

Open Source Modelling and Optimisation of Energy Infrastructure at Urban Scale

Final presentation

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Outline

- 1 Energy, Infrastructure, City
- 2 Mathematical modelling, optimisation, case study
- 3 Sustainable model use

Section 1

Energy, Infrastructure, City

Questions about Germany's Climate Action Plan 2050

(BMUB 2015/16)

1. How can the almost complete transition from fossil fuels to renewable energy sources for electricity generation be accomplished by 2050?

<http://www.klimaschutzplan2050.de/en/action-areas/energy-sector/>

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4. Which role do decentralised energy supply concepts play?

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Questions about Germany's Climate Action Plan 2050

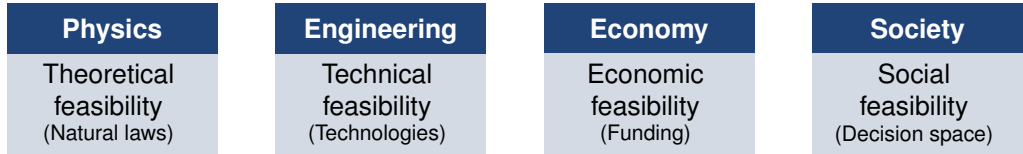
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1. How can the almost complete transition from fossil fuels to renewable energy sources for electricity generation be accomplished by 2050?
2. How can we build acceptance for a timely grid expansion?
3. What proportion of fossil fuel burning power stations do we need for a transitional period, and for how long?
4. Which role do decentralised energy supply concepts play?
5. How can the electricity and heating/cooling markets be more closely integrated [...]?

<http://www.klimaschutzplan2050.de/en/action-areas/energy-sector/>

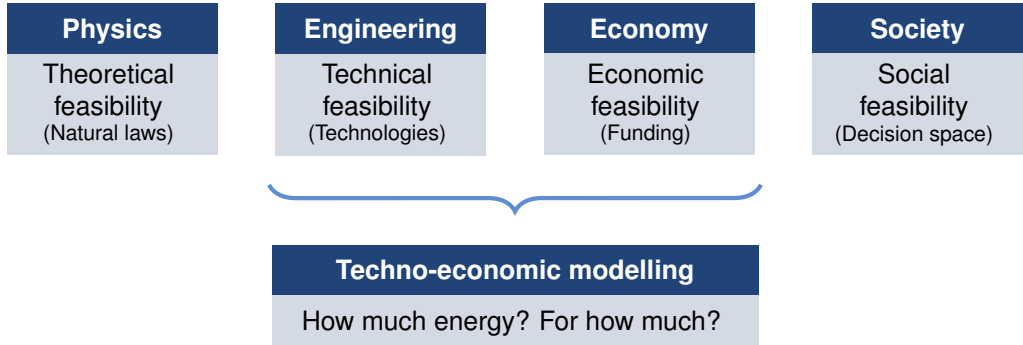
Perspective

Disciplines for investigating energy topics



Perspective

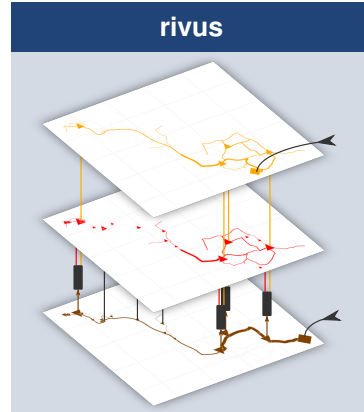
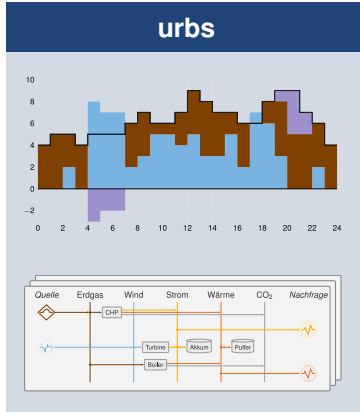
Disciplines for investigating energy topics

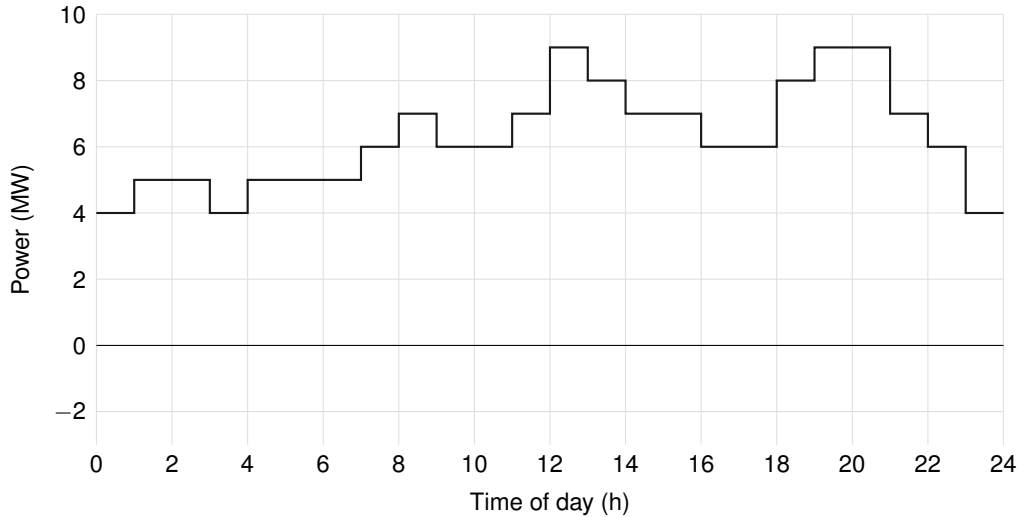


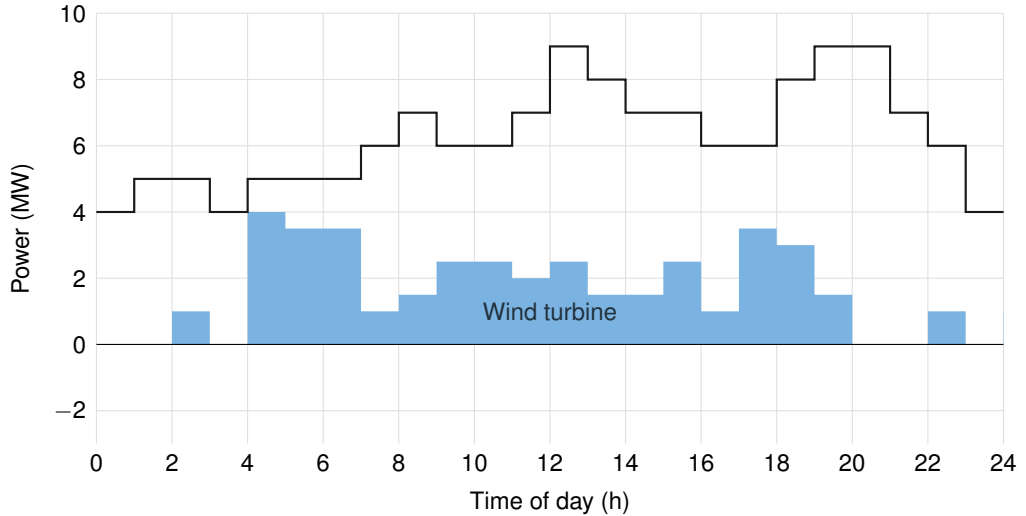
Section 2

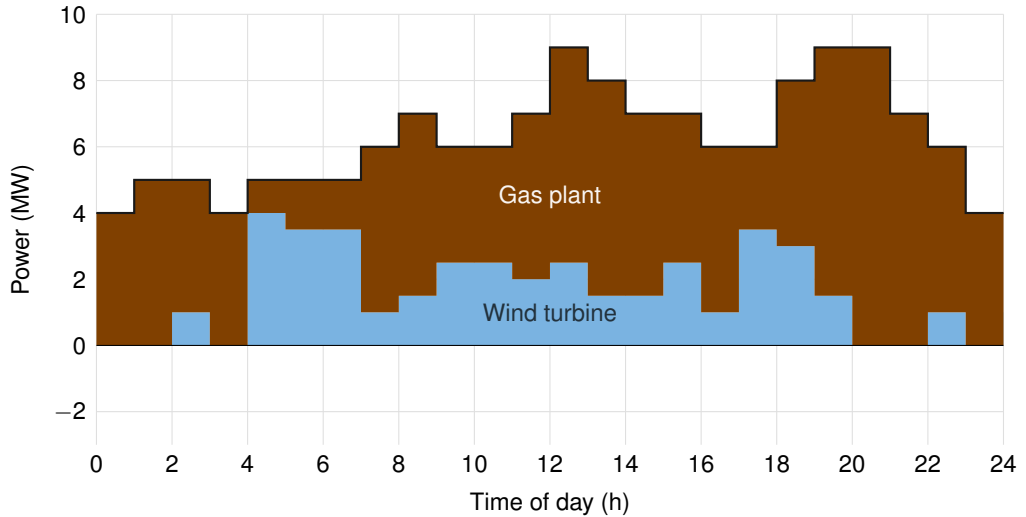
Mathematical modelling, optimisation, case study

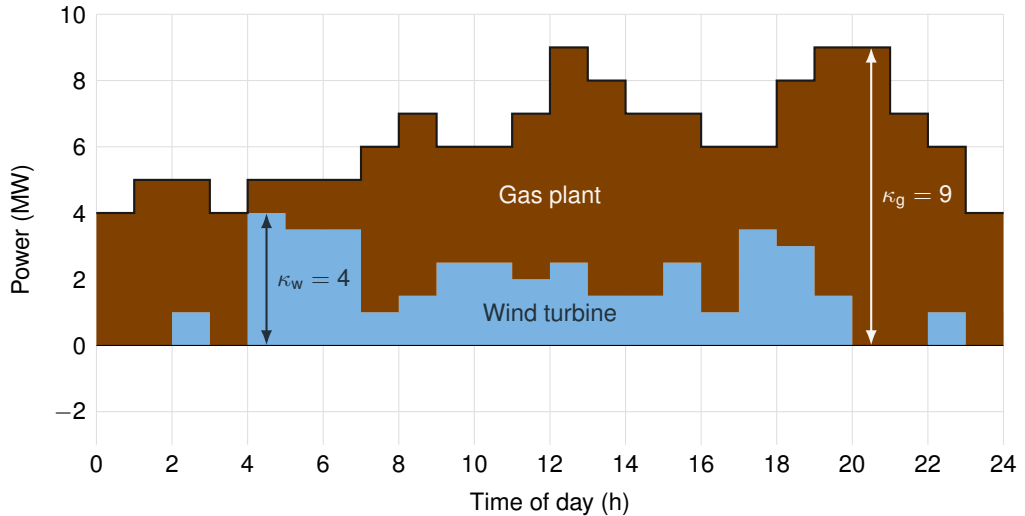
Model overview





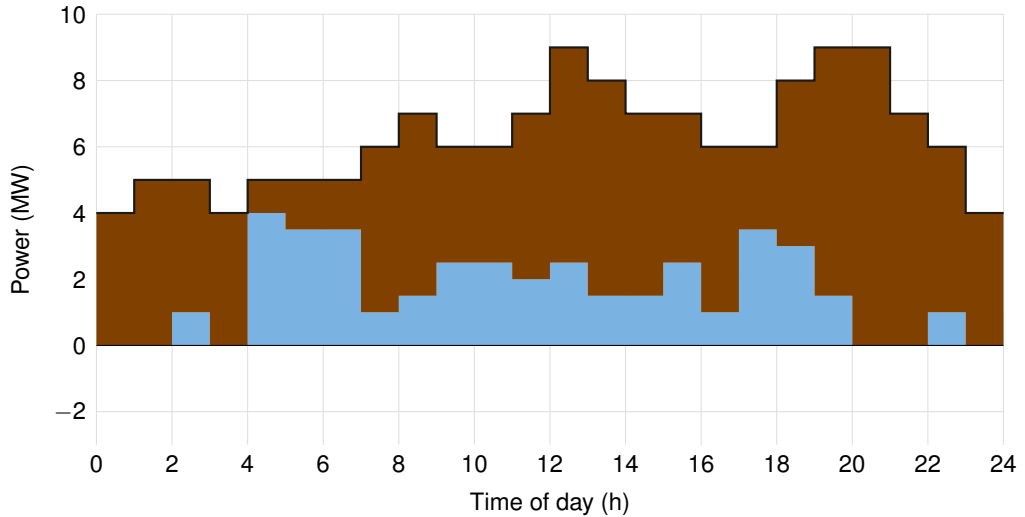






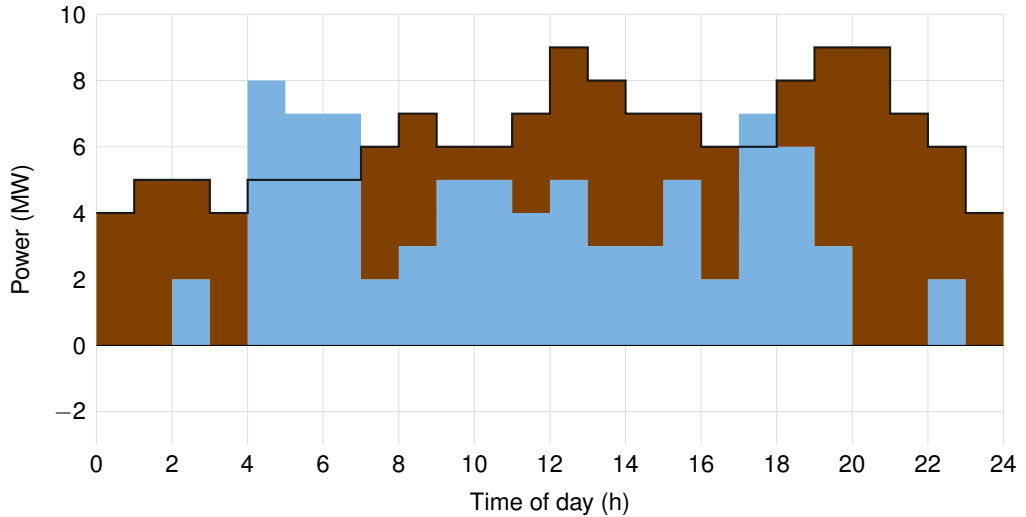
urbs

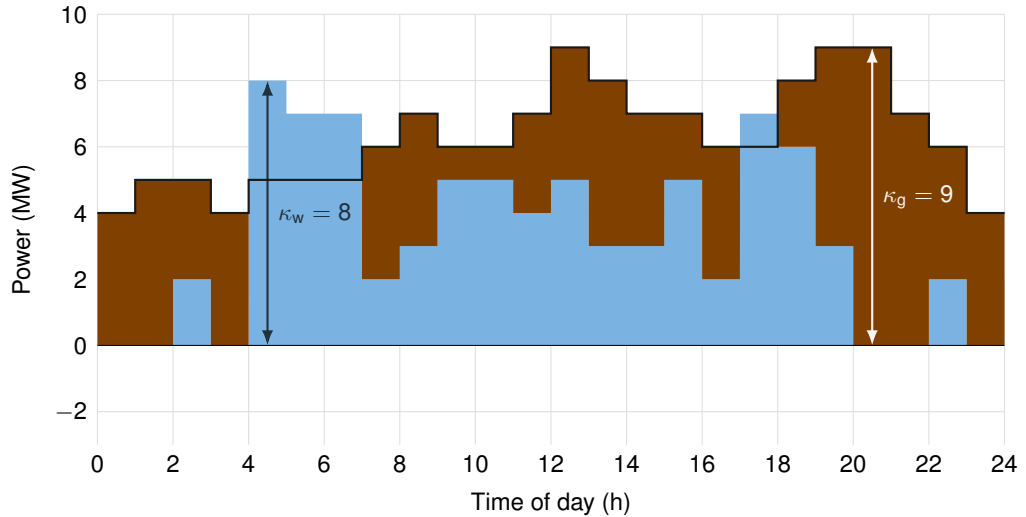
Principle illustrated



urbs

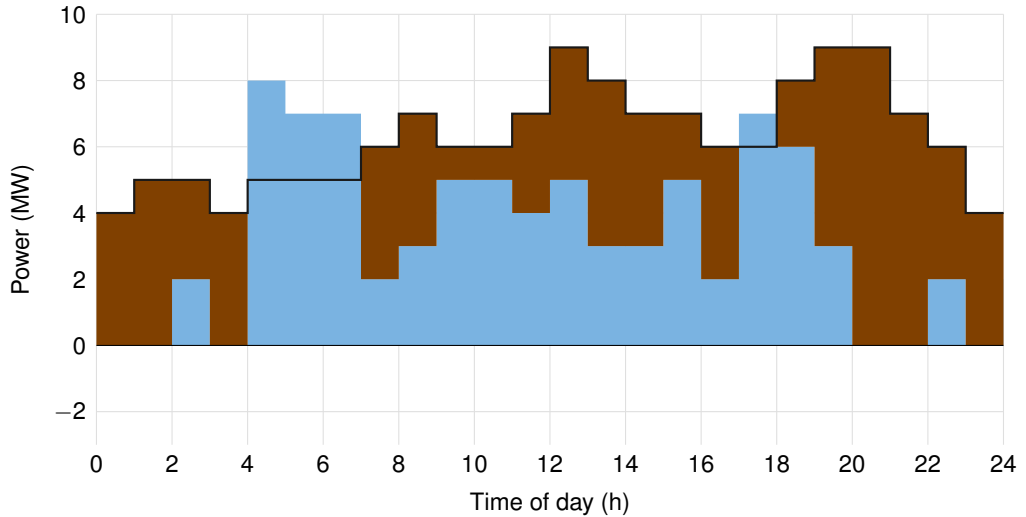
Principle illustrated

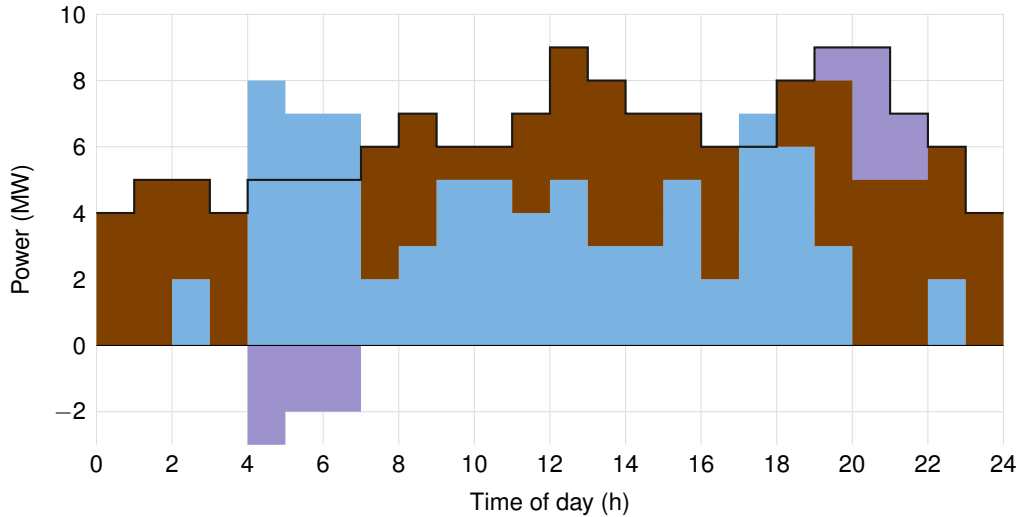


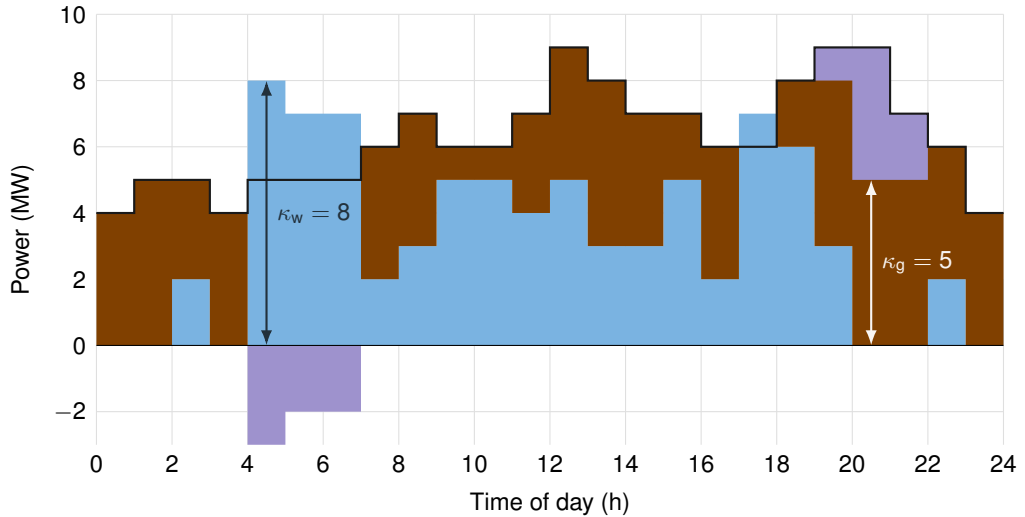


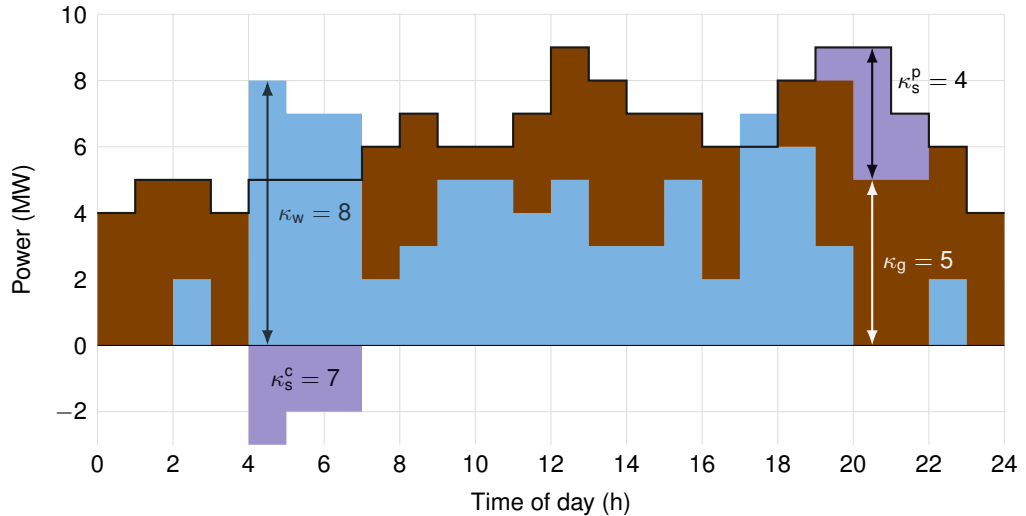
urbs

Principle illustrated









Notation as mathematical optimisation problem

Sets $t \in T, p \in P, s \in S, \dots$

Parameters d_t

Notation as mathematical optimisation problem

Sets $t \in T, p \in P, s \in S, \dots$

Parameters $d_t, k_p^{\text{fix}}, k_s^{\text{fix,c}}, k_s^{\text{fix,p}}$

Notation as mathematical optimisation problem

Sets $t \in T, p \in P, s \in S, \dots$

Parameters $d_t, k_p^{\text{fix}}, k_s^{\text{fix,c}}, k_s^{\text{fix,p}}, k_p^{\text{var}}, k_s^{\text{var}}, \dots$

Notation as mathematical optimisation problem

Sets	$t \in T, p \in P, s \in S, \dots$
Parameters	$d_t, k_p^{\text{fix}}, k_s^{\text{fix,c}}, k_s^{\text{fix,p}}, k_p^{\text{var}}, k_s^{\text{var}}, \dots$
Variables	$\kappa_p, \kappa_s^{\text{c}}, \kappa_s^{\text{p}}$

Notation as mathematical optimisation problem

Sets	$t \in T, p \in P, s \in S, \dots$
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Variables	$\kappa_p, \kappa_s^{\text{c}}, \kappa_s^{\text{p}}, \epsilon_{pt}, \epsilon_{st}^{\text{in}}, \epsilon_{st}^{\text{out}}, \epsilon_{st}^{\text{con}}, \dots$

Notation as mathematical optimisation problem

Sets	$t \in T, p \in P, s \in S, \dots$
Parameters	$d_t, k_p^{\text{fix}}, k_s^{\text{fix,c}}, k_s^{\text{fix,p}}, k_p^{\text{var}}, k_s^{\text{var}}, \dots$
Variables	$\kappa_p, \kappa_s^{\text{c}}, \kappa_s^{\text{p}}, \epsilon_{pt}, \epsilon_{st}^{\text{in}}, \epsilon_{st}^{\text{out}}, \epsilon_{st}^{\text{con}}, \dots$
Objective	$\min \sum_{p \in P} \left(k_p^{\text{fix}} \kappa_p + \sum_{t \in T} k_p^{\text{var}} \epsilon_{pt} \right) +$ $\sum_{s \in S} \left(k_s^{\text{fix,c}} \kappa_s^{\text{c}} + k_s^{\text{fix,p}} \kappa_s^{\text{p}} + \sum_{t \in T} k_s^{\text{var}} (\epsilon_{st}^{\text{in}} + \epsilon_{st}^{\text{out}}) \right)$

Notation as mathematical optimisation problem

Sets $t \in T, p \in P, s \in S, \dots$

Parameters $d_t, k_p^{\text{fix}}, k_s^{\text{fix,c}}, k_s^{\text{fix,p}}, k_p^{\text{var}}, k_s^{\text{var}}, \dots$

Variables $\kappa_p, \kappa_s^{\text{c}}, \kappa_s^{\text{p}}, \epsilon_{pt}, \epsilon_{st}^{\text{in}}, \epsilon_{st}^{\text{out}}, \epsilon_{st}^{\text{con}}, \dots$

Objective
$$\min \sum_{p \in P} \left(k_p^{\text{fix}} \kappa_p + \sum_{t \in T} k_p^{\text{var}} \epsilon_{pt} \right) +$$
$$\sum_{s \in S} \left(k_s^{\text{fix,c}} \kappa_s^{\text{c}} + k_s^{\text{fix,p}} \kappa_s^{\text{p}} + \sum_{t \in T} k_s^{\text{var}} (\epsilon_{st}^{\text{in}} + \epsilon_{st}^{\text{out}}) \right)$$

Constraints s.t. $\forall t \in T: \sum_{p \in P} \epsilon_{pt} + \sum_{s \in S} (\epsilon_{st}^{\text{out}} - \epsilon_{st}^{\text{in}}) = d_t$

...

Standard form of linear optimisation problems (LP)

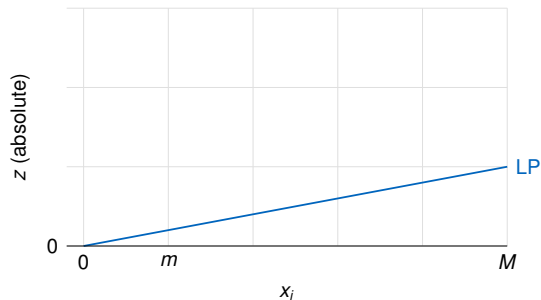
Generic form

$$\min_{\mathbf{x}} z = \mathbf{c}^T \mathbf{x}$$

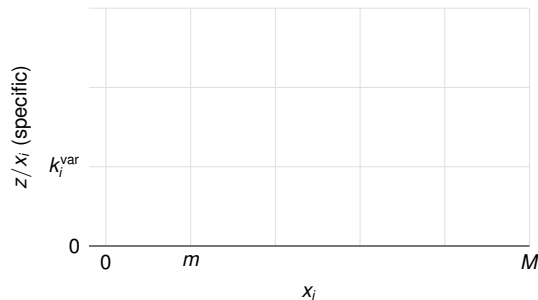
$$\text{s.t. } \mathbf{Ax} \leq \mathbf{b}$$

$$\text{with } \mathbf{x} \in \mathbb{R}^n, \mathbf{A} \in \mathbb{R}^{m \times n}, \\ \mathbf{b} \in \mathbb{R}^m, \mathbf{c} \in \mathbb{R}^n.$$

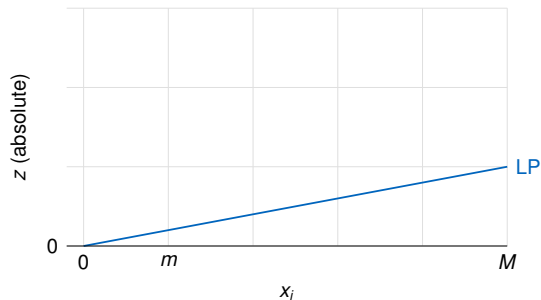
Mixed-integer linear programming (MILP)



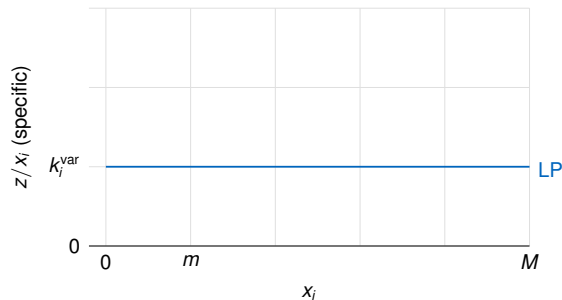
$$\begin{aligned} \text{LP} \quad & z = k_i^{\text{var}} x_i \\ & x_i \leq M \end{aligned}$$



Mixed-integer linear programming (MILP)

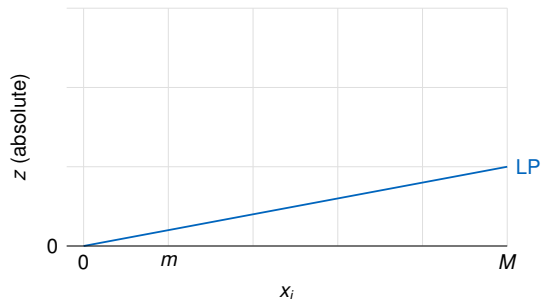


$$\text{LP} \quad z = k_i^{\text{var}} x_i$$
$$x_i \leq M$$



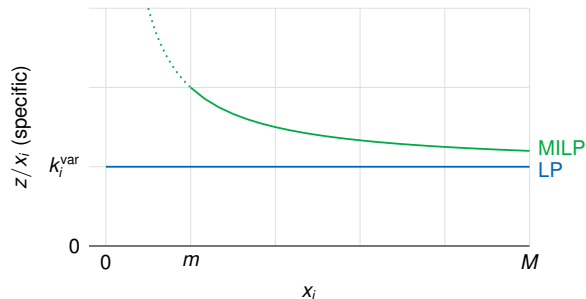
$$\text{LP} \quad \frac{z}{x_i} = k_i^{\text{var}} \equiv \text{const}$$

Mixed-integer linear programming (MILP)



$$\text{LP} \quad z = k_i^{\text{var}} x_i$$

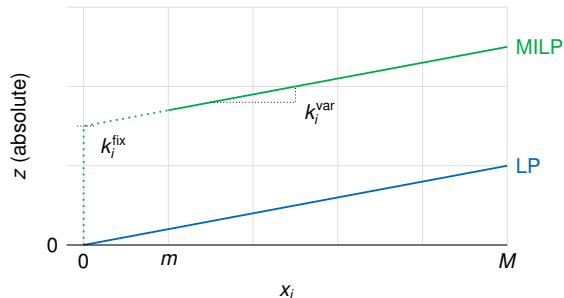
$$x_i \leq M$$



$$\text{LP} \quad \frac{z}{x_i} = k_i^{\text{var}} \equiv \text{const}$$

$$\text{MILP} \quad \frac{z}{x_i} = k_i^{\text{var}} + \frac{k_i^{\text{fix}}}{x_i}$$

Mixed-integer linear programming (MILP)



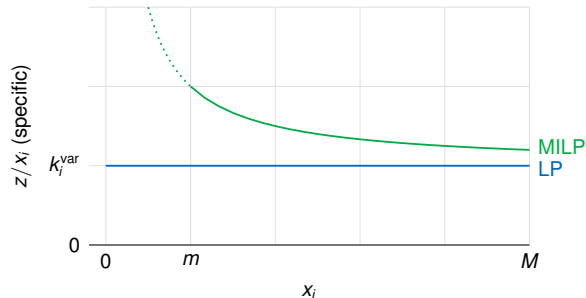
$$\text{LP} \quad z = k_i^{\text{var}} x_i$$

$$x_i \leq M$$

$$\text{MILP} \quad z = k_i^{\text{fix}} y_i + k_i^{\text{var}} x_i$$

$$y_i \in \{0, 1\}$$

$$m y_i \leq x_i \leq M y_i$$



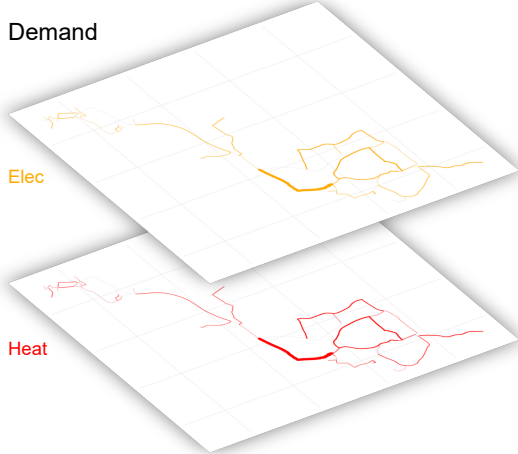
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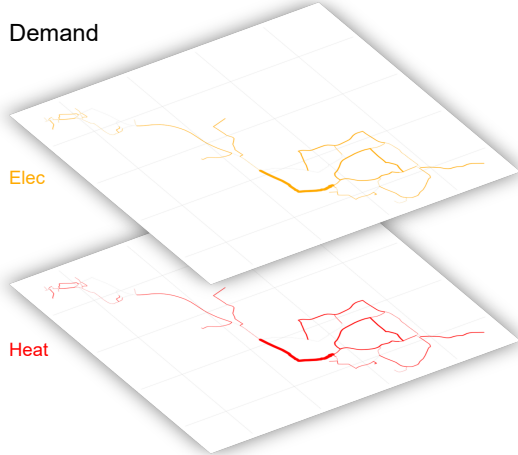
Demand

Elec

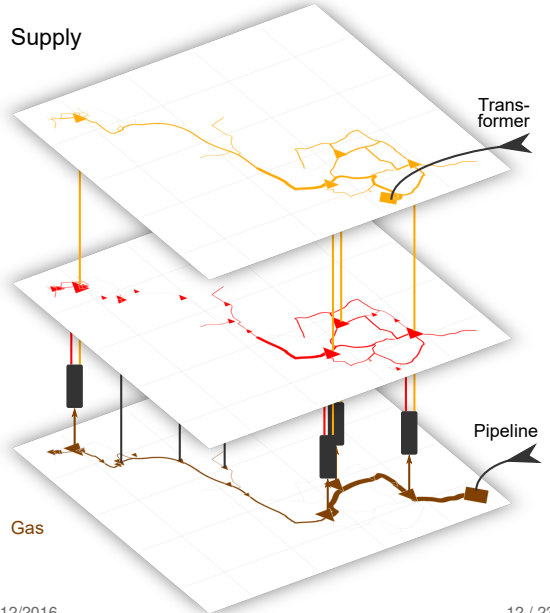
Heat

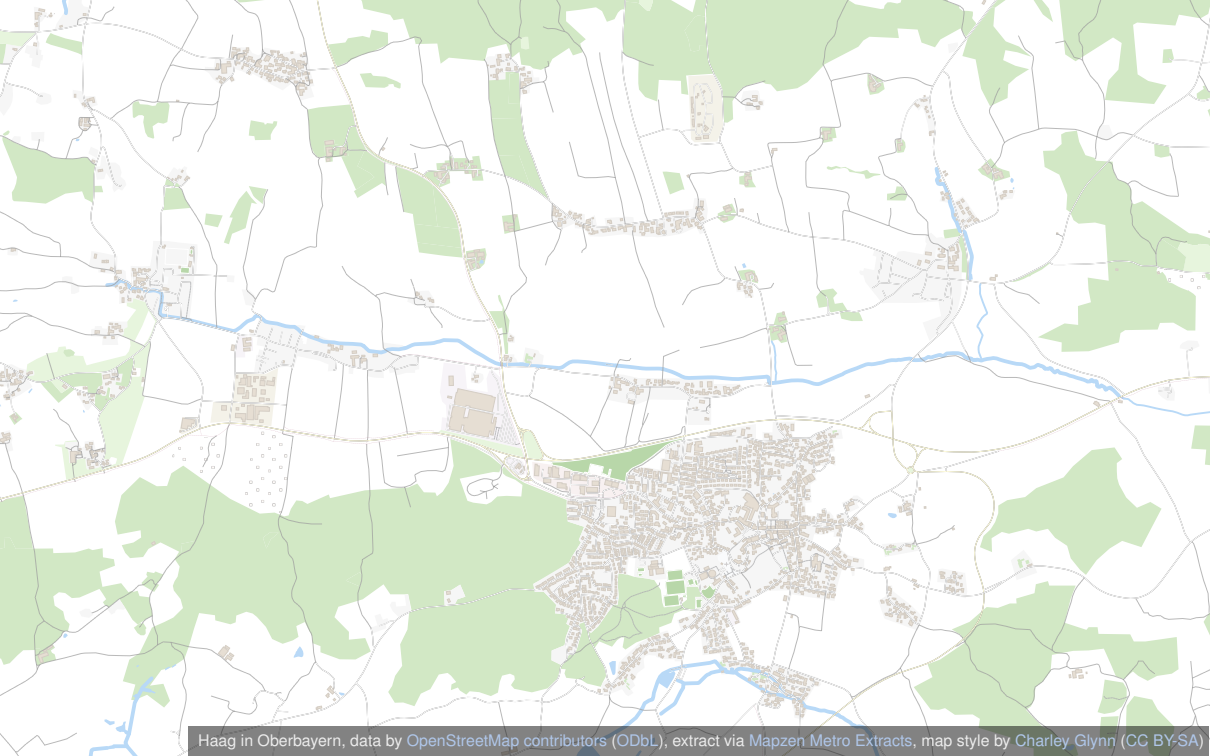


Demand



Supply



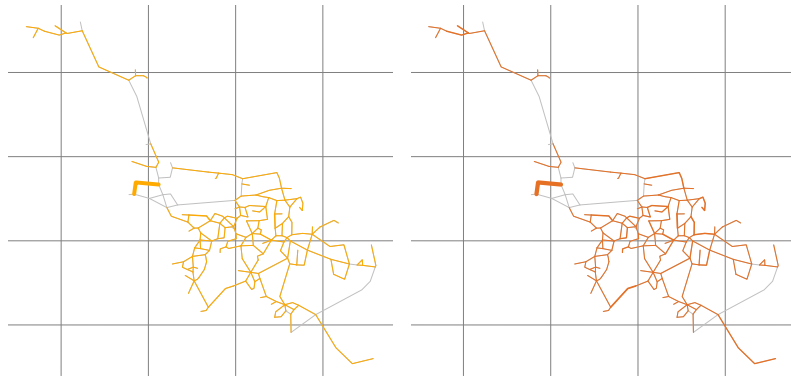


Moosham

Input data rivus

Electricity

Heat

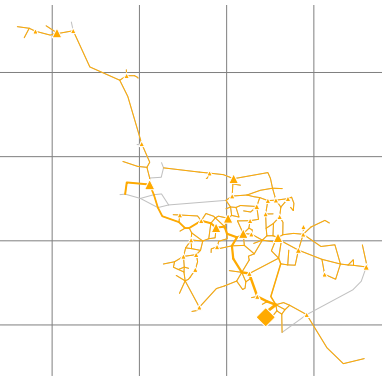


Light industry (Schletter) biggest single consumer

<https://github.com/tum-ens/rivus/data/haag15>

Result **rivus** – Capacities in scenario **base**

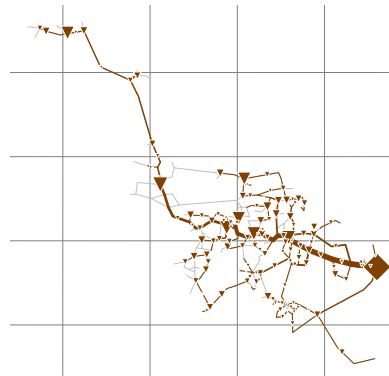
Electricity



Heat



Gas



Full networks for electricity and gas, several local heating networks

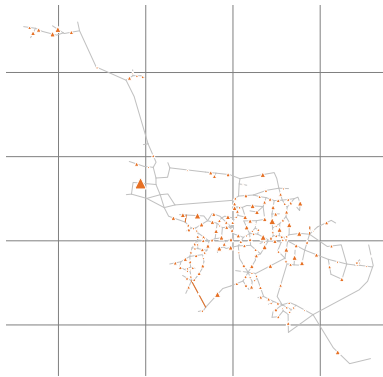
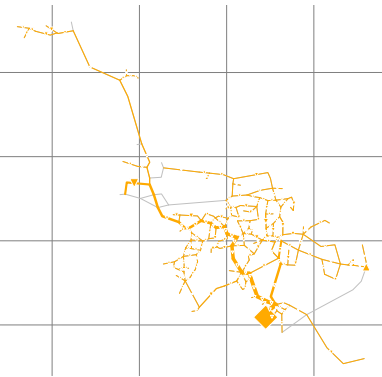
[https://github.com/tum-ens/rivus/runhg15.py:scenario_no_electric_heating\(\)](https://github.com/tum-ens/rivus/runhg15.py:scenario_no_electric_heating())

Result **rivus** – Capacities in scenario **future**

Electricity

Heat

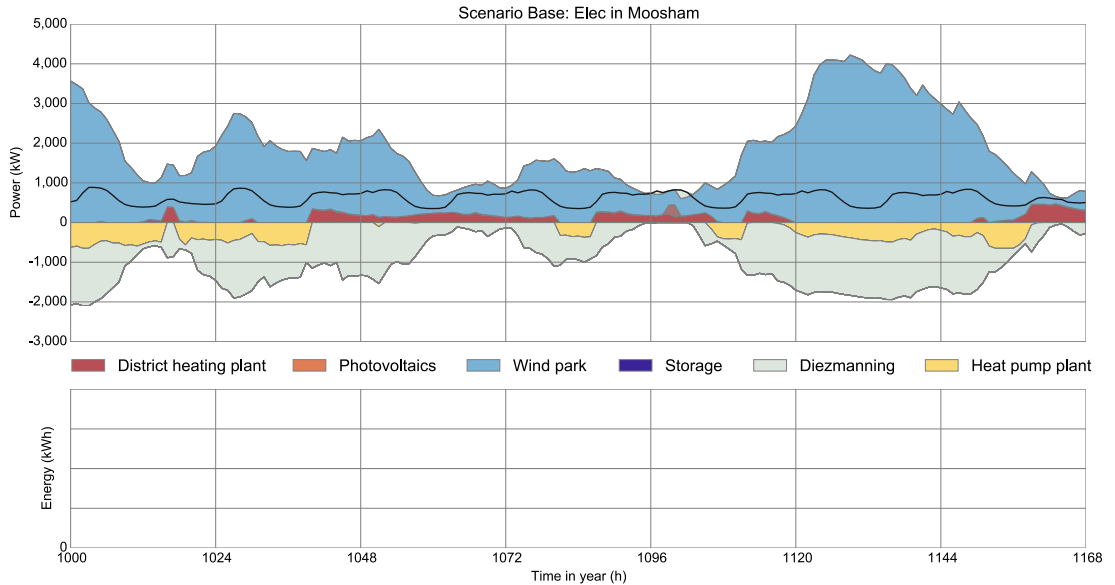
Gas



Strong electricity grid, no gas network, only heat pumps

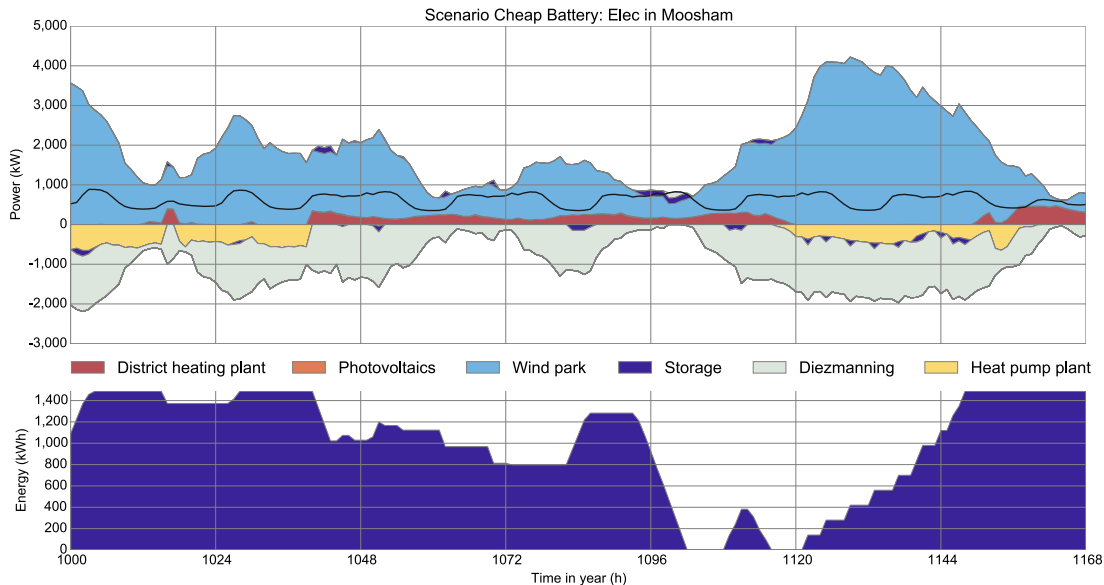
[https://github.com/tum-ens/rivus/runhg15.py:scenario_renovation\(\)](https://github.com/tum-ens/rivus/runhg15.py:scenario_renovation())

Result **urbs** – 1 week electricity in scenarios **base**



[https://github.com/ojdo/urbs/tree/haag15/rivhg15.py:scenario_base\(\)](https://github.com/ojdo/urbs/tree/haag15/rivhg15.py:scenario_base())

Result **urbs** – 1 week electricity in scenario **cheap battery**



[https://github.com/ojdo/urbs/tree/haag15/rivhg15.py:scenario_cheap_battery\(\)](https://github.com/ojdo/urbs/tree/haag15/rivhg15.py:scenario_cheap_battery())

Section 3

Sustainable model use

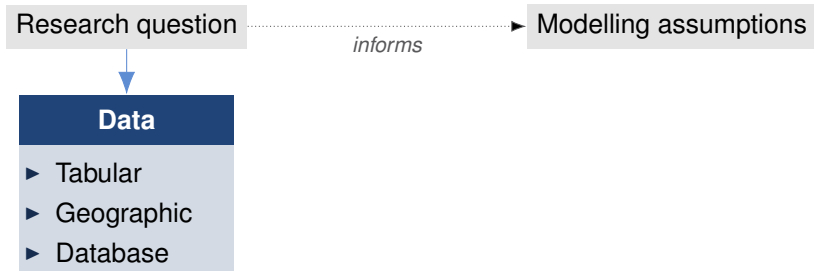
Optimisation model workflow

Research question

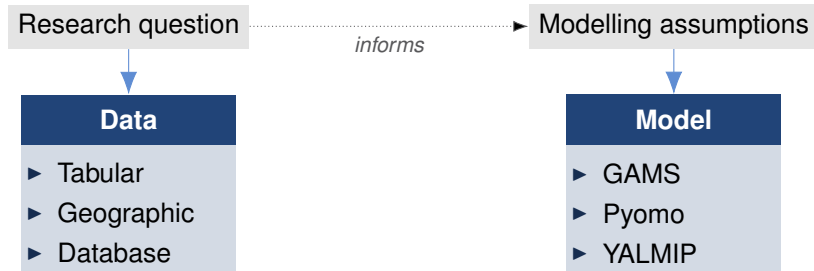
Optimisation model workflow



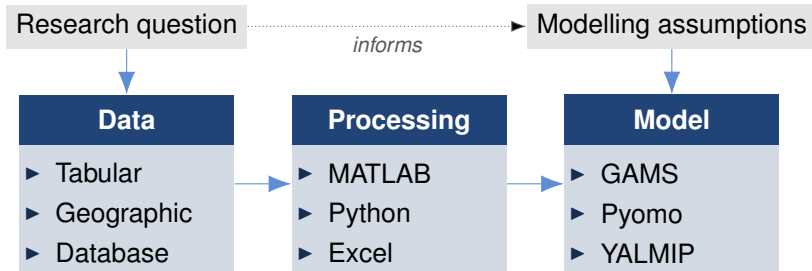
Optimisation model workflow



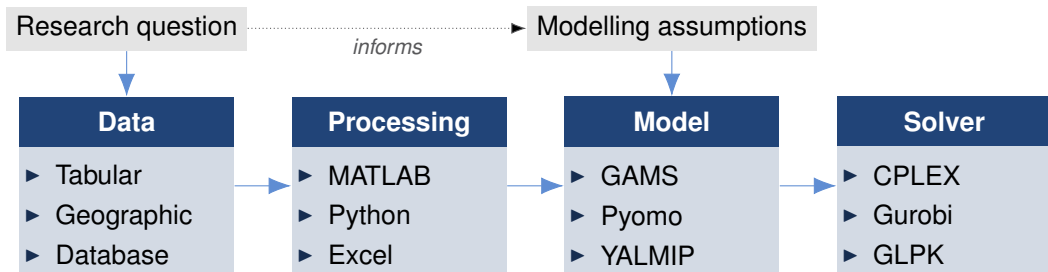
Optimisation model workflow



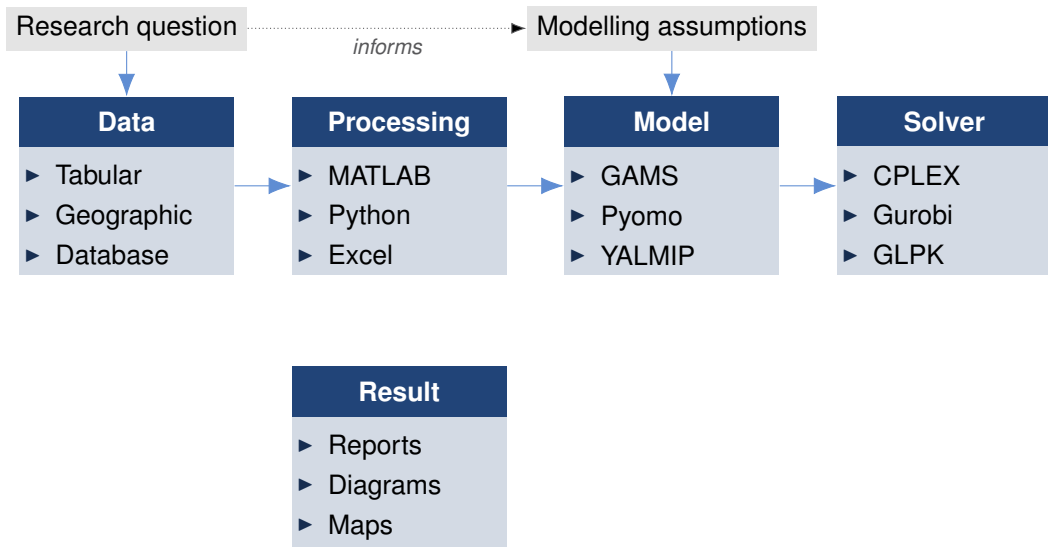
Optimisation model workflow



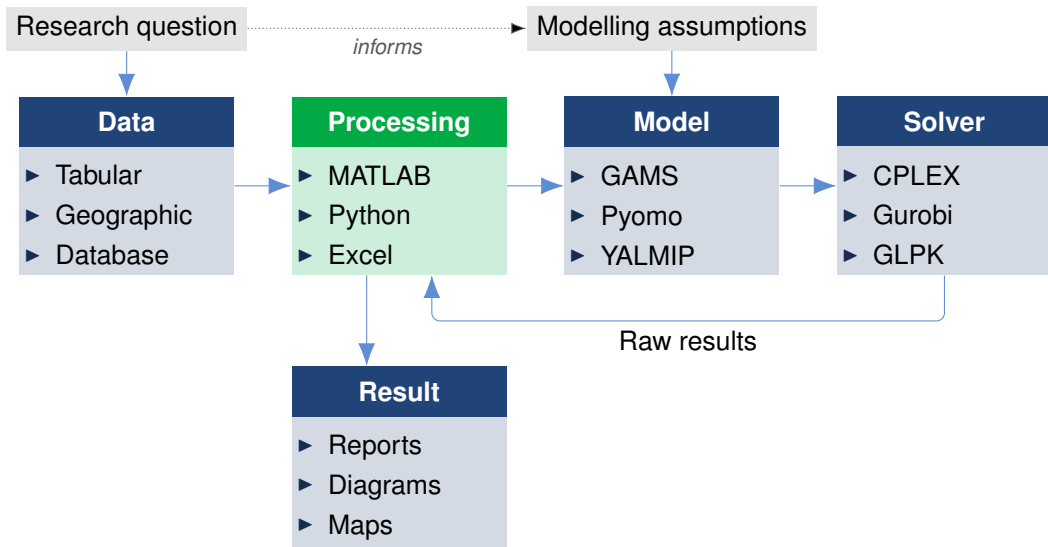
Optimisation model workflow



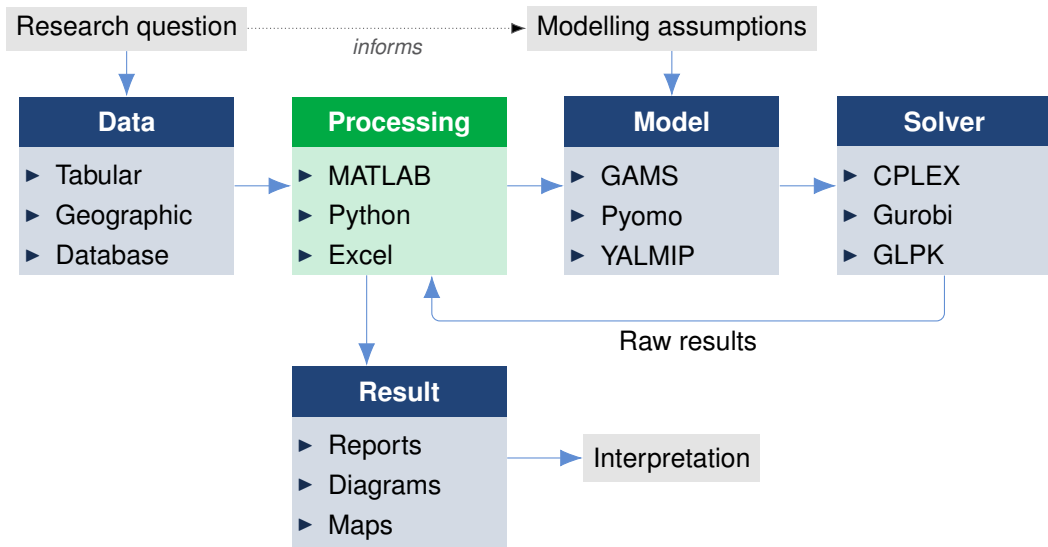
Optimisation model workflow



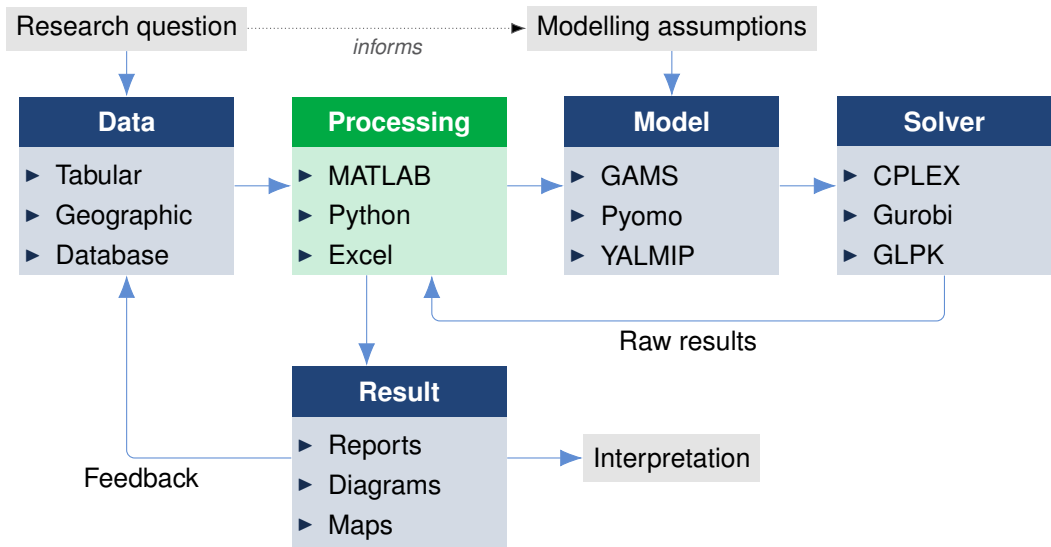
Optimisation model workflow



Optimisation model workflow



Optimisation model workflow



Distributed version control for scientific work



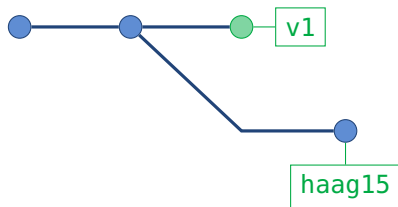
Distributed version control for scientific work



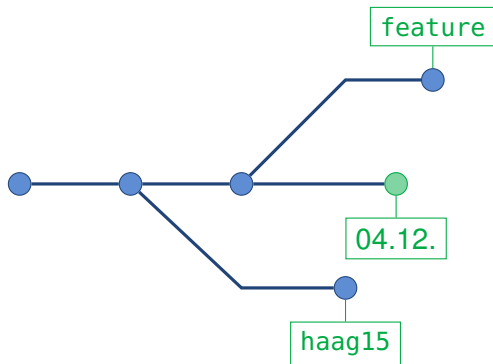
Distributed version control for scientific work



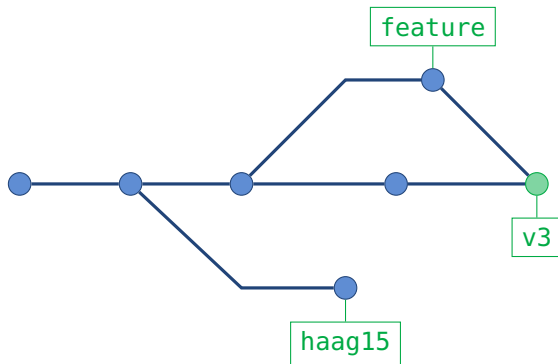
Distributed version control for scientific work



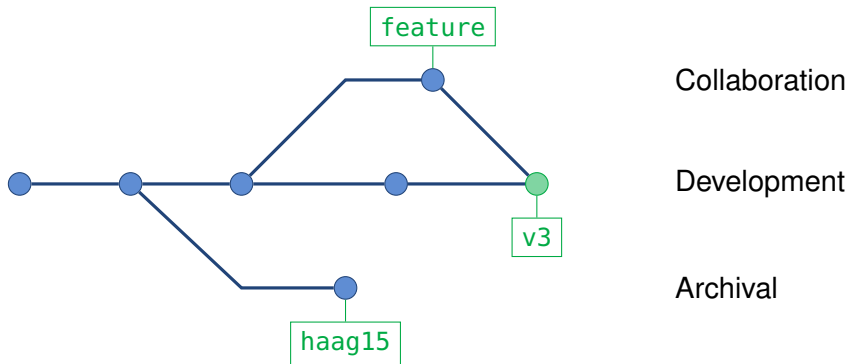
Distributed version control for scientific work

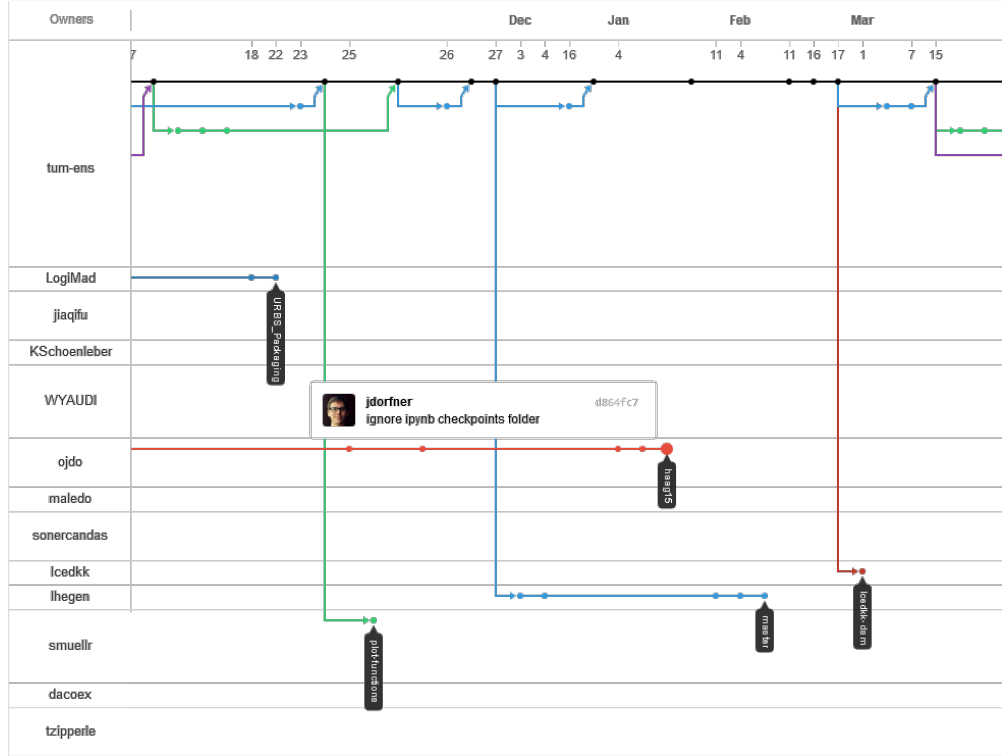


Distributed version control for scientific work



Distributed version control for scientific work





Conclusion

Infrastructure

Engineering

Technical
feasibility
(Technologies)

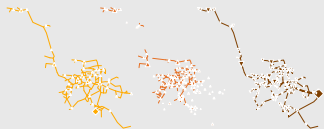
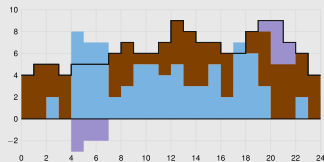
Economy

Economic
feasibility
(Funding)

Techno-economic modelling

How much energy? For how much?

Modelling



Open Source

