MESSAGE\textsubscript{ix} Workshop
Session 2: Building an Energy System Model (Part I)

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

MESSAGE\textsubscript{ix} Workshop (online), 8 June 2021
The MESSAGEix Modeling Framework

Recap...

- MESSAGEix is an open, version-controlled systems engineering **modeling framework**
- ix modeling **platform** *(ixmp)* is a data warehouse for facilitating high-powered modeling work
- python and R are the main interfaces for modelling using MESSAGEix
- MESSAGEix **mathematical model** is written and solved in GAMS
- Documentation of the MESSAGEix model and tutorials are available online: [https://docs.messageix.org](https://docs.messageix.org)
MESSAGEix framework: Building an energy system – Part 1

Agenda of this Session

- A note on optimization
- MESSAGEix mathematical model and its structure
- Working with MESSAGEix tutorials: building a simple model

➤ Voting feature will be used to measure how much time we should spend
After this tutorial

The goal is to...

- Learn about the logic behind the MESSAGEix energy system model
- Be able to work on a MESSAGEix model using Jupyter Notebook
- Be familiar with basic terminology of a MESSAGEix model

Requirements

- MESSAGEix framework installed and running
- Knowledge on energy systems
- Patience, motivation, and curiosity
Linear programming (LP)

**Finding the best (optimal) solution**

- The goal is to optimize a linear objective function
  \[ \text{Maximize} \quad c^T x \]
- There are a set of **decision variables**
- There are some constraints (bounds on or relationship between decision variables)
  \[ \text{subject to} \quad Ax \leq b \]
  \[ \text{and} \quad x \geq 0 \]

**Example: the best way to commute to work**

- **Decision variables**: walking, biking, bus, train, taxi, private car, car sharing
- **Objective function**: cheapest or fastest option (least environmental footprint, least walking option)
- **Constraints**: maximum 2 hours commute/day, maximum 300 euro/month, no later than 7 PM, ...
- **Feasible region**: usually there many alternative solutions but not all of them are feasible
Linear programming (LP) (reminder)

**Applications of LP**
- Production management
- Personnel management
- Marketing management
- Resource/inventory management
- Blending problem, etc

**Principle:**
Maximizing the utility
Or
Minimizing the cost
Energy Systems

**Different scales: community, city, country, region, and global**

- A system of energy resources, conversion/processing, transmission and distribution technologies, and services

Figure: Behnam Zakeri (IIASA)
MESSAGEix: a model for investment and planning

Minimizing total discounted cost of the system

- **Objective**: The least cost option for meeting certain services (demand) ➔ min $cT \cdot x$

- **System**: a network of technologies (processes), resources, and commodities (products)

- **Cost of the system**: installing/maintaining *capacity*, cost of *activity* (O&M), taxes, emission penalties, land use costs (if any), etc.

- **Constraints**: maximum use of a technology, growth/decline rates of activity, capacity factor, etc. ➔ $s.t.A \cdot x \leq b$

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A note on “capacity” and “activity” (MESSAGEix formulation)

- **Capacity**: installed units of a technology (e.g., 150 MW power plant)

- **Activity**: operation of that technology (e.g., 800 GWh)

- **Reminder**: capacity ≠ activity

  - capacity * capacity factor = activity
MESSAGE$_{ix}$ for Investment Planning

How can transition happen over multiple decades?

Electricity generation (TWh)

- Historical data
- Optimization years
- Demand

- Biomass
- Wind
- Solar
- Geothermal
- Hydro
- Nuclear
- Gas
- Oil
- Coal
MESSAGEix: a technology-based model

Technologies and resources meet demand

- Example technologies: electric car, reactor, pipeline, power plant, building, ship, industrial process

A sample technology: coffee machine

[Diagram of coffee machine with inputs and outputs: coffee beans, water, electricity, coffee powder, coffee, storage, grid, pipe, waste heat, useful (demand), emission, technology, (input) level, (output) level, (input) commodity, (output) commodity]
MESSAGEix: demand is exogenous (input)

Supply must meet demand under specified techno-economic parameters

Resources
Renewable potentials

Conversion/processing

Transmission & Distribution

Demand

PRIMARY

SECONDARY

FINAL

USEFUL

oil extraction    crude oil    oil refinery    light oil    pipeline/distribution    light oil    transport
MESSAGEix: A flexible tool for modeling different systems

Building a model in MESSAGEix

- There is no pre-defined sectors, technologies, commodities, etc.
- The level of technical detail depends on the user’s preferences and research questions
- Flexibility remains for temporal and spatial representation

![Diagram of a refinery with aggregate and detailed representation](image: www.azom.com)
**Sets:**
- List of elements for building a model
- Example: technology, commodity, node, emission

**Parameters:**
- Defining quantities (specification), e.g., lifetime, efficiency, costs
- Defining relationships between sets, e.g., input and output of technology
- Defining constraints, e.g., bounds and growth rates

**EQUATIONS:**
- Relationship between sets, parameters, VARIABLES, etc.
- Building the model

**VARIABLES:**
- Decision variables to meet the objective and constraints, e.g., ACT, CAP

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**MESSAGEix: Mathematical notation (GAMS)**

**Sets:**
- Technology, commodity, node, emission

**Parameters:**
- Defining quantities (specification), e.g., lifetime, efficiency, costs
- Defining relationships between sets, e.g., input and output of technology
- Defining constraints, e.g., bounds and growth rates

**EQUATIONS:**
- Relationship between sets, parameters, VARIABLES, etc.
- Building the model

**VARIABLES:**
- Decision variables to meet the objective and constraints, e.g., ACT, CAP
Building a MESSAGEix model

Different steps of modeling

- Creating a new scenario (or loading an existing one)
- Declaring required sets (*node*, *technology*, *commodity*, *level*, etc.)
- Defining required parameters (adding numeric data, relating sets to each other, etc.)
  - *demand*
  - *techno-economic parameters* (*lifetime*, *efficiency*, *investment cost*, *O&M cost*, etc.)
  - *bounds and dynamic constraints* (*growth rates*, *diffusion rates of technologies*)
- Solving the model
- Postprocessing and plotting
Building a MESSAGEix model (2)

Minimum information for building a model

- Sets: technology, node, commodity, level, mode (of operation), year
- Parameters
  - demand
  - output (of technologies)

⇒ In MESSAGEix efficiency of technologies is defined with two parameters: input, output

\[ eff = \frac{output}{input} \]
Homework

To be done before Wed 9 June 13:00 CEST

1. Try to extend the coffee machine example, for example, by adding another year in the model such as 2023 and defining demand for 380 cups of coffee in that year.

2. After downloading MESSAGEix tutorials, open Jupyter Notebook like what you did today, and run the Westeros Baseline scenario. Can you identify different steps of modeling as stated in the slide 14? We will review this tutorial together tomorrow.
Recap...

The MESSAGEix framework: Workflow of modeling

1. Interface
   - Python
   - Jupyter

2. Database
   - ixmp
   - ix

3. Model
   - MESSAGEix
   - Mathematical spec
   - GAMS
Thank you very much for your attention!

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