ESME Data References Book

Contents

1 Introduction

The Energy Technologies Institute (ETI) is a public-private partnership between global energy and engineering companies (BP, Caterpillar, EDF, Rolls-Royce, Shell) and the UK Government. ETI's work links industry, academia and government to develop energy technologies to help the UK address its long term emissions reduction targets.

ETI's strategy team works to identify valuable low carbon technology opportunities and to assess the strategic challenges surrounding the commercialisation of such new technologies. This work is underpinned by an analysis of the UK energy system including ETI's Energy System Modelling Environment (ESME – see http://www.eti.co.uk/project/esme/). Over time ESME has developed into one of the most powerful energy system models for the UK, with outputs and insights from the modelling used in a variety of contexts. In addition, ETI also works with a suite of other modelling tools which study low-carbon heating, renewable energy sources, transport technologies and more.

1.1 What is ESME?

ESME[1] is a least-cost optimisation model designed to explore technology options for a carbon-constrained energy system, subject to additional constraints around energy security, peak energy demand and more. ESME covers the power, transport, buildings and industry sectors, and the infrastructure that underpins them, in five year time-steps from 2010 to 2050. The paper *Modelling Low-Carbon Energy System Designs with the ETI ESME Model* which is available on the ETI website[2] gives an overview of ESME covering the approach and the key technical features of the model.

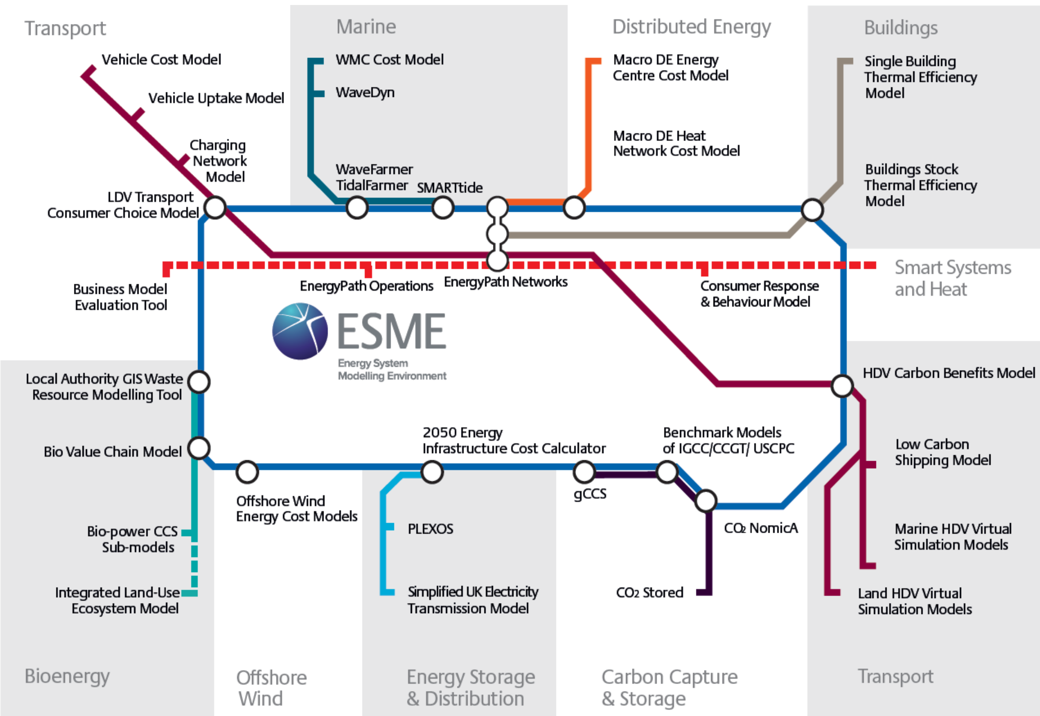

Figure 1. A schematic map of ETI projects and models which have been used to inform the ESME dataset. Each 'station' represents an ETI project or sector model which provides data to ESME.

1 http://www.eti.co.uk/project/esme/
2 http://www.eti.co.uk/wp-content/uploads/2014/04/ESME_Modelling_Paper.pdf

1.2 How to use this document

The main body of this document catalogues the sources used as underlying evidence for the data in the ETI's ESME model. This information takes the form of references to the outputs of ETI technology projects and/or third party published papers. The intention is to give signposts to the underlying evidence and to briefly state which data have been used and how, without giving detailed calculations. Note that this document does not contain the final numerical values in the ESME dataset. The ESME dataset itself is not published, but is available to users of the ESME model.

The purpose of this document is to give visibility of which sources have been used to populate the ESME datasets and to show how the ESME dataset is built on a foundation of strong evidence. For users of the ESME model, this document can be read alongside the ESME User Manual, and gives further guidance on appropriate ways to modify the data, e.g. in areas where a user holds alternative views or has access to alternative data sources.

Last but not least, it also provides a mechanism to improve the quality of the data used in the ESME model. ETI works hard to maintain the data it uses in its energy analysis, to keep it up to date and joined up with the best available information from ETI projects and beyond. Nevertheless it is easy to fall behind, especially in the areas where ETI does not have information from its own projects. Any reader who spots a technology for which there is more recent, or better quality, data available than that cited is encouraged to contact ETI with suggestions. Contact details are given on the ETI website, or emails can be sent to info@eti.co.uk (please include "ESME" in the email subject).

1.3 ESME Version Numbers

Square brackets are used in this document to indicate the ESME version in which a parameter was last updated. In Table 1 the dates are given corresponding to each ESME version number. For example [v3.3] indicates that the parameter in question was updated as part of the January 2014 release of ESME v3.3. Note that this indicates the last change to the value, but a parameter value may have been reviewed more recently and left unchanged.

ESME version	Date released
v1.0	Sep 2010
v1.1	Oct 2010
v1.2	Mar 2011
v2.0	Sep 2011
v3.0	Jul 2012
v3.1	Jan 2013
v3.2	Jul 2013
v3.3	Jan 2014
v3.4	Jul 2014
v3.41	Oct 2014
v3.5	Jan 2015
v4.0	Aug 2015
v4.1	Apr 2016
V4.2	Dec 2016

Table 1. ESME version numbers referred to in this document, and the corresponding release dates

1.4 Maintenance and governance of the ESME Data Sets

ETI maintains the data sets for the ESME model, updating the assumptions for particular technologies and adding new technologies in each successive version (Table 1). Although there is no fixed schedule for updates, new versions have been regularly designated once or twice a year since 2010.

The ESME model and the data sets used by ESME are owned by ETI. At present the model and the dataset are not published. In addition to their use by ETI they are available to the member organisations which have funded ETI (the UK Government plus BP, Caterpillar, EDF, Rolls-Royce and Shell), as well as to academics for use in academic research projects.

The modelling team at ETI collect the data used in updates to ESME, as well as modifying the database files to incorporate the new data and testing the new databases before release to ESME users. The length of this document, which only includes very brief summaries of the data sources used, demonstrates how building and maintaining the ESME dataset is a time consuming task. The ETI convenes a number of strategy advisory groups (SAGs) in different technology areas which are valuable in feeding our understanding on the latest science and technology developments. These groups provide significant support to ETI, particularly with identifying new reports and data published in the energy literature. ETI's advisory group on energy modelling includes modelling experts from each of the ETI member organisations, plus academics and expert consultants. This advisory group is an open and collaborative forum which has greatly helped the ETI throughout the development of the ESME model and its improvement in successive versions. However, governance of the process is led by ETI staff, who are independent of the ETI member organisations, and who make the final decisions on the data used in ESME based on the quality of the available sources.

2 Global Parameters

2.1 Financial Assumptions

The base year of the model is 2010 and all costs are quoted in 2010 pounds sterling throughout ESME. Standard currency conversion factors are given below. In order to translate cost data quoted in other years, it is recommended to use the UK Retail Prices Index (RPI) measure of inflation.

Year	Average € per £ for year	Average $ per £ for year
2002	1.59	1.50
2003	1.45	1.63
2004	1.47	1.83
2005	1.46	1.82
2006	1.47	1.84
2007	1.46	2.00
2008	1.26	1.85
2009	1.12	1.56
2010	1.17	1.55
2011	1.15	1.60
2012	1.23	1.58
2013	1.18	1.56
2014	1.24	1.65
2015	1.37	1.51

Table 2. Year-averaged currency exchange rates. Source: HMRC (link).

Year	Annual Average RPI %	Year Multiplier
1999	1.2	1.012
2000	2.5	1.025
2001	1.5	1.015
2002	1.3	1.013
2003	2.6	1.026
2004	2.7	1.027
2005	2.5	1.025
2006	2.8	1.028
2007	3.9	1.039
2008	3.6	1.036
2009	-0.9	0.991
2010	4.0	1.040
2011	4.5	1.045
2012	2.6	1.026
2013	2.4	1.024
2014	1.7	1.017
2015	0.3	1.003

Table 3. UK Retail prices index (RPIJ). Source: ONS (link)

Note that costs are used in ESME, not retail prices. Consequently the cost data used in the model excludes taxes, levies, subsidies and similar.

An investment rate of 8% (real) is assumed for the cost of capital for all technologies. This rate is used when annualising capital costs over the lifetime of a technology and when calculating the cost of interest during construction.

A discount rate of 3.5% is used for all net present value (NPV) calculations in ESME, including the calculation of total energy system cost 2010-50.

Working definitions for the key cost parameters relevant to technologies which are used in ESME are:

- Capital cost. This should be based on cost estimates for nth of a kind. Costs should include, where relevant: EPC cost, infrastructure connection costs, pre-licensing costs, technical and design costs, licensing costs and public inquiry costs. Contingency costs should be included but would normally be minimal for nth of a kind deployment. Land purchase costs and financing charges, such as interest during construction, should be excluded.
- Fixed costs. Costs such as operation and maintenance costs which are incurred per year regardless of level of usage. [NB fuel costs are not included]
- Variable costs. Costs such as operation and maintenance costs which are in proportion to the level of usage. [NB fuel costs and balancing costs are not included]

2.2 Emissions Constraint

The emissions constraint in ESME [v3.2] reflects the 2008 Climate Change Act which sets a legally binding target for the UK to reduce greenhouse gas emissions by at least 80% (from the 1990 baseline) by 2050. The ESME model tracks CO_2, but not other greenhouse gases (ghgs), so the emissions constraint applied on CO_2 emissions in ESME must take account of the expected abatement of other ghgs.

A budget of 55 $MtCO_2e$ in 2050 for non-CO_2 ghgs is the standard CCC assumption, see for example table 3.4 of *The Fourth Carbon Budget: Reducing emissions through the 2020s* (link). Using this, we infer a 2050 CO_2 target to be used in ESME of 105Mt, as shown in Figure 2.

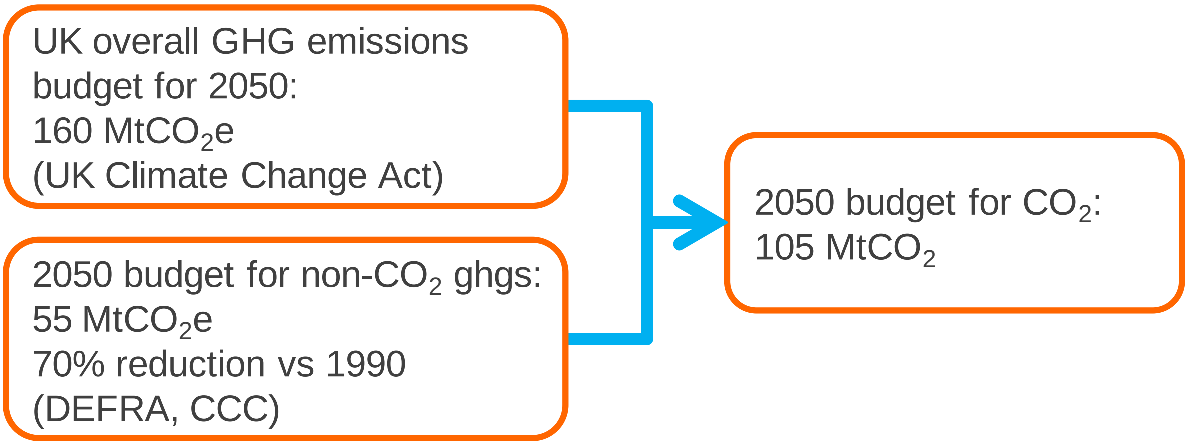

Figure 2. Summary of the approach to setting a CO_2 target in ESME which is consistent with the UK's greenhouse gas targets set by the Climate Change Act.

The various different sources of CO_2 are modelled in ESME in the following ways:

Category of CO_2 emissions	Representation in ESME
CO_2 liberated in consumption of fuels	Tracked via the energy flows in the core model
CO_2 from international aviation & shipping	Tracked via the energy flows in the core model
CO_2 from industrial processes	These emissions are incorporated into the industry sector technologies in the core model. Reference case emissions (2010 actual and future projections) were supplied by DECC & CCC in 2013.
CO_2 from other activity not included in the above categories[3]	ESME uses emissions data (2010 actual and future projections) supplied by DECC & CCC in all cases.
CO_2 from land use and land use change	Land use emissions of biomass used for energy are represented in the core model via the carbon footprint of the biomass resource. Other land use emissions not modelled in ESME.

Table 4. The different sources of CO_2, and how they are represented in the ESME model.

[3] The "Other Energy Supply" category in the *DECC Updated Energy & Emissions Projections* (link). This category comprises: manufacture of solid fuels and other energy industries; solid fuel transformation; exploration, production and transport of oils; offshore oil and gas (flaring and venting); power stations FGD; exploration, production and transport of gas.

3 Technology Data

In this section we give a brief summary of the underlying evidence and data sources for each technology in the ESME model. References to ETI projects give the corresponding 6-character ETI project code, e.g. CC2001 for the *Next Generation Capture Technologies* project in the CCS programme. ETI members can access deliverables from all ETI projects via the member portal.

Each Technology entry begins with a brief description of the technology explaining any acronyms. A typical scale is usually given in round brackets: this is not a parameter used by the ESME model, but is included simply to give a clear indication to the reader of the specific type of technology being represented in ESME.

Note that some technology parameters are inherently subjective and cannot in general be based on firm technical data from a single source. Unless stated otherwise the values of these parameters are based on judgements taken by ETI, usually based on information from a wide variety of sources and after discussion with expert advisors such as the corresponding ETI SAG. These parameters include:

- Maximum possible build/deployment rates for a technology in future decades.
- Range of uncertainty on the future cost of a technology.

Momentum effects

A number of data points are used to calibrate the base year of the ESME model (2010) and the early years of the pathway to the present reality of the UK energy system.

Existing stock data is populated in the ESME database for technologies across transport, power and buildings sectors. This data specifies the capacity of different types of technologies which already exists in the UK at the start of the pathway in 2010. This comprises the capacity (GW) of existing power stations, numbers of homes in each category, numbers of vehicles of each type and so on. A small number of technologies, just the large power stations, also have customised retirement profiles specified for their existing stock. In all cases the sources of information used for existing stock data are published reports, either UK Government statistics or from the operators of major power stations. This information is readily accessible via google, so in order to streamline this document we do not give the source for every technology's existing stock data in ESME.

The other aspect of 'momentum' is that for some technologies we know, or strongly expect, certain levels of capacity are going to be commissioned in the near-term future (e.g. power stations currently under construction). ESME includes 'minimum build' data for a number of technologies to reflect the current deployment trends of renewables (solar PV, onshore and offshore wind) and hybrid electric cars. In each case this data is based on review by ETI of recent published UK statistics, and for wind a review of the pipeline of projects in development and construction.

3.1 Conversion technologies: electricity

The following parameters apply to all the electricity generating technologies in ESME, and some have definitions which are specific to the configuration of the ESME model:

Peak contribution factors

Also known as capacity credit in other contexts. This is the percentage of capacity that statistically contributes to meeting the peak electricity demand of the year at a 95% confidence level. Unless stated otherwise the values in ESME are those adopted in [v3.0] as part of a project looking specifically at peak energy modelling in ESME.

Minimum load factors

Minimum loadfactors are specified in ESME for some electricity generating technologies in some timeslices. Minimum loadfactors are typically set for dispatchable power stations which play a backup or peaking role in the fleet. This is because ESME does not capture the hour-to-hour intermittency of renewables or variations in demand which in reality cause these plants to run. Unless stated otherwise the values in ESME are those adopted in [v2.0] and reviewed in the peak energy project [v3.0] based on comparison to the dispatch model PLEXOS.

Flexibility factor

The flexibility contribution factor in ESME represents the ability of an electricity generation technology either to contribute to meeting fluctuating electricity demand, or to place demands for flexibility on the system (associated with a negative factor). The factor represents the percentage of capacity by which output could be increased in one hour, or the percentage of capacity by which output could drop in one hour. Unless stated otherwise the values in ESME are those adopted in [v3.0] as part of a project looking specifically at peak energy modelling in ESME.

Grid connection level

Each technology is assigned an electricity grid connection level, from the high-voltage national transmission level down to local distribution network level. These are used for the purposes of estimating intra-node transmission and distribution losses. The level appropriate to each technology usually follows from the technology description in a straightforward way.

3.1.1 PC Coal

A pulverised coal power station (GW scale) with option to cofire biomass up to 10%.

Cost assumptions: capital and fixed costs [v3.3] and variable cost [v1.0] all based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

Efficiency assumptions: [v1.2] based on ETI CCS programme data.

Availability: Annual availability, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

Retirement profile of 2010 capacity: [v3.3] based on ETI review of data from the Environment Agency and plant operators' websites.

3.1.2 PC Coal with CCS

A pulverised coal power station (GW scale) with post-combustion carbon capture. A capture rate of 95% is assumed. Optional cofiring of biomass up to 10%.

Cost assumptions: capital cost [v4.1], fixed and variable costs [v1.0] all based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

Efficiency assumptions: [v4.1] based on ETI CCS programme data.

Availability: Annual availability [v1.0] based on ETI benchmarking project, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

3.1.3 IGCC Coal

An integrated gasification and combined cycle coal power station (GW scale) with option to cofire biomass up to 10%.

Cost assumptions: capital cost [v3.3], fixed and variable costs [v1.0] all based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

Efficiency assumptions: [v1.2] based on ETI CCS programme data.

Availability: Annual availability, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

3.1.4 IGCC Coal with CCS

An integrated gasification and combined cycle coal power station (GW scale) with pre-combustion carbon capture. A capture rate of 95% is assumed. Optional cofiring of biomass up to 10%.

Cost assumptions: capital cost [v4.1], fixed and variable costs [v1.0] all based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

Efficiency assumptions: [v4.1] based on ETI CCS programme data.

Availability: Annual availability [v1.0] based on ETI benchmarking project, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

3.1.5 CCGT

A combined cycle gas turbine power station (GW scale).

Cost assumptions: capital cost [v3.3] and fixed cost [v1.0] based on ETI CCS programme data, derived from various ETI projects including: *Next Generation Capture Technologies: Benchmarking* (CC2001) and *Next Generation Capture Technologies 2 Gas Capture* (CC1008).

Efficiency assumptions: [v1.2] based on ETI CCS programme data.

Availability: Annual availability, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

Retirement profile of 2010 capacity: [v3.2] based on *Updated energy and emissions projections: 2012*, DECC October 2012 (link).

3.1.6 CCGT with CCS

A combined cycle gas turbine power station (GW scale) with post-combustion carbon capture. A capture rate of 95% is assumed.

Cost assumptions: capital and variable costs [v4.1] and fixed cost [v1.0] all based on ETI CCS programme data, derived from various ETI projects including: *Next Generation Capture Technologies: Benchmarking* (CC2001) and *Next Generation Capture Technologies 2 Gas Capture* (CC1008).

Efficiency assumptions: [v4.1] based on ETI CCS programme data.

Availability: Annual availability [v1.0] based on ETI benchmarking project, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

3.1.7 OCGT

An open cycle gas turbine power station (500 MW scale).

Cost assumptions: capital and fixed costs [v1.0] based on ETI judgement relative to CCGT.

Efficiency assumptions: [v1.0] based on *Issue Brief: Natural Gas in Electricity Generation*, WBCSD 2006 (link)

Availability: Annual availability, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

Retirement profile of 2010 capacity: [v3.2] based on *Updated energy and emissions projections: 2012*, DECC October 2012 (link).

3.1.8 H2 Turbine

An open cycle gas turbine power station configured for firing hydrogen (500 MW scale).

Cost assumptions: capital and fixed costs [v3.4] based on ETI CCS programme data including the *Hydrogen Turbines* project (CC2009).

Efficiency assumptions: [v3.3] based on ETI CCS programme data.

Availability: Annual availability, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

3.1.9 Gas Macro CHP

A combined heat and power station based on a variant of an open cycle gas turbine (500 MW scale).

Cost assumptions: capital cost [v1.0] based on *Using the WADE model to investigate the relative costs of distributed generation (DG)*, BERR 2009 (link). Fixed cost [v1.0] based on judgement relative to OCGT.

Efficiency assumptions: [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Availability: Annual availability, peak availability factor, flexibility factor and minimum loadfactors [v3.0] based on peak energy project commissioned by ETI.

3.1.10 Biomass Macro CHP

A biomass-dedicated steam cycle combined heat and power station (150 MWe scale).

Cost assumptions: capital, fixed and variable costs [v3.4] based on data from ETI's *Biomass Value Chain Model* project (BI2002).

Efficiency assumptions: [v3.4] based on data from ETI's *Biomass Value Chain Model* project (BI2002).

Availability: [v3.4] based on data from ETI's *Biomass Value Chain Model* project (BI2002).

3.1.11 Nuclear (Legacy)

This technology represents the fleet of existing UK nuclear power stations in 2010 (Magnox, AGR & PWR).

Cost assumptions: Fixed cost [v1.0] based on *Impact on the Economy of the American Clean Energy and Security Act of 2009*, CRA May 2009 (link). Variable cost [v1.0] based on same source, combined with a contribution to a waste and decommissioning fund based on *UK Electricity Generation Costs Update*, Mott MacDonald June 2010 (link)

Efficiency assumptions: [v1.0] based on *Digest of UK Energy Statistics*, DECC 2009 (link).

Availability: [v3.2] based on ETI analysis of actual generation in *Digest of UK Energy Statistics*, DECC (link).

3.1.12 Nuclear (Gen III)

Third generation Nuclear fission power station (GW scale).

Cost assumptions: capital cost [v1.0] based on ETI judgement. Fixed cost [v1.0] based on *Impact on the Economy of the American Clean Energy and Security Act of 2009*, CRA May 2009 (link). Variable cost [v1.0] based on same source, combined with a contribution to a waste and decommissioning fund based on *UK Electricity Generation Costs Update*, Mott MacDonald June 2010 (link)

Efficiency assumptions: [v1.0] based on *Digest of UK Energy Statistics*, DECC 2009 (link).

Availability: [v3.0] based on peak energy project commissioned by ETI.

Build Constraints: site availability constraint [v4.0] based on data from the ETI project *Power Plant Siting Study* (ST2032).

3.1.13 Nuclear (Gen IV)

Fourth generation Nuclear fission power station (GW scale).

Cost assumptions: capital cost [v4.0] based on ETI judgement. Fixed cost [v4.0] based on *Impact on the Economy of the American Clean Energy and Security Act of 2009*, CRA May 2009 (link). Variable cost [v4.0] set relative to Nuclear (Gen III).

Efficiency assumptions: [v4.0] based on *Digest of UK Energy Statistics*, DECC 2009 (link).

Availability: [v4.0] based on peak energy project commissioned by ETI.

Build Constraints: site availability constraint [v4.0] reflects UK national strategy to build a single plant by 2050.

3.1.14 Nuclear (SMR)

A small modular reactor nuclear fission power station (300 MW scale).

Cost assumptions: capital and fixed cost [v4.0] based on data from ETI project *System Requirements for Alternative Nuclear Technologies* (ST2033). Variable cost set to match Nuclear (Gen III).

Efficiency assumptions: [v4.0] based on same source as above.

Availability: [v4.0] based on same source as above.

Build Constraints: site availability constraint [v4.0] based on data from the ETI project *Power Plant Siting Study* (ST2032).

Biomass Fired Generation

A biomass-dedicated steam turbine power station (500 MW scale)

Cost assumptions: capital and fixed costs [v1.0] based on large biomass steam turbine CHP from *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link). Variable cost [v1.0] based on judgement relative to coal power plant.

Efficiency assumptions: [v1.0] based on design efficiency of Port Talbot biomass plant.

Availability: [v3.0] based on peak energy project commissioned by ETI.

3.1.15 Converted Biomass Plant

A pulverised coal power station converted in whole or in part to dedicated biomass firing (500 MW scale).

Cost assumptions: capital, fixed and variable costs [v3.2] based on a *Biomass conversion of coal plant Final Report*, Committee on Climate Change October 2011 (link).

Efficiency assumptions: [v3.2] based on a *Biomass conversion of coal plant Final Report*, Committee on Climate Change October 2011 (link).

Availability: annual availability and capacity derating during conversion [v3.2] based on a *Biomass conversion of coal plant Final Report*, Committee on Climate Change October 2011 (link). Flexibility and peak contribution factors [v3.2] set by analogy to coal power stations.

3.1.16 IGCC Biomass

A biomass-dedicated integrated gasification and combined cycle power station (500 MW scale).

Cost assumptions: capital, fixed and variable cost [v4.2] based on ETI analysis, set relative to other IGCC costs in ESME.

Efficiency assumptions: [v4.2] based on ETI analysis, set relative to other IGCC technologies in ESME.

Availability: [v4.2] based on ETI analysis, set relative to other IGCC technologies in ESME.

3.1.17 IGCC Biomass with CCS

A biomass-dedicated integrated gasification and combined cycle power station (500 MW scale) with pre-combustion carbon capture. A capture rate of 95% is assumed.

Cost assumptions: capital cost [v4.1] based on ETI CCS programme data. Fixed and variable costs [v3.0] based on ETI judgment relative to IGCC Coal plants with CCS of the same capture rate.

Efficiency assumptions: [v4.1] based on ETI CCS programme data.

Availability: [v3.0] based on peak energy project commissioned by ETI.

3.1.18 Incineration of Waste

Waste incineration power plant (50 MW scale) based on Organic Rankine Cycle

Cost assumptions: capital and fixed costs [v1.0] based on ETI review of the sector, in particular the TSEC-Biosys consortium.

Efficiency assumptions: [v1.0] based ETI review of the sector, in particular the TSEC-Biosys consortium.

Availability: [v3.0] based on peak energy project commissioned by ETI.

3.1.19 Waste Gasification

Waste gasification power plant (50 MW scale).

Cost assumptions: capital costs [v4.1] based on data from ETI's bioenergy programme.

Efficiency assumptions: [v4.1] based on data from ETI's bioenergy programme.

Availability: [v4.1] set consistent with the peak energy project commissioned by ETI.

3.1.20 Waste Gasification with CCS

Waste gasification power plant (50 MW scale) with CCS.

Cost assumptions: capital costs [v4.1] based on data from ETI's bioenergy programme.

Efficiency assumptions: [v4.1] based on data from ETI's bioenergy programme.

Availability: [v4.1] set consistent with the peak energy project commissioned by ETI.

3.1.21 Anaerobic Digestion Gas Plant

An anaerobic digestion plant with gas clean-up for injection into the gas grid (1 MW scale)

Cost assumptions: capital and fixed costs [v4.2] based on *Renewable Heat Incentive - Biomethane Tariff Review - Impact Assessment*, DECC 2014 (link).

Efficiency assumptions: [v1.2] based on a review of data from *Barriers to Renewable Heat: Analysis of Biogas Options*, BERR September 2008 (link) and *Research, monitoring and evaluation of the Merseyside WDA/Orchid Environmental Ltd mechanical heat treatment plant in Huyton, Merseyside*, DEFRA 2010 (link).

Availability: [v4.2] set using same source as the capital and fixed costs.

3.1.22 Anaerobic Digestion CHP Plant

An anaerobic digestion combined heat and plant (1 MW scale)

Cost assumptions: capital and fixed costs [v4.2] based on *Small-Scale Generation Cost Update*, DECC 2015 (link).

Efficiency assumptions: [v1.2] based on a review of data from *Barriers to Renewable Heat: Analysis of Biogas Options*, BERR September 2008 (link) and *Research, monitoring and evaluation of the Merseyside WDA/Orchid Environmental Ltd mechanical heat treatment plant in Huyton, Merseyside*, DEFRA 2010 (link).

Availability: [v4.2] set using same source as the capital and fixed costs.

3.1.23 Oil Fired Generation

An oil-fired steam turbine power station (500 MW scale). Note that this technology is by default only used to represent existing plants and new deployment is prohibited.

Cost assumptions: capital cost [v1.0] is a nominal value, not used by ESME under default settings.

Efficiency assumptions: [v1.0] based on *Digest of UK Energy Statistics*, DECC 2009 (link).

Availability: [v3.0] based on peak energy project commissioned by ETI.

3.1.24 Offshore Wind (fixed)

Offshore wind turbines with fixed foundations (500 MW farm scale)

Cost assumptions: capital cost [v1.0] based on ETI Offshore Wind SAG road map and fixed cost [v4.0] based on data from ETI Offshore Wind programme.

Availability: annual availability [v1.0] based on *UK Electricity Generation Costs Update*, Mott MacDonald June 2010 (link). Peak availability factors and flexibility factor [v3.0] based on peak energy project commissioned by ETI.

3.1.25 Offshore Wind (floating)

Offshore wind turbines with floating foundations (500 MW farm scale)

Cost assumptions: capital cost and fixed costs [v4.0] based on data from ETI Offshore Wind programme.

Availability: annual availability [v4.0] based on data from ETI Offshore Wind programme. Peak availability factors and flexibility factor [v4.0] same as Offshore Wind (fixed).

Onshore Wind

Onshore wind turbines (500 MW farm scale)

Cost assumptions: capital and fixed costs [v1.0] based on *Impact on the Economy of the American Clean Energy and Security Act of 2009*, CRA May 2009 (link).

Availability: annual availability [v1.0] based on *Renewable Energy Data Technology Analyses: Wind 2006,* Renewable Energy Foundation June 2007. Peak availability factors and flexibility factor [v3.0] based on peak energy project commissioned by ETI.

3.1.26 Hydro Power

Conventional and run-of-river hydroelectric power stations (500 MW scale)

Cost assumptions: capital and variable costs [v1.0] based on *Energy Technology Perspectives 2008*, IEA 2008 (link), chapter 12.

Availability: annual availability [v1.0] based on *Digest of UK Energy Statistics*, DECC 2008 (link). Peak availability factors and flexibility factor [v3.0] based on peak energy project commissioned by ETI.

3.1.27 Tidal Stream

Tidal stream turbines (500 MW farm scale)

Cost assumptions: capital cost [v4.2] based on data from ETI's Offshore Renewables programme, fixed cost [v4.1] based on data from the ETI project *Tidal Energy Converter (TEC) System Demonstrator* (MA1007).

Availability: annual availability [v1.0] based on ETI Marine road map. Peak availability factors and flexibility factor [v3.0] based on peak energy project commissioned by ETI.

3.1.28 Wave Power

Wave energy convertors (500 MW farm scale)

Cost assumptions: capital and fixed cost [v4.1] based on data from the ETI project *Wave Energy Converter (WEC) System Demonstrator* (MA1008).

Availability: annual availability [v1.0] based on ETI Marine road map. Peak availability factors and flexibility factor [v3.0] based on peak energy project commissioned by ETI.

3.1.29 Tidal Range

Tidal barrage (500 MW scale)

Cost assumptions: capital and fixed cost [v1.0] based on *Energy Technology Perspectives 2008*, IEA 2008 (link), chapter 12.

Availability: annual availability, peak contribution and flexibility factors all [v3.0] based on peak energy project commissioned by ETI.

3.1.30 Severn Barrage

Tidal barrage across the river Severn (10 GW scale)

Cost assumptions: capital and fixed cost [v1.0] based on *Severn tidal power: options definitions report*, DECC April 2010 (link).

Availability: annual availability, peak contribution and flexibility factors all [v3.0] based on peak energy project commissioned by ETI.

3.1.31 Geothermal Plant (HSA) Heat Only

Geothermal heat plant (1 MW scale) accessing a hot sedimentary aquifer

Cost assumptions: capital and fixed costs [v3.2] based on data from *Geothermal Energy Potential in Great Britain and Northern Ireland*, SKM May 2012.

Efficiency assumptions: [v3.2] based on same source as above.

Build Constraints: maximum build quantity [v3.2] based on same source as above.

3.1.32 Geothermal Plant (HSA) Electricity & Heat

Geothermal heat and power plant (1 MW scale) accessing a hot sedimentary aquifer

Cost assumptions: capital and fixed costs [v3.2] based on data from *Geothermal Energy Potential in Great Britain and Northern Ireland*, SKM May 2012.

Efficiency assumptions: [v3.2] based on same source as above.

Build Constraints: maximum build quantity [v3.2] based on same source as above.

Availability: peak contribution and flexibility factors [v3.2] based on peak energy project commissioned by ETI.

3.1.33 Geothermal Plant (EGS) Electricity & Heat

Geothermal heat and power plant (1 MW scale) using an engineered geothermal system to access heat in the rock

Cost assumptions: capital and fixed costs [v3.2] based on data from *Geothermal Energy Potential in Great Britain and Northern Ireland*, SKM May 2012.

Efficiency assumptions: [v3.2] based on same source as above.

Build Constraints: maximum build quantity [v3.2] based on same source as above.

Availability: peak contribution and flexibility factors [v3.2] based on peak energy project commissioned by ETI.

3.1.34 Solar PV (Domestic)

Domestic roof-mounted solar photovoltaic cells (3 kW scale)

Cost assumptions: capital and fixed cost [v4.1] based on a literature review by ETI including:

- *Cost Reduction Potential of Large Scale Solar PV*, Solar Trade Association November 2014 (link)
- *Current and Future Cost of Photovoltaics*, Fraunhofer ISE for Agora Energiewende February 2015 (link)

Availability: annual availability by region [v3.1] based on the Photovoltaic Geographical Information System - Interactive Maps hosted by the JRC (link). Seasonal and diurnal availability [v4.1] based on the HelioClim database hosted on the SoDa website (link). Peak contribution and flexibility factors all [v3.0] based on peak energy project commissioned by ETI.

Efficiency: [v4.1] based on *Current and Future Cost of Photovoltaics*, Fraunhofer ISE for Agora Energiewende February 2015 (link).

3.1.35 Solar PV (Farm)

Ground-mounted solar photovoltaic cells (10 MW scale)

Cost assumptions: capital and fixed cost [v4.1] based on a literature review by ETI including:

- *Cost Reduction Potential of Large Scale Solar PV*, Solar Trade Association November 2014 (link)
- *Current and Future Cost of Photovoltaics*, Fraunhofer ISE for Agora Energiewende February 2015 (link)

Availability: annual availability by region [v3.1] based on the Photovoltaic Geographical Information System - Interactive Maps hosted by the JRC (link). Seasonal and diurnal availability [v4.1] based on the HelioClim database hosted on the SoDa website (link). Peak contribution and flexibility factors all [v3.0] based on peak energy project commissioned by ETI.

Efficiency: [v4.1] based on *Current and Future Cost of Photovoltaics*, Fraunhofer ISE for Agora Energiewende February 2015 (link).

3.1.36 Micro Wind

Roof-mounted wind turbine (0.5 kW scale)

Cost assumptions: capital cost [v1.0] based on data from the Energy Saving Trust (link)

Availability: annual availability [v1.0] based on ETI stakeholder workshop. Peak contribution and flexibility factors all [v3.0] based on peak energy project commissioned by ETI.

3.2 Conversion technologies: heat

Unless stated otherwise, the availability factors of all the space heat and hot water generating technologies in ESME have the same values. The values used were adopted in [v3.0] as part of a project looking specifically at peak energy modelling in ESME. A 90% instantaneous availability factor is modelled, but because the instantaneous heat demand varies significantly hour-to-hour, the effect of aggregating into an ESME timeslice is to smooth these variations out. Therefore a lower availability factor is appropriate to use at the timeslice resolution.

3.2.1 Oil boiler - space heat

A domestic oil boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on market review and ETI stakeholder review.

Efficiency assumptions: [v1.0] based on judgement relative to gas boiler.

Min Loadfactors and Min Build: [v3.3] based on ETI analysis to calibrate heat production to historic data from *Energy consumption in the UK* published by DECC (link), and to ensure existing stock can be replaced gradually between 2010-2030, but not sooner.

3.2.2 Oil Boiler - hot water

A domestic oil boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on market review and ETI stakeholder review.

Efficiency assumptions: [v3.0] based on judgement relative to gas boiler.

Min Loadfactors and Min Build: [v3.3] based on ETI analysis to calibrate heat production to historic data from *Energy consumption in the UK* published by DECC (link), and to ensure existing stock can be replaced gradually between 2010-2030, but not sooner.

3.2.3 Gas boiler - space heat

A domestic gas boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v3.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency assumptions: [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Min Loadfactors: [v4.2] based on ETI analysis, minimum usage level reflects usage as secondary ('back up') heating in a hybrid system with an air source heat pump.

3.2.4 Gas Boiler - hot water

A domestic gas boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v3.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency assumptions: [v3.0] based on *In-situ monitoring of efficiencies of condensing boilers and use of secondary heating,* DECC June 2009 (link).

Min Loadfactors: [v4.2] based on ETI analysis, minimum usage level reflects usage as secondary ('back up') heating in a hybrid system with an air source heat pump.

3.2.5 Micro CHP - space heat

A domestic gas fired micro CHP boiler (1kW(e), 10kW(th) scale) suitable for use with a conventional wet radiator system. Assumes solid oxide fuel cell technology.

Cost assumptions: capital cost [v1.0] based on *The Impacts of Distributed Generation on the Wider UK Energy System – Extension of the Project*, DEFRA April 2008 (link).

Efficiency assumptions: [v1.0] based on *The Impacts of Distributed Generation on the Wider UK Energy System – Extension of the Project*, DEFRA April 2008 (link).

3.2.6 Micro CHP - hot water

A domestic gas fired micro CHP boiler (1kW(e), 10kW(th) scale) suitable for use with a conventional wet radiator system. Assumes solid oxide fuel cell technology.

Cost assumptions: capital cost [v1.0] based on *The Impacts of Distributed Generation on the Wider UK Energy System – Extension of the Project*, DEFRA April 2008 (link).

Efficiency assumptions: [v1.0] based on *The Impacts of Distributed Generation on the Wider UK Energy System – Extension of the Project*, DEFRA April 2008 (link).

3.2.7 Biomass Boiler - space heat

A domestic biomass boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency assumptions: [v1.0] based on judgement relative to gas boiler.

3.2.8 Biomass Boiler - hot water

A domestic biomass boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency assumptions: [v1.0] based on judgement relative to gas boiler.

3.2.9 Electric Resistive Heating - space heat

A domestic electric boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency assumptions: [v1.0] based on ETI judgement.

3.2.10 Electric Resistive Heating - hot water

A domestic electric boiler (10kW scale) suitable for use with a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency assumptions: [v1.0] based on ETI judgement.

3.2.11 Heat Pump (Air Source, space heat)

A domestic scale air source heat pump (10kW scale) with a sufficiently high output temperature (e.g. 70˚C) that it can heat a house using a conventional wet radiator system.

Cost assumptions: capital cost [v4.1] based on data from the ETI project *Enabling Technologies (SS1101)* from ETI's Smart Systems and Heat programme. Note that this is the cost of the heat pump only, it is assumed that the heat pump is connected to a pre-existing conventional wet radiator system.

Efficiency assumptions: Coefficient of performance in summer, winter and peak winter conditions [v4.1] based on data from the ETI project *Enabling Technologies (SS1101)* from ETI's Smart Systems and Heat programme.

Build constraints: restrictions to categories of houses with minimum level of thermal efficiency [v3.2] and commercial buildings [v2.0] based on ETI analysis.

3.2.12 Heat Pump (Air Source, hot water)

A domestic scale air source heat pump (10kW scale) with a sufficiently high output temperature (e.g. 70˚C) that it can heat a house using a conventional wet radiator system.

Cost assumptions: capital cost [v4.1] based on data from the ETI project *Enabling Technologies (SS1101)* from ETI's Smart Systems and Heat programme.

Efficiency assumptions: Coefficient of performance in summer, winter and peak winter conditions [v4.1] based on data from the ETI project *Enabling Technologies (SS1101)* from ETI's Smart Systems and Heat programme.

Build constraints: restrictions to buildings [v3.2] mirror those for Heat Pump (Air Source, space heat) – it is assumed that this hot water technology is only deployed in houses which can also adopt an ASHP for space heating.

3.2.13 Heat Pump (Ground Source, space heat)

A domestic scale ground source heat pump (10kW scale) with a sufficiently high output temperature (e.g. 70˚C) that it can heat a house using a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link). Note that this is the cost of the heat pump only, it is assumed that the heat pump is connected to a pre-existing conventional wet radiator system.

Efficiency assumptions: Coefficient of performance [v3.0] based on a literature review including *The UK Supply Curve for Renewable Heat*, NERA July 2009 (link).

Build constraints: restrictions to categories of houses with minimum level of thermal efficiency and available space [v3.2] based on ETI analysis.

3.2.14 Heat Pump (Ground Source, hot water)

A domestic scale ground source heat pump (10kW scale) with a sufficiently high output temperature (e.g. 70˚C) that it can heat a house using a conventional wet radiator system.

Cost assumptions: capital cost [v1.0] based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link). Note that this is the cost of the heat pump only, it is assumed that the heat pump is connected to a pre-existing conventional wet radiator system.

Efficiency assumptions: Coefficient of performance [v3.0] based on a literature review including *The UK Supply Curve for Renewable Heat*, NERA July 2009 (link).

Build constraints: restrictions to buildings [v3.2] mirror those for Heat Pump (Ground Source, space heat) – it is assumed that this hot water technology is only deployed in houses which can also adopt a GSHP for space heating.

3.2.15 Solar Thermal (Domestic south facing)

Domestic roof-mounted solar hot water system (3 kW scale) including solar panels, hot water cylinder and a backup boiler.

Cost assumptions: system capital cost [v1.2], but note that the capital cost was changed in error in [v2.0] and corrected in [v3.5] to the previous value. Panel cost based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link). Other costs are based on a 2010 market review and solar irradiance data from the Photovoltaic Geographical Information System - Interactive Maps hosted by the JRC (link).

Availability: annual availability [v3.0] based on the Photovoltaic Geographical Information System - Interactive Maps hosted by the JRC (link).

Build constraints: restrictions to subset of houses [v1.2] based on literature review.

Efficiency: [v1.0] based on *Sustainable Energy – without the hot air*, Mackay (link).

3.2.16 Solar Thermal (Domestic non south facing)

Domestic roof-mounted solar hot water system (3 kW scale) including solar panels, hot water cylinder and a backup boiler.

Cost assumptions: system capital cost [v1.2], but note that the capital cost was changed in error in [v2.0] and corrected in [v3.5] to the previous value. Panel cost based on *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link). Other costs are based on a 2010 market review and solar irradiance data from the Photovoltaic Geographical Information System - Interactive Maps hosted by the JRC (link).

Availability: annual availability [v3.0] based on the Photovoltaic Geographical Information System - Interactive Maps hosted by the JRC (link).

Build constraints: restrictions to subset of houses [v1.2] based on literature review.

Efficiency: [v1.0] based on *Sustainable Energy – without the hot air*, Mackay (link).

3.2.17 District Heating (HD)

This technology represents a per-dwelling share of the cost of installing a district heating network, including pipework, connection and a hydraulic interface unit (HIU).

Cost assumptions: capital cost [v3.2] based on data and cost models from the ETI project *Macro DE* (DE2002). The cost model gives an estimate of installation costs and energy losses per MLSOA (middle layer super output area – see the ONS website link). Costs and losses are a function of heat demand density and road density. Each MLSOA is grouped into one of three cost tranches, or, if the costs are very high, not included in any tranche.

Build constraints: numbers of houses in each cost tranche in each region [v3.2] are based on the installation cost models from the ETI project *Macro DE* (DE2002).

Efficiency: energy loss factor [v3.2] also based on the cost models from the ETI project *Macro DE* (DE2002).

3.2.18 District Heating (MD)

This technology represents a per-dwelling share of the cost of installing a district heating network, including pipework, connection and a hydraulic interface unit (HIU).

Cost assumptions: capital cost [v3.2] based on data and cost models from the ETI project *Macro DE* (DE2002). The cost model gives an estimate of installation costs and energy losses per MLSOA (middle layer super output area – see the ONS website link). Costs and losses are a function of heat demand density and road density. Each MLSOA is grouped into one of three cost tranches, or, if the costs are very high, not included in any tranche.

Build constraints: numbers of houses in each cost tranche in each region [v3.2] are based on the installation cost models from the ETI project *Macro DE* (DE2002).

Efficiency: loss factor [v3.2] also based on the cost models from the ETI project *Macro DE* (DE2002).

3.2.19 District Heating (LD)

This technology represents a per-dwelling share of the cost of installing a district heating network, including pipework, connection and a hydraulic interface unit (HIU).

Cost assumptions: capital cost [v3.2] based on data and cost models from the ETI project *Macro DE* (DE2002). The cost model gives an estimate of installation costs and energy losses per MLSOA (middle layer super output area – see the ONS website link). Costs and losses are a function of heat demand density and road density. Each MLSOA is grouped into one of three cost tranches, or, if the costs are very high, not included in any tranche.

Build constraints: numbers of houses in each cost tranche in each region [v3.2] are based on the installation cost models from the ETI project *Macro DE* (DE2002).

Efficiency: loss factor [v3.2] also based on the cost models from the ETI project *Macro DE* (DE2002).

3.2.20 District Heating (Commercial floorspace)

This technology represents a per-floorspace share of the cost of installing a district heating network, including pipework, connection and a hydraulic interface unit (HIU).

Cost assumptions: capital cost [v3.0] based an ETI analysis combining data from *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link) and ETI project *Macro DE* (DE2002).

Build constraints: maximum proportion of floorspace for which district heating is permitted [v3.0] based on information from *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency: loss factor [v3.2] based on the cost models from the ETI project *Macro DE* (DE2002).

3.2.21 District Heating (Public floorspace)

This technology represents a per-floorspace share of the cost of installing a district heating network, including pipework, connection and a hydraulic interface unit (HIU).

Cost assumptions: capital cost [v3.0] based an ETI analysis combining data from *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link) and ETI project *Macro DE* (DE2002).

Build constraints: maximum proportion of floorspace for which district heating is permitted [v3.0] based on information from *The Potential and Costs of District Heating Networks*, Poyry April 2009 (link).

Efficiency: loss factor [v3.2] based on the cost models from the ETI project *Macro DE* (DE2002).

3.2.22 District Heating Biomass Boiler

A biomass boiler (MW scale) providing heat to a heat network.

Cost assumptions: capital and fixed costs [v3.0] based on *The UK Supply Curve for Renewable Heat*, NERA July 2009 (link).

Efficiency: [v3.0] based on *The UK Supply Curve for Renewable Heat*, NERA July 2009 (link).

3.2.23 District Heating Gas Boiler

A gas boiler (MW scale) providing heat to a heat network.

Cost assumptions: capital and fixed costs [v3.0] based on *The UK Supply Curve for Renewable Heat*, NERA July 2009 (link).

Efficiency: [v3.0] based on *The UK Supply Curve for Renewable Heat*, NERA July 2009 (link).

3.2.24 Heat Pump (Large Scale Marine)

A large heat pump (MW scale) providing heat to a heat network. The heat source could be sea water, tidal river water or mine water in abandoned coal mines.

Cost assumptions: capital cost [v3.1] based on ETI research of existing and proposed heat pumps in Scandinavia and China.

Efficiency: [v3.1] based on ETI research of existing heat pumps in Scandinavia.

3.2.25 Heat Offtake for District Heat Network

A retrofit to a large power station, taking water at 100˚C for a district heat network (500MW scale).

Cost assumptions: capital cost [v3.2] assumes a nominal 40km distance to the heat network. Cost based on ETI project *Macro DE* (DE2002) and *The relative competitive positions of the alternative means for domestic heating,* Torekov, Bahnsen & Qvale. Energy **32**, 2007, p. 627-633.

Efficiency: efficiency, or “z factor”, [v1.0] is based on standard thermodynamic calculations, e.g. see *The Determination of Z Ratio Information*, (*Combined heat and power quality assurance guidance note 28)*, DECC (link).

3.3 Conversion technologies: other

3.3.1 Lighting (CFL)

A compact fluorescent light fitting.

Cost assumptions: capital cost [v1.0] based on market review and ETI stakeholder review.

Efficiency and loadfactor assumptions: [v1.0]. Luminous efficacy (lumens/W) based on Energy Smart Library (link). Loadfactor based on lighting data from *Energy consumption in the UK* published by DECC (link) combined with simple estimate of number of domestic fittings.

3.3.2 Lighting (Incandescent)

A traditional incandescent light fitting.

Cost assumptions: capital cost [v1.0] based on market review and ETI stakeholder review.

Efficiency and loadfactor assumptions: [v1.0]. Luminous efficacy (lumens/W) based on Energy Smart Library (link). Loadfactor based on lighting data from *Energy consumption in the UK* published by DECC (link) combined with simple estimate of number of domestic fittings.

3.3.3 Lighting (LED)

An LED light fitting.

Cost assumptions: capital cost [v1.0] based on market review and ETI stakeholder review.

Efficiency and loadfactor assumptions: [v1.0]. Luminous efficacy (lumens/W) based on *Energy Efficiency of White LEDs*, USDOE June 2009 (link). Loadfactor based on lighting data from *Energy consumption in the UK* published by DECC (link) combined with simple estimate of number of domestic fittings.

3.3.4 Domestic Cooking (Electric)

A domestic electric cooker, representing the UK average.

Cost assumptions: capital cost [v1.0] based on simple market review.

Efficiency and loadfactor assumptions: Efficiency [v1.0] based on internet research, e.g. Energy Star ratings, U.S. Environmental Protection Agency (link). Loadfactor set in the peak energy project [v3.0].

3.3.5 Domestic Cooking (Gas)

A domestic gas cooker, representing the UK average.

Cost assumptions: capital cost [v1.0] based on simple market review.

Efficiency and loadfactor assumptions: Efficiency [v1.0] based on internet research, e.g. Energy Star ratings, U.S. Environmental Protection Agency (link). Loadfactor set in the peak energy project [v3.0].

3.3.6 Domestic Air Conditioning

An air conditioning system.

Cost assumptions: capital cost [v1.0] based on Toshiba Hushon price list (link).

Efficiency assumptions: Efficiency [v1.0] based on *Saving Energy Through Better Products and Appliances*, DEFRA December 2009 (link).

3.3.7 H2 Plant (Electrolysis)

A hydrogen production plant using electrolysis (500MW scale)

Cost assumptions: capital, fixed and variable costs [v4.2] based on a broad literature review which amongst others included: *A review of hydrogen production technologies for energy system models*, Dodds & MacDowall 2012 (link), *DOE Hydrogen and Fuel Cells Program Record* 14004, DOE 2014 (link), *Power-to-Gas, A UK Feasibility Study*, ITM Power *et al.* 2013 for the Technology Strategy Board.

Efficiency: [v4.2] based on the same broad literature review as for the cost assumptions.

3.3.8 H2 Plant (Coal Gasification with CCS)

A hydrogen production plant using gasification of coal (500MW scale). A capture rate of 95% is assumed. Optional cofiring of biomass up to 10%.

Cost assumptions: capital, fixed and variable costs [v4.1] all based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

Efficiency: [v4.2] based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

3.3.9 H2 Plant (Biomass Gasification)

A hydrogen production plant using gasification of biomass (500MW scale).

Cost assumptions: [v4.2] based on data from the ETI's Biomass Value Chain Model (BVCM).

Efficiency: [v4.2] based on data from the ETI's Biomass Value Chain Model (BVCM).

3.3.10 H2 Plant (Biomass Gasification with CCS)

A hydrogen production plant using gasification of biomass (500MW scale). A capture rate of 95% is assumed.

Cost assumptions: [v4.2] based on data from the ETI's Biomass Value Chain Model (BVCM).

Efficiency: [v4.1] based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

3.3.11 H2 Plant (SMR)

A hydrogen production plant using steam methane reforming (500MW scale).

Cost assumptions: [v4.2] based on data from the ETI project *Hydrogen Turbines* (CC2009) as well as a literature review including *Analyzing the Levelized Cost of Centralized and Distributed Hydrogen Production Using the H2A Production Model, Version 2*, NREL 2009 (link) and *Hydrogen Production Cost Estimate Using Biomass Gasification*, NREL 2011 (link).

Efficiency: [v4.2] based on the same sources as the cost assumptions above.

3.3.12 H2 Plant (SMR with CCS)

A hydrogen production plant using steam methane reforming (500MW scale). A capture rate of 95% is assumed.

Cost assumptions: capital, fixed and variable costs [v4.1] all based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

Efficiency: [v4.1] based on ETI CCS programme data, derived from various ETI projects including *Next Generation Capture Technologies: Benchmarking* (CC2001).

3.3.13 Biodiesel Production

A biodiesel production plant (500MW scale)

Cost assumptions: capital, fixed and variable costs [v1.2] based on a wide literature review which included

- *Liquid biofuels and hydrogen from renewable resources in the UK to 2050: a technical analysis*, E4tech for the Department for Transport, December 2003 (link)
- *Review of the potential for biofuels in aviation*, E4tech for the Committee on Climate Change, August 2009 (link)
- *Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, EC July 2011 (link)
- *Technology Roadmap: Biofuels for Transport*, IEA 2011 (link)
- *Comparative economics of biorefineries based on the biochemical and thermochemical platforms,* Wright & Brown (2007). Biofuels, Bioproducts and Biorefining **1**, p49-56.
- *Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland*, SAC for various Scottish Councils October 2005 (link)

Efficiency: [v1.2] based on same literature review as the cost data.

3.3.14 Biokerosine Production

A bio jet fuel production plant (500MW scale)

Cost assumptions: capital, fixed and variable costs [v1.2] based on a wide literature review which included

- *Liquid biofuels and hydrogen from renewable resources in the UK to 2050: a technical analysis*, E4tech for the Department for Transport, December 2003 (link)
- *Review of the potential for biofuels in aviation*, E4tech for the Committee on Climate Change, August 2009 (link)
- *Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, EC July 2011 (link)
- *Technology Roadmap: Biofuels for Transport*, IEA 2011 (link)
- *Comparative economics of biorefineries based on the biochemical and thermochemical platforms,* Wright & Brown (2007). Biofuels, Bioproducts and Biorefining **1**, p49-56.
- *Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland*, SAC for various Scottish Councils October 2005 (link)

Efficiency: [v1.2] based on same literature review as the cost data.

3.3.15 Biopetrol Production

A biopetrol production plant (500MW scale)

Cost assumptions: capital, fixed and variable costs [v1.2] based on a wide literature review which included

- *Liquid biofuels and hydrogen from renewable resources in the UK to 2050: a technical analysis*, E4tech for the Department for Transport, December 2003 (link)
- *Review of the potential for biofuels in aviation*, E4tech for the Committee on Climate Change, August 2009 (link)
- *Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, EC July 2011 (link)
- *Technology Roadmap: Biofuels for Transport*, IEA 2011 (link)
- *Comparative economics of biorefineries based on the biochemical and thermochemical platforms,* Wright & Brown (2007). Biofuels, Bioproducts and Biorefining **1**, p49-56.
- *Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland*, SAC for various Scottish Councils October 2005 (link)

Efficiency: [v1.2] based on same literature review as the cost data.

3.3.16 Biopetrol Production with CCS

A biopetrol production plant (500MW scale) with CCS capturing the pure stream of process CO2 liberated during the chemical reaction. CO2 is not captured from the combustion of biomass to generate process heat.

Cost assumptions: capital, fixed and variable costs [v4.1] based on a wide literature review which included

- *Liquid biofuels and hydrogen from renewable resources in the UK to 2050: a technical analysis*, E4tech for the Department for Transport, December 2003 (link)
- *Review of the potential for biofuels in aviation*, E4tech for the Committee on Climate Change, August 2009 (link)
- *Well-to-wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, EC July 2011 (link)
- *Technology Roadmap: Biofuels for Transport*, IEA 2011 (link)
- *Comparative economics of biorefineries based on the biochemical and thermochemical platforms,* Wright & Brown (2007). Biofuels, Bioproducts and Biorefining **1**, p49-56.
- *Economic Evaluation of Biodiesel Production from Oilseed Rape grown in North and East Scotland*, SAC for various Scottish Councils October 2005 (link)

Efficiency: [v4.1] based on same literature review as the cost data.

3.3.17 SNG Plant (Biomass Gasification)

A synthetic natural gas (i.e. methane) production plant (500MW scale).

Cost assumptions: [v4.2] based on data from the ETI's Biomass Value Chain Model (BVCM).

Efficiency: [v4.2] based on data from the ETI's Biomass Value Chain Model (BVCM).

3.3.18 SNG Plant (Biomass Gasification with CCS)

A synthetic natural gas (i.e. methane) production plant (500MW scale) with CCS. A capture rate of 63% is assumed (i.e. 95% capture rate on the methanation stage of the process) .

Cost assumptions: capital, fixed and variable costs [v4.2] all based on data from the ETI's Biomass Value Chain Model (BVCM).

Efficiency: [v4.1] based on a literature review including *Cost and Performance Baseline for Fossil Energy Plants Volume 2: Coal to Synthetic Natural Gas and Ammonia*, DOE/NETL July 2011 (link).

3.3.19 Domestic Appliances

A placeholder technology. It simply consumes electricity to mimic domestic appliance usage and has no cost or efficiency assumptions.

Load factor: [v3.0] varies by season and time of day as part of a project looking specifically at peak energy modelling in ESME.

3.3.20 Biofuel Substitution CO2 Credit

A placeholder technology. It converts the Biofuel Imports product into Liquid Fuel which can be used in the energy system by ESME, and collects the appropriate CO2 credit associated with the Biofuel Imports (see 5.1.2).

3.3.21 Biomass Importing CO2 Credit

A placeholder technology. It converts the "Biomass imports" resource into the "biomass" energy vector, and collects the appropriate CO2 credit associated with the biomass imports (see 5.1.3).

3.3.22 Dry Waste carbon accounting

A placeholder technology. It converts the "Dry Waste Resource" into the "Dry Waste" energy vector and gives the energy system the appropriate CO2 credit (see 5.1.8)

3.3.23 Biomass production (UK)

A placeholder technology. It converts the "UK Biomass" resource into the "biomass" energy vector and gives the energy system the appropriate CO2 credit (see 5.1.1)

3.3.24 Air Capture of CO2

A plant which captures CO2 from the atmosphere using a hydroxide absorbent system. Note that all CO2 from gas combustion is also captured.

Cost assumptions: capital and fixed costs [v2.0] based on *Direct Air Capture of CO2 with Chemicals*, American Physical Society June 2011 (link).

Efficiency: [v2.0] based on based on *Direct Air Capture of CO2 with Chemicals*, American Physical Society June 2011 (link).

3.4 Transport Technologies

The car technologies in ESME are segmented into two size categories: mini & small cars (A & B segments in the European Commission classification system) and medium & large cars (C & D segments). A car described as "A/B Segment" in ESME represents a weighted average of A and B segment cars, and similarly for a C/D Segment vehicle.

All cars share common assumptions for the average number of km driven per vehicle per year and the average number of passengers per vehicle per year. These parameters were updated in [v3.2] and are based on DfT data collected and processed under the small project to update the energy service demand data in ESME.

3.4.1 Car ICE

A liquid fuel internal combustion engine car.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006), fixed cost [v2.0] based on cost models delivered in the ETI project *Consumers & Vehicles* (TR1001).

Efficiency assumptions: [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006).

3.4.2 Car CNG

A compressed natural gas car. Note that each deployed car must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006). Fixed costs [v2.0] set relative ICE using cost models delivered in the ETI project *Consumers & Vehicles* (TR1001).

Efficiency assumptions: [v2.0] based on relative efficiencies compared to ICE cars from *Natural Gas Vehicles: Status, Barriers, and Opportunities,* Argonne National Laboratory August 2010 (link). Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.3 Car Hybrid

A hybrid electric car combining liquid fuel internal combustion engine with a battery and electric motor.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006), fixed cost [v2.0] based on cost models delivered in the ETI project *Consumers & Vehicles* (TR1001).

Efficiency assumptions: [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006).

3.4.4 Car PHEV

A hybrid electric car combining liquid fuel internal combustion engine with a battery and electric motor, with the facility to plug in and charge the vehicle while parked. Electric range 35-65 miles depending on vehicle size.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006), fixed cost [v3.1] based on cost models delivered in the ETI project *Consumers & Vehicles* (TR1001).

Efficiency assumptions: [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006).

3.4.5 Car Battery

A battery electric car with electric range of 200 miles.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006), fixed cost [v2.0] based on cost models delivered in the ETI project *Consumers & Vehicles* (TR1001).

Efficiency assumptions: [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006).

3.4.6 Car Hydrogen FCV

A hydrogen fuel cell car. Note that each deployed car must be accompanied by a unit of the hydrogen vehicle refuelling technology.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006). Fixed cost [v3.1] based on cost models from the ETI project *Consumers & Vehicles* (TR1001), modified to include additional O&M costs associated with running a hydrogen fuelling network (ETI analysis).

Efficiency assumptions: Hydrogen fuel consumption [v3.1] based on data from ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to add electrical energy used for compression to 700 bar in refuelling [v3.4].

3.4.7 Car Hydrogen ICE

A hydrogen internal combustion engine car. Note that each deployed car must be accompanied by a unit of the hydrogen vehicle refuelling technology.

Cost assumptions: capital cost [v4.2] based on outputs from the ETI project *Consumers Vehicles and Energy Integration* (TR1006). Fixed cost [v3.1] based on cost models from the ETI project *Consumers & Vehicles* (TR1001), modified to include additional O&M costs associated with running a hydrogen fuelling network (ETI analysis).

Efficiency assumptions: Hydrogen fuel consumption [v3.1] based on data from ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to add electrical energy used for compression to 700 bar in refuelling [v3.4].

3.4.8 HGV (ICE)

A heavy goods vehicle (max gross weight > 17 tonnes) with liquid fuel internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.9 HGV (ICE Euro 6)

A heavy goods vehicle (max gross weight > 17 tonnes) with liquid fuel internal combustion engine which meets the Euro 6 European emission standard (in force since 2014).

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.10 HGV (Gas SI)

A heavy goods vehicle (max gross weight > 17 tonnes) with a gas spark injection engine. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.11 HGV (Dual Fuel Port)

A heavy goods vehicle (max gross weight > 17 tonnes) with a diesel & gas dual fuel engine which injects the diesel straight into the cylinder. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.12 HGV (Dual Fuel Direct)

A heavy goods vehicle (max gross weight > 17 tonnes) with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.13 HGV (Hydrogen FCV)

A hydrogen heavy goods vehicle (max gross weight > 17 tonnes). Note that each deployed vehicle must be accompanied by a unit of the hydrogen vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.14 HGV (Flywheel Hybrid)

A heavy goods vehicle (max gross weight > 17 tonnes) with a diesel engine hybridised with a flywheel energy storage system.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.15 HGV (Gas SI Flywheel Hybrid)

A heavy goods vehicle (max gross weight > 17 tonnes) with a gas spark injection engine hybridised with a flywheel energy storage system. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.1] based on ETI analysis.

3.4.16 HGV (Dual Fuel Direct Flywheel Hybrid)

A heavy goods vehicle (max gross weight > 17 tonnes) with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold, hybridised with a flywheel energy storage system. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.1] based on ETI analysis.

3.4.17 MGV (ICE)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with liquid fuel internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.18 MGV (ICE Euro 6)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with liquid fuel internal combustion engine which meets the Euro 6 European emission standard (in force since 2014).

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.19 MGV (Gas SI)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with a gas spark injection engine. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.20 MGV (Dual Fuel Port)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with a diesel & gas dual fuel engine which injects the diesel straight into the cylinder. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.21 MGV (Dual Fuel Direct)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.22 MGV (Hydrogen FCV)

A hydrogen medium goods vehicle (max gross weight 7 – 17 tonnes). Note that each deployed vehicle must be accompanied by a unit of the hydrogen vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.23 MGV (Flywheel Hybrid)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with a diesel engine hybridised with a flywheel energy storage system.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.24 MGV (Gas SI Flywheel Hybrid)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with a gas spark injection engine hybridised with a flywheel energy storage system. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.1] based on ETI analysis.

3.4.25 MGV (Dual Fuel Direct Flywheel Hybrid)

A medium goods vehicle (max gross weight 7 – 17 tonnes) with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold, hybridised with a flywheel energy storage system. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.1] based on ETI analysis.

3.4.26 LGV (ICE)

A light goods vehicle (max gross weight < 7 tonnes) with liquid fuel internal combustion engine.

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.3] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

3.4.27 LGV (Gas SI)

A light goods vehicle (max gross weight < 7 tonnes) with a gas spark injection engine. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.3] based on the ETI analysis to set the efficiency relative to that of ICE LGVs. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.28 LGV (Dual Fuel Port)

A light goods vehicle (max gross weight < 7 tonnes) with a diesel & gas dual fuel engine which injects the diesel straight into the cylinder. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.4] based on ETI analysis combining data from various ETI projects on cars and on heavy duty vehicles. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.29 LGV (Dual Fuel Direct)

A light goods vehicle (max gross weight < 7 tonnes) with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.4] based on ETI analysis combining data from ETI projects on cars and on heavy duty vehicles. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.30 LGV (Hybrid)

A hybrid electric light goods vehicle (max gross weight < 7 tonnes).

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.3] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

3.4.31 LGV (BEV)

A battery electric light goods vehicle (max gross weight < 7 tonnes) with electric range of 200 miles.

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.3] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

3.4.32 LGV (PHEV)

A hybrid electric light goods vehicle (max gross weight < 7 tonnes) with the facility to plug in and charge the vehicle while parked. Electric range 65 miles.

Cost assumptions: capital and fixed costs [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

Efficiency assumptions: [v3.3] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database.

3.4.33 LGV (Hydrogen FCV)

A hydrogen light goods vehicle (max gross weight < 7 tonnes). Note that each deployed vehicle must be accompanied by a unit of the hydrogen vehicle refuelling technology.

Cost assumptions: capital cost [v3.4] based on cost models delivered in the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to increase the vehicle's range and tank size. Fixed cost [v3.4] also based on the cost models from the ETI project *Consumers & Vehicles* (TR1001), modified to include additional O&M costs associated with running a hydrogen fuelling network (ETI analysis).

Efficiency assumptions: [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database, and also modified to add electrical energy used for compression to 700 bar in refuelling [v3.4].

3.4.34 LGV (Hydrogen ICE)

A hydrogen internal combustion light goods vehicle (max gross weight < 7 tonnes). Note that each deployed vehicle must be accompanied by a unit of the hydrogen vehicle refuelling technology.

Cost assumptions: capital cost [v3.4] based on cost models delivered in the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to increase the vehicle's range and tank size. Fixed cost [v3.4] also based on the cost models from the ETI project *Consumers & Vehicles* (TR1001), modified to include additional O&M costs associated with running a hydrogen fuelling network (ETI analysis).

Efficiency assumptions: [v3.4] based on the ETI project *Consumers & Vehicles* (TR1001), modified by ETI analysis to estimate parameters for LGVs based on the car database, and also modified to add electrical energy used for compression to 700 bar in refuelling [v3.4].

3.4.35 Bus (ICE)

A bus with liquid fuel internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.36 Bus (Gas SI)

A bus with a gas spark injection engine. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.37 Bus (Dual Fuel Port)

A bus with a diesel & gas dual fuel engine which injects the diesel straight into the cylinder. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.38 Bus (Dual Fuel Direct)

A bus with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.39 Bus (Hybrid)

A hybrid bus.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.40 Bus (Hydrogen FCV)

A hydrogen bus. Note that each deployed vehicle must be accompanied by a unit of the hydrogen vehicle refuelling technology

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.0] based on ETI analysis.

3.4.41 Bus (Flywheel Hybrid)

A bus with a diesel engine hybridised with a flywheel energy storage system.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.42 Bus (Gas SI Flywheel Hybrid)

A bus with a gas spark injection engine hybridised with a flywheel energy storage system. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.1] based on ETI analysis.

3.4.43 Bus (Dual Fuel Direct Flywheel Hybrid)

A bus with a diesel & gas dual fuel engine which injects the diesel into the inlet manifold, hybridised with a flywheel energy storage system. Note that each deployed vehicle must be accompanied by a unit of the natural gas vehicle refuelling technology.

Cost assumptions: capital and fixed costs [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.1] based on data collected in the ETI Heavy Duty Vehicles programme. Electrical energy used for compression to 700 bar in refuelling [v4.1] based on ETI analysis.

3.4.44 Rail (Passenger Diesel)

A diesel fuelled passenger train, representing an average vehicle in the UK fleet.

Cost assumptions: capital cost [v1.0] is a nominal cost based on recent contracts awards for Bombardier locomotives & trains (link).

Efficiency assumptions: [v3.2] based on calibration of the 2010 CO2 emissions from railways, taken from the *Final UK greenhouse gas emissions national statistics* published by DECC (link) with the 2010 energy service demand data (see section 4).

3.4.45 Rail (Freight Diesel)

A diesel fuelled freight train, representing an average vehicle in the UK fleet.

Cost assumptions: capital cost [v1.0] is a nominal cost based on recent contracts awards for Bombardier locomotives & trains (link).

Efficiency assumptions: [v3.2] based on calibration of the 2010 CO2 emissions from railways, taken from the *Final UK greenhouse gas emissions national statistics* published by DECC (link) with the 2010 energy service demand data (see section 4).

3.4.46 Rail (Passenger Electric)

An electric passenger train, representing an average vehicle in the UK fleet.

Cost assumptions: capital cost [v1.0] is a nominal cost based on recent contracts awards for Bombardier locomotives & trains (link).

Efficiency assumptions: [v3.2] based on calibration of the 2010 data for electricity demand for railways, taken from the *Energy consumption in the UK* statistics published by DECC (link) with the 2010 energy service demand data (see section 4).

3.4.47 Maritime (International)

A diesel fuelled freight ship, representing an average vessel contributing to the UK share of international shipping emissions. Note that international shipping emissions in ESME are accounted on a bunker fuel basis, following the recommendation in *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*, Committee on Climate Change April 2012 (link).

Cost assumptions: capital cost [v1.0] is a nominal cost based on *Transport Statistics Report: Maritime Statistics 2008,* Department for Transport September 2009. Fixed cost [v4.0] is based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v3.2] based on calibration of the 2010 CO2 emissions from domestic and international shipping, based on shipping bunkers in *Final UK greenhouse gas emissions national statistics* published by DECC (link) and *Review of UK Shipping Emissions*, Committee on Climate Change November 2011 (link).

3.4.48 Maritime (Dual Fuel International)

A diesel/gas dual fuelled freight ship, representing an average vessel contributing to the UK share of international shipping emissions. Note that international shipping emissions in ESME are accounted on a bunker fuel basis, following the recommendation in *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*, Committee on Climate Change April 2012 (link).

Cost assumptions: capital cost [v4.0] is set relative to the “Maritime (International)” technology cost, based on data collected in the ETI Heavy Duty Vehicles programme. Fixed cost [v4.0] ibid.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.49 Maritime (Domestic)

A diesel fuelled freight ship, representing an average vessel contributing to UK domestic shipping.

Cost assumptions: capital cost [v1.0] is a nominal cost. Fixed cost [v4.0] is based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v3.2] based on calibration of the 2010 CO2 emissions from domestic and international shipping, based on the *Final UK greenhouse gas emissions national statistics* published by DECC (link) and *Review of UK Shipping Emissions*, Committee on Climate Change November 2011 (link).

3.4.50 Maritime (Dual Fuel Domestic)

A diesel/gas dual fuelled freight ship, representing an average vessel contributing to UK domestic shipping.

Cost assumptions: capital cost [v4.0] is set relative to the "Maritime (International)" technology cost, based on data collected in the ETI Heavy Duty Vehicles programme. Fixed cost [v4.0] ibid.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.51 Aviation (International)

A passenger aeroplane, representing an average of the UK aviation fleet. International aviation emissions in ESME are accounted on the basis of all departing flights, following the recommendation in *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*, Committee on Climate Change April 2012 (link). Note that this measure correlates very closely to the bunker fuel methodology (Box 2.1, p25, ibid.)

Cost assumptions: capital cost [v1.0] based on Airbus and Boeing 2008 price lists. Fixed cost [v1.0] based on Airline Monitor data (link).

Efficiency assumptions: [v3.5] based on projections in *Sustainable Aviation CO2 Roadmap,* Sustainable Aviation 2012 (link), following a review which also included *UK Aviation Forecasts*, Department for Transport January 2013 (link) and *Meeting the UK Aviation target – options for reducing emissions to 2050*, Committee on Climate Change December 2009 (link).

3.4.52 Aviation (Domestic)

A single-aisle passenger aeroplane, representing an average of the UK aviation fleet

Cost assumptions: capital cost [v1.0] based on Airbus and Boeing 2008 price lists. Fixed cost [v1.0] based on Airline Monitor data (link).

Efficiency assumptions: [v3.5] based on projections in *Sustainable Aviation CO2 Roadmap,* Sustainable Aviation 2012 (link), following a review which also included *UK Aviation Forecasts*, Department for Transport January 2013 (link) and *Meeting the UK Aviation target – options for reducing emissions to 2050*, Committee on Climate Change December 2009 (link).

3.4.53 Agricultural Vehicle (ICE)

A representative agricultural vehicle with a conventional internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.54 Wheeled Excavator (ICE)

A representative Wheeled Excavator vehicle with a conventional internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.55 Crawler Excavator (ICE)

A representative Crawler Excavator vehicle with a conventional internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.56 Medium Articulated Truck (ICE)

A representative Medium Articulated Truck (~240kW power rating) with a conventional internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.57 Large Articulated Truck (ICE)

A representative Large Articulated Truck (~380kW power rating) with a conventional internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.4.58 Medium Wheel Loader (ICE)

A representative Wheeled Loader (~200kW power rating) with a conventional internal combustion engine.

Cost assumptions: capital and fixed costs [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

Efficiency assumptions: [v4.0] based on data collected in the ETI Heavy Duty Vehicles programme.

3.5 Infrastructure technologies: storage

3.5.1 Pumped Storage of Electricity

A pumped-storage hydroelectricity system (10GWh scale).

Cost assumptions: capital costs [3.4] based on *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories July 2013 (link). The costs in appendix B are based on a series of vendor and OEM surveys.

Efficiency assumptions: [v3.4] based on the same source as the cost assumptions above.

3.5.2 Compressed Air Storage of Electricity

A compressed air storage system (10GWh scale) using underground salt caverns.

Cost assumptions: capital costs [3.4] based on *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories July 2013 (link). The costs in appendix B are based on a series of vendor and OEM surveys.

Efficiency assumptions: [v3.4] based on the same source as the cost assumptions above.

3.5.3 Battery – NaS

A Sodium-Sulphur battery (15MW, 100MWh scale) for stationary energy storage applications, e.g. frequency regulation and renewables integration applications.

Cost assumptions: capital costs for 2010 [v3.4] based on *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories July 2013 (link). The costs in appendix B are based on a series of vendor and OEM surveys. Future cost reductions based on ETI literature review & analysis.

Efficiency assumptions: Round trip efficiency and the range of permissible power to volume ratios are based on the same source as the cost assumptions above.

3.5.4 Battery – Li-ion

A Lithium-ion battery (5MW, 5MWh scale) for stationary energy storage applications, e.g. frequency regulation and renewables integration applications.

Cost assumptions: capital costs for 2010 [v3.4] based on *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories July 2013 (link). The costs in appendix B are based on a series of vendor and OEM surveys. Future cost reductions based on ETI literature review & analysis.

Efficiency assumptions: Round trip efficiency and the range of permissible power to volume ratios are based on the same source as the cost assumptions above.

3.5.5 Flow battery – Redox

A vanadium redox flow battery (5MW, 10MWh scale) for stationary energy storage applications, e.g. frequency regulation and renewables integration applications.

Cost assumptions: capital costs for 2010 [v3.4] based on *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories July 2013 (link). The costs in appendix B are based on a series of vendor and OEM surveys. Future cost reductions based on ETI literature review & analysis.

Efficiency assumptions: Round trip efficiency and the range of permissible power to volume ratios are based on the same source as the cost assumptions above.

3.5.6 Flow battery - Zn-Br

A Zinc-Bromine flow battery (5MW, 10MWh scale) for stationary energy storage applications, e.g. frequency regulation and renewables integration applications.

Cost assumptions: capital costs for 2010 [v3.4] based on *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA*, Sandia National Laboratories July 2013 (link). The costs in appendix B are based on a series of vendor and OEM surveys. Future cost reductions based on ETI literature review & analysis.

Efficiency assumptions: Round trip efficiency and the range of permissible power to volume ratios are based on the same source as the cost assumptions above.

3.5.7 Pumped Heat Storage of Electricity

An electricity storage system comprising a thermal store and a reciprocating heat pump/engine (10 MW scale)

Cost assumptions: capital costs [v4.1] based on data from the ETI Energy Storage and Distribution programme.

Efficiency assumptions: Round trip efficiency and the range of permissible power to volume ratios are based on the same source as the cost assumptions above.

3.5.8 Hydrogen Storage – shallow salt cavern

A hydrogen storage system (10GWh scale) using shallow underground salt caverns.

Cost assumptions: capital and fixed costs [v4.1] based on data from the ETI CCS programme, including the *Hydrogen Turbines* project (CC2009).

Efficiency assumptions: [v4.1] based on data from the ETI CCS programme, including the *Hydrogen Turbines* project (CC2009).

3.5.9 Hydrogen Storage – medium salt cavern

A hydrogen storage system (10GWh scale) using medium depth underground salt caverns.

Cost assumptions: capital and fixed costs [v4.1] based on data from the ETI CCS programme, including the *Hydrogen Turbines* project (CC2009).

Efficiency assumptions: [v4.1] based on data from the ETI CCS programme, including the *Hydrogen Turbines* project (CC2009).

3.5.10 Hydrogen Storage – deep salt cavern

A hydrogen storage system (10GWh scale) using deep underground salt caverns.

Cost assumptions: capital and fixed costs [v4.1] based on data from the ETI CCS programme, including the *Hydrogen Turbines* project (CC2009).

Efficiency assumptions: [v4.1] based on data from the ETI CCS programme, including the *Hydrogen Turbines* project (CC2009).

3.5.11 Geological Storage of CO2 - Southern North Sea

Permanent storage of CO2 in saline aquifers below the seabed.

Cost assumptions: capital and fixed costs [v4.2] based on data from the project *Strategic UK CO2 Storage Appraisal* CCS (link).

3.5.12 Geological Storage of CO2 - Central North Sea

Permanent storage of CO2 in saline aquifers below the seabed.

Cost assumptions: capital and fixed costs [v4.2] based on data from the project *Strategic UK CO2 Storage Appraisal* CCS (link).

3.5.13 Geological Storage of CO2 - East Irish Sea

Permanent storage of CO2 in saline aquifers below the seabed.

Cost assumptions: capital and fixed costs [v4.2] based on data from the project *Strategic UK CO2 Storage Appraisal* CCS (link).

3.5.14 Building Space Heat Storage

Domestic heat storage system using a hot water tank (50-100 litres).

Cost assumptions: [v3.0] based on a sample of market prices.

Efficiency assumptions: [v3.0] based on heat loss factors from *SAP 2009: The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, BRE March 2011 (link).

3.5.15 Building Hot Water Storage

Domestic hot water storage tank (50-100 litres).

Cost assumptions: [v3.0] based on a sample of market prices.

Efficiency assumptions: [v3.0] based on heat loss factors from *SAP 2009: The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, BRE March 2011 (link).

3.5.16 District Heat Storage

A hot water storage tank (50m^3 scale) providing heat storage for a heat network

Cost assumptions: [v3.2] based on *2050 options for decarbonising heat in buildings*, Element Energy Limited and AEA Group April 2012 (link).

Efficiency assumptions: [3.2] based on heat loss factors from *SAP 2009: The Government's Standard Assessment Procedure for Energy Rating of Dwellings*, BRE March 2011 (link).

3.6 Infrastructure technologies: transmission & distribution

3.6.1 Electricity Transmission Offshore

Electricity transmission for offshore renewables (100km, 1GW scale).

Cost assumptions: [v1.0] based on figure 5.4 of *Growth Scenarios for UK Renewables Generation and Implications for Future Developments and Operation of Electricity Networks*, BERR June 2008 (link).

Loss factors: [v1.0] based on same report as above.

3.6.2 Electricity Transmission Onshore

Onshore electricity transmission (220kV, 300MVA overhead line).

Cost assumptions: [v1.0] based on table 5.4 of *Growth Scenarios for UK Renewables Generation and Implications for Future Developments and Operation of Electricity Networks*, BERR June 2008 (link).

Loss factors: [v1.0] based on same report as above.

3.6.3 Electricity Distribution Network

Electricity distribution network, representing the average properties per region.

Cost assumptions: capital cost for capacity increase [v2.0] based on a literature review including

- *Distribution Price Control Review 3*, Ofgem
- *Review of Distributed Generation*, DTI & Ofgem, May 2007 (link)
- *Electricity distribution price control review - Second consultation*, Ofgem December 2003 (link)

Loss factors: [v4.2] based on Ofgem data for *Electricity Distribution Loss Percentages by Distribution Network Operator (DNO) Area* and “loss reduction strategy” documents published by each DNO under the RIIO-ED1 framework.

3.6.4 Captured CO2 transmission Offshore

Transmission pipelines to take captured CO2 to offshore storage sites.

Cost assumptions: capital and fixed costs [v4.2] based on data from the project *Strategic UK CO2 Storage Appraisal* CCS (link).

3.6.5 Captured CO2 transmission Onshore

Transmission pipelines to take captured CO2 to offshore storage sites.

Cost assumptions: [v3.3] based on pipeline costs from *CO2 NomicA*, the model for costing CO2 networks arising out of the ETI *UK Storage Appraisal* projects (CC1001, CC2008).

3.6.6 Hydrogen Transmission

Onshore hydrogen transmission pipelines (15" main, 30000 kg/hr)

Cost assumptions: [v1.0] based on p408 & p411 of *2005 Annual Progress Report for the DOE Hydrogen Program* (link).

Loss factors: [v1.0] based on p408 of the above report.

3.6.7 EV Charging Point (private off street)

An electric vehicle charging point.

Cost assumptions: [v3.1] based on data from the ETI project *Electricity Distribution and Intelligent Infrastructure* (TR1002).

3.6.8 EV Charging Point (workplace)

An electric vehicle charging point.

Cost assumptions: [v3.1] based on data from the ETI project *Electricity Distribution and Intelligent Infrastructure* (TR1002).

3.6.9 EV Charging Point (on street outside home)

An electric vehicle charging point.

Cost assumptions: [v3.1] based on data from the ETI project *Electricity Distribution and Intelligent Infrastructure* (TR1002).

3.6.10 Natural gas vehicle refuelling

A "per vehicle" share of refuelling infrastructure costs for natural gas vehicles.

Cost assumptions: capital cost [v2.0] (note this cost was previously included in the vehicle costs but is now tracked via this separate technology) based on a literature review of infrastructure costs for both natural gas and hydrogen vehicles including:

- *Create an Economic CNG Fueling Infrastructure by Adding Home Fueling and Small Stations*, FuelMaker Corporation January 2003 (link)
- *Steady State Model of Hydrogen Infrastructure for US Urban Areas*, Yang & Ogden 2007
- *Optimal Design of a Fossil Fuel-Based Hydrogen Infrastructure with Carbon Capture and Sequestration: Case Study in Ohio*, Johnson et al. April 2005 (link).
- *Cost of Some Hydrogen Fuel Infrastructure Options*, Argonne National Laboratory January 2002 (link)

3.6.11 Hydrogen vehicle refuelling

A "per vehicle" share of refuelling infrastructure costs for hydrogen vehicles.

Cost assumptions: capital cost [v3.1] (note this cost was previously included in the vehicle costs but is now tracked via this separate technology) based on a literature review of infrastructure costs for both natural gas and hydrogen vehicles (see 3.6.10) and ETI judgement.

3.6.12 Interconnector Benelux-Germany (Electricity)

A subsea electrical interconnector (GW scale).

Cost assumptions: not costed in ESME

Capacity assumption: [v3.0] based on a literature review including *Roadmap 2050 – A practical guide to a prosperous low-carbon Europe*, European Climate Foundation April 2010 (link).

3.6.13 Interconnector France (Electricity)

A subsea electrical interconnector (GW scale).

Cost assumptions: not costed in ESME

Capacity assumption: [v3.0] based on a literature review including *Roadmap 2050 – A practical guide to a prosperous low-carbon Europe*, European Climate Foundation April 2010 (link).

3.6.14 Interconnector Ireland (Electricity)

A subsea electrical interconnector (GW scale).

Cost assumptions: not costed in ESME

Capacity assumption: [v3.0] based on a literature review including *Offshore and Interconnector Techno-economic Studies*, EirGrid January 2011 (link).

3.6.15 Interconnector Nordel (Electricity)

A subsea electrical interconnector (GW scale).

Cost assumptions: not costed in ESME

Capacity assumption: [v3.0] based on a literature review including *Roadmap 2050 – A practical guide to a prosperous low-carbon Europe*, European Climate Foundation April 2010 (link).

3.7 Retrofit technologies

3.7.1 Retrofix (LD)

A package of insulation measures, applicable to ThP and ThM dwellings delivering 20-30% energy saving. The generic package includes: wall insulation, loft insulation, floor edge insulation, draught stripping, single room heat recovery, TRVs and zoned controls.

Cost assumptions: capital cost [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

Efficiency assumptions: saving on dwelling heat demand [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

3.7.2 Retrofix (MD)

A package of insulation measures, applicable to ThP and ThM dwellings delivering 20-30% energy saving. The generic package includes: wall insulation, loft insulation, floor edge insulation, draught stripping, single room heat recovery, TRVs and zoned controls.

Cost assumptions: capital cost [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

Efficiency assumptions: saving on dwelling heat demand [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

3.7.3 Retrofix (HD)

A package of insulation measures, applicable to ThP and ThM dwellings delivering 20-30% energy saving. The generic package includes: wall insulation, loft insulation, floor edge insulation, draught stripping, single room heat recovery, TRVs and zoned controls.

Cost assumptions: capital cost [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

Efficiency assumptions: saving on dwelling heat demand [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

3.7.4 Retroplus (LD)

A package of insulation measures, applicable to ThP and ThM dwellings delivering 35-45% energy saving. The generic package includes the Retrofix measures plus: floor insulation, window replacement and door replacement.

Cost assumptions: capital cost [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

Efficiency assumptions: saving on dwelling heat demand [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

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A package of insulation measures, applicable to ThP and ThM dwellings delivering 35-45% energy saving. The generic package includes the Retrofix measures plus: floor insulation, window replacement and door replacement.

Cost assumptions: capital cost [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

Efficiency assumptions: saving on dwelling heat demand [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

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Cost assumptions: capital cost [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

Efficiency assumptions: saving on dwelling heat demand [v3.2] based on ETI project *Optimising Thermal Efficiency of Existing Housing (OTEoEH)* (BU1001).

3.7.7 CCGT CCS Retrofit

A retrofit which converts the *CCGT* technology to *CCGT with CCS*.

Cost assumption: capital cost [v3.3] is assumed to be 120% of the cost difference between the capital costs of the 2 technologies.

3.7.8 IGCC Coal CCS Retrofit

A retrofit which converts the *IGCC Coal* technology to *IGCC Coal with CCS*.

Cost assumption: capital cost [v3.3] is assumed to be 120% of the cost difference between the capital costs of the 2 technologies.

3.7.9 PC Coal CCS Retrofit

A retrofit which converts the *PC Coal* technology to *PC Coal with CCS*.

Cost assumption: capital cost [v3.3] is assumed to be 120% of the cost difference between the capital costs of the 2 technologies.

3.7.10 PC Coal Biomass Retrofit

A retrofit which converts the *PC Coal* technology to *Converted Biomass Plant*.

See entry 3.1.15 on the *Converted Biomass Plant* for details of all the assumptions related to this retrofit.

3.8 Industry Technologies

3.8.1 Industry sector definitions used in ESME

In ESME the use of energy in industry is segmented into 9 sectors [v4.0] based on a combination of sector conventions from the *Digest of UK Energy Statistics*, DECC (link) and from *Energy consumption in the UK*, DECC (link). Although "Cement, ceramics, glass and lime" is not treated as a separate sector in *DUKES*, it is treated as a distinct sector in ESME (sector I7) because it is a major energy intensive industry in the UK with potential for sector-specific carbon abatement technologies.

Industry Sector	**ESME Abbreviation**	**Definition basis**
Iron and steel and non-ferrous metals	I1	Table 1.8 of *DUKES*
Chemicals	I2	Table 1.8 of *DUKES*
Metal products, machinery and equipment	I3	Table 1.8 of *DUKES*
Food, drinks and tobacco	I4	Table 1.8 of *DUKES*
Paper, printing and publishing	I5	Table 1.8 of *DUKES*
Other Industry	I6	Table 1.8 of *DUKES*: totals for "Other industries" and "Unclassified", minus Sector I7.
Cement, ceramics, glass and lime	I7	Table 4.10 of *ECUK*, "Manufacture of other non-metallic mineral products" (SIC 23)
Refineries	I8	Table 1.1 of *DUKES*: "Petroleum refineries" row
Agriculture	I9	Table 1.1 of *DUKES*: "Agriculture" row.

Table 5. Definitions of the 9 Industry sectors represented in ESME.

The energy use of each industrial sector is segregated into 6 generic categories termed production processes, based on data from *Energy consumption in the UK*, DECC (link). Note that not all industry sectors have a significant energy use in each of the 6 processes. A total of 39 sector / process combinations are represented in ESME [v4.0], rather than the full 54. See Table 10 for a complete list.

Production Process	**Abbreviation**
High temperature process	HTP
Low temperature process	LTP
Drying and separation	DaS
Motors	Mot
Space heating	SpH
Other	Oth

Table 6. Definitions of the 6 production processes into which energy use is allocated for each industrial sector in ESME.

For each of the 39 sector / process combinations represented in ESME an End Use Service product is defined using the above abbreviations. For example, the High temperature process in the Iron and steel and non-ferrous metals sector has an End Use Service product called "IND_I1_HTP". A demand for IND_I1_HTP is specified in the energy service demands of ESME (see section 4) and similarly for each of the 39 industry processes. The demand is given in units of "process energy demand relative to 2010". Hence in 2010 the total UK demand for every process is unity. In later years the demand for each increases or decreases according to 2 factors:

i. Sector / process output relative to 2010, and
ii. Sector / process energy intensity relative to 2010.

The trends in these 2 factors are set exogenously to the ESME model in the energy service demand data (see section 4).

3.8.2 Representation of industry processes as technologies in ESME

For each of the industry processes in ESME one or more technology is defined which can meet the associated demand. For example the following technologies can all satisfy the demand for IND_I1_HTP, to provide high temperature processes to the Iron and steel and non-ferrous metals sector:

Technology Name	Description
Industry I1 HTP Baseline	Baseline (2010) fuel mix
Industry I1 HTP Bio Sw	Baseline plus fuel switching in favour of biomass
Industry I1 HTP Bio Sw CCS	Baseline plus fuel switching in favour of biomass, plus CCS
Industry I1 HTP CCS	Baseline fuel mix plus CCS
Industry I1 HTP Elec Sw	Baseline plus fuel switching in favour of electricity
Industry I1 HTP Gas Sw	Baseline plus fuel switching in favour of gas
Industry I1 HTP Gas Sw CCS	Baseline plus fuel switching in favour of gas, plus CCS
Industry I1 HTP Hyd Sw	Baseline plus fuel switching in favour of hydrogen
Industry I1 HTP Hyd Sw CCS	Baseline plus fuel switching in favour of hydrogen, plus CCS

Table 7. The technologies available in ESME to satisfy demand for IND_I1_HTP.

Technologies with analogous names are defined for the other sectors and processes. All of the industry technologies were updated in ESME v4.0 based on a dedicated project which reviewed the representation of industrial energy use in ESME. The technologies for each process are defined in units relative to 2010. Therefore a total UK capacity of 1 unit of any of the technologies shown in Table 7 is sufficient to satisfy the total UK demand for IND_I1_HTP in 2010.

Note that the baseline industry technologies have only a nominal cost in ESME – there is no attempt to estimate the 'total cost' of current UK industry assets. All technologies which are alternatives to the baseline, such as the bottom 8 rows in Table 7, are given a cost in the ESME optimisation which is the additional cost, relative to the 'business as usual' baseline, reflecting the additional cost of carbon abatement measures.

Cost assumptions for industry process technologies: The capital and fixed costs of most fuel switching technologies [v4.0] are based on data from *Industrial Energy Use (UK)*, UKERC 2013 (link). In a small number of cases, where the UKERC database does not include a corresponding abatement technology, the costs are based on other items in the ESME database, e.g. the cost of a gas boiler, or gas power station. The costs for CCS [v4.1] cover capture costs and are based on *Potential for the application of CCS to UK industry and natural gas power generation*, Element Energy for the Committee on Climate Change, June 2010 (link).

Fuel switching potential: the maximum possible extent of fuel switching within each process [v4.0] is primarily based on the data in *Industrial Energy Use (UK)*, UKERC 2013 (link). In a small number of cases, where the UKERC database does not include a corresponding abatement technology**,** the fuel switching potential is a judgement based on an analysis of detailed energy use by subsector.

CCS capture potential: the maximum proportion of emissions amenable to CCS [v4.1] is based on the data in *Industrial Energy Use (UK)*, UKERC 2013 (link).

Industry technology loadfactors: variation of loadfactors by season and time of day [v3.0] were set during the peak energy project, based on Elexon data.

3.9 Buildings technologies

3.9.1 Dwellings

In ESME the stock of UK dwellings is segregated into segments based on dwelling size and thermal efficiency. The 12 basic archetypes are defined by 3 density categories and 4 thermal efficiency categories. In each category the data in ESME represents average values for that segment of the UK housing stock.

Category	Abbreviation	Definition
High Density	HD	flats & apartments
Medium Density	MD	semi-detached & terraced
Low Density	LD	detached & bungalows

Category	Abbreviation	Definition
Thermally Excellent	ThE	Passivhaus Standard
Thermally Good	ThG	SAP rating A-B
Thermally Medium	ThM	SAP rating C-D
Thermally Poor	ThP	SAP rating E-G

Table 8. Definitions of the 12 basic categories of dwellings represented in ESME.

In addition there are more thermal efficiency categories which correspond to dwellings retrofitted with packages of insulation measures, see section 3.7.

Cost assumptions for all dwellings: [v1.0] based on ETI analysis. Note that new dwellings are only permitted in ThE and ThG categories, to reflect UK building regulations.

Space heat requirements for all dwellings: [v1.0] based on ETI analysis of energy efficiency ratings (kWh/m^2/yr) and building floor area (m^2) taken from EST data, converted to heat required per heating degree day (HDD) per dwelling. The within-day patterns of heat demand [v3.0] were set during the peak energy project – see the ESME Space Heating Pre-processing Tool for full details.

Hot water requirements for all dwellings: [v1.0] based on data from *Measurement of Domestic Hot Water Consumption in Dwellings*, Energy Saving Trust (EST) 2008 (link). The within-day patterns of heat demand [v3.0] were set during the peak energy project, based on data from the same report.

Lighting requirements for all dwellings: [v3.2] calibrated to 2010 using *Energy consumption in the UK* published by DECC (link). Within-day patterns of lighting demand [v3.0] were set during the peak energy project, based on *State of the Art Modelling of Hydrogen Infrastructure Development for the UK: Geographical, temporal and technological optimisation modelling*, Policy Studies Institute June 2008 (link).

3.9.2 Floorspace (Commercial)

A representation of floorspace in commercial buildings (comprising the following categories of the service sector from *Energy Consumption in the United* Kingdom: Commercial Offices, Communication and Transport, Hotel and Catering, Other, Retail, Sport and Leisure, Warehouses).

Space heat requirement: annual heat demand [v1.0] taken as service sector average from data in *Energy consumption in the UK* published by DECC (link). The within-day patterns of heat demand [v3.0] were set during the peak energy project – see the ESME Space Heating Pre-processing Tool for full details.

Hot water requirement: annual heat demand [v1.0] taken as service sector average from data in *Energy consumption in the UK* published by DECC (link). The within-day patterns of heat demand [v3.0] were set during the peak energy project – see the ESME Space Heating Pre-processing Tool for full details.

Lighting requirements: [v3.2] calibrated to 2010 using *Energy consumption in the UK* published by DECC (link). Within-day patterns of lighting demand [v3.0] were set during the peak energy project, based on *State of the Art Modelling of Hydrogen Infrastructure Development for the UK: Geographical, temporal and technological optimisation modelling*, Policy Studies Institute June 2008 (link).

Electricity consumption: [v3.2] calibrated to 2010 using *Energy consumption in the UK* published by DECC (link). Within-day patterns of lighting demand [v3.0] were set during the peak energy project, based on Elexon data and *State of the Art Modelling of Hydrogen Infrastructure Development for the UK: Geographical, temporal and technological optimisation modelling*, Policy Studies Institute June 2008 (link).

3.9.3 Floorspace (Public)

A representation of floorspace in public buildings (comprising the following categories of the service sector from *Energy Consumption in the United* Kingdom: Education, Government, Health).

Space heat requirement: annual heat demand [v1.0] taken as service sector average from data in *Energy consumption in the UK* published by DECC (link). The within-day patterns of heat demand [v3.0] were set during the peak energy project – see the ESME Space Heating Pre-processing Tool for full details.

Hot water requirement: annual heat demand [v1.0] taken as service sector average from data in *Energy consumption in the UK* published by DECC (link). The within-day patterns of heat demand [v3.0] were set during the peak energy project – see the ESME Space Heating Pre-processing Tool for full details.

Lighting requirements: [v3.2] calibrated to 2010 using *Energy consumption in the UK* published by DECC (link). Within-day patterns of lighting demand [v3.0] were set during the peak energy project, based on *State of the Art Modelling of Hydrogen Infrastructure Development for the UK: Geographical, temporal and technological optimisation modelling*, Policy Studies Institute June 2008 (link).

Electricity consumption: [v3.2] calibrated to 2010 using *Energy consumption in the UK* published by DECC (link). Within-day patterns of lighting demand [v3.0] were set during the peak energy project, based on Elexon data and *State of the Art Modelling of Hydrogen Infrastructure Development for the UK: Geographical, temporal and technological optimisation modelling*, Policy Studies Institute June 2008 (link).

4 Energy service demand data

Energy demands in ESME are specified out to 2050 at the regional level. The energy services are the actual useful products that energy provides, such as ‘passenger km’ for private vehicles, ‘freight km’ for haulage, ‘lumens’ of light in the home etc. See Table 9 and Table 10 for a complete list. Different technologies are available for ESME to use to meet these services, e.g. electric cars or hydrogen fuel cell cars for ‘passenger km’. Since competing technologies may have different input fuels and efficiencies, the actual volume of energy required is not established until runtime, when ESME builds the cost-optimal supply side solutions to satisfy these demands. In doing so, ESME must balance energy supply and demand in each year, each region and each timeslice.

Establishing appropriate assumptions for energy service demands out to 2050 is clearly an area of considerable uncertainty. To ensure the robustness against a range of possible futures, there are three demand cases, each depicting a distinct coherent view of the world.

‘Back to the Future’ is the reference case, drawing on central government projections of population, GDP, and demand for energy services where these are available. Essentially the demands reflect official UK Government views of what the future may look like, or in areas not covered by the Government’s “official” view, this is ETI’s best estimate of most probable future based on the available Government data.

In addition two alternative cases are constructed based on different views of what the future may look like. In ‘Sharing Economy’ the population and the economy grow at a slightly higher rate, but our behaviours and preferences, as well as the composition of the economy, change considerably. In ‘the Great Stagnation’, GDP grows well below the historical average, and consequently energy services are constrained by lower incomes.

The ESME data on demand for energy services [v3.2] was updated in 2013 in a project lead by CRA Marakon. The final report of that project gives full details on the data sources used and the approach taken for each sector and each of the individual energy services.

In 2015 ESME [v4.0] introduced further disaggregation of the industry sectors, with the cement sector split out from the rest of the “other industry sector”, see Section 3.8. Demand for the new cement sector of industry was calculated by CRA following the same methodology. ESME [v4.0] also introduced a disaggregation of industrial energy demand into 6 “production processes” (see Section 3.8). The disaggregation was performed using *Energy consumption in the UK* published by DECC (link).

In 2015 ESME [v4.0] also introduced 6 new transport categories covering agricultural vehicles and off-road construction vehicles. Demand for these sectors was calculated by ETI following the same methodology, using data from DEFRA, Freedonia and the ETI HDV programme.

4.1 Heat demand data

The demand for heat in ESME results from a combination of demand for buildings (dwellings and commercial floorspace) and a separate set of “heating degree day” (HDD) data. The HDD preprocessing tool included with the ESME model performs calculations to estimate the number of HDDs required to heat each building type to the user-specified internal temperature. These calculations are based on:

- Regional degree day data processed from Met Office weather station data by Oxford University’s Environmental Change Institute (link)

- UK External temperature data from UKCIP02, climate change scenarios funded by DEFRA

Sector	Energy Service Demand	Unit	Code
Buildings	High density dwellings	million dwellings	BLD_RES_HGH
Buildings	Low density dwellings	million dwellings	BLD_RES_LOW
Buildings	Mid density dwellings	million dwellings	BLD_RES_MID
Buildings	Commercial floorspace	million sq metres	BLD_COM
Buildings	Public floorspace	million sq metres	BLD_PUB
Buildings	Domestic air conditioning	TWh	BLD_RES_ACN
Buildings	Domestic appliances	TWh	BLD_RES_APP
Buildings	Domestic cooking	TWh	BLD_RES_CKG
Transport	Domestic passenger aviation	billion passenger km	TPT_AVI_DOM
Transport	International passenger aviation	billion passenger km	TPT_AVI_INT
Transport	Passenger diesel rail	billion passenger km	TPT_RAL_PAS_DSL
Transport	Passenger electric rail	billion passenger km	TPT_RAL_PAS_ELC
Transport	Freight diesel rail	billion tonne km	TPT_RAL_FRT
Transport	Road passenger car (A/B segment)	billion vehicle km	TPT_CAR_B
Transport	Road passenger car (C/D segment)	billion vehicle km	TPT_CAR_CD
Transport	Road passenger bus	billion passenger km	TPT_ROD_PAS_BUS
Transport	Road freight HGV	billion tonne km	TPT_ROD_FRT_HGV
Transport	Road freight LGV	billion tonne km	TPT_ROD_FRT_LGV
Transport	Road freight MGV	billion tonne km	TPT_ROD_FRT_MGV
Transport	Maritime domestic freight	billion tonne km	TPT_MAR_DOM
Transport	Maritime international freight	billion tonne km	TPT_MAR_INT
Transport	Off-road agricultural vehicles	operating hours	TPT_OFF_AGR
Transport	Off-road medium articulated trucks	operating hours	TPT_OFF_CON_ATA
Transport	Off-road large articulated trucks	operating hours	TPT_OFF_CON_ATB
Transport	Off-road crawler excavator vehicles	operating hours	TPT_OFF_CON_CEX
Transport	Off-road wheeled excavator vehicles	operating hours	TPT_OFF_CON_WEX
Transport	Off-road medium wheeled loader vehicles	operating hours	TPT_OFF_CON_WLD

Table 9. The complete list of energy service demands in ESME [v4.0] for the Buildings and Transport sectors.

Sector	Energy Service Demand	Unit	Code
Industry	Sector I1 energy use for HTP	energy demand relative to 2010	IND_I1_HTP
Industry	Sector I1 energy use for Mot	energy demand relative to 2010	IND_I1_Mot
Industry	Sector I1 energy use for Oth	energy demand relative to 2010	IND_I1_Oth
Industry	Sector I2 energy use for HTP	energy demand relative to 2010	IND_I2_HTP
Industry	Sector I2 energy use for LTP	energy demand relative to 2010	IND_I2_LTP
Industry	Sector I2 energy use for Mot	energy demand relative to 2010	IND_I2_Mot
Industry	Sector I2 energy use for Oth	energy demand relative to 2010	IND_I2_Oth
Industry	Sector I2 energy use for SpH	energy demand relative to 2010	IND_I2_SpH
Industry	Sector I3 energy use for HTP	energy demand relative to 2010	IND_I3_HTP
Industry	Sector I3 energy use for LTP	energy demand relative to 2010	IND_I3_LTP
Industry	Sector I3 energy use for Mot	energy demand relative to 2010	IND_I3_Mot
Industry	Sector I3 energy use for Oth	energy demand relative to 2010	IND_I3_Oth
Industry	Sector I3 energy use for SpH	energy demand relative to 2010	IND_I3_SpH
Industry	Sector I4 energy use for DaS	energy demand relative to 2010	IND_I4_DaS
Industry	Sector I4 energy use for LTP	energy demand relative to 2010	IND_I4_LTP
Industry	Sector I4 energy use for Mot	energy demand relative to 2010	IND_I4_Mot
Industry	Sector I4 energy use for Oth	energy demand relative to 2010	IND_I4_Oth
Industry	Sector I5 energy use for DaS	energy demand relative to 2010	IND_I5_DaS
Industry	Sector I5 energy use for LTP	energy demand relative to 2010	IND_I5_LTP
Industry	Sector I5 energy use for Mot	energy demand relative to 2010	IND_I5_Mot
Industry	Sector I5 energy use for Oth	energy demand relative to 2010	IND_I5_Oth
Industry	Sector I5 energy use for SpH	energy demand relative to 2010	IND_I5_SpH
Industry	Sector I6 energy use for DaS	energy demand relative to 2010	IND_I6_DaS
Industry	Sector I6 energy use for HTP	energy demand relative to 2010	IND_I6_HTP
Industry	Sector I6 energy use for LTP	energy demand relative to 2010	IND_I6_LTP
Industry	Sector I6 energy use for Mot	energy demand relative to 2010	IND_I6_Mot
Industry	Sector I6 energy use for Oth	energy demand relative to 2010	IND_I6_Oth
Industry	Sector I6 energy use for SpH	energy demand relative to 2010	IND_I6_SpH
Industry	Sector I7 energy use for DaS	energy demand relative to 2010	IND_I7_DaS
Industry	Sector I7 energy use for HTP	energy demand relative to 2010	IND_I7_HTP
Industry	Sector I7 energy use for LTP	energy demand relative to 2010	IND_I7_LTP
Industry	Sector I7 energy use for Mot	energy demand relative to 2010	IND_I7_Mot
Industry	Sector I7 energy use for Oth	energy demand relative to 2010	IND_I7_Oth
Industry	Sector I7 energy use for SpH	energy demand relative to 2010	IND_I7_SpH
Industry	Sector I8 energy use for LTP	energy demand relative to 2010	IND_I8_LTP
Industry	Sector I8 energy use for Mot	energy demand relative to 2010	IND_I8_Mot
Industry	Sector I8 energy use for Oth	energy demand relative to 2010	IND_I8_Oth
Industry	Sector I8 energy use for SpH	energy demand relative to 2010	IND_I8_SpH
Industry	Sector I9 energy use for Oth	energy demand relative to 2010	IND_I9_Oth

Table 10. The complete list of energy service demands in ESME [v4.0] for the Industry sector.

5 Energy resources data

5.1.1 UK Biomass

Indigenous UK biomass, including energy crops as well as agricultural and forest residues.

Resource limit: The maximum available resource of biomass in ESME is a theoretical estimate of maximum UK production which would be economical and sustainable, and not displacing UK food production. The resource limit [v3.4] is based on scenarios from the ETI's Biomass Value Chain Model (BVCM). A large number of BVCM scenarios have analysed different crops, land availability and yield assumptions.

Emissions factors: The carbon content of the biomass resource plays an important part in the carbon budgets of ESME because the UK benefits from a CO2 emissions credit associated with the growth phase of the biomass. The growth-phase credit corresponds to 91% of the carbon content of the biomass, the other 9% being lost to emissions in processing, transportation or farming practices. The growth-phase credit [v4.2] and the carbon content [v4.2] are based on data from the ETI project *Ecosystem Land-Use Modelling* (BI2009).

Cost assumptions: The cost of the biomass resource [v1.0] is based on an ETI estimate of the production cost plus handling cost. Note that production cost is used, rather than market price, as an estimate of the net cost to the UK of the activity to produce biomass.

5.1.2 Biofuel Imports

Resource limit: Imported biofuel is constrained by a resource limit [v1.0] which is an estimate of the UK's `fair share' of global biofuels, based a *per* capita share of the 2050 global biofuel production in the IEA Blue Map scenario in *Energy Technology Perspectives 2010*, IEA 2010 (link).

Emissions factors: The carbon content assumption is that the CO2 emissions credit associated with the growth phase of the biomass covers 60% of the carbon content of the fuel, the other 40% being lost to emissions in processing, transportation or farming practices. The carbon content [v1.0] is based on ETI literature review.

Cost assumptions: The cost of biofuel imports [v1.0] is based on an estimate for the international wholesale market price. This is set at relative to future fossil fuel import prices in ESME, the cost premium being approximately 30%, an ETI assumption.

5.1.3 Biomass Imports

Resource limit: Imported biomass is constrained by a resource limit [v3.1] which reflects estimates of the size of the future global market and the proportion of the market accessible to the UK. The data is based on the *UK Bioenergy Strategy*, DECC 2012 (link) (the values in ESME are taken from the lower half of the DECC range).

Emissions factors: The carbon content assumption is that the CO2 emissions credit associated with the growth phase of the biomass covers 79% of the carbon content of the biomass, the other 21% being lost to emissions in processing, transportation or farming practices. The carbon content [v4.2] is based on data from the ETI project *Ecosystem Land-Use Modelling* (BI2009).

Cost assumptions: The cost of biomass imports [v3.1] is based on the medium scenario for international wholesale market price in the same report.

5.1.4 Liquid Fuel

The liquid fuel resource in ESME represents petrol, diesel and aviation fuel.

Emissions factor: [v3.1] is based on an average of values for petrol and diesel from *Digest of UK Energy Statistics*, DECC (link).

Cost assumptions: [v3.1] based on an average of the petrol and diesel prices in a 2010 literature review of fuel prices including DECC, IEA, EIA and CCC projections.

5.1.5 Coal

Emissions factor: [v1.0] is taken from *Digest of UK Energy Statistics*, DECC 2009 (link).

Cost assumptions: [v1.0] based on a 2010 literature review of fuel prices including DECC, Treasury and IEA.

5.1.6 Gas

Emissions factor: [v1.0] is taken from *Digest of UK Energy Statistics*, DECC 2009 (link).

Cost assumptions: [v3.0] based on the central gas price scenario of the *DECC Fossil Fuel Price Projections*, DECC October 2011.

5.1.7 Nuclear

The nuclear resource in ESME is measured in kWh of thermal energy released in the core of a reactor. 1kg of uranium corresponds to 1.1GWh of ESME nuclear resource based on 45,000 MWd/t burn-up of 3.5% enriched U in LWR, see *Heat Values of various fuels*, World Nuclear Association March 2010 (link).

Cost assumptions: [v3.0] based on a 2012 literature review of various price projections for uranium ore; processing costs from *Analysis of Uranium Supply to 2050*, IAEA May 2001 (link).

5.1.8 Dry Waste

The dry waste resource in ESME represents municipal, commercial and industrial waste, excluding agricultural and forest residues (which are treated as biomass).

Emissions factor: a biogenic content of 50% is assumed [v4.2] based on data from various ETI energy from waste projects.

Resource limit: [v4.1] based on data from the ETI Bioenergy programme.

Cost assumptions: [v4.1] based on ETI judgement on gate fees for waste.

5.1.9 Wet Waste

The wet waste resource in ESME represents food waste and agricultural & sewage slurries.

Emissions factor: wet waste is assumed to be carbon neutral.

Resource limit: [v4.1] based on data from the ETI Bioenergy programme.

Cost assumptions: [v1.0] based on ETI judgement and data from the ETI project *Energy from Waste* (DE2001).

5.1.10 Geothermal Heat

Resource limit: limits on geothermal resource by region are captured by constraints on the individual geothermal technologies, rather than by a limit on the resource product.

5.1.11 Hydro

The hydro resource in ESME is measured in kWh of electrical energy (hence all hydro technologies have a nominal efficiency of 100%).

Resource limit: [v1.0] based on technically feasible resource in *Scottish Hydropower Resource Study*, British Hydro Association August 2008 (link) and *England and Wales Hydropower Resource Assessment*, British Hydro Association October 2010 (link).

5.1.12 Wind

The wind resource in ESME is measured in kWh of electrical energy (hence all wind technologies have a nominal efficiency of 100%).

Resource limit: [v4.2] based on data from ETI's Offshore Renewables programme. Onshore wind resource limit [v1.0] based on *Quantification of Constraints on the Growth of UK Renewable Generating Capacity*, SKM June 2008 (link).

5.1.13 Solar

The solar resource in ESME represents solar irradiation energy (solar panels have different conversions efficiencies to produce hot water or electricity).

Resource limit: an ETI view on practical accessible resource [v4.1] based on twice the estimated total UK domestic roof area and using irradiation data from *Sustainable Energy – without the hot air*, Mackay (link).

5.1.14 Tidal Range

The tidal range resource in ESME is measured in kWh of electrical energy (hence all tidal range technologies have a nominal efficiency of 100%).

Resource limit: [v4.2] based on data from ETI's Offshore Renewables programme.

5.1.15 Tidal Stream

The tidal stream resource in ESME is measured in kWh of electrical energy (hence all tidal stream technologies have a nominal efficiency of 100%).

Resource limit: [v4.2] based on data from ETI's Offshore Renewables programme.

5.1.16 Wave

The wave resource in ESME is measured in kWh of electrical energy (hence all wave technologies have a nominal efficiency of 100%).

Resource limit: [v4.2] based on data from ETI's Offshore Renewables programme.