Energy system modelling in an uncertain world

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What is the ETI?

• The Energy Technologies Institute (ETI) is a public-private partnership between global industries and UK Government

Delivering...

• Targeted development, demonstration and de-risking of new technologies for affordable and secure energy

• Shared risk
What is the ETI?

System level strategic planning → Technology development & demonstration

Delivering knowledge & innovation
ETI Invests in projects at 3 levels

- **Knowledge Building projects**
  - Typically up to £5m, Up to 2 years

- **Technology Development projects**
  - Typically £5-15m, 2-4 years
  - TRL 3-5

- **Technology Demonstration projects**
  - Large projects delivered primarily by large companies, system integration focus
  - Typically £15-30m+, 3-5 years
  - TRL 5-6+
A national energy system design tool
Integrating power, heat, transport and infrastructure
searching for the lowest cost solution
Why do energy system modelling?

• Energy systems are subject to key decision points and path dependency; choices are long lived
• Energy systems are complex and inter-dependent, made more so by emissions reduction objectives
• Efforts to cut emissions are substitutable across power, heat, transport, industry and infrastructure
• ... but governed by well-understood physical laws, so quantitative modelling is capable of representing system interactions and capturing dynamics that would otherwise not be understood
ESME
A peer-reviewed national energy system design tool

Energy system design based on policy-neutral least cost optimisation

ESME is a central part of ETI’s energy system analysis

Insights from modelling are combined with evidence from technical experts

A view is taken on ETI “additionality” for all investments
Types of Debate that ESME is used to inform

• What might be ‘no regret’ technology choices and pathways to 2050?
• What is the total system cost of meeting the energy targets?
• What are the opportunity costs of individual technologies?
• What are the key constraints e.g. resources, supply constraints?
• How might accelerating the development of a technology impact the solution?
• How might uncertainty in resource prices and availability influence system design choices?
• Where should new generating capacity optimally be located?
• How might policies and consumer choices influence technology development?
ESME in use by ETI, its members and partners

- ESME developed to inform technology development choices and targets for ETI & members
- ESME used to inform policy work by DECC* and CCC+
- ETI Members are developing own versions for specific countries of interest
- ESME software licence available to academics for research projects.

* UK Government Department of Energy & Climate Change
+ Committee on Climate Change, a statutory UK body
Knowledge from across ETI programme areas is integrated in ESME
The ESME model and approach
The ESME modelling approach

- Least cost optimisation, policy neutral
- Deployment & utilisation of >250 technologies
- Probabilistic treatment of key uncertainties
- Pathway and supply chain constraints to 2050
- Spatial and temporal resolution sufficient for system engineering
Architecture Overview

Software Platforms:
- Microsoft Excel
- Microsoft SQL Server Express
- Aimms
- @Risk
- ESRI ArcView

GIS
- Mapping Tool

ESME GUI
- Control Interface
- Probability Simulations
- Technology Data
- Demand Data
- Product Specification

Optimiser
- Optimisation Engine

Database
- Data Storage

Global Parameters
- Results Manager
Typical ESME Outputs
ESME uncertainty analysis

- ESME is a Monte Carlo model
  - Ranges and probability distributions on uncertain inputs
  - Results are an ensemble of least-cost energy systems

- This effectively automates a large amount of sensitivity analysis
ESME uncertainty analysis

Examples of the assumptions used in ESME which are highly uncertain

1. Technology costs e.g. CCS power stations, Hydrogen Cars
   Cost improvement for novel technologies, efficiency improvements, safety, ...

2. Fuel prices e.g. gas price, oil price, imported biomass price
   International supplies, demand from other countries, shale gas, ...

3. Maximum UK resource for Biomass
   Sustainability questions, public acceptance, farmer acceptance, yields, ...
Electricity Generation Capacity (mean case)

Data 2014DC / Optimiser v3.4
Spread of ESME results for 2050 power capacity
Space heating results from ESME

Space Heat Production

TWh

2010 (Historic) 2020 2030 2040 2050

Ground Source Heat Pump
Air Source Heat Pump
Electric Resistive
Biomass Boiler
Gas Boiler
District Heating (detached)
District Heating (semi-det. & terraced)
District Heating (flats & apartments)
District Heating (commercial & public)
Heat demand variability in 2010

UK system has to cope with 6x heat demand swing
Existing gas distribution grid supports this

GB 2010 heat and electricity hourly demand variability - commercial & domestic buildings
R. Sansom, Imperial College
ESME space heating results: typical vs peak

GW

Typical summer day
Typical winter day
Peak demand day

-50 0 50 100 150 200 250 300 350

Ground Source Heat Pump
Air Source Heat Pump
Gas Boiler
Electric Resistive
District Heating (detached)
District Heating (semi-det. & terraced)
District Heating (flats & apartments)
District Heating (commercial & public)
Storage (water tank)
Sensitivity Analysis

Using the core ESME model:
• Monte Carlo results – ‘no-regret’ options, marginal choices
• 3 future UK demand cases – alternative socio-economic pathways for the UK
• Long list of “No technology X” sensitivities – opportunity cost metric
• Sensitivity to different CO₂ targets
• Sensitivity to improved/accelerated technology development

Beyond the core ESME model:
• Dispatch of the ESME electricity system is studied in PLEXOS
• More detailed buildings & heat optimisation
• More detailed peak day optimisation
Technology deployment
CCS appears a mainstay, offshore wind a critical hedge
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CCS appears a mainstay, offshore wind a critical hedge

- Increasing investment in transmission grid and backup power stations
- Overall annual utilisation of power stations drops from 60% to 40%
Using ‘opportunity cost’ to measure role of a technology in the system

Opportunity cost of technology X is defined by two alternative scenarios:

A. The least-cost energy system design using standard assumptions
B. The least-cost energy system design if technology X unavailable

Opportunity cost = Total Cost (B) – Total Cost (A)

= 0 if technology X is not present in the reference case (System A)

> 0 if technology X is present in System A.

Magnitude of the opportunity cost depends on the relationship between System A and System B: ‘substitution’ or ‘reconfiguration’
CCS and Biomass consistently have the highest opportunity costs
CCS is high value as it creates options
application of the same infrastructure for power, industry, enabling bioenergy usage and H2 production.

- ETI energy system modelling points to ‘energy system-wide’ value of CCS extending beyond low carbon electricity generation.

- Low carbon electricity from fossil fuels (DECC Demos).
- CCS with biomass (Drax programme).
- Gasification applications (ETI demos).
- CCS on industrial emissions (to follow).

- ‘Negative emissions’
- Flexible low carbon fuels (hydrogen, syngas).

- Enables continued use of fossil fuels where very expensive to replace.

- Low carbon energy diversity, portfolio of flexible low carbon energy vectors, option value & robustness in meeting carbon targets.
Potential implications for the UK...

Abatement costs

UK’s challenging 2050 CO2 target appears affordable with intelligent national energy system design and investment in technology development

Efficiency measures
waste heat recovery, building insulation, and efficient vehicles make a contribution under all emission reduction scenarios

*ETI targeting through SSH (£100m) and HDV (£40m) projects*

Nuclear
mature technology and appears economic under most emission reduction scenarios - primarily an issue of deployment (planning / licensing, supply-chain, finance etc)

*Cost impacts post-Fukushima need clarification – international approach needed*

Bioenergy
major potential for negative emissions via CCS and might include a range of conversion routes – H2, SNG, process heat

*ETI investing in science, logistics and value models*

Offshore Renewables
the marginal power technology and an important hedging option

*ETI investing in next generation, low cost, deepwater platform and turbine technology demonstrations*

CCS
a key technology lever given potential wide application in power, hydrogen and SNG (gas) production, and in industry sector

*ETI investing in separation, storage and system design – for coal, gas and biomass*

Natural gas
a key 2050 destination fuel for power, space heating, industrial process heat and potentially for heavy duty vehicle transport applications

*ETI addressing through SSH and HDV efficiency programmes*

Hydrogen
potentially important energy vector providing system flexibility (CCS and storage) and light vehicle transport applications

*ETI determining energy system flexibility benefits of using H2*
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