A model for the identification and optimal planning of emission reduction measures in urban energy systems

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Agenda

- Introduction
  - Motivation
  - Related work
- Method
  - Data acquisition: Demand structure; PV, Wind & Biomass potentials
  - Optimization of the urban energy system
- Results
  - Detailed scenario results
  - Scenario comparison
- Conclusion and outlook

Introduction

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Figure 1: Capital/large cities pledges in the UN NAZCA Database

City	Country	City's CO2e Reduction Target	Target Year	Baseline Year	Equivalent national target[4]
Amsterdam	NL	-40%	2025	1990	-17%
Berlin	DE	-40%	2020	1990	-40%
Brussels	BE	-30%	2025	1990	-16%
Copenhagen	DK	-100%	2025	-	-40%
London	UK	-60%	2025	1990	-35%
Madrid	ES	-35%	2020	2005	-10%
Paris	FR	-25%	2020	2004	-14%
Stockholm	SE	-44%	2015	1990	-40%
Vilnius	LT	-20%	2020	2010	+27%
Warsaw	PL	-20%	2020	2007	+9%

*Source : **NAZCA Database**, **European Effort Sharing Decision** and **LSE Global Climate Legislation Study***

source: [Cook 2015]

- Cities declare emission reduction targets & climate protection plans, e.g. Covenant of Mayors Initiative: **need for energy concepts**
- Local renewable energy & efficiency potentials exist, but their exact extent, optimal combinations and contribution towards reaching overarching goals are mostly unknown: **cities need decision support**
- Investment decisions are long term and capital intensive; interdependencies between technologies: **complexity of the problem**

⇒ **Mathematical models can provide decision support for urban planning**

Introduction
Related work

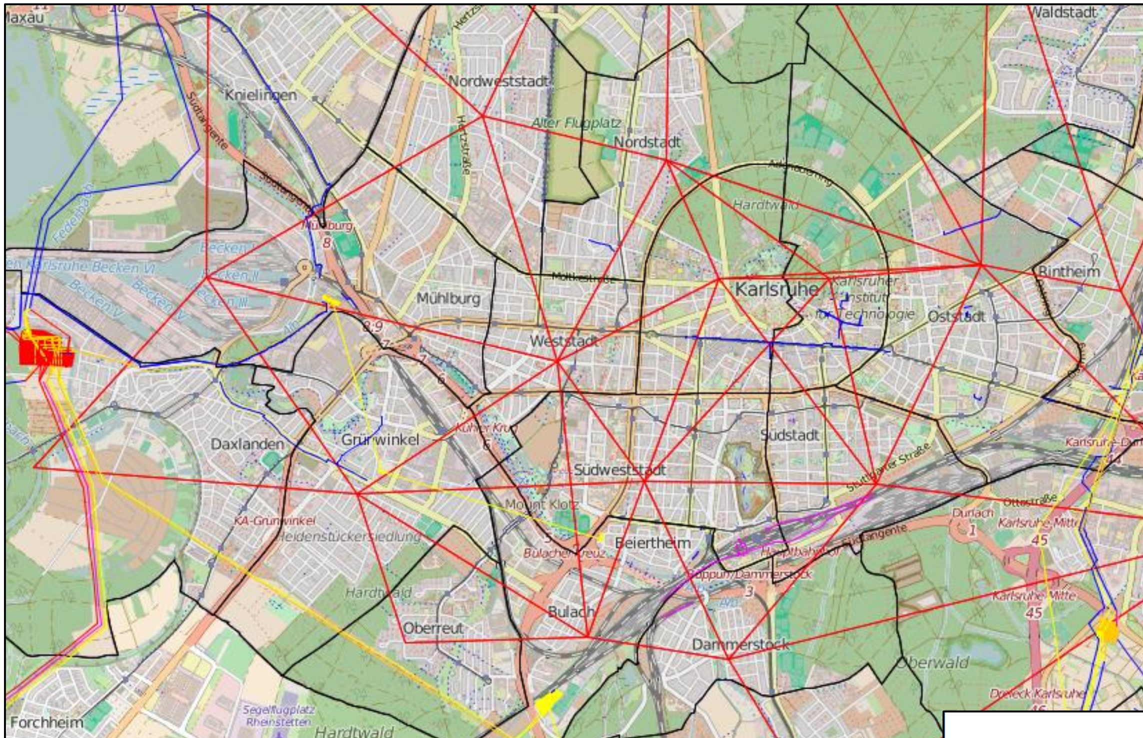
Requirements for model development:

- Analysis & Optimization of urban energy systems
  - Unit commitment and investment planning
    - Determination of potentials for renewable energies and energy efficiency
      - Technologies on supply and demand side
        - Transferability of the method

x	-	-	-	-	Several models, for a review see e.g. [Keirstead 2012]
x	x	-	-	-	deeco [Bruckner 1996]; URBS [Richter 2004]
x	x	-	x	-	iPlan [Winkelmüller 2006]; EnyCity [Gerbracht 2009]
x	(x)	-	x	-	KomMod [Eggers 2015]
(x)	-	x	x	-	Regionenmodell [Steinert 2015]
-	-	x	-	-	Many potential studies, for a review see [Angelis-Dimakis 2011]
x	x	x	x	x	Own development

⇒ **Existing models can not be used, since the required input data is not available in other regions**

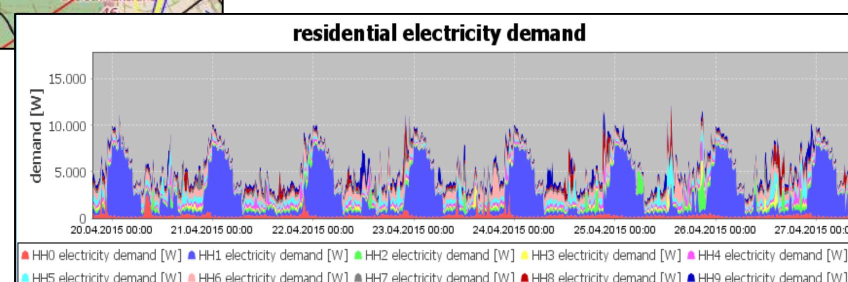
Method
Analysis of demand structure (1/2)



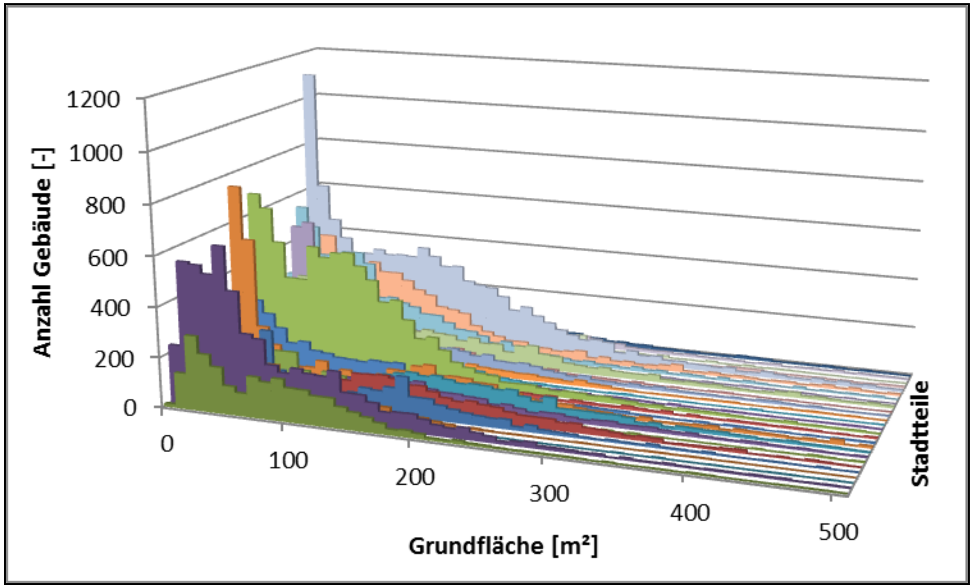
Geodata: OpenStreetMap

Infrastructure: Availability of power-, gas- and district heating grids

Electricity demand simulation based on appliance ownership and user activity profiles

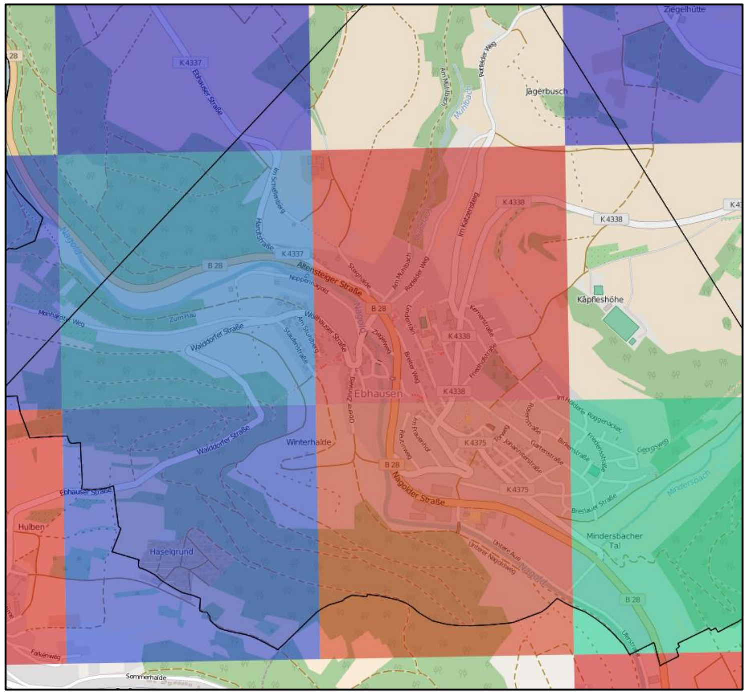


Method
Analysis of demand structure (2/2)



Buildings: Creation of a typology, based on sizes and age distribution

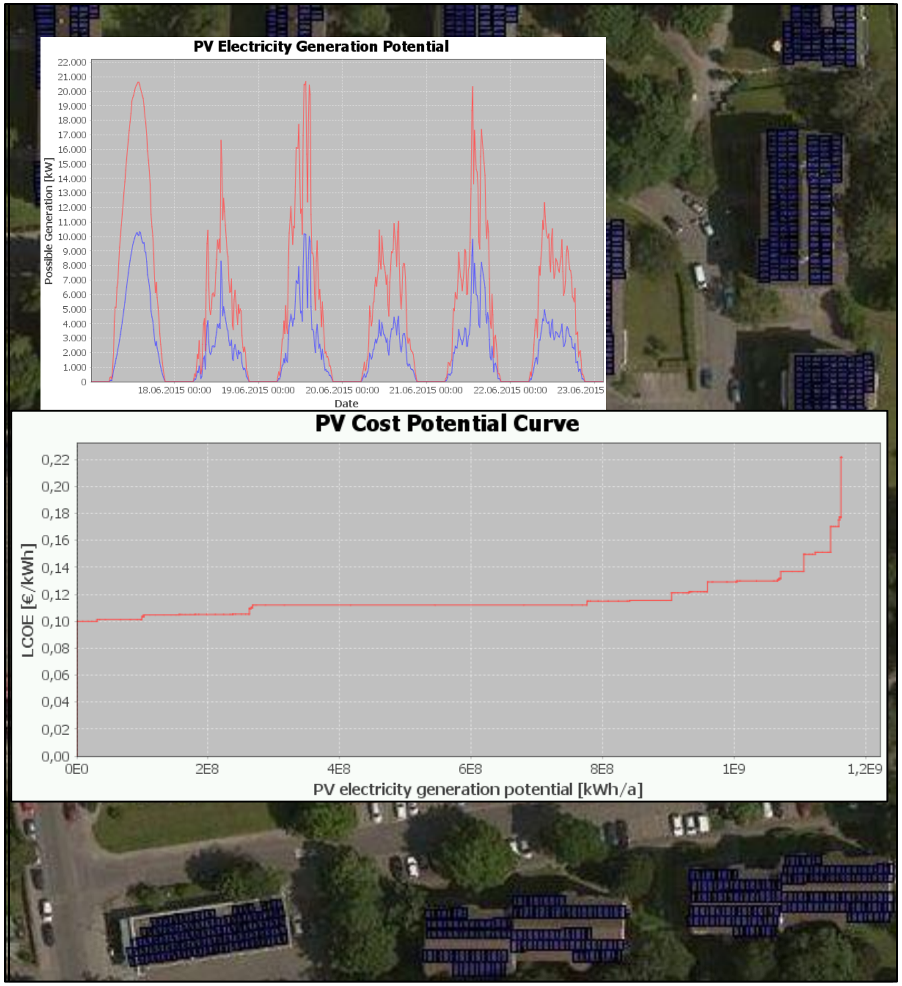
Heat demand mapping based on building types and technology configurations



Geodata: OpenStreetMap

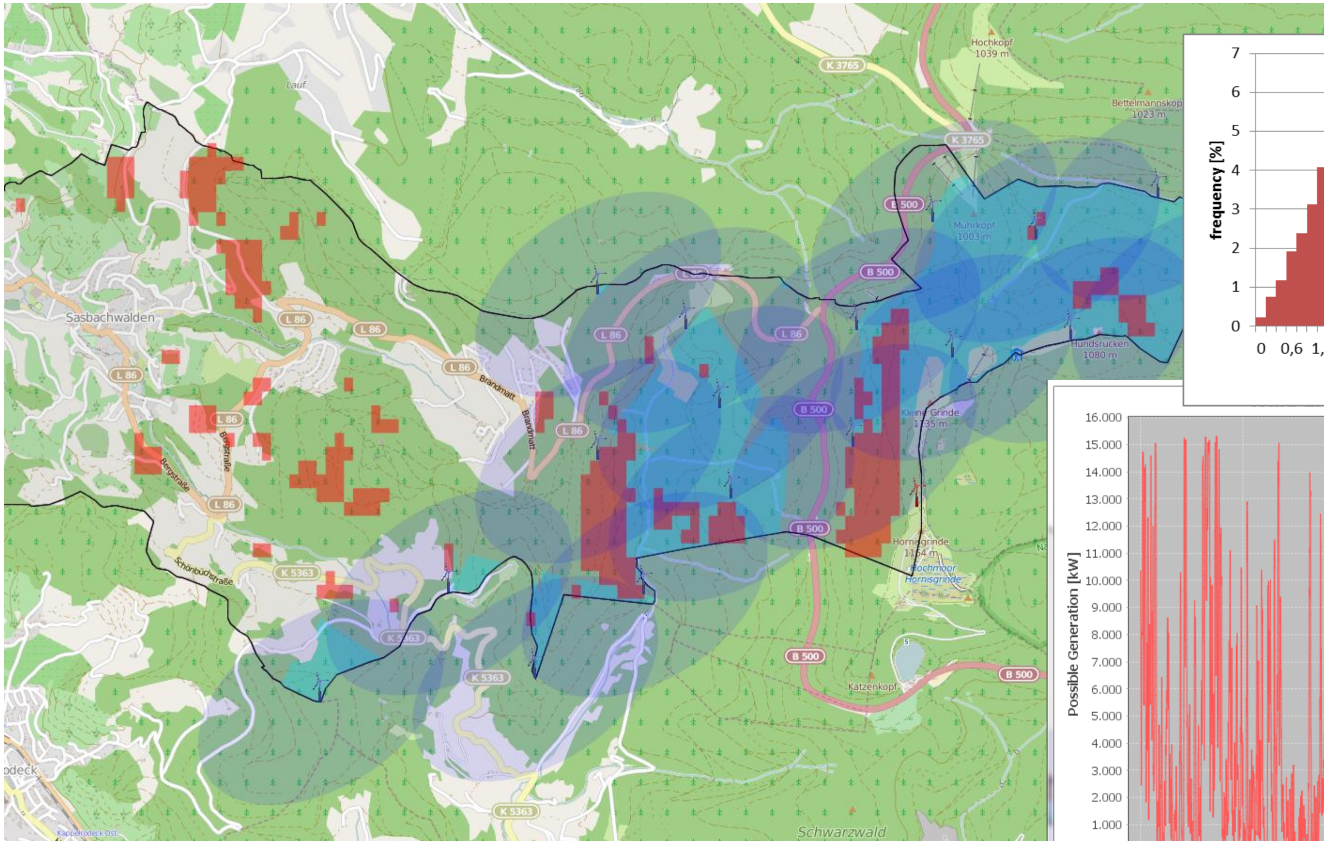
Method
PV potential estimation

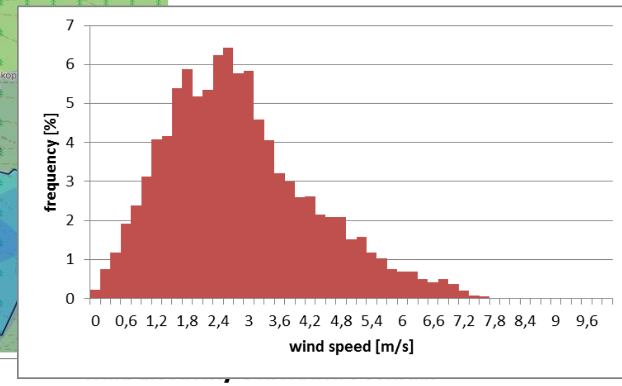
- Data gathering
  - Building footprints
  - Satellite images
- Determination of roof orientations through line detection algorithms
- Detection of roof structures like chimneys, roof windows, etc.
- Algorithm iterates stepwise over usable areas, places as many modules as possible
- simulation of irradiation, energy yield & costs calculation

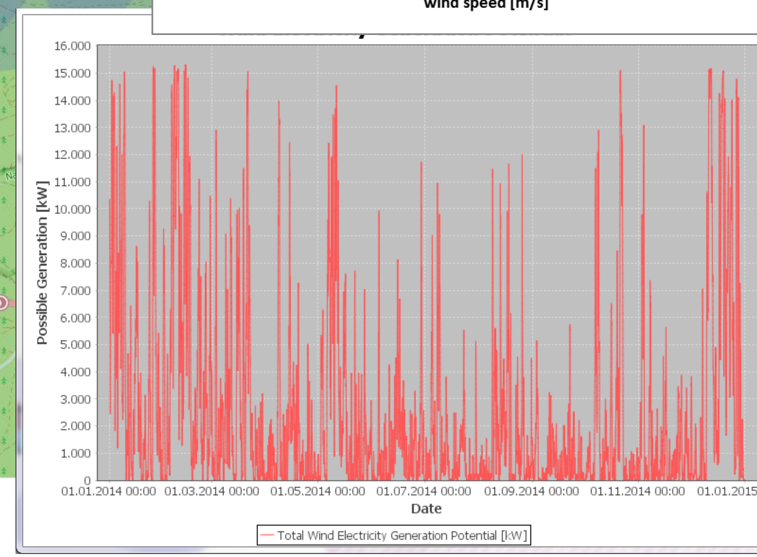


Geodata: OpenStreetMap, Satellite images: Bing Maps
more details in: [Mainzer 2016]

Method
Wind potential estimation



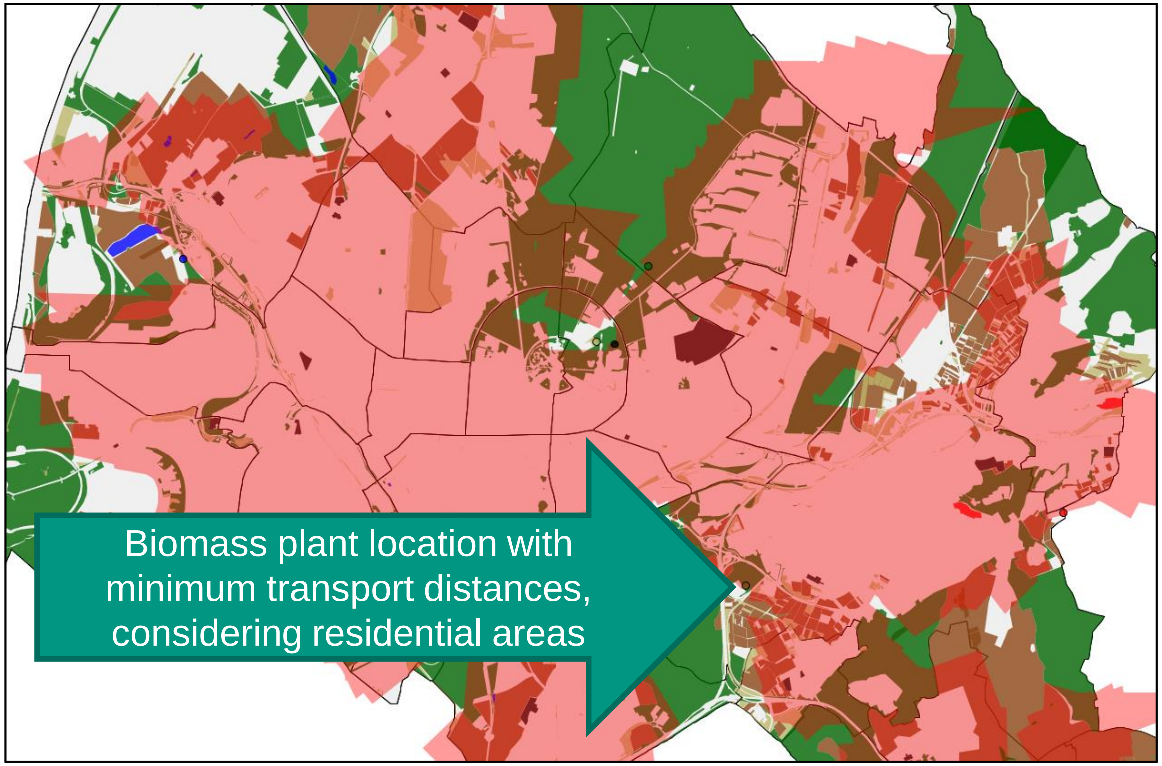




Geodata: OpenStreetMap; Topography: NASA SRTM

- Determination of available area considering landuse, topography
- Choice of turbines based on wind frequency distribution & characteristics

Method
Biomass potential estimation

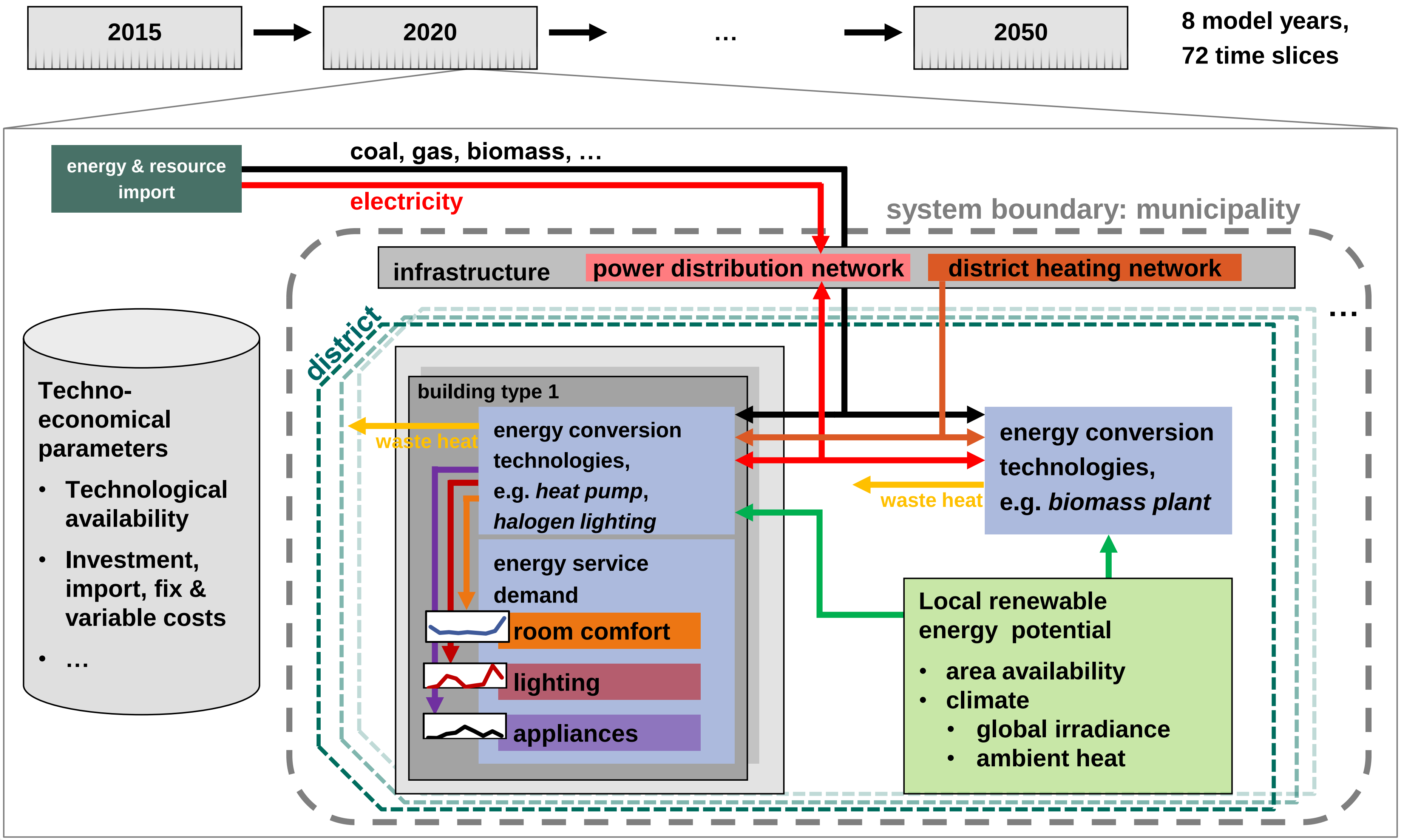


Geodata: OpenStreetMap

- Landuse (forests, farmland, …) => Determination of suitable areas
- Calculation of optimal conversion path: biogas plant, biomass-CHP, …
- Determination of optimal biomass plant location by minimization of transport distances, considering also distances to settlements, direction of wind (to minimize odor)

Method

Optimization of the urban energy system



Method
Optimization of the urban energy system

- Methodology: Mixed-integer linear programming (MILP), implemented in GAMS

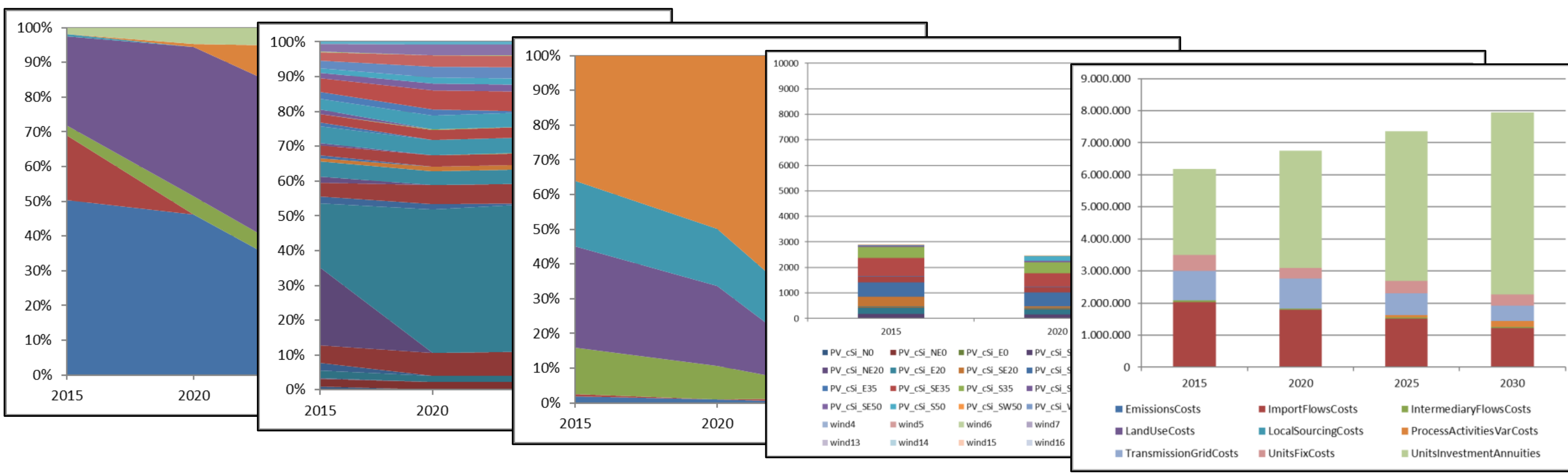
- objective function(s): minimize…
  - …Total discounted system cost
  - …CO_2 emissions
  - …Energy import

$$min \sum_{my \in \text{YEARS}} \left(\alpha_{my} * N_{my} * \begin{pmatrix} ImportFlowsCosts_{my} \\ +TransmissionGridCosts_{my} \\ +IntermediaryFlowsCosts_{my} \\ +UnitsInvestmentAnnuities_{my} \\ +UnitsFixCosts_{my} \\ +ProcessActivitiesVarCosts_{my} \\ +EmissionsCosts_{my} \\ +LandUseCosts_{my} \\ +LocalSourcingCosts_{my} \end{pmatrix} \right)$$

- constraints
  - energy balance
  - maximum energy flows
  - land use & available potentials
  - emission restrictions
  - cost restrictions
  - …

Results
Detailed scenario results

- Optimal choice & combination of technologies
  - heating systems
  - building insulation
  - appliances…
- Optimal degree of renewable energy utilization
- Development of costs, emissions, energy import and primary energy consumption for different scenarios



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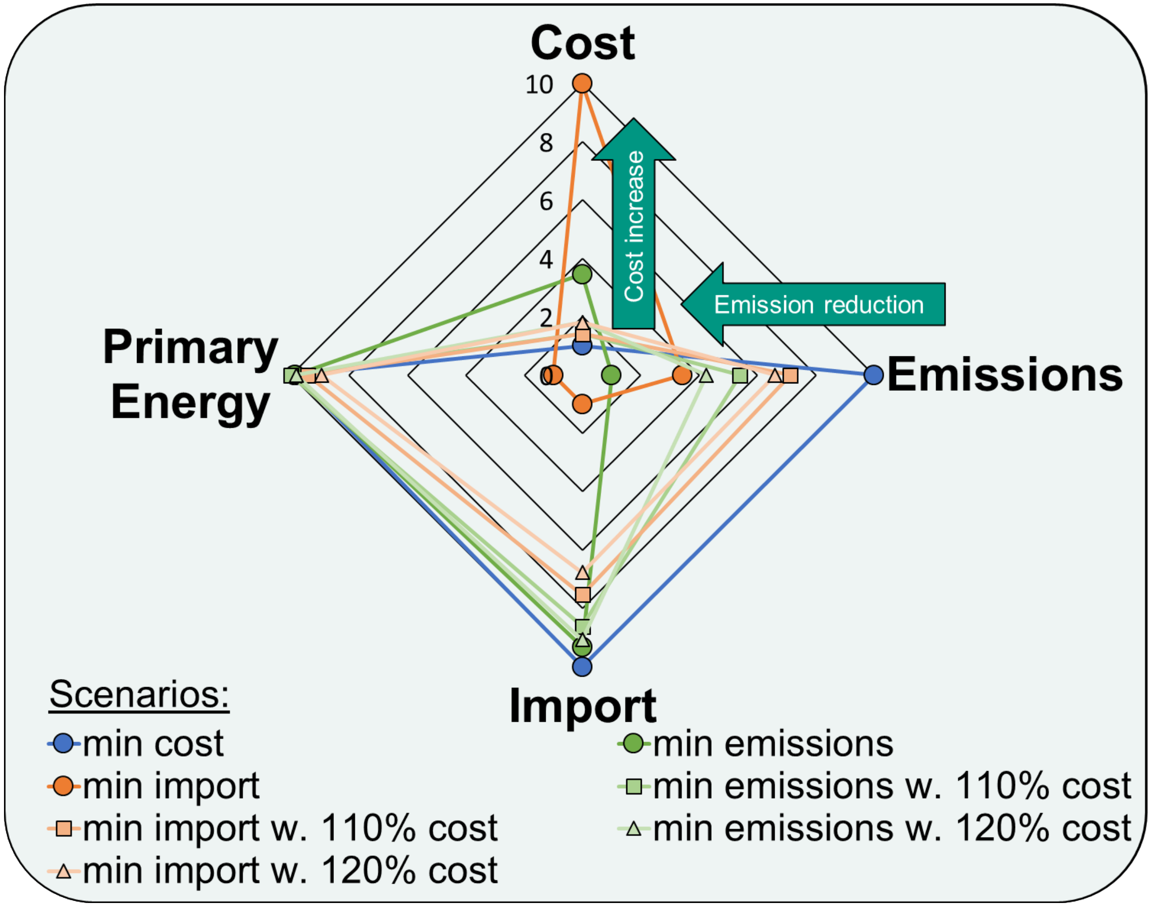
Results
Scenario comparison



- 3 *extreme scenarios*: what is possible in terms of emissions, costs, etc.
- With values derived from these extreme scenarios, *trade-off scenarios* can be found
- This can also be used to *increase the level of autarky* cost-effectively

⇒ **Trade-offs: e.g. significant emission reduction can be achieved with only minor additional costs**

Conclusion and outlook

- Mathematical models can provide **decision support for urban planning**
- Energy system models need to provide **automated methods for data acquisition** in order to be transferrable to other cities
- The presented model provides these methods and thus enables urban planners to **find optimal pathways for reaching their specific targets**

- Application to case study demonstrates its use and possible results:
  - In cost-minimization scenario, targets may not be reached
  - Further scenario comparisons can reveal **advantageous trade-off scenarios**

- Further work:
  - Additional scenarios (especially price development)
  - implementation of sensitivity analysis
  - Application and validation with more (international) case studies

Literature & Related Publications

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Thank you very much for your attention

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