

CELSIUS Talk:

New approaches to understanding
and evaluating the risks of DH
investments

2016.08.24

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smart cities

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 314441.



Appraising Investment in District Heating Networks: Accounting for Strategic Interdependencies and Risks

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Outline

- The challenges of 'smart cities' investment appraisal
- Limitations of existing appraisal techniques
- Alternative, real options based, appraisal techniques
- Application to Bunhill Heat and Power network in London
- Conclusions



Smart cities investment appraisal

- All investment appraisal is difficult
- But appraising 'smart cities' investments is particularly difficult:
 - Interdependent portfolios of projects, rather than individual projects
 - Many different agents involved, acting both collaboratively and competitively
 - Involves radically different forms of asset class (e.g., physical vs digital)
 - Many sources of risk (e.g., technological, political, regulatory, demand etc.)
 - Emphasis typically on development and expansion hence dynamic strategy, not one-off investment, is required

Existing appraisal methods

- Existing appraisal methods in both public and private sector are largely based on relatively simple techniques such as cost-benefit analysis (CBA) and the Internal Rate of Return (IRR)
- However, these techniques have major limitations:
 - Cannot consider inter-dependencies
 - Cannot accommodate strategic behaviour (one's own and that of others)
 - Assume analysts have perfect knowledge of the future
 - Ignore the (dynamic) flexibility in decision making available to management
 - Cannot accommodate learning over time



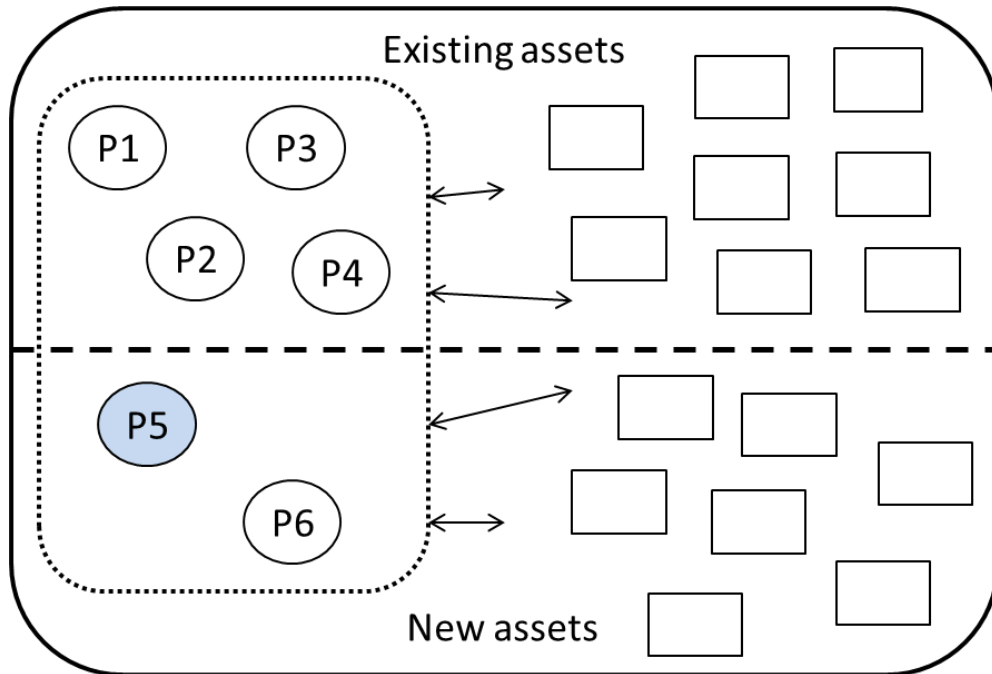
Portfolio-based appraisal methods

- In recent work, one of my PhD students, **Sebastian Maier**, has developed a new portfolio-based framework for the appraisal of smart cities investments
- This framework systematically links:
 - *Real Options Analysis* to enable the characterisation and management of multiple sources of risk
 - *Multi-criteria Analysis* to account for multiple objectives of different decision makers
 - *Infrastructure interdependencies* modelling to incorporate “system of systems” properties
 - *Game Theory* to model strategic behaviours of decision makers



Independence and interdependence

Independent



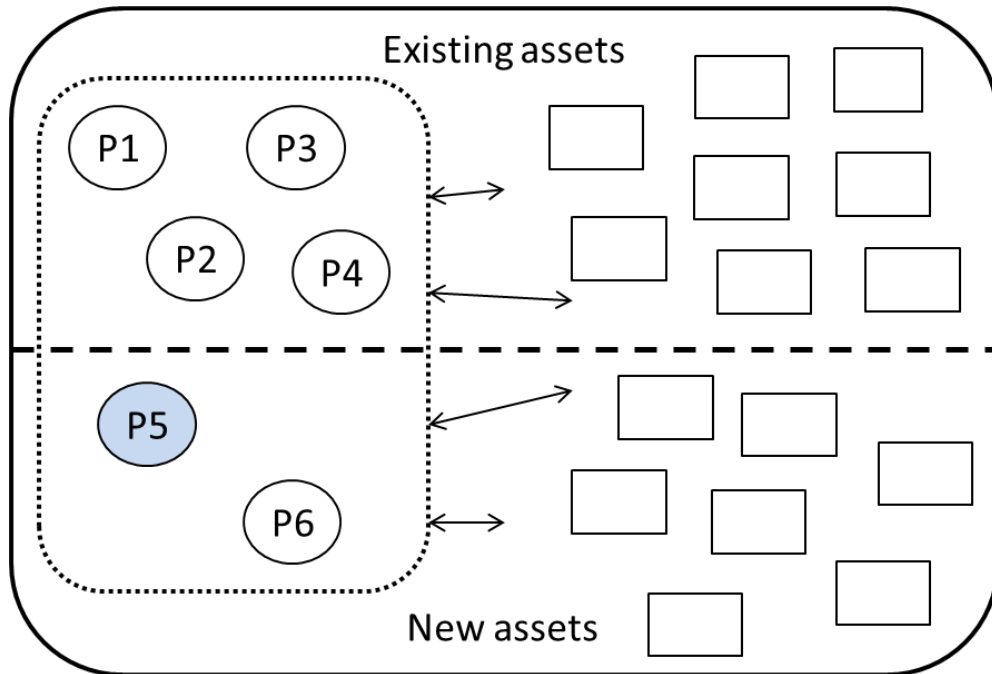
Value of portfolio

$$G_0^P(\{S_{i,0}\}_{i \in \mathcal{I}}) = \sum_{i \in \mathcal{I}} G_{i,0}(S_{i,0}).$$



Independence and interdependence

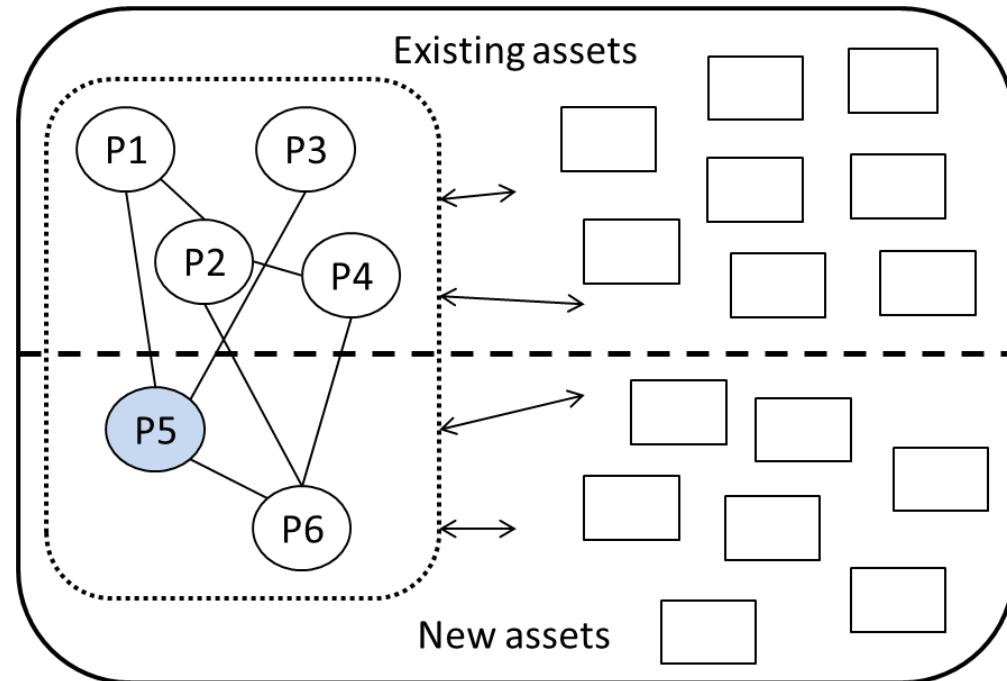
Independent



Value of portfolio

$$G_0^P(\{S_{i,0}\}_{i \in \mathcal{I}}) = \sum_{i \in \mathcal{I}} G_{i,0}(S_{i,0}).$$

Interdependent



Value of portfolio

$$G_0^P(\{S_{i,0}\}_{i \in \mathcal{I}}) \neq \sum_{i \in \mathcal{I}} G_{i,0}(S_{i,0}).$$

Example of interdependence: DH & CHP (1)



District Heating (DH) network

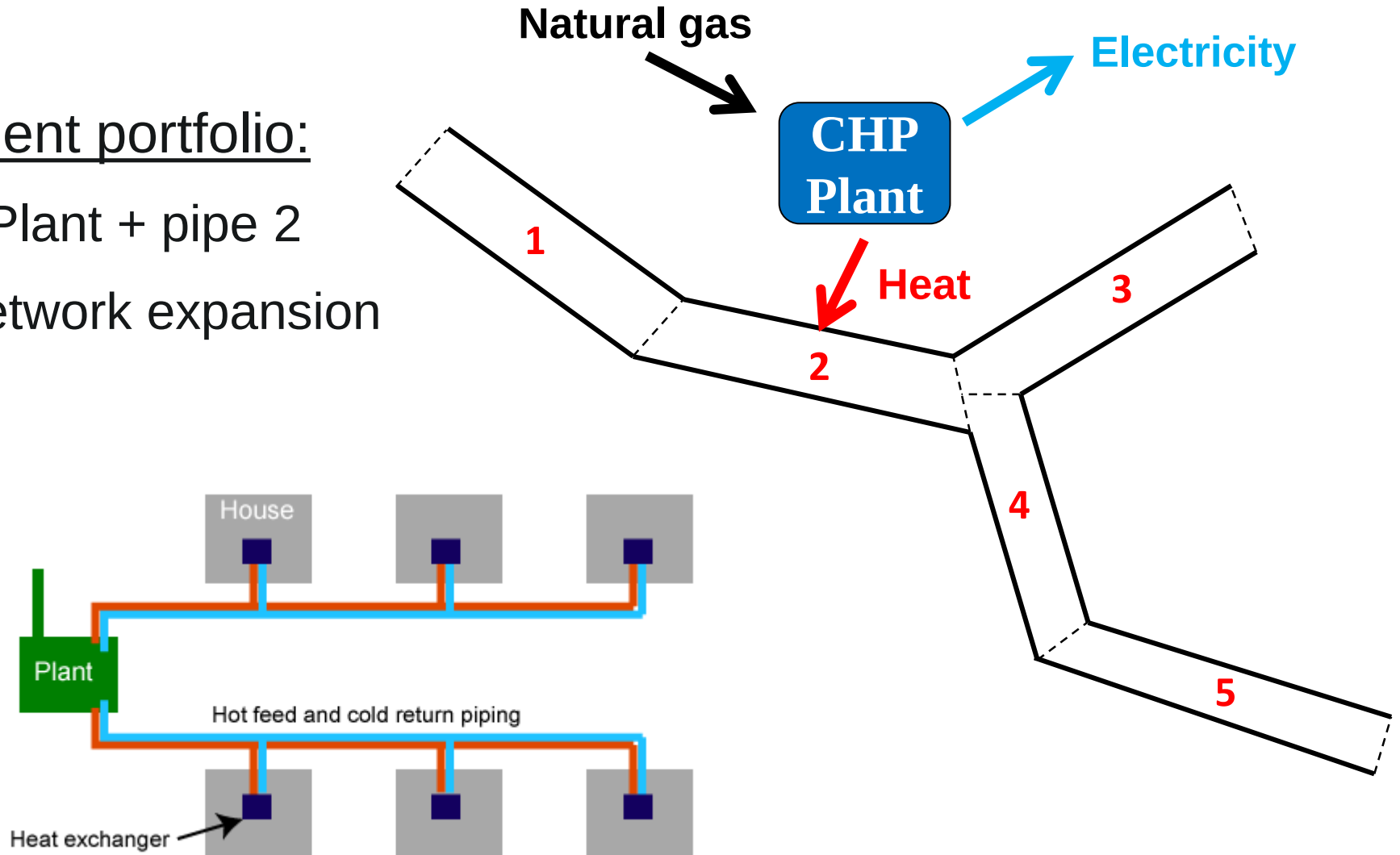
Combined Heat & Power (CHP) plant



Example of interdependence: DH & CHP (2)

Investment portfolio:

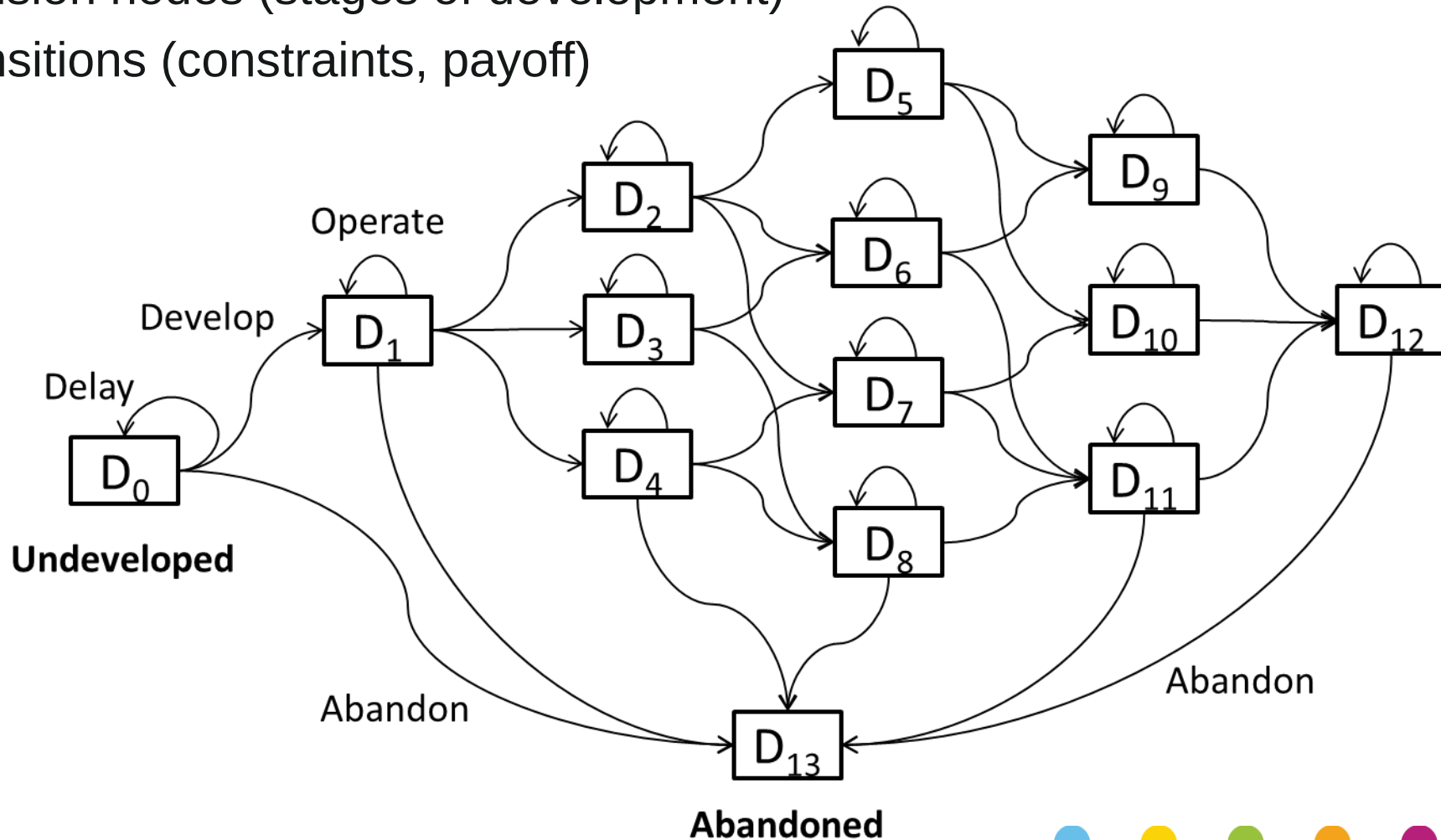
-) CHP Plant + pipe 2
-) DH network expansion



Example of interdependence: DH & CHP (3)

Influence diagram:

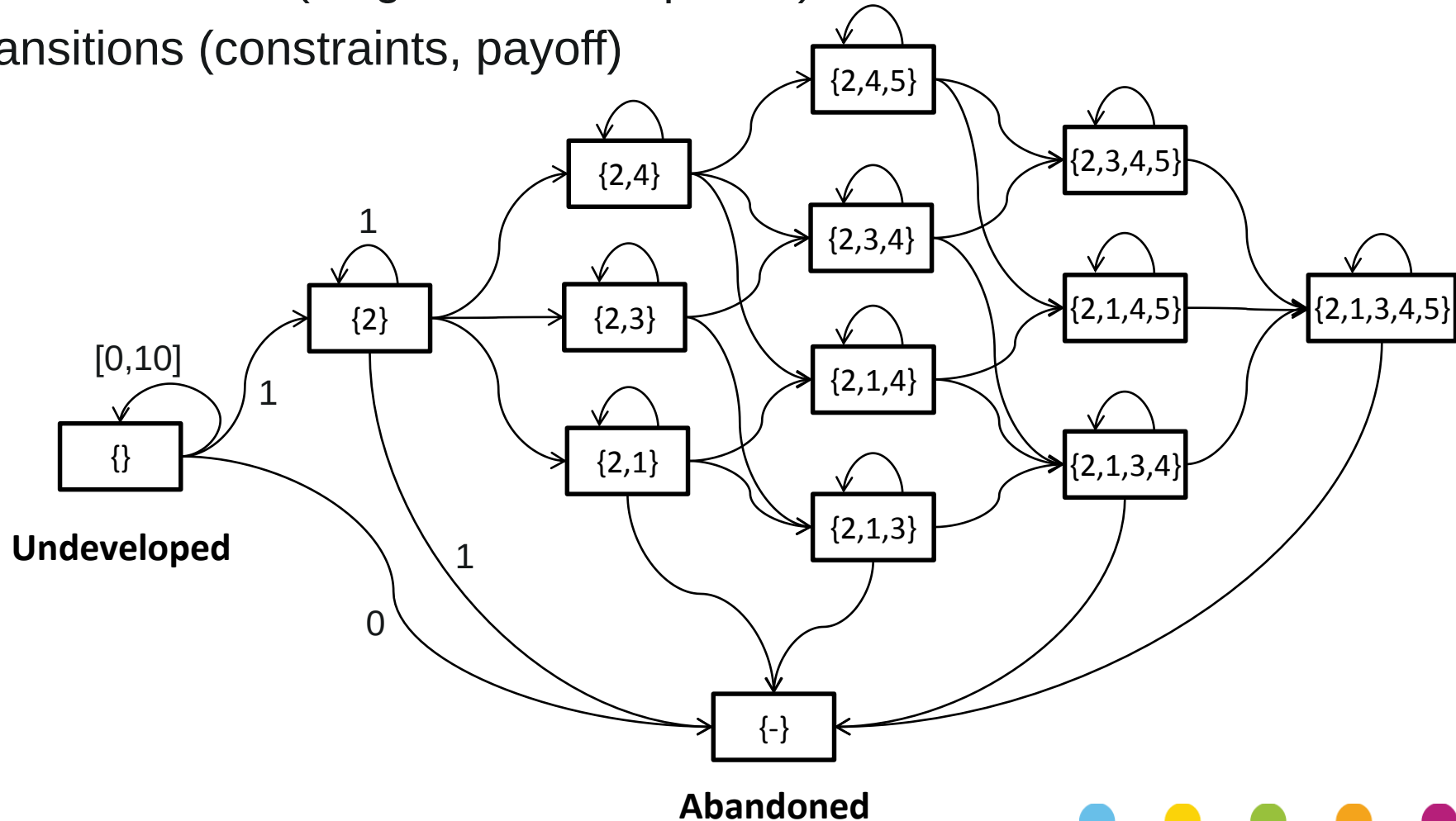
- Decision nodes (stages of development)
- Transitions (constraints, payoff)



Example of interdependence: DH & CHP (4)

Influence diagram:

- Decision nodes (stages of development)
- Transitions (constraints, payoff)



Example of interdependence: DH & CHP (5)

- Input parameters:

- Risk free rate: 4.5%
- Economic life: 35 years
- Capital costs and annual (year 0) costs & revenues
- GBM to model stochastic behaviour of annual costs and revenues
 - cost: drift: 2%, volatility: 3%
 - revenue: drift: -0.5%, volatility: 1.5%
- LSM approach: powers of the underlying, 9 terms, 100,000 paths

- Numerical results:

- Our portfolio approach:

→ Portfolio value: £89,000

- NPV (without flexibilities):

$\{\}, \{2\}, \{2,1\}, \{2,1,3\}, \{2,1,3,4\}, \{2,1,3,4,5\}$

→ NPV = -£13,000

Time	Node	Decision(s)
0	{}	Delay until year 2
2	{}	Develop CHP plant + pipe 2
3	{2}	Operate for 3 yrs
6	{2}	Operate for 1 yr + develop pipe 1
7	{2,1}	Operate for 1 yr + develop pipe 4
8	{2,1,4}	Operate for 2 yrs
10	{2,1,4}	Operate for 1 yr + develop pipe 5
11	{2,1,4,5}	Operate for 4 yrs
15	{2,1,4,5}	Operate for 1 yr + develop pipe 3
16	{2,1,3,4,5}	Operate for 21 yrs
37	{2,1,3,4,5}	Abandon



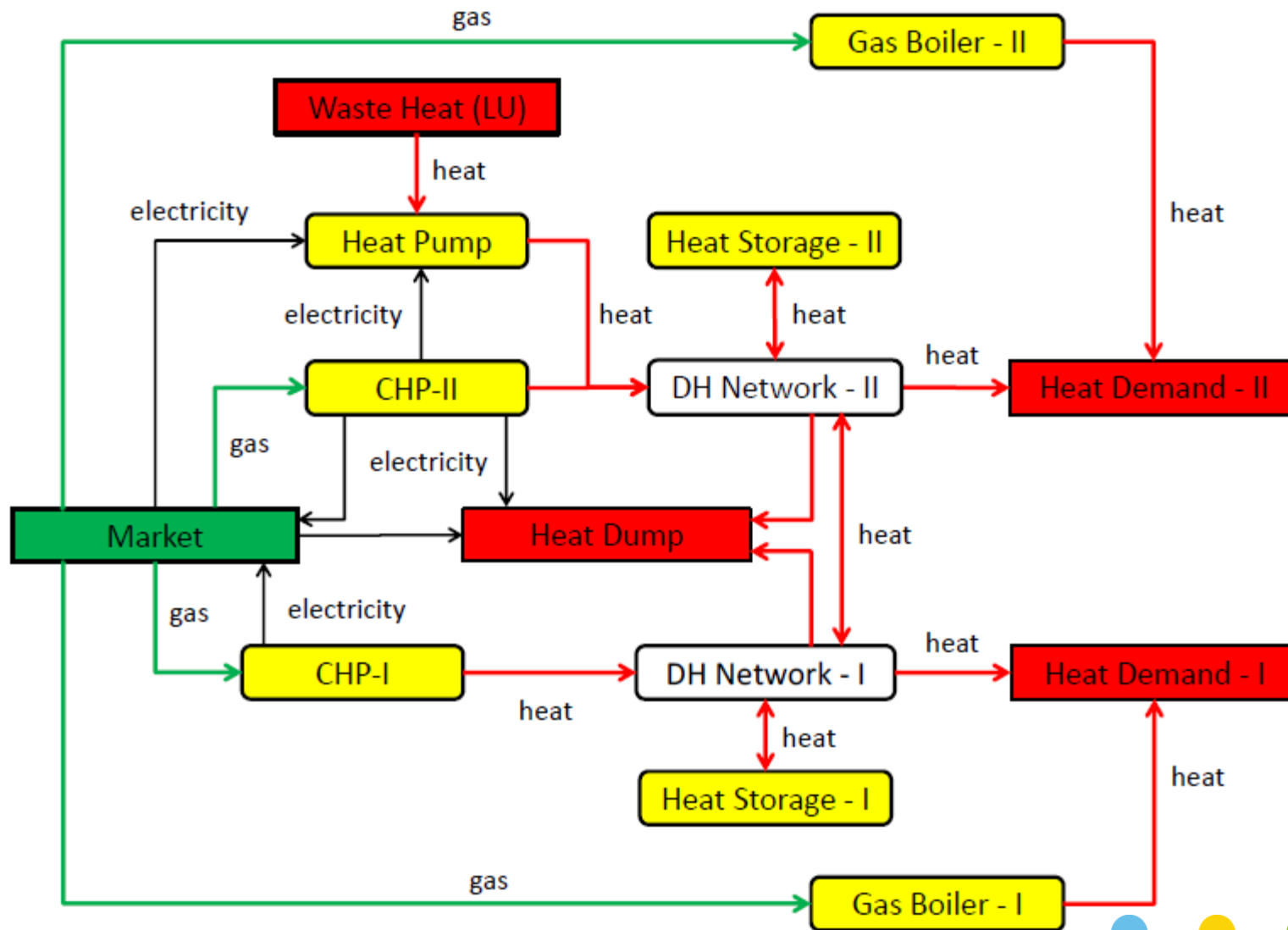
Bunhill Heat and Power network (1)



Figure: [http://www.islington.gov.uk/publicrecords/library/Environmental-protection/Information/Guidance/2015-2016/\(2016-03-15\)-Bunhill-Heat-Network-Map.pdf](http://www.islington.gov.uk/publicrecords/library/Environmental-protection/Information/Guidance/2015-2016/(2016-03-15)-Bunhill-Heat-Network-Map.pdf)

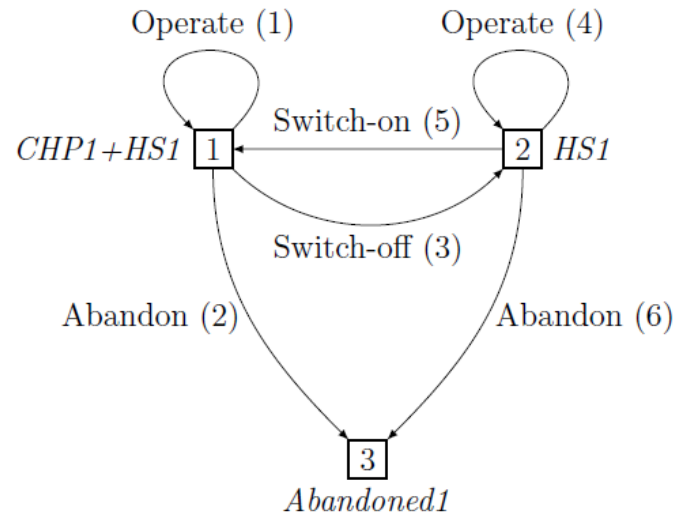


Bunhill Heat and Power network (2)

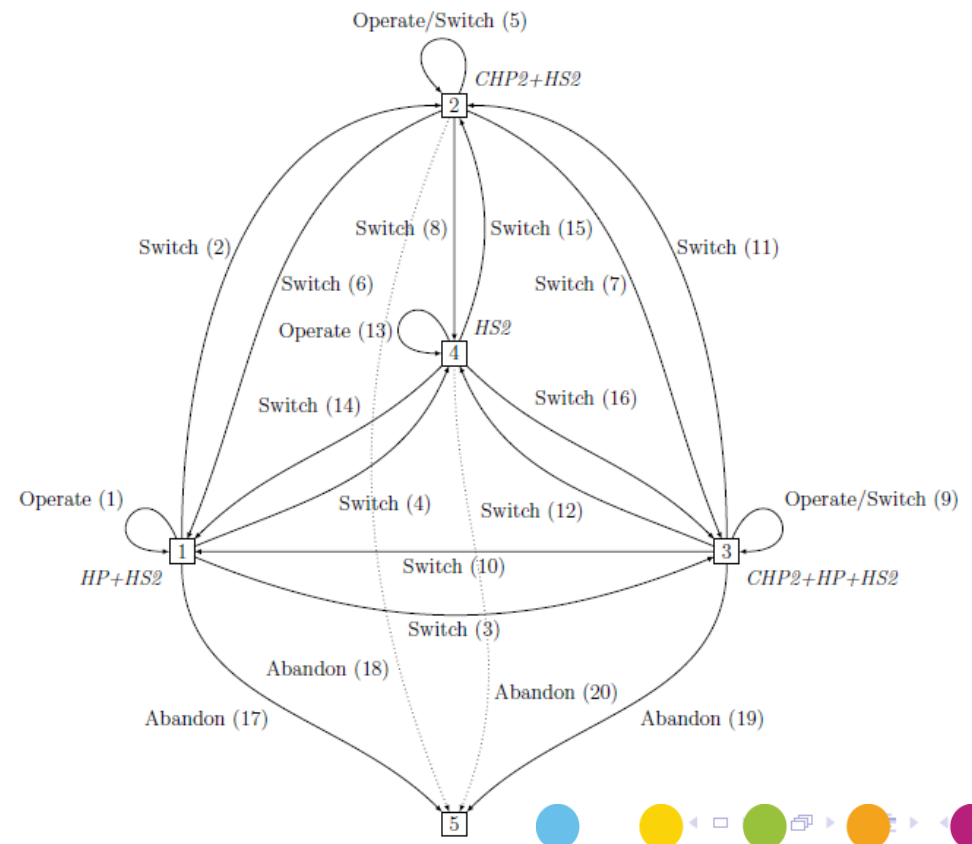


Bunhill Heat and Power network (3)

- Operational flexibility available in Bunhill 1:



- Operational flexibility available in Bunhill 2:



Conclusions

- The challenges of appraising DH investments illustrate many of the wider issues affecting 'smart cities' investment appraisal
- Existing appraisal techniques such as CBA and IRR are inadequate
- Our new real options based approach enables the representation of interdependencies, risks, flexibilities and strategic behaviour
- The approach is more complex but still practically applicable
- Further applications to DH and other smart cities investments are underway



Publications

- Lambert R.S.C., Maier S., Polak J.W., and Shah. N., (2016) "Optimal phasing of district heating network investments using multi-stage stochastic programming". *International Journal of Sustainable Energy Planning and Management*, **9**, 57-74.
- Maier S., Polak J.W., and Gann D.M., (2016) "Valuing strategic interactions in systemic urban infrastructure investments using option games: A portfolio-based approximate dynamic programming approach." In: *Proceedings of the 20th Annual International Real Options Conference*, Oslo and Trondheim, Norway.
- Maier S., Polak J.W., and Gann D.M., (2015) "Appraising a portfolio of interdependent physical and digital urban infrastructure investments: A Real Options approach." In: *Proceedings of the 19th Annual International Real Options Conference*, Athens and Monemvasia, Greece.

