Optimal multi-stage district heat expansion planning using real options

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4DH
4th Generation District Heating Technologies and Systems
Presentation Outline

1. Rationale
2. Phasing Model
3. Formulation 1: Conditional Value at Risk
4. Formulation 2: Real Options (LS-MC)
5. Example
6. Conclusions and Future Work
Rationale

- UK district heating projects consist of seed networks and fully built out projects
- Phasing is a very important aspect of economic viability
- The net present value approach does not take into account all strategic aspects or flexibility of phasing (including recourse actions)
- Typical NPV or IRR based analysis does not take uncertainty into account (one-off decision for the whole duration of the project)
- Some trade-offs are time dependent
- Inherent uncertainty of feasibility studies
Phasing Model

\[ NPV = \sum_{t=0}^{N} DCF_t = \sum_{t=0}^{N} \frac{R_t - C_t}{(1 + r)^t} \]

\( R_t = \text{heat sales} + \text{electricity sales} \)
\( C_t = \text{CAPEX} + \text{OPEX} + \text{REPEX} \)
\( \text{CAPEX} = \text{production units} + \text{network} \)
\( \text{OPEX} = \text{Fuel Costs} + \text{maintenance costs} + \text{pumping costs} + \text{'admin' costs} \)

\[ \max_{a_{i,t,s} \in \mathcal{A}} \lambda CVaR_{\alpha}(\{NPV_s, p_s\}_{s \in S}) + (1 - \lambda) \mathbb{E}(\{NPV_s, p_s\}_{s \in S}) \]

s.t.
- Topology constraints (Adjacency of Nodes)
- Chronology constraints
- Energy Flows at each node/vertex
- Hydraulics (pressure drops velocity as pipe sizing constraints)
- CHP/boiler sizing
- Non-anticipativity constraints

Maximize the expected value of the NPV
MILP problem
Integer variables are selection/existence of asset \( a_{i,t,s} \) number \( i \) at time \( t \) for scenario \( s \)

Scenarios to represent uncertainty:
- Connection of future buildings
- electricity and gas prices
- refurbishment rate
Influence diagram and real options

- Option to delay
- Option to expand
- Option to abandon
- Sequencing options
Influence diagram and real options

Representing list of possible states for heat network and possible transitions
Problem Formulation

\[ G_t(S_t) = \max_{\delta} \sum_{h \in b^D(S_t)} F_{h,t}(S_t) \cdot \delta_h \]

s.t.

\[ \delta_h \in \{0,1\}, \forall h \in b^D(S_t) \]
\[ \delta_h \in \mathcal{A}(S_t), \forall h \in b^D(S_t) \]

\[ S_{t+\Delta h} = S^M(S_t, \delta_h), \forall h \in b^D(S_t) \]

\[ F_{h,t}(S_{i,t}) = \Pi_{h,t}(S_t) + \mathbb{E}_t[e^{-r\Delta h}G_{t+\Delta h}(S_{t+\Delta i,h})], \forall h \in b^D(S_t) \]

Solve optimal stopping problem using dynamic programming (Maier et al, 2015)
Notations

- $\mathcal{D}$ set of decision nodes
- $\mathcal{H}$ set of transitions (real options)
- $F_{h,t}(S_t)$ value of option $h \in \mathcal{H}$ at time $t \in \mathcal{T}_h$ in state $S_t \in S$
- $G_t(S_t)$ optimal value of portfolio of options available at time $t \in \mathcal{T}_D$ in state $S_{i,t}$
- $\mathcal{T}_D$ set of decision dates
- $\Delta_h$ duration of options $h$
- $b^D(S_t)$ the set of incoming transitions for state $S_t$
- $\delta_h$ decisions to exercise any available option at state $S_t$
- $\mathcal{A}(S_t)$ feasible region (set of linear constraints of possible transitions)
- $\Pi_{h,t}(S_t)$ is the NPV of stochastic net cash flow of option $h$ at state $S_t$
Influence diagram formulation
• Determine aggregate steps, energy flows, capex, opex, repex, transition costs, operating costs using ‘robust’ MILP model
• Use consistent aggregate candidate steps and applying real option sequencing optimization using a simplified influence diagram and the LS-MC method.

original topology

Aggregate steps

Step-wise expansion/growth
Example

• Hypothetical example of UK eco-town of Marston Vale. 47 nodes.
• Production units: peak boilers (pre-existing) and gas engines CHP units.
• UK department of energy and climate change electricity and gas prices forecasts
• Uncertain future demand due to energy efficiency measures and uncertainty of future connections for some new developments
• 10,000 Monte-Carlo simulations for different electricity and gas prices paths.

Example
Conclusions and Future Work

• Real options allows for the representation of the modular nature of DHN expansions
• Real options and stochastic programming are useful to represent the inherent uncertainty surrounding DH infrastructure projects

Future work #1: real life case study on London Borough of Islington Network, integration with UK national heat map

Future work #2: represent co-evolution of heat supply and demand and interaction with electricity grid (game theoretical? agent based modelling?)
References

• Maier, S., Polak, J., 2015. Appraising a Portfolio of Interdependent Physical and Digital Urban Infrastructure Investments: A Real Options Approach. 


• National Heat Map: http://tools.decc.gov.uk/nationalheatmap/

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