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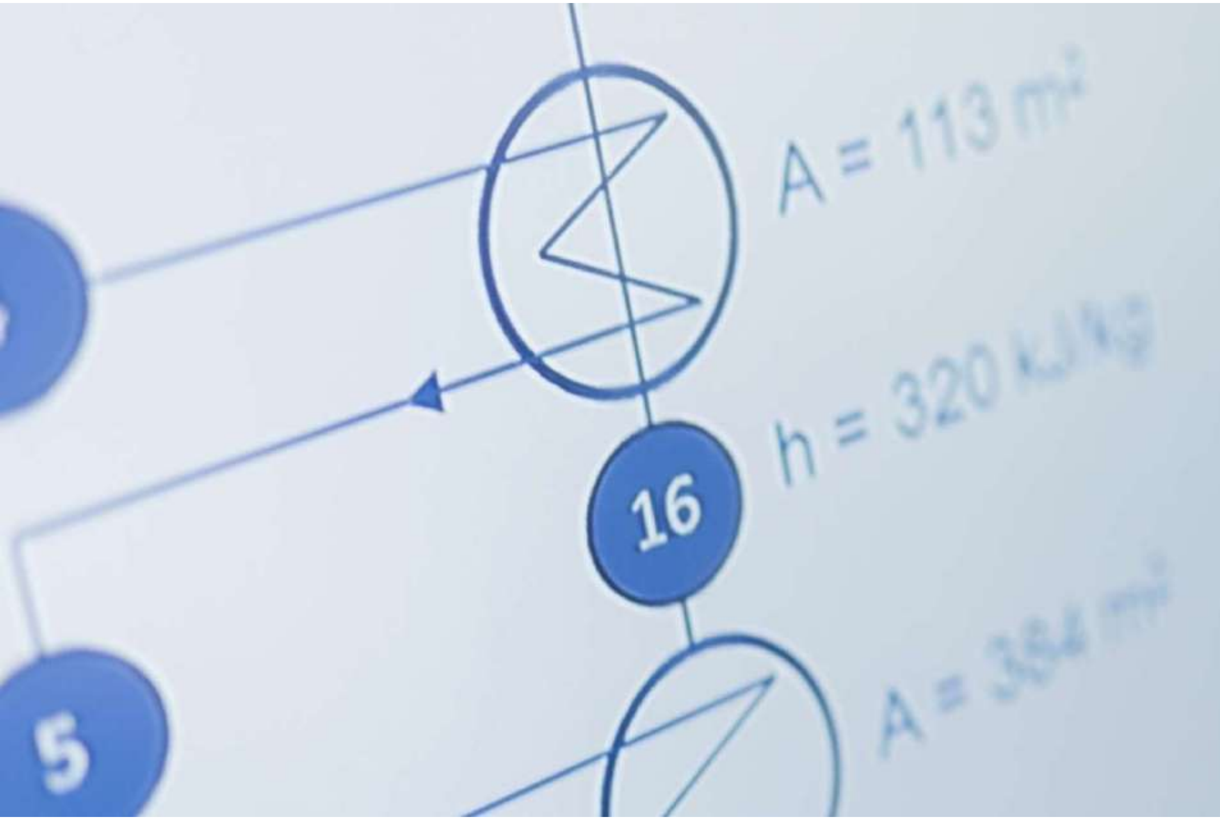

Introduction to Energy System Modelling and the TIMES Modelling Framework

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Course content

Day 1

- Introduction: UrGe4Hy Project, University of Stuttgart, and IER
- Basics of Energy planning and the role of Energy System models
- Showcase: Results and analyses possible with energy system models – overview of insights
- Introduction to the Uruguayan Energy System (Dr. Mariana Corengia)
- Troubleshooting installation issues

Day 2

- Introduction on how to build and use a model
- Hands-on presentations and exercises

Day 3

- Hands-on presentations and exercises
- Future/further applications of modelling
- Evaluation of students
- Evaluation and feedback on course

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Introduction on how to build and use a model

Basic Components of the TIMES Model Generator

image: ewi

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Agenda

- Introduction
    - TIMES Model Generator
    - Linear Programing Model
    - Example
- TIMES Components
    - The Reference Energy System
    - Inputs and Outputs
    - Commodities
    - Processes
    - Spatial and Temporal Resolution
    - Modelling Steps
- VEDA2.0

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Introduction - TIMES Model Generator

- TIMES (The Integrated Markal Efom System) is a bottom-up optimization model.
  - Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA)
- Developed for long-term energy planning and determining least-cost decarbonization pathways.
- It maps an energy system in a technologically detailed manner as a network of processes and goods in the form of a so-called reference energy system.
- Actors can have prefect foresight / myopiccal approach.
- Analysis of competition and substitution effects between technologies.
- Detailed representation of results: energy flows, new capacities, emissions, costs
- By specifying framework conditions, various issues can be formulated.
  - e.g. the most cost-effective way to reach greenhouse gas reduction targets in compliance with technical and ecological restrictions.

Introduction - Linear Programming model

- a general objective function *z* can be formulated as:

$$z\colon\ c_0 = \sum_{k=1}^{n} c_k \,.\, x_k \ + c \overset{!}{=} min$$

- under the constraints *r* :

r_i: $a_{ik} \cdot x_k \leq b_i$ (i = 1,…, m)

- The right hand side (RHS) constants *b* and the and the variables *x* may not be negative

$b_i \geq 0$

$x_k \geq 0$ (k = 1,….., n)

Introduction - Example

- Two power plant units with the rated power of $x_{1,up}$ = 100 MW and $x_{2,up}$ = 50 MW are used for covering the energy demand in a supply area.
- The plants are to be used for of at least 85 MW of their capacity.
- Because of technical reasons, unit 1 must be operated with a minimum capacity of $x_{1,low}$ = 25 MW and unit 2 with a minimum capacity of $x_{2,low}$ = 15 MW.
- Due to limited feedstock, the total power may not exceed 170 MW.
- This should be done optimally in order to minimize costs.

  - restrictions:

$r_1: x_1 \geq 0$ MW
$r_2: x_2 \geq 0$ MW
$r_3: x_1 \leq x_{1,up}$ = 100 MW
$r_4: x_2 \leq x_{2,up}$ = 50 MW
$r_5: x_1 \geq x_{1,low}$ = 25 MW
$r_6: x_2 \geq x_{2,low}$ = 15 MW
$r_7: x_1 + x_2 \geq 85$ MW
$r_8: x_1 + x_2 \leq 170$ MW

Introduction - Example

- The time-related operating costs *c* for the stationary operation of the units can be approximated as:

$$c_i\ (x_i) = FOM_i + VOM_i\ \cdot\ x_i$$

FOM = fixed operating and maintenance costs

VOM = variable operating and maintenance costs

	Unit	Power plant 1	Power plant 2
FOM	$€/_{h}$	150	125
VOM	$€/_{MWh}$	60	80

$$c_o\ (x_1;\ x_2) =\ c_1\ (x_1) +\ c_2\ (x_2)$$

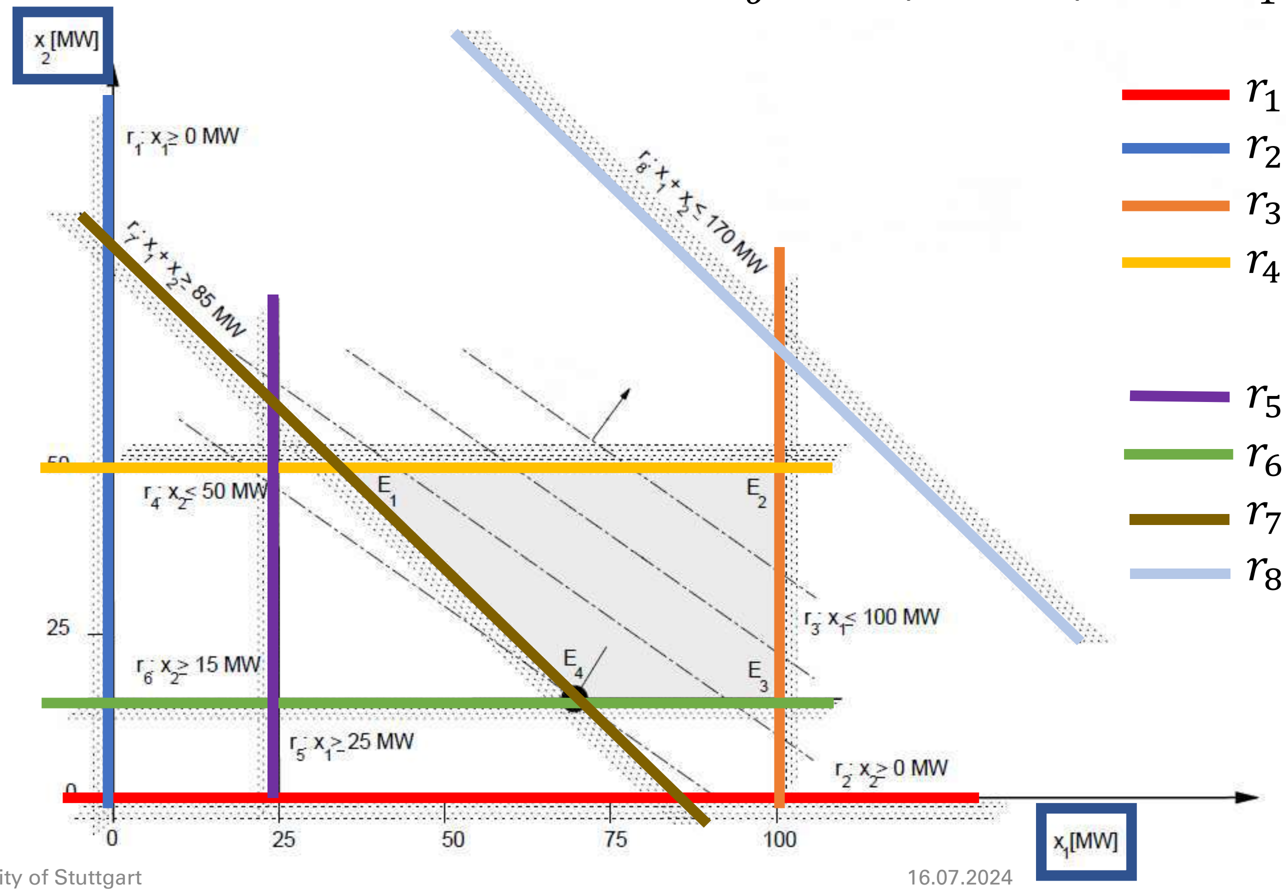
c_1= 150 €/h + 60 €/MWh · x_1

c_o= 275 €/h + 60 €/MWh · x_1 + 80 €/MWh · x_2 = min

c_2= 125 €/h + 80 €/MWh · x_2

Introduction - Example: Graphical solution

c_o = 275 €/h + 60 €/MWh · x_1 + 80 €/MWh · x_2 = min



$r_1: x_1 \geq 0$ MW

$r_2: x_2 \geq 0$ MW

$r_3: x_1 \leq x_{1,o} = 100$ MW

$r_4: x_2 \leq x_{2,o} = 50$ MW

$r_5: x_1 \geq x_{1,u} = 25$ MW

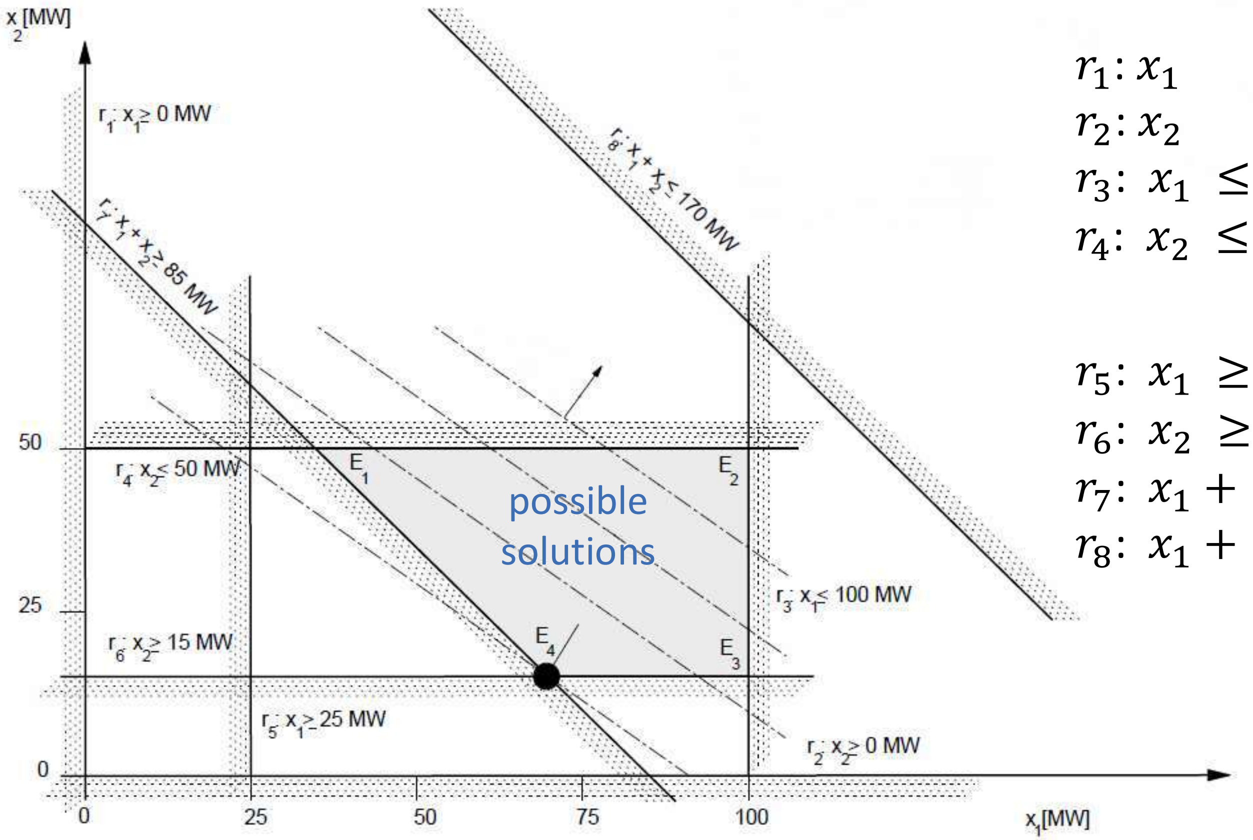
$r_6: x_2 \geq x_{2,u} = 15$ MW

$r_7: x_1 + x_2 \geq 85$ MW

$r_8: x_1 + x_2 \leq 170$ MW

Introduction - Example: Graphical solution

c_o = 275 €/h + 60 €/MWh · x_1 + 80 €/MWh · x_2 = min

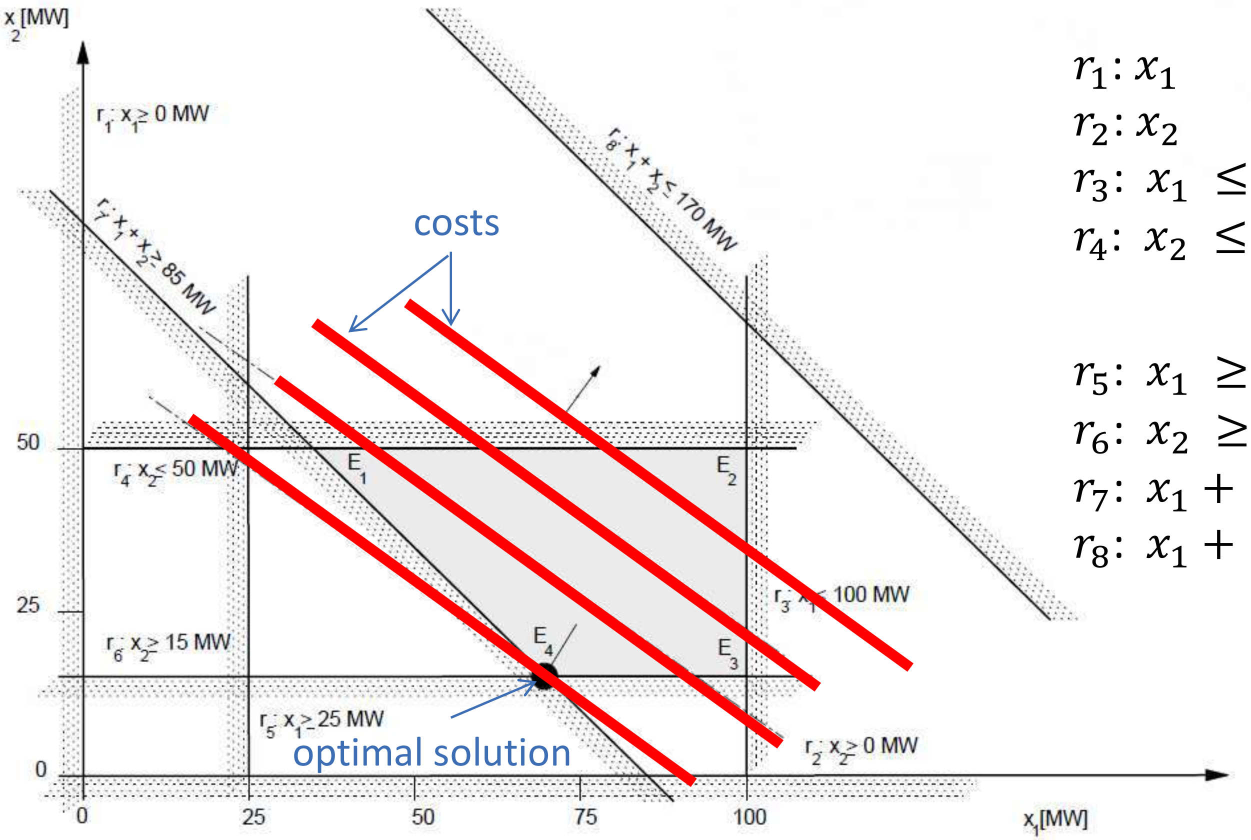


$$r_1: x_1 \geq 0 \text{ MW}$$
$$r_2: x_2 \geq 0 \text{ MW}$$
$$r_3: x_1 \leq x_{1,o} = 100 \text{ MW}$$
$$r_4: x_2 \leq x_{2,o} = 50 \text{ MW}$$

$$r_5: x_1 \geq x_{1,u} = 25 \text{ MW}$$
$$r_6: x_2 \geq x_{2,u} = 15 \text{ MW}$$
$$r_7: x_1 + x_2 \geq 85 \text{ MW}$$
$$r_8: x_1 + x_2 \leq 170 \text{ MW}$$

Introduction - Example: Graphical solution

c_o = 275 €/h + 60 €/MWh · x_1 + 80 €/MWh · x_2 = min



$r_1: x_1 \geq 0$ MW

$r_2: x_2 \geq 0$ MW

$r_3: x_1 \leq x_{1,o}$ = 100 MW

$r_4: x_2 \leq x_{2,o}$ = 50 MW

$r_5: x_1 \geq x_{1,u}$ = 25 MW

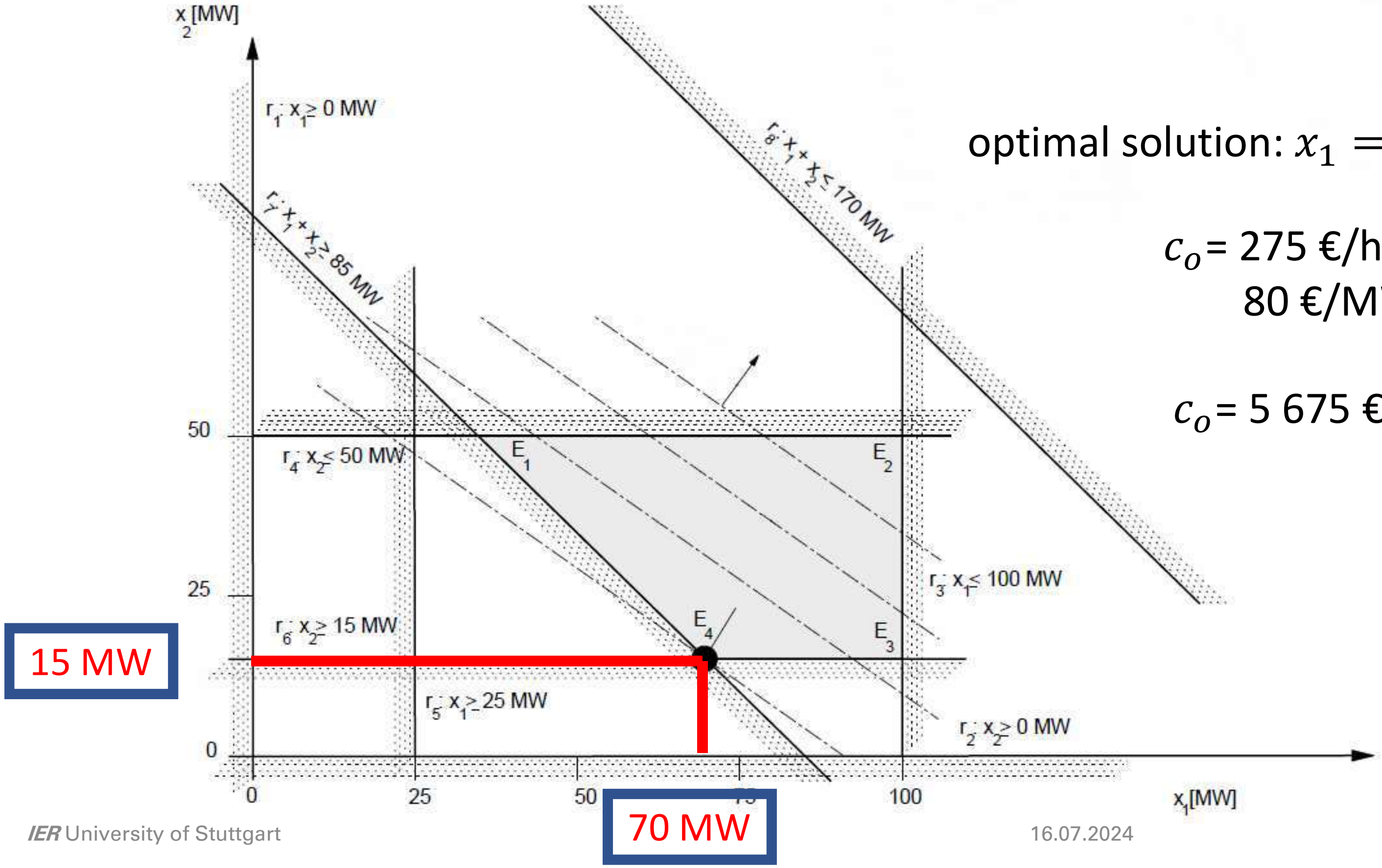
$r_6: x_2 \geq x_{2,u}$ = 15 MW

$r_7: x_1 + x_2 \geq 85$ MW

$r_8: x_1 + x_2 \leq 170$ MW

Introduction - Example: Graphical solution

c_o= 275 €/h + 60 €/MWh · x_1 + 80 €/MWh · x_2 = min



optimal solution: $x_1 = 70$ MW , $x_2 = 15$ MW

c_o= 275 €/h + 60 €/MWh · 70 MW +
80 €/MWh · 15 MW

c_o= 5 675 €/h

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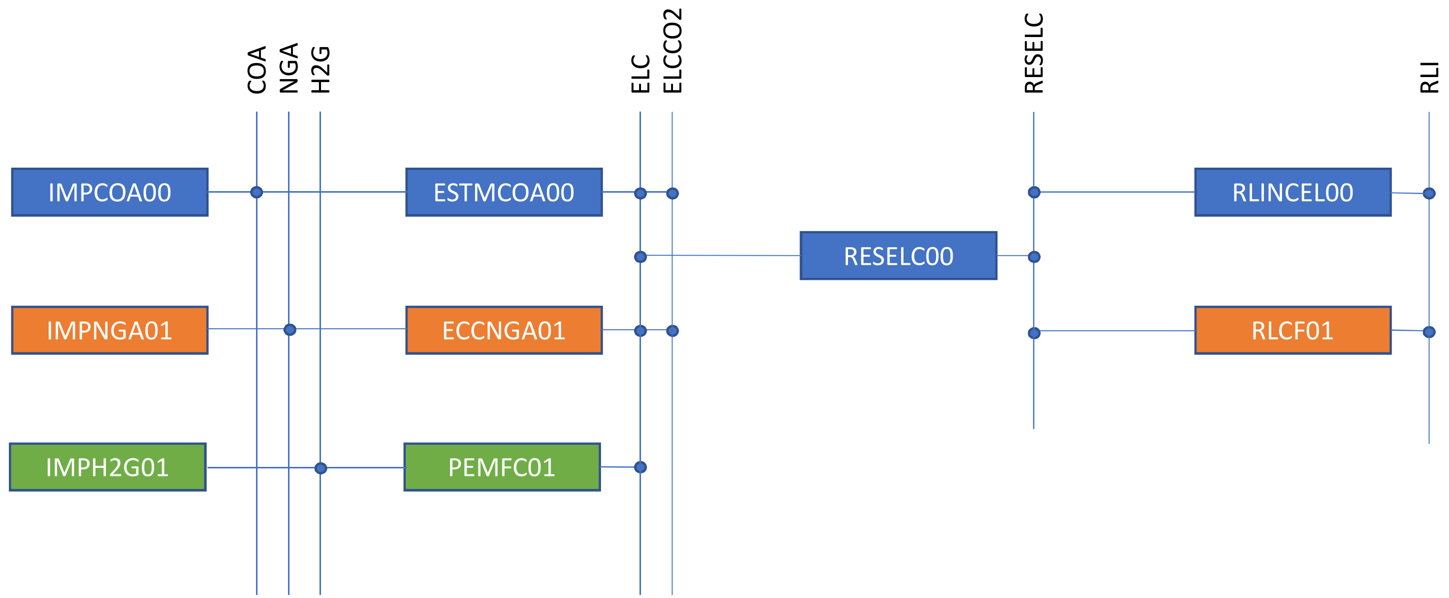
TIMES Components - The Reference Energy System (RES)

- **Reference Energy System (RES)**
  - Representation of energy system as network consisting of processes and commodities
  - **Commodities** (e.g. energy carriers, emissions)
    → Represented as vertical lines in the diagram
  - **Processes** (e.g. technologies)
    → Represented as a box in the diagram
  - **Commodity flows**
    → Represented as the horizontal line in the diagram between the commodities and the processes

TIMES Components - The Reference Energy System (RES)

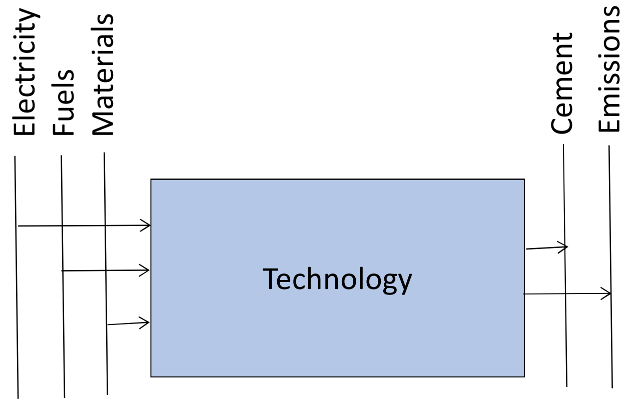
- Reference Energy System (RES)
  - Representation of energy system as network consisting of processes and commodities



TIMES Components - Inputs & Outputs

- Inputs:
  - *Demands*
    - (Base year and projections)
  - *Technical*
    - (Existing capacities, efficiencies, lifetime, starting year for new technologies, retirement profiles, inputs/outputs, …)
  - *Economic*
    - (Investment costs, fixed operational and maintenance costs, delivery costs, commodity prices…)
  - *Environmental*
    - (Emission coefficients, environmental targets…)

- Outputs:
  - The least cost solution to produce **demands** while satisfying **constraints**.
    - Technology investments (capacity and related costs)
    - Technology annual activities (input and output)
    - Emission trajectories
    - Marginal prices of commodities
    - Total discounted system cost



TIMES Components - Commodities

(Vertical Lines on RES)

- DMD Demands (e.g. electricity, residential cooling, cement…)
- ENV Emissions (e.g. fuel related CO2f, CH4f, N2Of and process related CO2p, CH4p, N2Op…)
- NRG Energy (e.g. electricity, heat, coal, natural gas, hydrogen…)
- MAT Materials (e.g. clinker, raw iron, hydrogen as feedstock…)

TIMES Components - Processes

- Types of Processes
  - **Base Year Techs** (residual capacity, name ending 00)
  - **New Techs** (investment costs, starting year, name ending 01, 02…)
  - **Mining** (national resources, requires no input, start with MIN)
  - **Import** (trade between regions, start with IMP)
  - **Dummies** (help avoiding model infeasibilities, very high costs, IMP*Z)
    - IMPDEMZ (Demands)
    - IMPMATZ (Materials)
    - IMPNRGZ (Energy)

TIMES Components - Parameters

Time-independent parameters

- Inputs
- Outputs
- Capacity to activity ratio

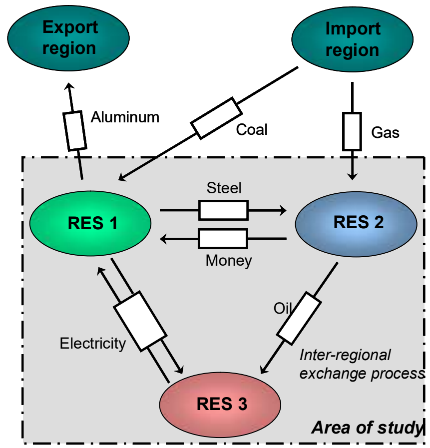
Time sensitive parameters

- **Base year technologies**
  - FOM, VAR costs
  - Efficiency
  - *Emissions (fuel/process)
  - Residual capacity
  - No reinvestment

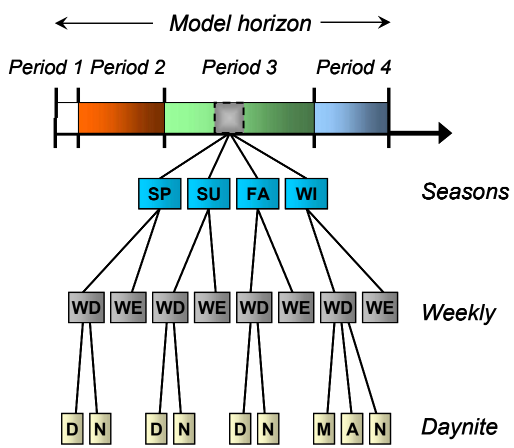
- **New technologies**
  - Investment costs
  - FOM, VAR costs
  - Efficiency
  - *Emissions (fuel/process)
  - Availability of the technology
  - Lifetime

TIMES Components – Spatial and Temporal Resolution

- Spatial Resolution
  - Internal and External Regions
  - Multiple regions where trade of commodities can take place in both directions
  - Obtain commodities from outside of system boundaries at a price
  - Dummies (very high costs, allows the model to avoid infeasibilities)

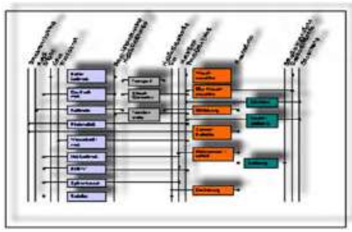


- Temporal Resolution
  - Annual, seasonal, day/night, hourly….
  - Milestone years, Time Horizon…

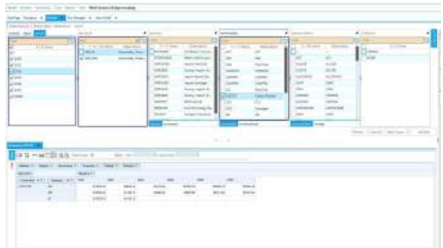


TIMES Components - Modelling steps

RES

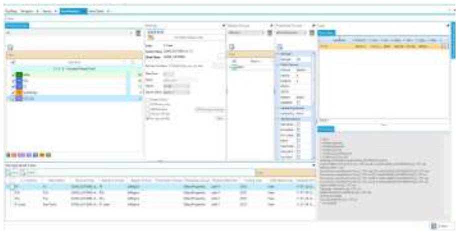


Analysis of results in VEDA



Data Collection / Excel

Model management / in VEDA



Solving (<u>G</u>eneral <u>A</u>lgebraic <u>M</u>odeling <u>S</u>ystem and solver)

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VEDA2.0

- Veda2.0 is a **data handling** system for **TIMES.**

- It is based on a **modular approach** that organizes the model input data, and results, into an integrated database.
    - Information is visible via tabular browsing (data cubes) and network diagrams.
    - easy to **activate/deactivate/rep**lace sectors or regions. Different analysts should be able to work on different sectors or regions in parallel.

- Veda2.0 **can read a wide variety of layouts** - timeseries, regions in columns, attributes in columns etc., to **minimize structural pre-processing**.

- **Veda2.0 displays and manages data** (e.g. which scenarios to include in the model runs) however all **data editing should take place in Excel**

VEDA2.0

- **StartPage**
  - Shows the list of model folders on the directory

- **Modules:**
  - **Navigator** (keyboard shortcut F6) - to see all Excel files that are included in the model.
  - **Browse** (F7) - for a tabular view of the input data - across all Excel files.
  - **Items List** - lists of all items - processes, commodities, commodity groups, and user constraints.
  - **Items Detail** (F8) - to see topology and input parameters for items.
  - **Run Manager** (F9) - to define and run cases.
  - **Results** (F10) - to analyze model output.