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

Motivation

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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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?

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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?

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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?

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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?
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/

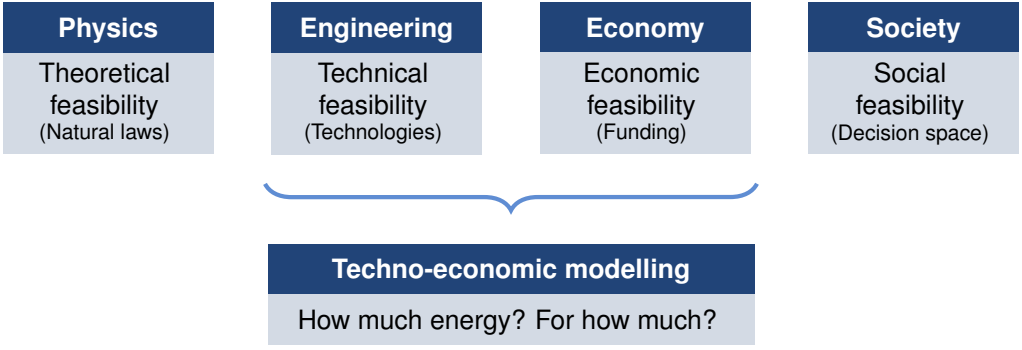
Perspective

Disciplines for investigating energy topics

Physics	Engineering	Economy	Society
Theoretical feasibility (Natural laws)	Technical feasibility (Technologies)	Economic feasibility (Funding)	Social feasibility (Decision space)

Perspective

Disciplines for investigating energy topics

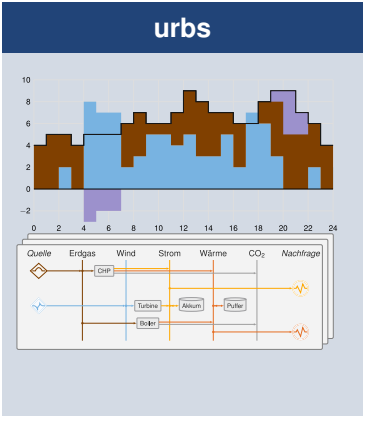


Section 2

Mathematical modelling, optimisation, case study

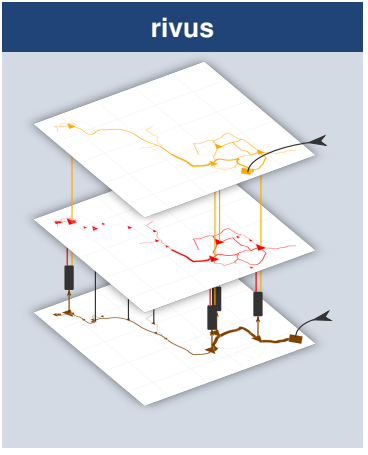
Model overview

urbs



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

rivus



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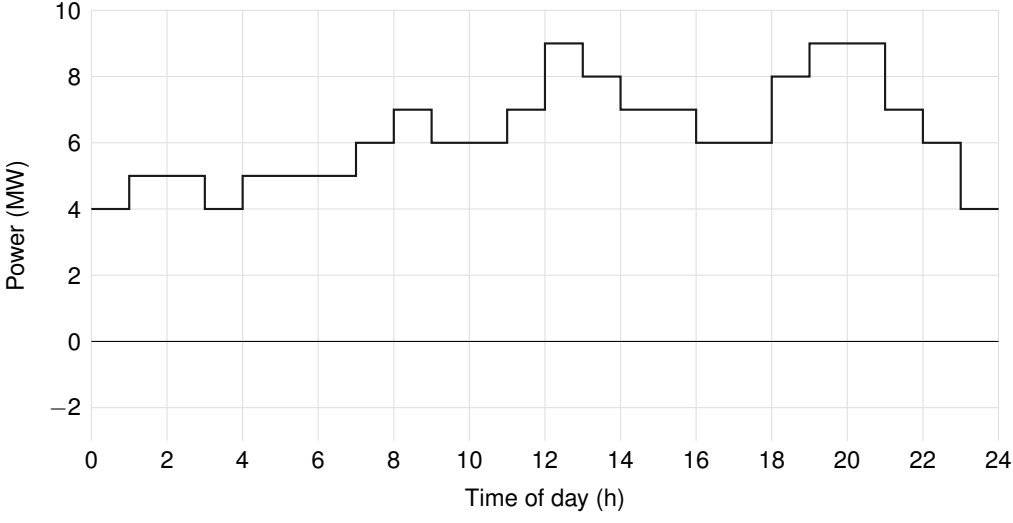
urbs

Principle illustrated



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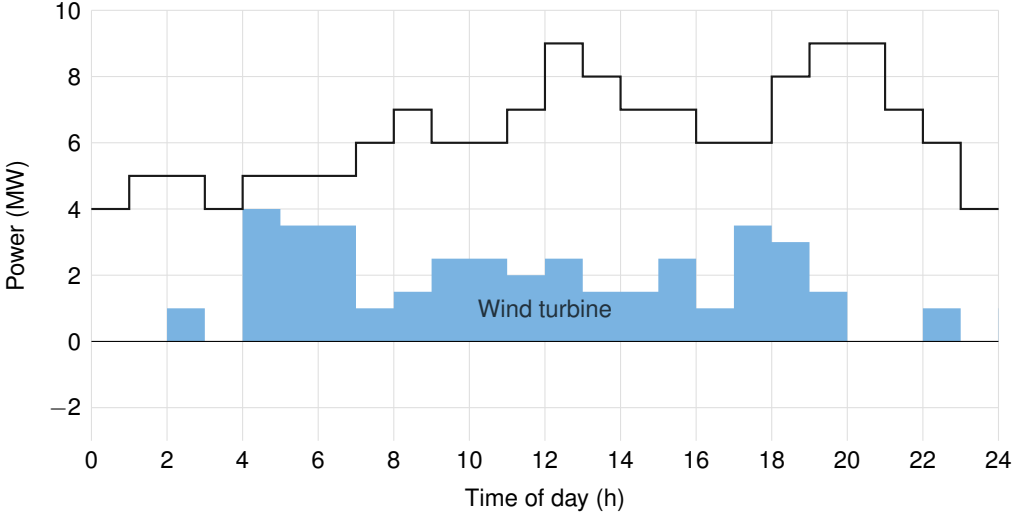

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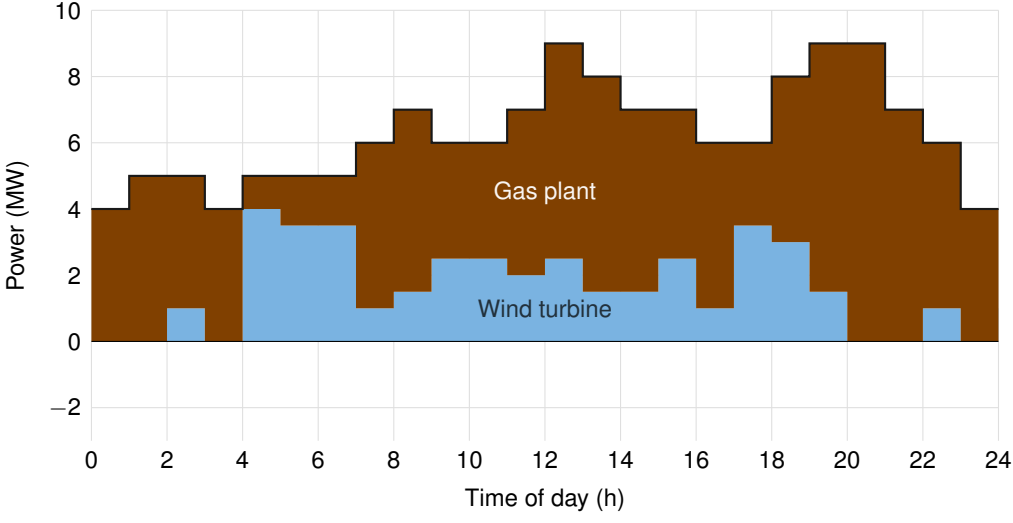

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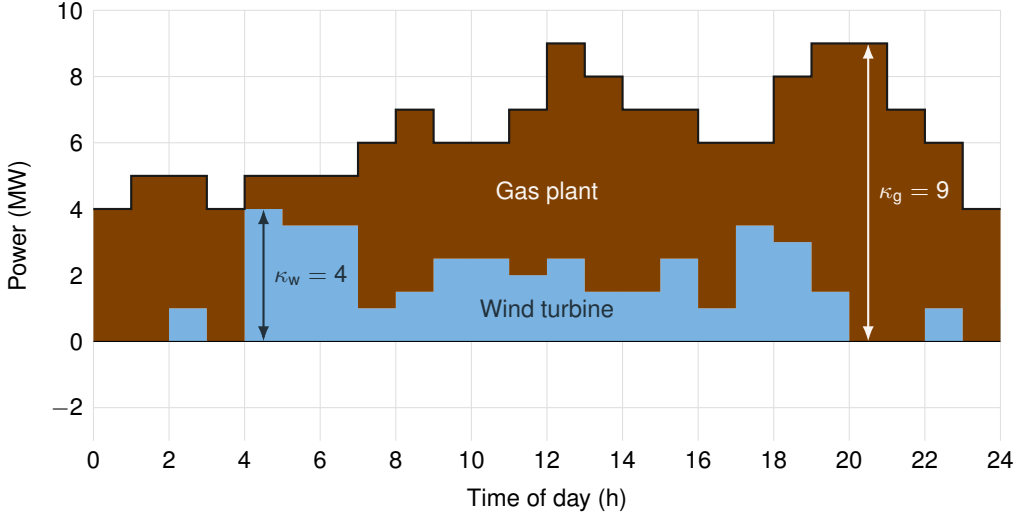

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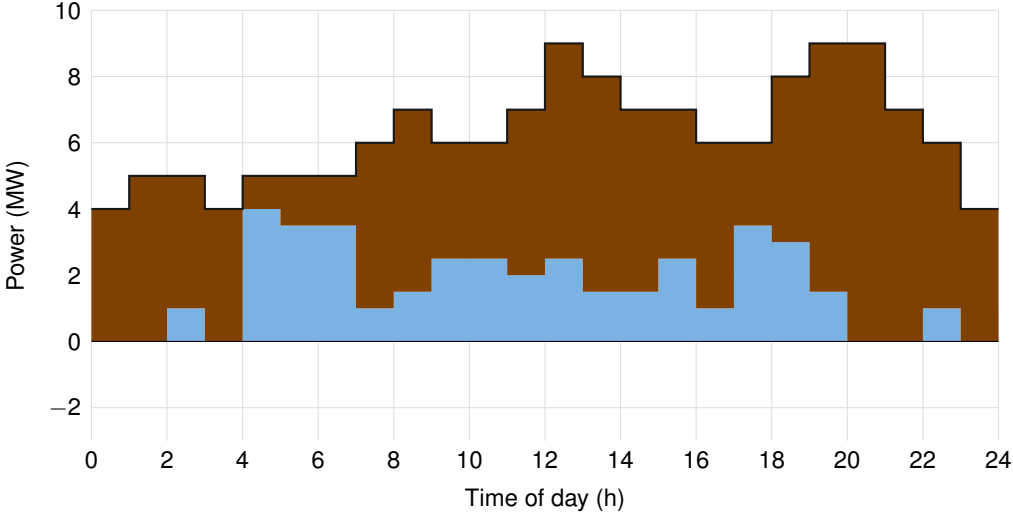

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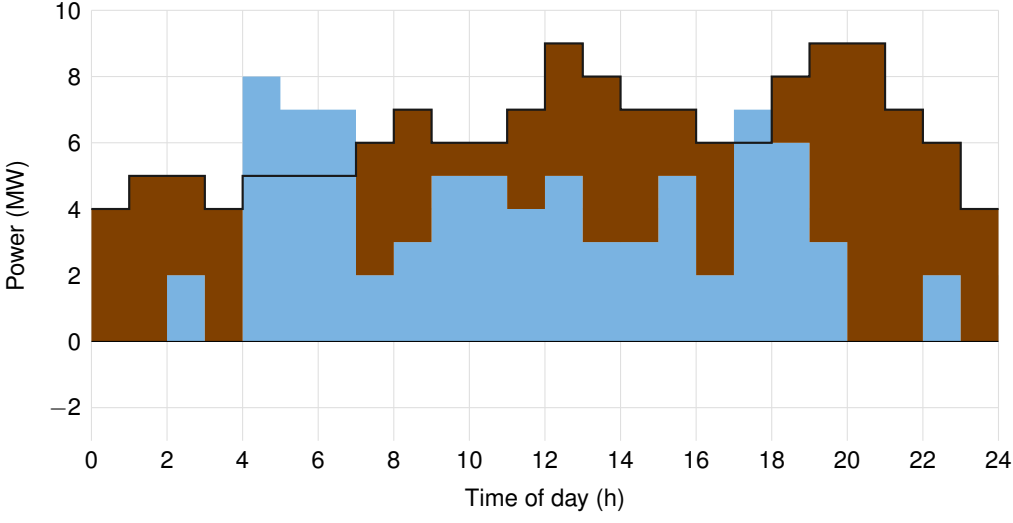

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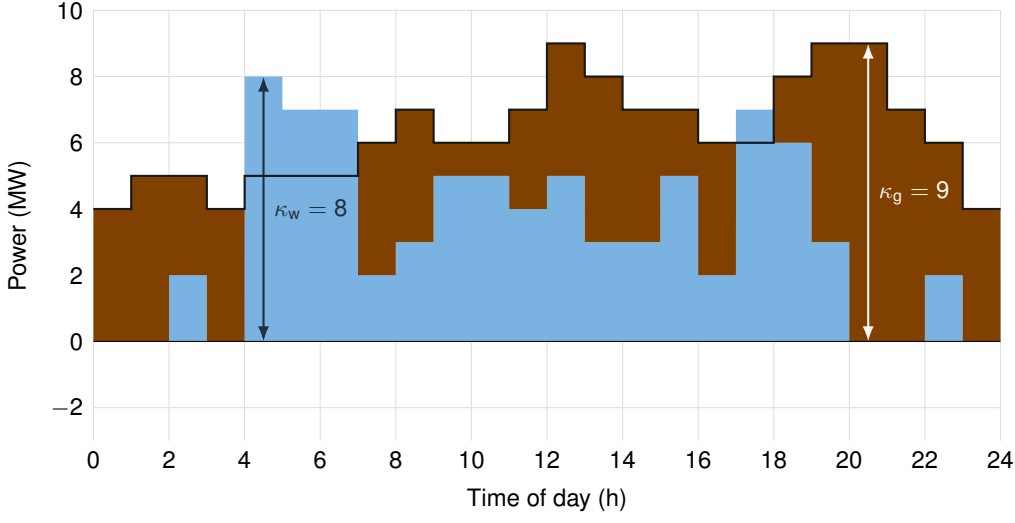

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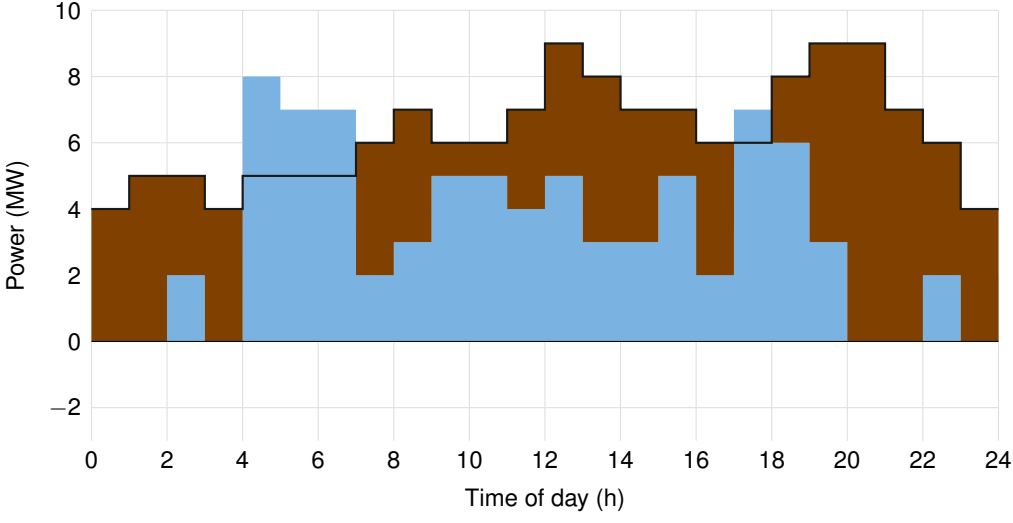

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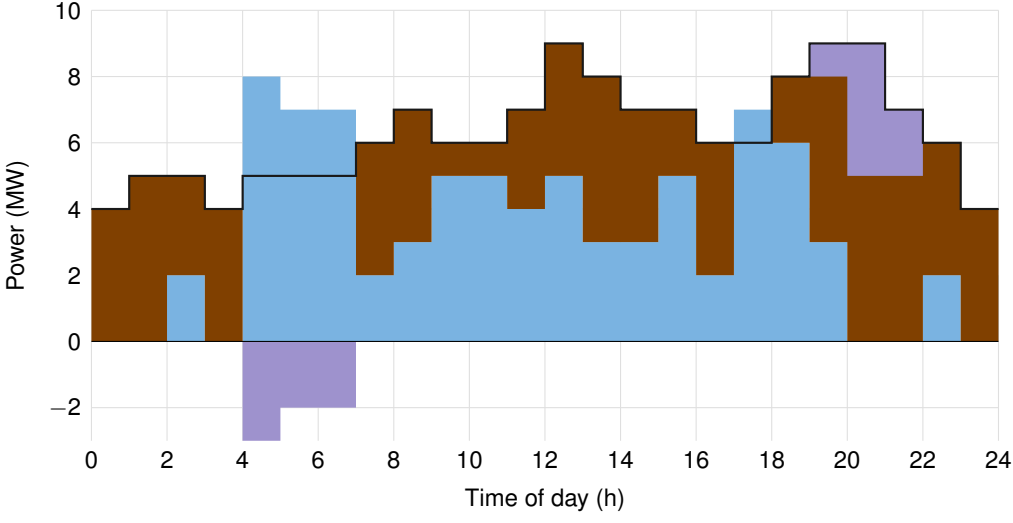

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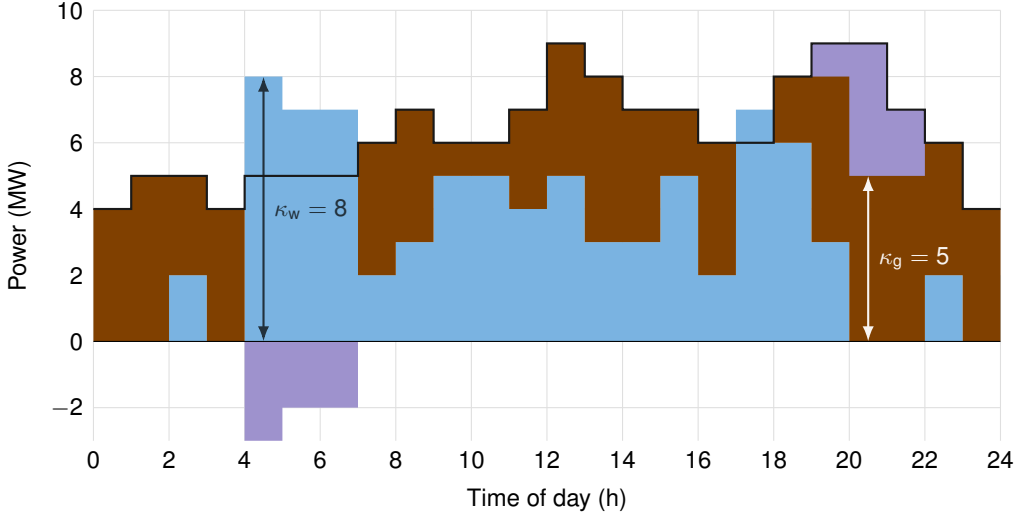

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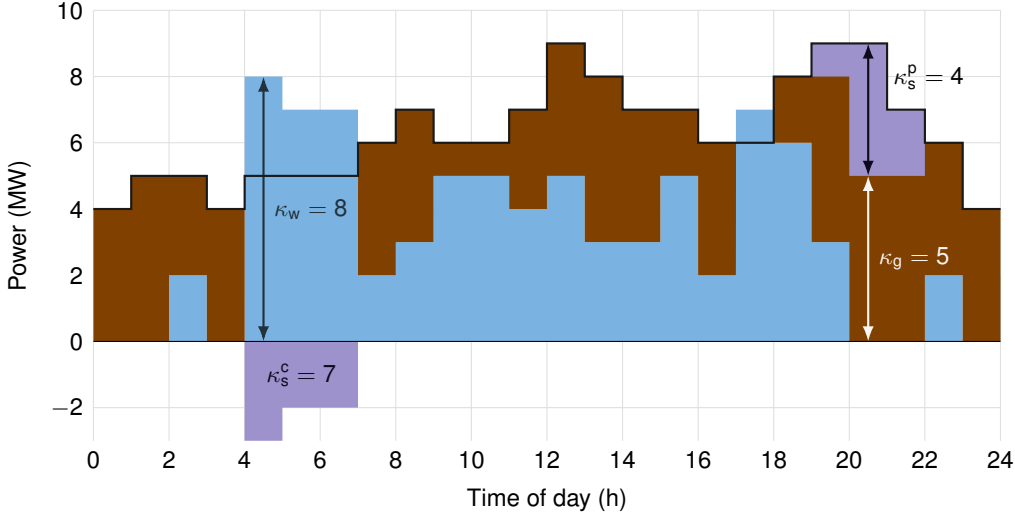

Notation as mathematical optimisation problem

Sets	$t \in T,\ p \in P,\ s \in S,\ \ldots$
Parameters	d_t

Notation as mathematical optimisation problem

Sets	$t \in T,\ p \in P,\ s \in S,\ \ldots$
Parameters	$d_t,\ k_p^{\text{fix}},\ k_s^{\text{fix,c}},\ k_s^{\text{fix,p}}$

Notation as mathematical optimisation problem

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

Notation as mathematical optimisation problem

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

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Notation as mathematical optimisation problem

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

Notation as mathematical optimisation problem

$$
\begin{aligned}
\text{Sets} \quad & t \in T,\ p \in P,\ s \in S,\ \dots \\
\text{Parameters} \quad & d_t,\ k_p^{\text{fix}},\ k_s^{\text{fix,c}},\ k_s^{\text{fix,p}},\ k_p^{\text{var}},\ k_s^{\text{var}},\ \dots \\
\text{Variables} \quad & \kappa_p,\ \kappa_s^{\text{c}},\ \kappa_s^{\text{p}},\ \epsilon_{pt},\ \epsilon_{st}^{\text{in}},\ \epsilon_{st}^{\text{out}},\ \epsilon_{st}^{\text{con}},\ \dots \\
\text{Objective} \quad & \min \sum_{p \in P} \left(k_p^{\text{fix}} \kappa_p + \sum_{t \in T} k^{\text{var}} \epsilon_{pt} \right) + \\
& \sum_{s \in S} \left(k_s^{\text{fix,c}} \kappa_s^{\text{c}} + k_s^{\text{fix,p}} \kappa_s^{\text{p}} + \sum_{t \in T} k_s^{\text{var}} \left(\epsilon_{st}^{\text{in}} + \epsilon_{st}^{\text{out}} \right) \right) \\
\text{Constraints} \quad & \text{s.t. } \forall t \in T\colon \ \sum_{p \in P} \epsilon_{pt} + \sum_{s \in S} \left(\epsilon_{st}^{\text{out}} - \epsilon_{st}^{\text{in}} \right) = d_t \\
& \dots
\end{aligned}
$$

Standard form of linear optimisation problems (LP)

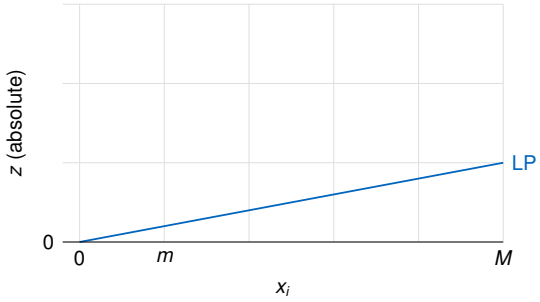
Generic form

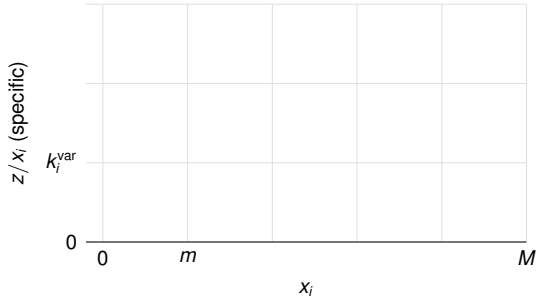
$$\min_{\boldsymbol{x}} z = \boldsymbol{c}^{\mathsf{T}}\boldsymbol{x}$$

$$\text{s.t. } \boldsymbol{A}\boldsymbol{x} \leq \boldsymbol{b}$$

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

Mixed-integer linear programming (MILP)





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

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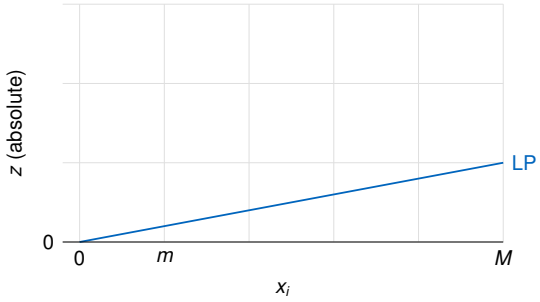

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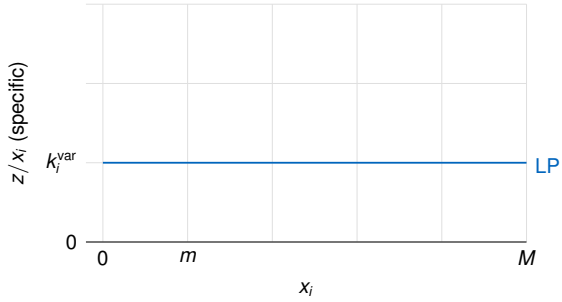

LP $\quad \dfrac{z}{x_i} = k_i^{\text{var}} \equiv \text{const}$

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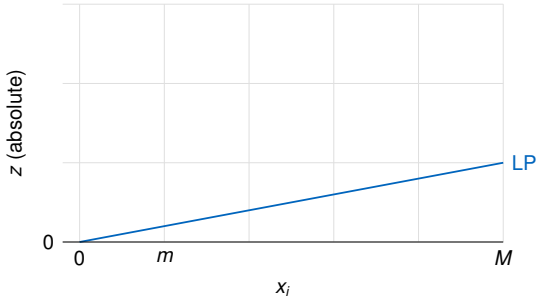

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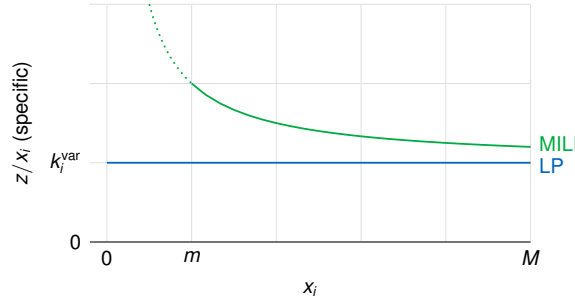
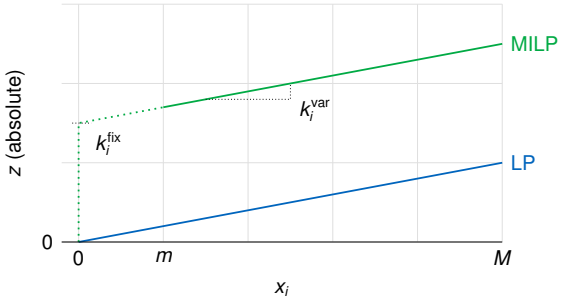
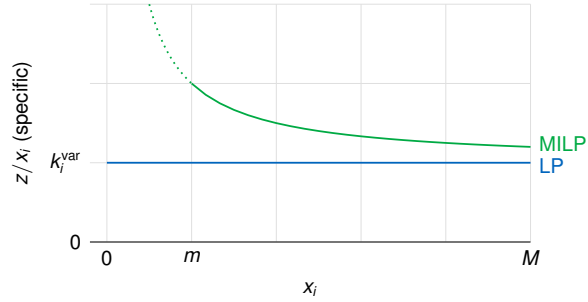


LP $\quad \dfrac{z}{x_i} = k_i^{\text{var}} \equiv \text{const}$

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

Mixed-integer linear programming (MILP)





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

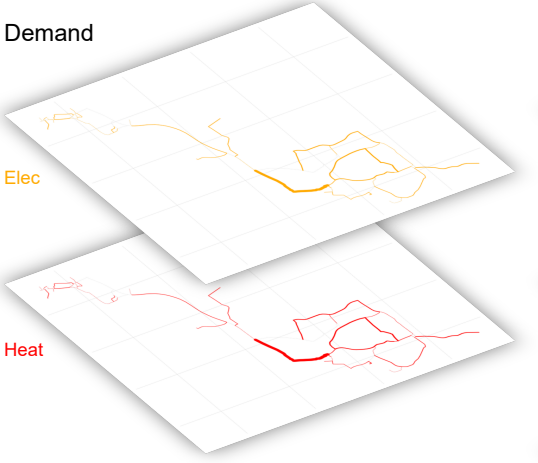
$$\text{MILP} \quad z = k_i^{\text{fix}} y_i + k_i^{\text{var}} x_i$$
$$y_i \in \{0, 1\}$$
$$m\, y_i \leq x_i \leq M\, y_i$$

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

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

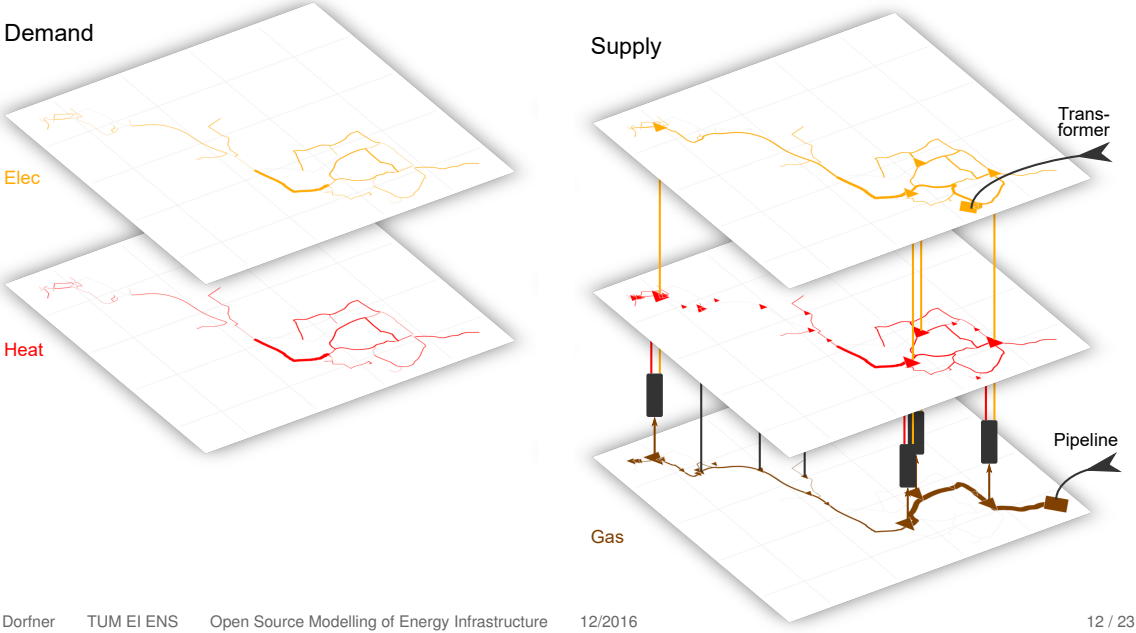
rivus

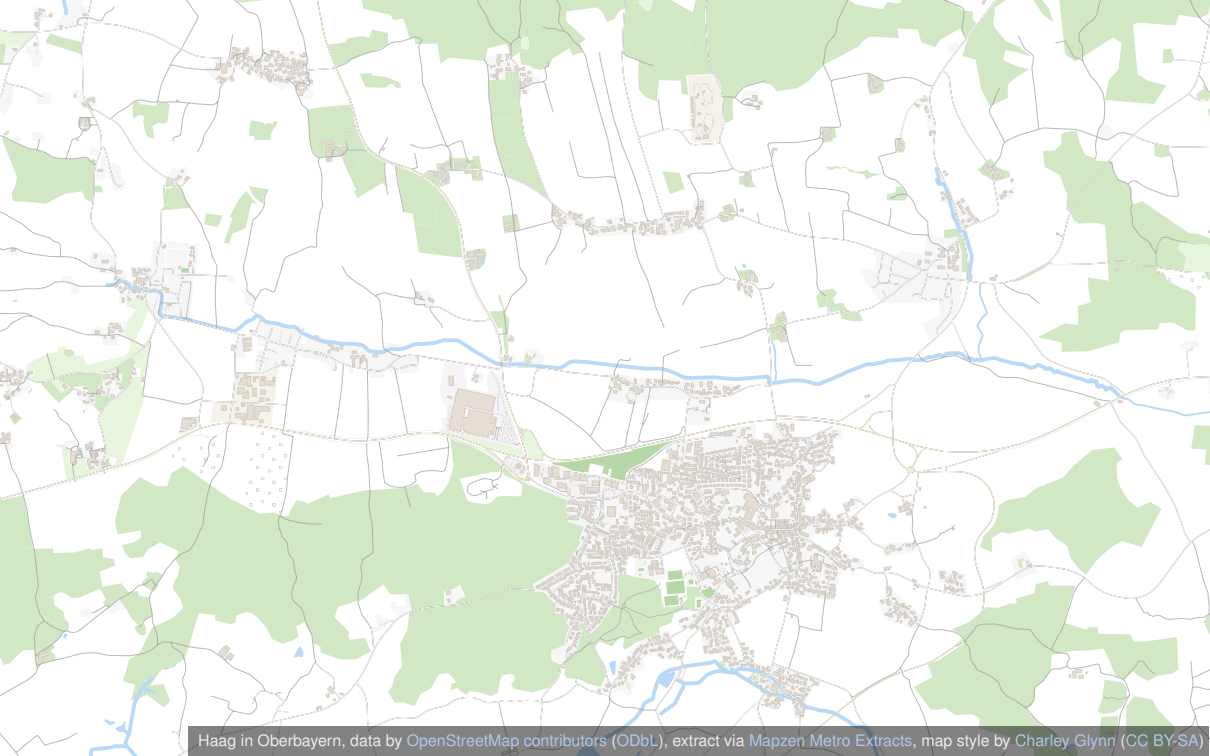
Principle illustrated

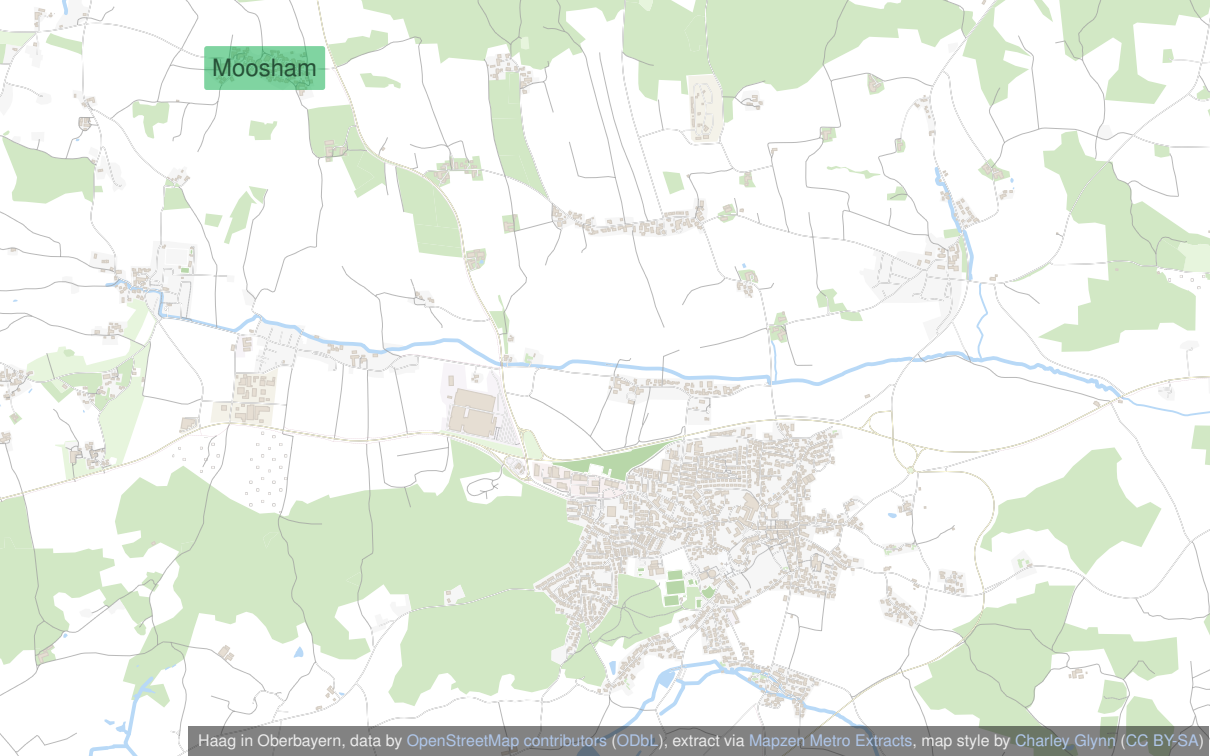


rivus

Principle illustrated




Haag in Oberbayern, data by OpenStreetMap contributors (ODbL), extract via Mapzen Metro Extracts, map style by Charley Glynn (CC BY-SA)



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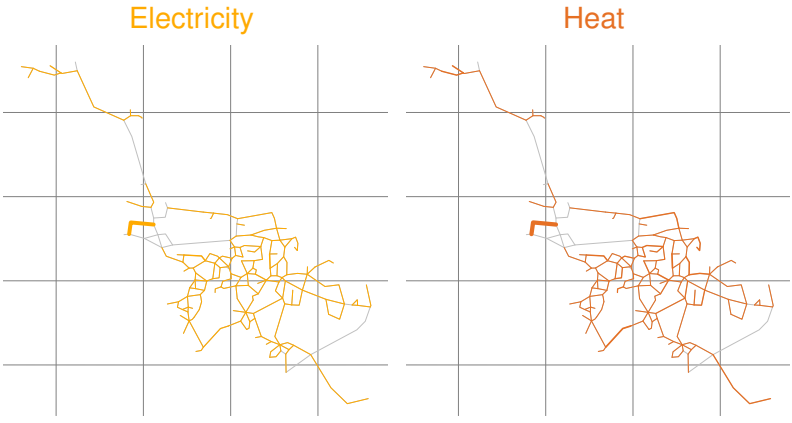
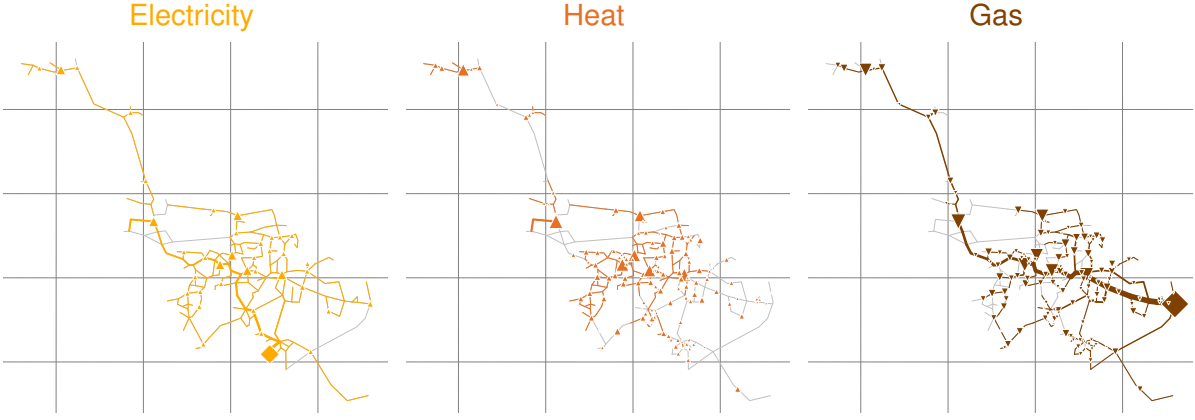
Input data **rivus**



Light industry (Schletter) biggest single consumer

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

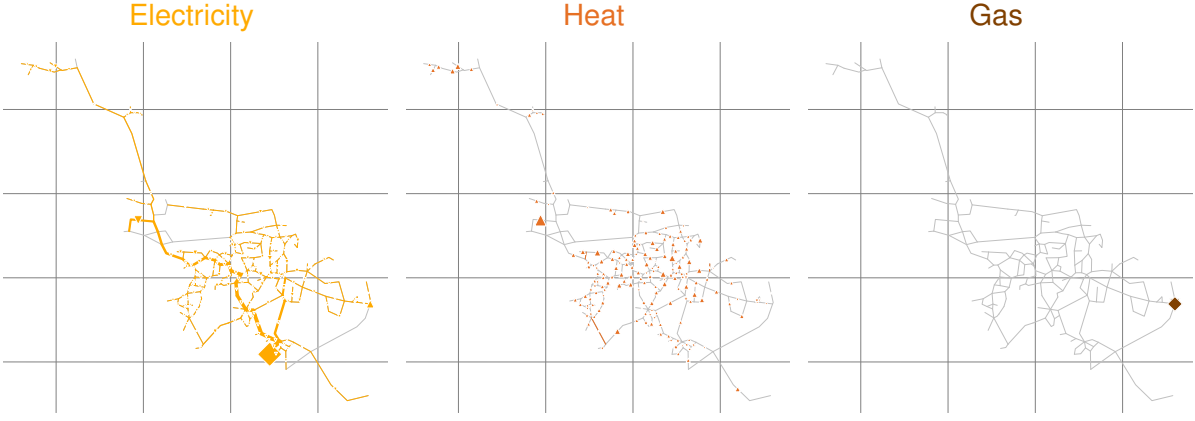
Result **rivus** – Capacities in scenario base



Full networks for electricity and gas, several local heating networks

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

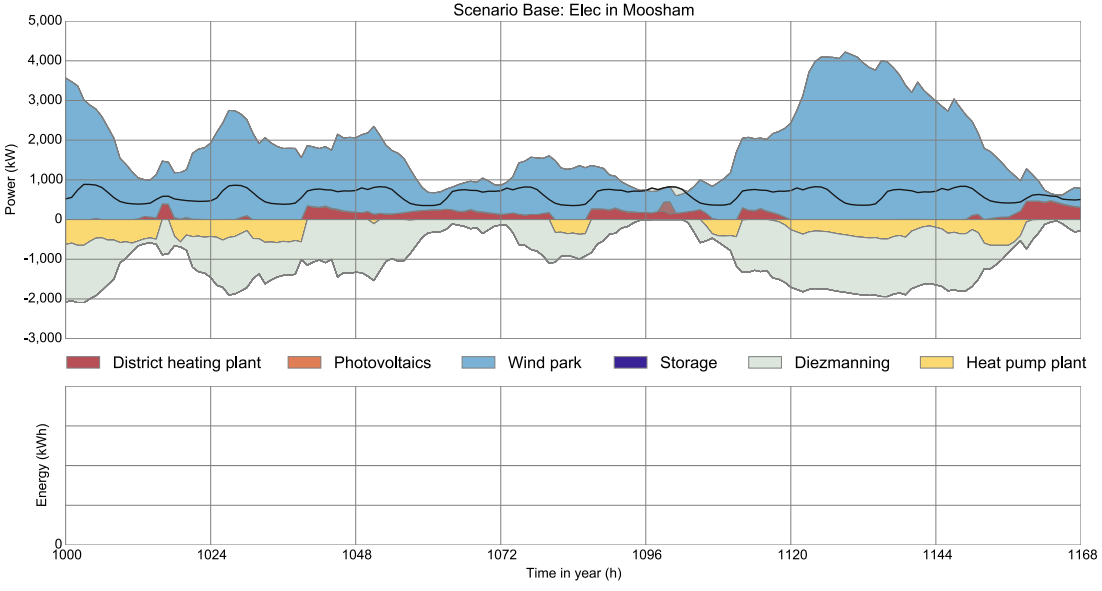
Result **rivus** – Capacities in scenario future



Strong electricity grid, no gas network, only heat pumps

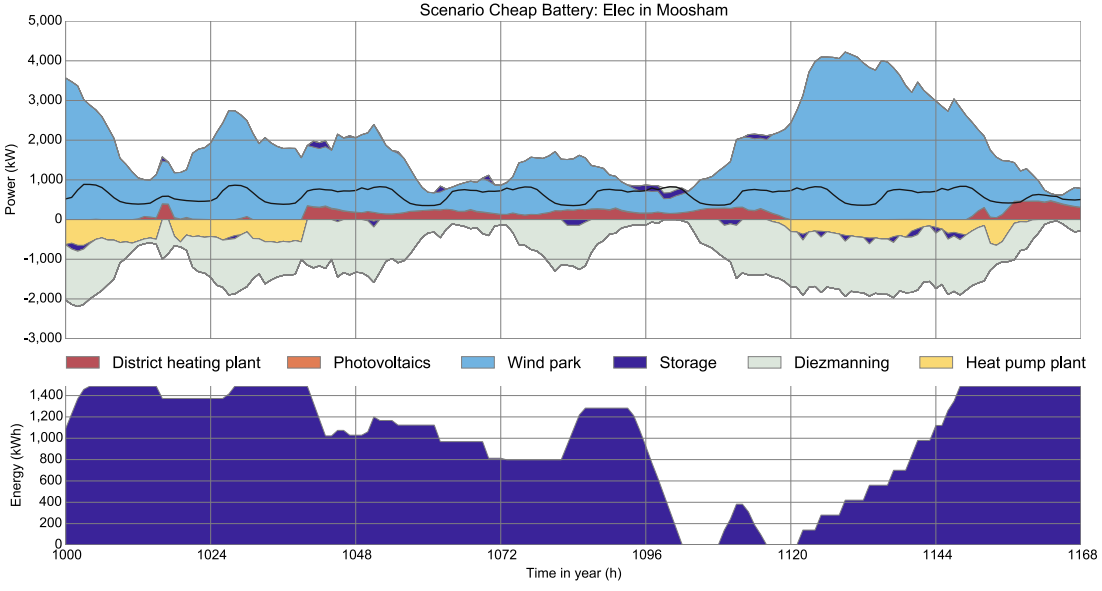
`https://github.com/tum-ens/rivus/runhg15.py:scenario_renovation()`

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



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

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



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

Section 3

Sustainable model use

Optimisation model workflow

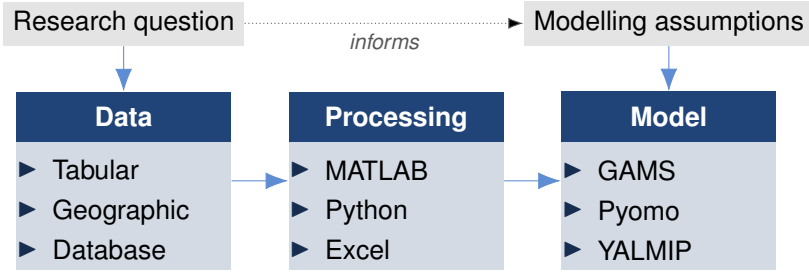
Research question

Optimisation model workflow

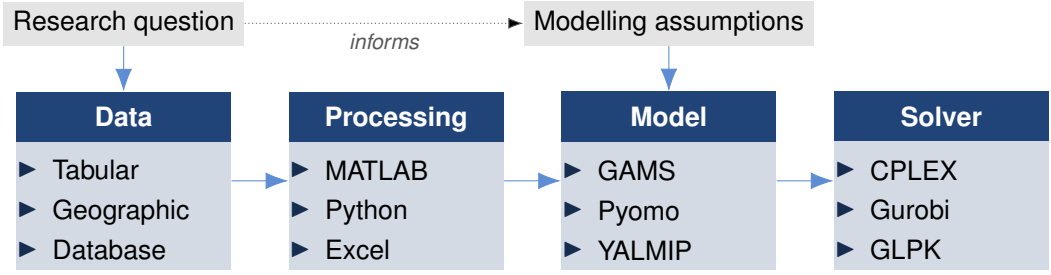
Optimisation model workflow

Optimisation model workflow

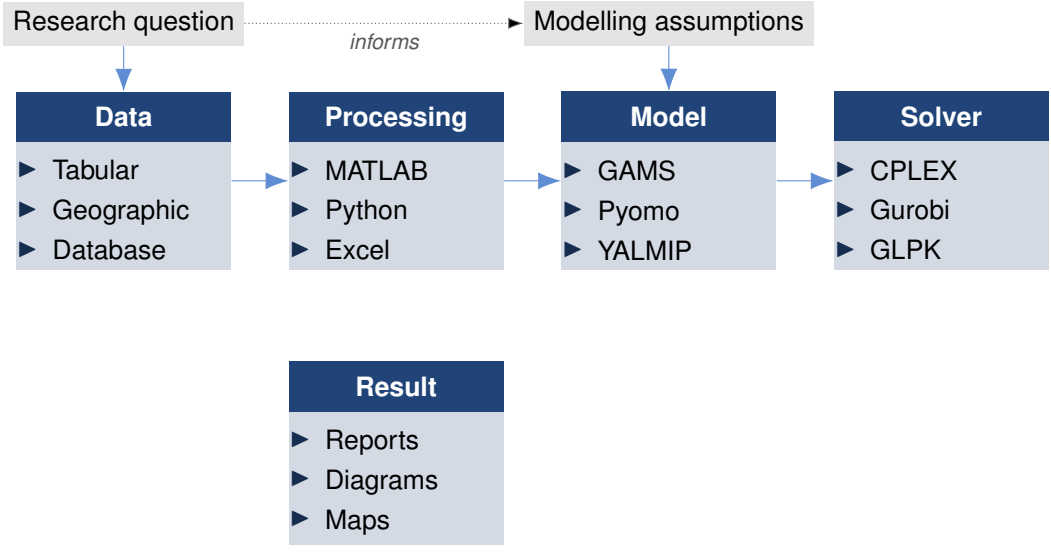
Optimisation model workflow



Optimisation model workflow



Optimisation model workflow



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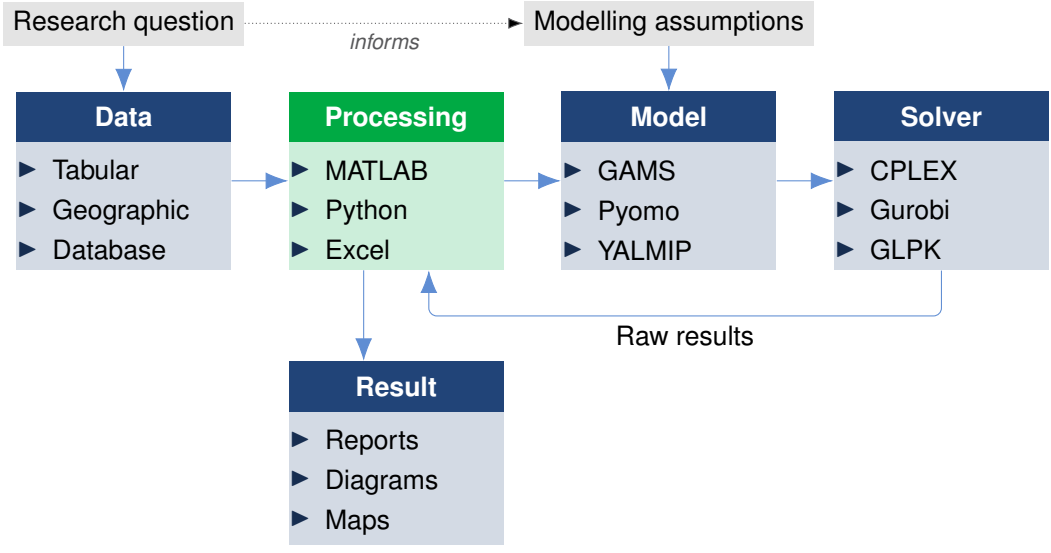
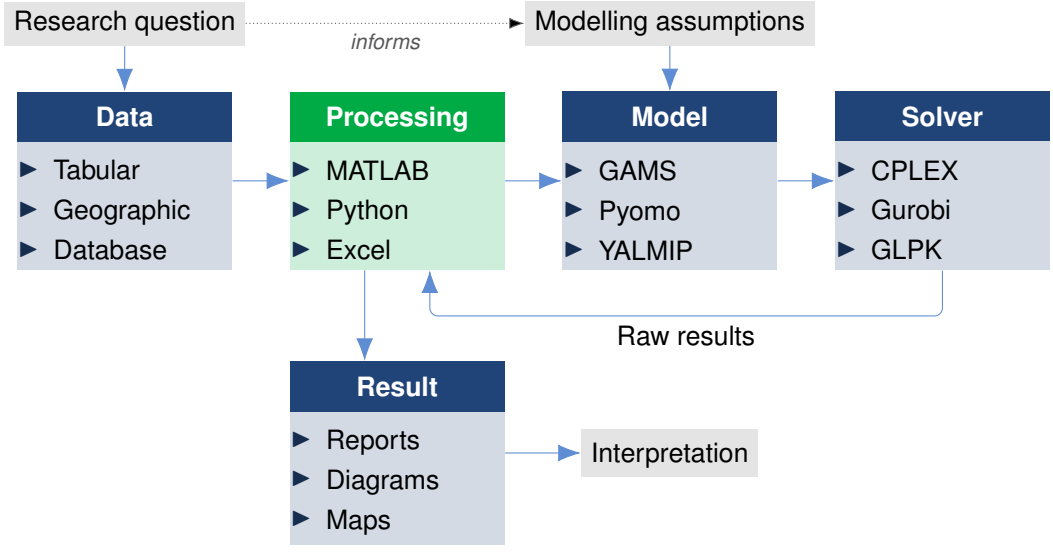
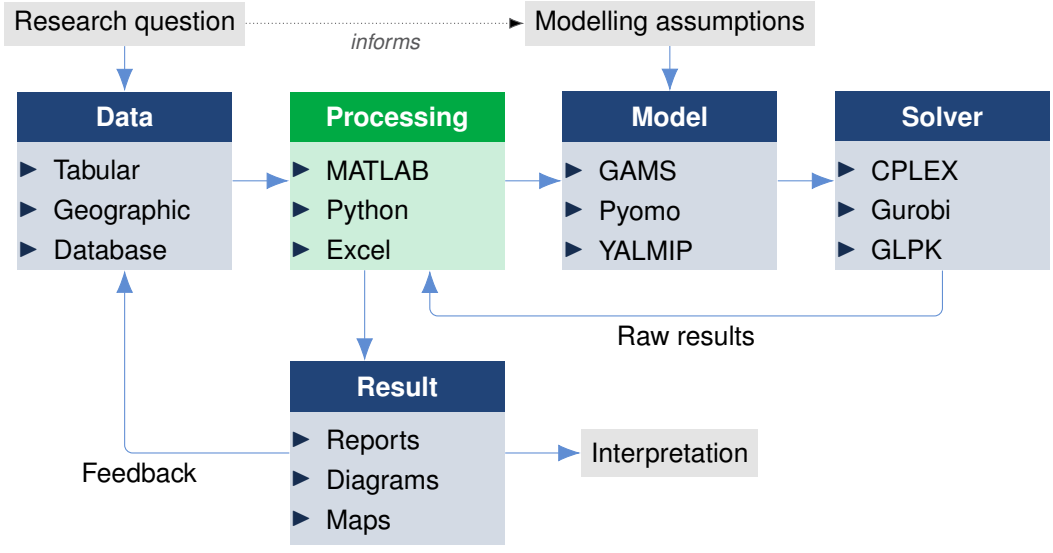


Optimisation model workflow



Optimisation model workflow

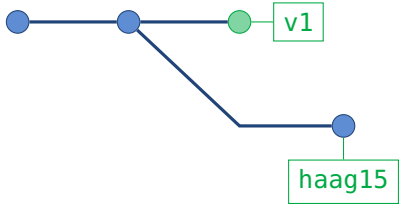


Distributed version control for scientific work

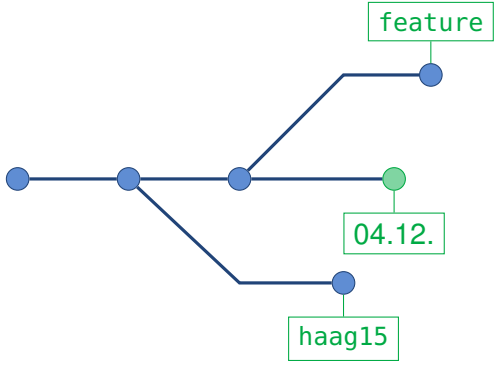
Distributed version control for scientific work

Distributed version control for scientific work

Distributed version control for scientific work



Distributed version control for scientific work



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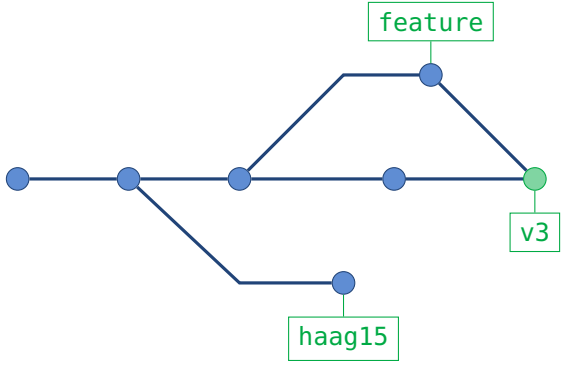
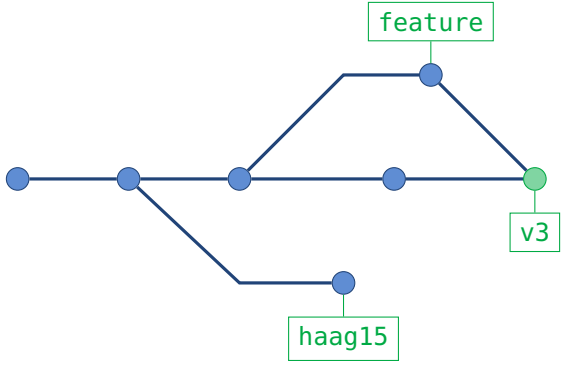


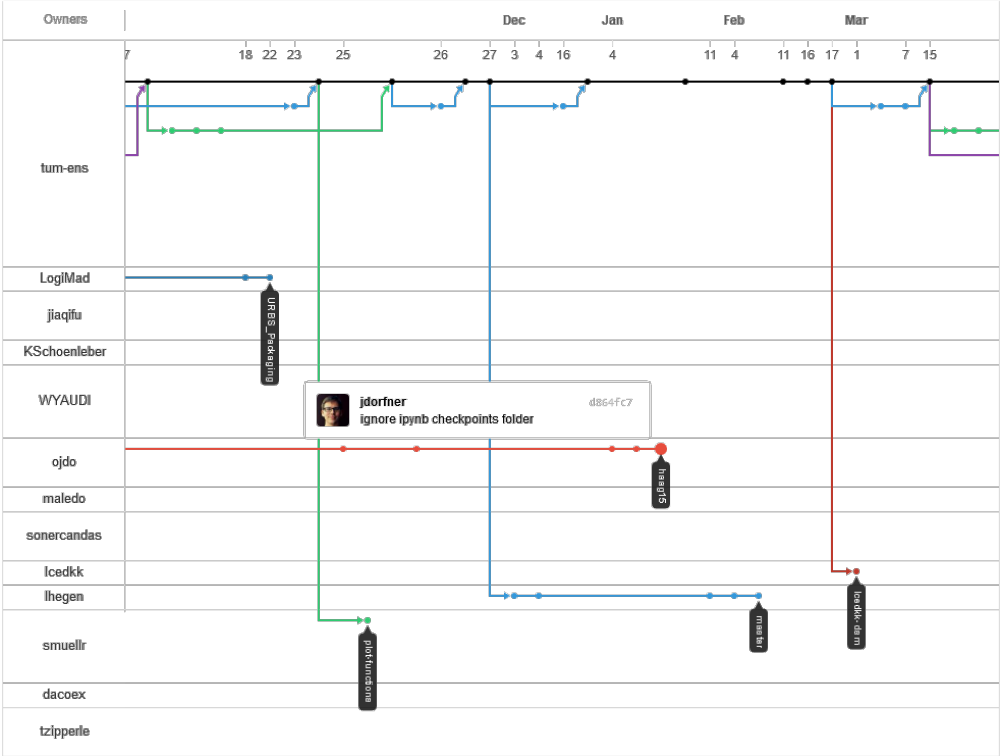
Distributed version control for scientific work



Collaboration

Development

Archival


Owners
Dec
Jan
Feb
Mar
7
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tum-ens
LogiMad
URBS_Packaging
jiaqifu
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ignore ipynb checkpoints folder
ojdo
haesleS
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sonercandas
Icedkk
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Icedkk-dam
master
smuellr
plotfunctions
dacoex
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Conclusion

Infrastructure

Engineering

Technical feasibility (Technologies)

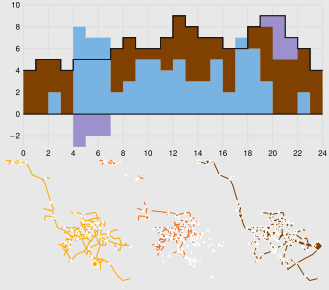
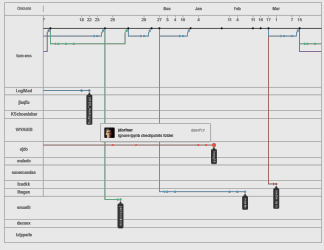
Economy

Economic feasibility (Funding)

Techno-economic modelling

How much energy? For how much?

Modelling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