGE

- The MESSAGE model was developed at IIASA since 1982
- It is a (usually linear) systems optimization model coupled with a macro-economic equilibrium problem
- The framework can be used for large-scale energy-system- and integrated-assessment modeling
- The name “MESSAGE” is used for...
  - the “software” aka the model generator aka the *framework*
  - the dataset of the global IAM instance used at IIASA, usually referred to as “MESSAGE<sub>ix</sub>-GLOBIOM”

Recent publications:

- LowEnergyDemand: Grubler et al., Nature Energy, 2018
- Scenarios for the *CD-LINKS* project: McCollum et al., Nature Energy, 2018

# The MESSAGE<sub>ix</sub> framework

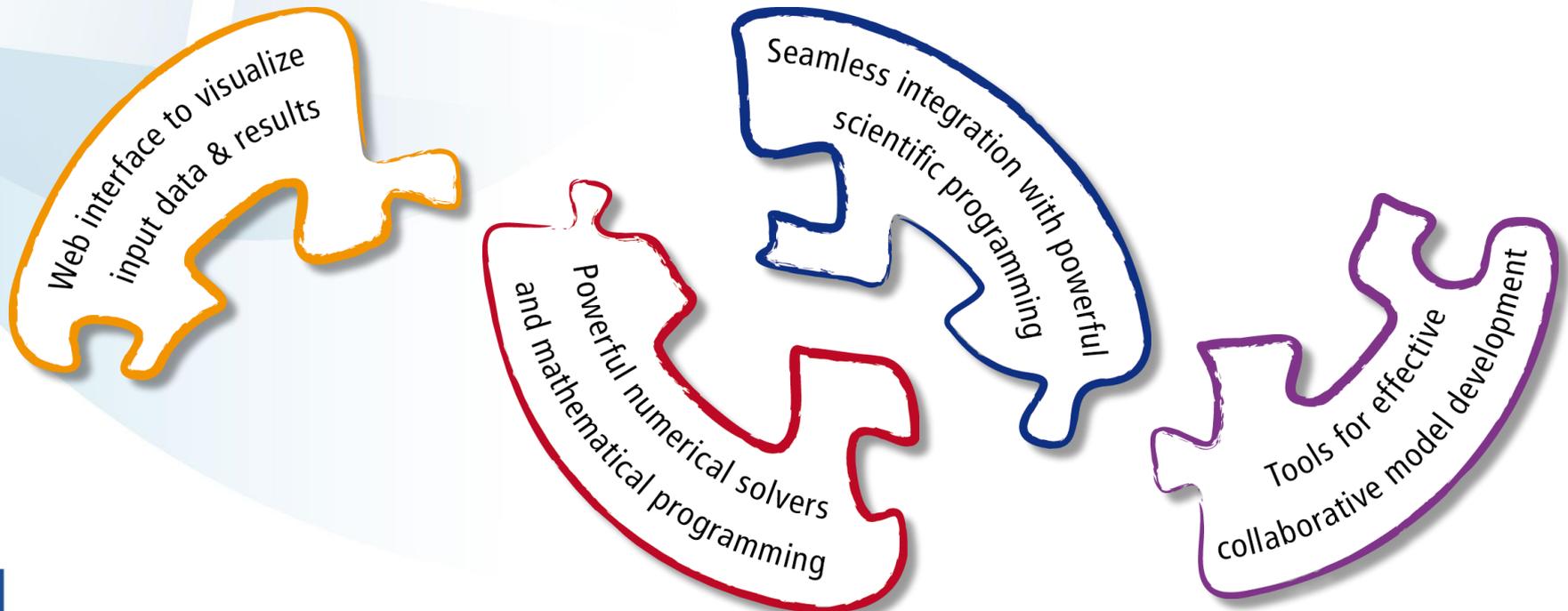
An *i*ntegrated modeling platform for *x*-cutting analysis

*Goal:* Develop a platform for streamlined modeling

... using state-of-the-art tools for data processing,

... building versatile & powerful mathematical models,

... and applying best practice of collaborative research



# The new MESSAGE<sub>ix</sub> framework

An *integrated* modeling platform for *x*-cutting analysis

*Goal:* Develop a platform for streamlined modeling

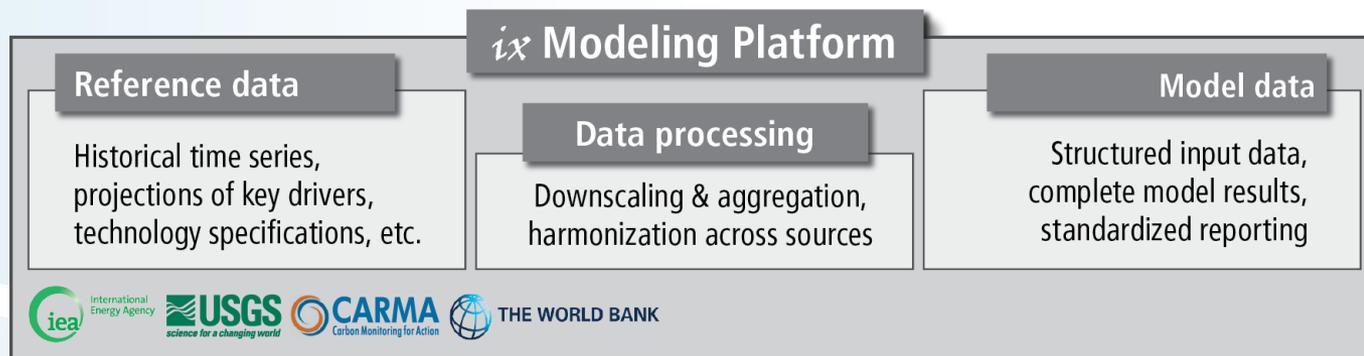
- ... using state-of-the-art tools for data processing,
- ... building versatile & powerful mathematical models,
- ... and applying best practice of collaborative research

*Vision:* Facilitate integration of models & scientific analysis

- ... between different disciplines and fields, including economics, engineering, geophysical, social sciences
- ... across spatial and temporal levels of disaggregation
- ... guaranteeing the highest level of transparency and scientific reproducibility for a wide audience

# The new MESSAGE<sub>ix</sub> framework

It's all about the data...



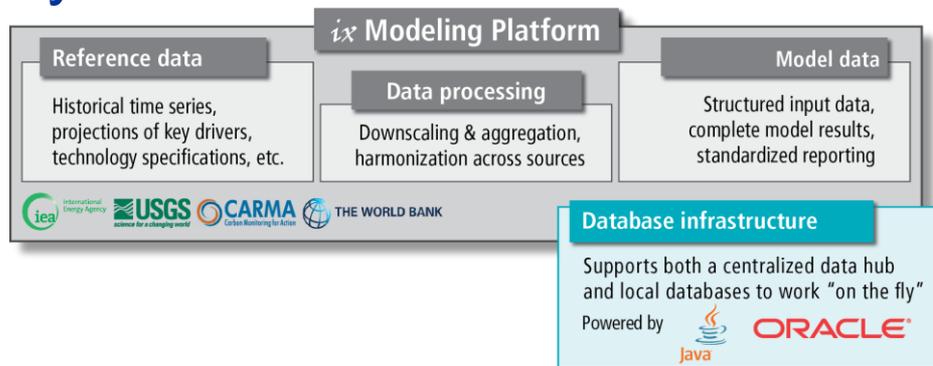
- All modeling & scientific analysis hinges on data availability
- ... reference data required for calibration and verification
- ... version-controlled input data is crucial for development
- ... standardized data processing tools and a common data interface facilitates efficient workflows

# The new MESSAGE<sub>ix</sub> framework

Supported by a high-performance database architecture

The platform...

- ... is based on a Java interface as gateway to the data
- ... supports both an ORACLE database backend for high-performance, heavy-use modeling and local, file-based databases for working “on the fly”



# The new MESSAGE<sub>ix</sub> framework

A simple gateway for researchers and a wider audience

Web interface to visualize input data & results

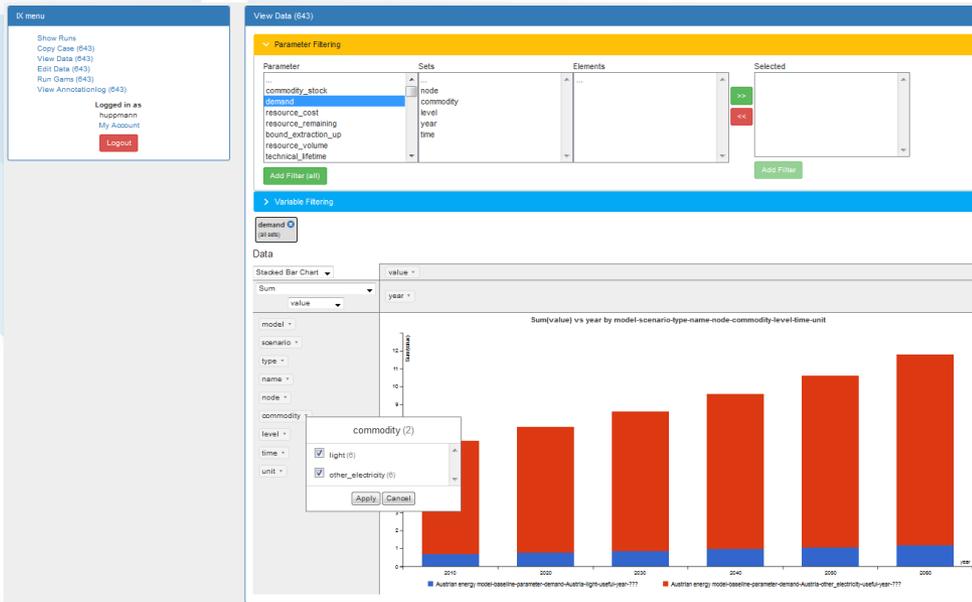
## Web-based user interface

### Features

- ✓ Visualization of input data & model results
- ✓ Intuitive drag & drop tables and graphs
- ✓ Data import & export using MS Excel



Powered by



## ix Modeling Platform

### Data processing

Downscaling & aggregation, harmonization across sources

### Model data

Structured input data, complete model results, standardized reporting

## Database infrastructure

Supports both a centralized data hub and local databases to work "on the fly"

Powered by



ORACLE



# The new MESSAGE<sub>ix</sub> framework

## Interfaces to scientific programming for advanced users

```
In [1]: import ixmp as ix
In [2]: # launch the IX modeling platform
        using the local default database
        mp = ix.Platform(dbtype='HSQLDB')
In [3]: model = "Austrian energy model"

#-----
# load package

source(file.path(Sys.getenv("IXMP_R_PATH"),
                 "ixmp.R"))

In [4]: # launch the IX modeling platform
        mp <- Platform()

In [5]: #-----
        # specify the model and scenario name

model <- "canning problem"
scen <- "standard"

In [6]: #-----
        # load a datastructure from the database

ds <- mp$DataStructure(model, scen)

#-----
# retrieve the demand as a dataframe

demand <- ds$par("demand")
```



### Scientific programming API

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



### Web-based user interface

#### Features

- ✓ Visualization of input data & model results
- ✓ Intuitive drag & drop tables and graphs
- ✓ Data import & export using MS Excel

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### Reference data

Historical time series, projections of key drivers, technology specifications, etc.



### ix Modeling Platform

### Data processing

Downscaling & aggregation, harmonization across sources

### Model data

Structured input data, complete model results, standardized reporting

### Database infrastructure

Supports both a centralized data hub and local databases to work "on the fly"

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ORACLE

Seamless integration with powerful scientific programming

# The new MESSAGE<sub>ix</sub> framework

Connected to high-performance numerical programming

The platform has an interface to GAMS, a versatile software for mathematical programming & optimization.

MESSAGE<sub>ix</sub> is the first model fully integrated in the *ix* modeling platform...

Powerful numerical solvers  
and mathematical programming

## Suite of mathematical models

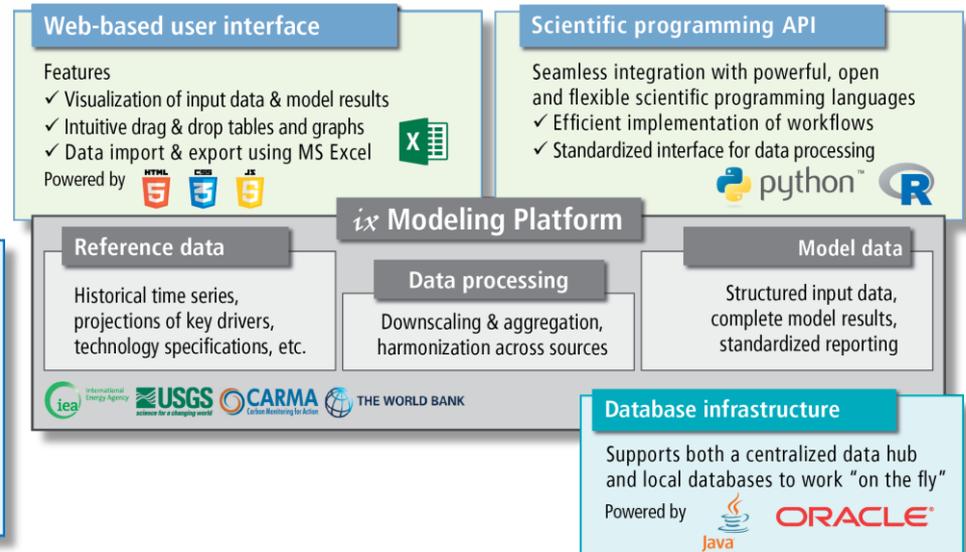
MESSAGE<sub>ix</sub> & MACRO

Versatile spatial systems-economic model

- ✓ Perfect-foresight or recursive-dynamic approach
- ✓ Easy to add new features & extensions
- ✓ Flexible spatial & temporal detail



## Water-land integration



# The new MESSAGE<sub>ix</sub> framework

Implementing tools for comprehensive documentation

The platform ensures transparency and intelligibility of code through “auto-documentation” of all codes & packages

Detailed documentation web pages of the mathematical equations are generated automatically from L<sup>A</sup>T<sub>E</sub>X 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 av
* capacity summed over all vintages, including the technology capacity factor :math:`capacity\_fac
*
* .. 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)
=I= duration_time (time) * capacity_factor (node, inv_tec, vintage, year, time) * CAP (node, inv_t

```



**Scientific programming API**

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

**IIASA** International Institute for Applied Systems Analysis

Page contents

- Model run script
- Sets and mappings definition
- Parameter definition
- Mathematical formulation (core model)
  - Notation declaration
  - Mathematical notation of sets
  - Decision variables
- Objective function
  - The objective function of the MESSAGE<sub>ix</sub> core model
  - Equation OBJECTIVE
- Resource and commodity section [-]
- Technology section [-]
  - Technical and engineering constraints [-]
    - Equation CAPACITY\_CONSTRAINT
    - Equation CAPACITY\_MAINTENANCE
    - Equation OPERATION\_CONSTRAINT
    - Equation MIN\_UTILIZATION\_CONSTRAINT

**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  $capacity\_factor_{n,t,y}$ .

$$\sum_m ACT_{n,t,y^V,y,m,h} \leq duration^H_h \cdot capacity\_factor_{n,t,y^V,y,h} \cdot CAP_{n,t,y^V,y} \quad t \in T^{INV}$$

where  $T^{INV} \subseteq T$  is the set of all technologies for which investment decisions and capacity constraints are relevant.

Equation CAPACITY\_MAINTENANCE

This constraint deals with fixed costs for operation and maintenance (O&M) of technology capacity\_maintenance. Capacity must be maintained over time until decommissioning (no mothballing), and fixed O&M costs must be paid immediately after commissioning

$$CAP_{n,t,y^V,y} \leq remaining\_capacity_{n,t,y^V,y} \cdot \begin{cases} duration^Y_v \cdot historical\_new\_capacity_{n,t,y^V} \\ duration^Y_v \cdot CAP\_NEW_{n,t,y^V} \\ CAP_{n,t,y^V,y-1} \end{cases}$$

Versatile spatial modeling

- ✓ Perfect for distributed models
- ✓ Easy to add new technologies
- ✓ Flexible spatial aggregation

Water



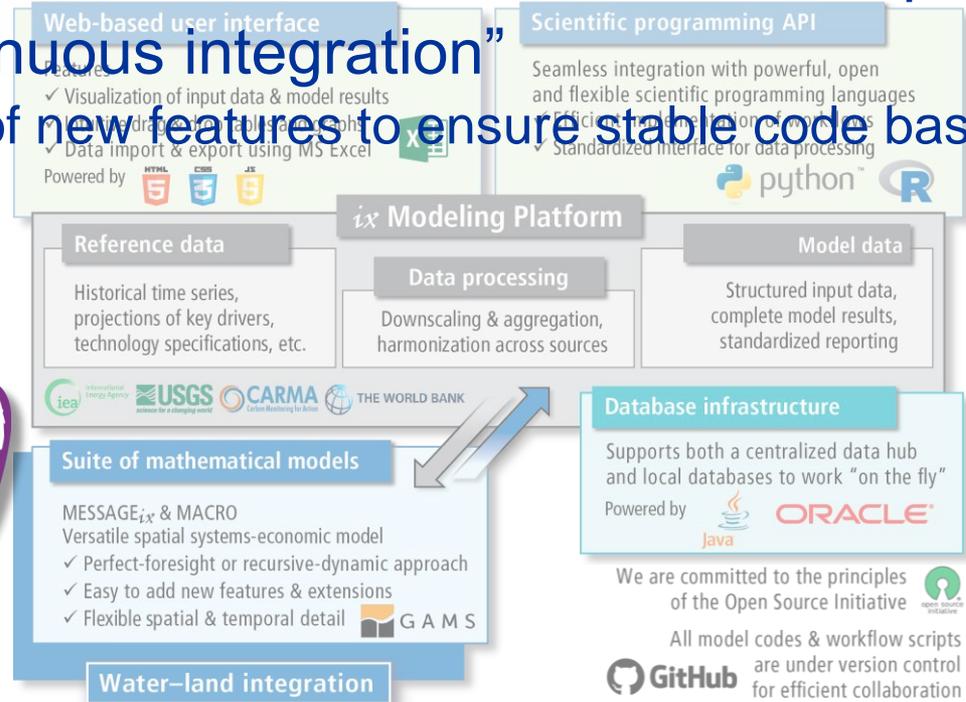
# The new MESSAGE<sub>ix</sub> framework

Geared towards best-practice in collaborative research

- The platform facilitates collaborative model development
- ... through comprehensive data version control
- ... by moving to “script-based” data processing & analysis
- ... using full version control of all model codes and scripts
- ... implementing “continuous integration”
- ... automated unit-testing of new features to ensure stable code base

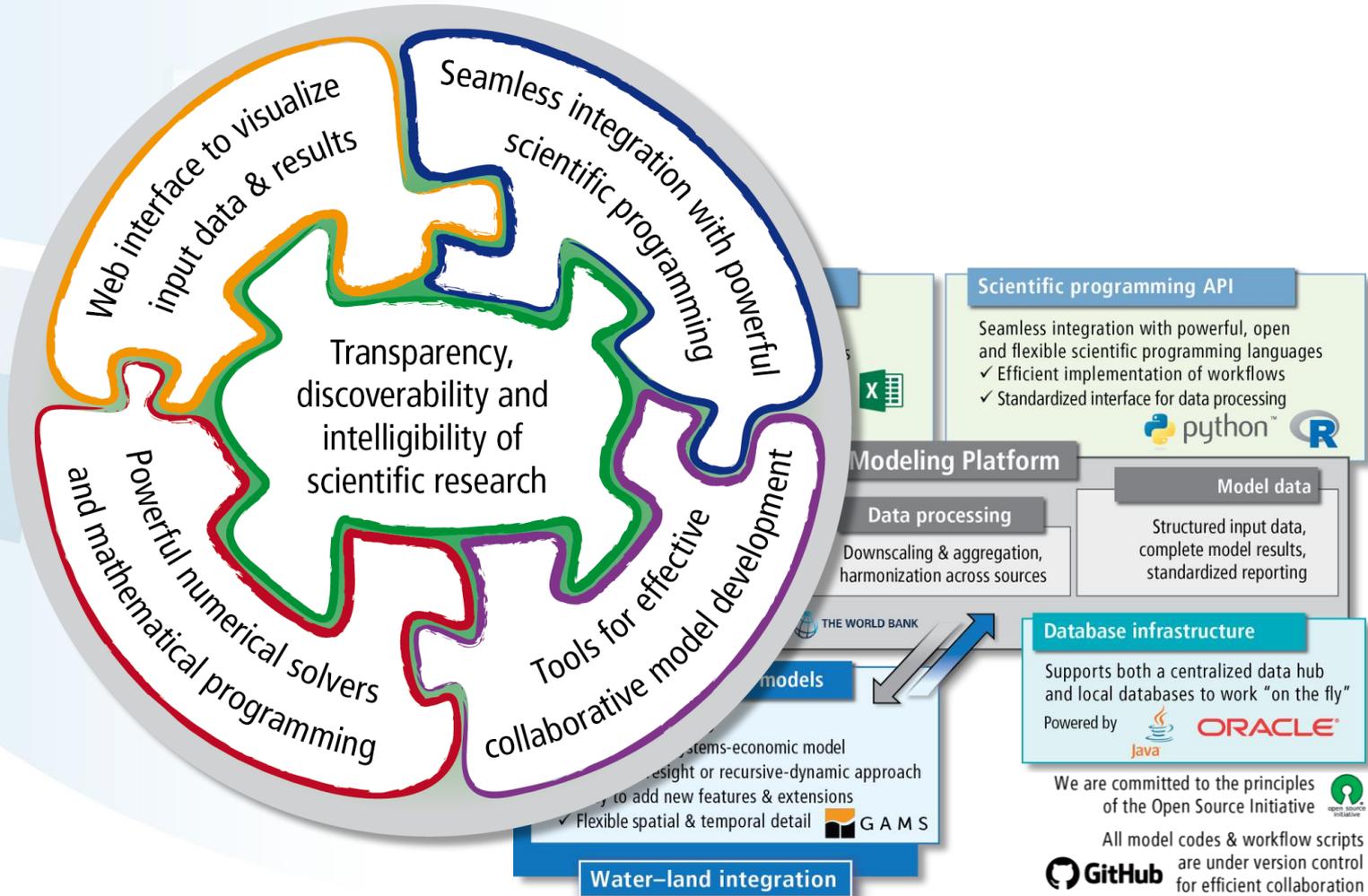


Tools for effective collaborative model development



# The new MESSAGE<sub>ix</sub> framework

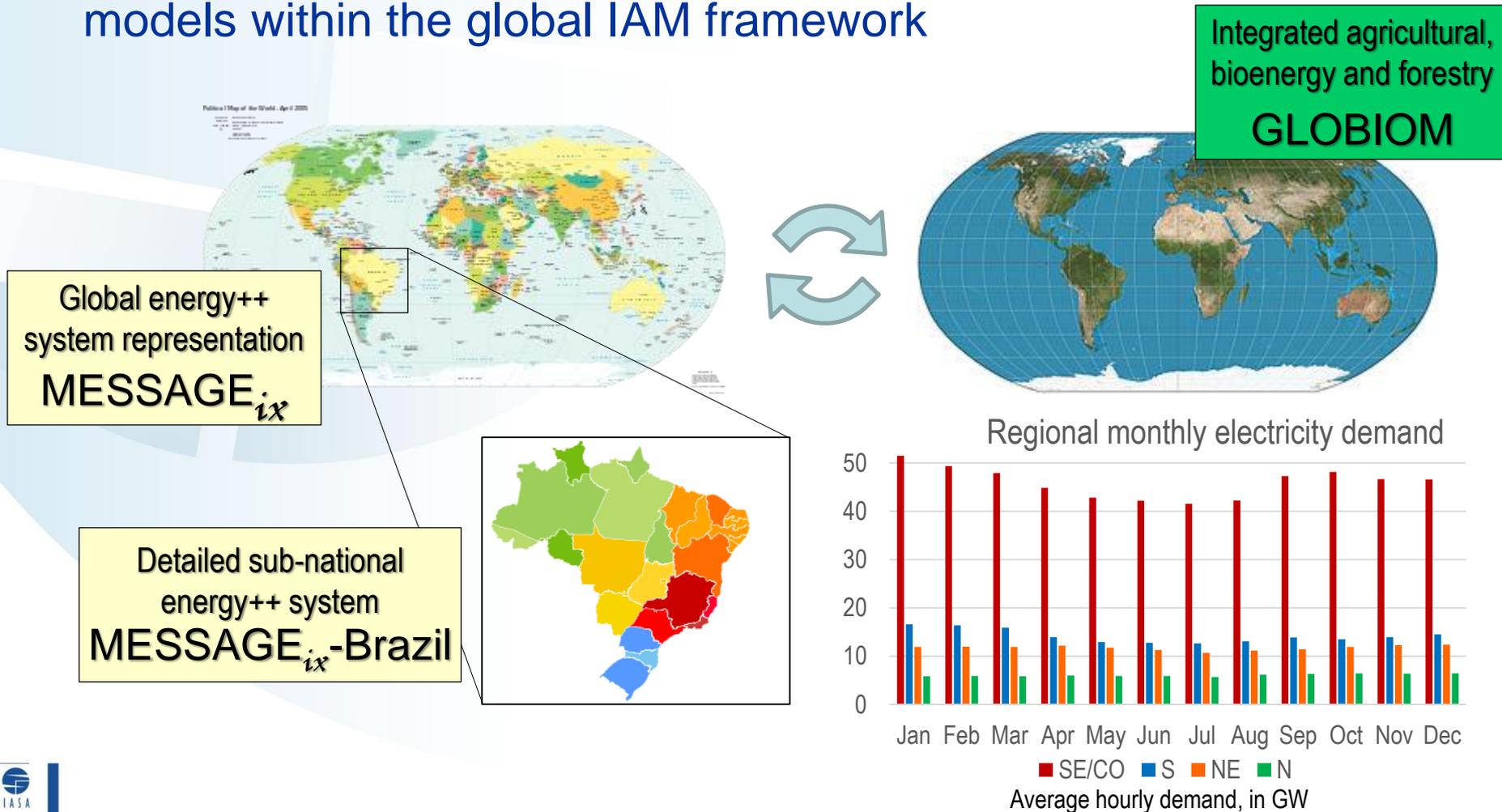
Facilitating transparency and reproducibility of research



# A new model integration methodology

An example of the platform's "raison-d'être"

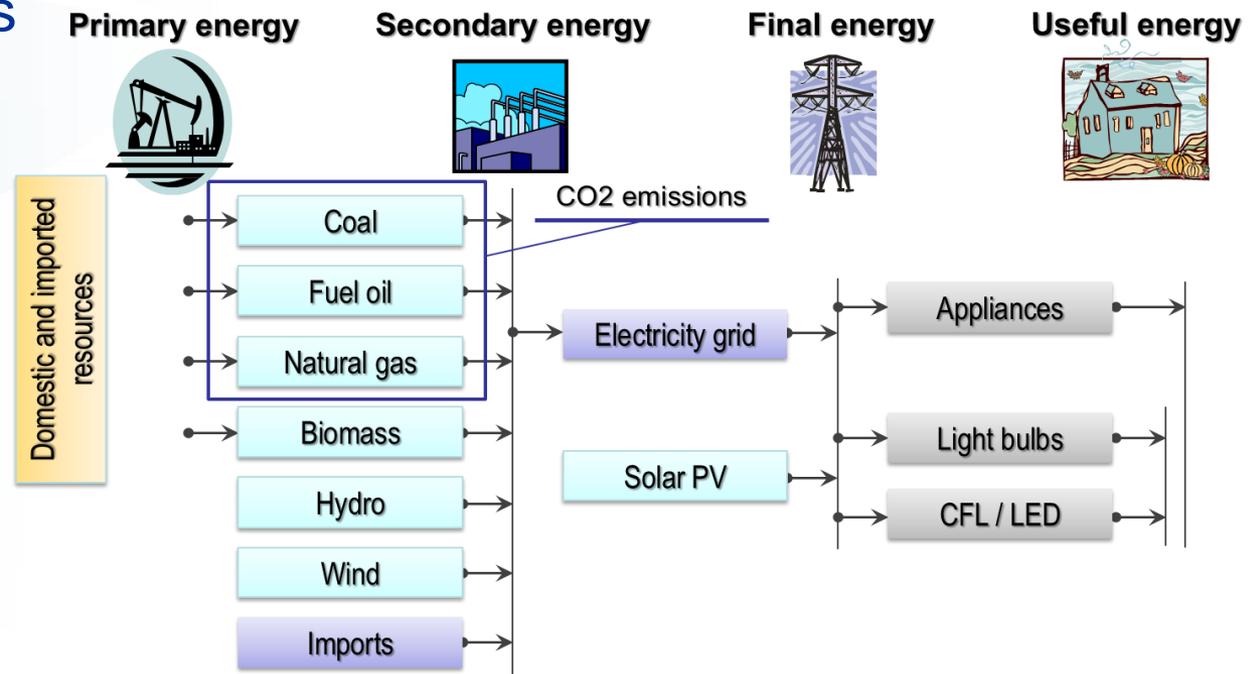
Current project: Develop "nesting" methodology of sub-national models within the global IAM framework



# A simple tutorial – MESSAGE<sub>ix</sub> Austria

## Developing a stylized energy system model

- The public release of the framework includes several tutorials to guide new users into using the framework
- The MESSAGE<sub>ix</sub> Austria tutorial develops a stylized model using IEA statistics and other techno-economic data
- The tutorial illustrates how to use MESSAGE<sub>ix</sub> for policy and scenario analysis



# More information on MESSAGE<sub>ix</sub>

Our aim is to develop an open and vibrant community

- Released under an APACHE 2.0 open-source license
- Currently used for teaching at TU Wien & Politecnico Milano
- Framework documentation and mathematical formulation:

[MESSAGEix.iiasa.ac.at](https://messageix.iiasa.ac.at)

- Community forum and mailing list hosted as Google group:

[groups.google.com/d/forum/message\\_ix](https://groups.google.com/d/forum/message_ix)

- Open-source code hosted on GitHub:

[www.github.com/iiasa/message\\_ix](https://www.github.com/iiasa/message_ix)

- Scientific reference:

Daniel Huppmann, Matthew Gidden, et al.

*The MESSAGEix Integrated Assessment Model and the ix modeling platform*. 2018, in review.

Electronic pre-print available at [pure.iiasa.ac.at/15157/](https://pure.iiasa.ac.at/15157/).



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science for global insight

*Thank you very much for your attention!*

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