Programme Area: Energy Storage and Distribution

Project: Impact Analysis

Title: Future Networks: Impact Analysis Heat Final Report

Abstract:

This deliverable provides the final report for the heat case studies that have been assessed as part of the project. Please refer to the Executive Summary on Page 11 for an overview of the report content.

Context:

This project assessed the potential impact of selected, identified innovations on specific types of network (relating to heat, gas, electricity and hydrogen). Generic modelled networks will be developed utilising the 2050 Energy Infrastructure Cost Calculator model developed by a separate ETI project to understand the expected costs of certain types of network. The modelled networks will provide 'business as usual data' and a useful basis for further understanding of the impact of identified innovations in terms of overall cost and network performance.

Disclaimer:
The Energy Technologies Institute is making this document available to use under the Energy Technologies Institute Open Licence for Materials. Please refer to the Energy Technologies Institute website for the terms and conditions of this licence. The Information is licensed ‘as is’ and the Energy Technologies Institute excludes all representations, warranties, obligations and liabilities in relation to the Information to the maximum extent permitted by law. The Energy Technologies Institute is not liable for any errors or omissions in the Information and shall not be liable for any loss, injury or damage of any kind caused by its use. This exclusion of liability includes, but is not limited to, any direct, indirect, special, incidental, consequential, punitive, or exemplary damages in each case such as loss of revenue, data, anticipated profits, and lost business. The Energy Technologies Institute does not guarantee the continued supply of the Information. Notwithstanding any statement to the contrary contained on the face of this document, the Energy Technologies Institute confirms that the authors of the document have consented to its publication by the Energy Technologies Institute.

BUROHAPPOLD
ENGINEERING

Energy Infrastructure Outlook 2050

Innovation Impact Analysis - Heat - Final Report

029656

5 January 2016

Revision 03

Revision	Description	Issued by	Date	Checked
00	Draft for review	HC	11/6/15	AY
01	Final following ETI comments	HC	21/7/15	AY
02	Final issue / minor changes	HC	13/11/15	AY
03	Final issue following ETI comments / minor changes	HC	05/01/16	AY

\\srv-london03\Project Filing\029656 ETI Energy Infrastructure Pathways 2050\F99 Network Innovations Impact Analysis\04 Cost Analysis\Final Drafts - Jan16\160105 AGC 029656 Innovation Impact Analysis - Heat - Final Report 03.docx

This report has been prepared for the sole benefit, use and information of Energy Technologies Institute for the purposes set out in the report or instructions commissioning it. The liability of Buro Happold Limited in respect of the information contained in the report will not extend to any third party.

author	**Angeliki Gkogka;Henrietta Cooke**
date	**05/01/16**
approved	**Alasdair Young**
signature	
date	**05/01/16**

..

Contents

Table of Tables

Table of Figures

Glossary

Term	Definition
Abandonment	A term used in the context of the ICC to refer to the end of life of an asset and the costs associated with its removal / decommissioning. Abandonment costs are included in Lifecycle costs.
Assembly	A term used in the context of the ICC. These are collections of Components compiled using quantity multipliers to produce composite costs for these Assemblies.
Carrier pipe	Pipe that carries fluid, in this case water. It is protected with exterior casing.
Compact village	Small settlement of houses independent of a bigger urban centre. Here it is considered to have its own isolated heat network.
Component	A term used in the context of the ICC. This is lowest level to which capital costs are disaggregated.
First costs	In this study, the term first costs refers to the initial capital cost incurred on installation of new equipment or decommissioning of existing commitment. First costs are the indexed costs at the date of installation / decommissioning and are not discounted.
Heat load diversity	Maximum possible heat demand as a ratio of the maximum theoretical heat demand at a single point in time.
Lifecycle	A term used in the context of the ICC to refer to the cost profile of an asset over its life including new build, minor and major refurbishment and ultimate abandonment / decommissioning.
Losses	As energy is transported from the point of generation through to the point of use, some of it will get lost from the system through leakage or other factors. These losses have various causes and have a cost associated with them, based on the energy price. The cost of these losses is not included in the ICC.
Net Present Value	This is the combined value of all future cash flows associated with a project discounted back to 2015. Net Present Value is the term used in the ICC however it should be noted that, as all cash flows in the cost tool are in fact costs (ie no 'values' or revenues are included), strictly the term should be Net Present Cost.
Normalised cost	The total cost of undertaking a project divided by a single parameter such as network length to give a cost per km or population to give a cost per capita.
Plate heat exchanger	Equipment that allows heat transfer from one medium to another. Metal plates allow this heat transfer between two fluid flows.
Project	A term used in the context of the ICC. Projects are collections of Assemblies with specific quantity multipliers combined to produce whole Project cost estimates.
Refurbishment	A term used in the context of the ICC to refer to the minor and major overhaul of an asset during its life.
Repurposing	Modifying the system to make it capable of carrying a different substance from the one for which it was originally designed (e.g. natural gas pipeline repurposed to carry hydrogen).
Secondary side systems	Heat systems that supplement primary heat sources.
Service connection pipe	Connecting pipes that branch off the gas main pipeline to supply end consumers.
Special crossings	When pipelines cross features such as rivers, railways or roads.
Substation	Equipment that allows heat transfer from a district heating network to an individual building's heat system.
Twin pipe	Flow and return pipes that are insulated in a single casing.
Two pipe	Flow and return pipes that are insulated in separate casings.

Acronyms

Term	Definition
BoQ	Bill of Quantities
Capex	Capital Expenditure
HIU	Heat Interface Unit
ICC	Infrastructure Cost Calculator
MEAV	Modern Equivalent Asset Value
MSOA	Middle layer super output area
NPV	Net Present Value
Opex	Operational Expenditure
Repex	Replacement Expenditure

1 Executive Summary

1.1 Project overview

This study brings together two strands of work within the ETI focused on understanding the cost and performance of energy infrastructure in the UK. On the one hand, the research projects undertaken by various teams looking at specific scenarios and innovations, and on the other, the Infrastructure Cost Calculator (ICC – formerly referred to as the Energy Infrastructure Outlook 2050 Cost Tool), an analysis tool based on an extensive database of energy infrastructure costs.

The research questions addressed can be divided into two broad categories:

- Firstly, questions around the configuration and cost of representative (or 'generic') networks applicable to particular situations.
- Secondly, questions around the potential impact of selected, identified innovations on specific types of network.

This report considers the research questions posed in relation to heat. Separate reports are available for electricity, natural gas and hydrogen.

The work undertaken here made use of the first version of the ICC and as such also acted as a testing phase. Some issues arose in relation to the output of the tool particularly in respect of the treatment of operational and lifecycle costs. These findings are being fed into a parallel project to develop a second version.

1.2 Key findings

Some findings are the same across all projects. These include:

- First costs are higher at later installation dates. This is due to the impact of the real-term cost trends in the ICC applied to labour, material and plant costs. There are clearly alternative views on cost trajectories and these will influence the relative impact of deferring installation.
- NPV[1] (Capex plus Opex) is lower for projects installed at a later date. Two factors come into play here: one, as expected, is the impact of discounting; the other is the way in which lifecycle costs are modelled in the ICC and the fact that the analysis has been undertaken for a fixed period of 60 years (2015 to 2075) irrespective of the installation date. Lifecycle costs include for a major refurbishment (100% of new build costs) at a fixed period after first instalment. For later installation dates, this major refurbishment may be beyond the analysis period and therefore not included in the NPV calculation.
- Opex costs represent a relatively small proportion of whole life costs. It should be noted that the modelling of Opex is to be revised in the next version of the ICC which may influence the outturn values (see Section 3.2.4). Note also that Opex does not include the cost of any energy lost from the system.

---

[1] In this study, the term Net Present Value (NPV) refers to the combined cash flows of a project over the project period discounted back to 2015. Note that as all cash flows in this analysis are costs (ie no revenues are included), strictly the term should be Net Present Cost. NPV is used to be consistent with the terminology used in the ICC.

A summary of findings specific to each project is given in Table 1-1.

Table 1-1 Key findings for heat network research projects

Ref	Research question	Key findings
GENERIC NETWORKS		
H-G-17	Representative heat network model: district heating networks modelled for semi-urban, urban and London areas at different populations sizes / densities	• Connections, including service pipes running from the mains to the buildings, are the major element of network cost in more urban areas while main pipework is the major element in more rural areas reflecting the density of connections in the area. • 300mm pipework costs represent the highest share of the network costs. This is because they represent the highest share of network length as they serve a wide range of loads prevalent in all the analysed MSOAs. The predominance of the 300mm pipework costs in the study is partly a limit of the ICC which has only 3 no. pipe diameter sizes (150, 300, 450mm). In practice, smaller pipe diameters might be used. • First cost per connection is highest in urban areas and lowest in London areas, with semi-urban areas being in the middle of the range. This is because the density (and hence pipe length per connection) of the urban areas in this exercise is closer to that of semi-urban areas than London. Thus the additional costs of installation in urban areas outweighs the shorter pipe length so that urban costs per connection are higher than semi-urban ones. In contrast, comparing urban with London, although installation costs in London are higher than urban in general, the higher connection density in London (and hence shorter pipe length per connection) outweighs the higher costs so that overall costs per connection in London are lower than urban. • This trend is slightly different with NPV per connection. Urban costs are still the highest but instead semi-urban costs are lower than London costs. This is due to the difference in the relative share of Assemblies (connections and pipework) combined with their different lifecycle profiles (25 and 40 years respectively). This means connections are replaced more frequently and as they form a greater share of network first cost in London have a greater impact on NPV than in lower density areas where they form a lower percentage of the network cost. • These results are based on a small sample of areas mapped in GIS. Further data points could be usefully obtained by mapping more areas and testing whether the semi-urban – urban – London trend described above still holds. • The trends illustrate that in pure cost terms, not including revenues, there may be areas outside of the higher density urban areas which make more sense for heat networks. For example semi-urban areas which have access to low cost sources of heat (e.g. waste heat from energy from waste) may be more viable than high density areas where heat sources may be more expensive (e.g. small scale natural gas fired CHP).
H-G-18	Representative heat network model - compact villages: district heating networks modelled for a compact village with a single population size	• The results are consistent with those of H-G-17 with these relatively low density areas having higher NPV and costs per connection compared with those of more dense semi-urban areas.
H-G-19	Representative heat network model - connecting networks: substations and interconnecting pipework of 2 different lengths and 3 different loads in London, urban and semi-urban contexts	• The network costs represent the main share of the cost of connection, being over 70% in all cases. The share is lower in more dense urban areas where pipe lengths are lower and so the substations account for a greater share of the costs. • Network costs take a greater share of total cost as the load increases due to the higher costs of the larger pipe diameters required. • Costs per km increase moving from semi-urban to London reflecting the greater costs of installation in more congested urban areas.

Ref	Research question	Key findings
		• Costs per MW decrease with increasing size. The difference is particularly marked between 5MW and 20MW as, although a slightly larger substation is required, the cost is more than offset by the higher load. • Costs could be further reduced by using direct connections e.g. substations would not have heat exchangers between networks and the water in each network would mix between them. This is common in well developed heat network markets but less common in the UK where concerns regarding liability or mismatches in age of networks tend to prevent this. • When assessing the potential for interconnection of heat networks the benefits are often to do with more efficient or higher utilisation of the central plant due to greater scale and diversity of loads. This benefit is not captured in the analysis. Similarly, no value is attached to increased resilience.
INNOVATIONS		
H-I-20	Cost impact of reducing network temperature: impact of using flexi-polymer pipe in place of 150mm steel pipe in the same contexts and configurations as in H-G-17	• The unit cost (in 2015) of the 150mm flexi-polymer pipe is £1,705,400/km compared with £1,812,800/km for steel. Both costs refer to installation in an urban environment. The market for steel versus polymer has not been assessed and growth in the polymer market could lead to reduced costs. • As a consequence of the lower unit costs, first costs of the innovation are lower than those of the counterfactual. However, NPV costs are higher. This is due to the differing lifecycles of the two products – flexi-polymer has a shorter life (25 years in the ICC) than steel, thus the costs of replacement during the product life outweigh the lower initial costs. This is also true of the cost per connection. This assumption may be challenged in practice but there is limited data in this area. • The same trends identified in H-G-17 in respect of the cost per connection in different contexts applies to flexi-polymer. • Flexi polymer is not used in the service pipes, due to the tool costing the service pipes as part of the connection costs. • The tool does not pick up the potential to use a lower diameter pipe when using polymer pipe due to the reduced frictional losses from the smoother surface. Often 1 size smaller pipework can be used.

1.3 Further work

Further work could be undertaken on some of the tasks as follows:

- H-G-17 (and H-I-20): The reliance on single locations to represent particular types of location remains a limitation of the analysis. Further work could include the analysis of additional locations to better understand and develop general cost trends.

In addition, all tasks could be re-run in the second version of the ICC. This version will use a revised approach to modelling Opex and lifecycle costs which should address the issue encountered in this study in relation to the use of a fixed analysis period. ICC v2 will also incorporate different costs trends which will also impact on results.

2 Introduction

2.1 Overview

The ETI and its Members are interested in the cost effective deployment of energy infrastructure in the UK. By 2050 the UK will need to be meeting stringent targets requiring an 80% reduction in CO_2 emissions, whilst maintaining a sufficient supply of energy. In order to appropriately assess the opportunities for meeting these targets, it is necessary to understand, amongst other things, the costs and performance of the energy infrastructure that will carry energy from where it is generated to where it is consumed.

The study brings together two strands of work within the ETI aimed at addressing these issues. On the one hand, the research projects undertaken by various teams looking at specific variations and innovations, and on the other, the Infrastructure Cost Calculator (ICC – formerly referred to as the Energy Infrastructure Outlook 2050 Cost Tool), an analysis tool based on an extensive database of energy infrastructure costs. The tool is being used to enable the research teams to answer specific research questions.

The research questions addressed in this study can be divided into two broad categories:

- Firstly, questions around the configuration and cost of representative (or 'generic') networks applicable to particular situations. These network models are required to understand the expected costs, etc of certain types of typical network, the intention being to enable expedited assessment of certain types of network (at a high level) in future as the need arises, e.g. through making adjustments to the models provided as part of this work.
- Secondly, questions around the potential impact of selected, identified innovations on specific types of network. For example, questions around the difference in cost and performance between repurposing natural gas pipelines to carry hydrogen and building hydrogen pipelines from scratch. The generic networks provide the counterfactual against which the innovations can be compared.

This report considers the research questions posed in relation to heat. Separate reports are available for electricity, natural gas and hydrogen.

The study was undertaken by BuroHappold with the Sweett Group and a team of external specialists to validate the technical scoping (see Appendix A).

2.2 Approach and methodology

An overarching methodology was developed applicable to all research questions. As illustrated in Figure 2-1, key steps were to:

1. Agree the outline scope of each of the research questions with ETI.
2. Develop a detailed scope for each of the research questions including a clearly defined network design and associated Bill of Quantities (BoQ).

An important aspect of this step was to ensure that, as far as possible, the network designs were representative of the particular situation being modelled. To support this, a team of experts was engaged to provide a robust approach to validation and to ensure that assumptions and simplifications made were reasonable. The detailed scoping methodologies are particular to each research question and are covered in the relevant chapter of this report. Full copies of all Detailed Scoping reports are available separately from the ETI.

3. Cost the network design using the ICC, including costing any additional infrastructure elements not already available. For this step, the details of the Bill of Quantities generated during the detailed scoping phase were input to the tool under various contexts, capacities and timescales, thereby generating a number of data points on which to perform the analysis.

4. Analyse the cost data generated by the ICC in the context of the research question and, where relevant, compare the cost of the innovation with that of the generic counterfactual.

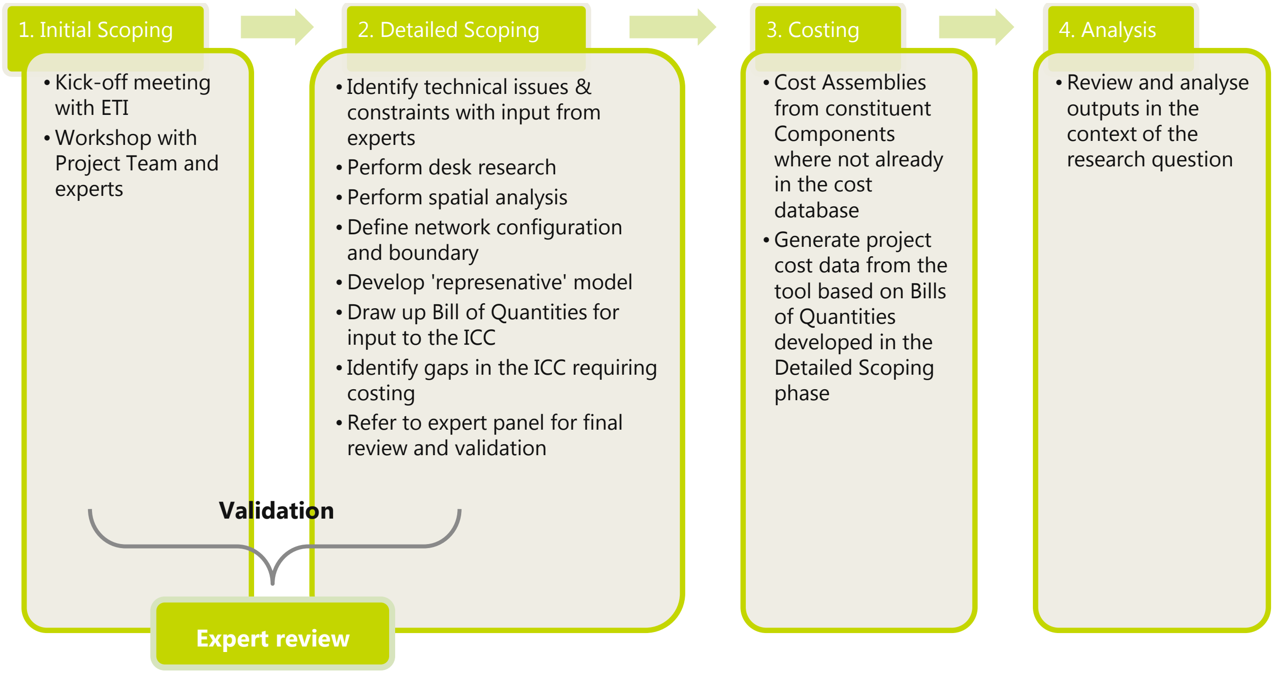


Figure 2-1 Outline methodology applied to all research questions

The ICC that underpins this analysis is a tool that was commissioned by ETI in 2012 and created by Buro Happold and the Sweett Group. It contains a wealth of information on the capital and operational costs of infrastructure related to the four energy vectors, electricity, gas, heat and hydrogen. To provide context for readers of this report, further background information on the structure and functionality of the tool is provided in Chapter 3.

2.3 Scope

A summary of the heat research questions covered in this study is provided in Table 2-1. As noted above, these questions arose from within ETI's operational and strategic teams, and as such are specific to particular areas of work on which they are engaged. The table outlines the context of each research project and the value this analysis provides.

Table 2-1 Summary of heat research questions covered in this study

Ref	Title	Description	Context / value added
GENERIC NETWORKS			
H-G-17	Representative heat network model	Order of magnitude costs and performance. Provide a reference for heat network cost at various populations and population densities.	Semi-urban, urban and London. Provides generic costs per connection that can be applied to different population contexts and densities.
H-G-18	Representative heat network model - compact villages	Order of magnitude costs and performance. Provide a reference for heat network cost in relation to compact villages.	Semi-urban. Provides generic costs per connection for compact villages.
H-G-19	Representative heat network model - connecting networks	Order of magnitude costs and performance. Provide a reference for heat network cost of connecting existing heat networks.	Semi-urban, urban and London. Provides generic costs per MW connected for different connection lengths.
INNOVATIONS			
H-G-20	Cost impact of reducing network temperature	Alternative pipe materials (flexi-polymer) that can be used at lower temperatures compared with steel under different populations and densities as modelled in H-G-17.	Semi-urban, urban and London. Provides analysis of the impact of the innovation of using flexi-polymer pipe materials on cost out turn.

2.4 Report structure

This report synthesises the work undertaken on each of the research questions and presents and discusses the findings. A chapter is included for each question using the project reference provided in Table 2-1. The analysis is based on the detailed scoping exercise that was undertaken for each project. The Detailed Scoping reports are available separately from the ETI.

An overview of the ICC is provided in Chapter 3 to provide context to the reader when interpreting the results.

3 Infrastructure Cost Calculator

3.1 Introduction

This chapter explains the workings of the ICC in the context of this study. Full details of its structure and operation can be found in the ETI Energy Infrastructure 2050 Final Report, 22 November 2013, available from the ETI.

This chapter should be considered as a reference chapter to provide background to the interpretation of the data.

3.2 Cost Tool overview

The ICC is a structured database containing cost data for a broad spectrum of infrastructure elements for electricity, gas, heat and hydrogen in respect of transmission, distribution, conversion, connection and storage. It was developed over a two year period by Buro Happold in close association with the Sweett Group, combining expertise in technical design and cost modelling. The tool is under development with a second version due to be released towards the end of 2015. The analysis presented in this report was undertaken using the first version, completed in November 2013.

The following sections highlight some of the key features of the tool that are of relevance to this study.

3.2.1 Tool structure

The tool uses a modular approach to build up costs, from Component to Assembly to Project as shown in Figure 3-1.

- **Components** represent the lowest level to which capital costs are disaggregated. For example, civil engineering cost Components may include excavation, filling, surface re-instatement, etc.

- **Assemblies** are collections of Components compiled using quantity multipliers to produce composite costs for these Assemblies. Components are assembled for new build, refurbishment, re-purposing and abandonment within Assemblies, as appropriate. Assemblies are the key 'building blocks' of the tool with each Assembly being clearly defined in a technical diagram that gives the element boundary, typical configuration and capacity range.

  The name given to each Assembly includes the following descriptors:

  - Vector: Electricity, Gas, Heat, Hydrogen
  - Function: Transmission, Distribution, Conversion, Connection, Storage
  - Mode: eg. 50°C, 70°C, 120°C
  - Rating: eg 450mm heat network
  - Installation: Buried, Overhead, Offshore, Tunnelled, None

  This naming structure is used wherever Assemblies are referred to in this report.

- **Projects** are collections of Assemblies with specific quantity multipliers combined to produce whole Project cost estimates. Projects can be attributed with specific context (urban, rural, etc), scale and region to allow Assembly costs to be appropriately modified during calculations.

This study makes use of the Project functionality of the tool. A detailed description of how this works and how the data flows from Component to Assembly to Project is provided Appendix B.

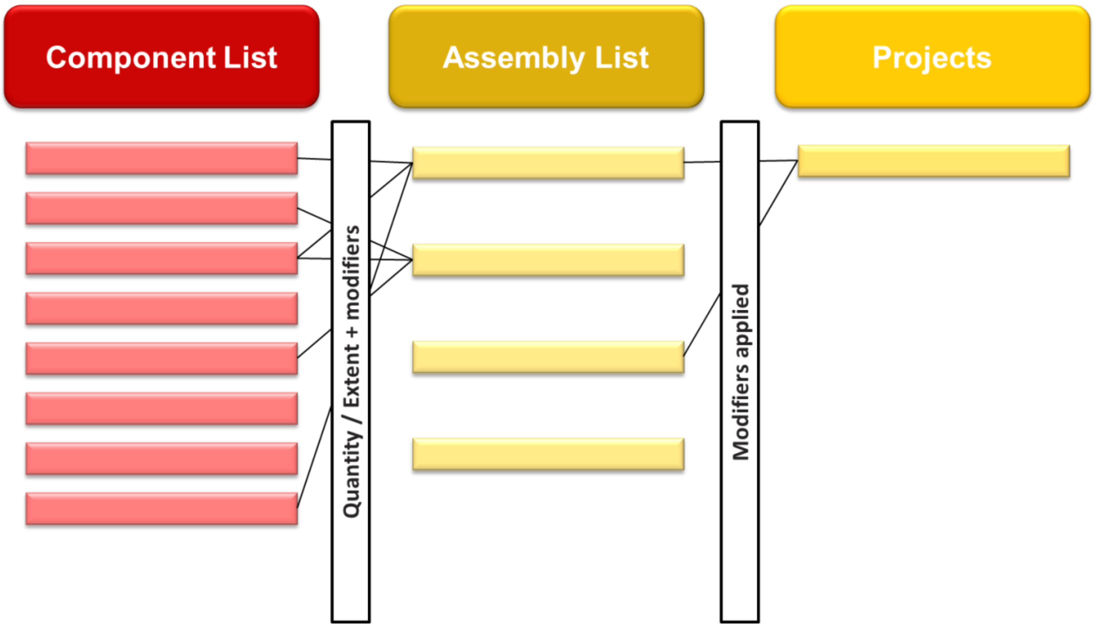


Figure 3-1 Outline of Infrastructure Cost Model structure

3.2.2 Cost data

The approaches to capital and operational costs in the tool are different, primarily due to the difference in availability of data.

Capital costs are derived using a 'bottom up' approach whereby each Component is costed separately as data is generally available at this level. The data has been built up from a number of sources which vary in quality from strong to weak. Items for which data is weakest are generally those which are relatively new and for which there are few precedents. The quality of the data is referenced within the tool.

A more 'top down' approach is used for operational costs, based on regional and / or network wide data that reflects the way that networks tend be managed and reported upon, particularly in the case of the regulated utilities. Operational costs include for direct and indirect costs and are based on the published network costs of the Distribution Network Operators (DNOs)[2]. Profiles for changes in operating costs over time are described in Section 3.2.4 below.

---

[2] For a full description of how operational costs were applied in the tool, see the *ETI Energy Infrastructure 2050 Final Report*, 22 November 2013, available from the ETI, in particular Chapter 7 and Appendix G, *Opex Framework for Energy Infrastructure*, PPA Energy, April 2013.

3.2.3 Component cost rate modifiers

All Components are given a baseline cost, split into materials, labour and plant. In order to reflect the fact that costs vary in different contexts and under different circumstances, modifications (expressed in percentage changes) to this baseline cost are allowed for. Thus for example, while the baseline cost for civils associated with the installation of 12" LP gas pipeline in a rural context might be £135/m, the ICC assumes that semi-urban costs are 130% of this and urban costs are 400%. Similarly, cost rate modifiers are applied for different scales of installation, and different environments such as ground conditions.

To take account of the variation of costs across the UK, the current version of the ICC applies Regional Tender Price Indices as extracted from Building Cost Information Service (BCIS). Thus for example, the cost of projects installed in London are inflated by 122% against the 'All of UK' baseline.

3.2.4 Operational and lifecycle cost profiles

The ICC recognises that different infrastructure elements are likely to have different cost profiles over time. This is accounted for through the application of different operational cost and lifecycle cost profiles.

- **Operational cost profiles**: The most significant impact on operational costs over an asset's life is the failure rate and therefore the need for reactive maintenance. The failure rate is assumed to be mainly influenced by the asset type, either active or passive. On this basis, two profiles are incorporated into the tool to represent the variation in operating cost over the life of the asset (from 0 to 100% of the defined asset life) as illustrated in Figure 3-2. The area under each profile curve is taken as the total operating cost for the asset over its life and the operating cost in any given year is determined as a proportion of the total operating cost that is applied in that year[3].

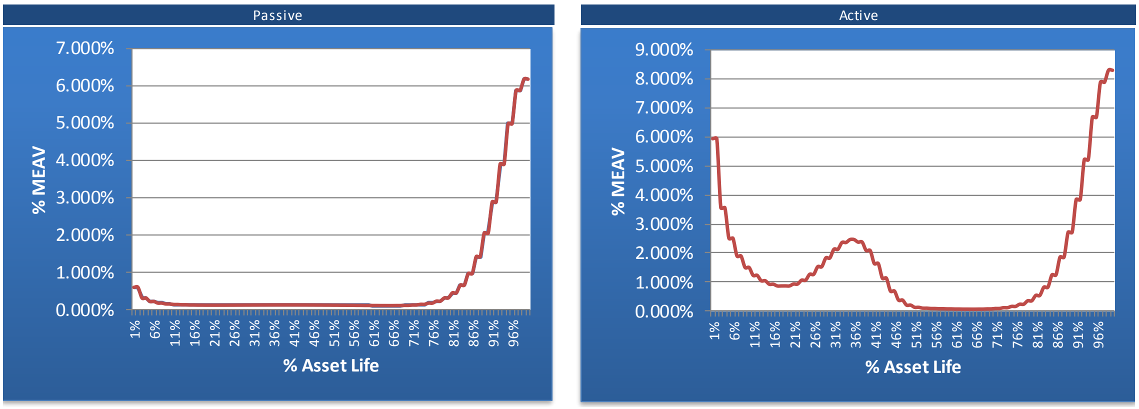


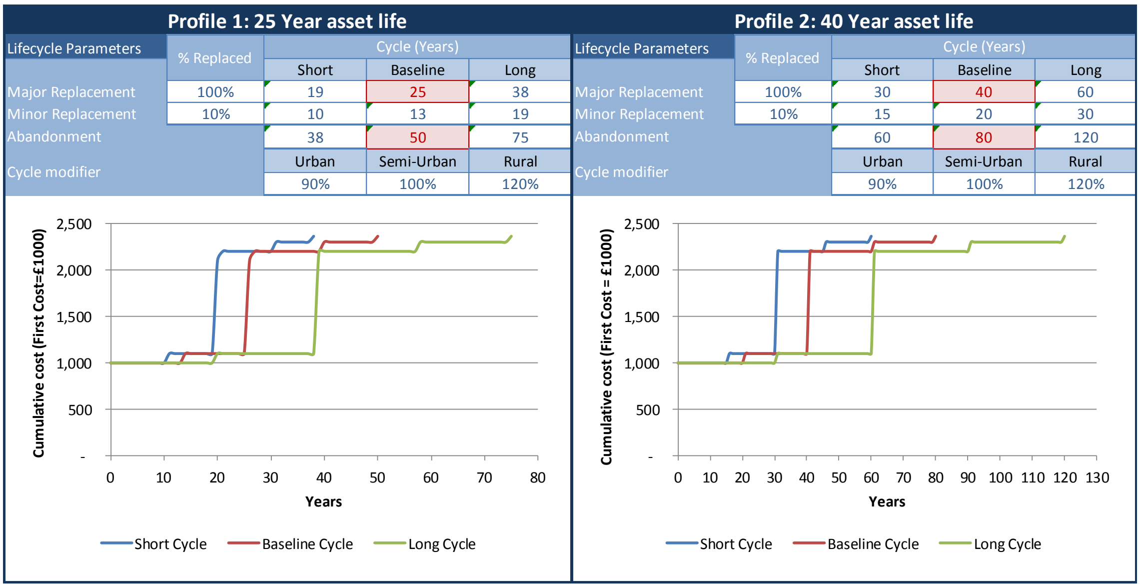
Figure 3-2 Passive and Active Opex profiles in the ICC v1[4]

---

[3] The modelling of Opex and lifecycle costs will be changed in v2 of the ICC. In v1, Opex comprises failure costs and indirect Opex only, with cyclical replacements of capital equipment and abandonment being modelled through the lifecycle profiles as described here. In v2, the method will use combined Weibull curves to represent failure costs, indirect Opex and replacements of capital equipment, with these latter costs being spread over a number of years, rather than all at once as in v1.

[4] MEAV is the Modern Equivalent Asset Value and is used as the basis for calculating operational costs.

- **Lifecycle cost profiles**: The lifecycle profile defines the periods of major and minor replacement and the percentage replaced in each of these cycles. It also includes abandonment at end of life. The cycles are deemed to differ according to context (ie assets are assumed to have a shorter lifecycle in an urban context than in a rural one). Two examples of lifecycle profiles used in the tool are shown in Figure 3-3^{3}.



Profile 1: 25 Year asset life

Lifecycle Parameters	% Replaced	Cycle (Years)		
		Short	Baseline	Long
Major Replacement	100%	19	25	38
Minor Replacement	10%	10	13	19
Abandonment		38	50	75
Cycle modifier		Urban	Semi-Urban	Rural
		90%	100%	120%

Profile 2: 40 Year asset life

Lifecycle Parameters	% Replaced	Cycle (Years)		
		Short	Baseline	Long
Major Replacement	100%	30	40	60
Minor Replacement	10%	15	20	30
Abandonment		60	80	120
Cycle modifier		Urban	Semi-Urban	Rural
		90%	100%	120%

Figure 3-3 Lifecycle profiles in the ICC v1

3.2.5 Trends

The tool includes two specific types of cost trend that are applied to Component data.

The first are general real-term cost trends applied specifically to labour, materials and plant. High, medium and low increase trends are allowed for within the ICC, with the default trend – used in this analysis – being medium (Figure 3-4). Alternative versions of these trends are being developed for future analysis.

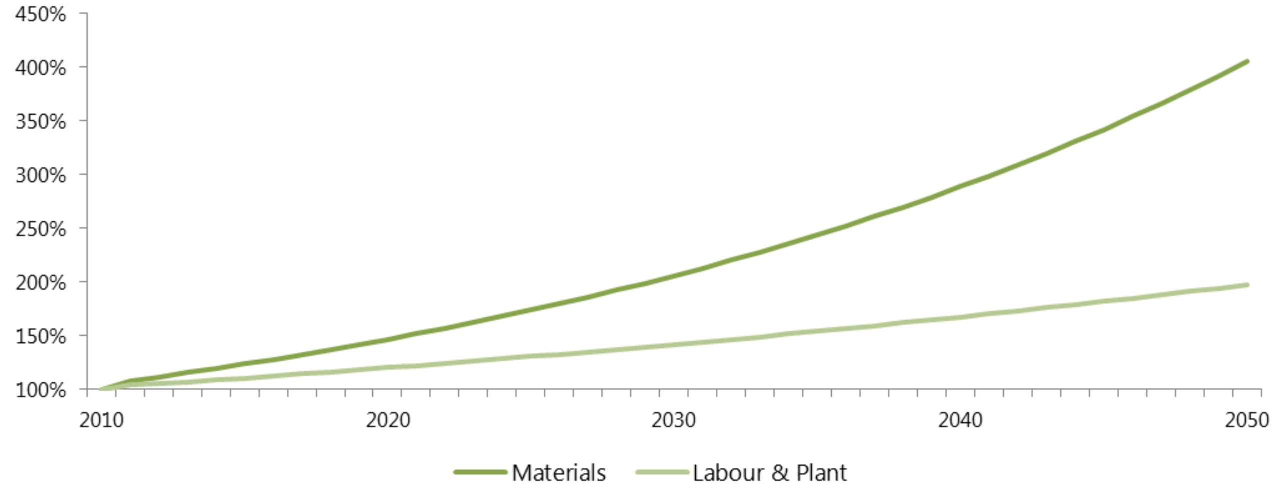


Figure 3-4 Medium general real-term cost trends as applied in the analysis

The second are technology cost curves that relate to the different cost trajectories arising as a consequence of the maturity of the underlying technology. Five curves are available within the ICC as illustrated in Figure 3-5. These are taken from a report prepared by EA Technology for Ofgem[5] and are made up as follows:

Type 1; Rising (based on an average of the Steel and Aluminium cost curves)

Type 2; Flat (to represent no change in cost)

Type 3; Shallow reduction (based on an average of offshore wind farm costs and flat line)

Type 4; Medium reduction (based on the cost curve for offshore wind farms)

Type 5; High reduction (based on the cost curve for laptops)

The majority of Components are categorised as Type 2 (flat) but steeper reduction curves are applied to more innovative technologies.

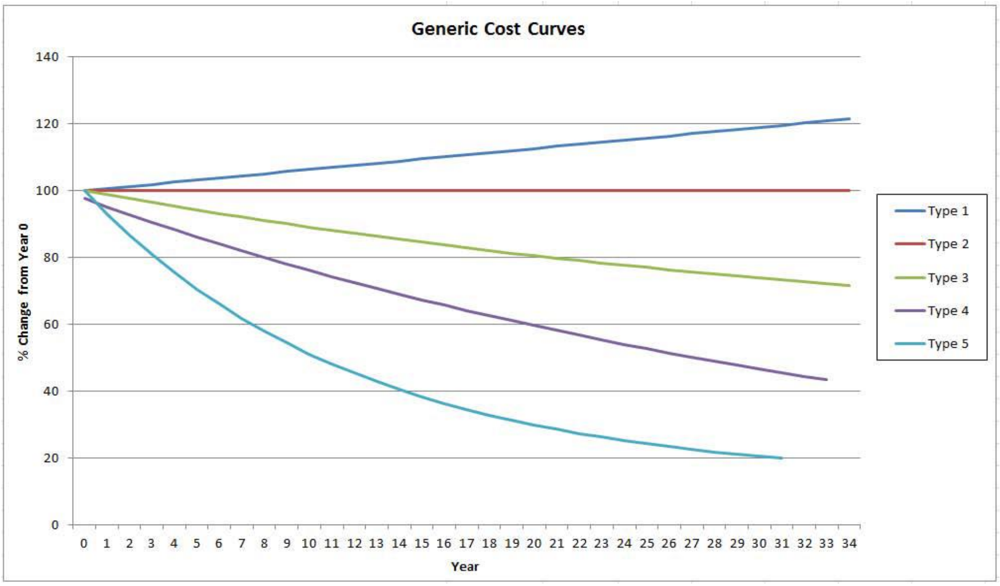


Figure 3-5 Technology cost curves incorporated into the ICC v1

3.2.6 Projects

For the purposes of this study, the key functionality of the tool is the costing of Projects. A Project is essentially a Bill of Quantities (BoQ) based on a specific network design, the BoQ comprising a list of Assemblies each with a particular quantity.

Project costs are built up within the database such that cost data flows from the Components through to the Assemblies and on to the Project. As noted above, the tool allows for baseline costs to be modified according to particular circumstances of installation. Thus for example, different projects may be installed in different ground conditions, or in different contexts (urban, semi-urban, rural) resulting in different out turn costs.

---

[5] http://www.ofgem.gov.uk/Networks/SGF/Publications/Documents1/WS3%20Ph2%20Report.pdf

A detailed description of how the cost rate modifiers are applied and the data flows from Component to Assembly to Project is provided in Appendix B.

3.3 Application of the ICC in this study

This section outlines how the ICC has been used in this study, describing the treatment of all input variables and the derivation of outputs.

3.3.1 Inputs

As noted above, the ICC allows for a variety of factors to be specified in order to tailor the analysis to the specifics of a particular project. For this study, some of these have been applied specifically for each project while some have been fixed across all projects as a practical response to managing the amount of data generated. A description of each variable is given below.

1. Add on costs (contingencies etc): these are calculated as a percentage of Capex and have been set at the same rate for all projects in this analysis as detailed in Table 3-1.

Table 3-1 Add on costs applied to all projects

Parameter	Description / details	Value
Project management, Engineering, etc	% to be added to Capex	12%
Preliminaries	% to be added to Capex	15%
Contractor overheads and profit	% to be added to Capex	5%
Contingencies	% to be added to Capex	10%

2. Cost trends for labour, materials and plant: all projects use the Baseline trend (see Section 3.2.5).
3. Technology maturity: these are specified at Component level depending on the nature of the Component (see Section 3.2.5).
4. Installation conditions: excavation difficulty, ground contamination and ground water are the same for all projects as outlined in Table 3-2.

Table 3-2 Ground conditions applied to all projects

Parameter	Condition	% of ground in specified condition
Excavation difficulty	Ground is soft and clean. No rock or hard material	60%
	Intermittent rock / hard material (20% by volume)	30%
	Prolific rock / hard material (75% by volume)	10%
Ground contamination	Ground is clean and inert	50%
	Ground is mildly contaminated	30%
	Ground is heavily contaminated	20%
Ground water	Little or no ground water	80%
	Intermittent dewatering required	20%
	Continuous dewatering required	0%

5. Region: all projects (rural, semi-urban and urban) are designated as 'All of UK' with the exception of the London context which is designated as London (see Section 3.2.3).

6. Context: this is a variable within the analysis, thus projects are defined as urban, semi-urban or rural as specified in the relevant Detailed Scoping document.

7. Optimism bias: this is the same for all projects as outlined in Table 3-3.

Table 3-3 Optimism bias applied to all projects

Parameter	Description / details	Value
Optimism bias	% Increase to estimated NPV to allow for Optimism Bias:	Capital Expenditure
	Lower	6%
	Upper	66%

7. Cash flow parameters: these are the same for all projects as outlined in Table 3-4. In particular it is important to note that cash flows are derived for the period 2015 to 2075 (ie a 60 year period) regardless of installation date. Thus a project installed in 2040 will have cash flows over the period 2040 to 2075 and these cash flows will be discounted back to 2015.

Table 3-4 Cash flow parameters applied to all projects

Parameter	Description / details	Value
Start year	This is the date at which the NPV is calculated.	2015
Lifecycle Assessment Period (years)	This is the total period over which project cash flows are assessed.	60 years
Discount rate	From 2015	3.5%
	From 2046	3.0%

3.3.2 Outputs

The key outputs from the ICC used in the analysis are the Net Present Value (NPV)[6] of the capital and operational costs over the project life; the first cost, being the initial capital cost, undiscounted; and the relative cost of different Assemblies within the network. These are described below.

- **The capital cost NPV** is the NPV of cash flows associated with the initial installation of the asset plus those associated with replacement and abandonment. Cash flows are initially discounted at 3.5% and at 3.0% from 2046.

---

[6] Note, throughout this report, the term Net Present Value (NPV) has been used to refer to discounted cash flows as this is a convention as used in the ICC. However, it should be noted that as all cash flows are in fact costs (ie no 'values' or revenues are included), strictly the term should be Net Present Cost.

An example of these cash flows is illustrated in Figure 3-6. This graph is an output of the tool and shows the annual cash flows associated with capital and replacement costs for a new build hydrogen distribution network including pipes, conversion stations and connections. The project assumes all assets are installed in 2020, with subsequent cash flows associated with minor and major replacement cycles occurring periodically thereafter. As noted in Section 3.2.4 above, the minor and major replacement cycles are determined by the lifecycle profile attributed to the Assemblies in the project as annotated in the graph below.

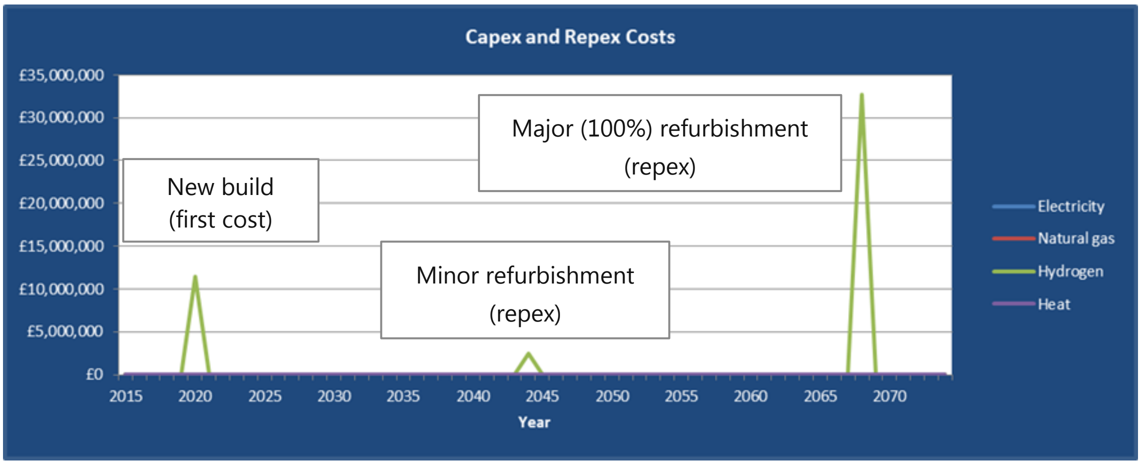


Figure 3-6 Graphical output from ICC showing capital and replacement cost cash flows over the life of a project with assets installed in 2020

An important point to take into account in the interpretation of the results in this report is the impact on lifecycle costs of deferring installation. Thus, if the same network shown above were installed in 2040 rather than 2020, the lifecycle cash flows would be as illustrated in Figure 3-7. The new build costs are now in 2040 and are higher than in 2020 due to the impact of inflation (Figure 3-4) with the minor refurbishment occurring in 2064. However, as the period for calculating the NPV is fixed at 60 years from 2015, the major replacement is beyond the end of the assessment period and therefore not included in the cash flow. This can have a significant impact on NPV when comparing costs at different installation dates.

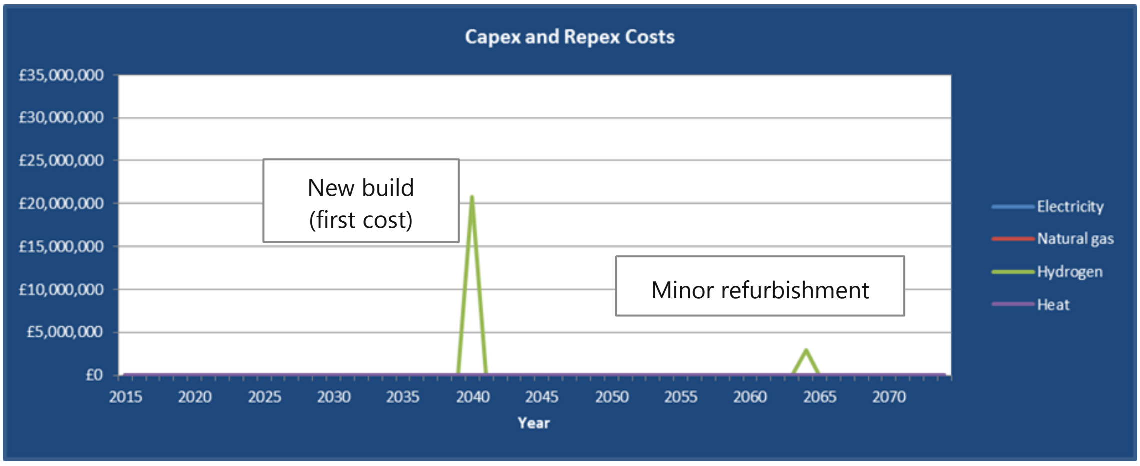


Figure 3-7 Graphical output from ICC showing capital and replacement cost cash flows over the life of a project with assets installed in 2040

- **The Opex NPV** is the NPV of all operational cost cash flows associated with all Assemblies in the Project over the assumed project life.

  An example of these cash flows is illustrated in Figure 3-8. This graph is an output of the tool and shows the annual cash flows associated with operational costs for a new build hydrogen distribution network including pipes, conversion stations and connections. As noted in Section 3.2.4 above, operational costs are determined by the operational cost profile attributed to the Assemblies in the project.

Figure 3-8 Graphical output from ICC Cost Tool showing operational cost cash flows over the life of a project

- **First cost** is the undiscounted cost of the initial installation of the asset including preliminaries and contingencies etc. but without considering replacement and abandonment. This has been included in the analysis to contextualise costs excluding Repex and Opex. First costs are higher at later installation dates due to the impact of the future cost trends (see Figure 3-4.

- **Relative cost of Assemblies:** The analysis also explores the relative costs of different Assemblies within a network to understand key cost drivers. The costs being compared are the total undiscounted costs of all Capex and repex associated with that Assembly over the project life.

3.4 Considerations and limitations

The cost outputs of the tool and thus the analysis arising need to be viewed with the following issues in mind:

- Technical scope

  As noted above, the key units or 'building blocks' in the tool are the Assemblies. Each Assembly is defined so as to be representative in terms of configuration, capacity, size etc of a 'typical' piece of infrastructure. Given the wide number of alternative designs and configurations available in practice, it is recognised that selecting a single 'typical' design reduces the accuracy of a detailed study. For the purposes of this high level study however, the designs within the tool are considered to be adequate. Where no appropriate Assembly was available in the tool for a particular research question, a new one was added.

- Opex

  The approach taken to operational costs was simplified for the purposes of this first version of the tool. These are being refined for the second version.

- Losses

  No account is taken of losses occurring over the network. Losses were not included in the tool due to their dependence on network design, which is outside the scope of the tool.

- Lifecycle profiles

  Three lifecycle profiles are included in the tool, all of which include for a major (100%) replacement after a certain period. The inclusion of lifecycle costs in the Capex NPV influences results particularly where installation occurs at different dates given that the assessment period remains fixed (ie 60 years from 2015 to 2075).

  It should be noted that the modelling of lifecycle costs will be revised in the next version of the tool, taking a more probabilistic approach and thereby allowing for cash flows to be smoothed. In addition, lifecycle costs will be included in with Opex costs rather than with Capex costs.

- Project cost parameters

  The tool allows for the variation of a number of different parameters in relation to ground conditions, prelims costs, optimism bias etc. For the purposes of this initial study, these have been fixed for all projects. They can however be varied should more detailed analysis be required at a later date.

- Economic trends

  Subsequent to the initiation of this project, the economic trends for materials, labour and plant costs have been revised. These revisions have not been taken into account in this analysis.

Overall, the results of the analysis need to be considered in the context of the first version of the ICC. As well as providing cost information for ETI research teams, the exercise has also identified issues to be addressed in the second version of the tool.

4 H-G-17 Representative Heat Model

4.1 Research question overview and scope

The analysis provides a reference heat network cost at various populations and population densities. It provides ETI with the basis on which to evaluate the capital and operating cost of heat networks including connections to buildings. It is also used to evaluate the innovation opportunities around use of alternative materials (project H-I-20 in Chapter 7).

4.2 Design of a representative network

The network design was based on current conventions in relation to pipe materials, sizes[7] and connections. To devise a representative network model over different populations and population densities, spatial analysis was undertaken in GIS for selected areas in the UK. MSOAs were selected where the population and area represent a population density appropriate for the different contexts – London, Urban, Semi-urban and Rural – as shown in Table 4-1. As the mean population of an MSOA is 7,860, several MSOAs are grouped together to arrive at the larger populations.

Table 4-1 Population densities for the different network contexts

Context	**London**	**Urban**	**Semi-urban**
Area selected	Camden	Exeter	Redcar
Population density (people/hectare)	>100	~50	~30

An example of the output of this work is shown in Figure 4-1, where a suitable heat network has been mapped to serve buildings in a particular area (Middle layer Super Output Area[8]).

The split of consumer connection types has been divided according to the number of existing natural gas customer connections split into domestic and non-domestic in the studied area. To estimate the number of connections and associated peak loads, DECC MSOA level energy data was obtained. To provide the split between the different pipe diameters a methodology was developed based on the existing capacities in the ICC. The approximate ratios for the pipework length are as follows and correspond to recent BuroHappold project experience:

- 450mm 0-6%
- 300mm 31-40%
- 150mm 54-65%.

---

[7] Pipe diameters used were those available in the Infrastructure Cost Calculator (Nov 2013) ie. 450mm, 300mm or 150mm. For full details of the network design see the Detailed Scoping document available separately from ETI

[8] Super Output Areas are areas defined by the Office for National Statistics for the purposes of gathering statistics in England and Wales. MSOAs have a population of between 5,000 and 15,000.

Figure 4-1 Example MSOA heat network as mapped in GIS

Figure 4-2 shows a heat network schematic, indicating flow and return pipes and connections to a range of different load types (domestic, commercial and industrial). The cost scope is made up of:

- Pipework: the district heating mains and branches including all buried pipework and trenching
- Connections: the service pipes and the substations within buildings[9].
- No heat generation equipment is included.

---

[9] Heat network is split to service pipe network and trunk network. Trunk network is the main distribution network while service pipes connect the main distribution network to the demand point.

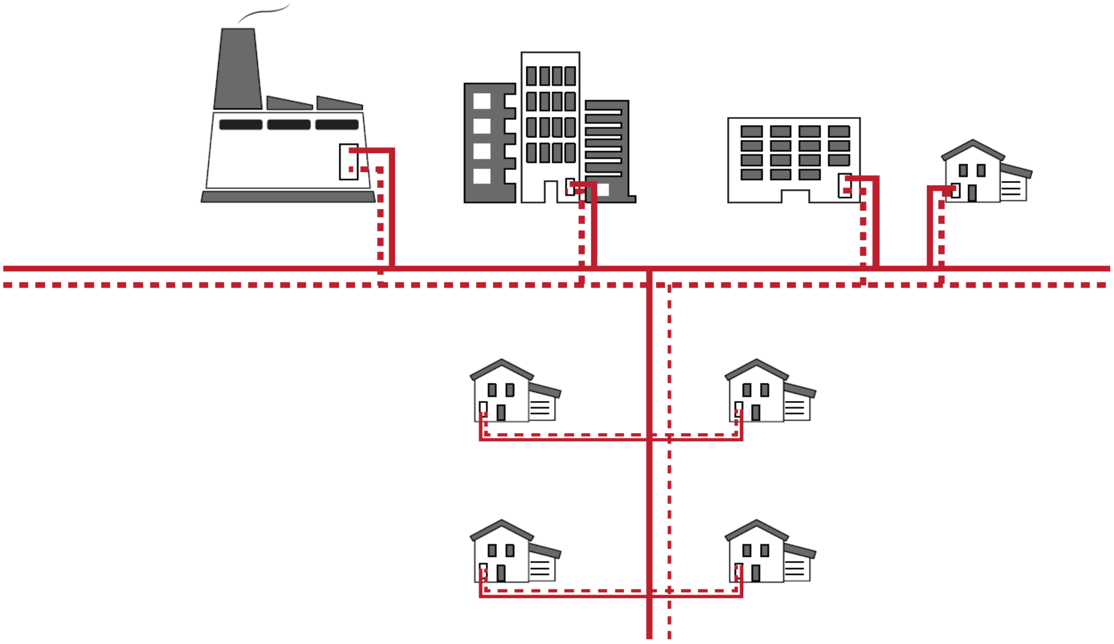


Figure 4-2 Heat network schematic

Based on the network design and spatial analysis described above, Table 4-1 shows the number of connections and network lengths assumed for each of the different contexts and populations. These nine variations were costed at two installation dates, 2020 and 2030.

Table 4-2 Network lengths and connections for different populations and contexts

Context	**Population**	**No. connections**				**Network length**					
		Domestic*	Commercial	Industrial	Total	Average Service pipe (m)	450mm (km)	300mm (km)	150mm (km)	Trunk (km)	Total (km)
London	7,500	3,389	18	4	3,411	16.5	0.8	5.5	7.8	14.1	70.5
London	20,000	9,858	72	16	9,946	16.6	2.5	16.3	22.9	41.6	206.7
London	50,000	22,925	161	36	23,122	16.5	5.6	37.1	51.7	94.4	475.2
Urban	7,500	3,148	6	-	3,154	18.8	1.3	8.2	13.7	23.1	82.5
Urban	20,000	9,270	25	3	9,298	18.7	3.6	23.5	38.8	66	239.7
Urban	50,000	21,357	140	29	21,526	18.6	8.3	53.4	87.3	148.9	549.2
Semi-urban	7,500	2,730	6	-	2,736	19.7	-	10.7	16.1	26.8	80.7
Semi-urban	20,000	10,102	26	3	10,131	19.8	3.5	34.2	62.1	99.7	300.4
Semi-urban	50,000	21,942	44	5	21,991	19.7	6.7	78.3	137.9	222.9	656.9

** This includes non-domestic loads using domestic connections (e.g. small shops)*

4.3 Results and Analysis

Based on the quantities in Table 4-2, 18 cost data sets were generated using the ICC. Each data set is representative of a different variation eg. heat network costs for London, installed in 2020, serving an area with population 7,500 people. The project cost parameters (eg ground conditions) are the same for each variation (see Section3.3.1).

Table 4-3 shows the NPV Capex, NPV Opex and NPV Total as well as the first costs of each variation for installation dates of 2020 and 2030. As discussed in Section 3.3.2, first costs (undiscounted) include new build costs plus preliminary costs, contractors costs, PM engineering, land costs and contingencies but exclude any lifecycle replacement costs; NPV Capex represents the installation costs plus all lifecycle costs (which include all replacement cycles and abandonment costs - Repex – to the extent that these occur before the project end); and NPV Opex takes into account operational costs over the life of the project.

Table 4-3 NPV (Capex and Opex) and first cost for each variation

Installation date	Context	Population	Connections	Total network length (km)	First Cost £m	NPV Capex £m	NPV Opex £m	NPV Total £m
2020	London	7,500	3,411	70.5	103.5	217.9	23.7	241.6
	London	20,000	9,946	206.7	301.0	635.3	68.9	704.1
	London	50,000	23,122	475.2	680.4	1,443.4	155.8	1,599.3
	Urban	7,500	3,154	82.5	116.1	229.6	26.3	255.9
	Urban	20,000	9,298	239.7	326.9	650.9	74.2	725.1
	Urban	50,000	21,526	549.2	742.1	1,485.3	168.4	1,653.8
	Semi-urban	7,500	2,736	80.7	88.5	159.0	20.3	179.3
	Semi-urban	20,000	10,131	300.4	333.4	598.1	76.4	674.5
	Semi-urban	50,000	21,991	656.9	735.3	1,318.3	168.6	1,486.9
2030	London	7,500	3,411	70.5	134.4	169.8	18.9	188.6
	London	20,000	9,946	206.7	391.2	494.7	54.9	549.6
	London	50,000	23,122	475.2	884.8	1,122.2	124.3	1,246.5
	Urban	7,500	3,154	82.5	149.8	182.8	20.8	203.6
	Urban	20,000	9,298	239.7	422.3	517.2	58.6	575.8
	Urban	50,000	21,526	549.2	958.8	1,177.9	133.2	1,311.1
	Semi-urban	7,500	2,736	80.7	114.9	137.3	16.1	153.3
	Semi-urban	20,000	10,131	300.4	432.9	516.4	60.5	576.9
	Semi-urban	50,000	21,991	656.9	954.6	1,137.8	133.4	1,271.2

The following sections break down these costs to better understand their implications and any underlying trends.

4.3.1 Analysis: Assemblies

This section provides a breakdown of the key elements of cost[10] within the network.

The cost of the top five Assemblies is shown in Table 4-4 to Table 4-6 as a percentage of the total cost. The Assemblies are grouped by context to show the differences between them.

Figure 4-3 shows the overall share of costs of the two primary cost groups, pipelines and connections.

Table 4-4 Percentage share of total cost of the top 5 Assemblies – London

Installation date	Population	Domestic connections	Trunk network (300mm)	Trunk network (150mm)	Trunk network (450mm)	Commercial connections
2020	7,500	47.7%	26.8%	17.1%	7.0%	0.9%
	20,000	47.6%	26.0%	17.2%	7.4%	1.3%
	50,000	48.6%	25.8%	16.9%	6.9%	1.2%
2030	7,500	35.8%	33.3%	21.2%	8.7%	0.7%
	20,000	35.7%	32.4%	21.4%	9.2%	0.9%
	50,000	36.7%	32.3%	21.0%	8.7%	0.9%

Table 4-5 Percentage share of total cost of the top 5 Assemblies – Urban

Installation date	Population	Domestic connections	Trunk network (300mm)	Trunk network (150mm)	Trunk network (450mm)	Commercial connections
2020	7,500	35.4%	31.3%	24.0%	9.0%	0.3%
	20,000	36.6%	30.5%	23.9%	8.5%	0.4%
	50,000	36.9%	30.3%	23.5%	8.1%	0.9%
2030	7,500	24.9%	36.5%	27.9%	10.6%	0.2%
	20,000	25.9%	35.8%	27.9%	10.0%	0.3%
	50,000	26.3%	35.7%	27.6%	9.5%	0.6%

Table 4-6 Percentage share of total cost of the top 5 Assemblies – Semi urban

Installation date	Population	Trunk network (300mm)	Trunk network (150mm)	Domestic connections	Trunk network (450mm)	Commercial connections
2020	7,500	44.0%	29.8%	26.0%	-	0.2%
	20,000	36.8%	30.6%	25.5%	6.8%	0.2%
	50,000	38.2%	30.8%	25.2%	5.6%	0.2%
2030	7,500	44.3%	29.8%	25.7%	-	0.2%
	20,000	37.0%	30.6%	25.3%	6.9%	0.2%
	50,000	38.4%	30.8%	24.9%	5.7%	0.2%

---

[10] The term 'cost' used here is in the context of the ICC which calculates total Assembly cost over the entire project life, including all Capex and Repex cash flows (undiscounted).

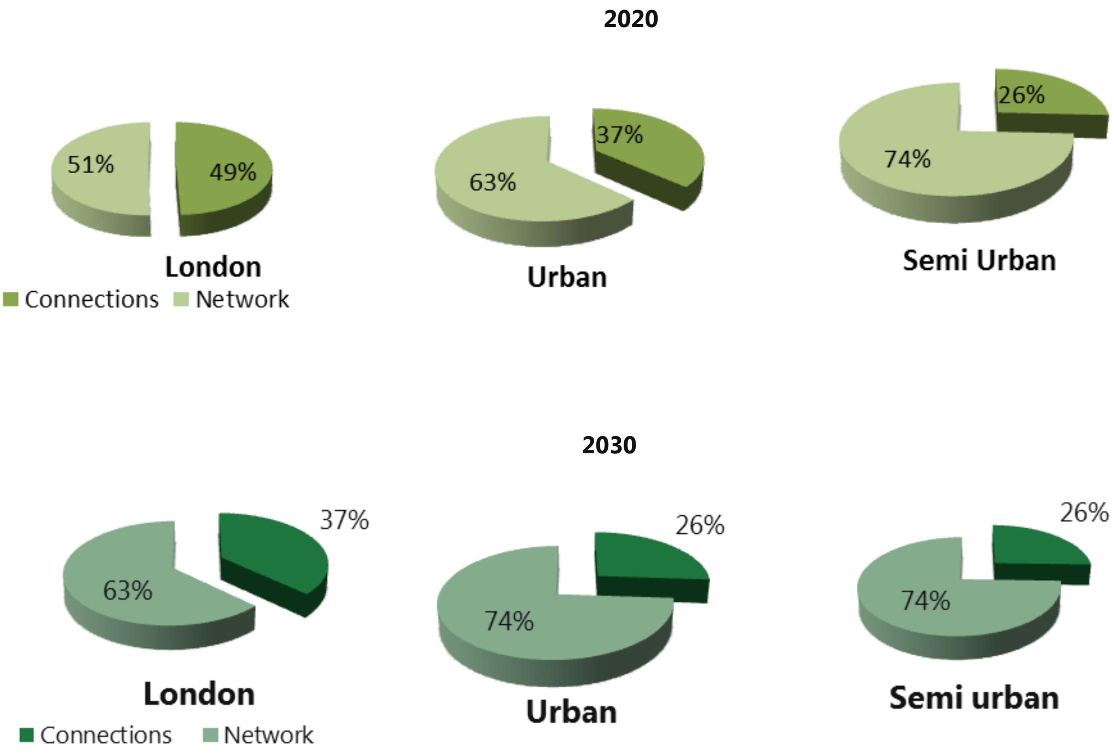


Figure 4-3 Relative share of connection and network costs at installation dates 2020 and 2030

Key points to note are as follows:

- The share of the cost of the network which serves average demand (300mm network for domestic installations) is much higher than the costs of the other types of network. This is because 300mm pipes are used to serve a wide range of demand from 1.5 MW up to 18 MW and therefore make up a major proportion (35-40%) of the length of the trunk network. This in turn has an impact on their share of costs.
- The share of total costs represented by connections falls as density falls, thus, in London areas, connections represent almost 50% of costs, while in semi-urban areas, they represent around 25% in 2020 (Figure 4-3). This effect is less marked in 2030 for reasons described below.
- The relative share of each of the main cost types changes between installations in 2020 and 2030 as a consequence of lifecycle profiles of the different Assemblies (pipework is on a 40-year cycle, connections are on a 25-year cycle)[11]. This is more marked in London and urban areas, where the relative share of the cost of connections falls between 2020 and 2030, than in semi urban areas where it remains the same.

  The analysis period is fixed at 60 years between 2015 and 2075. For installations in 2020, connections are replaced twice and pipework only once while for installations in 2030, both connections and network are replaced only once. As a result, the total Capex and repex costs of connections installed in 2020 is considerably higher than the equivalent costs if they were installed in 2030. In contrast, the differential between costs of networks installed in 2020 and 2030 is less marked (as there is only one replacement in each case).

---

[11] As noted in Section 3.2.4, the approach to modelling lifecycle costs is to be changed in Version 2 of the ICC which may impact this finding

In London and urban areas where connections make up the major share of cost, the difference between 2020 and 2030 is therefore more significant than in semi-urban areas where networks make up the major share of costs.

4.3.2 Analysis: Normalised costs

Three normalised costs have been analysed:

- First costs per connection
- First costs per km of network
- NPV (Capex, Opex, Total) per connection

In addition, the correlation between connection density (connections per square km) and first cost has been assessed.

Table 4-8 gives the first cost per km of trunk network and per connection. It shows that:

- Installation costs per km are higher in denser, more urban areas ranging from an average of £7.26m per km in London areas to £3.31m per km in semi-urban areas (in 2020). This is due to higher external costs (labour costs, contractors, land costs etc) in a more urban environment.
- The first cost per connection shows a slightly different trend being highest in urban areas at an average of £35.5k per connection but lowest in London at an average of £30.0k per connection with semi-urban areas being in the mid range at £32.9k per connection (2020 values).

  This is explained by the interaction between average network length per connection and increased costs associated with urban and London areas. As shown in Table 4-7, unit costs are higher in London than in urban areas generally, however, the average network length is lower due to London being more dense. The trade-off of these factors means that urban areas are more expensive per connection than London. In contrast, unit costs are lower in semi-urban areas, and the increase in network length per connection is not significantly higher, thus the trade-off here means that urban areas are also more expensive per connection than semi-urban.

Table 4-7 Comparison of various factors among different contexts

Context	Trunk network per connection (m)	Domestic connections - assembly capital cost (£/Nr) - baseline	Trunk network 300mm- assembly capital cost - baseline (£/km)	Land cost per hectare – baseline (£/ ha)
London	4.1	5,002	3,875,700	120,000
Urban	7.1	4,100	3,176,800	100,000
Semi urban	9.9	3,900	2,162,500	100,000

Table 4-8 First cost per km of trunk network and per connection

Installation date	Context	Population	First cost per km of trunk network (£ million)	Average cost / km by context (£ million)	First Cost per connection (£ million)	Average cost per connection by context (£ million)
2020	London	7,500	7.34	7.26	30,335	30,010
	London	20,000	7.24		30,265	
	London	50,000	7.21		29,428	
	Urban	7,500	5.03	4.99	36,806	35,482
	Urban	20,000	4.95		35,162	
	Urban	50,000	4.98		34,477	
	Semi-urban	7,500	3.30	3.31	32,335	32,892
	Semi-urban	20,000	3.34		32,904	
	Semi-urban	50,000	3.30		33,438	
2030	London	7,500	9.53	9.44	39,414	39,005
	London	20,000	9.40		39,333	
	London	50,000	9.37		38,268	
	Urban	7,500	6.49	6.44	47,502	45,821
	Urban	20,000	6.40		45,417	
	Urban	50,000	6.44		44,543	
	Semi-urban	7,500	4.29	4.30	41,981	42,706
	Semi-urban	20,000	4.34		42,728	
	Semi-urban	50,000	4.28		43,408	

Table 4-9 shows the Total NPV per connection at both installation dates, in all contexts and populations. The split between Capex and Opex is also shown. These results are illustrated in Figure 4-4.

Table 4-9 NPV per connection for each different variation

Installation date	Context	Population	NPV Capex per connection £	NPV Opex per connection £	NPV Total per connection £	Average NPV per connection per context £
2020	London	7500	63,877	6,938	70,816	70,259
	London	20000	63,872	6,925	70,797	
	London	50000	62,427	6,739	69,166	
	Urban	7500	72,792	8,342	81,134	78,649
	Urban	20000	70,008	7,979	77,987	
	Urban	50000	69,002	7,825	76,826	
	Semi-urban	7500	58,113	7,411	65,525	66,573
	Semi-urban	20000	59,035	7,546	66,581	
	Semi-urban	50000	59,949	7,665	67,614	
2030	London	7500	49,771	5,530	55,302	54,824
	London	20000	49,739	5,521	55,260	
	London	50000	48,533	5,377	53,910	
	Urban	7500	57,961	6,587	64,548	62,462
	Urban	20000	55,622	6,306	61,928	
	Urban	50000	54,721	6,188	60,909	
	Semi-urban	7500	50,178	5,869	56,047	56,933
	Semi-urban	20000	50,971	5,975	56,946	
	Semi-urban	50000	51,738	6,067	57,806	

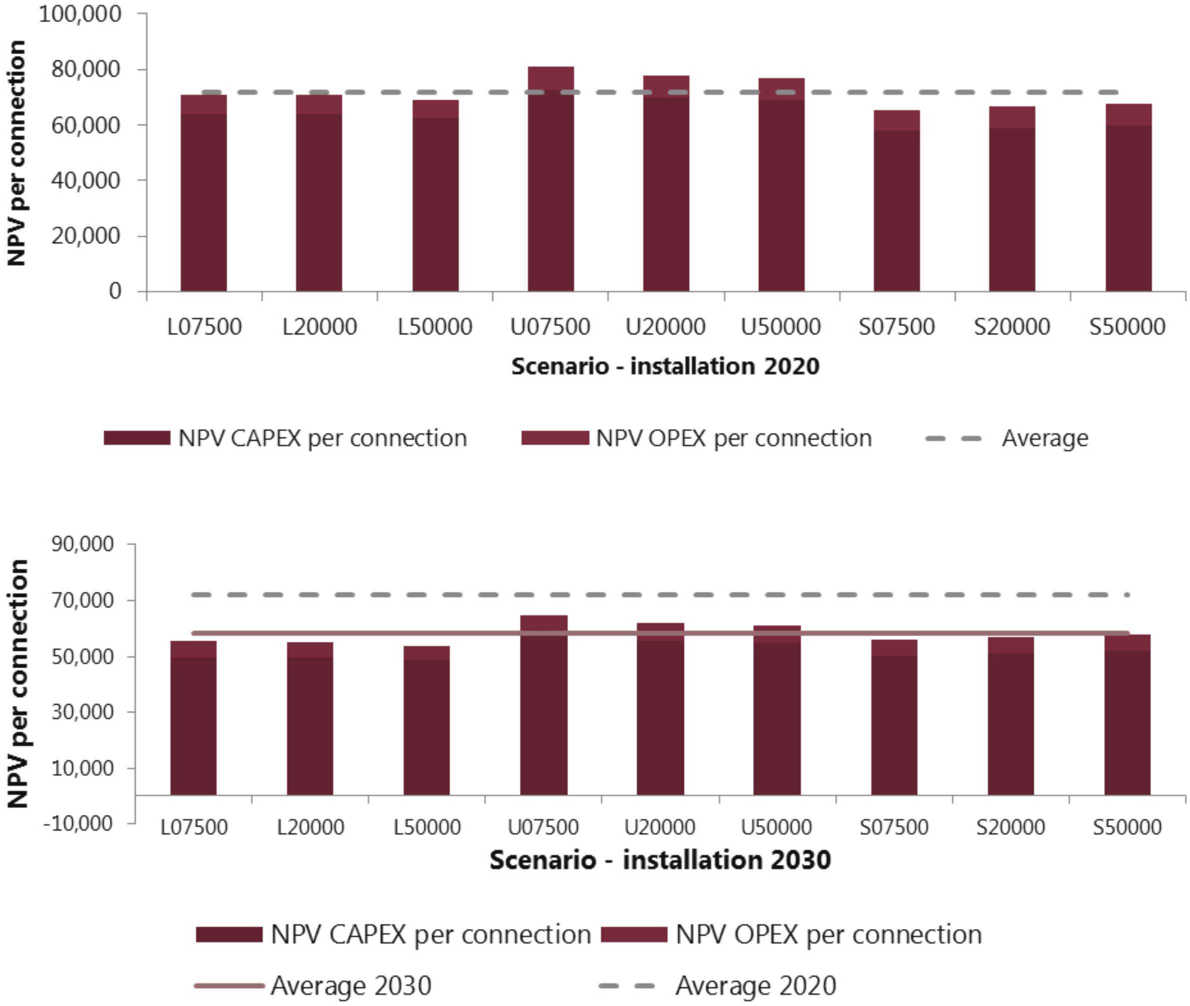


Figure 4-4 Capex and Opex NPV per connection at various contexts and installation dates

Table 4-8 and Figure 4-4 show that:

- The NPV per connection is highest for urban installations at £78.6k compared with £70.3k for London and £66.6k for semi-urban installations. This trend is slightly different to the one identified for first costs described above and is due to the difference in the relative share of Assemblies (connections and pipework) combined with their different lifecycle profiles (25 and 40 years respectively).
- NPV per connection does not change significantly with population size.
- NPV per connection falls for the later installation dates due to the impact of discounting.
- NPV Capex represents around 90% of total NPV and Opex only 10% in all variations. Note that Opex excludes any losses along the network.

To further explore the relationship between spatial configuration and cost, the correlation between the first costs per connection and the density of connections has been calculated as shown in Figure 4-5. London represents the highest density (around 5,000 connections per square km) while semi urban areas represent the lowest density (around 1,200 connections per square km).

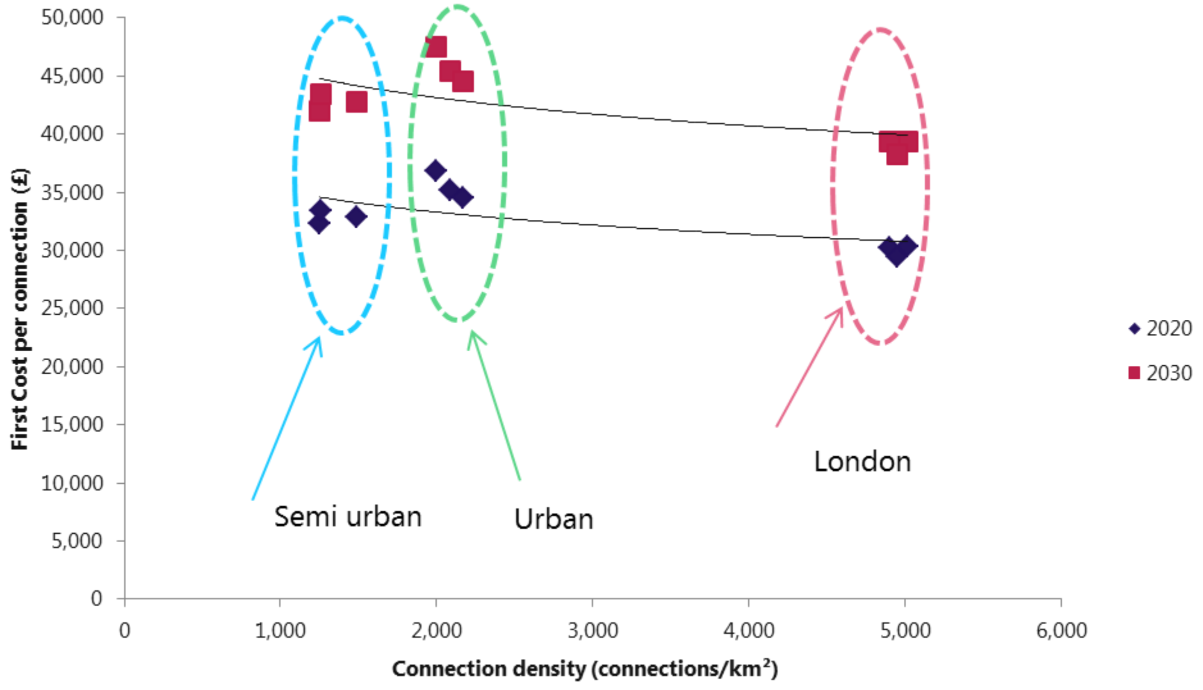


Figure 4-5 Variation of first cost per connection with connection density per km^2

- Figure 4-5 indicates that the costs per connection are lower in London than in a semi-urban area. In this case, the additional costs of installation are outweighed by the higher density (and hence shorter network length per connection).

- In contrast, costs per connection in an urban area are higher than in a semi-urban area (as was also noted in Table 4-8 and Table 4-9 above). In this case, the higher costs of installation in more congested urban areas is not outweighed by the increase in density (which is clear from Figure 4-5 is only slightly higher than for semi-urban).

- Costs per connection in London are lower than in an urban area because, although installation costs are deemed to be higher in London, the significantly higher density increase more than offsets this.

4.4 Limitations and further work

The nature of the project and the high level of the analysis leads to some limitations that could affect the outputs as follows:

- As the modelling approach has been based on using the road network as a proxy for heat network length there will be some errors arising from this. Changes in network length would affect the costs of the installation.

- The network has not been dimensioned in detail as the ICC does not contain sufficient granularity of pipe sizing to allow for this. For instance, in cases where a 200mm pipe network would be adequate for the demand of heat, the tool uses 300mm pipe network because of lack of more dimensions.
- The impact of utilities diversions has not been considered. For larger diameter pipework in urban areas this can significantly increase costs.
- The cost analysis does not include losses which would impact on lifecycle costs.

As noted in Section 3.4, there are a number of considerations to be taken into account in relation to the design and modelling assumptions contained in the first version of the ICC used for this study. In particular, cost trends and the treatment of Opex and lifecycle costs are to be revised in future versions which could impact on these results.

Aside from re-running the analysis in the new version of the tool, further work could include mapping additional MSOAs and adding different pipe sizes to the tool to enable a more detailed network design.

5 H-G-18 Representative Heat Model – Compact Villages

5.1 Research question overview and scope

This analysis is intended to provide a reference heat network cost for compact villages. It provides ETI with the basis on which to evaluate the capital and operating cost of heat networks including connections to buildings.

5.1.1 Design of a representative network

The network design was based on current conventions in relation to pipe materials, sizes and connections. A representative network in a compact village was developed based on the Spatial Analysis Methodology. An example of the output of this work is shown in Figure 5-1, where a suitable heat network has been mapped to serve buildings in a particular area.

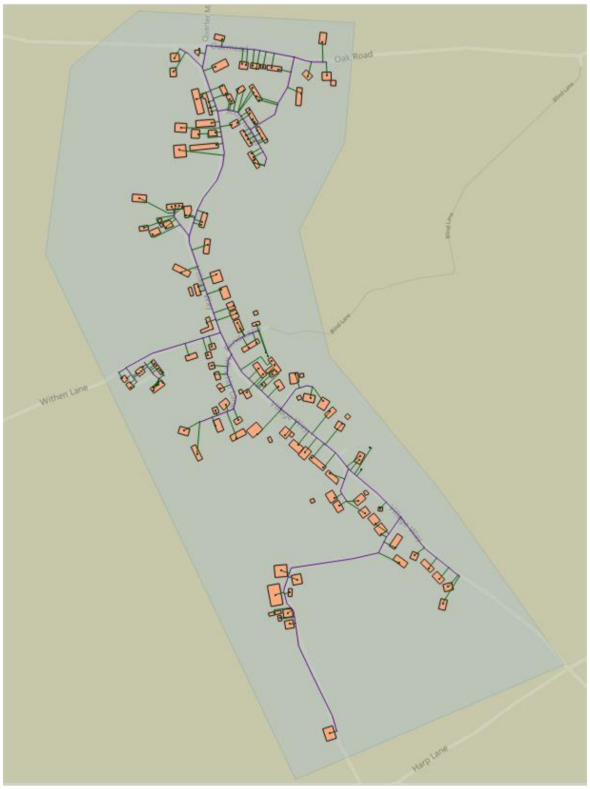


Figure 5-1 Example compact village heat network as mapped in GIS

Consumer connection types were split into domestic and non-domestic based on the number of existing natural gas customer connections in the wider area of the MSOA. The following proportion of domestic and non-domestic connections was assumed:

- 98% - 30kW domestic connections
- 1% - 30kW non-domestics connections (same size as residential but with 70% diversity)
- 1% - 250kW commercial connections

In the case of heat distribution within the compact village the load was low enough to require pipes of 150mm diameter only (i.e. no need for 300mm or 450mm pipes).

Figure 5-2 provides an outline network schematic indicating the network scope for costing purposes. District heating mains and branches including all buried pipework and trenching, service pipes and substations within buildings are included.

The total population of the compact village is 530.

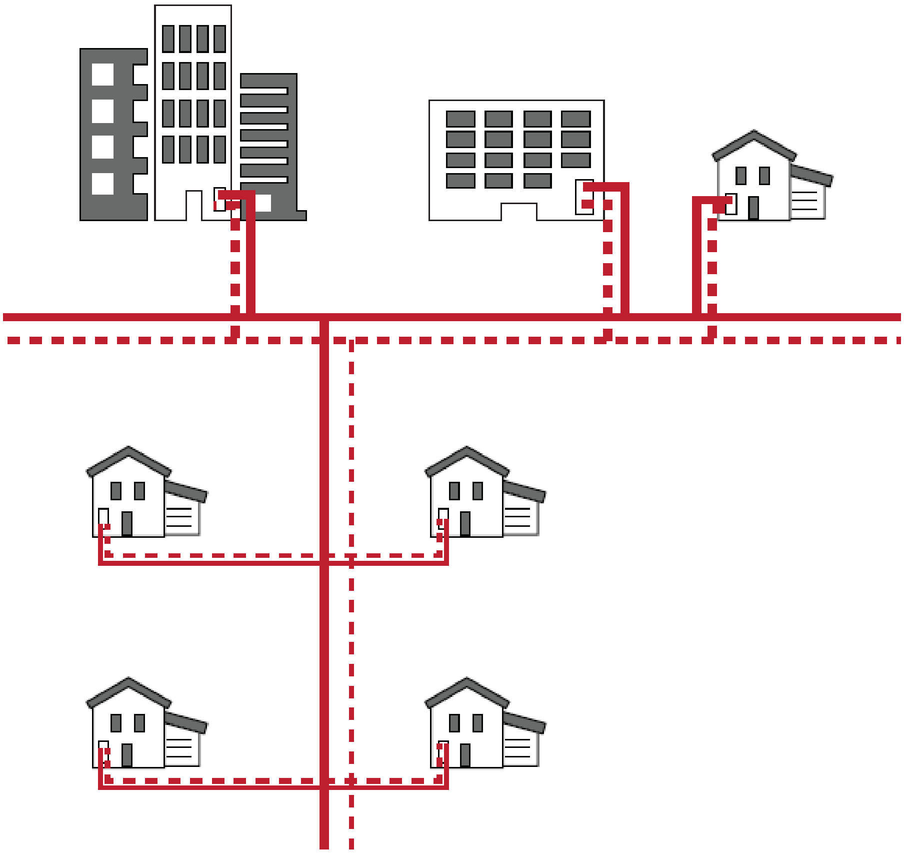


Figure 5-2 Outline network schematic

Table 5-1 and Table 5-2 outline the BoQ and project variants respectively. Cost data is generated by the ICC tool for each possible permutation of the project variants in the tables below.

Table 5-1 Bill of Quantities

Analysis code	No. connections					Average service pipe length (m)	Trunk network length (km)				Total network length (km)	Total network length per connection (km)
	Domestic	Non-domestic using domestic	Commercial	Industrial	Total		450mm	300mm	150mm	Total trunk network length		
Compact Village	169	1	1	0	171	19.8	-	-	3.2	3.2	6.6	38,5

Table 5-2 Project variants

Parameter	Variants	Application / notes
Installation date	2020 2030	Each date applied to each of the other variants
Capacity / pipe diameter	As in Table 5-1	Based on population and context
Length	As in Table 5-1	Based on population and context
Context	Compact Village	Linked to population
Mode	New build	All costs new build

This task comprises three Assemblies:

- Distribution: 150mm heat network
- Connection: Domestic HIU heat connection
- Connection: Commercial heat centre heat connection

Service pipes are included in the connection Assemblies.

5.2 Results and analysis

ICC output data for this task is given in Table 5-3. This includes NPV Capex, Opex and total, as well as first costs. As discussed in Section 3.3.2, first costs (undiscounted) include new build costs plus preliminary costs, contractors costs, PM engineering, land costs and contingencies but exclude any lifecycle replacement costs; NPV Capex represents the installation costs plus all lifecycle costs (which include all replacement cycles and abandonment costs - Repex – to the extent that these occur before the project end); and NPV Opex takes into account operational costs over the life of the project.

Table 5-3 Base output data

Installation date	Context	Pipe diameter (mm)	Total network length (km)	First cost (£m)	NPV Capex (£m)	NPV Opex (£m)	NPV Total (£m)
2020	Compact village	150	6.6	6.2	10.6	1.4	12.0
2030	Compact village	150	6.6	8.0	6.5	1.1	7.7

First costs and total NPV are plotted for each permutation in Figure 5-3.

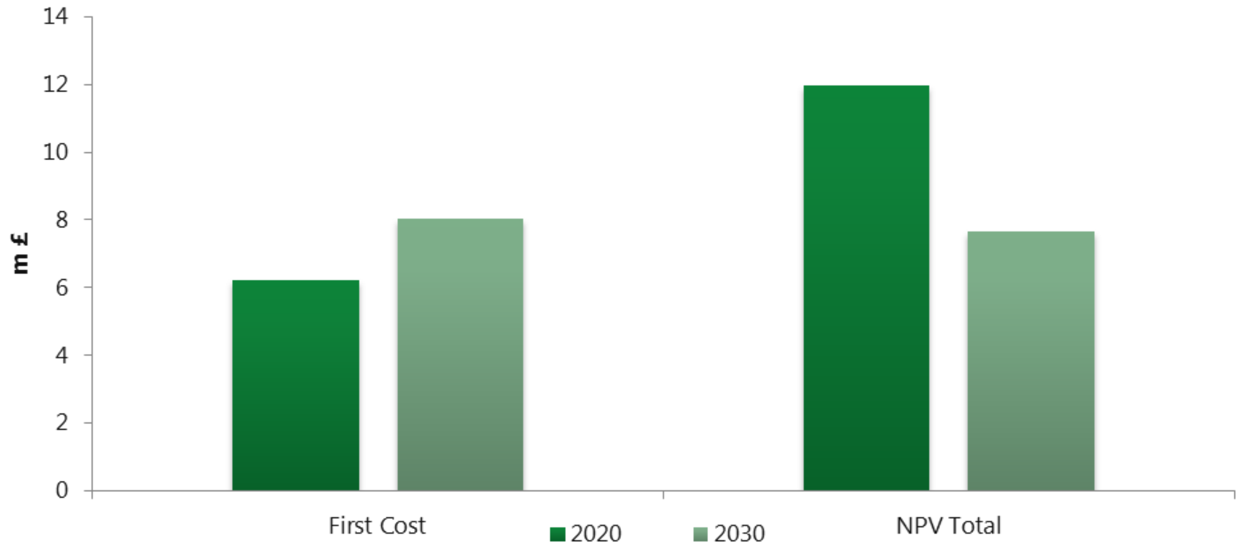


Figure 5-3 First cost and total NPV

Key findings:

- First costs are higher with a 2030 installation date than in 2020 due to the impact of cost trends (Section 3.2.5).
- NPV is lower with a 2030 installation date than in 2020 due to the impact of discounting.

5.2.1 Analysis: Assemblies

This section provides a breakdown of the key elements of cost within the network.

The cost of the top five Assemblies is shown in Table 5-4 as a percentage of the total cost. The Assemblies are grouped by context to show the differences between them.

Figure 5-4shows the overall share of costs of the two primary cost groups, pipelines and connections.

Table 5-4 Percentage share of total cost of the top 5 Assemblies

Installation date	Context	Domestic connections	Trunk network (150mm)	Commercial connections
2020	Compact village	26%	73.5%	0.5%
2030	Compact village	47.2%	51.8%	0.9%

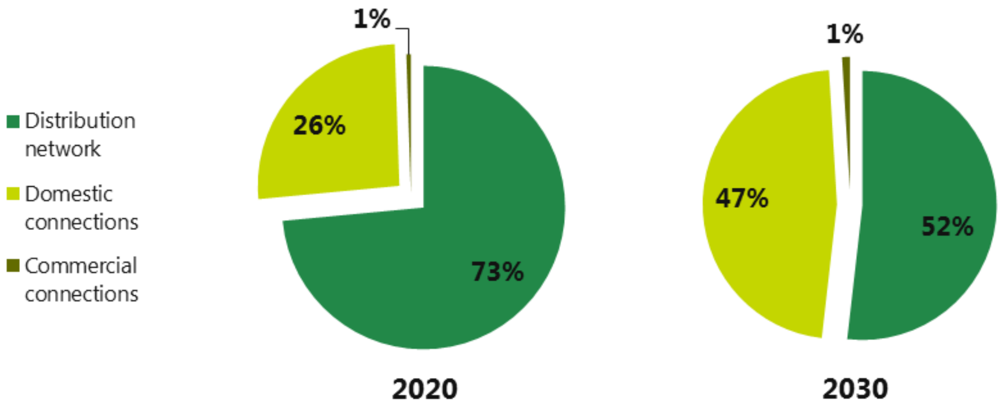


Figure 5-4 Relative share of total costs of connections and pipework – 2020 and 2030

Key findings:

- Costs of trunk network contribute ~75% of total assembly costs in 2020 and ~50% in 2030, which is associated with the lifecycle of the trunk network and the end date of project as discussed in Section 4.3.1 for H-G-17 .
- Villages have low population densities, therefore distribution networks must be longer to service all connection points. In comparison with urban or London contexts from other tasks, the share of distribution costs in the compact village are higher and similar to the semi-urban figures.

5.2.2 Analysis: Normalised costs

Four sets normalised costs have been analysed:

- NPV (Capex, Opex, Total) per connection
- First costs per connection
- NPV (Capex, Opex, Total) per km of trunk network
- First costs per km of trunk network

Table 5-5 shows the first cost and NPV(Capex, Opex and Total) per connection.

Table 5-6 shows the first cost and NPV(Capex, Opex and Total) per km of trunk network.

Table 5-5 First cost and NPV per connection

Installation date	Context	First costs per connection (£/connection)	NPV Capex per connection (£/connection)	NPV Opex per connection (£/connection)	NPV Total per connection (£/connection)
2020	Compact village	36,374	61,787	8,264	70,051
2030	Compact village	46,996	38,263	6,529	44,791

Table 5-6 First cost and NPV per km of trunk network

Installation date	Context	First costs per km of trunk network (£m/km)	NPV Capex per km of trunk network (£m/km)	NPV Opex per km of trunk network (£m/km)	NPV Total per km of trunk network (£m/km)
2020	Compact village	1.9	3.3	0.4	3.7
2030	Compact village	2.5	2.0	0.3	2.4

Normalised costs for this exercise display the same trends as the results presented in Section 5.2. This is due to the fact that the only variable was the installation date (i.e. network length, pipe diameter and context were constant for both projects).

5.3 Limitations and further work

The following are limitations to this study:

- The installation date was the only variable. This limits the useful analysis that can be drawn from results.
- This cost analysis does not include losses or pumping energy which would impact on lifecycle costs.

As noted in Section 3.4, there are a number of considerations to be taken into account in relation to the design and modelling assumptions contained in the first version of the ICC used for this study. In particular, cost trends and the treatment of Opex and lifecycle costs are to be revised in future versions which could impact on these results.

It may be interesting to investigate a wider range of variables, or to look at more / less compact villages to provide better granularity on the cost impact of population density.

6 H-G-19 Representative Heat Model – Interconnection

6.1 Research question overview and scope

This analysis is intended to provide a reference network for interconnections between existing district heating systems at various capacities, population densities and distances. It provides ETI with the basis on which to evaluate capital costs for various scales and contexts of interconnection between existing district heating systems.

6.1.1 Design of representative network

The basis of network design is based on two existing sets of interconnected heat networks:

- Pimlico to Whitehall (approx. 2km);
- Stratford City to ExCel Centre (approx. 5km).

Figure 6-2 shows the interconnection of two heat networks and Figure 6-1 provides a map showing existing district heating pipework from energy centre to connection point.

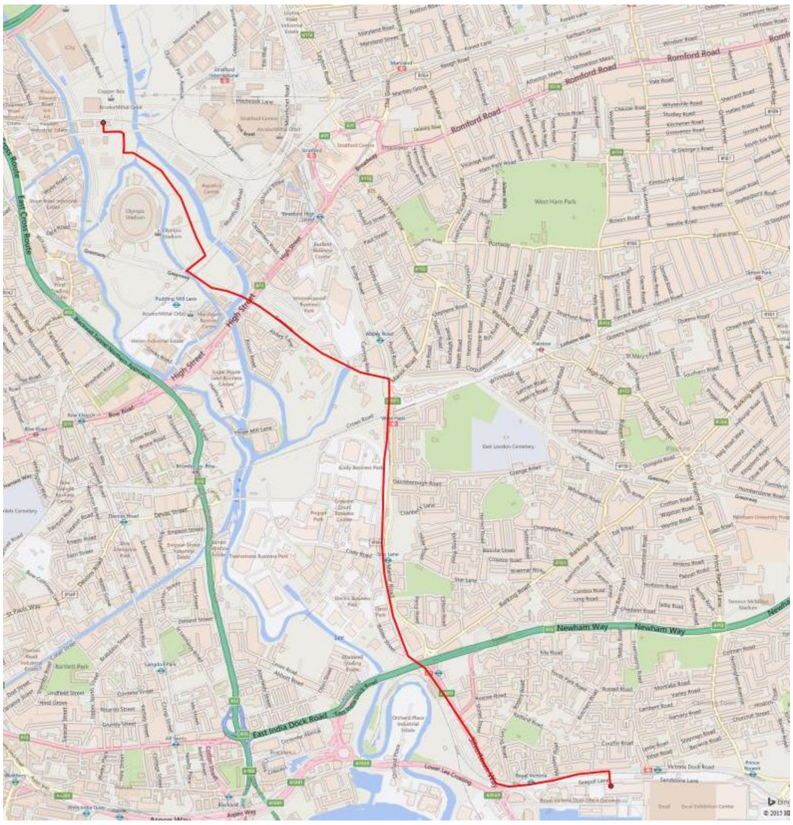


Figure 6-1 Example of interconnecting two heat networks (Stratford City – ExCel Centre)

Figure 6-2 Example of interconnecting two heat networks (Pimlico – Whitehall)[12]

The schematic given in Figure 6-3 demonstrates a typical interconnection strategy between two remote heat networks via heat substations. Direct connections are also possible and likely to have lower cost.

---

[12] Decentralised Energy Delivery : The Business Case, Case study 2: Westminster Energy, Tim Starley – Grainger, Westminster City Council

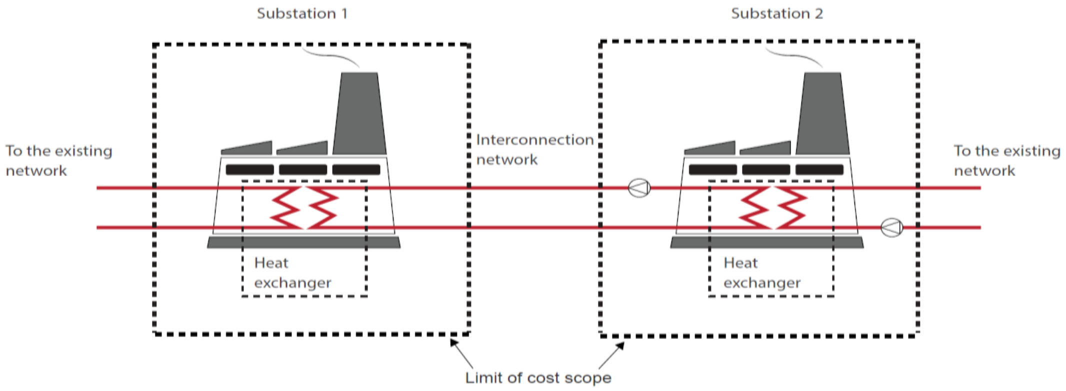


Figure 6-3 Outline network schematic

Table 6-1 and Table 6-2 provide the BoQ and project variants for this analysis[13].

Table 6-1 Bill of quantities

Context	Load (MW)	Network length			Number of heat exchange substations
		Diameter: 450 mm	*Diameter: 300 mm*	*Diameter: 150 mm*	
London	2	-	-	2km 5km	2 x 18 MW
	5	-	2km 5km	-	2 x 18 MW
	20	2km 5km	-	-	2 x 30MW
Urban	2	-	-	2km 5km	2 x 18 MW
	5	-	2km 5km	-	2 x 18 MW
	20	2km 5km	-	-	2 x 30MW
Semi-urban	2	-	-	2km 5km	2 x 18 MW
	5	-	2km 5km	-	2 x 18 MW
	20	2km 5km	-	-	2 x 30MW

Table 6-2 Project variants

Parameter	Variants	Application / notes
Installation date	2020 2030	Each date applied to each of the other variants

---

[13] Note there has been a slight change from the Detailed Scoping which had 10MW as the maximum capacity using 300mm pipes. By increasing the maximum capacity to 20MW, the analysis is extended to include 450mm network.

Capacity / pipe diameter	As in Table 6-1	Based on population and context
Length	As in Table 6-1	Each length applied to each of the other variants
Context	London Urban Semi-urban	Linked to population
Mode	New build	All costs new build

6.2 Results and analysis

Based on the quantities in Table 6-1, 36 cost data sets were generated using the ICC. Each data set is representative of a different variation eg. heat network costs for London, installed in 2020, serving an area with population 7,500 people.

Table 6-3 shows the NPV Capex, NPV Opex and NPV Total as well as the first costs of each variation for installation dates of 2020 and 2030. As discussed in Section 3.3.2, first costs (undiscounted) include new build costs plus preliminary costs, contractors costs, PM engineering, land costs and contingencies but exclude any lifecycle replacement costs; NPV Capex represents the installation costs plus all lifecycle costs (which include all replacement cycles and abandonment costs - Repex – to the extent that these occur before the project end); and NPV Opex takes into account operational costs over the life of the project.

Table 6-3 Base output data

Installation date	Context	Heat load (MW)	Pipe diameter (mm)	Pipe length (km)	First cost (£m)	NPV Capex (£m)	NPV Opex (£m)	NPV total (£m)
2020	London	2	150	2	6.4	11.7	1.4	13.2
	London		150	5	12.8	23.5	2.9	26.4
	Urban		150	2	5.2	9.6	1.2	10.8
	Urban		150	5	10.5	19.3	2.4	21.6
	Semi-urban		150	2	4.0	6.8	0.9	7.7
	Semi-urban		150	5	8.0	13.9	1.8	15.7
2030	London		150	2	8.3	9.6	1.2	10.7
	London		150	5	16.5	19.4	2.3	21.7
	Urban		150	2	6.8	7.8	0.9	8.8
	Urban		150	5	13.5	15.9	1.8	17.8
	Semi-urban		150	2	5.2	5.9	0.7	6.7
	Semi-urban		150	5	10.3	11.9	1.4	13.3
2020	London	5	300	2	15.6	27.9	3.6	31.4
	London		300	5	34.3	60.8	7.8	68.7
	Urban		300	2	12.8	22.8	2.9	25.8
	Urban		300	5	28.1	49.9	6.4	56.3
	Semi-urban		300	2	9.3	15.8	2.2	18.0
	Semi-urban		300	5	20.2	34.7	4.7	39.4
2030	London		300	2	20.2	23.2	2.8	26.0

Installation date	Context	Heat load (MW)	Pipe diameter (mm)	Pipe length (km)	First cost (£m)	NPV Capex (£m)	NPV Opex (£m)	NPV total (£m)
	London		300	5	44.2	50.9	6.1	57.0
	Urban		300	2	16.6	19.0	2.3	21.3
	Urban		300	5	36.3	41.7	5.0	46.7
	Semi-urban		300	2	12.1	13.6	1.7	15.3
	Semi-urban		300	5	26.3	29.6	3.7	33.3
2020	London	20	450	2	25.9	46.0	6.0	52.0
	London		450	5	58.2	103.0	13.4	116.4
	Urban		450	2	21.3	37.7	4.9	42.6
	Urban		450	5	47.7	84.5	11.0	95.4
	Semi-urban		450	2	15.4	26.1	3.6	29.7
	Semi-urban		450	5	34.2	58.4	8.0	66.4
2030	London		450	2	44.1	21.7	3.5	25.2
	London		450	5	98.3	47.0	7.7	54.7
	Urban		450	2	36.2	17.8	2.9	20.7
	Urban		450	5	80.6	38.5	6.3	44.9
	Semi-urban		450	2	26.5	13.1	2.1	15.2
	Semi-urban		450	5	58.5	28.1	4.6	32.7

These results demonstrate that for the same network length and capacity projects in the London context have higher costs than those in an urban context, whilst urban projects have higher costs than semi-urban costs. This is due to the difference in labour costs between the project contexts, i.e. in London labour costs will be higher than in all other contexts, whilst semi-urban labour costs will be lower than the other contexts. The logistics costs of the installation are also higher in London, such as costs for traffic management. In addition, land costs in London are 20% higher than costs in urban and semi urban contexts.

The cost of connecting energy centres that are 5km apart is approximately double that of connecting energy centres 2km apart. More detailed analysis of the impact of network length and capacity is included in 6.2.2.

6.2.1 Analysis: Assemblies

The top Assemblies for each load are shown in Table 6-4 to Table 6-6. There are two Assemblies per project – the pipe network and the heat substations. The Assemblies are grouped by heat load for ease of comparison.

Table 6-4 Relative share of Assembly costs for 2MW heat load capacity (150mm pipe diameter)

Pipe length	Installation date	2020			2030		
	Context	London	Urban	Semi-urban	London	Urban	Semi-urban
	Assembly						
2 km	*Pipe network*	71.4%	71.4%	77.7%	78.4%	78.4%	76.5%
	Heat substation	28.6%	28.6%	22.3%	21.6%	21.6%	23.5%
5 km	*Pipe network*	85.7%	85.7%	89.4%	89.7%	89.7%	88.7%
	Heat substation	14.3%	14.3%	10.6%	10.3%	10.3%	11.3%

Table 6-5 Relative share of Assembly costs for 5MW heat load capacity (300mm pipe diameter)

Pipe length	Installation date	2020			2030		
	Context	London	Urban	Semi-urban	London	Urban	Semi-urban
	Assembly						
2 km	*Pipe network*	87.8%	87.8%	90.6%	91.3%	91.3%	90.1%
	Heat substation	12.2%	12.2%	9.4%	8.7%	8.7%	9.9%
5 km	*Pipe network*	94.4%	94.4%	95.7%	96.1%	96.1%	95.5%
	Heat substation	5.6%	5.6%	4.3%	3.9%	3.9%	4.5%

Table 6-6 Relative share of Assembly costs for 20MW heat load capacity (450mm pipe diameter)

Pipe length	Installation date	2020			2030		
	Context	London	Urban	Semi-urban	London	Urban	Semi-urban
	Assembly						
2 km	*Pipe network*	88.1%	88.1%	90.8%	81.1%	81.1%	78.5%
	Heat substation	11.9%	11.9%	9.2%	18.9%	18.9%	21.5%
5 km	*Pipe network*	94.7%	94.7%	95.9%	91.1%	91.1%	89.7%
	Heat substation	5.3%	5.3%	4.1%	8.9%	8.9%	10.3%

Comparing Table 6-4 to Table 6-6 it is clear that an increased heat load increases the network costs relative to the heat substation costs. This is because the higher loads require larger and more expensive pipes but the costs of the heat exchanger remains the same.

This increase is more marked in moving from 2MW to 5MW than from 5MW to 10MW. This is a consequence of the relative pipe costs for the different diameters with 300mm pipes being around 75% more expensive than 150mm but 450mm being only around 50% more expensive than 300mm.

The heat network also becomes a more significant assembly cost when the context of the interconnection project moves from London/urban to semi-urban, due to lower pipework costs in semi-urban areas. This is because the urban substation is 1.25 more expensive than semi urban, while urban network is 1.6 higher than semi urban network.

6.2.2 Analysis: Normalised costs

Four normalised costs have been analysed:

- Total NPV per MW of capacity
- Total NPV per km of network
- First costs per MW of capacity
- First costs per km of network

Table 6-7 shows the first cost and total NPV per MW of capacity and km of network at both installation dates and in all contexts.

Table 6-7 First cost and total NPV per MW of capacity and km of distribution network

Installation date	Context	Heat load (MW)	Pipe diameter (mm)	Pipe length (km)	First cost per MW (£m/MW)	NPV per MW(£m/MW)	First cost per km (£m/km)	NPV per km (£m/km)
2020	London	2	150	2	3.2	6.6	3.2	6.6
	London		150	5	6.4	13.2	2.6	5.3
	Urban		150	2	2.6	5.4	2.6	5.4
	Urban		150	5	5.3	10.8	2.1	4.3
	Semi-urban		150	2	2.0	3.9	2.0	3.9
	Semi-urban		150	5	4.0	7.9	1.6	3.1
2030	London		150	2	4.1	5.4	4.1	5.4
	London		150	5	8.2	10.8	3.3	4.3
	Urban		150	2	3.4	4.4	3.4	4.4
	Urban		150	5	6.8	8.9	2.7	3.6
	Semi-urban		150	2	2.6	3.3	2.6	3.3
	Semi-urban		150	5	5.1	6.7	2.1	2.7
2020	London	5	300	2	3.1	6.3	7.8	15.7
	London		300	5	6.9	13.7	6.9	13.7
	Urban		300	2	2.6	5.2	6.4	12.9
	Urban		300	5	5.6	11.3	5.6	11.3
	Semi-urban		300	2	1.9	3.6	4.6	9.0
	Semi-urban		300	5	4.0	7.9	4.0	7.9
2030	London		300	2	4.0	5.2	10.1	13.0
	London		300	5	8.8	11.4	8.8	11.4
	Urban		300	2	3.3	4.3	8.3	10.7
	Urban		300	5	7.3	9.3	7.3	9.3
	Semi-urban		300	2	2.4	3.1	6.0	7.7
	Semi-urban		300	5	5.3	6.7	5.3	6.7
2020	London	20	450	2	1.3	2.6	13.0	26.0
	London		450	5	2.9	5.8	11.6	23.3
	Urban		450	2	1.1	2.1	10.6	21.3
	Urban		450	5	2.4	4.8	9.5	19.1
	Semi-urban		450	2	0.8	1.5	7.7	14.9
	Semi-urban		450	5	1.7	3.3	6.8	13.3
2030	London		450	2	1.7	2.2	16.9	21.6
	London		450	5	3.8	4.8	15.1	19.4
	Urban		450	2	1.4	1.8	13.8	17.7
	Urban		450	5	3.1	4.0	12.4	15.9
	Semi-urban		450	2	1.0	1.3	10.1	12.7
	Semi-urban		450	5	2.2	2.8	8.9	11.2

Figure 6-4 and Figure 6-5 shows graphically the outputs of Table 6-7.

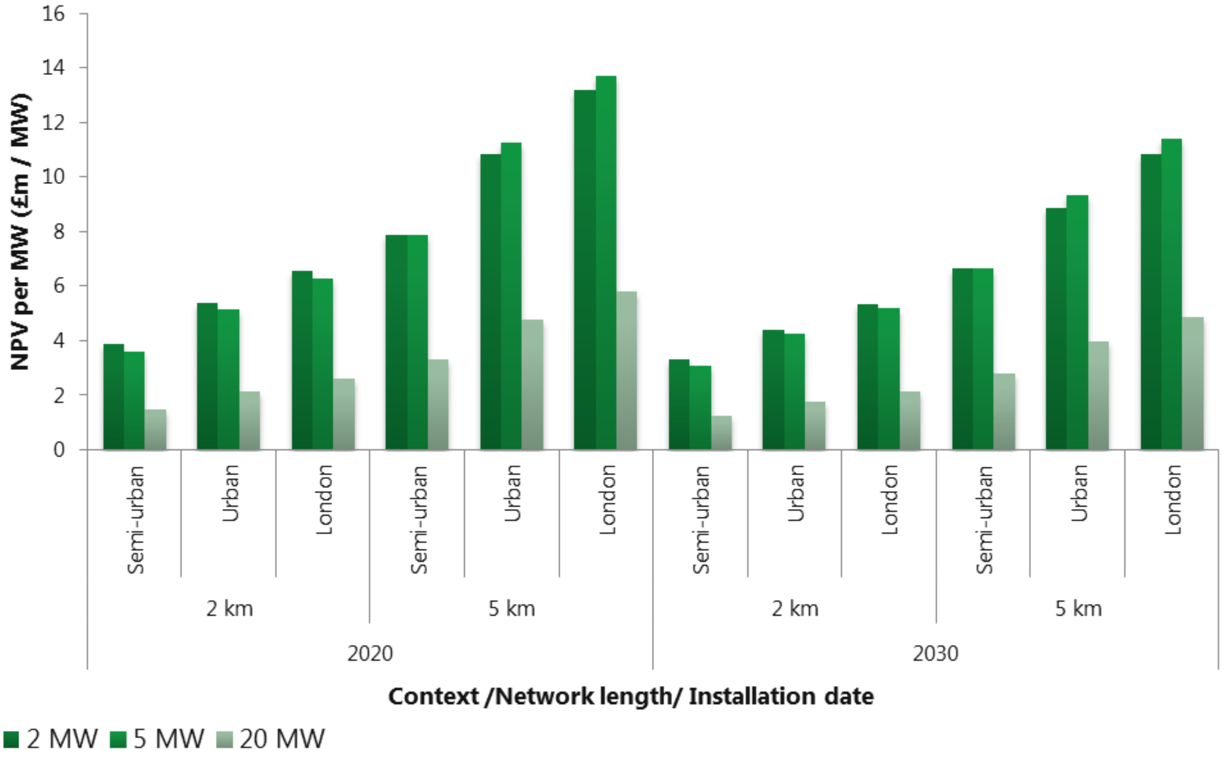


Figure 6-4 Total NPV per MW of network capacity in different context, installation dates and length of network

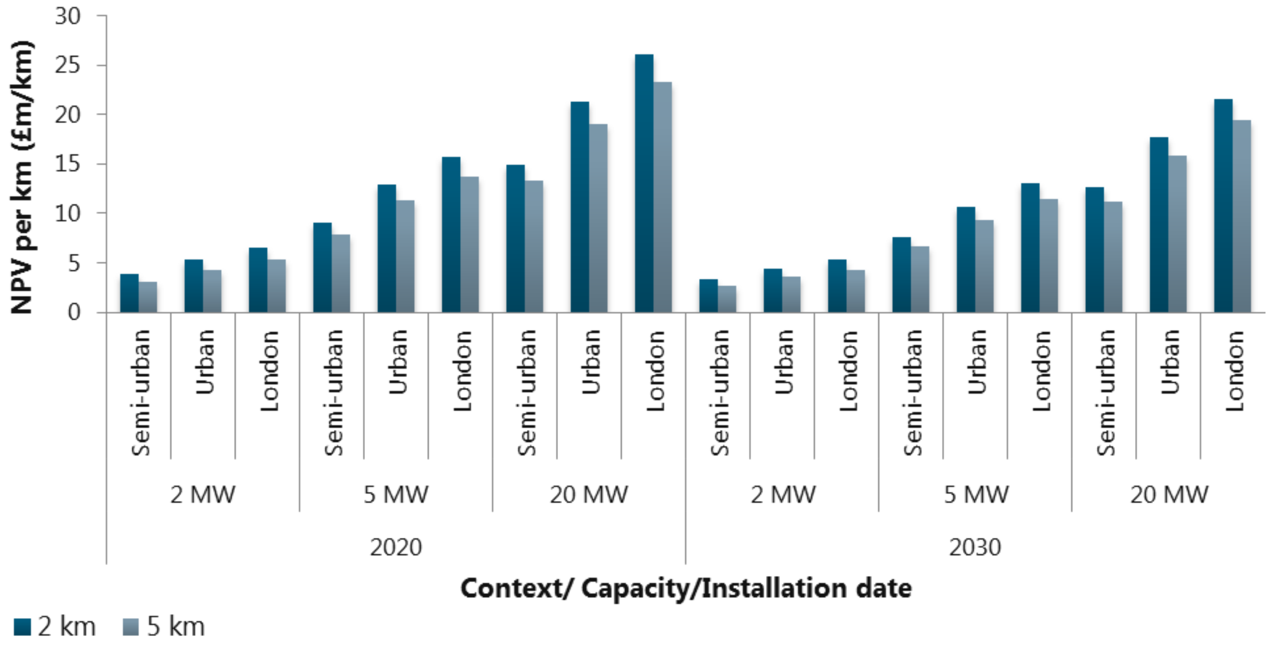


Figure 6-5 Total NPV per km of network length in different context, installation dates and capacity of network

The analysis of normalised costs shows that:

- The normalised costs follow the same trend as the absolute costs in relation to the differences between contexts (ie. for the same capacity and installation date, the cost per km and per MW increases from semi urban to urban to London).
- In 2 km network length, considering same context, the cost per MW heat reduces for every additional MW added to the network. The increase in the costs, though, is not proportional to the increase of the MW.
- In 5 km network the first cost as well as the total NPV per MW increases from 2 MW to 5MW. This increase is due to the fact that 2 and 5 MW capacity network use the same capacity substation but different capacity of distribution network. As a result, as the length of the network increases, its impact on costs becomes more significant.
- For the same context, capacity and installation date the costs per km of heat network falls with the increase in the length.

6.3 Limitations and further work

The Assemblies include an allowance for valves and crossings. More detailed design work and bill of quantities would be required to tailor this to each context. No allowance has been made for major infrastructure barriers.

The analysis is based on two simple systems designed within the context of the ICC. More detailed design work would give a wider range of results from which some rules of thumb in relation to system size and proximity could be developed. In addition, further analysis could include exploring the costs of connecting more than two networks, in which case, apart from an increase in length, there would also be an increase in the number of substations.

As noted in Section 3.4, there are a number of considerations to be taken into account in relation to the design and modelling assumptions contained in the first version of the ICC used for this study. In particular, cost trends and the treatment of Opex and lifecycle costs are to be revised in future versions which could impact on these results.

7 H-I-20 Cost impact of reducing network temperature

7.1 Research question overview and scope

This research questions was concerned with understanding the cost implications of using different temperature networks versus the reference heat networks provided in H-G-17 as the counterfactual. In particular, running a heat network at lower temperatures allows the use of pipeline materials other than steel which, as an innovation, could have implications for cost. Alternative network topology designs in low heat demand areas are also possible[14].

The basis of the network design is the same as for H-G-17 with the comparison being between conventional steel pipes and other materials. For this project, two alternative pipe materials – flexi-polymer and flexi-steel – were compared in terms of basic characteristics that influence factors such as heat losses, service life, installation, cost-effectiveness and resilience of the network.

Flexi-polymer pipes offer an innovative solution which offers high insulation performance through Polyutherane (PU) foam. The cost analysis undertaken here is in relation to this material. Costs were not available for the flexi-steel pipes so no quantification of this innovation has been undertaken.

Based on the spatial and other analysis, Table 7-1 shows the number of connections and network lengths assumed for each of the different contexts and populations. These nine variations were costed at two installation dates, 2020 and 2030.

Table 7-1 Bill of Quantities

Analysis code	**No. connections**					**Average service pipe length (m)**	**Trunk network length (km)**				**Total network length (km)**
	Domestic*	Non-domestic using domestic	Commercial	Industrial	Total		450mm	300mm	160mm (flexi – polymer)	Total trunk network length	
L07500	3,366	23	18	4	3,411	16.5	0.8	5.5	7.8	14.1	70.5
L20000	9,768	90	72	16	9,946	16.6	2.5	16.3	22.9	41.6	206.7
L50000	22,725	200	161	36	23,122	16.5	5.6	37.1	51.7	94.4	475.2
S07500	2,723	7	6	0	2,736	19.7	-	10.7	16.1	26.8	80.7
S20000	10,070	32	26	3	10,131	19.8	3.5	34.2	62.1	99.7	300.4
S50000	21888	54	44	5	21,991	19.7	6.7	78.3	137.9	222.9	656.9
U07500	3141	7	6	0	3,154	18.8	1.3	8.2	13.7	23.1	82.5
U20000	9239	31	25	3	9,298	18.7	3.6	23.5	38.8	66.0	239.7
U50000	21184	173	140	29	21,526	18.6	8.3	53.4	87.3	148.9	549.2

** This includes non-domestic loads using domestic connections*

---

[14] Qualitative analysis was provided in the Detailed Scoping phase in relation to alternative approaches to network topology aimed at reducing service network length. As the ICC includes the service pipe within the connections cost assembly, it was not possible to quantify the alternative topologies' impact on costs.

As 160mm is the maximum available diameter of flexi polymer pipes based on UK market research, only the 150mm steel pipes have been replaced with flexi polymer pipes. .

7.2 Results and Analysis

Based on the quantities in Table 7-1, 18 cost data sets were generated using the ICC. Each data set is representative of a different variation eg. heat network costs for London, installed in 2020, serving an area with population 7,500 people. The project cost parameters have remained unchanged in each variation.

Table 7-2 includes NPV Capex, NPV Opex, total NPV and first costs for projects installed in 2020 and 2030, for various contexts and populations. The outputs of the counterfactual are also displayed. As discussed in Section 3.3.2, first costs (undiscounted) include new build costs plus preliminary costs, contractors costs, PM engineering, land costs and contingencies but exclude any lifecycle replacement costs; NPV Capex represents the installation costs plus all lifecycle costs (which include all replacement cycles and abandonment costs - Repex – to the extent that these occur before the project end); and NPV Opex takes into account operational costs over the life of the project.

The unit cost (in 2015) of the 150mm flexi-polymer pipe is £1,705,400/km compared with £1,812,800/km for steel. Both costs refer to installation in an urban environment.

Table 7-2 Base cost output data - innovation vs counterfactual

Installation date	Context	Population	First costs (m£)	NPV Capex (m£)	NPV Opex (m £)	NPV Total (m£)
Innovation: Reduce network temperature – use of flexi polymer pipe lines						
2020	London	7,500	101.7	231.0	23.0	254.0
	London	20,000	295.8	673.8	67.1	740.8
	London	50,000	668.8	1,529.3	151.8	1,681.1
	Urban	7,500	113.5	248.5	25.4	273.9
	Urban	20,000	319.7	704.4	71.7	776.1
	Urban	50,000	725.8	1,605.6	162.8	1,768.4
	Semi-urban	7,500	86.0	160.5	19.5	180.0
	Semi-urban	20,000	323.7	603.8	73.3	677.1
	Semi-urban	50,000	713.8	1,331.1	161.7	1,492.7
2030	London	7,500	132.3	174.2	18.6	192.8
	London	20,000	384.9	507.6	54.1	561.7
	London	50,000	870.7	1,150.9	122.6	1,273.5
	Urban	7,500	146.7	189.1	20.4	209.5
	Urban	20,000	413.5	535.1	57.6	592.6
	Urban	50,000	939.1	1,218.2	130.8	1,348.9
	Semi-urban	7,500	111.8	142.0	15.7	157.7
	Semi-urban	20,000	421.2	534.7	59.1	593.8
	Semi-urban	50,000	928.6	1,178.5	130.2	1,308.7
Counterfactual – use of steel pipe lines						
2020	London	7,500	103.5	217.9	23.7	241.6
	London	20,000	301.0	635.3	68.9	704.1
	London	50,000	680.4	1,443.4	155.8	1,599.3
	Urban	7,500	116.1	229.6	26.3	255.9
	Urban	20,000	326.9	650.9	74.2	725.1
	Urban	50,000	742.1	1,485.3	168.4	1,653.8
	Semi-urban	7,500	88.5	159.0	20.3	179.3
	Semi-urban	20,000	333.4	598.1	76.4	674.5
	Semi-urban	50,000	735.3	1,318.3	168.6	1,486.9
2030	London	7,500	134.4	169.8	18.9	188.6
	London	20,000	391.2	494.7	54.9	549.6
	London	50,000	884.8	1,122.2	124.3	1,246.5
	Urban	7,500	149.8	182.8	20.8	203.6
	Urban	20,000	422.3	517.2	58.6	575.8
	Urban	50,000	958.8	1,177.9	133.2	1,311.1
	Semi-urban	7,500	114.9	137.3	16.1	153.3
	Semi-urban	20,000	432.9	516.4	60.5	576.9
	Semi-urban	50,000	954.6	1,137.8	133.4	1,271.2

Figure 7-1 shows the Opex and Capex NPV of both the innovation and its counterfactual.

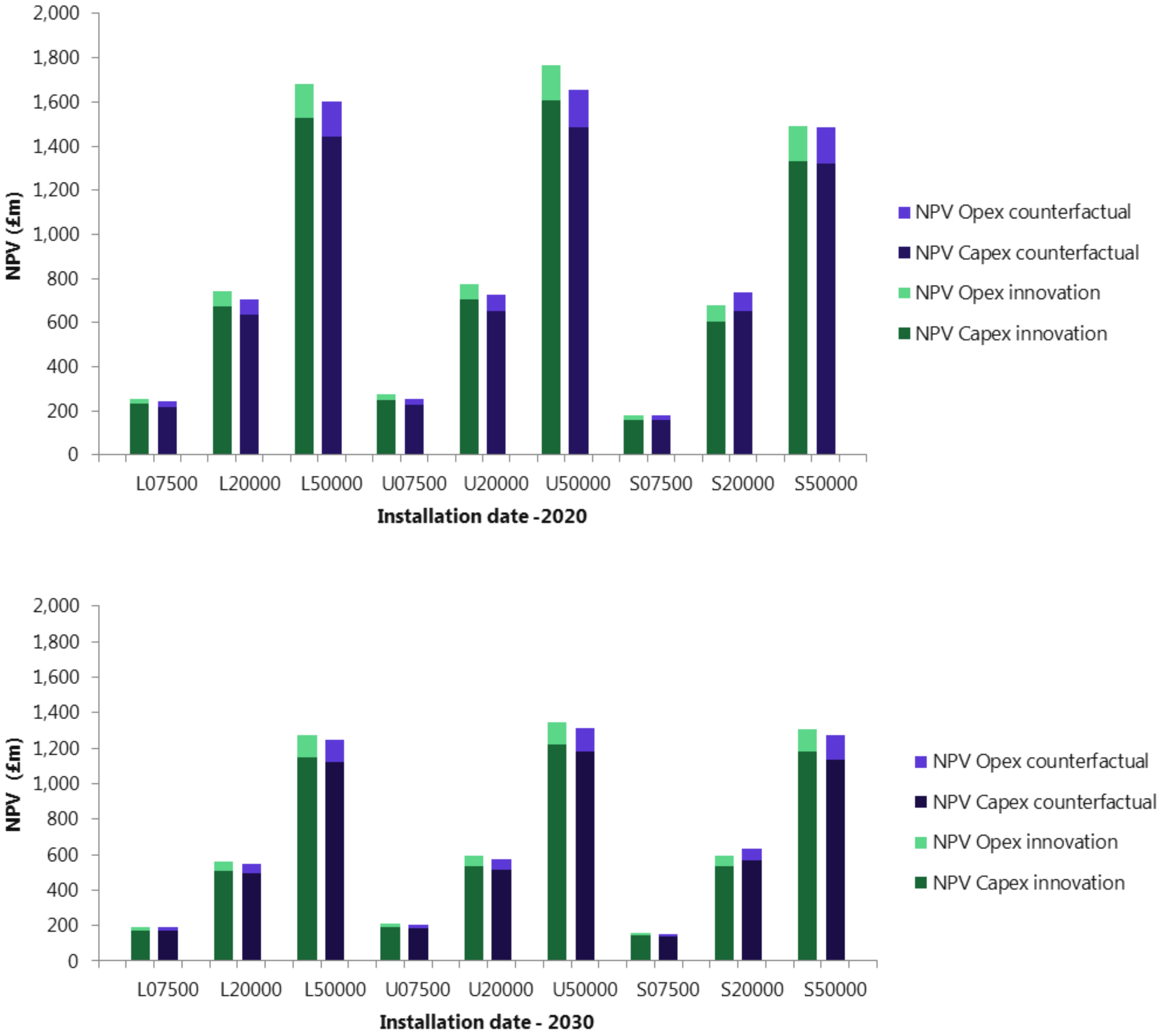


Figure 7-1 NPV (Capex and Opex) NPV of innovation and counterfactual in all variations

7.2.1 Analysis: Assemblies

This section provides a breakdown of the key elements of cost within the network.

The impact of the top five Assemblies on project costs is presented in Figure 7-2 as a percentage of the total costs. The variations have been grouped by population density.

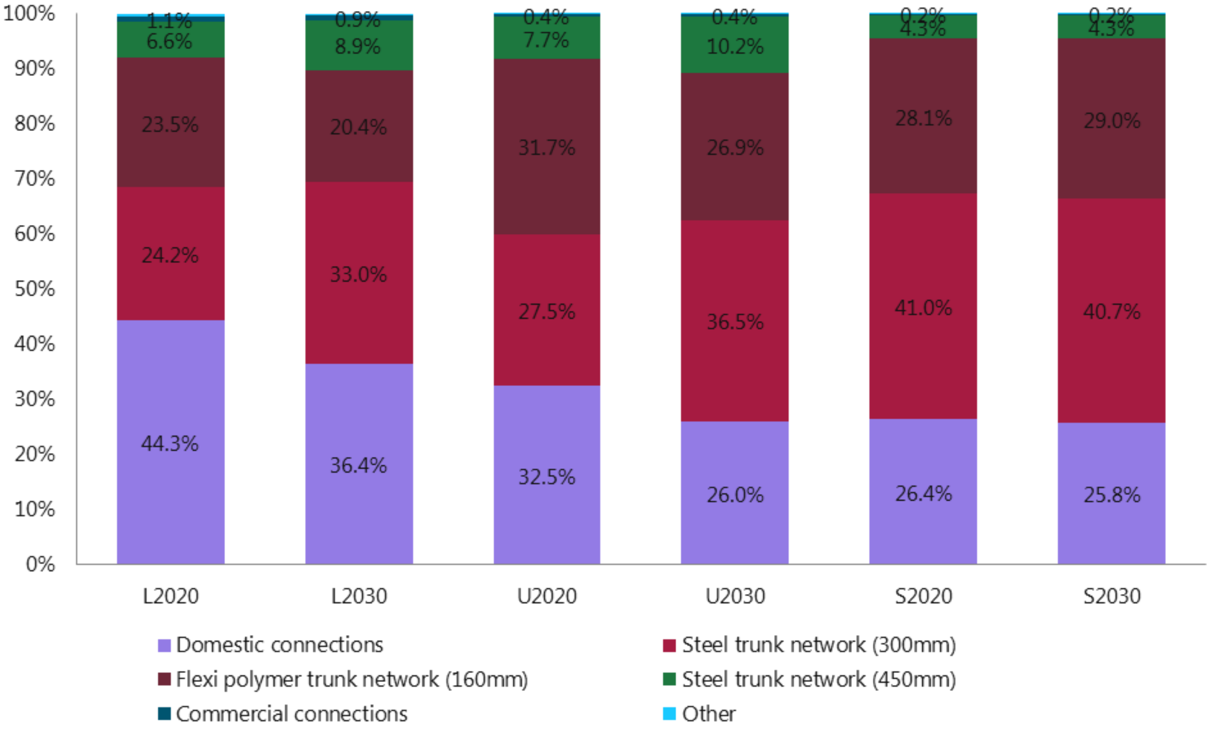


Figure 7-2 Assembly costs as a percentage of total cost – innovation

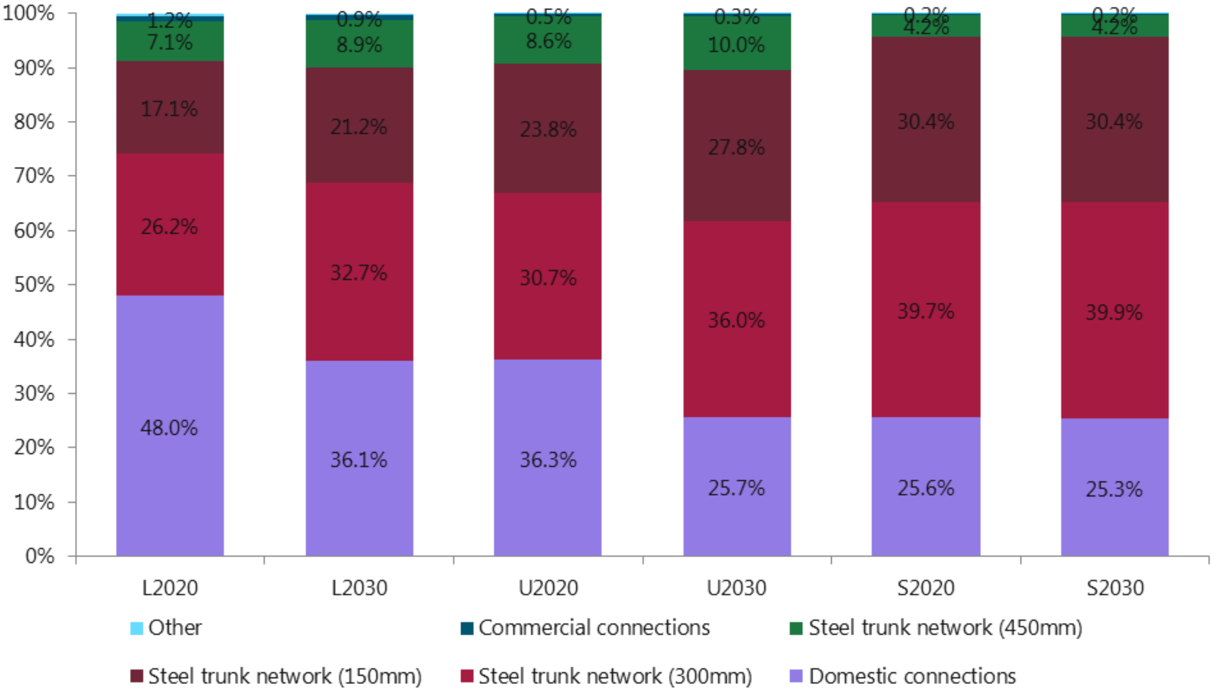


Figure 7-3 Assembly costs as a percentage of total cost – counterfactual

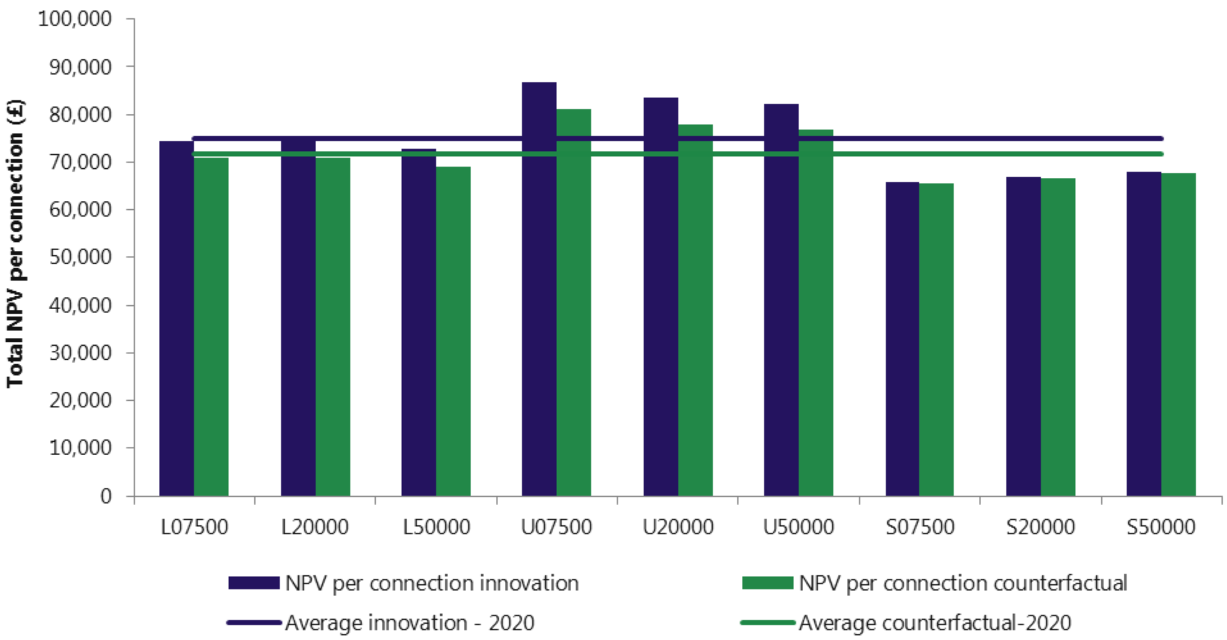
Figure 7-2 and Figure 7-3 show that the trends in the relative share of total costs of different Assemblies within the network are similar for the innovation and counterfactual. Connection costs are more significant in London, while network costs are more significant in urban and semi urban environments. Thus, the share of total costs represented by connections falls as density falls, while the share of total costs represented by the network increases in less dense areas.

7.2.2 Analysis: Normalised costs

Two normalised costs have been analysed:

- Total NPV per connection
- First costs of installation per connection

The normalised costs of the innovation are compared with those of the counterfactual as calculated for H-G-17 in Chapter 4 as illustrated in Figure 7-4 (total NPV per connection) and Figure 7-5 (first costs per connection).



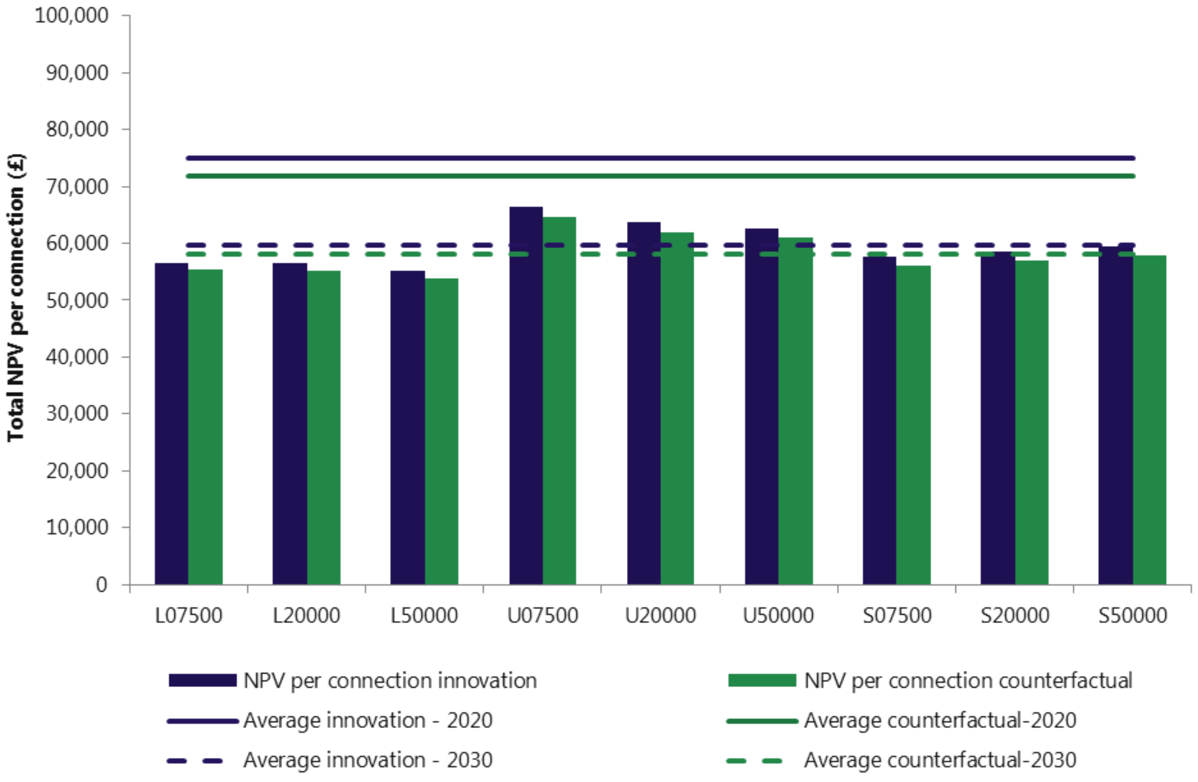
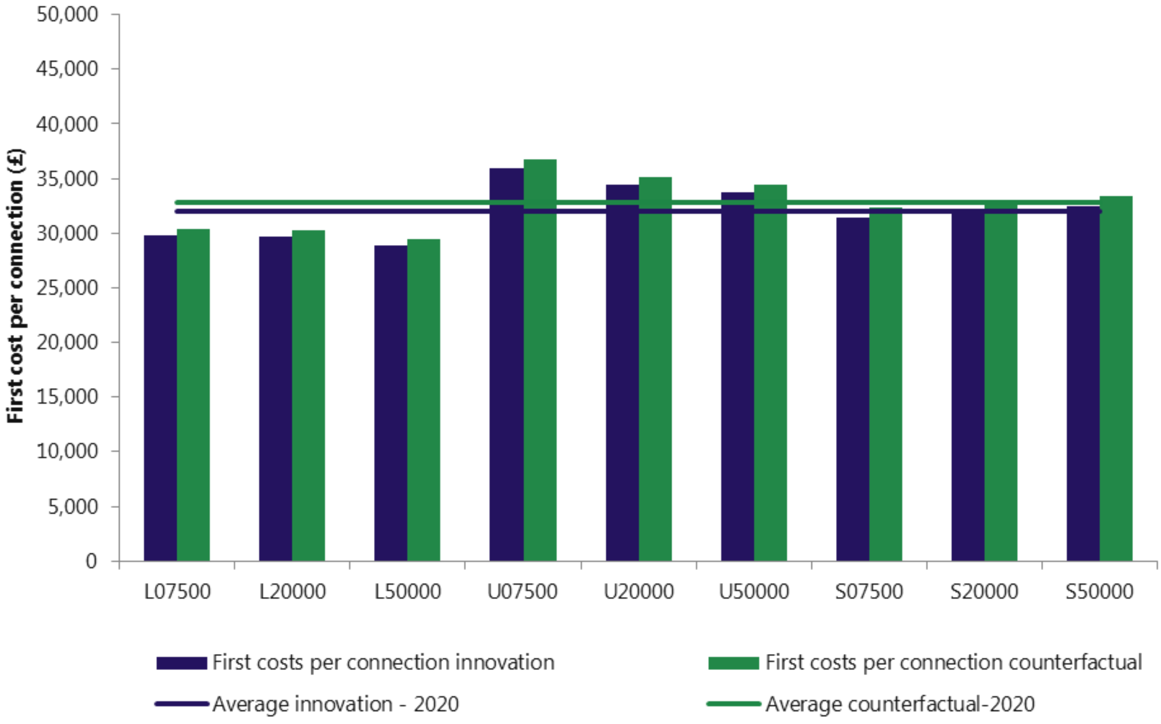


Figure 7-4 NPV Total per connection for the innovation and counterfactual for different contexts and populations (top graph 2020; bottom graph 2030)



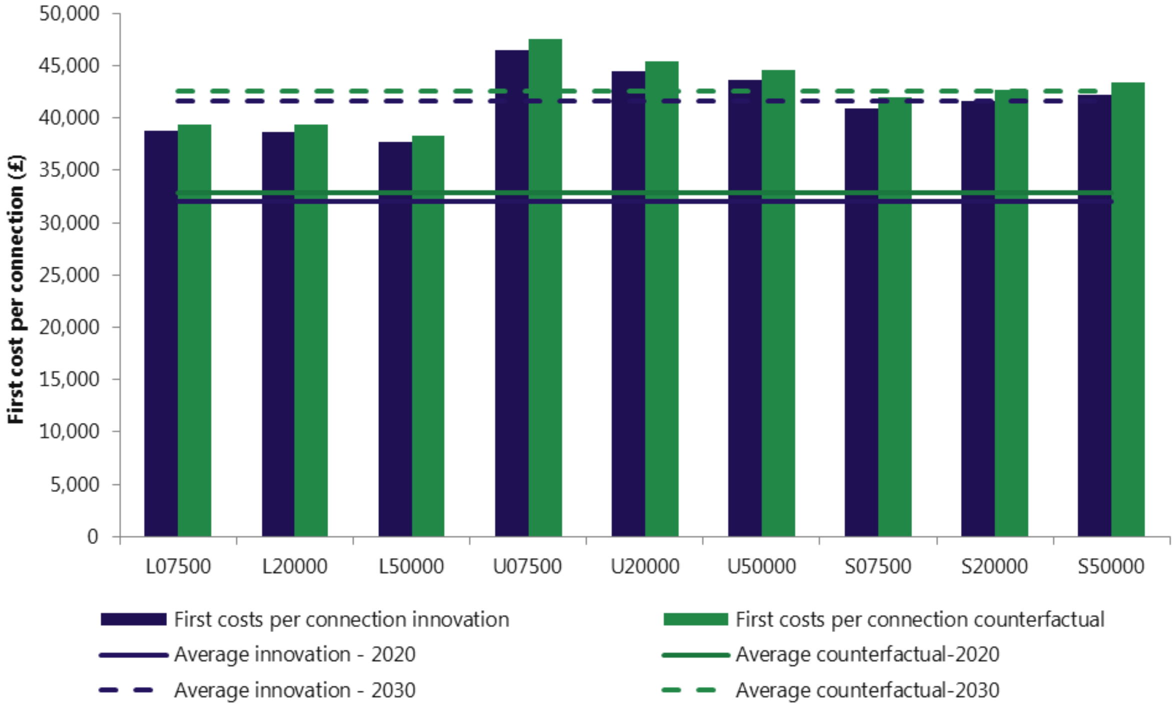


Figure 7-5 First costs per connection for the innovation and counterfactual for different contexts and populations (top graph 2020; bottom graph 2030)

The analysis of Figure 7-4 and Figure 7-5 suggests that:

- The NPV per connection, which represents the whole life costs of the project per connection, is higher in the innovation task (for the same installation date and context) than in the counterfactual
- The first costs per connection, are higher in the counterfactual than in the innovation

This suggests that the innovative approach is more expensive over the whole life cycle of the project despite costing less on initial installation.

The main reasons for this are :

- The flexi-polymer pipe installation generates low first costs due to lower labour, material and plant costs. It should be noted that the installation method is quick, simple and cost effective due to use of long coils.
- The replacement and abandonment costs are higher in the case of flexi-polymer, as flexi-polymer has a shorter lifecycle than steel (a 25-year cycle compared with a 40-year lifecycle).

Other considerations in relation to the innovation are:

- As flexi-polymer is an innovative product there is the potential for costs to reduce over time should it be widely adopted. In this case, future prices could fall in relation to steel, therefore reducing the costs of replacement.
- Heat losses are not included in the calculation of Opex and therefore do not impact on whole life performance. It is expected that flexi-polymer pipe network would have less losses than steel thus the whole life costs of the innovation would reduce.

One of the main limitations of the innovation is that flexi-polymer pipes are only available in limited diameter sizes. As a result, they can only serve a small range of demand. Increasing flexi-pipe diameters would make it possible to use them for higher loads. It is not possible at this stage to estimate whether the increase in diameter of flexi-pipes would result in a proportional increase in their costs.

7.3 Limitations and further work

Limitations are similar to those outlined for H-G-17.

As noted in Section 3.4, there are a number of considerations to be taken into account in relation to the design and modelling assumptions contained in the first version of the ICC used for this study. In particular, cost trends and the treatment of Opex and lifecycle costs are to be revised in future versions which could impact on these results.

8 Summary

8.1 Key results

Some findings are the same across all projects. These include:

- First costs are higher at later installation dates. This is due to the impact of the cost trends in the ICC which inflate labour, material and plant costs over time (see Section3.2.5). There are clearly alternative views on cost trajectories and these will influence the relative impact of deferring installation.
- NPV (Capex plus Opex) is lower for projects installed at a later date. Two factors come into play here: one, as expected, is the impact of discounting; the other is the way in which lifecycle costs are modelled in the ICC and the fact that the analysis has been undertaken for a fixed period of 60 years (2015 to 2075) irrespective of the installation date. Lifecycle costs include for a major refurbishment (100% of new build costs) at a fixed period after first instalment. For later installation dates, this major refurbishment may be beyond the analysis period and therefore not be included in the NPV calculation.
- Opex costs represent a relatively small proportion of whole life costs. It should be noted that the modelling of Opex is to be revised in the next version of the ICC which may influence the outturn values. Note also that Opex does not include the cost of losses. This is to be expected for buried pipe networks where much of the maintenance cost is in installation cost (e.g. quality control) and preventative measures (e.g. water treatment) rather than regular servicing as the asset is not accessible.

A summary of findings specific to each project is given in Table 8-1.

Table 8-1 Key findings for heat network research projects

Ref	**Research question**	**Key findings**
GENERIC NETWORKS		
H-G-17	Representative heat network model: district heating networks modelled for semi-urban, urban and London areas at different populations sizes / densities	• Connections, including service pipes running from the mains to the buildings, are the major element of network cost in more urban areas while main pipework is the major element in more rural areas reflecting the density of connections in the area. • 300mm pipework costs represent the highest share of the network costs. This is because they represent the highest share of network length as they serve a wide range of loads prevalent in all the analysed MSOAs. The predominance of the 300mm pipework costs in the study is partly a limit of the ICC which has only 3 no. pipe diameter sizes (150, 300, 450mm). In practice, smaller pipe diameters might be used. • First cost per connection is highest in urban areas and lowest in London areas, with semi-urban areas being in the middle of the range. This is because the density (and hence pipe length per connection) of the urban areas in this exercise is closer to that of semi-urban areas than London. Thus the additional costs of installation in urban areas outweighs the shorter pipe length so that urban costs per connection are higher than semi-urban ones. In contrast, comparing urban with London, although installation costs in London are higher than urban in general, the higher connection density in London (and hence shorter pipe length per connection) outweighs the higher costs so that overall costs per connection in London are lower than urban. • This trend is slightly different with NPV per connection. Urban costs are still the highest but instead semi-urban costs are lower than London costs. This

Ref	Research question	Key findings
		is due to the difference in the relative share of Assemblies (connections and pipework) combined with their different lifecycle profiles (25 and 40 years respectively). This means connections are replaced more frequently and as they form a greater share of network first cost in London have a greater impact on NPV than in lower density areas where they form a lower percentage of the network cost. • These results are based on a small sample of areas mapped in GIS. Further data points could be usefully obtained by mapping more areas and testing whether the semi-urban – urban – London trend described above still holds. • The trends illustrate that in pure cost terms, not including revenues, there may be areas outside of the higher density urban areas which make more sense for heat networks. For example semi-urban areas which have access to low cost sources of heat (e.g. waste heat from energy from waste) may be more viable than high density areas where heat sources may be more expensive (e.g. small scale natural gas fired CHP).
H-G-18	Representative heat network model - compact villages: district heating networks modelled for a compact village with a single population size	• The results are consistent with those of H-G-17 with these relatively low density areas having higher NPV and costs per connection compared with those of more dense semi-urban areas.
H-G-19	Representative heat network model - connecting networks: substations and interconnecting pipework of 2 different lengths and 3 different loads in London, urban and semi-urban contexts	• The network costs represent the main share of the cost of connection, being over 70% in all cases. The share is lower in more dense urban areas where pipe lengths are lower and so the substations account for a greater share of the costs. • Network costs take a greater share of total cost as the load increases due to the higher costs of the larger pipe diameters required. • Costs per km increase moving from semi-urban to London reflecting the greater costs of installation in more congested urban areas. • Costs per MW decrease with increasing size. The difference is particularly marked between 5MW and 20MW as, although a slightly larger substation is required, the cost is more than offset by the higher load. • Costs could be further reduced by using direct connections e.g. substations would not have heat exchangers between networks and the water in each network would mix between them. This is common in well developed heat network markets but less common in the UK where concerns regarding liability or mismatches in age of networks tend to prevent this. • When assessing the potential for interconnection of heat networks the benefits are often to do with more efficient or higher utilisation of the central plant due to greater scale and diversity of loads. This benefit is not captured in the analysis. Similarly, no value is attached to increased resilience.
INNOVATIONS		
H-I-20	Cost impact of reducing network temperature: impact of using flexi-polymer pipe in place of 150mm steel pipe in the same contexts and configurations as in H-G-17	• The unit cost (in 2015) of the 150mm flexi-polymer pipe is £1,705,400/km compared with £1,812,800/km for steel. Both costs refer to installation in an urban environment. The market for steel versus polymer has not been assessed and growth in the polymer market could lead to reduced costs. • As a consequence of the lower unit costs, first costs of the innovation are lower than those of the counterfactual. However, NPV costs are higher. This is due to the differing lifecycles of the two products – flexi-polymer has a shorter life (25 years in the ICC) than steel, thus the costs of replacement during the product life outweigh the lower initial costs. This is also true of the cost per connection. This assumption may be challenged in practice but there is limited data in this area. • The same trends identified in H-G-17 in respect of the cost per connection in different contexts applies to flexi-polymer. • Flexi polymer is not used in the service pipes, due to the tool costing the

Ref	Research question	Key findings
		service pipes as part of the connection costs. - The tool does not pick up the potential to use a lower diameter pipe when using polymer pipe due to the reduced frictional losses from the smoother surface. Often 1 size smaller pipework can be used.

8.2 Further work

Areas for further work relate to the scope of some tasks and to issues arising from the design of the ICC. These are discussed below.

8.2.1 Scope related issues

- H-G-17 (and H-I-20): The reliance on single locations to represent particular types of location remains a limitation of the analysis. Further work could include the analysis of additional locations to better understand and develop general cost trends.

8.2.2 ICC issues

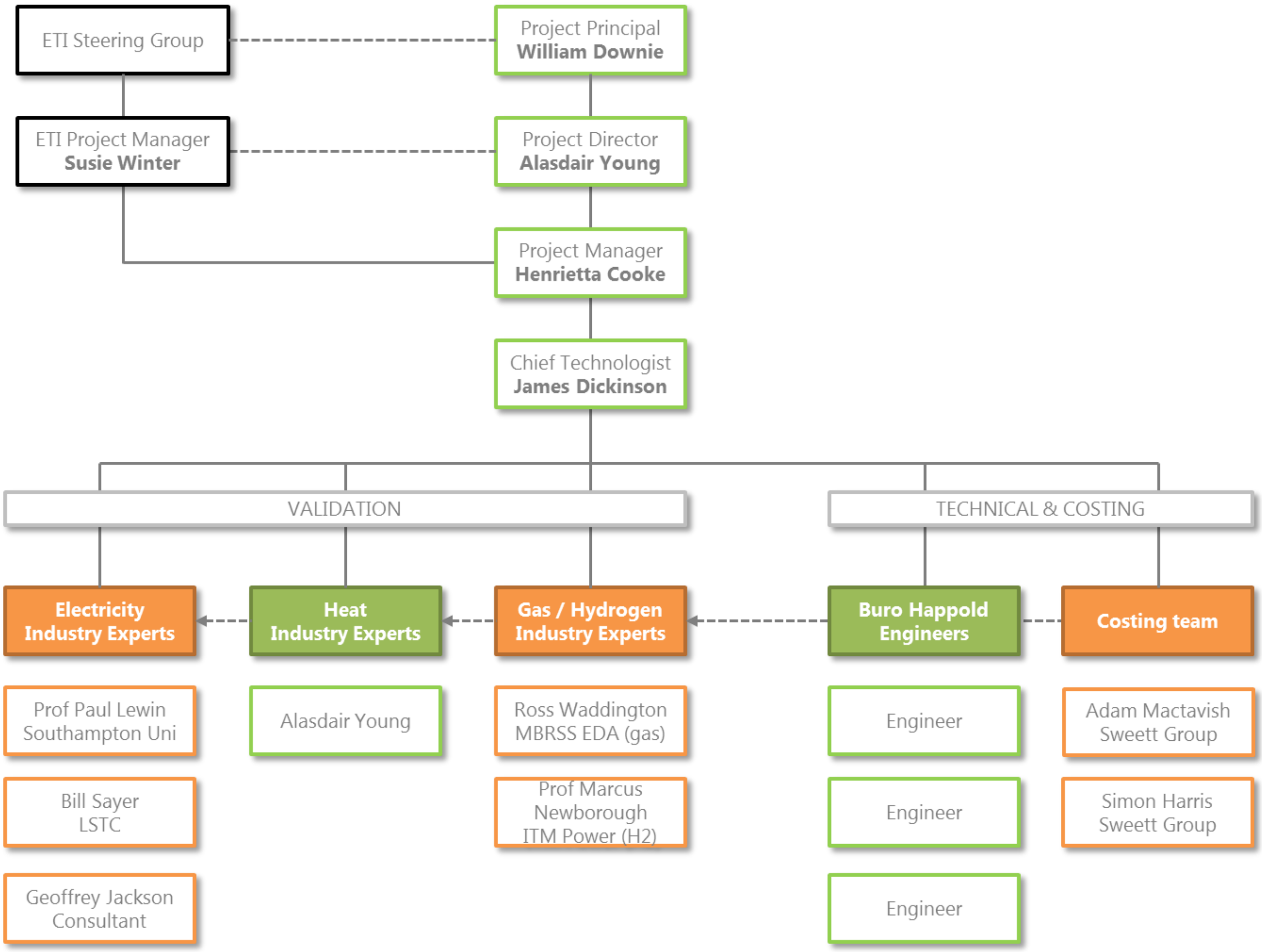
Analysis undertaken for a number of tasks raises the question as to whether the single assessment window (2015-2075) for all projects is appropriate. The primary reason this has arisen as an issue is the manner in which lifecycle costs are modelled in the ICC. As described in Section 3.2.4, lifecycle profiles are applied to each Assembly such that cash flows associated with minor and major refurbishments and with ultimate abandonment are deemed to occur in full in certain years. The effect of this is that a major refurbishment may be scheduled to occur beyond the analysis period for installations made at a later date. In the new version of the ICC, this approach is to be replaced with one that takes a more probabilistic view of replacement costs such that they are spread over the life of the asset. This approach would mitigate the effect of having a fixed analysis period.

Cost trends are being revised in the new version of the ICC.

The impact of the above suggests that further work could include re-running all tasks in the new version of the ICC. Sensitivity to cost trends could also be tested.

Appendix A Project Team

The overall project team is given in the organogram with details of the industry experts in the table below.



Role	**Individual** **Experience & qualifications**
Industry Expert – Electricity Provision of expert advice and design validation in relation to HVDC and transmission voltage HVAC cabling and power electronics	**Professor Paul Lewin, Southampton University** BSc (Hons), PhD, CEng, FIET, FIEEE Professor Lewin is Professor of Electrical Power Engineering in the School of Electronics and Computer Science, where he is also head of the Tony Davies High Voltage Laboratory. His research interests are within the generic areas of applied signal processing and control. Within high voltage engineering this includes condition monitoring of HV cables and plant, surface charge measurement, HV insulation/dielectric materials and applied signal processing. In the area of automation he is particularly interested in the practical application of repetitive control and iterative learning control algorithms. He is Vice President (Technical) of the IEEE Dielectrics and Electrical Insulation Society as well as an Associate Editor of the IEEE Transactions on Dielectrics and Electrical Insulation.
Industry Expert – Electricity Provision of expert advice and design validation in relation to AC Overhead Lines at all voltages	**Bill Sayer, LSTC Ltd** I. Eng. MIET Bill is currently a consultant with LS Transmission Consultancy Ltd where his key responsibilities are overhead line design, engineering specifications, component design/ specification, product evaluation and formulating construction procedures (wood pole and steel towers up to 400kV). Prior to working at LSTC, he was design manager for overhead lines for Balfour Beatty Utility solutions where he was responsible for the management of all engineering design issues on steel tower and wood pole overhead lines up to 400kV operation. He is Chairman BSI PEL/11 committee - Overhead Lines and UK Delegate CENELEC TC/11 WG9 – Revision to EN 50341 OHL Design > 45kV.
Industry Expert – Electricity Provision of expert advice and design validation in relation to AC Overhead Lines at all voltages	**Peter Papanastasiou, LSTC Ltd** BSc (Hons) C. Eng. MICE, FEANI (Eur Ing) Peter is a Director of LS Transmission Consultancy Ltd which has as its core business feasibility studies, topographical and ground surveys, concept and detailed design for projects for the Railway and High Voltage Electrical Power Engineering industries, in particular Overhead Lines and Substations in the power sector.
Industry Expert – Electricity Provision of expert advice and design validation in relation to electricity distribution focused on below ground electricity cabling at distribution voltages and substations.	**Geoffrey Jackson, Consultant** BSC (Hons) C. Eng Geoffrey has a long career in the electricity distribution sector from the operational level through general supervision to project management, including the installation, commissioning, safe operation, maintenance and dismantling of HV switchgear to 33kV, high and low voltage cables and cablejointing, high and low overhead lines. Other experience includes: • Project management including planning, design, tender issue and appraisal, construction and commissioning. • Extensive experience in asset condition appraisal and asset management with particular emphasis on switchgear, transformers and high voltage lines and cables.
Industry Expert – gas / hydrogen Provision of expert advice and design validation in relation to gas and hydrogen networks at all pressures.	**Ross Waddington, E Donald & Associates** Incorporated Engineer – Institute of Gas Engineers and Managers (IGEM) Ross is an Associated Director at E Donald & Associates. He is a highly experienced Senior Consultant Engineer specialising in all forms of pipeline engineering. As a Senior Manager has led multi-disciplined design teams on major Regeneration and large scale Renewable Energy projects across the UK.

Role	**Individual** **Experience & qualifications**
Industry expert – hydrogen Provision of expert advice in relation to hydrogen infrastructure	**Marcus Newborough, ITM Power** FREng CEng MSc PhD Marcus is Development Director at ITM Power where he supervises the analysis of existing and new electrolyser applications, hydrogen system design requirements for business development opportunities and demonstration projects, and the development of electrolyser products. Prior to joining ITM, he was a Research Chair at Herriot-Watt University where he led the Heriot-Watt Energy Academy as a pan-university mechanism for building partnerships in energy-related research. He established a research group which investigated pathways to a lower-carbon energy system, focusing on the assessment of demand side solutions in buildings, micro-generation, DSM and hydrogen energy systems.

Appendix B Project cost functionality

Extract from:

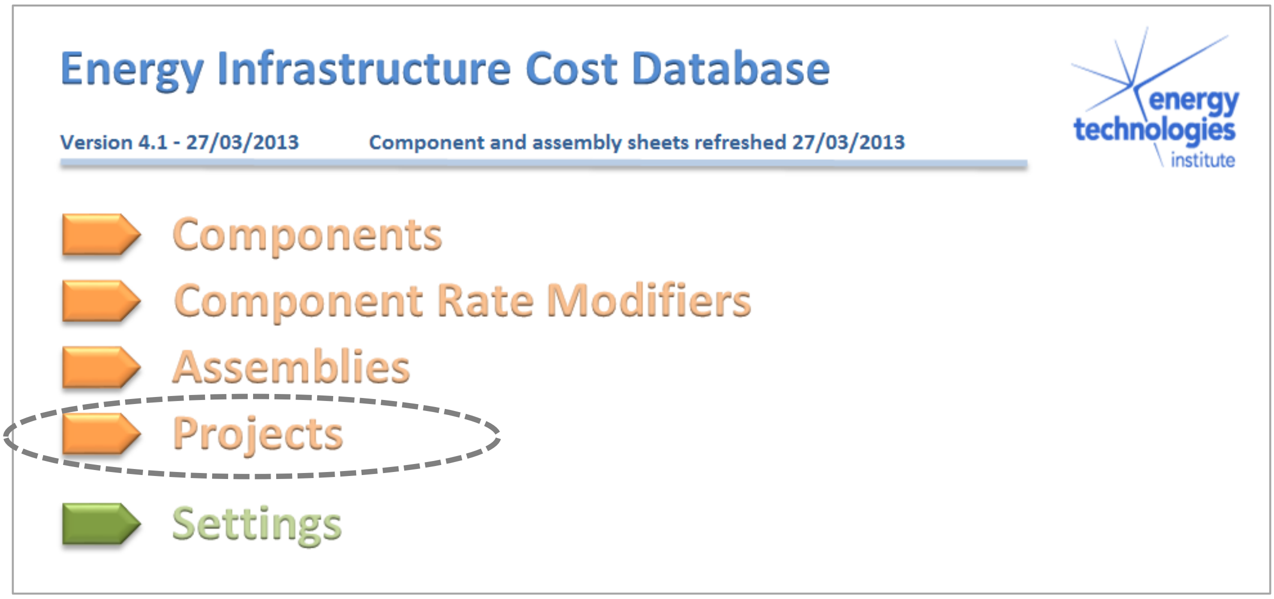
Energy Infrastructure 2050 Final Report, 22 November 2013, available from the ETI

Overview

The model contains a wealth of information and is provided with a number of tools and interfaces to enable users to adapt it to their needs and to extract data in ways that are both meaningful and useful. Its modular structure ensures that it is 'future proof' in that new Components and Assemblies can be added as required, either as more detailed cost data becomes available or an innovative technology becomes available. Data is also available to be extracted for use in other models or form as it is all in Excel cells which can be read by other applications or spread sheet tools.

It is anticipated that the primary use of the model will be in exploring the costs of projects and comparing options to help determine an optimal solution. In this chapter an overview of the Project functionality is provided along with some specific examples of questions the model can help in answering.

As mentioned elsewhere in this report, it must be noted that **the cost model does not allow for any form of system design.** Projects need to be designed as a separate exercise such that they can be expressed as a 'bill of quantities' (BoQ)[15] of constituent Assemblies. This 'bill of quantities' is used to model various aspects of the Projects for comparative purposes.



Energy Infrastructure Cost Database

Version 4.1 - 27/03/2013 Component and assembly sheets refreshed 27/03/2013

Figure B—1: Screen shot of start page of Infrastructure Cost Model

---

[15] The term 'bill of quantities' is used to refer to the data required to be input to the cost model in order to extract overall project costs. The quantity of each Assembly used to build the Project is required and this is input via the Project Data sheet of the model. This is further explained in the User Manual.

Project functionality

The Project functionality is a key analytical tool within the Cost Model. It enables users to cost systems of Assemblies which can be compared under different variations. In particular it allows for:

- The analysis of Projects of any scale or level of complexity from a single Assembly of a single vector to a multiple range of Assemblies across different vectors
- The creation of Projects that involve a transition over time such as the repurposing of gas to hydrogen over a 20 year period, or the inclusion of a transformative technology mid-way through the analysis period
- The modification of future cost trends so as to take into account the user's view of market factors both at a Project wide scale and individually for differing technologies as encapsulated by Components. These modifications can reflect general economic assumptions (such as labour rates / skills shortages) and technology specific assumptions such as the impacts of technology maturity and rates of deployment.

The details of how Projects are created within the model are provided in the User Manual. Key aspects of their structure and use are provided below.

Project cost calculation

Cost build up from Components and Assemblies

The calculation of Project costs uses the maximum and minimum capital cost of all Components to determine upper and lower bounds of total Project cost over the Project life. Project baseline cost is determined using rate modifiers, described in Section 7.3.3 and as outlined schematically in Figure 8—2, applying a simplified triangular Monte Carlo simulation model using the maximum, minimum and most likely cost values and allowing the user to interrogate cost probabilities based on Component cost variability.

A Project can specify quantities of Assemblies at different operational stages, that is new build, refurbished, repurposed or abandoned, each to be added at a specific period. Costs of each operational stage are built up for each Assembly and then for the Project as a whole based on:

- Capital costs
- Lifecycle costs
- Operating costs

The build-up of each of these cost profiles at the Component and Assembly level is described in Chapter 7. The user has the option to define each of the rate modifiers at the Project level or for individual Assemblies. The Project contains cost profile information for each Assembly covering each year of the defined lifecycle period.

Operating costs over this period will vary as the asset ages in line with the operating cost profile assigned to the Assembly and the major and minor replacements scheduled in the assembly lifecycle plan. For new build Assemblies there is no existing asset to be replaced, repurposed or abandoned, however for other Assembly options the operating costs presented are the net cost after an existing Assembly has been removed. The impact of this is the removal of the annual operating costs associated with the existing Assembly that is being refurbished, repurposed or abandoned.

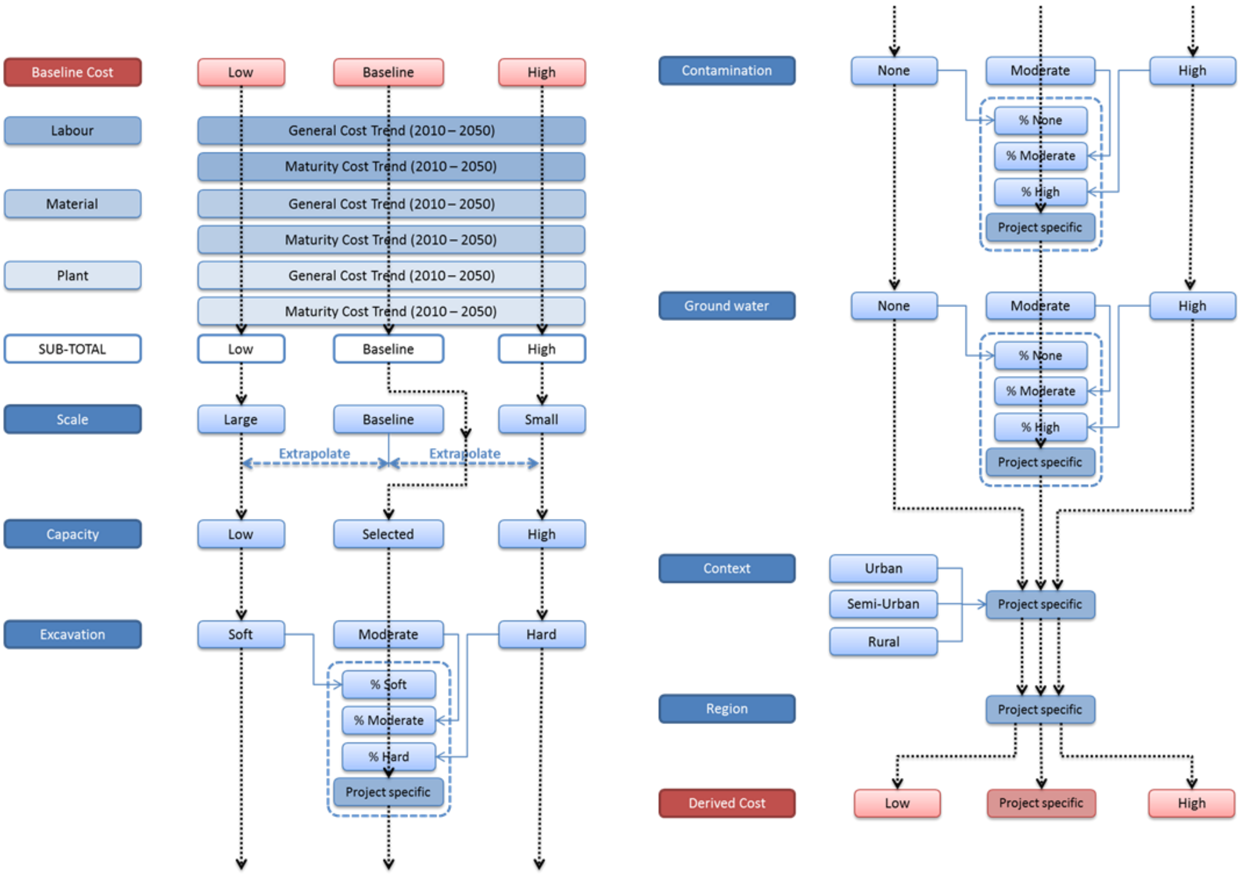


Figure B—2: schematic to illustrate application of Rate Modifiers to Projects

Project Level costs and adjustments

There are a number of costs that are applied directly at Project level. These include project management, preliminaries, contractor overheads and profit, and contingencies. These are added as a percentage mark-up applied to the capital and lifecycle costs incurred in each year of the project once the project Assembly costs have been calculated.

It is also possible to modify costs specifically for the Project. Key adjustments include:

- Cost trends: labour / materials / plant. For each a high, baseline or low rate increase can be selected.
- Ground conditions: excavation difficulty, ground contamination and ground water. For each factor, a percentage can be specified to reflect the proportion of ground conditions expected to be encountered on the Project.

- Optimism bias: There is a demonstrated, systematic, tendency for project appraisers to be overly optimistic. The HM Treasury Green Book[16] advises that, to address this tendency, “appraisers should make explicit, empirically based adjustments to the estimates of a project’s costs, benefits, and duration”. The Infrastructure Cost Model includes the facility for users to apply Optimism bias factors following HM Treasury Green Book guidance. The model includes a default upper and lower bound however this can be adjusted by the user if required.

Project Dashboard

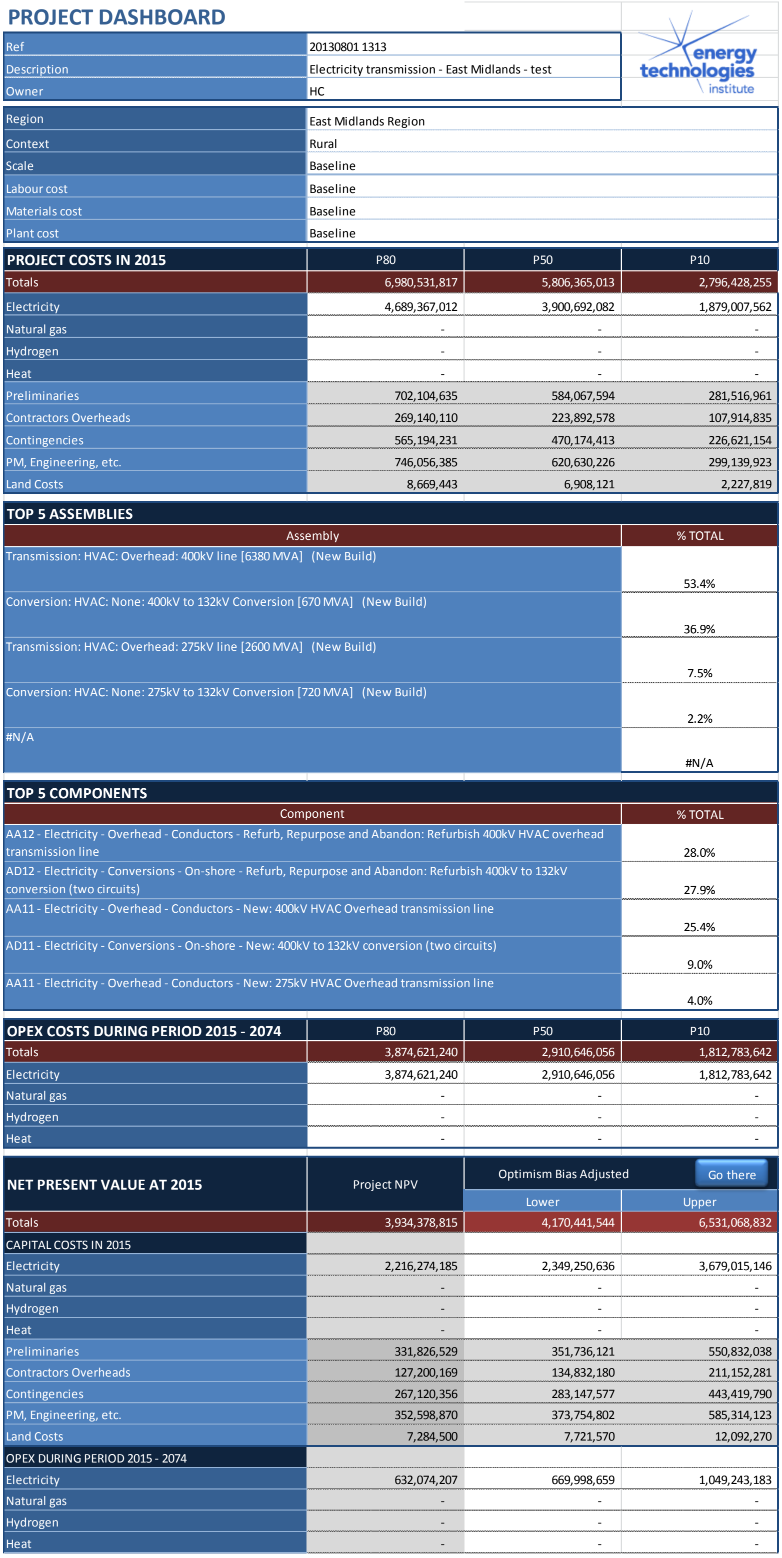
The Project Dashboard presents total Project costs over the specified project life by vector and by cost type (capital and operational) (Figure 8—3) and displays these graphically as a cumulative cash flow (Figure 8—4).

A breakdown of the top five Assemblies and Components in terms of their percentage of total cost is provided to give a view on which aspects of the Project might be deemed critical and potential targets for innovation.

A Net Present Value (NPV) calculation is also calculated. NPV is a useful tool to provide comparative costs to enable comparison of two different projects bringing them back to the same year. Effectively this provides a discounted life cycle cost and will always be negative as there are no revenues. The discount rate set in the model is 3.5% however this can be changed by the user as required (Figure 8—3).

---

[16] https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent



PROJECT DASHBOARD

Ref	20130801 1313
Description	Electricity transmission - East Midlands - test
Owner	HC

Region	East Midlands Region
Context	Rural
Scale	Baseline
Labour cost	Baseline
Materials cost	Baseline
Plant cost	Baseline

PROJECT COSTS IN 2015	P80	P50	P10
Totals	6,980,531,817	5,806,365,013	2,796,428,255
Electricity	4,689,367,012	3,900,692,082	1,879,007,562
Natural gas	-	-	-
Hydrogen	-	-	-
Heat	-	-	-
Preliminaries	702,104,635	584,067,594	281,516,961
Contractors Overheads	269,140,110	223,892,578	107,914,835
Contingencies	565,194,231	470,174,413	226,621,154
PM, Engineering, etc.	746,056,385	620,630,226	299,139,923
Land Costs	8,669,443	6,908,121	2,227,819

TOP 5 ASSEMBLIES

Assembly	% TOTAL
Transmission: HVAC: Overhead: 400kV line [6380 MVA] (New Build)	53.4%
Conversion: HVAC: None: 400kV to 132kV Conversion [670 MVA] (New Build)	36.9%
Transmission: HVAC: Overhead: 275kV line [2600 MVA] (New Build)	7.5%
Conversion: HVAC: None: 275kV to 132kV Conversion [720 MVA] (New Build)	2.2%
#N/A	#N/A

TOP 5 COMPONENTS

Component	% TOTAL
AA12 - Electricity - Overhead - Conductors - Refurb, Repurpose and Abandon: Refurbish 400kV HVAC overhead transmission line	28.0%
AD12 - Electricity - Conversions - On-shore - Refurb, Repurpose and Abandon: Refurbish 400kV to 132kV conversion (two circuits)	27.9%
AA11 - Electricity - Overhead - Conductors - New: 400kV HVAC Overhead transmission line	25.4%
AD11 - Electricity - Conversions - On-shore - New: 400kV to 132kV conversion (two circuits)	9.0%
AA11 - Electricity - Overhead - Conductors - New: 275kV HVAC Overhead transmission line	4.0%

OPEX COSTS DURING PERIOD 2015 - 2074	P80	P50	P10
Totals	3,874,621,240	2,910,646,056	1,812,783,642
Electricity	3,874,621,240	2,910,646,056	1,812,783,642
Natural gas	-	-	-
Hydrogen	-	-	-
Heat	-	-	-

NET PRESENT VALUE AT 2015	Project NPV	Optimism Bias Adjusted	
		Lower	Upper
Totals	3,934,378,815	4,170,441,544	6,531,068,832
CAPITAL COSTS IN 2015			
Electricity	2,216,274,185	2,349,250,636	3,679,015,146
Natural gas	-	-	-
Hydrogen	-	-	-
Heat	-	-	-
Preliminaries	331,826,529	351,736,121	550,832,038
Contractors Overheads	127,200,169	134,832,180	211,152,281
Contingencies	267,120,356	283,147,577	443,419,790
PM, Engineering, etc.	352,598,870	373,754,802	585,314,123
Land Costs	7,284,500	7,721,570	12,092,270
OPEX DURING PERIOD 2015 - 2074			
Electricity	632,074,207	669,998,659	1,049,243,183
Natural gas	-	-	-
Hydrogen	-	-	-
Heat	-	-	-

Figure B—3: Screen shot of Project Dashboard - top section

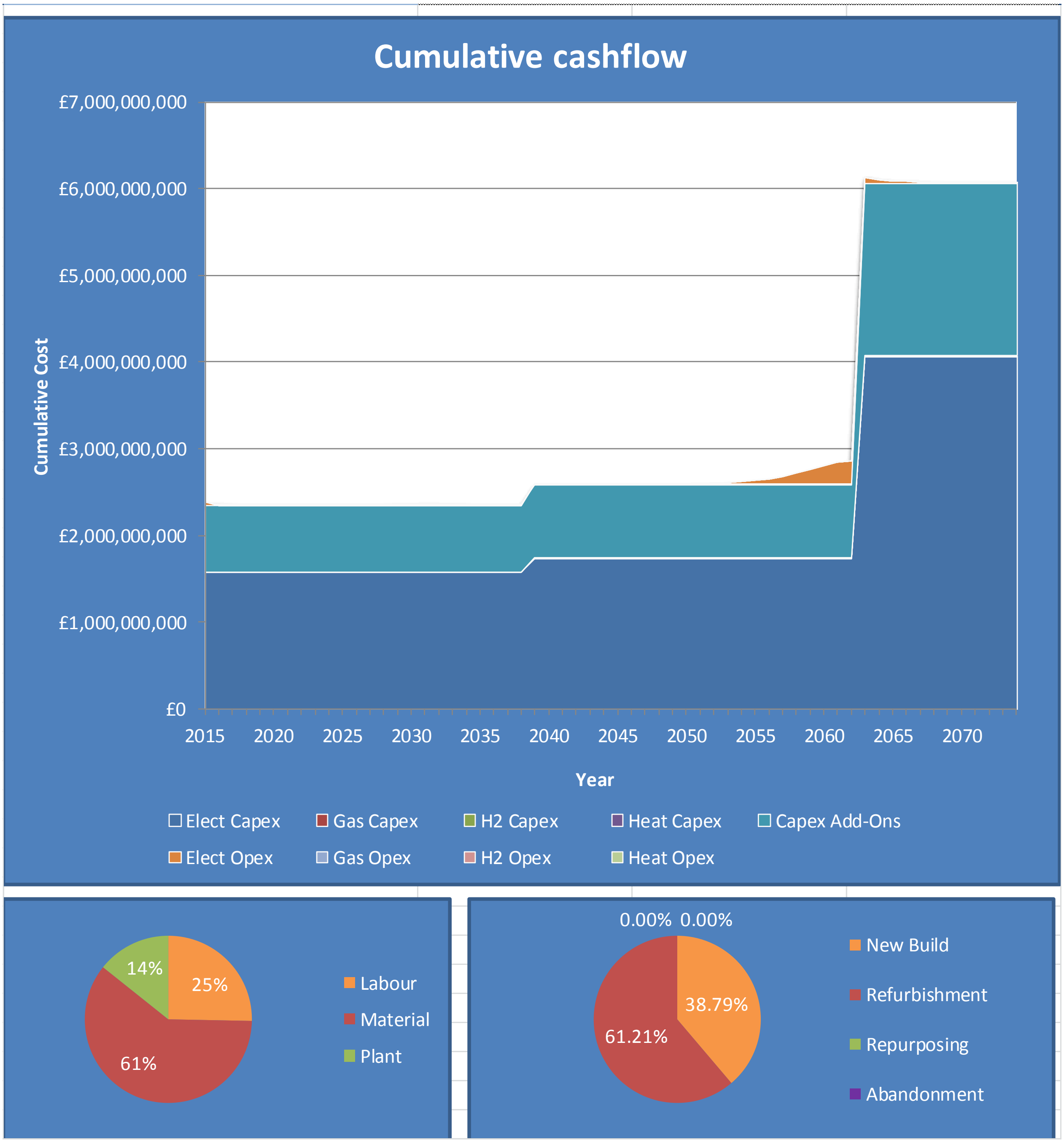


Figure B—4: Screen shot of Project Dashboard - bottom section

Examples of uses

There are a number of ways in which the model can support analysis and decision making in respect of energy projects and strategy. Table 8-1 outlines a variety of potential variations along with an explanation of how the cost model can be used. Limitations in each case are also discussed. Note that for all these, the data can be exported directly from the model (capital and operational costs on an annual basis) for analysis in other models and tools.

Table B—2 Examples of variations which could be informed by the model

	Variation / objective	Model capability	Limitations / factors to consider
1	To compare the cost of implementing a new hydrogen system vs repurposing of existing gas system over any period up to 2050	Two separate Projects need to be input by the user developed based on a 'bill of quantities' for each system. The detail attached to each BoQ should include the dates of the addition or repurposing, and provide any relevant context regarding locality, ground conditions etc. The user can adjust cost rate modifiers as required to match system design assumptions and views of cost trends for each vector. The model will provide cost out turns for each Project which can be compared.	Given that the system is designed outside the model, the results should be straightforward to achieve. There could be issues over the availability of all Assemblies included in the relevant system designs. Either the 'next best' can be selected or new Components and Assemblies can be added. The model will not give any information on relative system efficiency as this is provided separately in the Technical Scoping Tables (see Section 3.3.2).
2	To compare the cost of implementing a new electrical network to support a certain level of demand vs a gas network or heat network to support the same demand	As above, separate Projects can be input to the model based on appropriate BoQs for the system design for each vector.	As above, the results should be straightforward to achieve. Note that the Project functionality does not allow for capital costing only and is set up to provide whole life costs for the specified project period. However data can be readily extracted for analysis elsewhere.
3	To compare the ratio of Opex vs Capex for an electrical network, a gas network and a hydrogen network for supporting a certain level of demand for a particular region within the UK	As above, separate Projects can be input to the model based on appropriate BoQs for the system design for each vector. Opex and Capex are presented separately on the Project dashboard and can be extracted for analysis elsewhere.	The relevant ratio would have to be calculated outside the model. The model will not give any information on relative system efficiency as this is provided separately in the Technical Scoping Tables (see Section 3.3.2).
4	To explore the transitional cost differences of developing an electrical network over a period of 30 years based on small capacity increments vs large scale deployment at strategic intervals	The model allows for input of different Assemblies at different time periods over any period up to 150 years. Thus it can accommodate alternative assumptions regarding the time and scale of deployment. Again, it relies upon the development of suitable BoQs and the relevant time of their deployment. In this case, two separate Projects would be input by the user and the two sets of results compared.	Given that the system is designed outside the model, the results should be straightforward to achieve. There could be issues over the availability of all Assemblies included in the relevant system designs. Either the 'next best' can be selected or new Components and Assemblies can be added. The model will not give any information on relative system efficiency as this is provided separately in the Technical Scoping Tables (see Section 3.3.2).

	Variation / objective	**Model capability**	**Limitations / factors to consider**
5	To examine the cost of decommissioning the UK gas network between now and 2050 and determining the optimum cost path to do this.	The user would need to input the quantities of the existing gas assets into a Project. For each Assembly, a start date before the Project start would need to be specified to reflect the age of the asset. The model will then calculate refurbishment and abandonment costs according to the life cycle profile adopted for that Assembly. A bespoke life cycle profile could be added if required.	The model cannot determine an 'optimum' cost pathway as it is not constructed as an optimisation tool in this sense. The user would have to experiment with alternative pathways and compare costs by inputting a new Project for each individually.
6	To explore how the losses of a network determine its feasibility on a regional basis in supporting certain supply and demand infrastructures – do this analysis across different vectors.	Not possible within the model as losses are provided separately as percentages of annual energy flow within the Technical Scoping Tables and would require a better understanding of network configuration and energy flows through the network. A detailed system analysis is required.	Losses are provided as percentages in the Technical Scope Tables attached to the model (see Section 3.3.2).

Angeliki Gkogka;Henrietta Cooke
Buro Happold Limited
17 Newman Street
London
W1T 1PD
UK

T: +44 (0)207 927 9700
F: +44 (0)870 787 4145
Email: henrietta.cooke@burohappold.com

Angeliki Gkogka;Henrietta Cooke
Buro Happold Limited
17 Newman Street
London
W1T 1PD
UK

T: +44 (0)207 927 9700
F: +44 (0)870 787 4145
Email: henrietta.cooke@burohappold.com