SECURING LOCAL ENERGY SUPPLY THROUGH MUNICIPAL ENERGY AUTONOMY: ASSESSING THE FEASIBILITY OF INCREASED DISTRICT HEATING FROM GERMAN BIOGAS PLANTS

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Agenda

- Background and motivation
- Biogas plants survey, research question and objectives
- Methodology for supply, demand and district heating assessment
- Preliminary results for survey plants and whole Germany
- Sensitivity analysis and critical appraisal of method
- Summary and outlook
Motivation for energy autonomy

- Background: decreasing LCOEs for PV and “grid parity” make own generation/consumption increasingly economically attractive

![Graph showing FIT, Prices, Costs over time with key: FIT = feed-in tariff, Household electricity price, gross, Household electricity price, net, Full costs of fossil/nuclear with external costs, PV new, small building, PV new, ground/large building, PV average FIT]
Energy autonomous villages and regions

Definition of energy autonomy:
• Mostly electricity
• Mostly on an annual basis

Options for energy autonomy:
• Fluctuating supply: PV and wind
• Base-load supply: Bioenergy and Geothermal
• Demand reduction and management
• Waste heat recovery and integration

http://www.wege-zum-bioenergiedorf.de/bioenergiedoerfer/

http://100ee.deenet.org/

As of: January 2013

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Survey of biogas plant operators

- January to September 2016, 2724 contacted, of which 602 surveyed
- Based on members of the Biogas Trade Association, hence southern Germany is over-represented
- Representative survey in terms of year of installation and size of plant
- Survey focussed on heat generation and use
- Most plants use only a small proportion of the heat
- Most common reasons e.g. low summer demand, expiry of EEG support, not economical, large distance to nearest heat sink, users not willing to pay heat price etc.

Herbes et al. 2017
Research question and objectives

**Research question:** how can this excess heat be optimally connected to neighbouring heat sinks and what are the associated costs for the survey plants and the whole of Germany?

**Objectives:**

- Determine the nearest nearby sinks for heat demand
- Estimate the total costs and CO2 savings to connect these sources and sinks through district heating
- Determine the optimal allocation of sources to sinks based on:
  - The best temporal agreement between demand and supply (energy autonomy idea)
  - The lowest CO2-abatement costs
- Scale up the results from the survey to the whole of Germany
Overall methodology

- Distance matrices of:
  - CLC to CLC
  - Biogas plant to CLC

  - Select biogas plant
  - Find 50 nearest CLCs
  - Calculate CO2 abatement costs
  - Select CLC with min. CO2 abatement costs
  - Find 25 nearest CLCs to selected CLC
  - All heat from BGP used?
    - yes
    - no
      - Heat demand of CLC covered?
        - yes
        - no
          - CLC is removed
          - BGP is removed

  - Biogas plant survey:
    - heat fraction
    - installed capacity
    - full load hours

  - CORINE Land Use Data (urban fabric)

  - CLC: Corine Land Cover Category
  - BGP: Biogas plant

  - N.B.: the (re-)calculation is only carried out for CLCs that have changed (supply and demand) since the previous iteration
  - N.B.: the selected CLC can be used as a source for further CLC sinks according to shortest distance

  - Apply supply and demand profiles

  - Assumptions relating to the profiles of heat generation and demand

  - ~50,000 areas
  - ~100 plants
  - Select plants with heat excess and match with national inventory
  - ~600 plants

  - Select CLC 111 and 112

  - Factor: 90% of total
  - All heat from all BGP's used?
    - yes
    - no
  - Connection is removed

  - N.B.: The connection already exists and is not newly „built“

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Method for district heating costs

1. From biogas plant to the settlement, $C_{\text{pipeline}} = 200 \, \text{€/m}$

2. Within the settlement based on distribution capital cost $C_d$:

$$C_d = \frac{a \cdot l}{Q_s} = \frac{a \cdot (C_1 + C_2 \cdot d_a)}{p \cdot \alpha \cdot q \cdot w} \quad (\text{€/GJ})$$

The four new parameters in the denominator are defined as:

$$p = \frac{P}{A_L} \quad \text{(number/m}^2\text{)}$$

$$\alpha = \frac{A_B}{P} \quad \text{(m}^2\text{/capita)}$$

$$q = \frac{Q_s}{A_B} \quad \text{(GJ/m}^2\text{a)}$$

$$w = \frac{A_L}{L} \quad \text{(m)}$$

**Linear Heat Density Reformulation (LHDR)**:

$$LHDR = p \cdot \alpha \cdot q \cdot w \left(\frac{\text{GJ}}{\text{m}^2\cdot\text{a}}\right)$$

- if $LHDR > 1.5$: $d_a = 0.0486 \times \log (LHDR) + 0.007$
- else: $d_a = 0.02$

- if $e < 0.4$: $w = 137.5$
- else: $w = 60$

**Parameters**

- $\alpha$: specific building space [m$^2$/capita]
- $a$: annuity factor [-]
- $A_L$: living area [m$^2$]
- $A_B$: building floor area [m$^2$]
- $C_d$: distribution capital cost [€]
- $C_1$: construction cost constant [€/m]
- $C_2$: construction cost coefficient [€/m$^2$]
- $d_a$: average pipe diameter [m]
- $e$: plot ratio [-]
- $I$: total network investment [€]
- $L$: distribution heat network length [m]
- $P$: population density [number/m$^2$]
- $Qs$: heat sold [GJ/a]
- $q$: specific heat demand [GJ/m$^2$.a]
- $w$: effective width [m]

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Persson & Werner 2011, Persson et al. 2017
Method for heat demand and CO2 abatement

- Heat demand for CLC area \( i \), \( H_{CLC,i} \) estimated based on:
  - Area, type and age of buildings within a municipality
  - Building typologies given annual specific heating demands

\[
H_{CLC,i} = \sum_{t=1}^{n} SH_i A_{L,i}
\]

- CO2 abatement for CLC area \( i \) \( CO2_{SAVE,i} \) is determined as the CO2 emissions from object-based heating that are displaced by the (new) district heating

\[
CO2_{SAVE,i} = H_{CLC,i} \sum_{t=1}^{n} SH_i \sum_{j=1}^{n} EF_{i,j} f_{i,j}
\]

- CO2 abatement costs are the total costs of district heating divided by the total CO2 abatement

\[
CO2_{COST,i} = \frac{C_d,i + l_{pipeline,i} \cdot C_{pipeline,i}}{CO2_{SAVE,i}}
\]

- CO2 emissions factor [tCO2/kWh]
- Fraction of fuel \( j \) used for heating
- Distribution capital cost [€]
- District heating pipeline cost [€/m]
- Distance from biogas plant to urban area [m]
Preliminary results for ~100 survey plants
Location of survey plants and allocation procedure
Scale-up methodology for ~10,000 German plants

- **Distance matrices of:**
  - CLC to CLC
  - Biogas plant to CLC

- **Select biogas plant**
- **Find 50 nearest CLCs**
- **Calculate CO2 abatement costs**
- **Select CLC with min. CO2 abatement costs**
- **Find 25 nearest CLCs to selected CLC**

**N.B.:** the (re-)calculation is only carried out for CLCs that have changed (supply and demand) since the previous iteration.

**N.B.:** the selected CLC can be used as a source for further CLC sinks according to shortest distance.

- **Apply supply and demand profiles**
- **Assumptions relating to the profiles of heat generation and demand**
- **~50,000 areas**
- **~10,000 plants**

- **Biogas plant register and EnergyMap.info**
- **Select CLC 111 and 112**
- **Biogas plant survey:**
  - heat fraction
  - installed capacity
  - full load hours
- **~100 plants**
- **~600 plants**

- **CORINE Land Use Data (urban fabric)**

- **Select plants with heat excess and match with national inventory**

- **~5,000 areas**

**CLC: Corine Land Cover Category**

**BGP: Biogas plant**

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Preliminary results for all German biogas plants
Sensitivity analysis of key parameters

[Graph showing the relationship between Total CO2 abatement (MtCO2/a) and Variation from baseline assumption. The graph includes multiple lines representing different parameters such as Mean abatement cost, Mean CO2 cost_vector, CO2 Saving, a_fact - Sum of CO2_save_vector, C - Sum of CO2_save_vector, In_sp - Sum of CO2_save_vector, w - Sum of CO2_save_vector, a_fact - Mean of CO2_cost_vector, C - Mean of CO2_cost_vector, In_sp - Mean of CO2_cost_vector, w - Mean of CO2_cost_vector.]

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Critique of method

- Uncertain costs: sensitivity analysis
- Heat supply:
  - Existing district heating networks not considered (cf. PETA)
  - Possible double counting of heat supply where some plants already supply nearby settlements
- Heat demand:
  - Energy mix for heating: national averages used
  - Only CLC areas 111 and 112 (no industry) >> better coherent urban areas (cf. PETA)
- Connection of supply and demand
  - Assumed profiles for supply and demand
  - Topology and obstacles not considered
  - Distance to centre of settlement >> overestimate costs
Summary and outlook

- Survey of around 600 biogas plants used to estimate potential for district heating for local settlements
- Only 100 plants used due to lack of heat and issues with matching these plants with the national inventory >> suggest a technical potential of 25 ktCO2/a, with 15 ktCO2/a at costs lower than 70 €/tCO2
- If scaled up to Germany, with 10000 plants, the technical potential is about 2.5 MtCO2/a or 0.1% of total annual CO2 emissions (1 MtCO2/a below 70 €/tCO2)
- Strongest cost sensitivities to the annuity factor and the LHDR (w)
- Weaknesses especially relate to use of national averages (fuel mix) and neglecting existing DH networks
- Key aspect to consider is the financing and business model, e.g. partnership of plant operator and local utility, considering that the heat is currently wasted
- Most of these will be addressed in the final stages of this work
Thank you very much for your attention!

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