Geothermal Energy and Biomass Integration in Urban Systems: a Case Study
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Outline:

- Introduction
- Methodology
- Models
- Scenarios
- Conclusions
INTRODUCTION
The global context

Growing trend in energy consumption, mainly from non OECD countries

$\text{CO}_2$ Emissions 2050 = $2x$ emissions today

IPCC 2013: climate has changed due to human activities

To target the $2^\circ$C $\Delta T$ limit $\text{CO}_2$ emissions need to be halved by 2050

Sources:
- Copenhagen Diagnosis 2009, with MIT data taken from Sokolov et al. 2009.
- IPCC 2013 report, Climate change 2013 - The physical science basis
INTRODUCTION

The global context

Global primary energy consumption:

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 80%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1% (2008)</td>
<td>3% el.</td>
<td>5% th.</td>
</tr>
<tr>
<td>10.2% (2008)</td>
<td>~3x</td>
<td></td>
</tr>
</tbody>
</table>

50% of worldwide population
71% of energy related GHG

Sources:

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INTRODUCTION
The case study of Lausanne

Energy Balance
Lausanne [GWh]

Year 2012

- Primary energy: 3308.3
- Final energy: 2788.1

59.5% Oil products
17.3% Municipal Solid Waste
23.1% Natural Gas
15.4 kt/y in the MSWI

59% Bioenergy and waste water
2.5% Other renewables

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INTRODUCTION

The case study of Lausanne

Potential: 50-100 kt/y

Sources:
INTRODUCTION
Literature review & Goals

Geothermal & Biomass integration:
• Strategic research priority in Europe
• Multi-objective optimization for urban systems (Gerber et al., 2013)
• Low-depth geothermal + HP, biogas and SNG from biomass (Alberg Østergaard et al., 2010)
• 35.5 MWₑ hybrid plant (CA, USA)
• Hybrid NG-geothermal-biomass system for Cornell University (Lukawski et al., 2013)

Goals:
• Complete urban system model: current situation (2012) and future scenarios (2035)
• Geothermal and biomass options for the urban energy strategy
• Pinch analysis: integration of excess geothermal heat during the summer

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METHODOLOGY
Urban system model

Resources
- NG
- Oil
- Diesel
- Petrol
- Wood
- Electricity
- MSW
- Waste water

Electricity & Mobility
- Car NG
- Car Petrol
- Car Diesel
- Car PHEV
- Bus NG
- Trolley Bus
- Bus Diesel
- Metro
- Hydro

Decentralized heat
- Boiler NG
- Boiler Oil

DHN production
- EGS 6km
- EGS 5km
- EGS 4.2km
- aquif. 3.8km
- ORC 6km SC
- ORC 5km
- ORC 4.2km
- ORC 3.8km

Demand
- dhn

Multiperiod problem

<table>
<thead>
<tr>
<th>Period</th>
<th>Months</th>
<th>[h]</th>
</tr>
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<tbody>
<tr>
<td>Summer</td>
<td>June to September</td>
<td>2928</td>
</tr>
<tr>
<td>Winter</td>
<td>November to March</td>
<td>3624</td>
</tr>
<tr>
<td>Mid-season</td>
<td>October, April, May</td>
<td>2208</td>
</tr>
<tr>
<td>Peak</td>
<td>-</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Resource Balance Layers
- Electricity [kW]
- Natural Gas [kW]
- Wet wood [t]
- Dry wood [t]
- Diesel [kW]
- Petrol [kW]
- Mobility [Mpkm]
- Mobility public [Mpkm]
- Oil [kW]
- Heat DHN
- Heat Decentralized
- MSW [t]
- Waste water (dry sludge) [t]

Heat Cascade Layer
- thermal streams (integrated) [°C]
METHODOLOGY

Performance indicators

Total Annual Cost $[\text{CHF}_{2012}/\text{year}]$: Annualized investment cost and maintenance for technologies ($tech$) + cost of resources ($res$: fuels and electricity imports)

\[
C_{TOT} = C_{\text{INV,an}} + C_{OP} + C_{O&M} = \sum_{tech} {i(i+1)^{n_{tech}} \over (1+i)^{n_{tech}} - 1} C_{\text{INV,tech}} + \sum_{res} C_{OP,\text{res}} + \sum_{tech} C_{O&M,\text{tech}}
\]

IPCC GWP 100a $[\text{kt}_{\text{CO}_2\text{-eq.}}/\text{year}]$: LCA approach $\rightarrow$ emissions due to construction + emissions from resources

\[
Em_{TOT} = Em_{\text{constr,an}} + Em_{OP} = \sum_{tech} {Em_{\text{constr,tech}} \over n_{tech}} + \sum_{res} Em_{OP,\text{res}}
\]

Advantage: indicators refer to the complete urban system $\rightarrow$ no need of assuming prices of heat/electricity within the system or of using avoided emissions
METHODOLOGY

Calculation framework

**Technology models**

- MILP optimization problem definition
  - (OSMOSE platform)

**Scenario definition:** $f_{\text{use}}(u,t)$, parameters

- MILP problem resolution (AMPL)
  - Obj: Operating cost
  - Mass/energy balance
  - Heat Cascade

- $f_{\text{mult}}(u,t)$

**Post-computation**

Performance indicators calculation:

- $C_{TOT}$, $Em_{TOT}$

Sources:


MODELS
Geothermal

Gradient: 30°C/km

Sources:
- Tacher, Laurent. An attempt of deep geological stratigraphical model in the area of Lausanne city. 2014.
## MODELS

### Geothermal

|----------|------------|------------------|-----------|-----------|-----------------------------|----------------|----------------|

### Energy conversion cycles:

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Fluid</th>
<th>$\varepsilon_{\text{el}} [-]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORC SC 6 km</td>
<td>R134a</td>
<td>18.1%</td>
</tr>
<tr>
<td>ORC 5 km</td>
<td>R134a</td>
<td>14.9%</td>
</tr>
<tr>
<td>ORC 4.2 km</td>
<td>R134a</td>
<td>13.1%</td>
</tr>
<tr>
<td>ORC 3.8 km</td>
<td>R134a</td>
<td>13.2%</td>
</tr>
<tr>
<td>Kalina 6 km</td>
<td>NH$_3$/H$_2$O</td>
<td>12.3%</td>
</tr>
</tbody>
</table>

Sources:
MODELS
Woody biomass

- Heat
- SNG
- Electricity
- Oil

1 kg/s → 8.3 MW
Wet (50% wt)
LHV* = 8.3 MJ/kg

Pyrolysis:

7.23 MW (ε_th = 87.15%)

Air dryer:

1.93 MW
0.14 MW

9.24 MW
Dry (15% wt)
LHV* = 15.8 MJ/kg

1.42 MW
0.14 MW
0.08 MW

Gasification (SNG):

5.8 MW

5.56 MW

5.51 MW (ε_th = 95%)

5.28 MW (ε_th = 95%)

SNG can be used for cogeneration and transport

*LHV on a wet basis

Sources:
MODELS
Woody biomass

<table>
<thead>
<tr>
<th>Model</th>
<th>Lifetime</th>
<th>$C_{INV,1}$ [MCHF]</th>
<th>$C_{INV,2}$ [MCHF]</th>
<th>GWP $[t_{CO2-eq}/$unit]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air dryer</td>
<td>50 [11]</td>
<td>0</td>
<td>1.07</td>
<td>76.16</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>25</td>
<td>0</td>
<td>10.44 [26]</td>
<td>181.1</td>
</tr>
<tr>
<td>Gasification</td>
<td>25</td>
<td>0</td>
<td>36 [25]</td>
<td>27.98</td>
</tr>
</tbody>
</table>

Modeling of the demand (2012):

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DHN</td>
<td>Decentralized</td>
</tr>
<tr>
<td>Summer</td>
<td>59.46</td>
<td>18.07</td>
<td>59.81</td>
</tr>
<tr>
<td>Winter</td>
<td>83.02</td>
<td>63.73</td>
<td>210.9</td>
</tr>
<tr>
<td>Mid-season</td>
<td>77.13</td>
<td>31.11</td>
<td>102.3</td>
</tr>
<tr>
<td>Peak</td>
<td>124.7</td>
<td>108.5</td>
<td>410.85</td>
</tr>
</tbody>
</table>

Sources:
### SCENARIOS

#### Scenario list

**2012 → 2035**

- Population growth: +0.7%/year
- DHN: +2%/year
- Same overall heat demand
- Same transportation and electricity demand per capita
- Public transportation: 19.5% → 28.5%
- Increased efficiencies for boilers and transportation
- +31 MWₑ hydroelectric turbine
- Higher share of gas boilers in decentralized
- Electricity import: 20% CCGT + renewables

<table>
<thead>
<tr>
<th>#</th>
<th>Year</th>
<th>Woody Biomass</th>
<th>Geothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2012</td>
<td>15.4 kt/y MSWI</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>2035</td>
<td>15.4 kt/y MSWI</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>2035</td>
<td>15.4 kt/y MSWI</td>
<td>3.8 km direct use</td>
</tr>
<tr>
<td>3</td>
<td>2035</td>
<td>15.4 kt/y MSWI</td>
<td>4.2 km direct use</td>
</tr>
<tr>
<td>4</td>
<td>2035</td>
<td>15.4 kt/y MSWI</td>
<td>6 km Kalina</td>
</tr>
<tr>
<td>5</td>
<td>2035</td>
<td>15.4 kt/y MSWI</td>
<td>5 km ORC</td>
</tr>
<tr>
<td>6</td>
<td>2035</td>
<td>100 kt/y Boiler (wet)</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>2035</td>
<td>100 kt/y Boiler (dry)</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>2035</td>
<td>100 kt/y pyrolysis</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>2035</td>
<td>100 kt/y gasification</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>2035</td>
<td>100 kt/y pyrolysis</td>
<td>4.2 km direct use</td>
</tr>
<tr>
<td>11</td>
<td>2035</td>
<td>100 kt/y pyrolysis</td>
<td>4.2 km ORC</td>
</tr>
<tr>
<td>12</td>
<td>2035</td>
<td>100 kt/y pyrolysis</td>
<td>6 km Kalina</td>
</tr>
<tr>
<td>13</td>
<td>2035</td>
<td>100 kt/y gasification</td>
<td>5 km direct use</td>
</tr>
<tr>
<td>14</td>
<td>2035</td>
<td>100 kt/y gasification</td>
<td>6 km Kalina</td>
</tr>
<tr>
<td>15</td>
<td>2035</td>
<td>100 kt/y gasification</td>
<td>3.8 km ORC</td>
</tr>
<tr>
<td>16</td>
<td>2035</td>
<td>100 kt/y Boiler (dry)</td>
<td>6 km ORC</td>
</tr>
<tr>
<td>17</td>
<td>2035</td>
<td>100 kt/y Boiler (dry)</td>
<td>4.2 km direct use</td>
</tr>
</tbody>
</table>
SCENARIOS

Results

Compared to 2012:
- 18.3 MCHF/year
- 55.3 kt CO2-eq./year
+ Investment costs
- Full use of MSWI in summer
- Efficiency
- Public transportation
SCENARIOS

Results

![Graph with scenarios and cost analysis](image)

- **GWP 100a [kton CO2-eq/year]**
- **Total Annual Cost [MCHF/year]**

- **Scenarios**
  - Base case 2035
  - Geothermal only
  - Wood only
  - Geothermal & Wood

- **Distances**
  - 4.2 km direct heat
  - 6 km Kalina
  - 5 km ORC
  - 3.8 km direct heat

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**Introduction**

**Methodology**

**Models**

**Scenarios**

**Conclusions**
SCENARIOS

Results

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GWP 100a [ktCO2-eq/year]

Total Annual Cost [MCHF/year]

- Base case 2035
- Geothermal only
- Wood only
- Geothermal & Wood

Scenarios

- 1
- 2
- 5
- 7
- 8
- 9

- Pyrolysis
- Gasification

- Wet wood in boiler
- Dry wood in Boiler

Scenarios

- 3
- 4
- 6

- 356
- 358
- 360
- 362
- 364
- 366
- 368
- 370

26/01/2015
SGW2015 – Stanford University – S. Moret*, L. Gerber, F. Amblard, E. Peduzzi, F. Maréchal
SCENARIOS
Results

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GWP 100a [kton CO2-eq/year]

Total Annual Cost [MCHF/year]

Base case 2035
Geothermal only
Wood only
Geothermal & Wood

Pyrolysis 4.2 km direct use
Pyrolysis 6 km Kalina
Pyrolysis 4.2 km ORC

Scenarios

12
14
10

13
11

15

17

520 530 540 550 560 570 580 590 600 610

356 358 360 362 364 366 368 370
SCENARIOS

Results
SCENARIOS

Results

- Base case 2035
- Geothermal only
- Wood only
- Geothermal & Wood

Dry wood in boiler
4.2 km direct use
Wood dried with excess heat in summer

GWP 100a [ktCO₂-eq/year]
Total Annual Cost [MCHF/year]

Scenarios

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Results – GWP 100a breakdown

Scenarios

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Results – Total Annual Cost breakdown

<table>
<thead>
<tr>
<th>Total annual cost [MCHF/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>MSWI/WWTP</td>
</tr>
</tbody>
</table>

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Results – Total Annual Cost breakdown

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Conclusions

• Complete model of a urban energy system → strategic energy planning

• Geothermal: direct use is the most interesting option, followed by cogeneration. ORC is less interesting

• Biomass: If combustion is considered, burning wood for DHN supply is the best option. Gasification to SNG allows substitution in transportation and efficient cogeneration

• Interesting option (low CAPEX) is the use of excess heat in summer for wood drying → storage of the excess heat for combustion during winter (100% renewable DHN)
CONCLUSIONS

Future work

• Inclusion of logistics, storage and other energy conversion options
• Unique MILP formulation for urban systems planning
• Increased spatial and temporal resolution
• Uncertainty
Thank you for your attention!
Questions?