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Optimal multi-stage district heat expansion planning using real options

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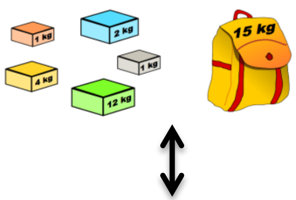
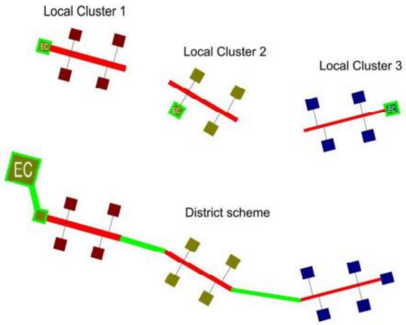
Presentation Outline

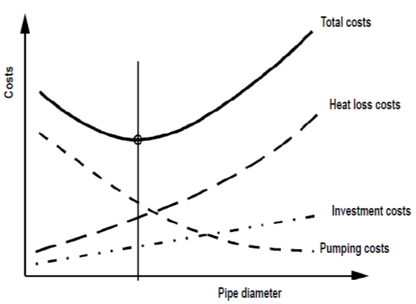
1. **Rationale**
2. **Phasing Model**
3. **Formulation 1: Conditional Value at Risk**
4. **Formulation 2: Real Options (LS-MC)**
5. **Example**
6. **Conclusions and Future Work**

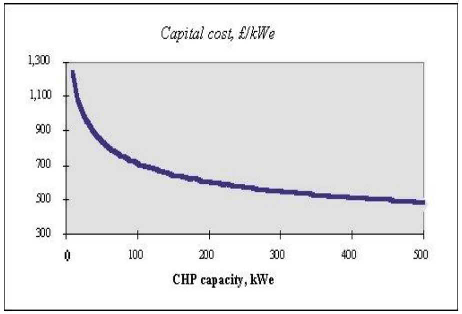
Rationale

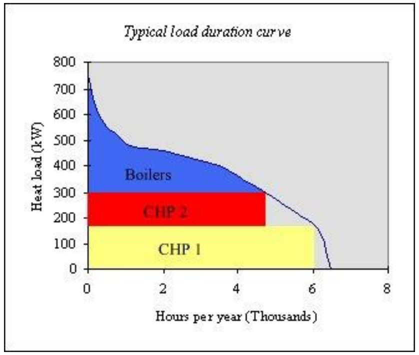
- UK district heating projects consist of seed networks and fully built out projects
- Phasing is a very important aspect of economic viability
- The net present value approach does not take into account all strategic aspects or flexibility of phasing (including recourse actions)
- Typical NPV or IRR 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

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

$$R_t = heat\ sales + electricity\ sales$$

$$C_t = CAPEX + OPEX + REPEX$$

$$CAPEX = production\ units + network$$

$$OPEX = Fuel\ Costs + maintenance\ costs + pumping\ costs + 'admin'\ costs$$

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

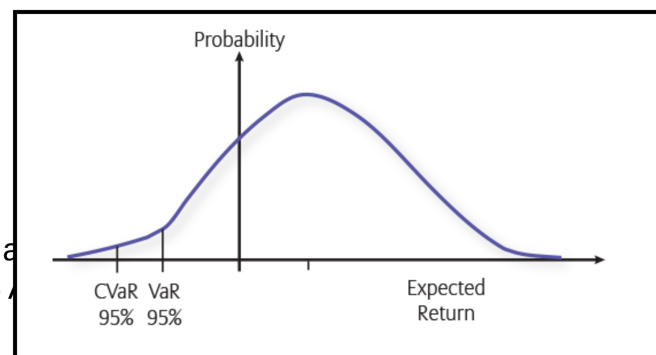
s.t.

- *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



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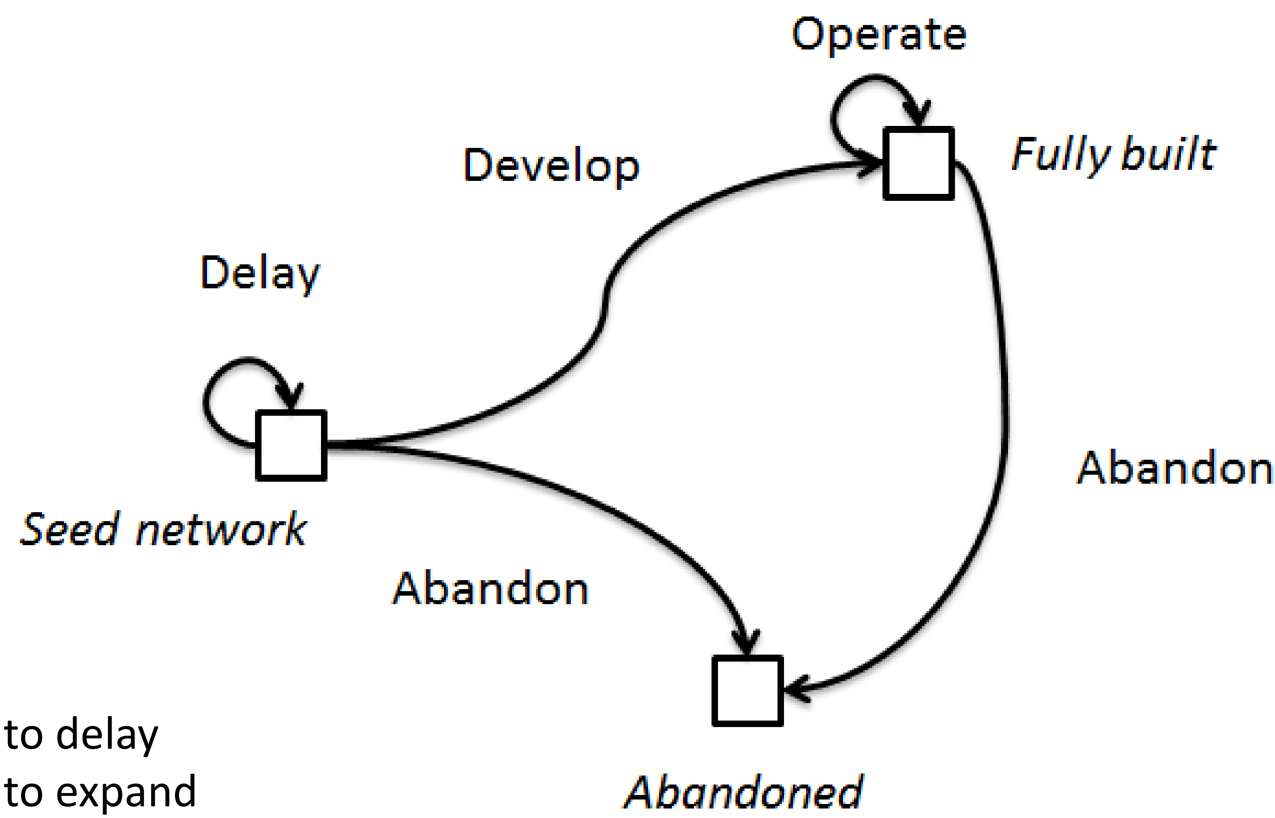
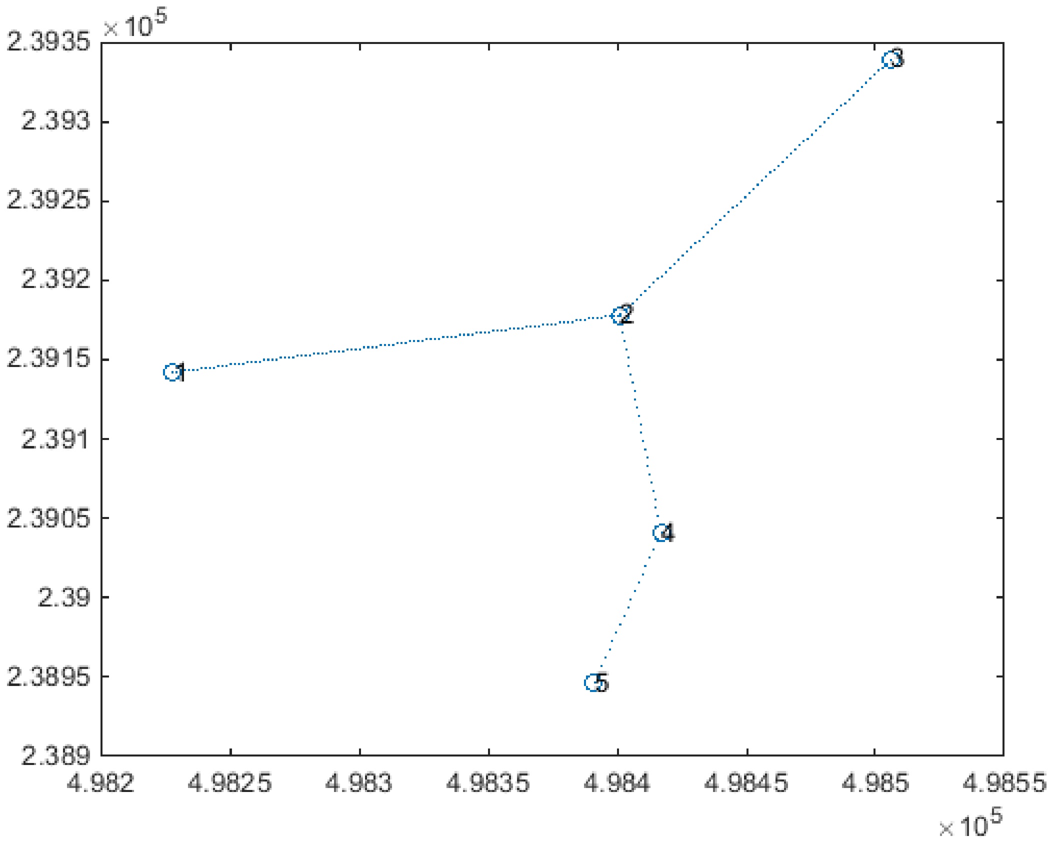
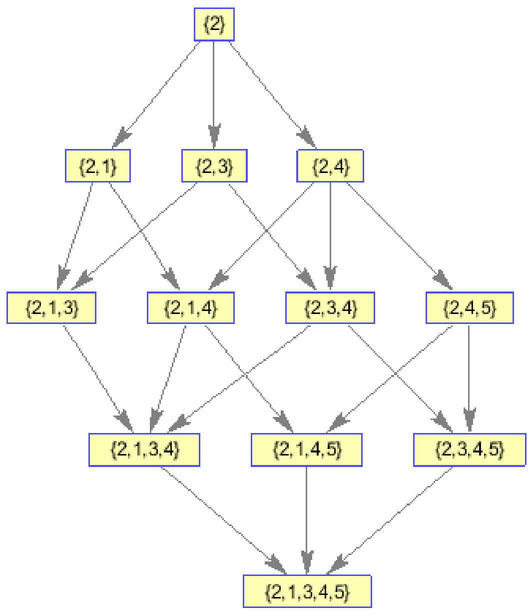
Influence diagram and real options



- 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

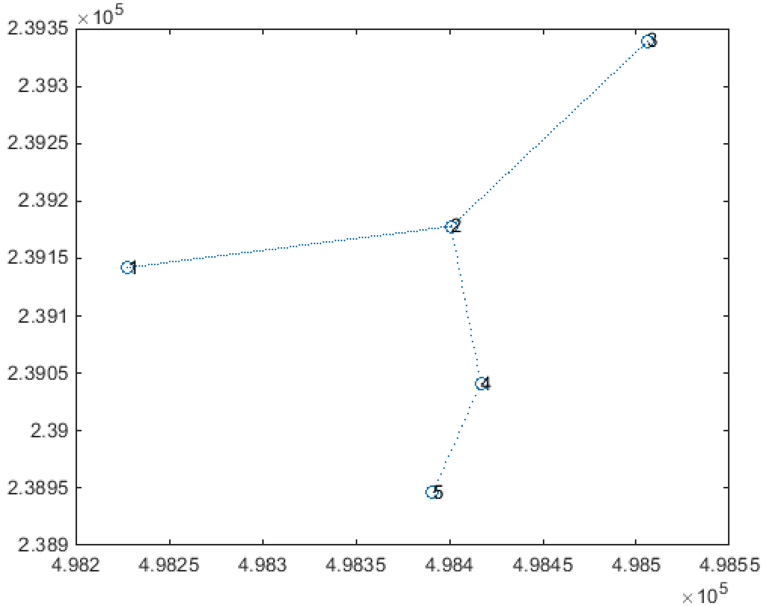
Problem Formulation

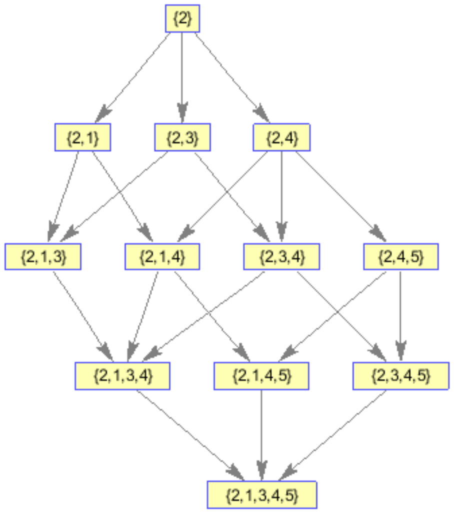
$$G_t(S_t) = \max_{\delta} \sum_{h \in b^D(S_t)} F_{h,t}(S_t).\delta_h$$

$s.t.$

$$\delta_h \in \{0,1\}, \forall h \in b^D(S_t)$$
$$\delta_h \in \mathcal{A}(S_t), \forall h \in b^D(S_t)$$
$$S_{t+\Delta_h} = S^M(S_t, \delta_h), \forall h \in b^D(S_t)$$
$$F_{h,t}(S_{i,t}) = \Pi_{h,t}(S_t) + \mathbb{E}_t\left[e^{-r\Delta_h} G_{t+\Delta_h}\left(S_{t+\Delta_{i,h}}\right)\right], \forall h \in b^D(S_t)$$

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

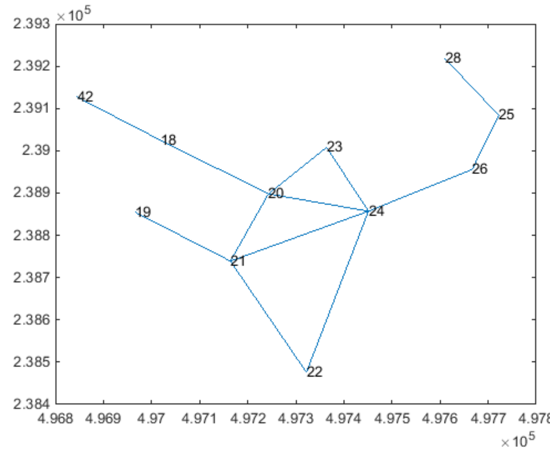


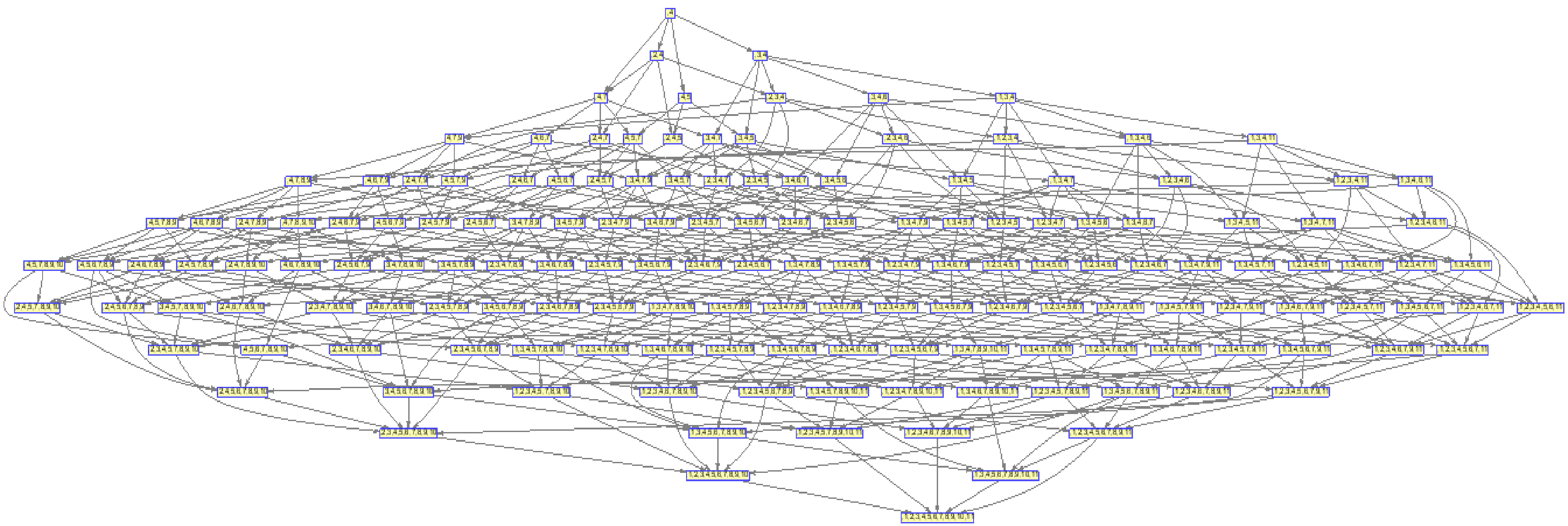


Notations

- $\mathcal{D}$ 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 $S_t \in \mathcal{S}$
- $G_t(S_t)$ 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
- Δ_h duration of options h
- $b^D(S_t)$ the set of incoming transitions for state S_t
- δ_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
- $\mathcal{T}_h$ set of exercising times for option h

Influence diagram formulation



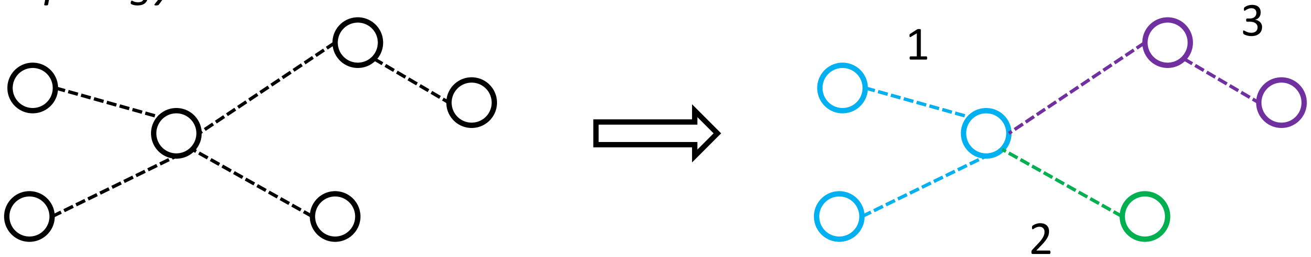


step-wise procedure

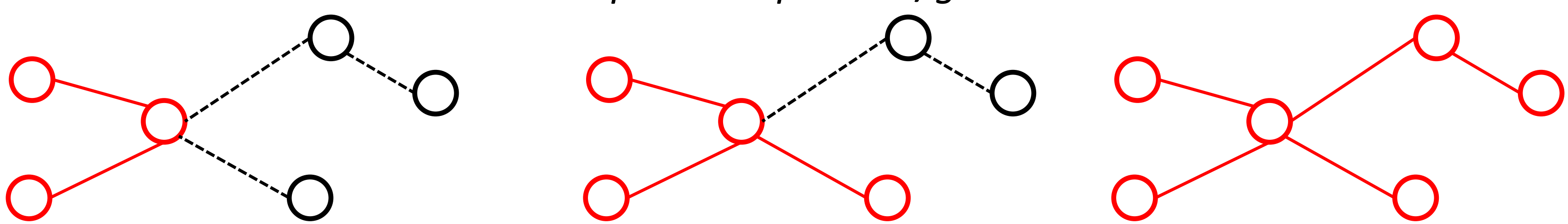
- Determine *aggregate* steps, energy flows, capex, opex, repex, transition costs, operating costs using ‘*robust*’ MILP model
- Use consistent aggregate candidate steps and applying *real option sequencing* optimization using a *simplified influence diagram* and the LS-MC method.

original topology

Aggregate steps

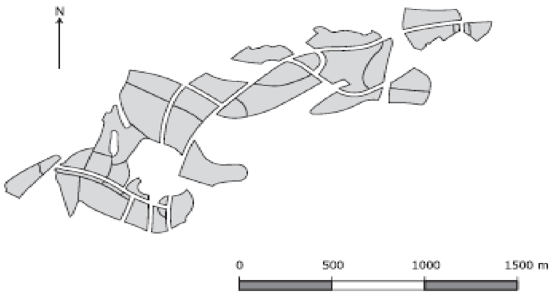


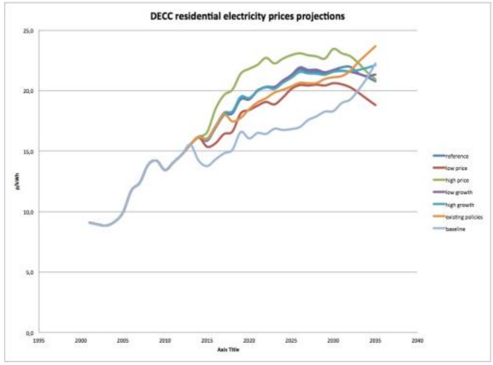
Step-wise expansion/growth

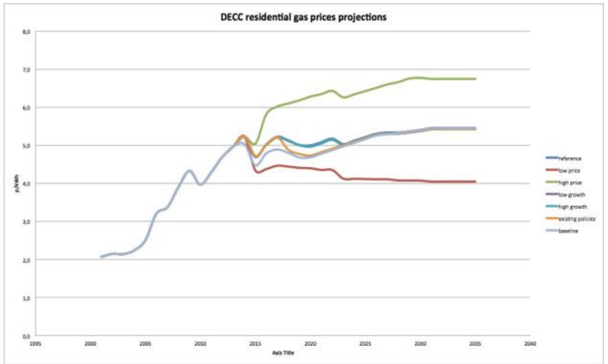


Example

- 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.

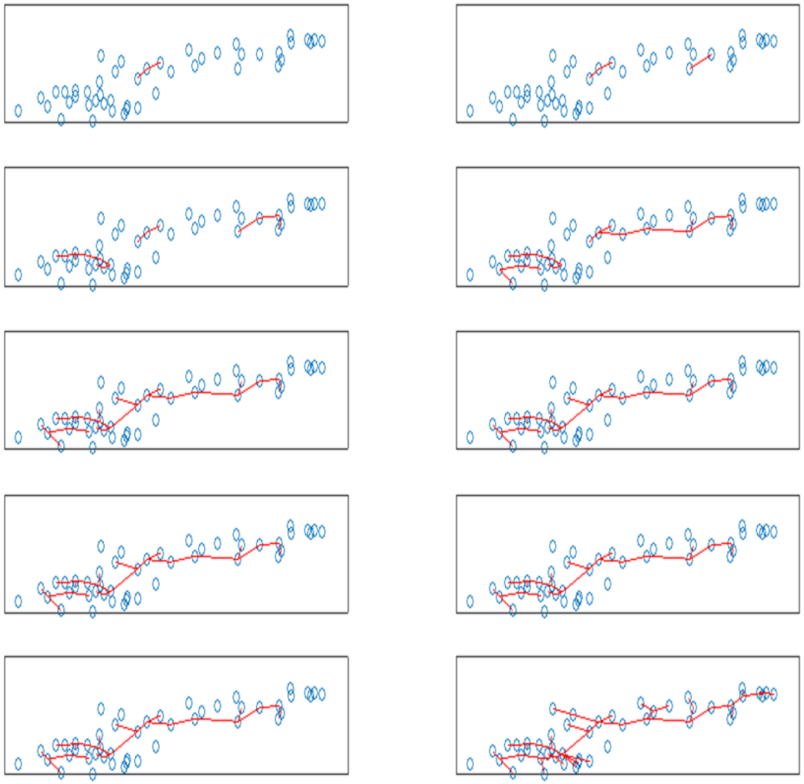


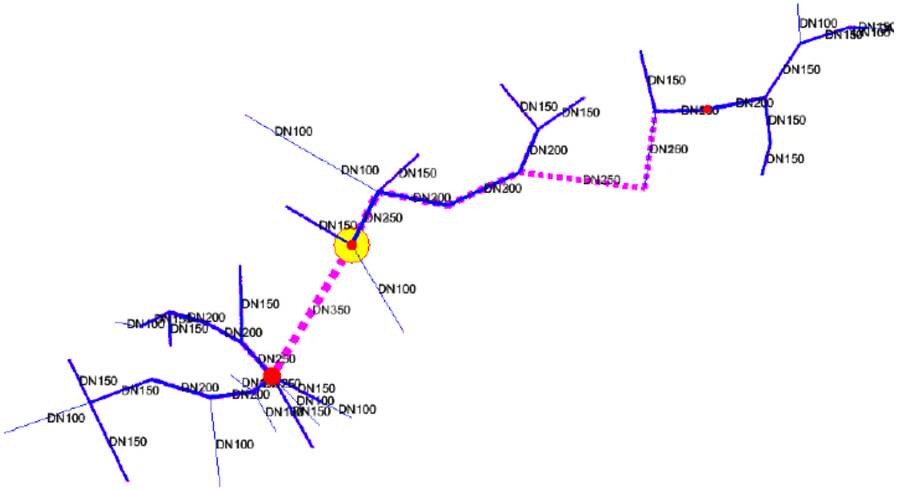




source: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2014 (annex M)

Example





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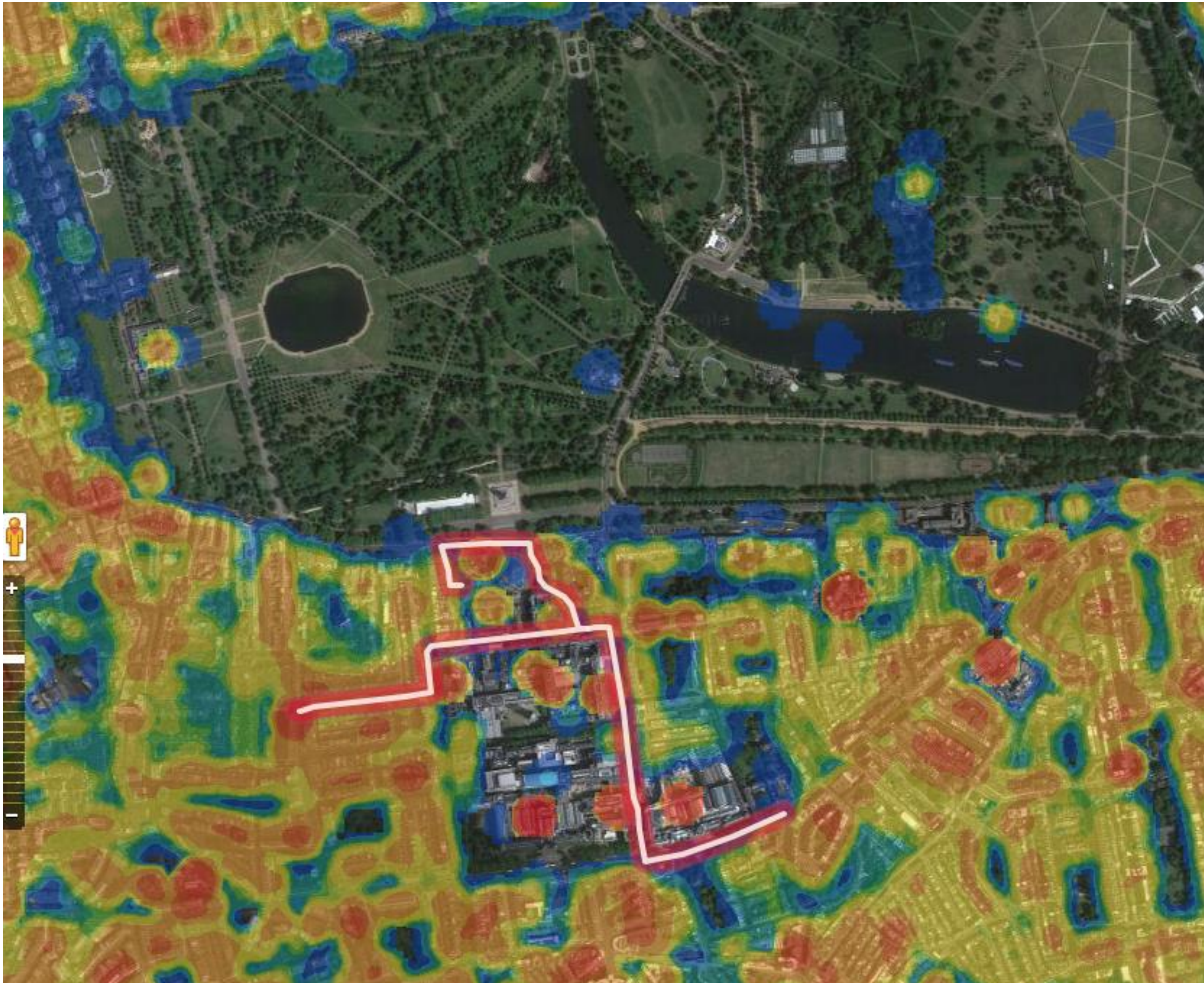

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References

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- DECC, 2014. Energy and Emissions Projections 2015 https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2014 (annex M)
- National Heat Map: http://tools.decc.gov.uk/nationalheatmap/

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