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
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

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

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

**Analysis of demand structure (1/2)**

**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

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

Biomass potential estimation

- 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

- Techno-economical parameters
  - Technological availability
  - Investment, import, fix & variable costs
  - ...

- System boundary: municipality

- 2015 → 2020 → ... → 2050
  - 8 model years,
  - 72 time slices

- Energy & resource import
  - Coal, gas, biomass, ...

- Electricity

- Infrastructure
  - Power distribution network
  - District heating network

- Energy conversion technologies, e.g. heat pump, halogen lighting

- Energy service demand
  - Room comfort
  - Lighting
  - Appliances

- Energy conversion technologies, e.g. biomass plant

- Local renewable energy potential
  - Area availability
  - Climate
    - Global irradiance
    - Ambient heat
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

- **Constraints**
  - energy balance
  - maximum energy flows
  - land use & available potentials
  - emission restrictions
  - cost restrictions
  - ...

\[
\min \sum_{m,y \in \text{YEARS}} \alpha_{my} \cdot N_{my} \cdot \left( \text{ImportFlowsCosts}_{my} + \text{TransmissionGridCosts}_{my} + \text{IntermediaryFlowsCosts}_{my} + \text{UnitsInvestmentAnnuities}_{my} + \text{UnitsFixCosts}_{my} + \text{ProcessActivitiesVarCosts}_{my} + \text{EmissionsCosts}_{my} + \text{LandUseCosts}_{my} + \text{LocalSourcingCosts}_{my} \right)\]
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
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

- Killinger, S.; Mainzer, K.; et al. (2015): A regional optimisation of renewable energy supply from wind and photovoltaics with respect to three key energy-political objectives. In Energy. DOI: 10.1016/j.energy.2015.03.050.
Thank you very much for your attention

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