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District heating systems modeling: A gamification approach

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Serious game

The objectives:

• to simulate and show the interaction between different stakeholders in the heating sector of a fictional town;
• to simulate and show how existing fossil fuel-based heating systems can be developed and transformed to the green, sustainable ones (from 2GDH and 3GDH to 4GDH and 5GDHC concepts);
• to increase knowledge and raise awareness of students, engineers, involved citizens, building owners, investors, local authorities, decision-makers and all who are interested in sustainable development of both technical, economic, ecological and sociopolitical aspects related to the heating sector and potential advantages of low-temperature district heating.
### Initial conditions

<table>
<thead>
<tr>
<th>Population [mln people]</th>
<th>Fossil fuel share [%]</th>
<th>Number of CHP plants [-]</th>
<th>Generation of district heating [-]</th>
<th>Share of demand covered by</th>
<th>CHP plants [%]</th>
<th>Individual gas boilers [%]</th>
<th>Players in the 1st round [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1-0.2</td>
<td>100</td>
<td>2</td>
<td>2 and 3</td>
<td>15</td>
<td>50</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>
Roles and goals of players:

1. **The government**  
   (1 player)  
   Goals:  
   • CO₂ reduction  
   • Approval rating

2. **Producers**  
   (up to 4 players, a half is newcomers)  
   Goals:  
   • Profit growth  
   • Share of the market

3. **Consumers**  
   (up to 9 players)  
   Goals:  
   • Low heat costs
Model of heat supply sector

- Producers
- Consumers
- Government

Technical:
- Plants, networks
- Maintenance

Economic:
- Incentives, measures
- Public acceptance

Heat supply:
- Individual supply options
- Buildings refurbishment
- Low-energy houses

Ecological:
- Plants, networks
- Maintenance

Socio-political:
- Incentives, measures
- Public acceptance

Producers
- Revenue
- Loan

Consumers
- Subsidies
- Taxes

Government
- Subsidies
- Taxes

Producers/Consumers
- Income
- Loan

Policies
- Ratings

DH contracts
- Sectors of economy
Gameplay

The sequence of actions within a round:
1. Initial conditions and random events (gas and oil prices fluctuations, political and economic instabilities, natural disasters, global pandemics and so on) set up boundary conditions for a round.
2. Producers and consumers identify the subdistricts where heat is needed and the plants, networks, building stock with expiring technical lifetime; the government plans how to spend budget money and identifies its sociopolitical priorities;
3. Producers and consumers use calculation tools (simplified algorithms on annual basis) to estimate levelized cost of heat (LCOH) and CO$_2$ emissions for different heat supply options (decentralized, centralized, fossil fuels, renewables); the government considers subsidizing producers and consumers.
4. Interaction between the government, producers and consumers via a built-in chat or in person.
5. Decision-making phase.
6. Assessing economic and ecological results of a round and rating the government.

The game consists of 5 rounds each representing a 5-year period (25 years in total). Before the start, the orientation round is played.
1. **The government**
   - Which sectors of economy to allocate budget money for the next round to;
   - Which green projects of producers and consumers to support financially;

2. **Producers**
   - Which plant to build and where;
   - Old plants’ replacement;
   - Which consumers to connect to the network;

3. **Consumers**
   - Individual plants or district heating;
   - Old individual plants’ replacement;
   - Which producer (DH) to sign contract with;
   - Building stock renovation;
### Available heat supply options

<table>
<thead>
<tr>
<th>Individual heating</th>
<th>District heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>gas boiler</td>
<td>deep geothermal energy plant</td>
</tr>
<tr>
<td>biomass boiler</td>
<td>large-scale heat pump</td>
</tr>
<tr>
<td>groundwater source heat pump</td>
<td>solar thermal power plant</td>
</tr>
</tbody>
</table>
Calculation tool for consumers

Input data

- Heat and cold demand;
- Type of plant
- Average annual COP
- Specific CO₂ emissions
- CO₂ tax
- Prices of fuel and electricity
- CAPEX of plant
- Inflation rate and discount rate

Calculation tool

Output data

- Levelized cost of heat
- CO₂ emissions
Calculation tool for producers

Input data

- **Additionally**
  - Subdistrict(s)
  - Land and building space area
  - Linear heat density
  - Trench length;
  - CAPEX (pipes, substations, TES)
  - Margin rate

Output data

- Heat tariff
- CO₂ emissions
### Draft/idea of game map

- 9 districts – 9 consumers;
- 9 districts are further divided into 9 subdistricts;
- Plants and the network appear on the map when built by producers;
- Different shades of the color represent population (heat) density;
- The map should be interactive; events and menus should appear on click.
Players’ decisions as well as their responses to random events shape the course of the game.

IND – individual supply option
DHC – district heating and cooling
CHP – combined heat and power plant
ST – solar thermal
HP – heat pump
BM – biomass boiler
DG – deep geothermal
Model of DH transformation in the game

- **Pre-insulated polymer pipes**
  - <30 °C
  - <70 °C

- **Transitional state**
  - <70 °C
  - <100 °C

- **Pre-insulated steel pipes**
  - Steel pipes
  - <100 °C
  - <120 °C

- **Nearly zero-energy buildings**
  - Low-energy buildings
  - New

- **Transitional state**
  - Refurbished

- **Existing building stock**
  - Old

Priority of development

- **Network (distribution)**

- **Energy source (generation)**
  - Low-Exergy
  - High-Exergy
  - Fossil fuels
  - Biomass

- **Buildings (consumption)**
  - Low-Exergy
  - High-Exergy
  - Waste heat
  - Shallow geothermal
  - Solar thermal
  - Deep geothermal
  - Nearly zero-energy buildings
  - Low-energy buildings

- **Low-Exergy**
  - Fossil fuels
  - Biomass

- **High-Exergy**
  - Waste heat
  - Shallow geothermal
  - Solar thermal
  - Deep geothermal
  - Nearly zero-energy buildings
  - Low-energy buildings

- **Low Exergy**
  - Low-Exergy
  - High-Exergy

- **High Exergy**
  - Fossil fuels
  - Biomass

- **5GDHC**
- **4GDH**
- **3GDH**
- **2GDH**
Draft of interface

Initial conditions

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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>0.70</td>
<td>0.30</td>
<td>0.311</td>
<td>0.156</td>
<td>216.00</td>
<td>117.00</td>
<td>25.00</td>
<td>1.5</td>
</tr>
</tbody>
</table>

NW3
--- select a location for a plant ---
--- where to build network ---
bio_CHP_1
--- select a type of pipelines ----
3GDH_type

Annual heat demand of subdistrict NW3

<table>
<thead>
<tr>
<th>Heat load [MW]</th>
<th>Heat load (covered) [MW]</th>
<th>Annual heat demand [MWh/a]</th>
<th>Annual heat demand (covered) [MWh/a]</th>
<th>Specific domestic hot water demand [kWh/(m²*a)]</th>
<th>Specific space heating demand [kWh/(m²*a)]</th>
<th>Floor area [m²]</th>
<th>Possibility to connect to LTDH [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.12</td>
<td>0.00</td>
<td>6580.00</td>
<td>0.00</td>
<td>23</td>
<td>131.6</td>
<td>42560</td>
<td>Refurbishment is needed</td>
</tr>
</tbody>
</table>

Characteristics of heat supply source

<table>
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</thead>
<tbody>
<tr>
<td>17.00</td>
<td>148920.00</td>
<td>25</td>
<td>0.00</td>
<td>18.91</td>
<td>840.1</td>
<td>2.9</td>
<td>0.15</td>
<td>3.06</td>
<td>0.847</td>
</tr>
</tbody>
</table>
Feedback

- Questions
- Comments
- Improvements
- Remarks
- Criticism

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