



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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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/>

Physics

Theoretical
feasibility
(Natural laws)

Engineering

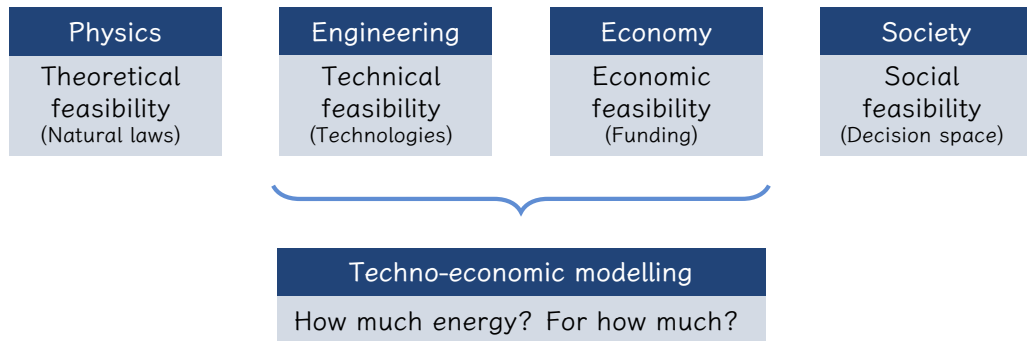
Technical
feasibility
(Technologies)

Economy

Economic
feasibility
(Funding)

Society

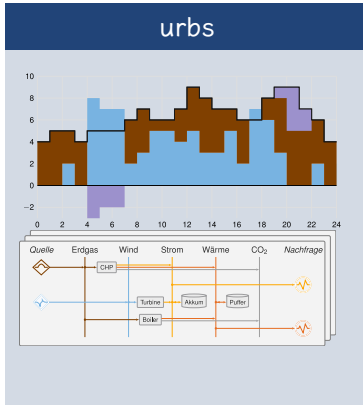
Social
feasibility
(Decision space)



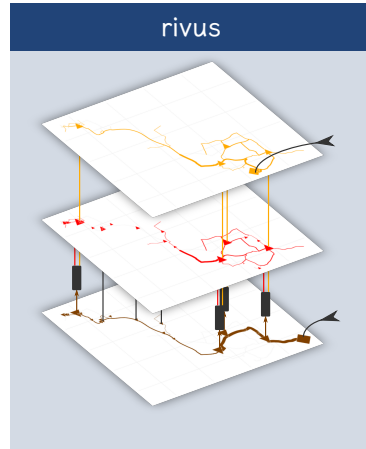
Section 2

Mathematical modelling, optimisation, case study

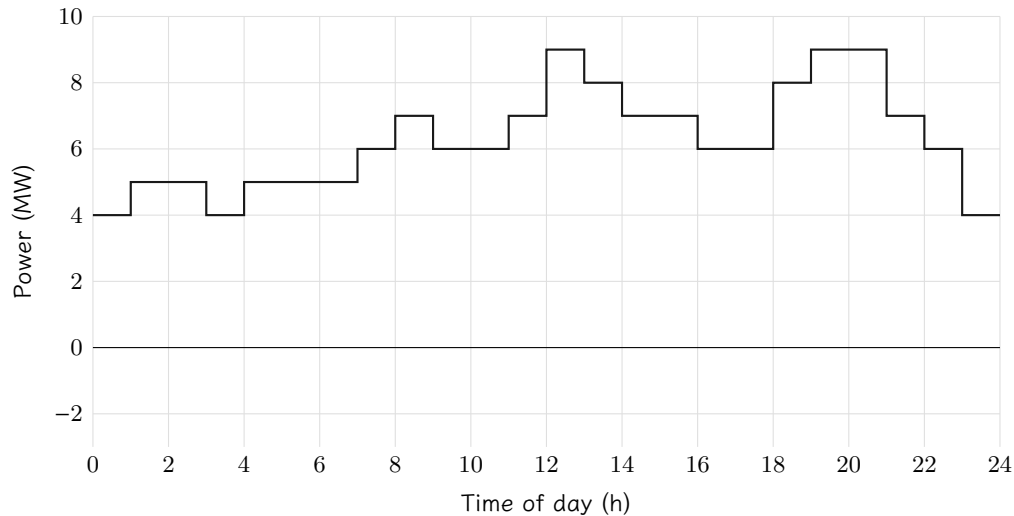
Model overview

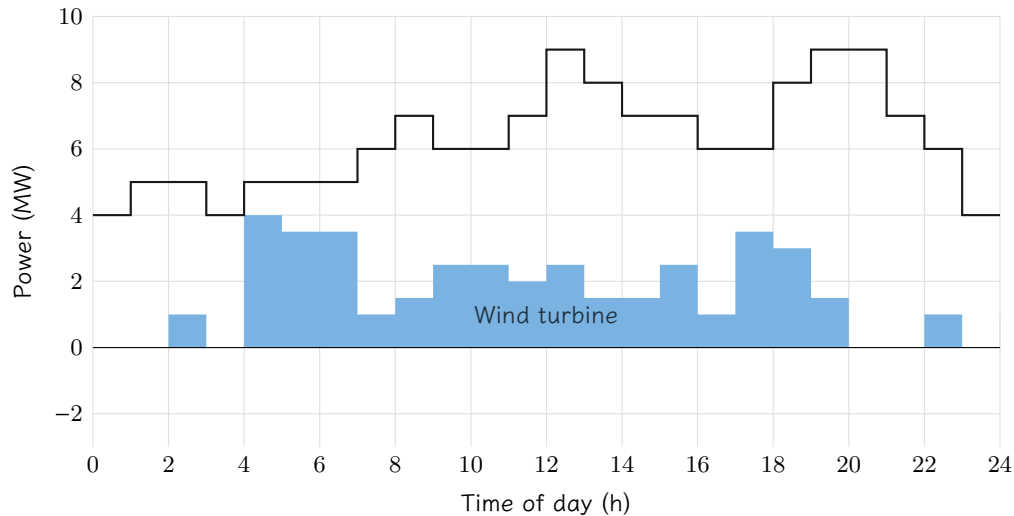


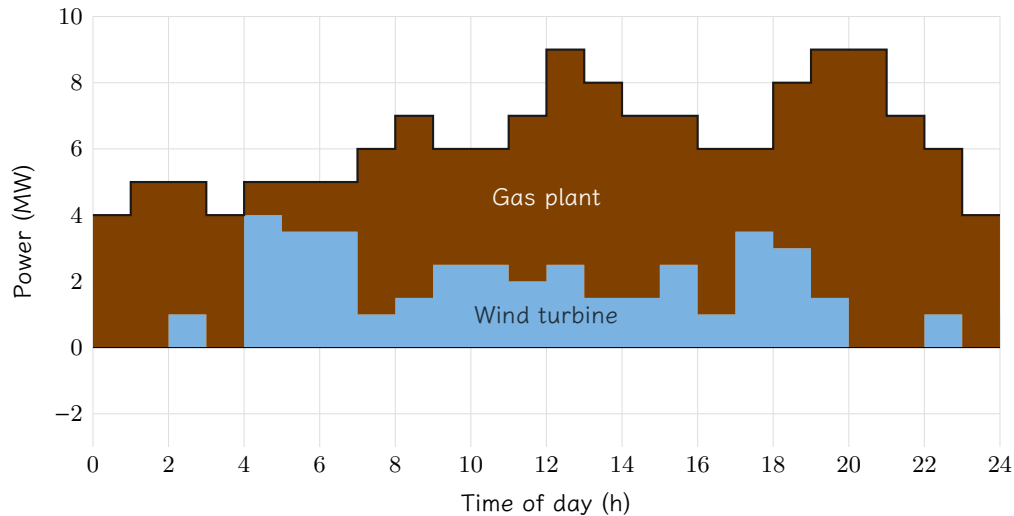
<https://github.com/tum-ens/urbs>

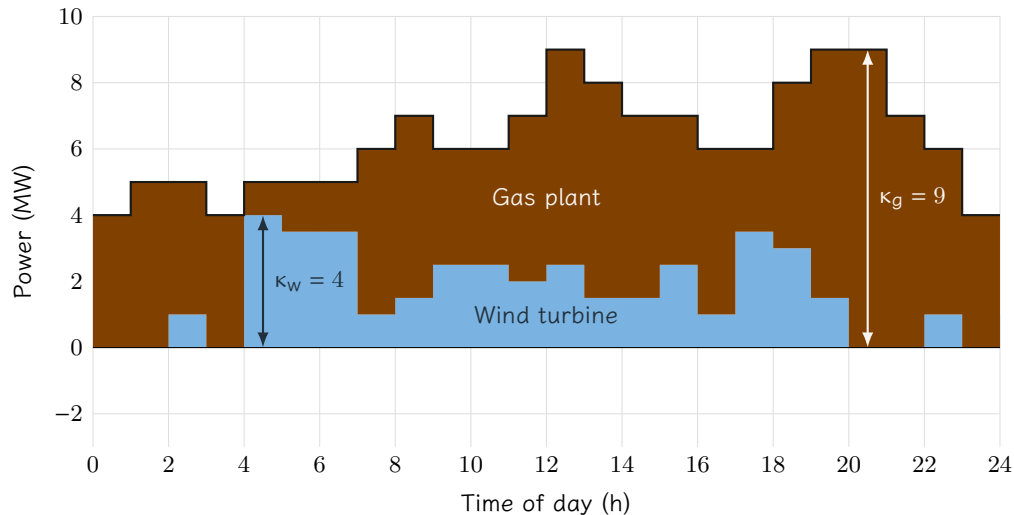


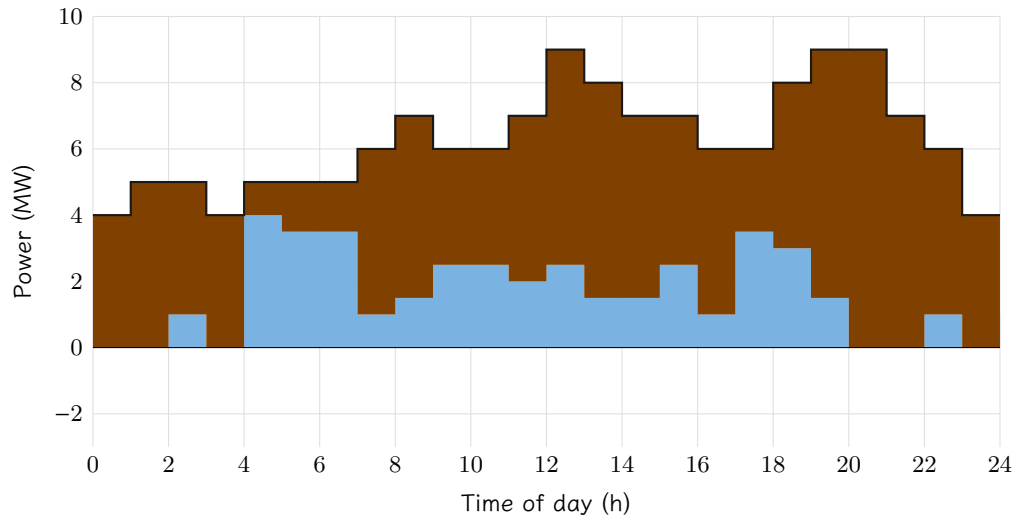
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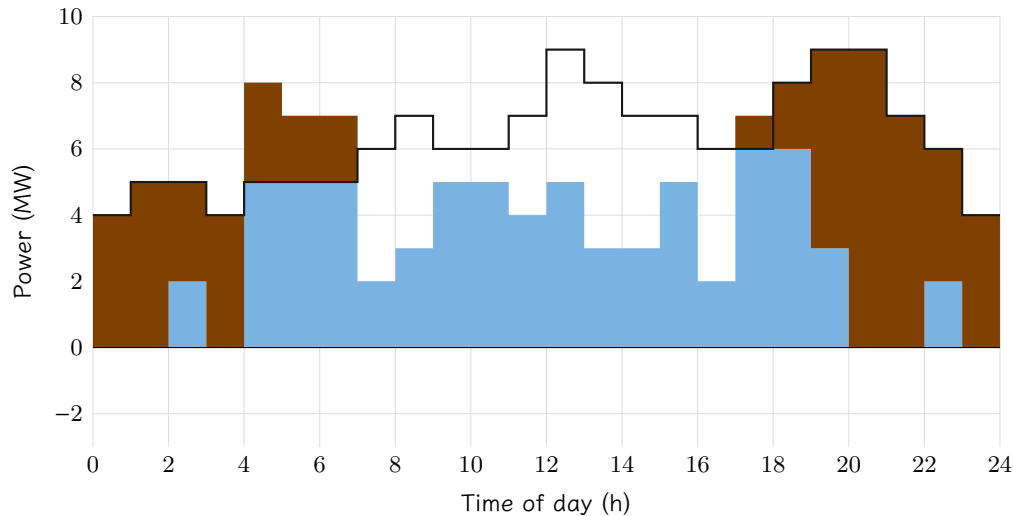


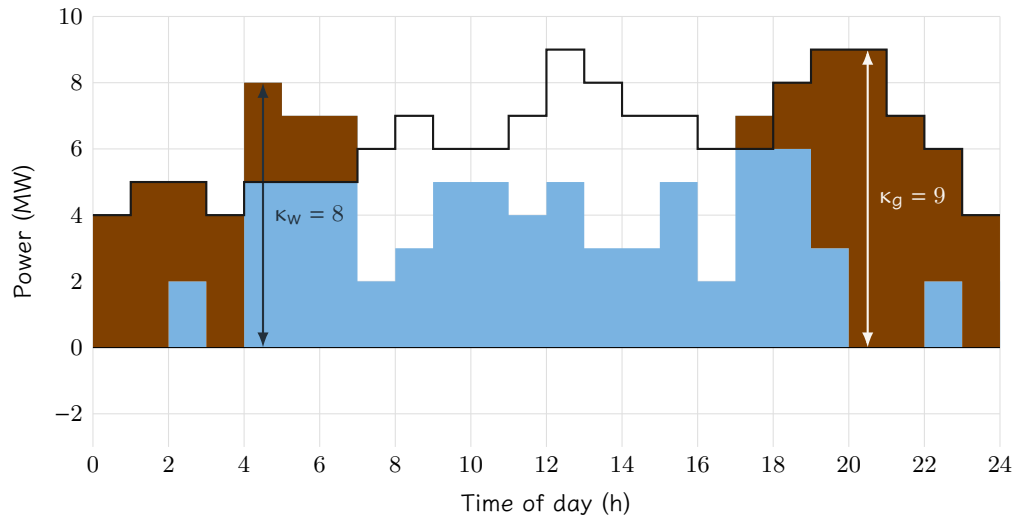


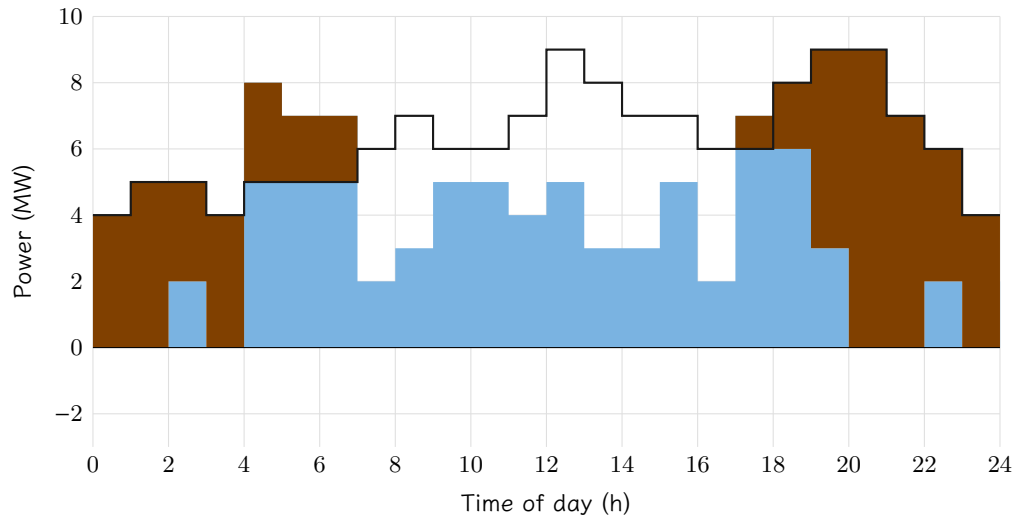


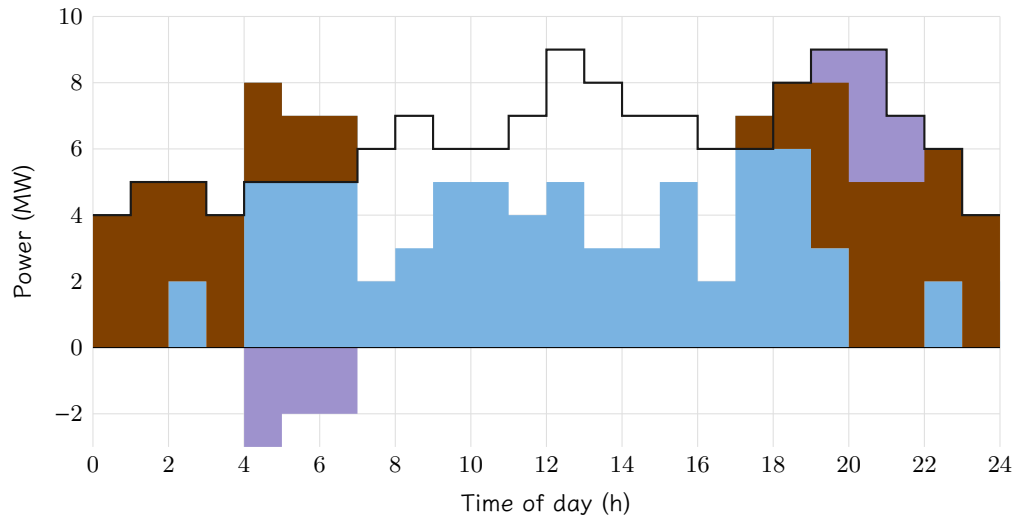


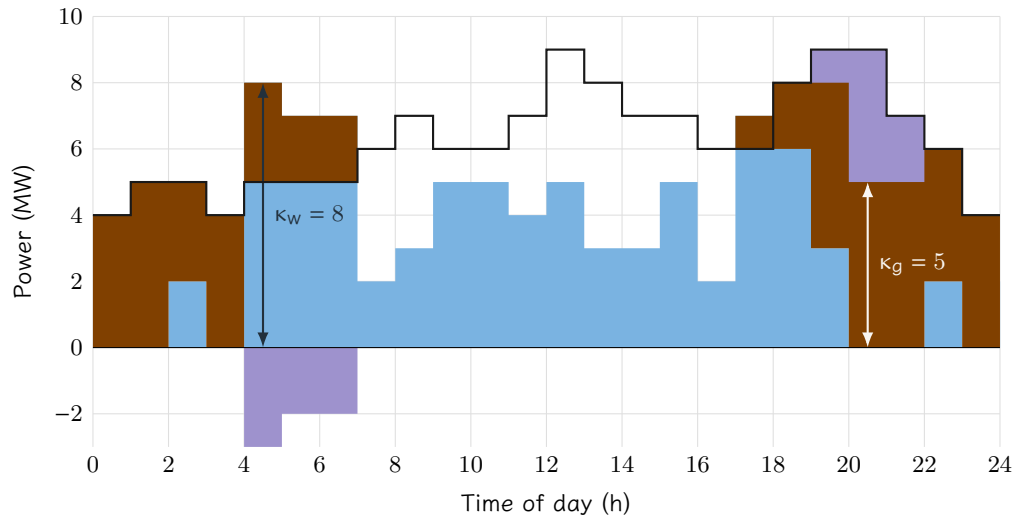


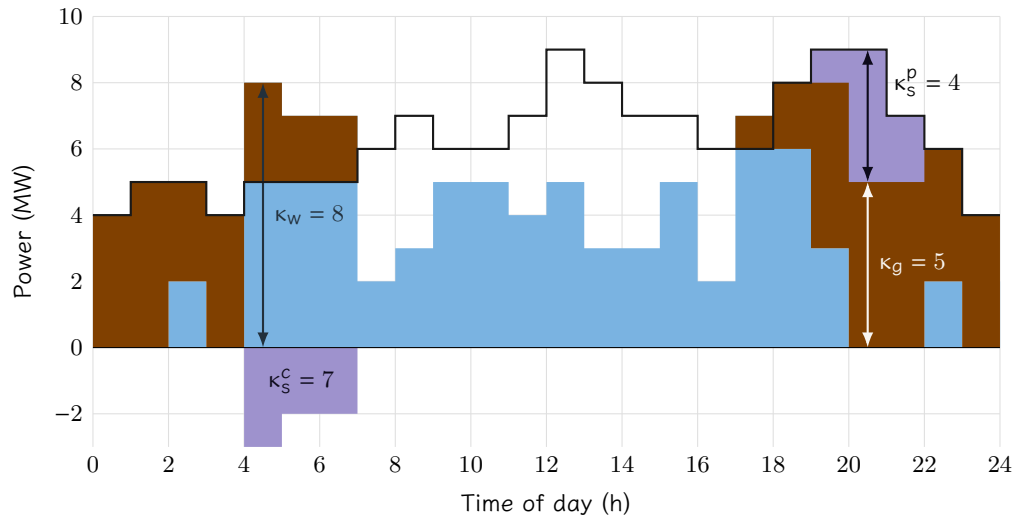












Notation as mathematical optimisation problem

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

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Notation as mathematical optimisation problem

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

Parameters $d_t, \kappa_p^{\text{fix}}, \kappa_s^{\text{fix},c}, \kappa_s^{\text{fix},p}, \kappa_p^{\text{var}}, \kappa_s^{\text{var}}, \dots$

Variables $\kappa_p, \kappa_s^c, \kappa_s^p$

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

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

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

Standard form of linear optimisation problems (LP)

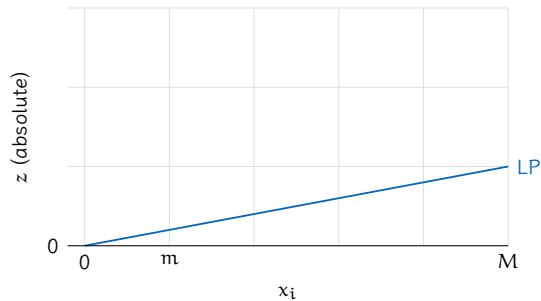
Generic form

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

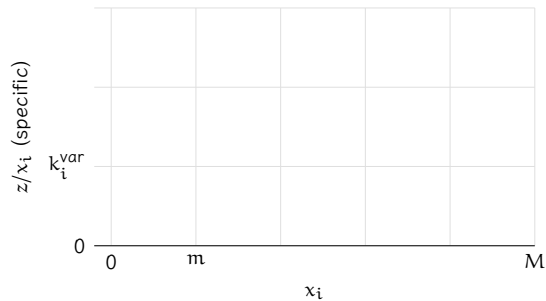
$$\text{s.t. } \mathbf{Ax} \leq \mathbf{b}$$

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

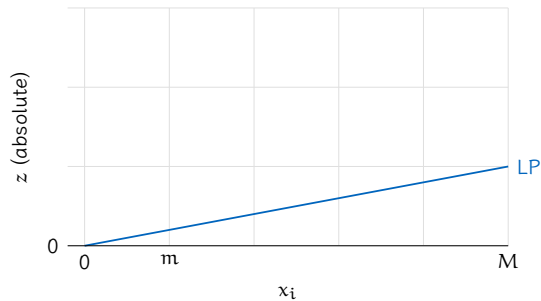
Mixed-integer linear programming (MILP)



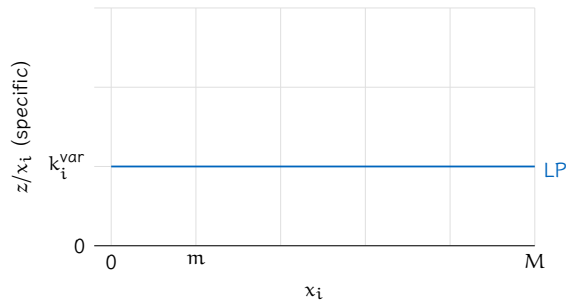
$$\begin{aligned} \text{LP} \quad & z = k_i^{\text{var}} x_i \\ & x_i \leq M \end{aligned}$$



Mixed-integer linear programming (MILP)

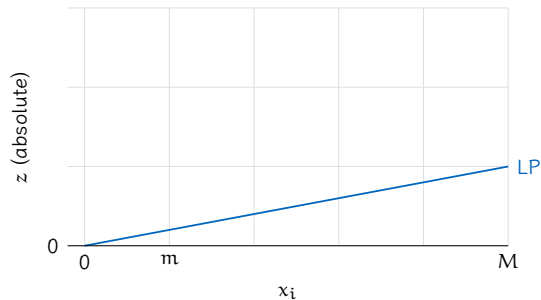


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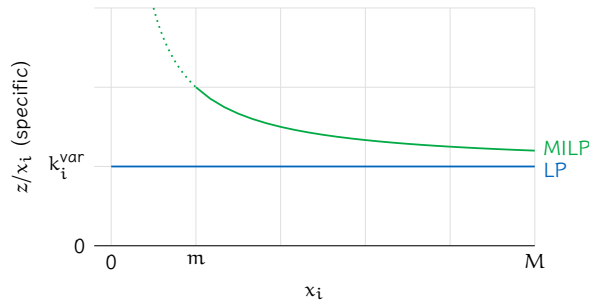
$$\text{LP} \quad \frac{z}{x_i} = k_i^{\text{var}} \equiv \text{const}$$

Mixed-integer linear programming (MILP)



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

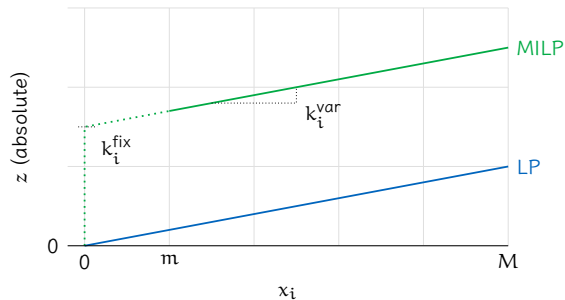
$$x_i \leq M$$



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

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

Mixed-integer linear programming (MILP)



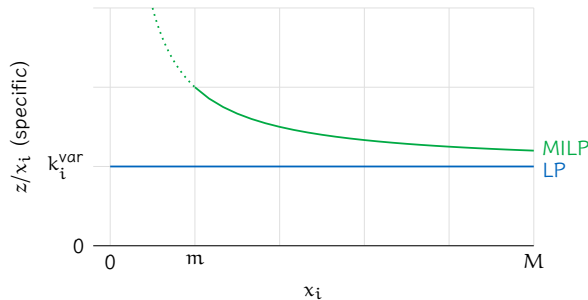
$$\text{LP} \quad z = k_i^{\text{var}} x_i$$

$$x_i \leq M$$

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

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

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



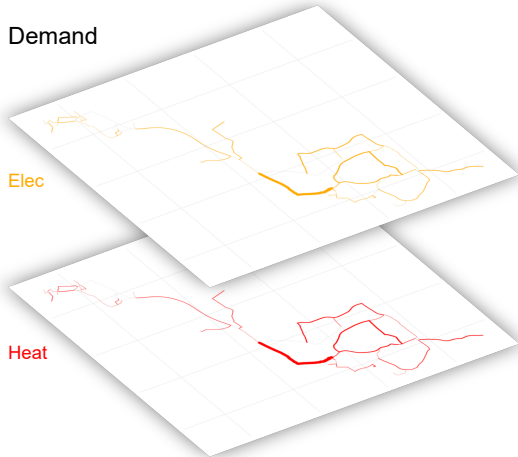
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Demand

Elec

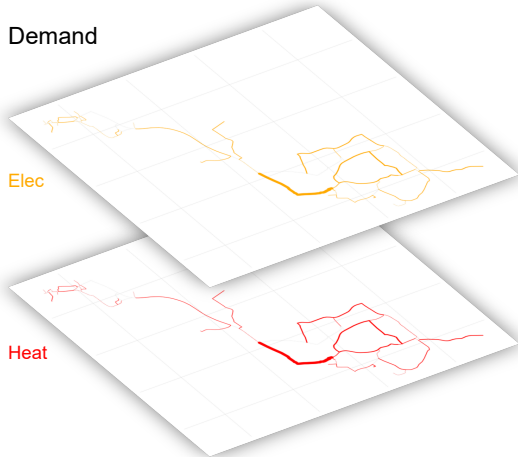
Heat



Demand

Elec

Heat

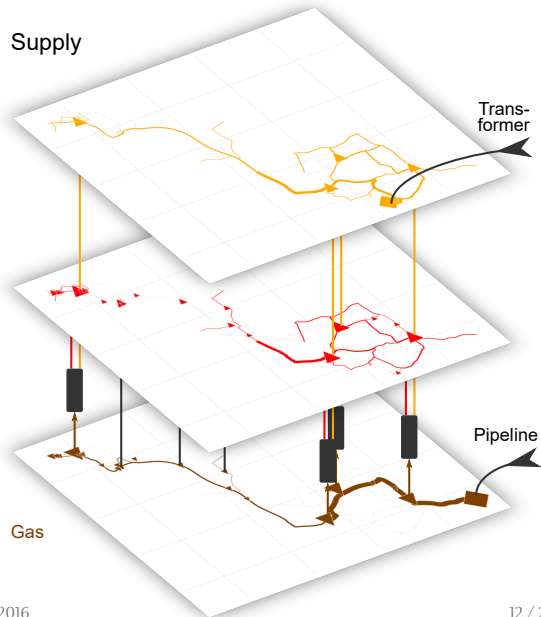


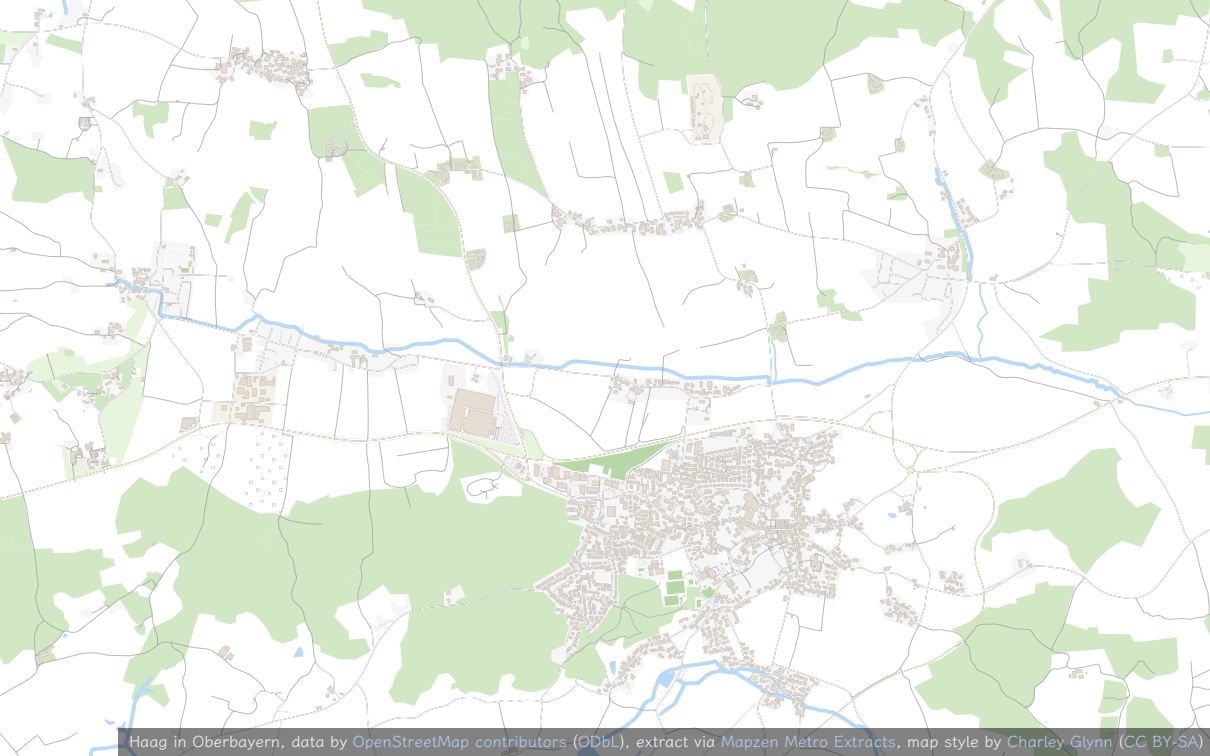
Supply

Gas

Trans-
former

Pipeline



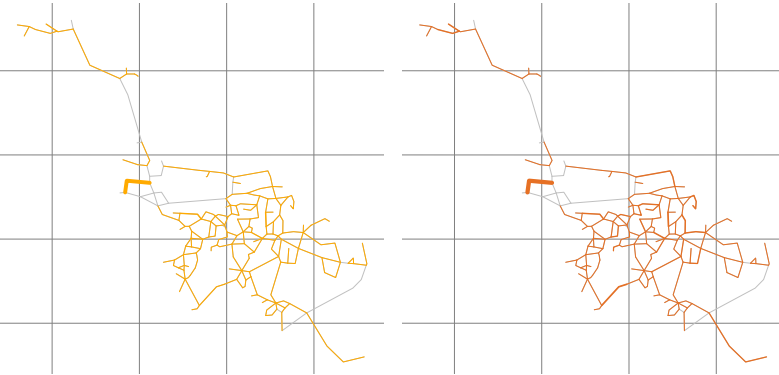


Moosham

Input data rivus

Electricity

Heat

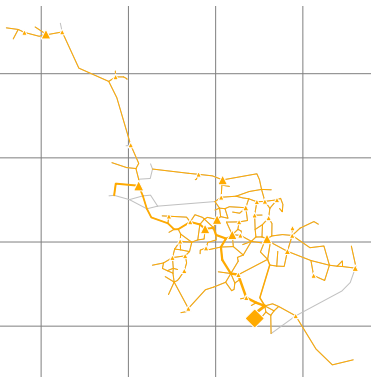


Light industry (Schletter) biggest single consumer

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

Result rivus -- Capacities in scenario **base**

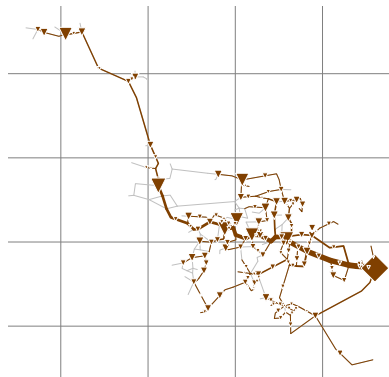
Electricity



Heat



Gas



Full networks for electricity and gas, several local heating networks

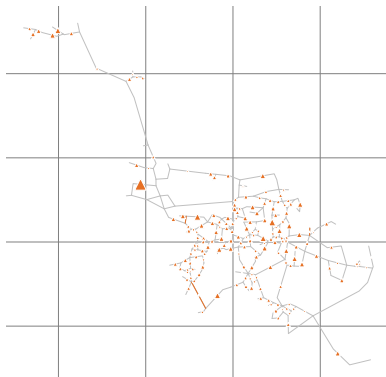
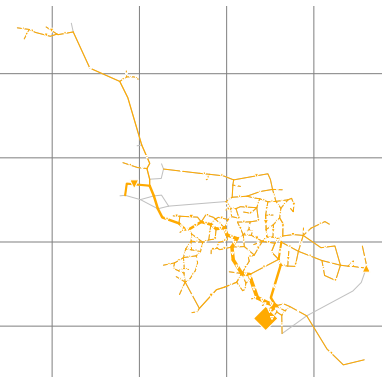
[https://github.com/tum-ens/rivus/runhg15.py:scenario_no_electric_heating\(\)](https://github.com/tum-ens/rivus/runhg15.py:scenario_no_electric_heating())

Result rivus -- Capacities in scenario future

Electricity

Heat

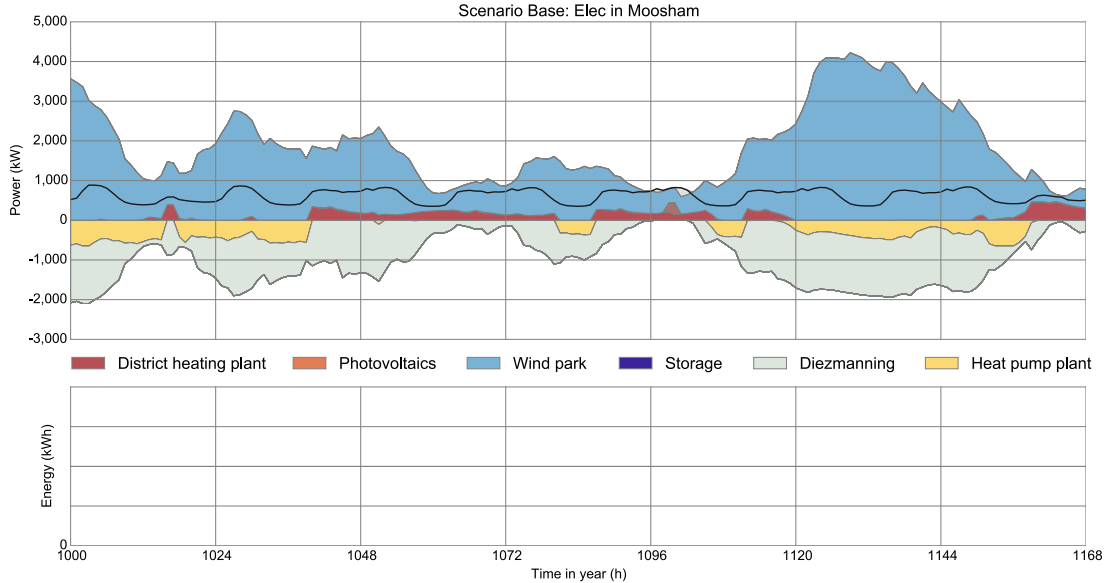
Gas



Strong electricity grid, no gas network, only heat pumps

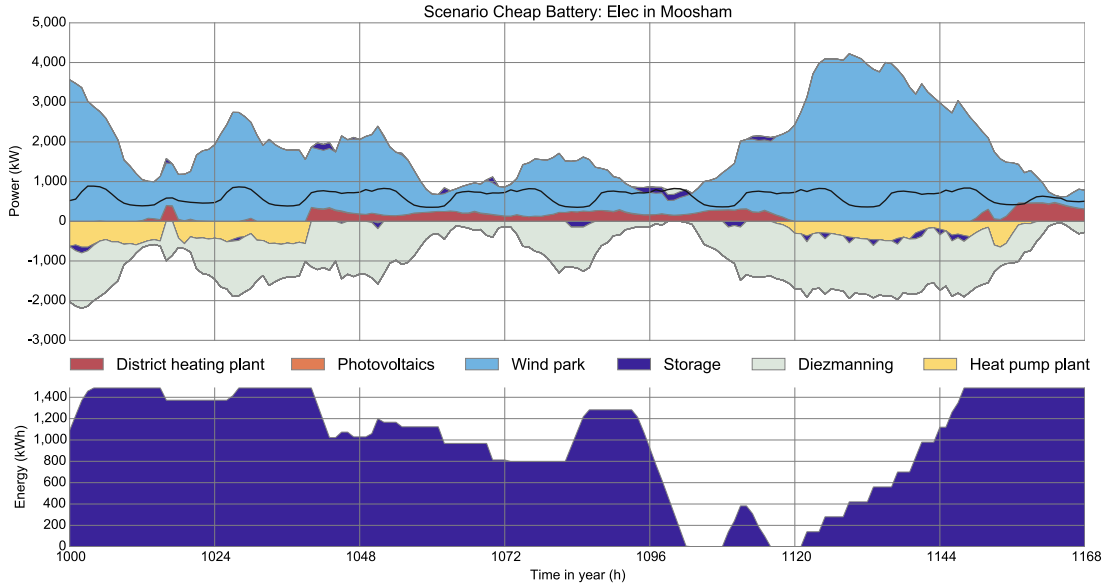
[https://github.com/tum-ens/rivus/runhg15.py:scenario_renovation\(\)](https://github.com/tum-ens/rivus/runhg15.py:scenario_renovation())

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())

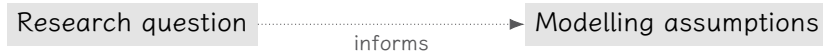
Section 3

Sustainable model use

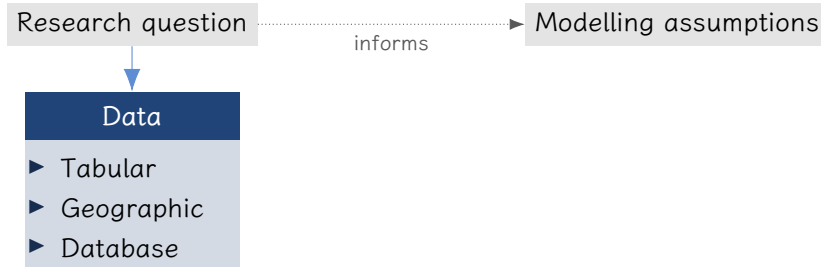
Optimisation model workflow

Research question

Optimisation model workflow



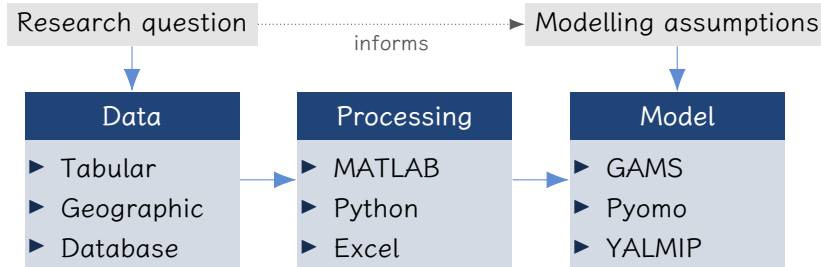
Optimisation model workflow



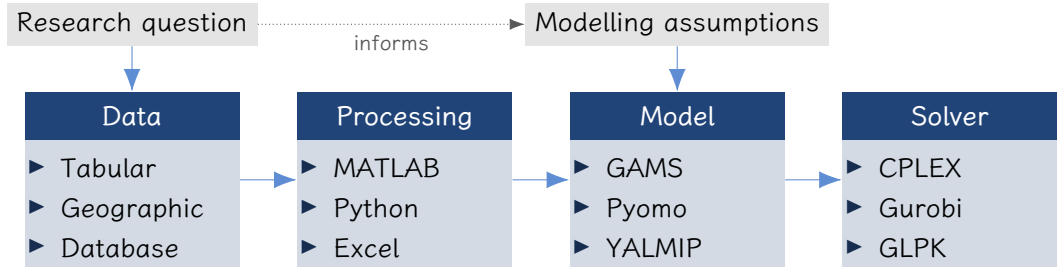
Optimisation model workflow



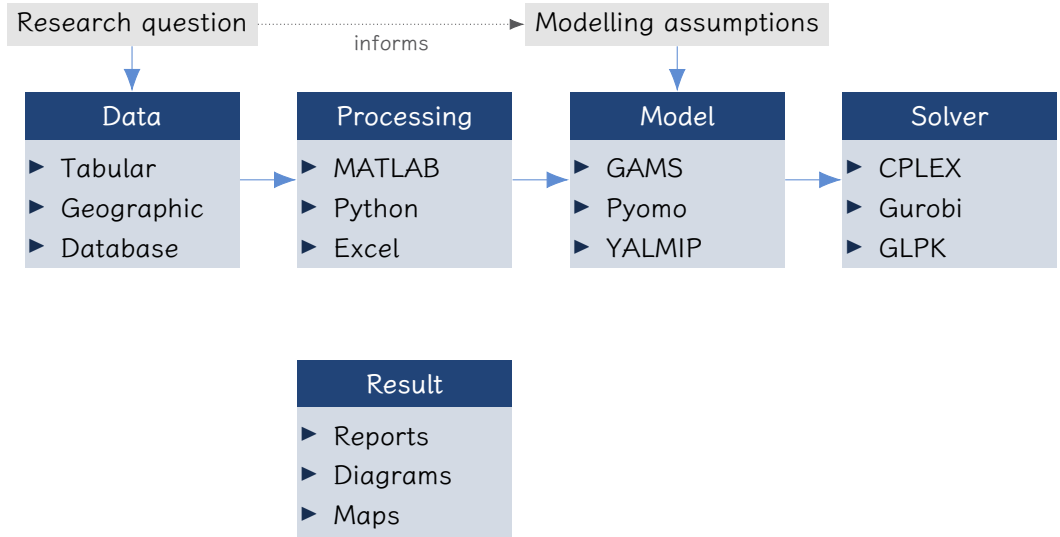
Optimisation model workflow



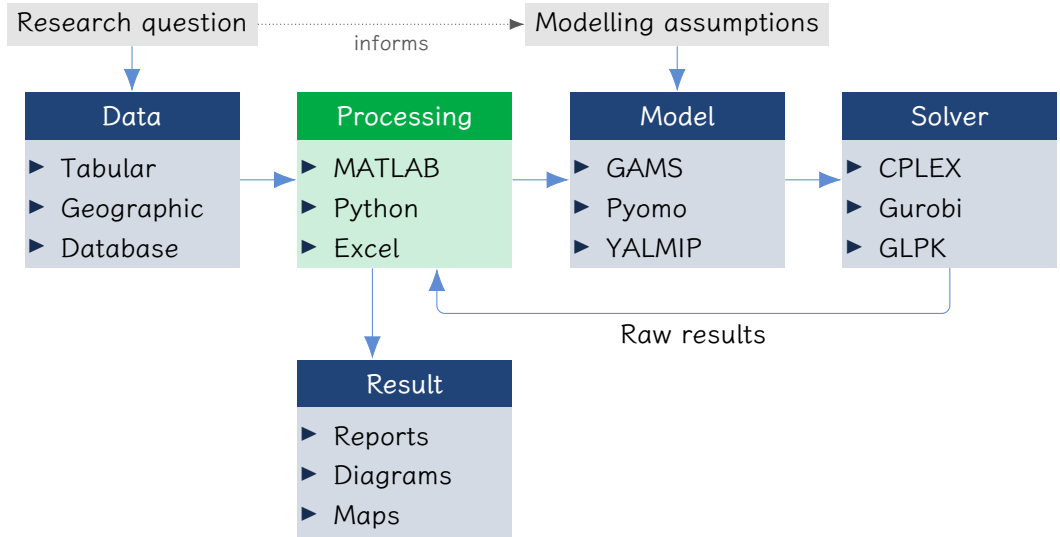
Optimisation model workflow



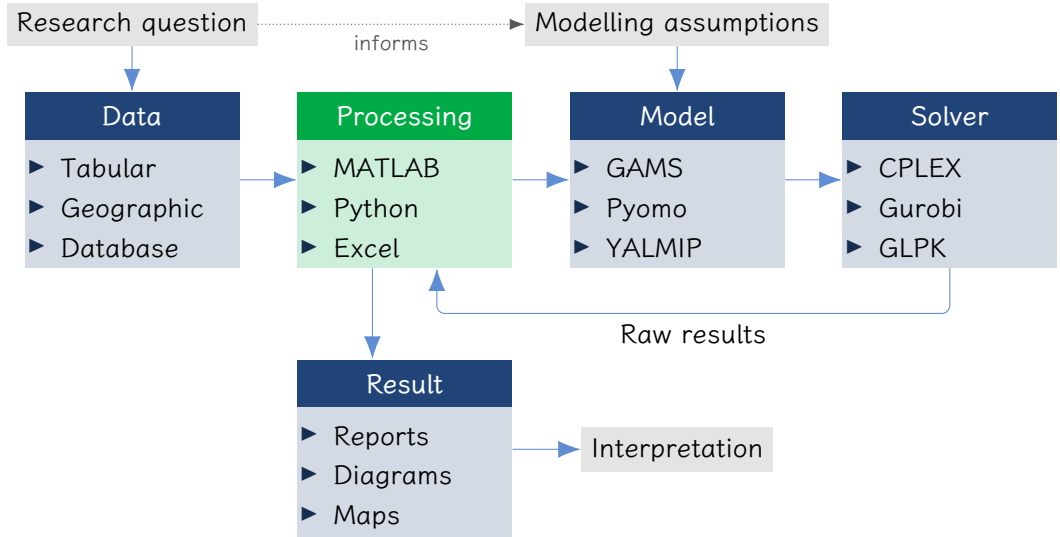
Optimisation model workflow



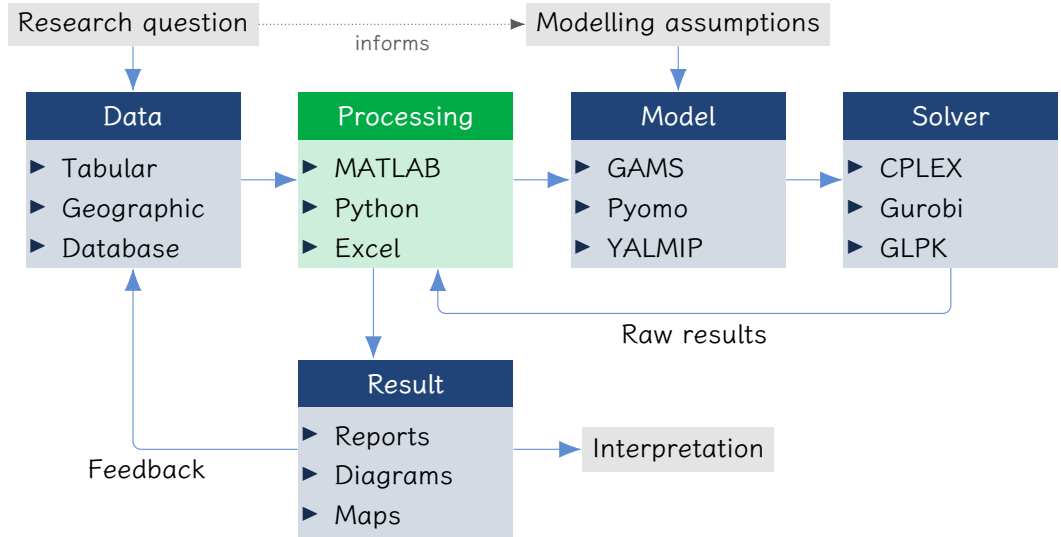
Optimisation model workflow



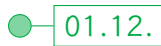
Optimisation model workflow



Optimisation model workflow



Distributed version control for scientific work



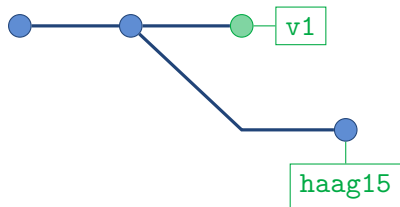
Distributed version control for scientific work



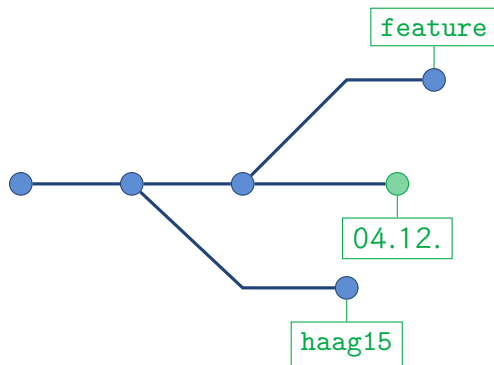
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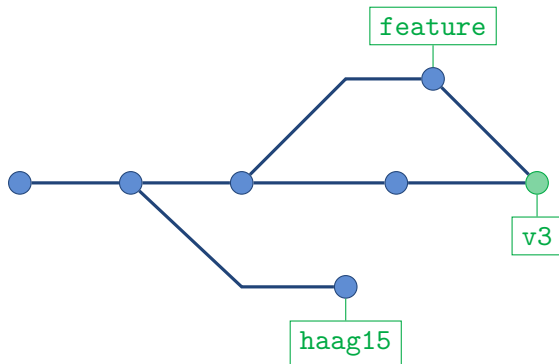
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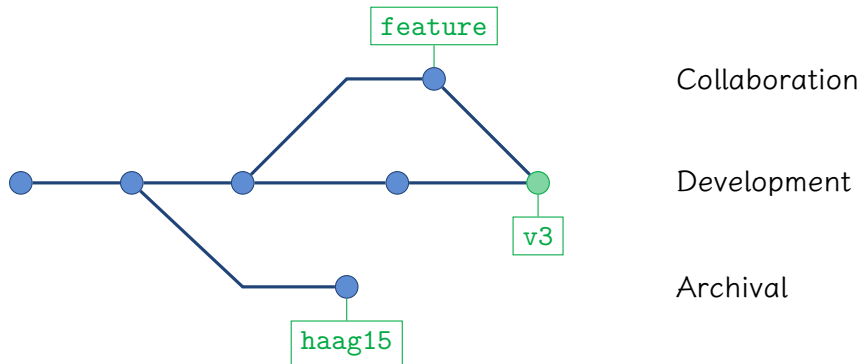
Distributed version control for scientific work

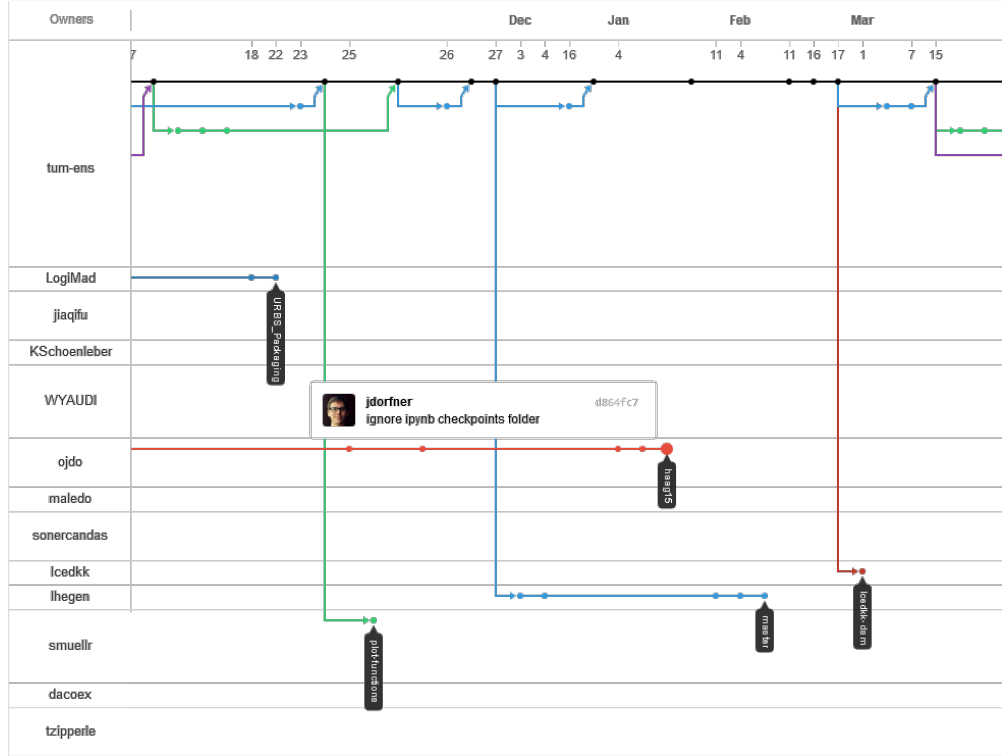


Distributed version control for scientific work



Distributed version control for scientific work





Conclusion

Infrastructure

Engineering

Technical
feasibility
(Technologies)

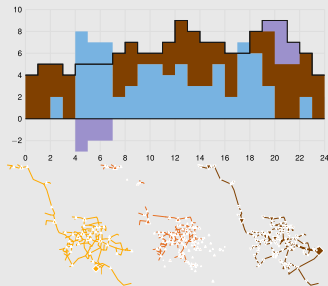
Economy

Economic feasibility
(Funding)

Techno-economic modelling

How much energy? For how much?

Modelling



Open Source

