urbs – an Open Source Linear Optimization Framework

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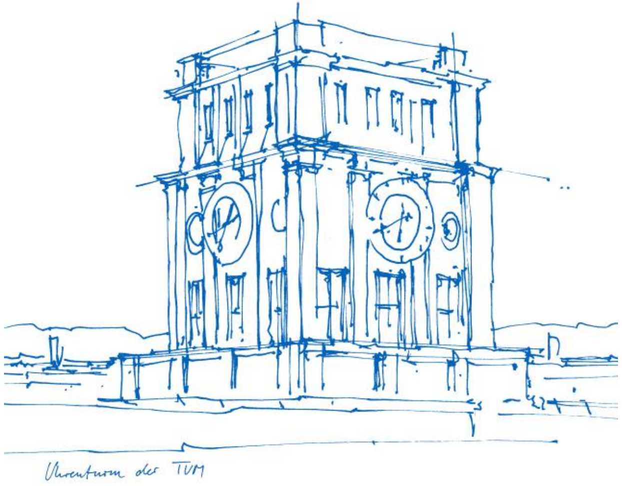

Agenda

1. Basic information
2. Toolchain & modeling approach
3. Renewable energy system
4. Mathematical basics
5. Research questions
6. Installing / Setting up urbs
7. Demonstration
8. Questions & discussion

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1. **Basic information**
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3. **Reference energy system**
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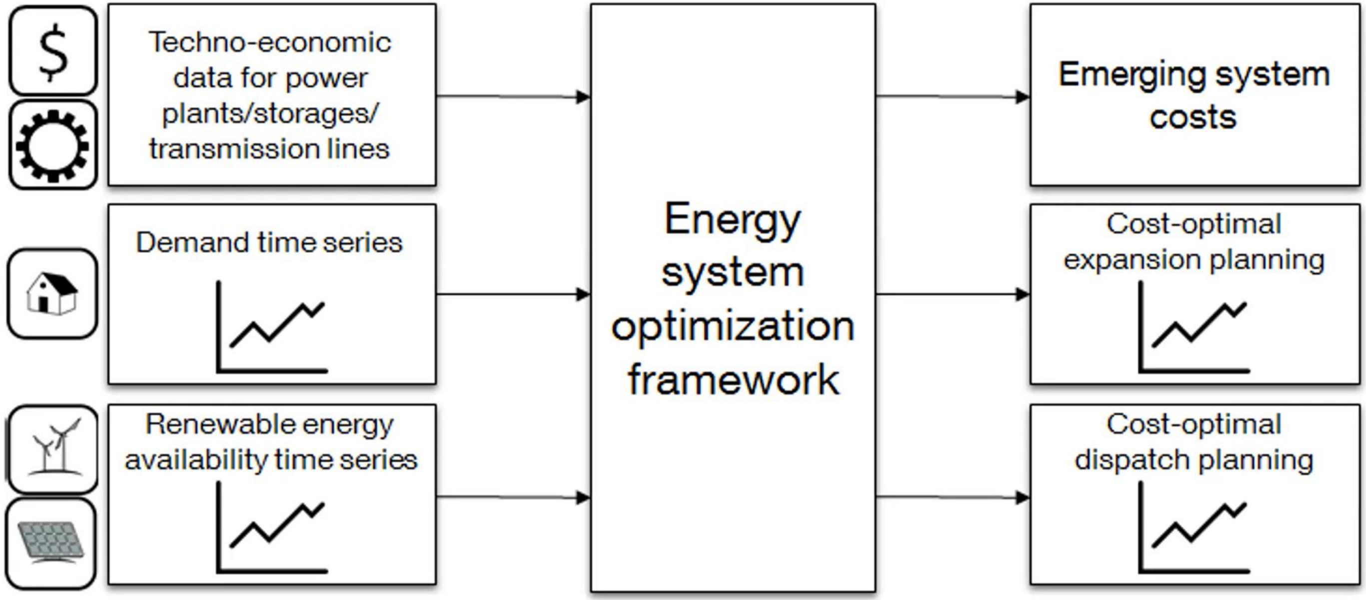
Basic information



urbs

Model

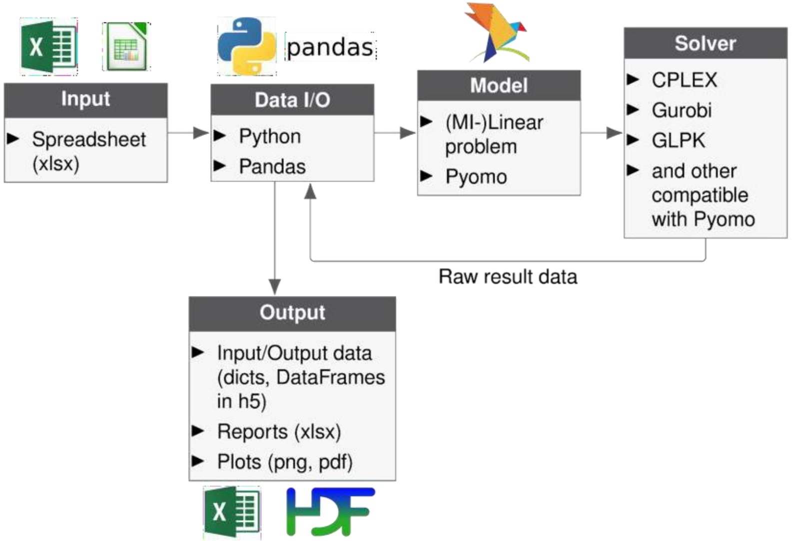
- Linear optimization model for capacity expansion and unit commitment
- Minimizes total costs (investments, fixed costs as well as variable costs) while ensuring that energy balances are met at all times (and sites)

Resolution

Temporal resolution:

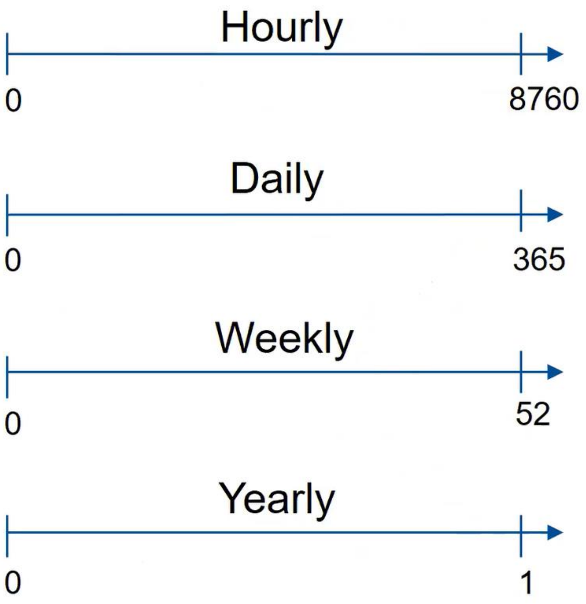
- Given time interval (e.g. one year) or intertemporal optimization with support timeframes
- Variable time steps (e.g. hours, 15 minutes)
- Perfect foresight

Arbitrary regional scales (Countries, counties, cities…)



Resolution

Temporal resolution



Spatial resolution

Country-level

- Node 1: Uruguay

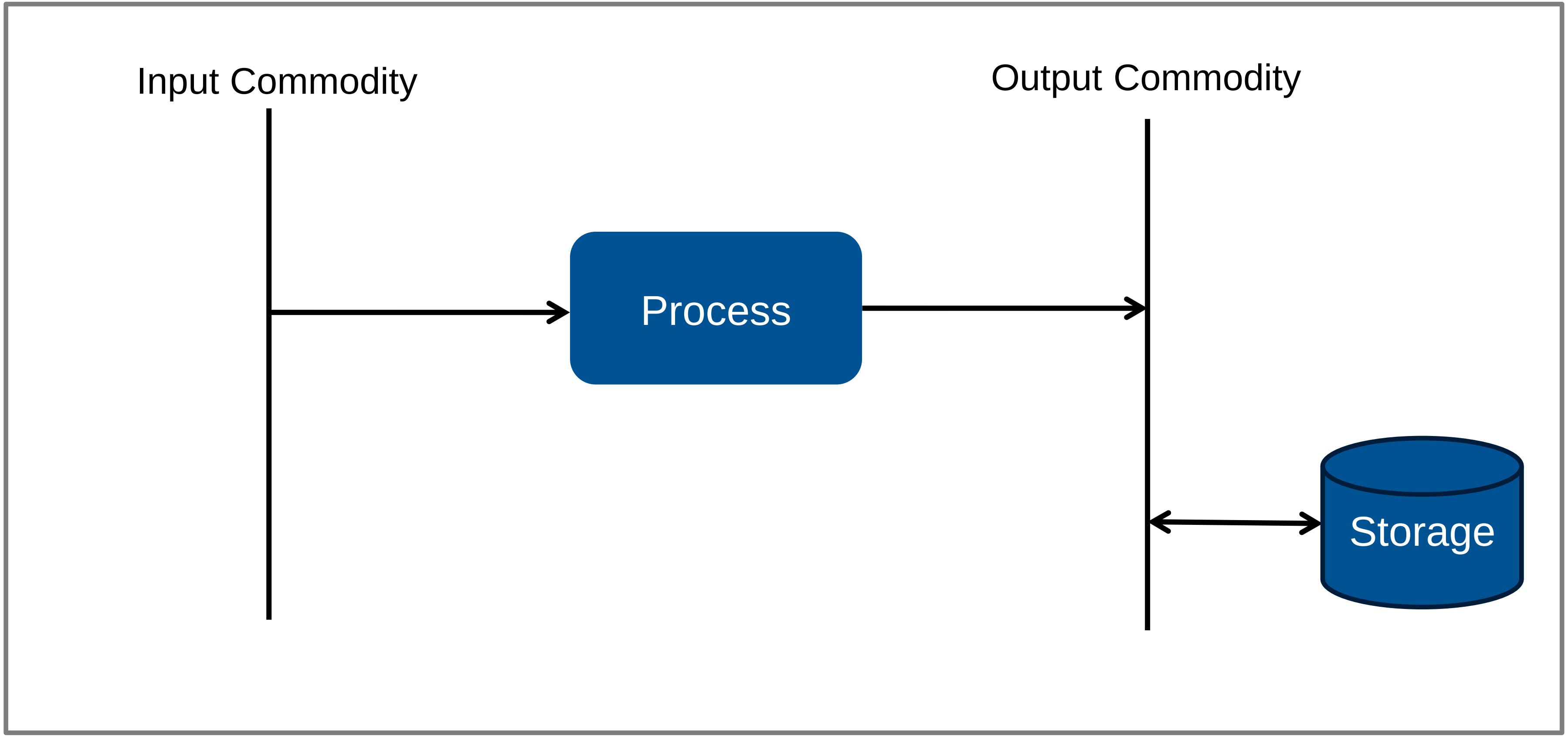
Isolated or point systems

- Node 1: One powerplant
- Node 1: One village/city

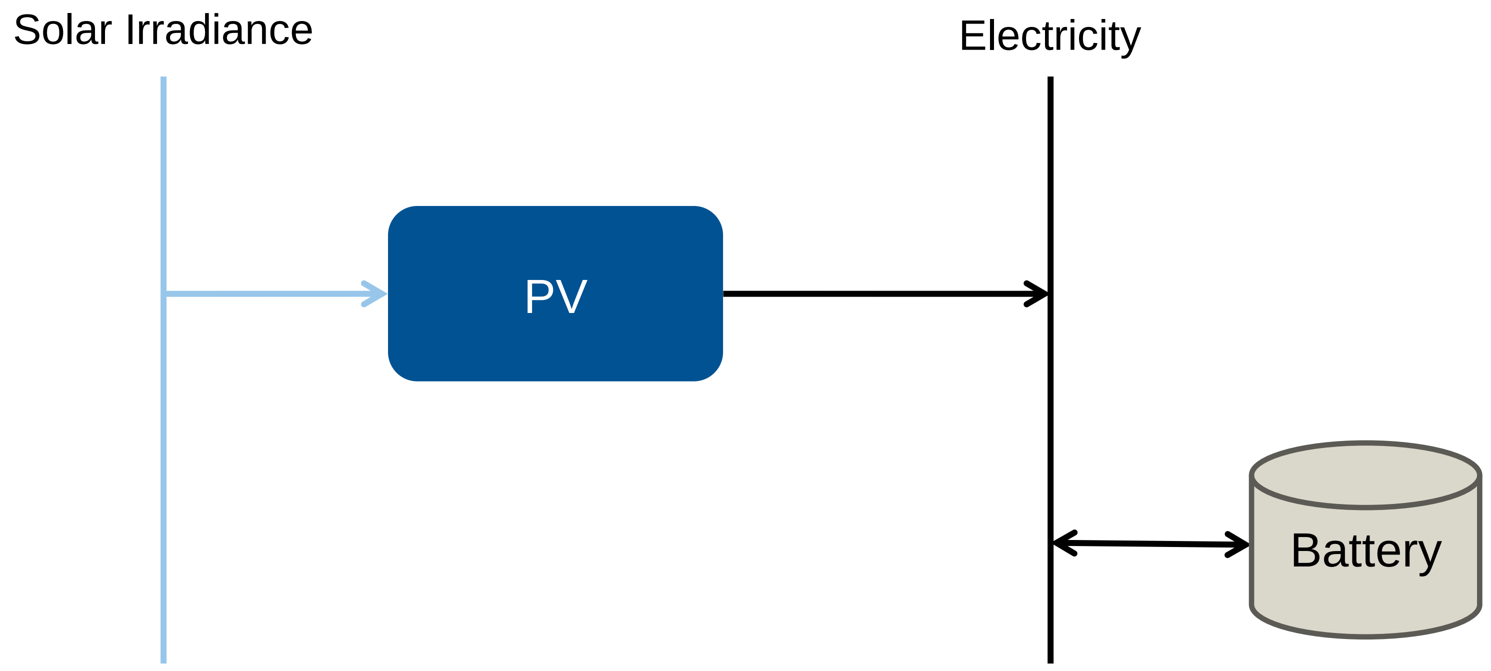
Department-level

- Node 1: Montevideo
- Node 2: Canelones
- Node 3: Maldonado
- ….
- Node 19: Artigas

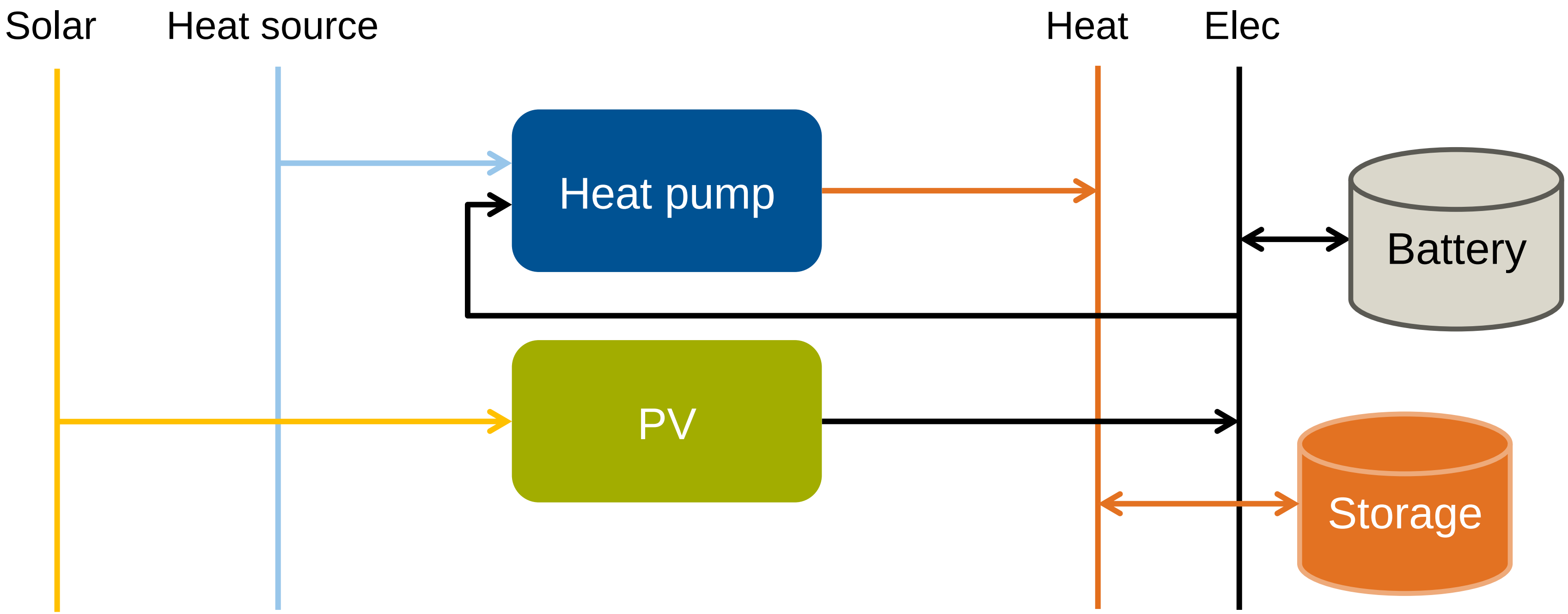
RES - Reference energy system (I)



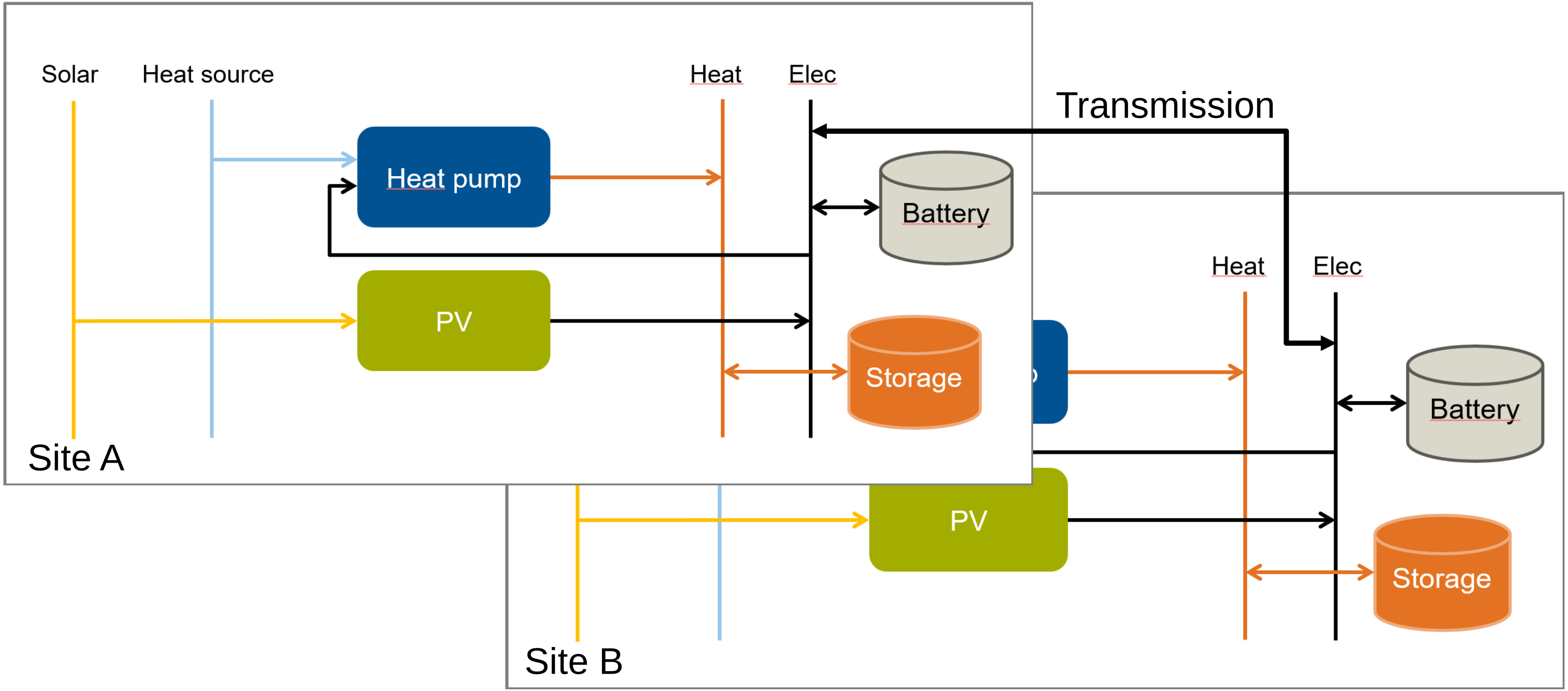
RES - Reference energy system (II)



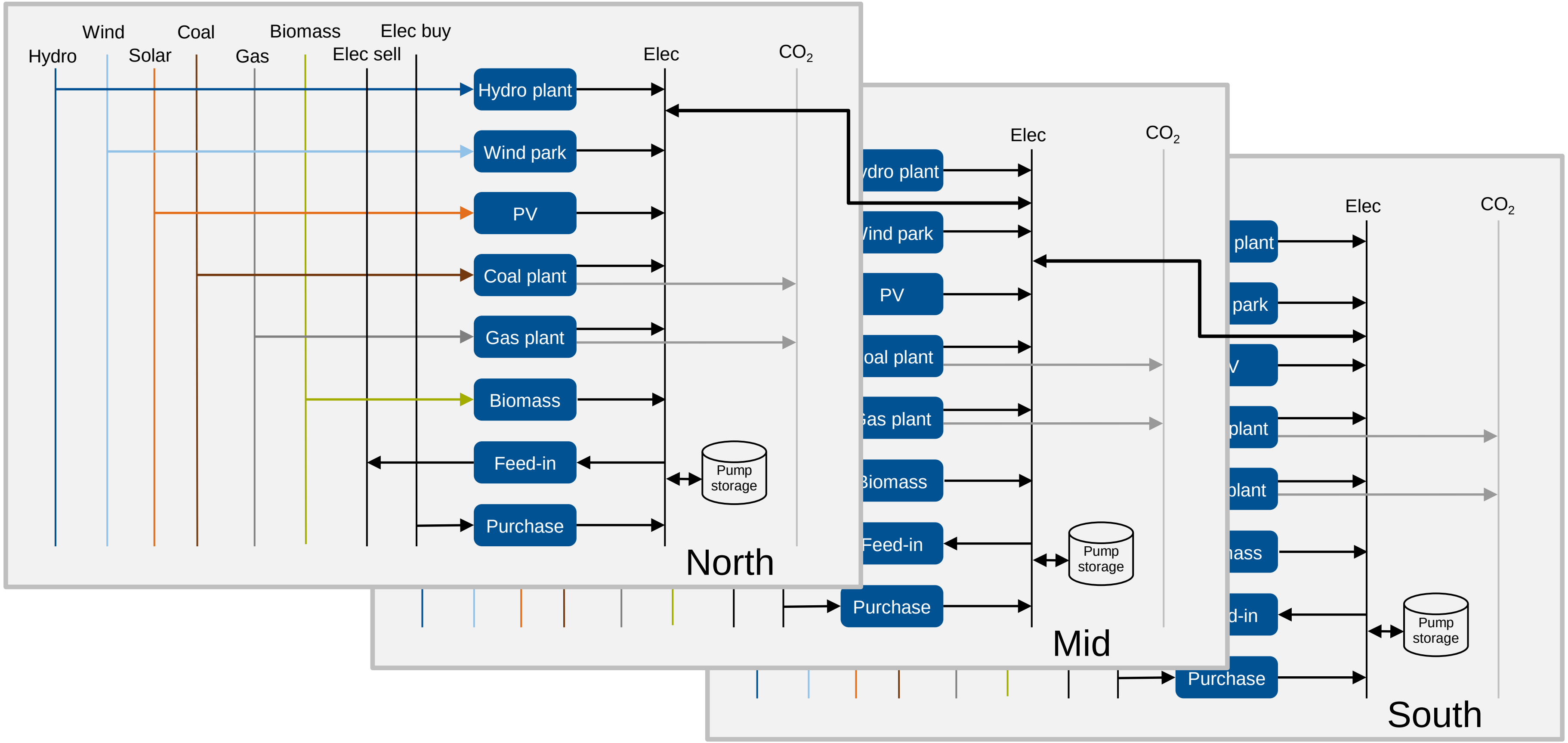
RES - Reference energy system (III)



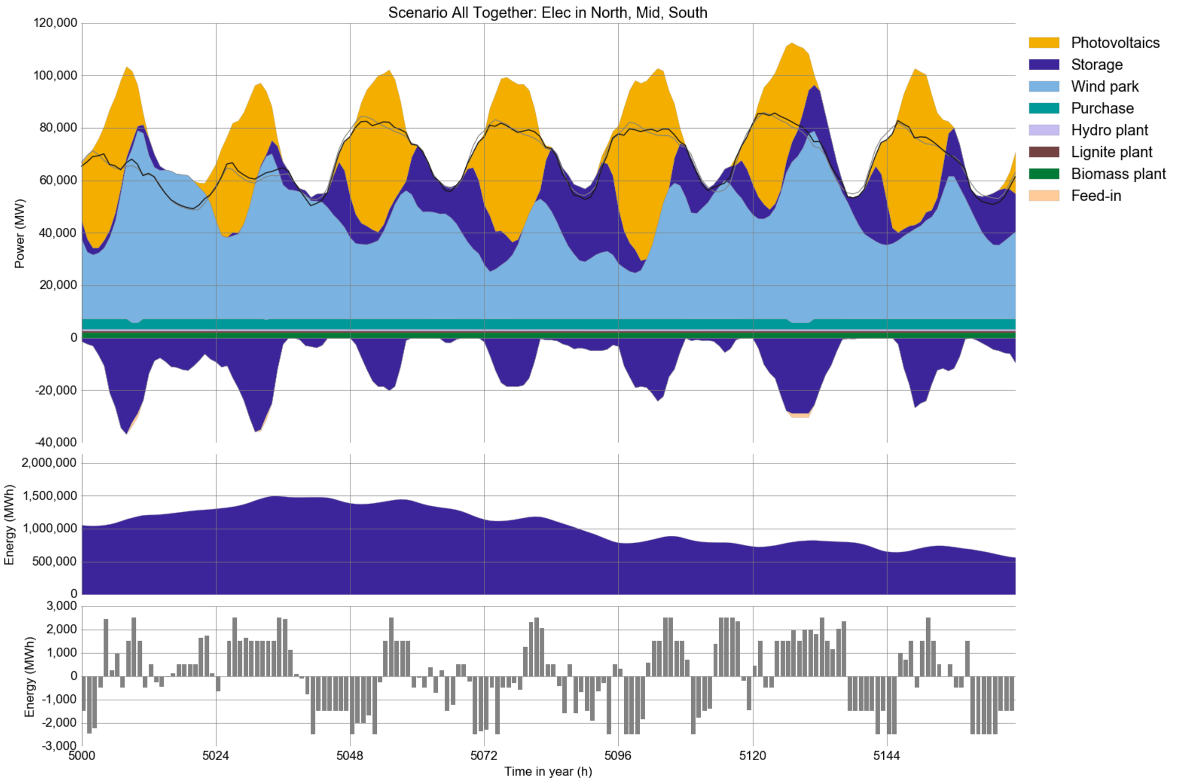
RES - Reference energy system (IV)



RES - Reference energy system (V)



Sample Output



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1. Basic information
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4. **Mathematical basics / What happens behind**
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Nomenclature

Set	Subsets	Description
$t \in T$	T_m, t_0, t_N	Time steps, modelled time steps, initial/final time step
$v \in V$	—	Sites
$a \in A$	A_v^p, A_v^s	Arcs, incoming/outgoing arcs in site v
$c \in C$	C_st, C_sup, C_env, C_dem	Commodities, commodity type subsets
$p \in P$	C_{vp}^in, C_{vp}^out	Processes and their input/output commodities
$s \in S$	S_{vc}	Storage, storing commodity c
$f \in F$	F_{vc}^exp, F_{vc}^imp	Transmission, exporting/importing transmission

Commodity

Different types of commodities:

- Demand: timeseries, one value for each timestep
- SupIm: intermittent supply (e.g. solar), one value between 0 and 1 for each timestep
- Stock: price per unit, units can be limited (max, maxperhour)
- Env: similar to Stock, additional constraints

Site	Commodity	Type	price	max	maxperhour
Mid	Solar	SupIm	#NV	#NV	#NV
Mid	Wind	SupIm	#NV	#NV	#NV
Mid	Hydro	SupIm	#NV	#NV	#NV
Mid	Elec	Demand	#NV	#NV	#NV
Mid	Coal	Stock	7	inf	inf
Mid	Lignite	Stock	4	inf	inf
Mid	Gas	Stock	27	inf	inf
Mid	Slack	Stock	999	inf	inf
Mid	Biomass	Stock	6	inf	inf
Mid	CO2	Env	0	inf	inf

Constraints:

- Commodity balance:

$$\mathrm{CB}(v,c,t) = \sum_{p|c\in C_{vp}^{\mathrm{in}}} \epsilon_{vcpt}^{\mathrm{in}} - \sum_{p|c\in C_{vp}^{\mathrm{out}}} \epsilon_{vcpt}^{\mathrm{out}} + \sum_{s\in S_{vc}} \left(\epsilon_{vst}^{\mathrm{in}} - \epsilon_{vst}^{\mathrm{out}}\right) + \sum_{\substack{a\in A_v^{\mathrm{s}} \\ f\in F_{vc}^{\mathrm{exp}}}} \pi_{aft}^{\mathrm{in}} - \sum_{\substack{a\in A_v^{\mathrm{p}} \\ f\in F_{vc}^{\mathrm{imp}}}} \pi_{aft}^{\mathrm{out}}$$

- **Vertex equation**:

$$\forall v \in V, c \in C^{\mathrm{V}}, t \in T:$$

$$\rho_{vct} - \mathrm{CB}(v,c,t) - d_{vct} \geq 0$$

Process

Site	Process	inst-cap	cap-lo	cap-up	max-grad	min-fract	inv-cost	fix-cost	var-cost	wacc	depreciation	area-per-cap
Mid	Hydro plant	0	0	1.400	inf	0	1.600.000	20.000	0,0	0,07	50	#NV
Mid	Wind park	0	0	13.000	inf	0	1.500.000	30.000	0,0	0,07	25	#NV
Mid	Photovoltaics	0	15.000	160.000	inf	0	600.000	12.000	0,0	0,07	25	14000
Mid	Gas plant	0	0	80.000	4,80	0,25	450.000	6.000	1,6	0,07	30	#NV
Mid	Slack powerplant	999.999	999.999	999.999	inf	0	0	0	100,0	0,07	1	#NV
Mid	Lignite plant	0	0	60.000	0,90	0,65	600.000	18.000	0,6	0,07	40	#NV
Mid	Biomass plant	0	0	5.000	1,20	0	875.000	28.000	1,4	0,07	25	#NV

Define capacity limits and costs

Constraints:

- Total installed capacity:

$$\forall v \in V, p \in P: \qquad \kappa_{vp} = K_{vp} + \hat{\kappa}_{vp}$$

- Process capacity limits:

$$\forall v \in V, p \in P: \qquad \underline{K}_{vp} \leq \kappa_{vp} \leq \overline{K}_{vp}$$

Process - Commodity

Process	Commodity	Direction	ratio	ratio-min
Hydro plant	Hydro	In	1,00	#NV
Hydro plant	Elec	Out	1,00	#NV
Wind park	Wind	In	1,00	#NV
Wind park	Elec	Out	1,00	#NV
Photovoltaics	Solar	In	1,00	#NV
Photovoltaics	Elec	Out	1,00	#NV
Gas plant	Gas	In	1,00	1,20
Gas plant	Elec	Out	0,60	#NV
Gas plant	CO2	Out	0,20	0,24
Coal plant	Coal	In	1,00	1,40
Coal plant	Elec	Out	0,40	#NV
Coal plant	CO2	Out	0,30	0,42
Lignite plant	Lignite	In	1,00	2,00
Lignite plant	Elec	Out	0,40	#NV
Lignite plant	CO2	Out	0,40	0,80
Biomass plant	Biomass	In	1,00	#NV
Biomass plant	Elec	Out	0,35	#NV
Biomass plant	CO2	Out	0,00	#NV

Define efficiency of processes

Constraints:

- Process input/output definitions:

$$\forall v \in V, p \in P, t \in T:$$

$$\epsilon^{\text{in}}_{vpct} = \tau_{vpt} r^{\text{in}}_{pc}$$

$$\epsilon^{\text{out}}_{vpct} = \tau_{vpt} r^{\text{out}}_{pc}$$

- Process throughput limit:

$$\forall v \in V, p \in P, t \in T:$$

$$\tau_{vpt} \leq \kappa_{vp}$$

Storage

Site	Storage	Commodity	inst-cap-c	cap-lo-c	cap-up-c	inst-cap-p	cap-lo-p	cap-up-p	eff-in	eff-out	inv-cost-p	inv-cost-c
Mid	Hydrogen	Elec	0	0	inf	0	0	inf	0,64	0,64	42.000	6,54
Mid	Pump storage	Elec	0	60.000	inf	0	8.000	inf	0,94	0,94	100.000	0
South	Hydrogen	Elec	0	0	inf	0	0	inf	0,64	0,64	42.000	6,54
South	Pump storage	Elec	0	163.000	inf	0	500	inf	0,94	0,94	100.000	0
North	Hydrogen	Elec	0	0	inf	0	0	inf	0,64	0,64	42.000	6,54
North	Pump storage	Elec	0	700.000	inf	0	1.500	inf	0,94	0,94	100.000	0

Storage for defined commodity, again capacities and cost have to be defined

Additional definition of power and storage level

Constraints:

- Storage state:

$$\forall v \in V, s \in S, t \in T_\mathrm{m}: \quad \epsilon^\mathrm{con}_{vst} = \epsilon^\mathrm{con}_{vs(t-1)} + \epsilon^\mathrm{in}_{vst} \cdot e^\mathrm{in}_{vs} - \epsilon^\mathrm{out}_{vst} / e^\mathrm{out}_{vs}$$

- Storage content and power:

$$\forall v \in V, s \in S: \qquad \kappa^\mathrm{c}_{vs} = K^\mathrm{c}_{vs} + \hat{\kappa}^\mathrm{c}_{vs} \qquad \kappa^\mathrm{p}_{vs} = K^\mathrm{p}_{vs} + \hat{\kappa}^\mathrm{p}_{vs}$$

Transmission

Site In	Site Out	Transmission	Commodity	eff	inv-cost	fix-cost	var-cost	inst-cap	cap-lo	cap-up	wacc	depreciation
Mid	North	hvac	Elec	0,90	1.650.000	16.500	0	0	0	inf	0,07	40
South	Mid	hvac	Elec	0,90	1.650.000	16.500	0	0	0	inf	0,07	40
South	North	hvac	Elec	0,85	3.000.000	30.000	0	0	0	inf	0,07	40
North	Mid	hvac	Elec	0,90	1.650.000	16.500	0	0	0	inf	0,07	40
Mid	South	hvac	Elec	0,90	1.650.000	16.500	0	0	0	inf	0,07	40
North	South	hvac	Elec	0,85	3.000.000	30.000	0	0	0	inf	0,07	40

Connection to exchange defined commodity between two regions, more realistic power grid modelling

Constraints:

- Total transmission capacity:

$$\forall a \in A, f \in F: \qquad \kappa_{af} = K_{af} + \hat{\kappa}_{af}$$

- Transmission output and input:

$$\forall a \in A, f \in F, t \in T: \qquad \pi^{\text{out}}_{aft} = \pi^{\text{in}}_{aft} e_{af} \qquad \pi^{\text{in}}_{aft} \leq \kappa_{af}$$

Objective function

Cost function:

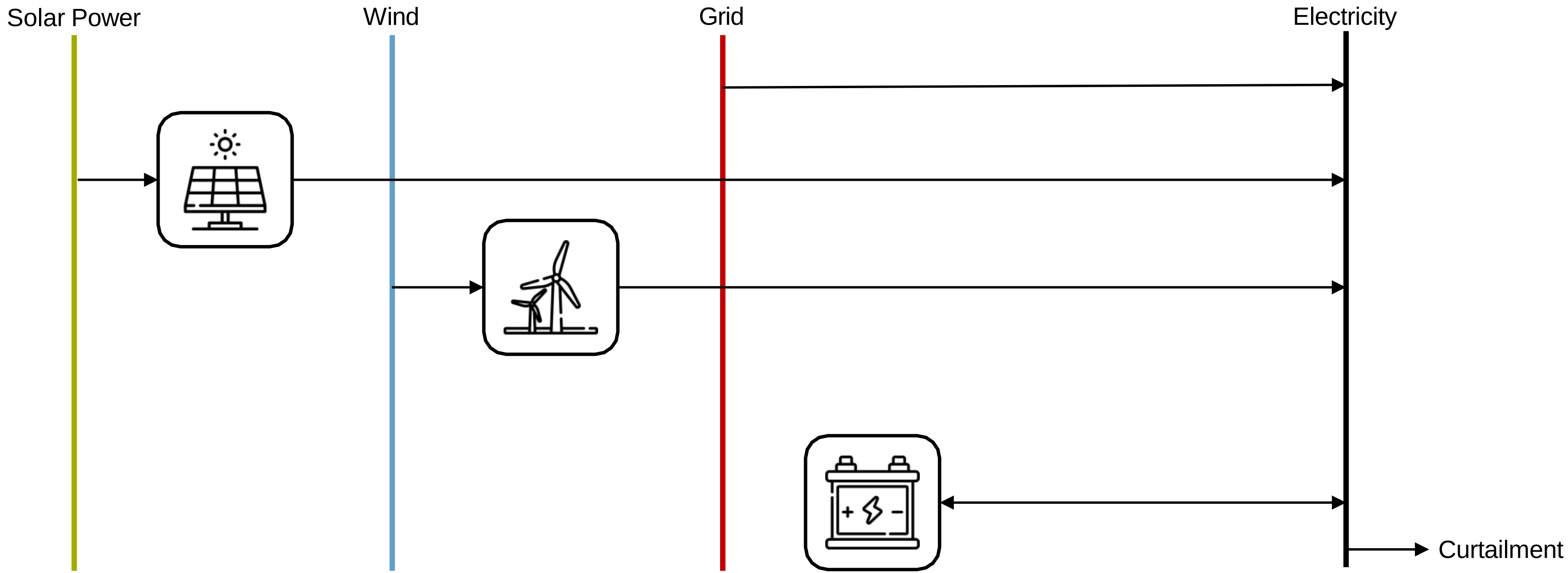
$$\zeta = \zeta_{\text{inv}} + \zeta_{\text{fix}} + \zeta_{\text{var}} + \zeta_{\text{fuel}}$$

$$\zeta_{\text{inv}} = \sum_{\substack{v\in V\\ p\in P}} \hat{\kappa}_{vp} k_{p}^{\text{inv}} + \sum_{\substack{v\in V\\ s\in S}} \left(\hat{\kappa}_{vs}^{\text{c}} k_{vs}^{\text{c,inv}} + \hat{\kappa}_{vs}^{\text{p}} k_{vs}^{\text{p,inv}} \right) + \sum_{\substack{a\in A\\ f\in F}} \hat{\kappa}_{af} k_{af}^{\text{inv}}$$

$$\zeta_{\text{fix}} = \sum_{\substack{v\in V\\ p\in P}} \kappa_{vp} k_{vp}^{\text{fix}} + \sum_{\substack{v\in V\\ s\in S}} \left(\kappa_{vs}^{\text{c}} k_{vs}^{\text{c,fix}} + \kappa_{vs}^{\text{p}} k_{vs}^{\text{p,fix}} \right) + \sum_{\substack{a\in A\\ f\in F}} \kappa_{af} k_{af}^{\text{fix}}$$

$$\zeta_{\text{fuel}} = w \sum_{t\in T_{\text{m}}} \sum_{v\in V} \sum_{c\in C_{\text{stock}}} \rho_{vct} k_{vc}^{\text{fuel}} \Delta t$$

Example problem



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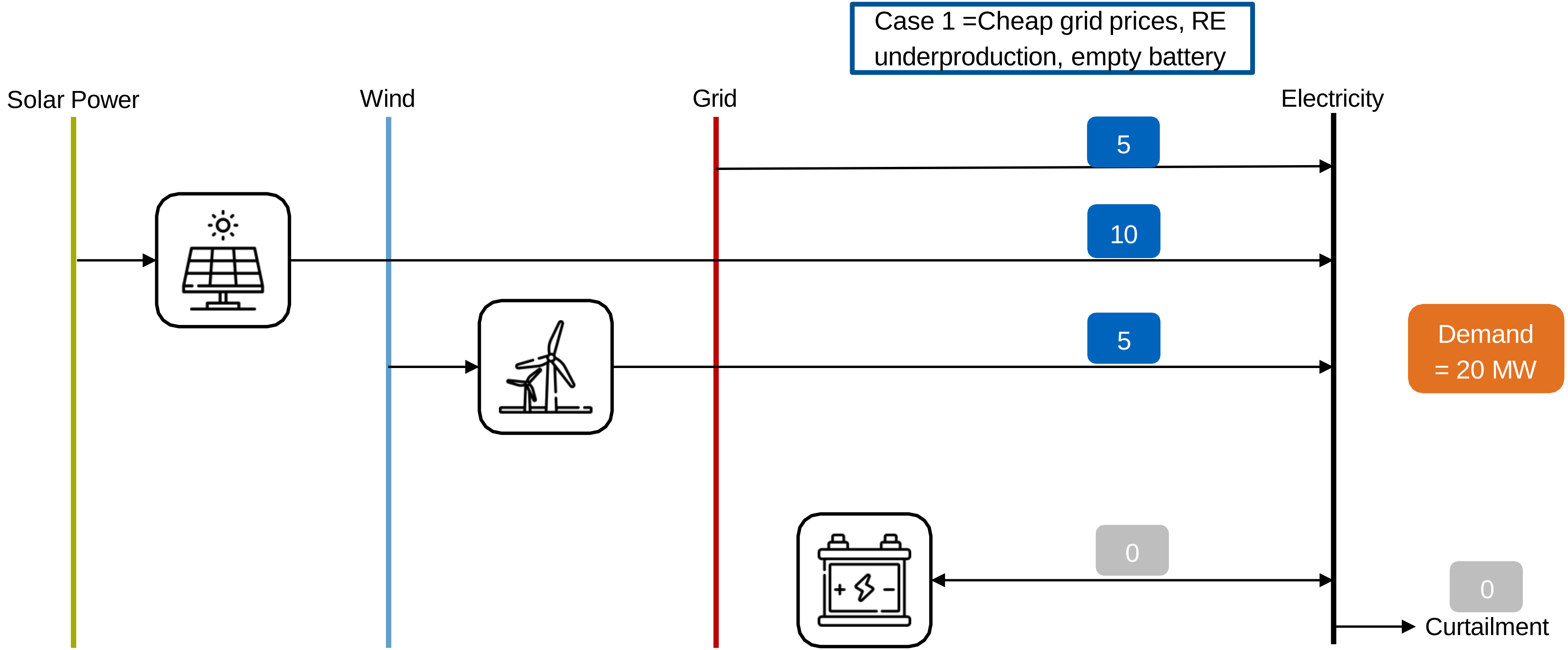

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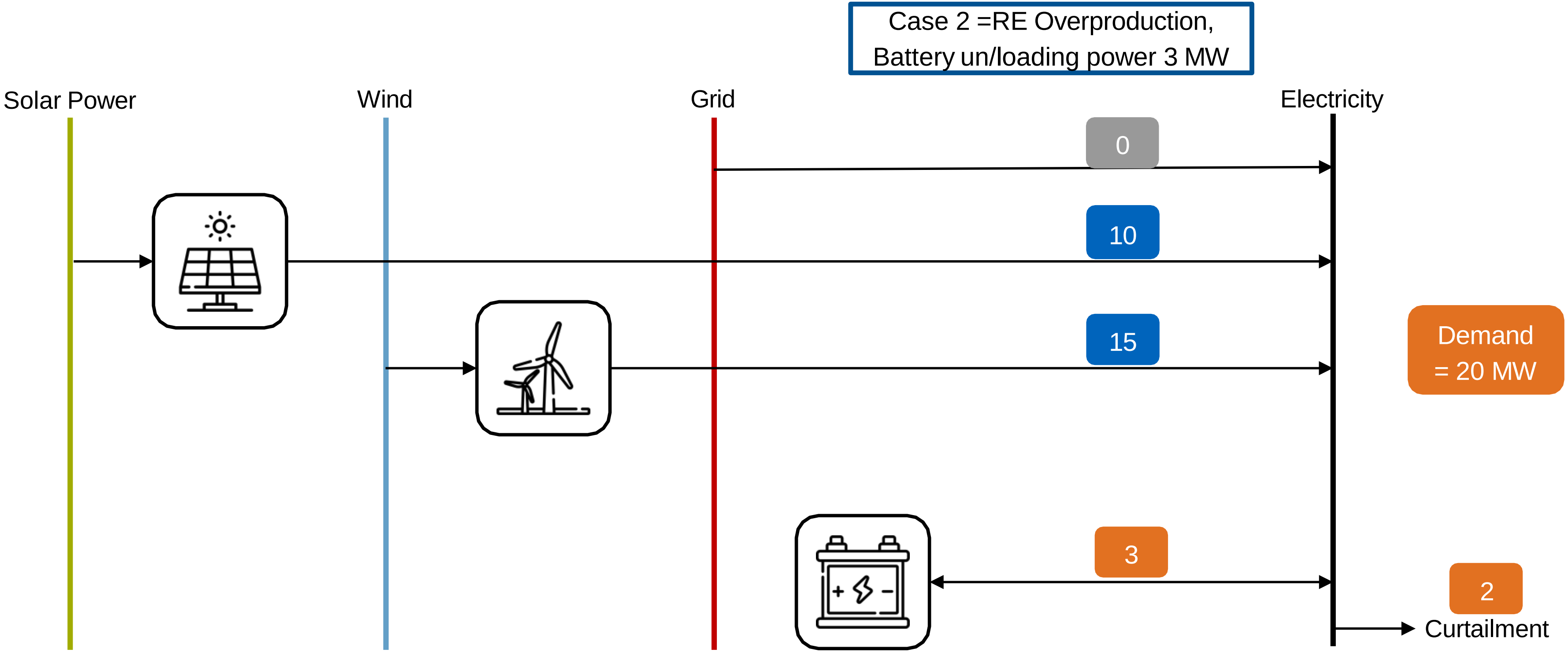

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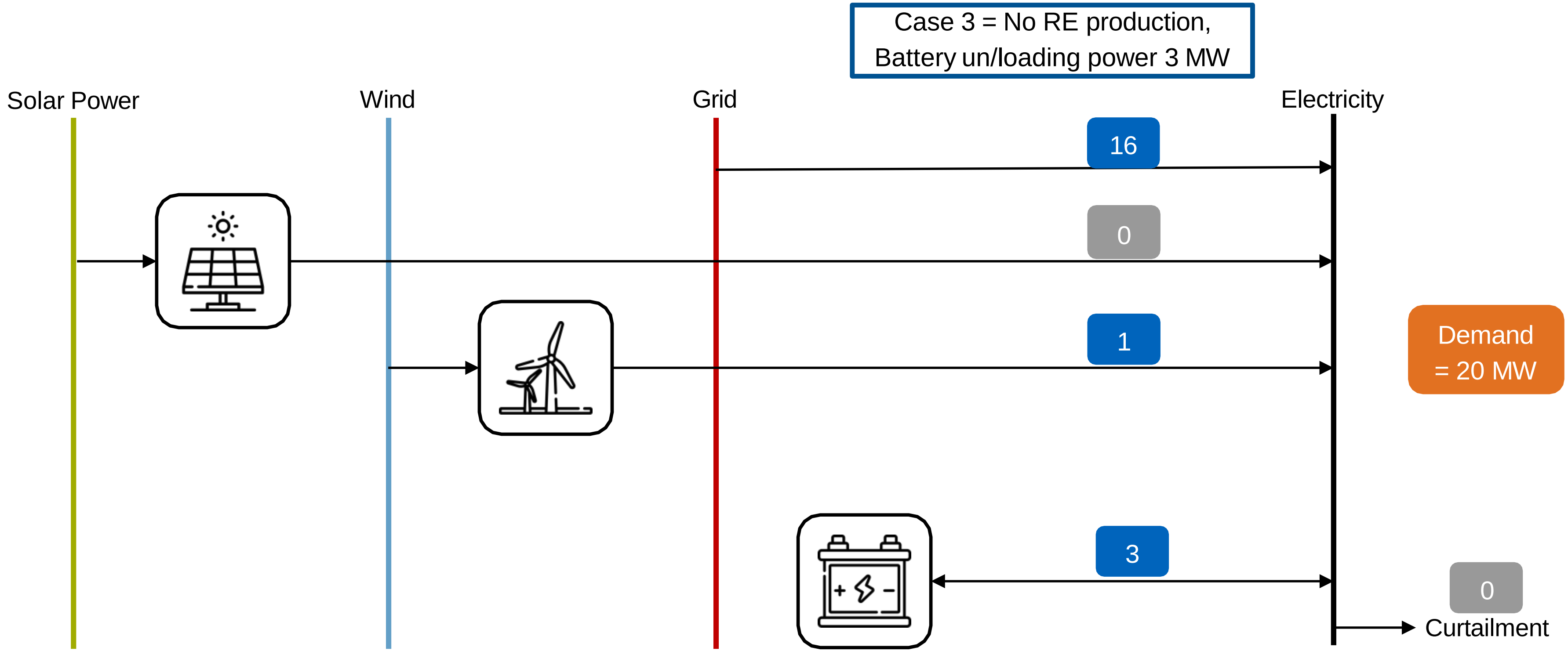


Key takeaways

When setting up your processes and commodities is important to define:

- Slack, Grid feed in or any fossil fuel process that can supply energy when there is no RE Generation

- Curtailment to give the possibility to get rid of the over generation

  - ➢ Remember: Necessary to have processes that can balance Generation and Demand in all of the time steps

- Define costs, processes, commodities and interactions in the same units (predefined MW)

Agenda

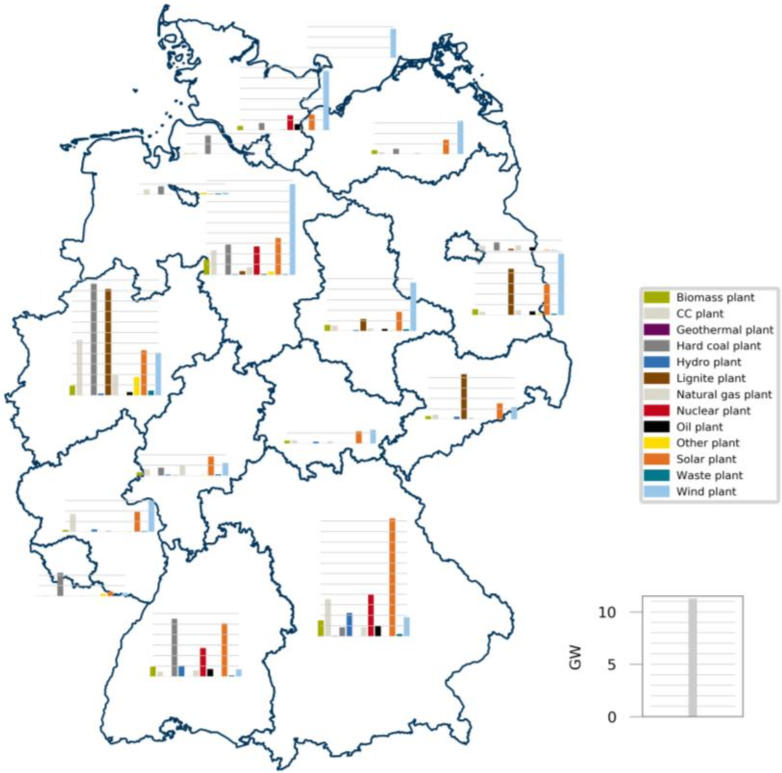
Research questions: System models

Electricity models for:

- Continents: Europe, ASEAN region
- Countries: Germany, Mexico, Ecuador, Colombia
- Regions: Bavaria
- Cities: Haag, Augsburg, Greifswald, Guadalajara, Munich
- Houses: Integration of electric vehicles and higher self-consumption

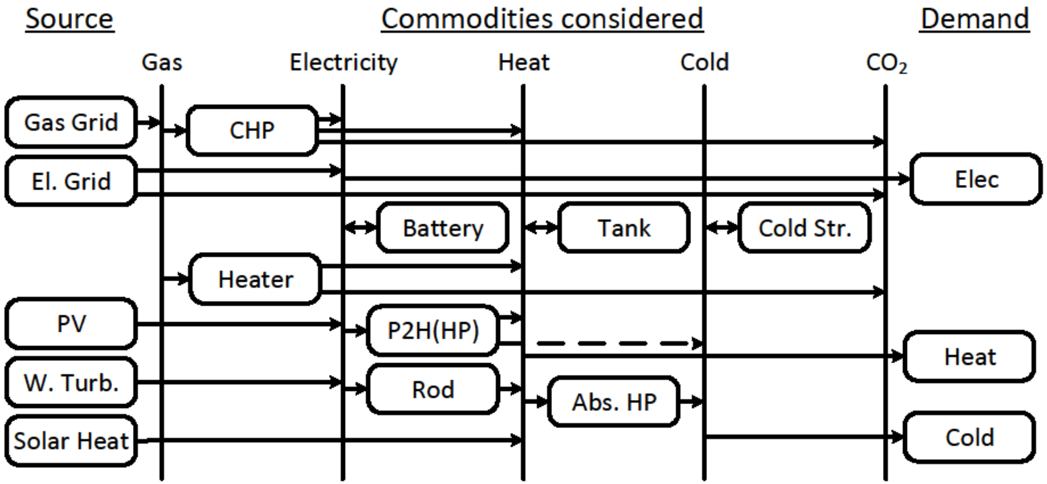
Optimal expansion and dispatch planning for whole electricity system

Scenarios for future developments to provide optimal recommendations for action



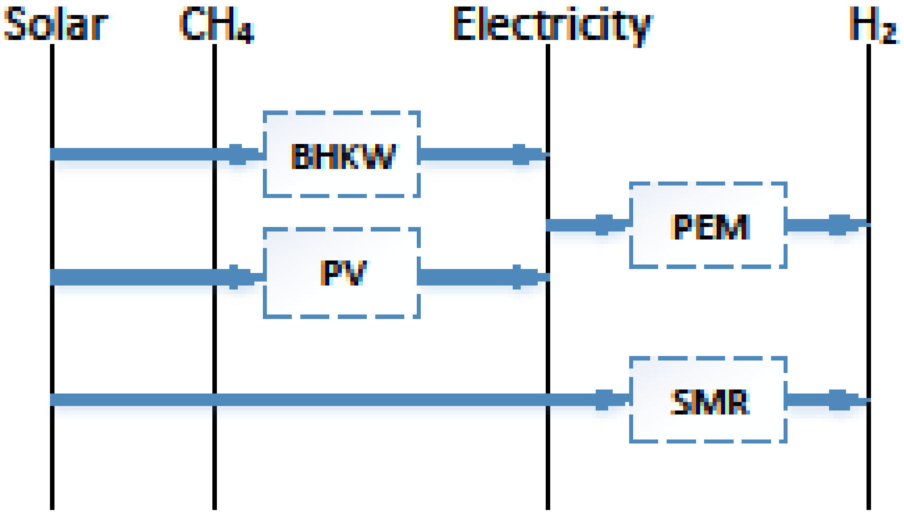
Research questions: Campus project

- Economic and ecological optimal expansion and dispatch for a business park over a long period (Intertemporal model)
- Modeling of electricity, heat and cold
- Optimization of PV expansion with different types of orientations and area demand
- Separate study based on campus model: resilience of energy systems



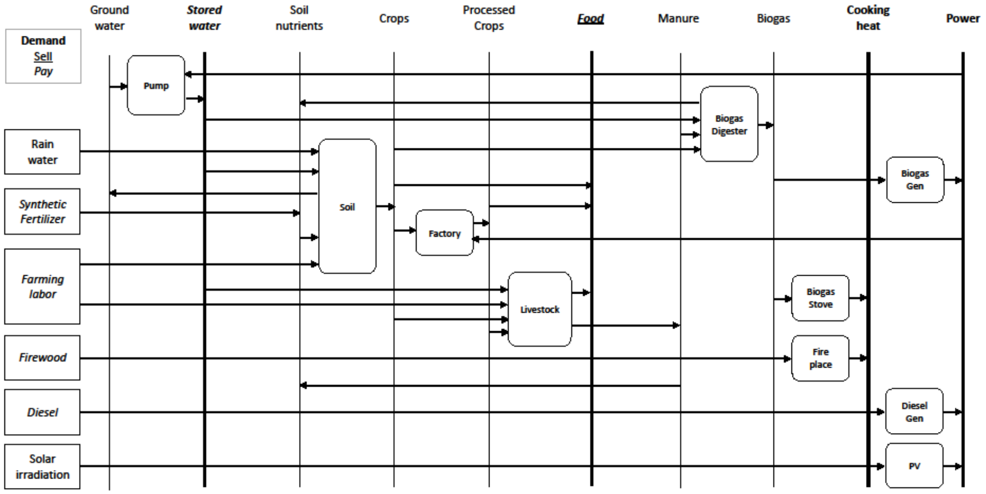
Research questions: LCA analysis

- Taking emissions and energy demand of building phase of power plants into account
- Life-cycle-assessment of electrolysis in the context of energy systems
- German electricity system



Research questions: Developing countries

- Decentralized energy-water-food system
- Data measurement in student projects in Zimbabwe
- First attempts of realizing the system in Africa



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Consultation hours

To help with the installation and setup of urbs

Tomorrow 28.08.2024
15:00 – 18:00

Room: 406