International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

TU WIEN

Lecture 4:
Developing your own energy system scenarios

Open-Source Energy System Modeling
TU Wien, VU 370.062

Dipl.-Ing. Dr. Daniel Huppmann

Please consider the environment before printing this slide deck

Part 1

A high-level overview of the open-source energy system model MESSAGE$_{ix}$

The MESSAGE$_{ix}$ framework: Goals and Vision

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,

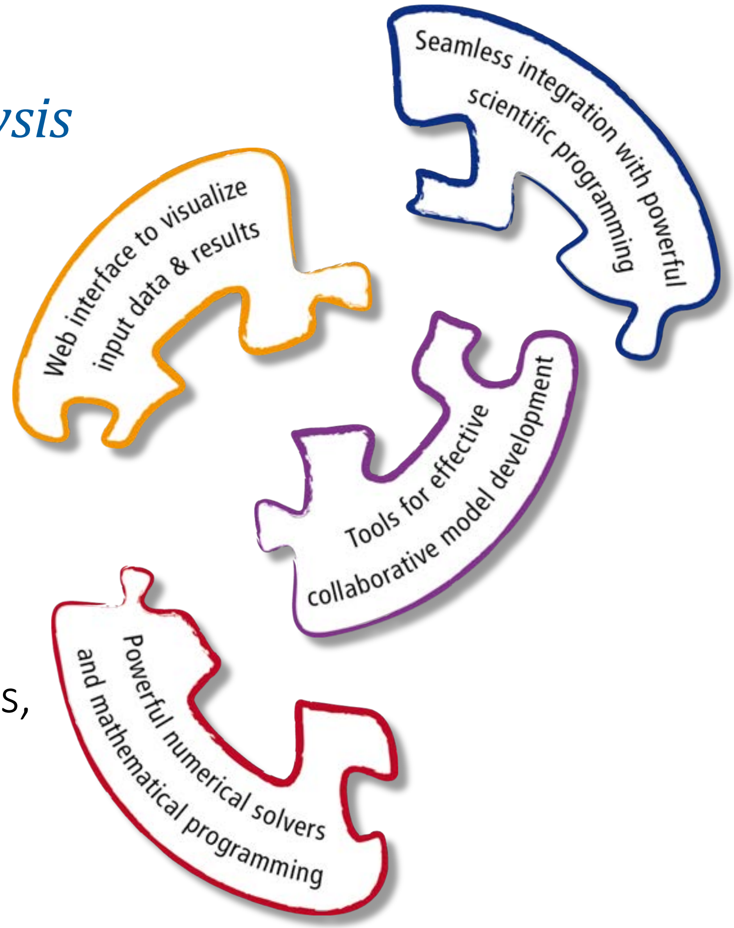
⇒ applying best practice of collaborative research

Vision: Facilitate integration of models & scientific analysis

... between different disciplines and fields including economics, engineering, geophysical, and social sciences

... across spatial and temporal levels of disaggregation

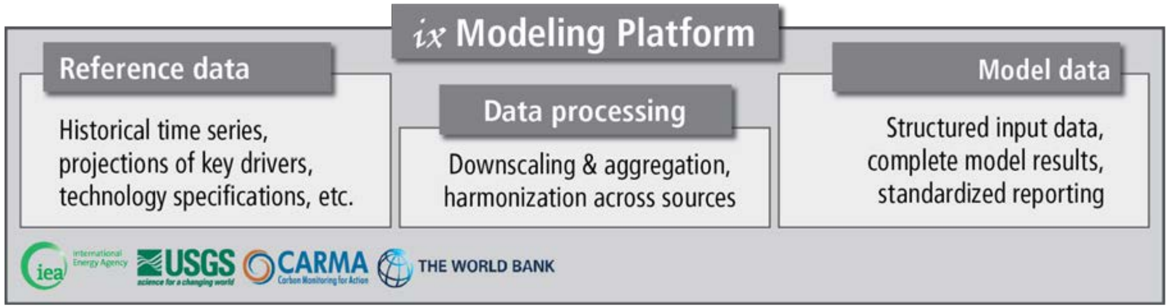
... while guaranteeing the highest level of transparency and scientific reproducibility for a wide audience



Key features of the ix modeling platform

The MESSAGE$_{ix}$ framework: Data management

A central data management warehouse



Good data management is crucial for modeling & scientific analysis:

… version-controlled and traceable input data for model development

… reference data for calibration and verification

… efficient workflows based on standardized data processing tools and a common data interface

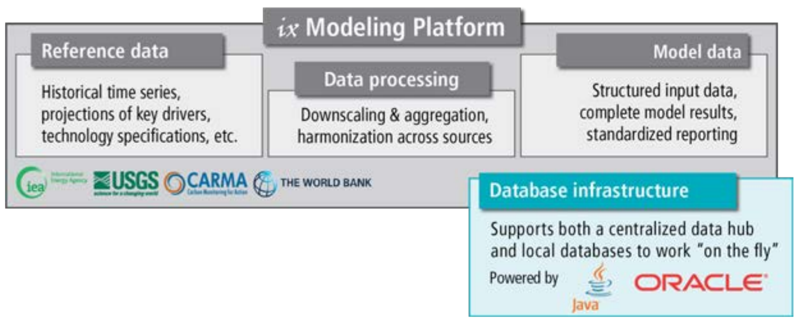
The MESSAGE$_{ix}$ framework: Database backend

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, collaborative modeling and local, file-based databases for getting started or working "on the fly"

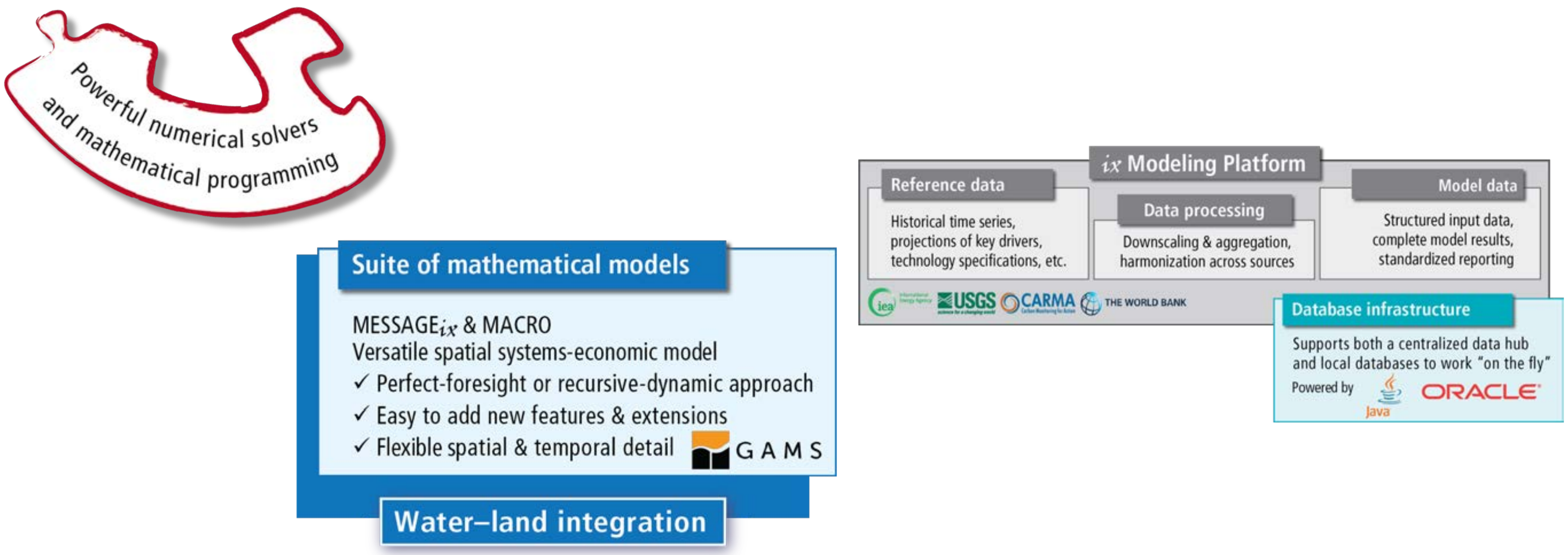


The MESSAGE$_{ix}$ framework: Integration with GAMS

Connected to high-performance numerical programming

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

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



The MESSAGE$_{ix}$ framework : Scientific programming

Interfaces to scientific programming for advanced users

```
In [1]: import ixmp

In [2]: # launch the IX modeling platform
        using the local default database
        mp = ixmp.P

In [3]: model = "Au
        scen = "bas
        annot = "st

        scenario =

        annotation=
            scheme=

In [4]: horizon =
        firstyear =

In [5]: scenario .a
        scenario .a
        "firstmodel

In [6]: country = '
        ds.add_set(
```

python

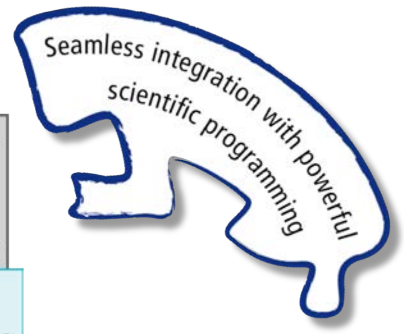
```
#------------------------------------------
# load package

require('Rixmp')

# launch the IX modeling platform
mp <- Platform()

#------------------------------------------
# specify the model and scenario name

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

#------------------------------------------
# load a datastructure from the database

scenario <- mp$Scenario(model, scen)

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

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

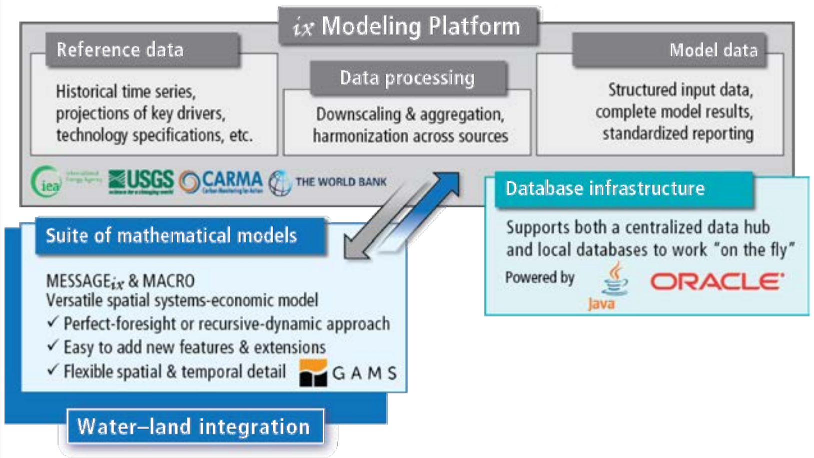
R

Scientific programming API

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

python™ R





The MESSAGEix framework: Collaborate research

Geared towards best-practice in collaborative research

The platform facilitates collaborative model development

... through comprehensive data version control

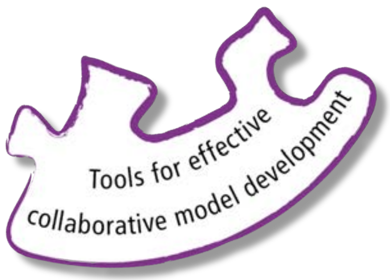
... by moving to "script-based" data processing & analysis

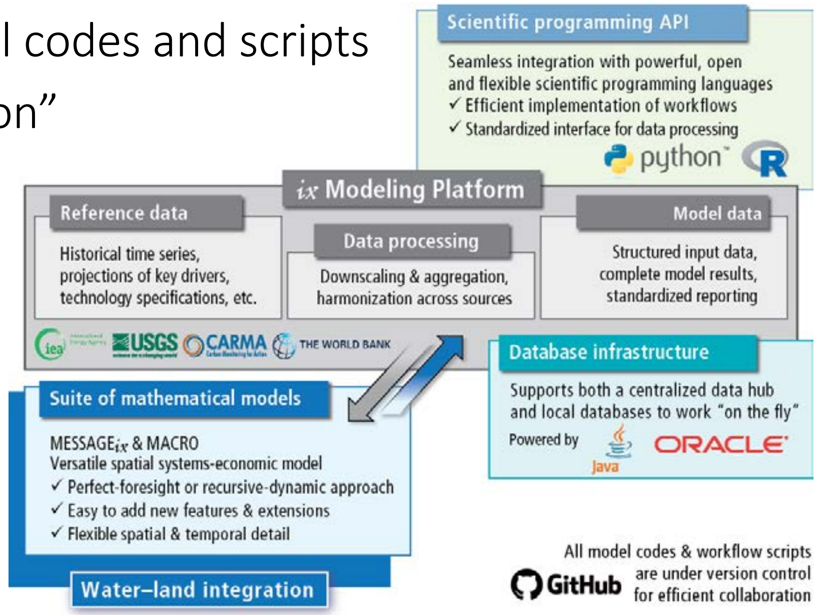
... using full version control of all model codes and scripts

... implementing "continuous integration"

⇒ automated testing of new features
to ensure stable code base

GitHub





The MESSAGE$_{ix}$ framework: Documentation

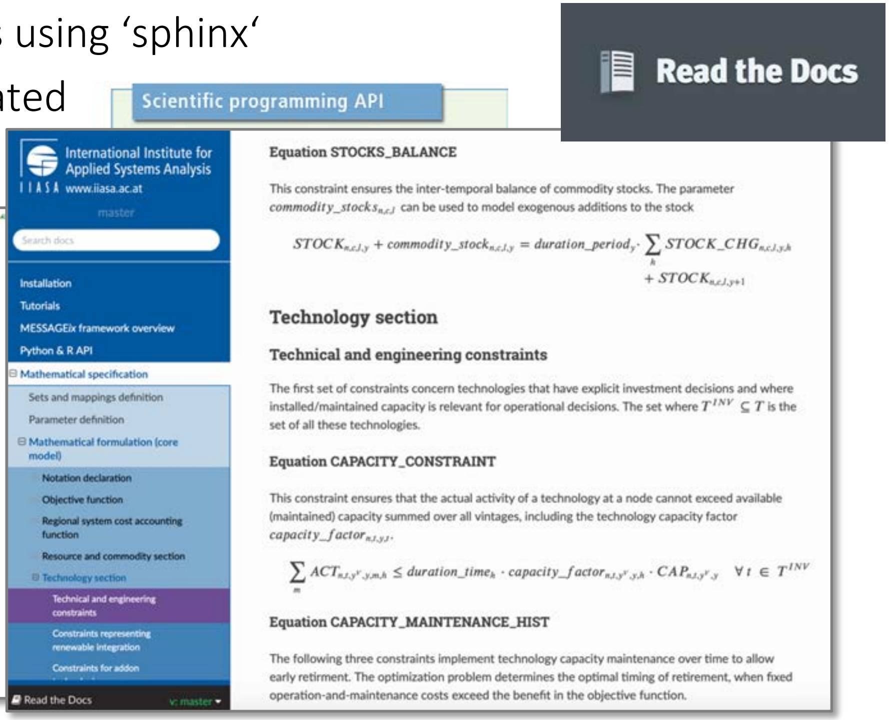
Implementing tools for comprehensive documentation

The framework ensures transparency and intelligibility through “auto-documentation” of all codes & packages on readthedocs.org

⇒ Documentation of all scientific programming packages using ‘sphinx‘

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

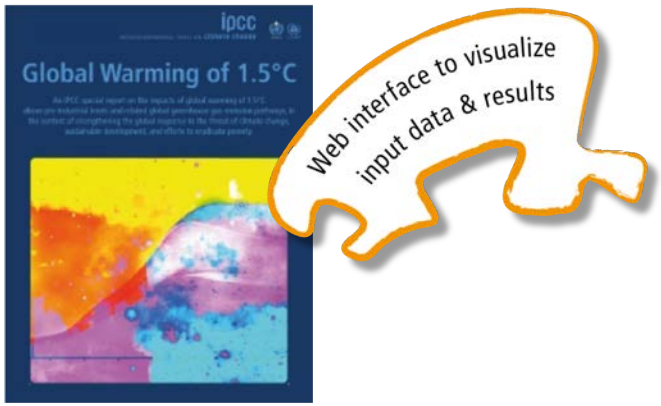
```
*----------------------------------------------------------------------------------------------*
***
* Technology section
* ------------------
*
* Technical and engineering constraints
* ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
*
* Equation CAPACITY_CONSTRAINT
* """"""""""""""""""""""""""""
* This constraint 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$_{ix}$ framework: Interactive web user interface

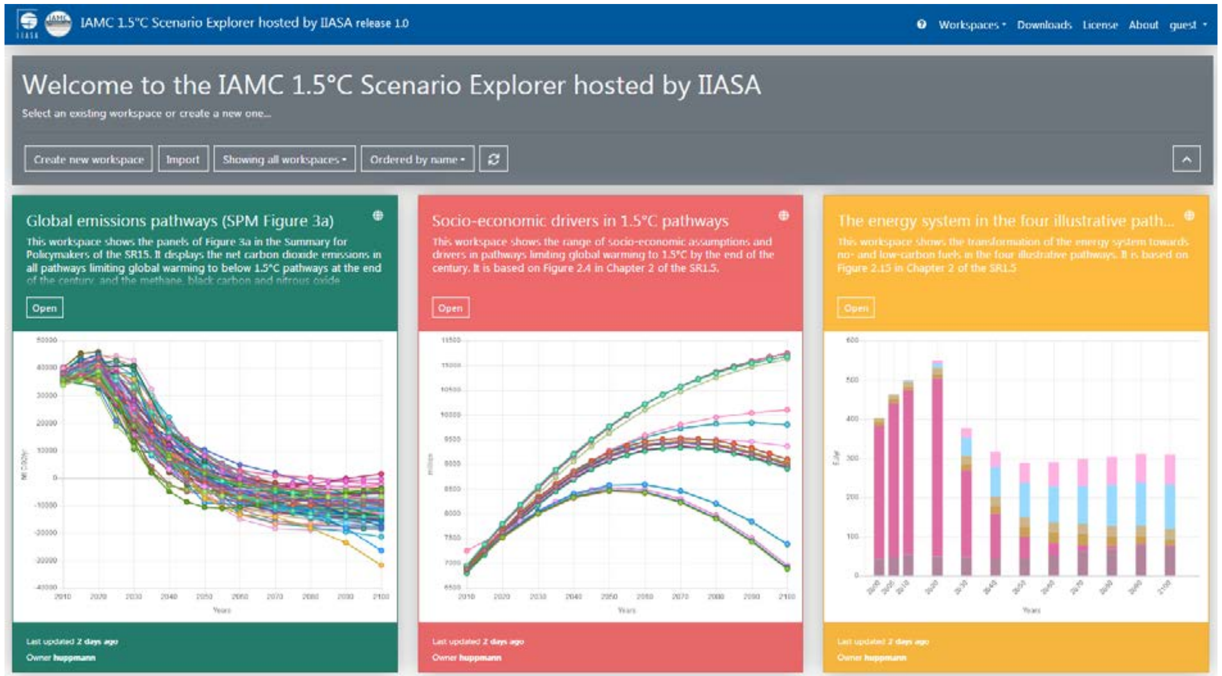
An intuitive gateway to modeling data for researchers and a wider audience

The "IAMC 1.5°C Scenario Explorer" presenting an ensemble of pathways supporting the IPCC SR15 assessment is powered by the web user interface of the ix modeling platform



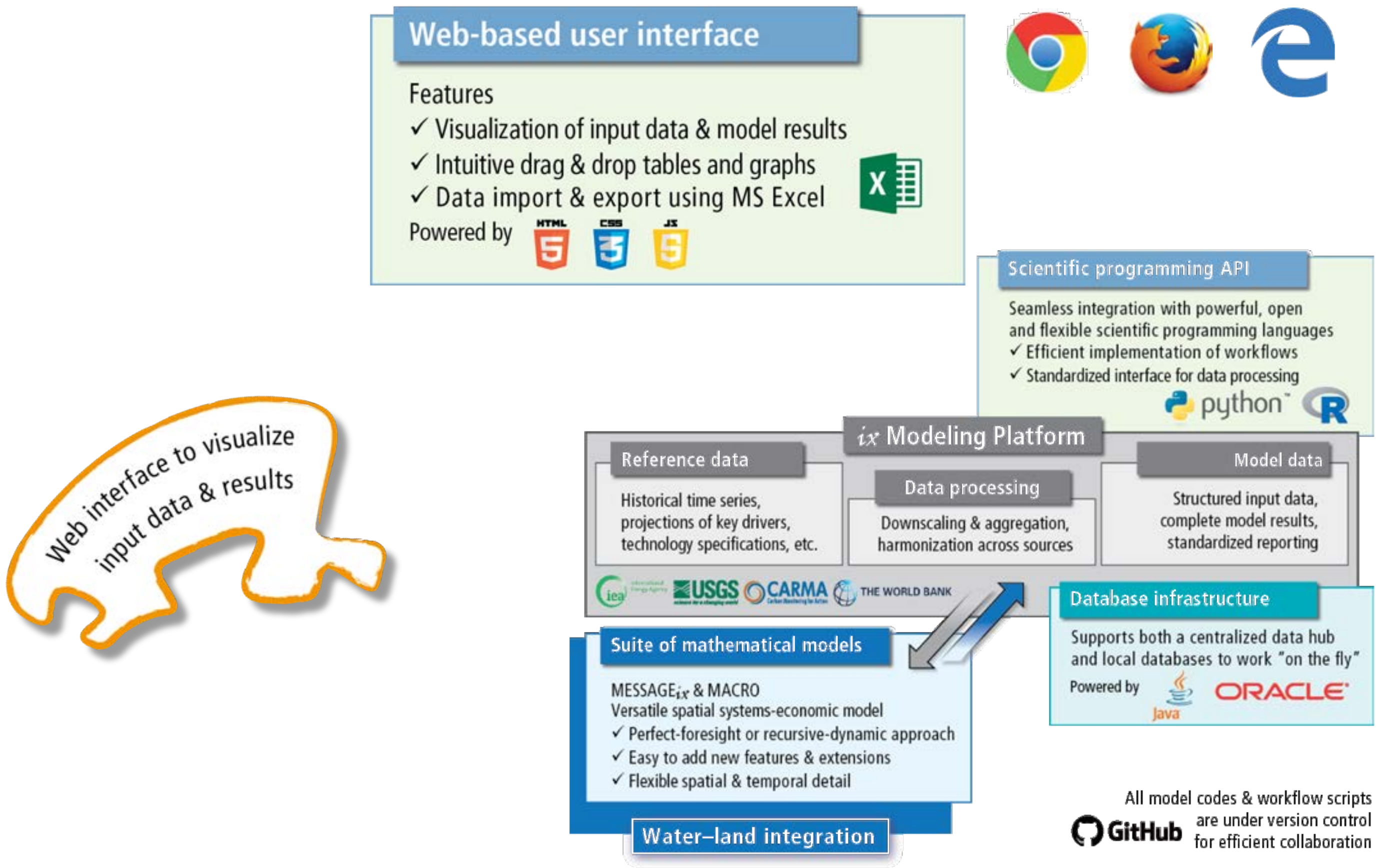
Special Report on *Global Warming of 1.5°C*
(IPCC SR15, http://www.ipcc.ch/report/sr15/)

Visit the Scenario Explorer at https://data.ene.iiasa.ac.at/iamc-1.5c-explorer



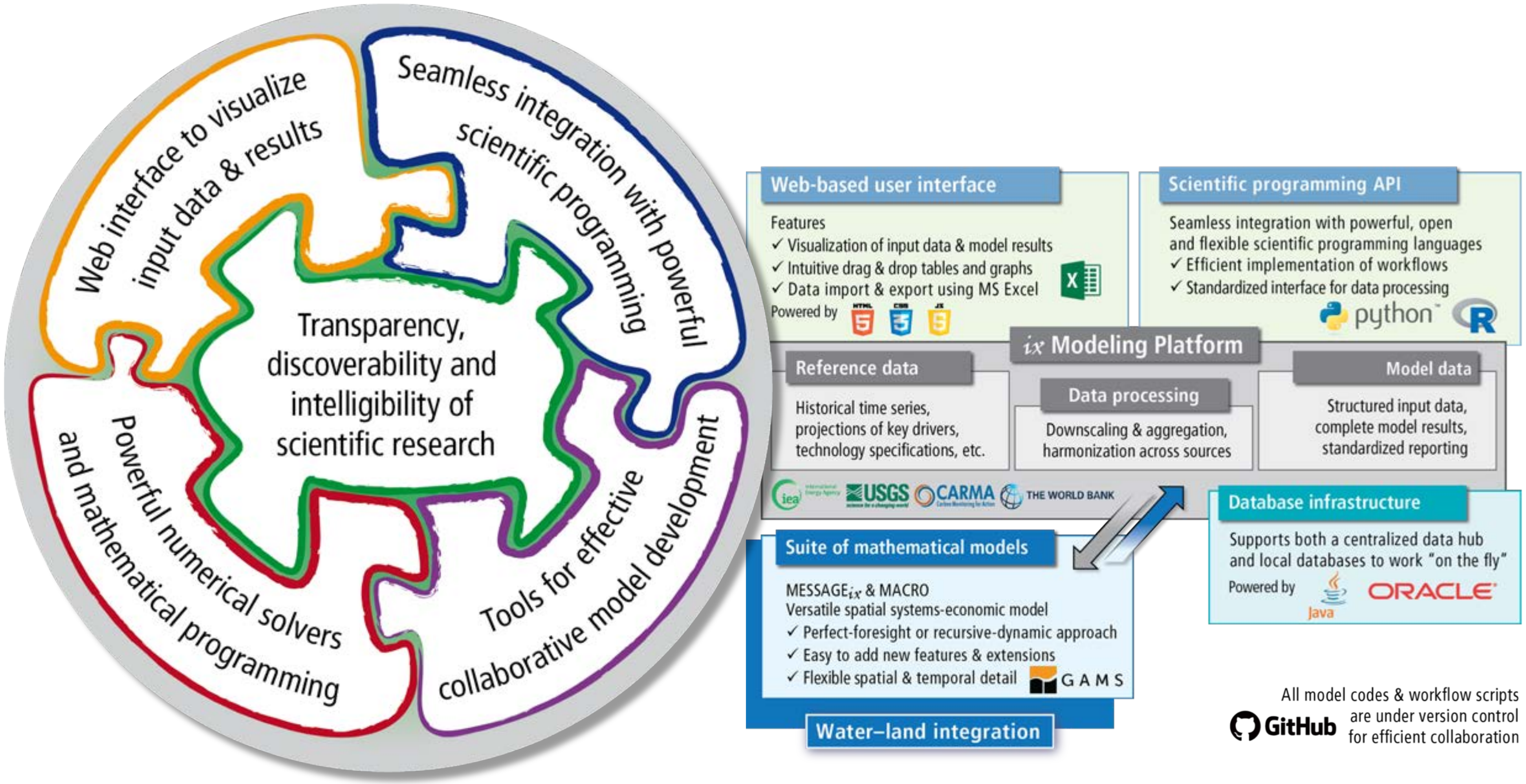
The MESSAGE$_{ix}$ framework: Interactive web user interface

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



The MESSAGE$_{ix}$ framework

Facilitating transparency and reproducibility of research



Working with the MESSAGE$_{ix}$ framework

Practical considerations where MESSAGE$_{ix}$ differs from other frameworks

Installation:

⇒ When installing public release versions via pip or anaconda, you don't need to worry

⇒ To get the bleeding-edge developments, make sure that you install the corresponding branches from the GitHub repositories `ixmp` and `message_ix`

⇒ Known issue on Mac: `versioneer` is sometimes confused, delete installation from `site-packages` directory manually if necessary

Your scientific workflow:

⇒ Don't re-run your scenario assessment notebooks over and over again, because this will create a new scenario instance in the database every time

⇒ Instead, remove the `` `version=new` `` argument to load an existing scenario and adapt the script accordingly

Working with the MESSAGE$_{ix}$ framework

Practical considerations where MESSAGE$_{ix}$ differs from other frameworks

Integration with GAMS:

⇒ The GAMS code is installed (copied) to the Python `site-packages` directory, so if you make changes in your `git` folder, it won't have any effect on your model run

⇒ This actually makes a lot of stuff simpler for the Python installation (says @gidden)

⇒ But you can set your `git` folder as the model folder
(i.e., where the `message_ix` package looks for the MESSAGEix-GAMS code)
using this command line interface (CLI):

```
$ messageix-config --model_path /path/to/model
```

Part 2

How to start developing your own energy system scenarios?

Considerations for developing a new (energy system) model

What do you need to build an energy system

- A “reference energy system” (RES)
  ⇒ The technologies, commodities, levels
- Regional specification
- Time horizon
- Assumptions (projections)
  ⇒ Costs (investment, capacity, variable)
  ⇒ Demand for energy and other commodities
  ⇒ Bounds on trade, diffusion of new technologies, etc.
- Policies on emissions (taxes, bounds) and sustainable development policies

To make learning MESSAGEix more fun, we developed
a suite of tutorials based on the TV show “Game of Thrones”

Homework assignment

Let there be light in Westeros

Create new notebook(s) starting with a clone of a MESSAGEix Westeros tutorial scenario.

- Add a new technology for LEDs (which is more expensive than light bulbs per energy service)
  - ⇒ Show that the results of the baseline scenario do not change
  - ⇒ Investigate under which carbon price the LED technology becomes economically viable
  - ⇒ Assume different maximum diffusion rates for this new technology and compare the share of electricity from coal and wind depending on the diffusion rates
- Add a new technology “gas power plant”
  - ⇒ Assume realistic cost parameters and lifetimes for this power plant type (include references your sources in the notebook)
  - ⇒ Is there a “sweet spot” of prices on carbon such that coal, wind and gas are used at the same time?

The notebooks should not just show one solution, but illustrate/document your solution approach

Thank you very much for your attention!

Dr. Daniel Huppmann

Research Scholar – Energy Program

International Institute for Applied Systems Analysis (IIASA)
Schlossplatz 1, A-2361 Laxenburg, Austria

huppmann@iiasa.ac.at
http://www.iiasa.ac.at/staff/huppmann