Optimal Planning of Urban Infrastructure Networks for Multiple Energy Carriers

Operations research in engineering

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Section 1

Introduction

Modelling

Translating the abstract *rules* concerning the **decision space** of a certain topic into mathematical equations. Here, these equations then form an optimisation problem.

Energy infrastructure

Every technical component between

- transformer substation and the power outlet and
- gas pipeline and a warm house,

in other words: energy conversion (local and plants), distribution networks for providing electricity and heat.

Introduction

Conceptual problem formulation

Main question

In an ideal sandbox world (greenfield planning),

- which energy carriers
- energy distribution networks and
- energy conversion process

should be employed where to satisfy our energy demands?

Introduction
Motivation

Tabelle 8:
Anwendungsbilanz 2012 für den Haushaltssektor
in PJ

	Raum-wärme	Warm-wasser	Prozess-wärme	Prozess kälte	Mech. Energie	Beleuch-tung	IuK	Insge-samt
Strom	31,4	68,7	140,6	104,9	12,3	46,4	89,0	493,3
Erdgas	708,0	172,1	3,4	--	--	--	--	883,5
Heizöl	421,8	80,6	--	--	--	--	--	502,4
Fern-wärme	154,4	18,4	--	--	--	--	--	172,8
Holz	247,2	18,7	--	--	--	--	--	265,9
Kohle	51,0	1,3	--	--	--	--	--	52,3
Solar	0,9	4,5	--	--	--	--	--	5,4
Wärme-pumpe	35,6	2,0	--	--	--	--	--	37,6
Insgesamt	1 650,3	366,3	144,0	104,9	12,3	46,4	89,0	--

Anwendungsbilanzen 2011 und 2012 für den Sektor Private Haushalte by RWI Essen, 2013 http://ag-energiebilanzen.de/

Section 2

Methods

Methods

rivus: Optimal infrastructure network planning

Input

- Energy demand
- Street network graph
- Technology portfolio
- Cost and technical parameters
- Commodity source points

→ **rivus** →

Output

- Infrastructure network
- Conversion capacities
- Total costs
- Commodity usage
- CO_2 emissions

Methods

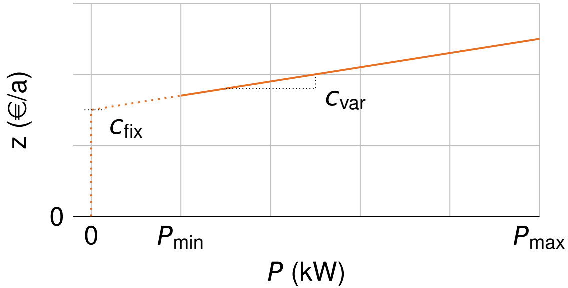
Mathematical modelling: Fixed cost formulation

One binary decision variable $x \in \{0, 1\}$ allows to approximate economics of scale: Higher capacities P (kW) lead to lower specific costs z (€/a):

$$z = c_{fix}x + c_{var}P \qquad (1)$$

$$P \leq x\,P_{max} \qquad (2)$$

$$P \geq x\,P_{min} \qquad (3)$$



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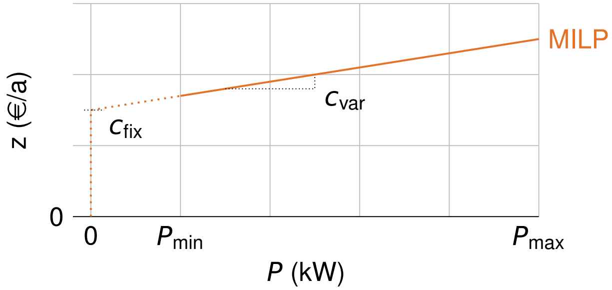

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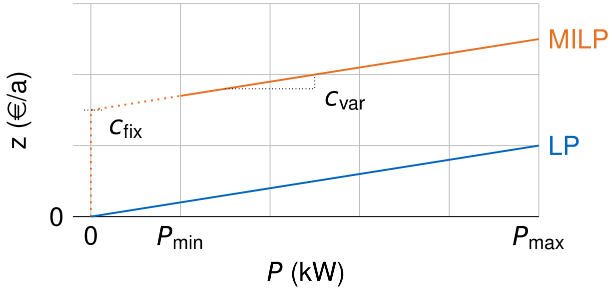

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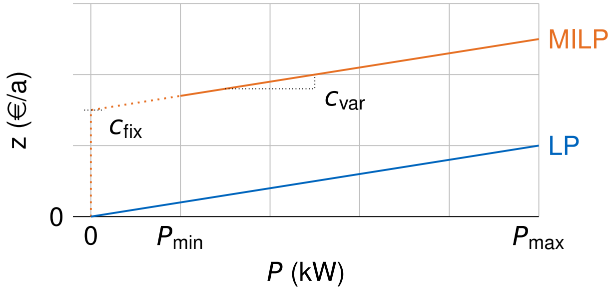
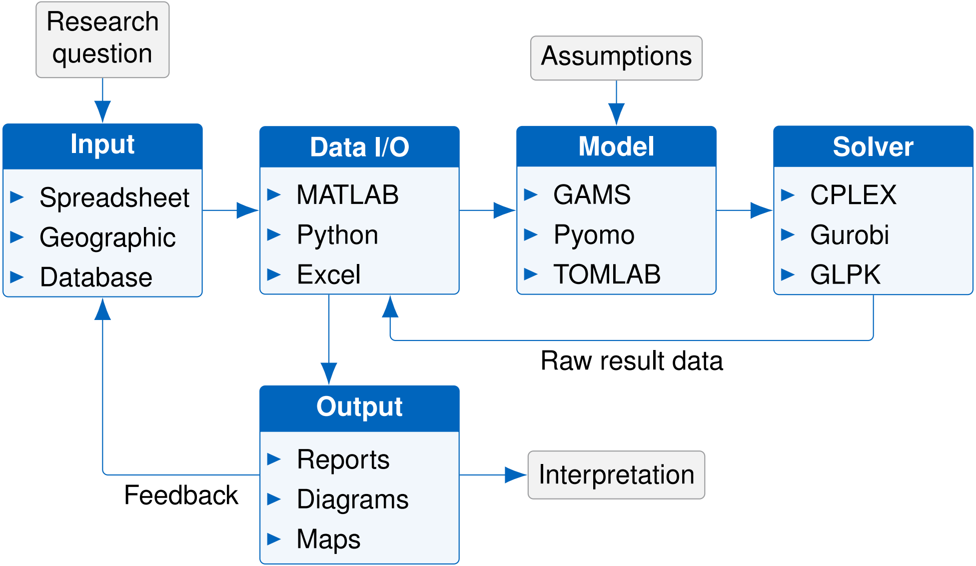


Drawback: binary variables *can* make problem much harder to solve.

Methods

Schema of modelling and optimisation toolchains

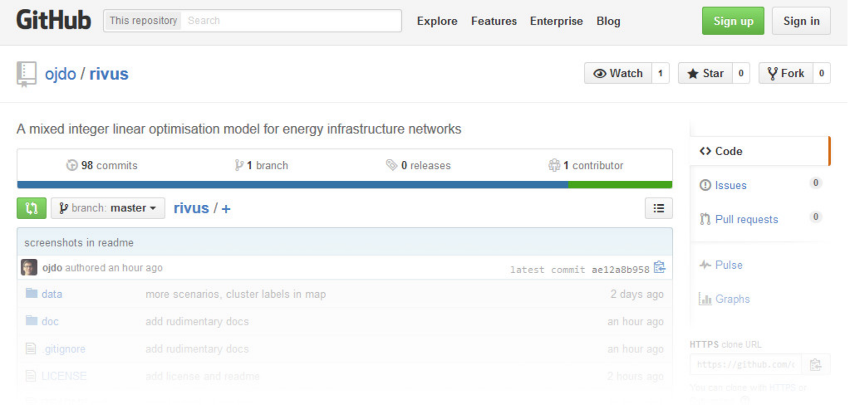


Methods

Reproducibility

All models are public. Results can be reproduced, verified and criticised.

- `https://github.com/tum-ens/urbs` (capacity planning, unit committment)
- `https://github.com/ojdo/rivus` (infrastructure networks)



Methods

Automation by software stack

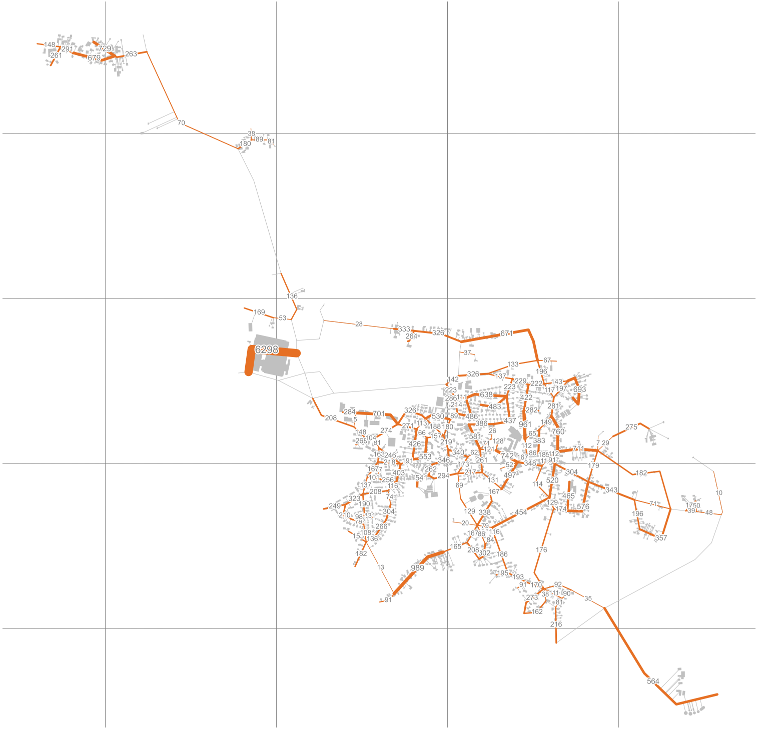
Heavily relying on existing packages for diverse tasks:

- **Python** as scripting language, for automation and code structure
- **Pandas** for data pre- and post-processing
- **Pyomo** for mathematical modelling, solver interfaces
- **SciPy** stack for general purpose algorithms and visualisation
- **IPython** (and Notebook) for exploratory programming
- **Geographic** packages for crafting custom geoprocessing algorithms

Section 3

Case study

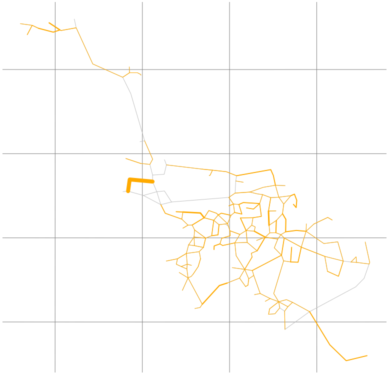

Isener Str.
Dorfstraße
Rainbach
Kirchdorf
12
E552
15
Haag in Oberbayern
Reiter Str.
Bilder © 2015 DigitalGlobe,GeoBasis-DE/BKG,Kartendaten © 2015 GeoBasis-DE/BKG (©2009), Google



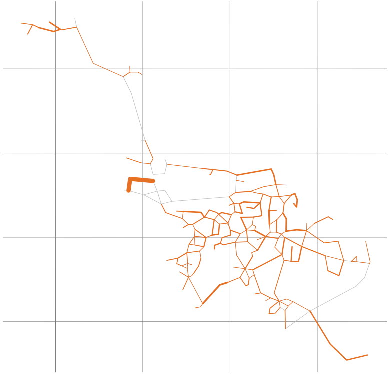
Spatial demand distribution

Aggregated peak demand (kW) per street segment

Electricity



Heat



Aggregation
from 1738 buildings
to 203 edges
for smaller problem

Total peak demand

Electricity 26.7 MW

Heat 47.6 MW

Input data overview

Data

Geographic	1738 buildings, 203 edges, 153 vertices, 2 source vertices
Buildings	mainly residential, some commercial, few big industrial
Peak demand	26.7 MW electric, 47.6 MW heat
Full-load hours	3620 h electric, 2700 h heat
Time resolution	5 time steps (2 for peak loads, 3 represent steady state)

Scenarios

Both: green-field planning, i.e. no existing infrastructure assumed

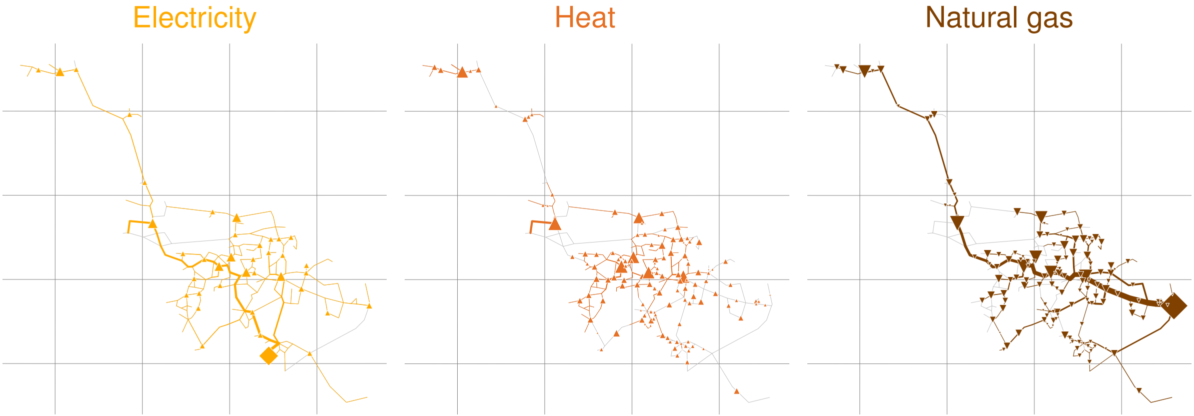
Scenario	Description
Today	cogeneration of heat & power from natural gas
Future	heat pumps (effective efficiency > 100 %)

Section 4

Results

Capacities in scenario Base

Network capacities and conversion unit capacities (both kW)

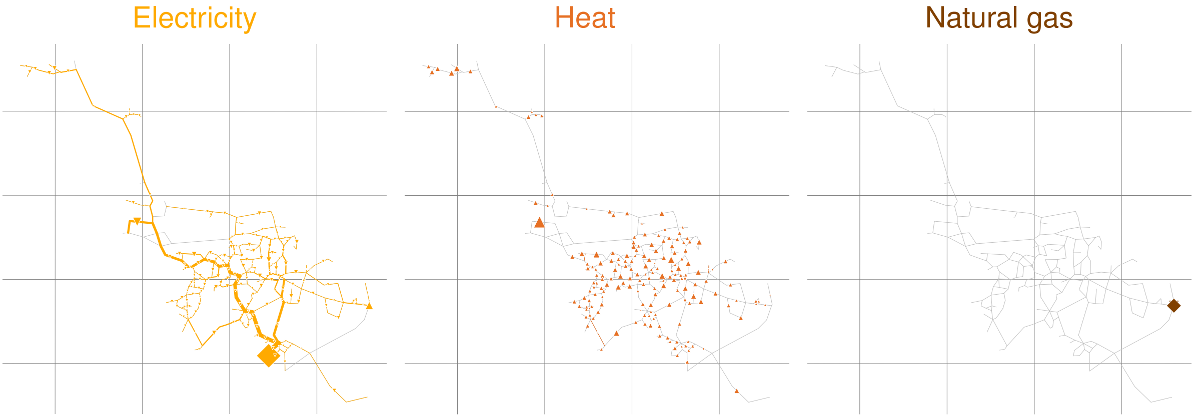


Full electric grid, full gas grid; heat generated locally from gas

`https://github.com/ojdo/rivus/runhg15.py:scenario_no_electric_heating()`

Capacities in scenario Future

Network capacities and conversion unit capacities (both kW)



Fuller electric grid, no gas grid; heat generated locally in heat pumps

`https://github.com/ojdo/rivus/runhg15.py:scenario_renovation()`

Section 5

Conclusion

Conclusion

What to remember?

Modelling is useful tool to explore sensitivities in unknown decision space (a.k.a. operations research)

Reproducibility browse or try it out for yourself
`https://github.com/tum-ens/urbs` (stable)
`https://github.com/ojdo/rivus` (fresh beta)

Infrastructure coupling of sectors electricity, heat (and others) will play key role in future energy system (yes, *now* it sounds obvious)

> *The conclusions of most good operations research studies are obvious.*
>
> – Robert E. Machol (1917–1998)