Developing a city energy modelling tool and approach

Nick Lomax
Energy Saving Trust
30 North Colonnade,
Canary Wharf,
London, E14 5GP
UK
nick.lomax@est.org.uk

Prof. Mark Barrett
UCL Energy Institute
14 Upper Woburn Place
London WC1H 0NN
UK
mark.barrett@ucl.ac.uk

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Abstract

The Energy Saving Trust and UCL Energy Institute have developed a new model, tool, and approach to assist cities in making energy planning decisions. As energy systems become more devolved and less centralised, cities will play an increasingly important role in defining energy infrastructure. Decisions relating to energy consumption and generation are also becoming more complex and often involve multiple stakeholders with varying, and sometimes conflicting, objectives. SiCEDS – the 'Stakeholder interactive City Energy Demand Simulator' – allows city stakeholders to produce, share and understand the impact of decisions on a variety of outputs. The model includes the energy consumed and generated by domestic and commercial buildings in a city. The initial model has been piloted in Birmingham and Exeter, with funding from InnovateUK.

The SiCEDS tool allows stakeholders to build scenarios by altering a variety of inputs including:

- the future energy efficiency mix of buildings
- the source of heat for buildings
- the volume, modal split and power of transport
- the level and efficiency of local generation

The SiCEDS tool will then produce outputs for the city across a time horizon to 2050. These outputs include the overall level of energy demand, the level of CO_2 and NO_X emissions, the peak demand on the grid and the level of fuel poverty.

The outputs can be viewed in time series charts, maps and exported as tables for further analysis. The process that has been developed alongside the tool is designed to allow stakeholders to efficiently develop and collaborate on different scenarios. Stakeholders could include local authority planning, development and energy officers, private developers, community energy companies, landowners, planning consultants and others.

The aim of the approach is to improve the efficiency with which different local energy and transport demand scenarios can be generated and shared. The approach has been demonstrated in the cities of Birmingham and Exeter and can now be rolled out within other cities globally.

Introduction

Cities and Local Authorities have to manage and plan for increasingly complex, and often competing, drivers and outputs. Cities must strategically plan for a growing population, changes in demographics, changes in travel and changes in the energy system. A key challenge for cities is in understanding the impact of different strategic options on their stakeholders, infrastructure and target outcomes. For example, a policy to encourage electric vehicle usage could support an air pollution reduction strategy but what would the impact be on the carbon outputs or energy requirements of a city? A forecasted increase in population could require a city to consider either setting policy to encourage a new development in one particular area of a city or to encourage development across the city through 'infilling' existing buildings. Again, they will need to consider the impact of these approaches across a range of different outputs and targets – transport needs, CO_2 emissions, air pollution, energy requirements and fuel poverty.

The current approach to developing strategic plans in cities is complex and time consuming. Multiple consultants are used to generate evidence bases that are used to analyse options. Often these evidence bases and initial plans focus on one particular area or output such as energy, transport or affordable housing. Once the plans have been developed they are subject to extensive consultation and conflicts between them are often found.

It is against this background that the Energy Saving Trust and UCL Energy Institute began to explore how a city energy modelling tool could contribute to the city planning process. A feasibility study was completed in 2014 with the aim of understanding how such an approach could add value to the planning process and whether there would be demand for it. The feasibility study identified that a modelling approach could add value to the strategic planning process in a city and it also provided high level requirements for the tool:

- Decisions on energy infrastructure impact and are impacted on by multiple stakeholders. Currently, different policy themes (e.g. energy infrastructure policy, fuel poverty policy, transport policy) are often analysed in isolation. The tool should provide a consistent methodology and allow comparison of scenarios.
- Policies are currently supported by evidence bases that are often produced by consultants. The tool should enable planners to generate more of the implications of policies internally with reduced reliance on consultants. This should reduce cost and improve the speed and efficiency of policy development.
- Accessibility to finance is unlocked by policy certainty and clarity of a development opportunity. The tool should include an ability to generate business cases for different investment options. Costs of different scenarios will be compared by modelling the capital investment, ongoing maintenance and servicing costs and fuel costs.
- Reducing levels of funding within local authorities are resulting in reduced levels of human resource and sharing of resource between local authorities. The tool should provide a consistent approach to enable resource sharing. For example, the tool could be shared and centrally coordinated for a number of neighbouring local authorities.

Following the feasibility study the development of the tool itself began in April 2015. The tool and approach is referred to as the Stakeholder interactive City Energy Demand Simulator – SiCEDS. The initial development has been carried out with the cities of Birmingham and Exeter in the UK. The approach has been informed by feedback and insight gained from a range of city stakeholders including sustainability and planning officers, developers and consultants.

Objective and approach

The objective of the SiCEDS tool is to aid city energy and environment planning and implementation by allowing stakeholders to produce and compare different energy scenarios and to develop them in a collaborative manner. A high-level outline of this process is:

1. Agree on current policy baseline
2. Identify problems and policy aims
3. Stakeholders explore different policies aided by the SiCEDS tool
4. Stakeholders collaborate to develop policies that most effectively meet the policy aims
5. The outputs are used to gain political and wider acceptance and buy-in

This process could be facilitated through a forum where different assumptions about future changes to the city in scenarios can be made and the energy, economic and other impacts can be modelled.

Modelling approach

The SiCEDS modelling process begins by the user developing a scenario, normally starting with a base scenario that matches current 'business as usual' policy. There are three main areas where users can modify scenarios: stationary demand (mostly buildings), transport and supply (electricity, gas, district heat). The model covers all energy demand in the city, including domestic, commercial and industrial consumption. The user can then develop scenarios by modifying the inputs to understanding the impact on different outputs.

The overall model structure is shown below. The calculations for each year modelled follow this sequence:

1. Calculate the spatiotemporal energy service needs of the stationary and transport sectors.
2. Model the transport demands, modal and technology shares.
3. Allocate heating methods of stationary consumers to the different possible vectors and technologies (gas, electricity,

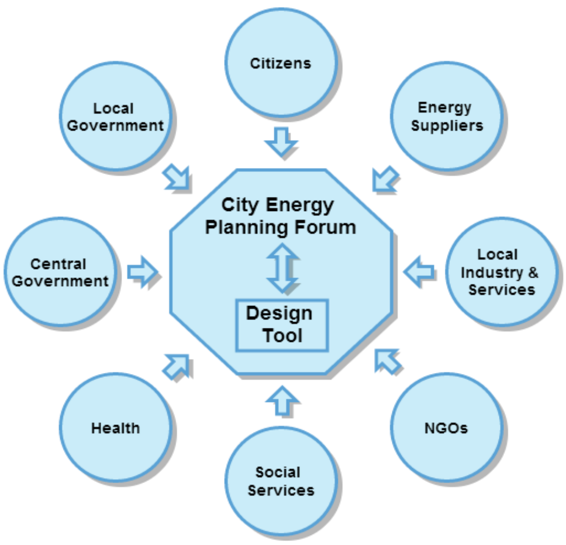

Figure 1. SiCEDS collaborative planning approach.

Table 1. Inputs and outputs of the SiCEDS model.

Inputs	Outputs
Existing stationary demand • Energy efficiency performance mix • Source of heating **New stationary demand** • Number of new build properties • Energy efficiency performance of new buildings • Source of heating **District heating** • Heat load density threshold • Proportion of heat delivered • Heat supply mix **Local generation** • Solar PV penetration • Efficiency of solar PV **Transport** • Modal split • Load factor • Technology split	**Delivered energy** • Delivered energy by end use **Generation** • Amount of locally generated PV and CHP energy **Emissions** • CO_2, NO_x and PM2.5 **Transport** • Distance by mode • Energy/fuel used **District heating** • Energy delivered through district heating **Air pollution and health** • Excess deaths and years lost resulting from air pollution **Cost** • Fuel and infrastructure costs **Fuel poverty** • Number of fuel poor households **Impact on electricity network** • Daily electricity profile

district heat, CHP) and calculate energy deliveries accounting for consumers system efficiencies (boilers, HPs, etc.).

4. Model the district heating scheme designs and operations. This gives additional consumption and generation.
5. Model the electricity system including consumer and public heat CHP, solar PV, other generators, and network peaks and losses.
6. Use national energy prices and infrastructure costs to calculate delivered energy costs.
7. Delivered energy costs are used with income and housing costs to estimate fuel poverty.
8. Use air pollution emissions to estimate concentrations and health impacts.
9. Results are output.

MODEL GRANULARITY AND BASE DATA

The underlying base data behind the buildings data model is formed from individual property level data sets. In order for the model and outputs to be manageable these buildings are assigned to archetypes.

The model can be run at a three different geographic levels: Middle Level Super Output Area (MSOA – average population of 7,200), Lower Level Super Output Area (LSOA – average population of 1,500) and 1 Km grid square.

The approach to modelling heat demand can be used as an example of how the tool uses archetypes to generate outputs. The basic driver of city heat demand is people and the services they require. The amounts of heat used also depend on technologies employed, particularly buildings, and heat demand depends on the efficiencies of these. The policies for efficiency - particularly relating to building efficiency - and heat supply are therefore interlinked. The spatial distributions of populations and buildings can be combined with the archetypes data to calculate energy service demands by the three geographic levels outline above.

The data behind the current model is from the same source for both Birmingham and Exeter. It is expected that cities may want to use their own data, for example on planned or imminent developments. A process for importing the local data to the model will be developed when the tool is rolled out to other cities. On deployment in a new city the base assumptions for population growth, current heat strategy, current transport expectations etc will need to be set-up within the model inputs.

Tool user interface

The key challenge when developing the user interface has been ensuring it is practicable in terms of the data input required, the ease and speed of running the model, and the volume and utility of results. The development approach taken and potential future developments are discussed below. A challenge identified in the feasibility study and subsequent discussions was the difficulty of different stakeholders using different computer systems and also the challenge of Local Authority staff installing third party software on their computers. The user interface has therefore been designed to work directly within an internet browser without requiring the installation of additional software.

INPUT OF SCENARIOS

As outlined above the SiCEDS tool can model scenarios from a large range of inputs for each year between 2015 and 2050. This flexibility is useful when trying to recreate policy scenarios in the model but risks complexity in the set-up of scenarios. During discussions with city stakeholders it was felt that a number of 'super-users' within a city will set-up and modify scenarios. The outputs of the scenarios will then be reviewed and discussed by a wider group of stakeholders. An open spreadsheet platform – Google Sheets – has been used for 'super-users' to create different scenarios. The users can modify the inputs outlined above for different years between 2015 and 2020. Once the scenario has been set-up for the different types of input by the 'super-user' they can be selected by other users on the main SiCEDS interface.

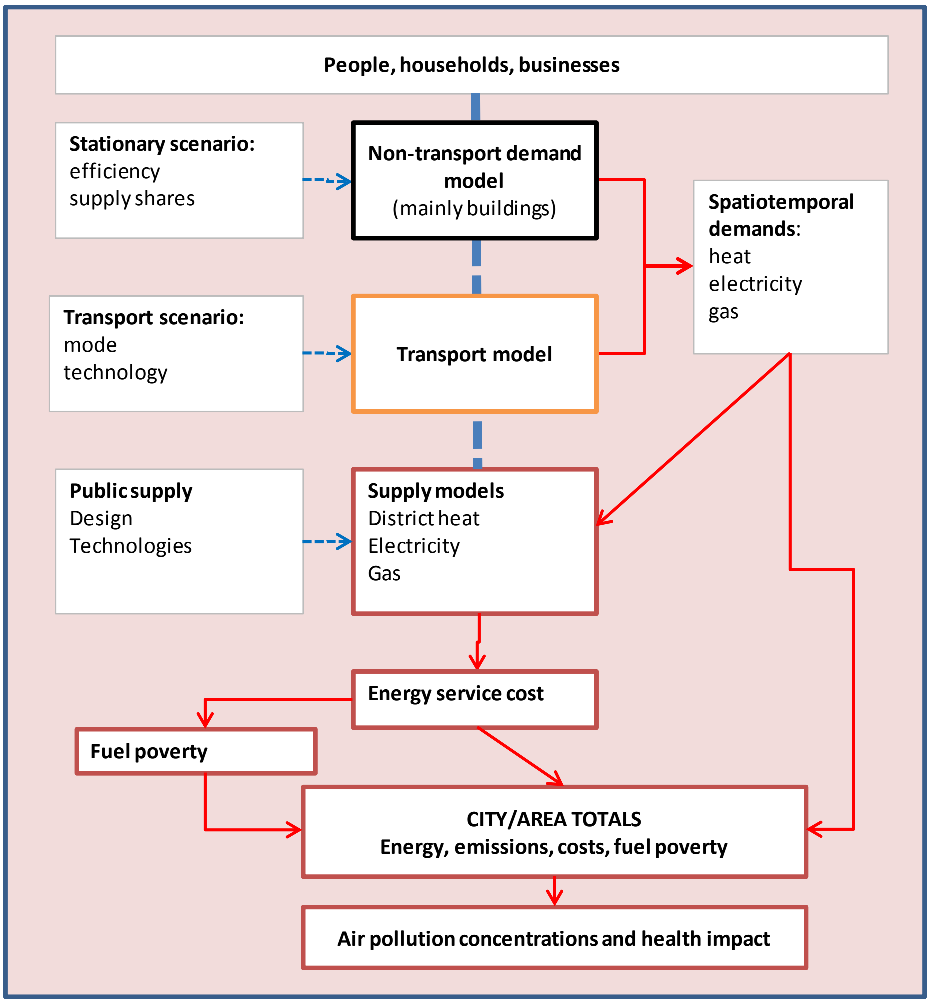

Figure 2. SiCEDS model flow.

DISPLAY AND ANALYSIS OF OUTPUTS

The outputs of the SiCEDS tool can be viewed in time series charts and maps and can be exported as tables for further analysis. For each of the output themes, outlined in Table 1, a user can view how the output for the scenario changes across time and space. They can also analyse or split the data in different ways, for example by only looking at domestic energy consumption or by cutting the data by another subset.

Testing and evaluation

Owing to the ambitious scope and technical challenges of the SiCEDS project, the model has considerable complexity and treads new ground in terms of energy systems modelling. It is essential that the methodologies and data that it uses are peer-reviewed and can be relied upon by users to provide robust results ('can the results be trusted?'). Testing is also required of the presentation of the results in the GUI ('is it engaging?'), the deployment of this as a commercially viable and reliable product ('can it be broken?'), and the clarity and practical usefulness of the results which it can provide potential users ('is it practically useful?').

A test plan has been developed that includes testing by the developers (internal), the wider project stakeholder group (internal), and external peer review and user testing. Rigorous internal testing is essential to ensure that project outputs are of a high quality before they are seen by stakeholders. Whilst undertaking external testing during the development process provides creative input, mitigates the effect of "group-think" amongst the development team, and will help to highlight the areas with most commercial and practical value.

REVIEWING THE MODEL OUTPUTS

The outputs of the final version of the model will be compared with:

- outputs from earlier prototype versions of the model.
- alternative real-world estimates, projections and observations

This element of evaluation is currently taking place at the time of writing. A future updated draft will include a summary of the outputs of the evaluation.

ASSESSING USER ENGAGEMENT

Testing the tool, predominantly with stakeholders from within Birmingham and Exeter, has provided further feedback on how this approach could be used and further developments that may be necessary.

Example use cases:

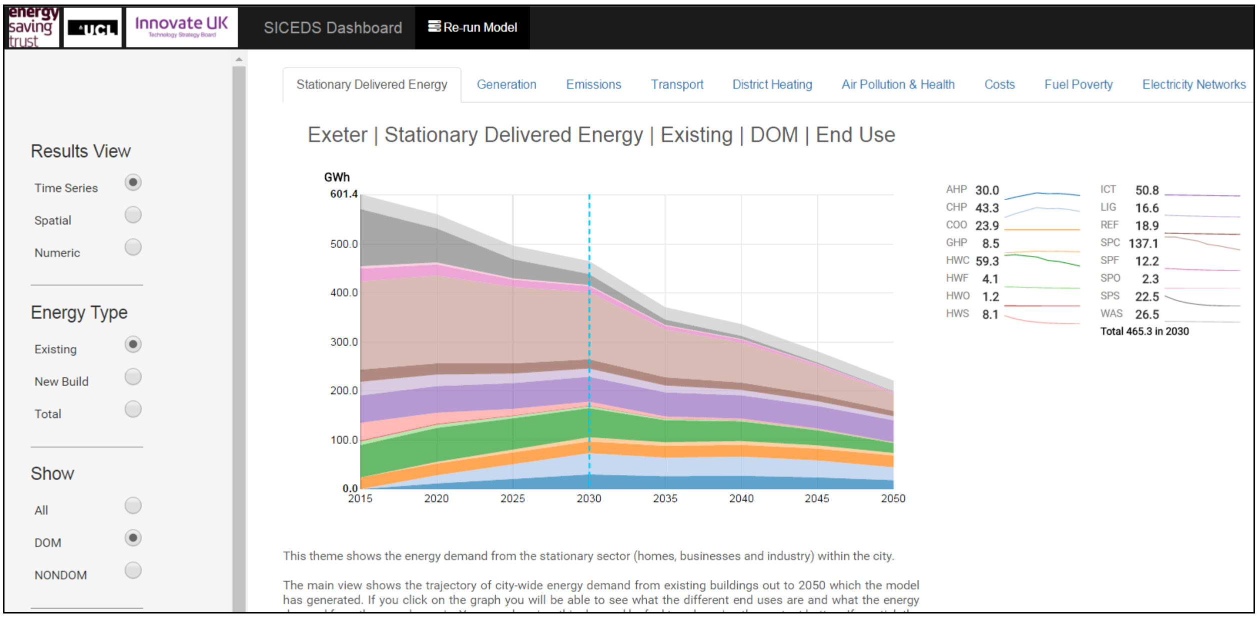

Figure 3. SiCEDS tool time series output view.

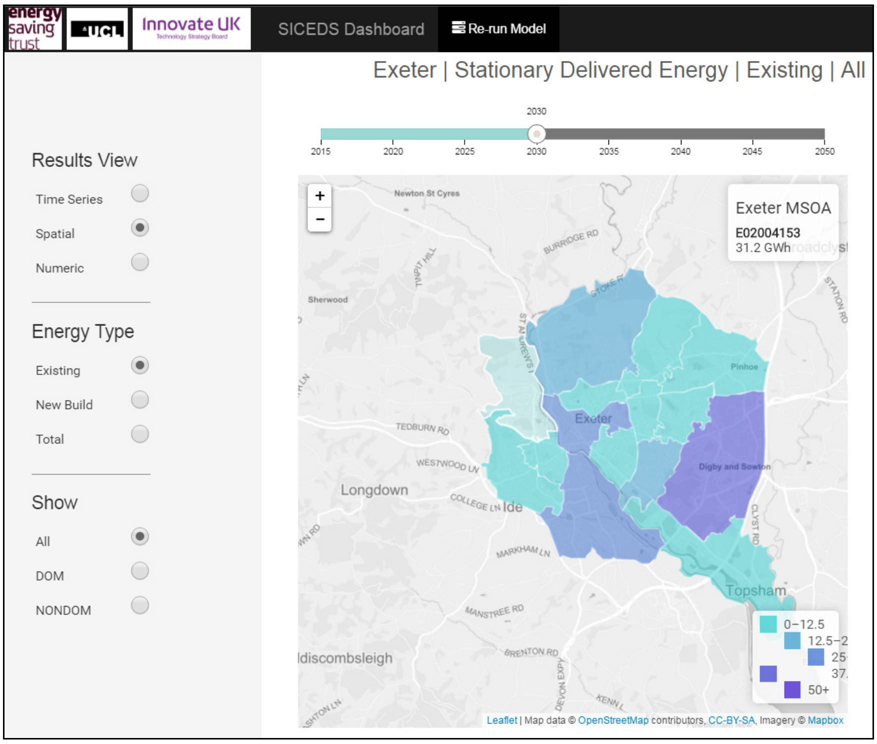

Figure 4. SiCEDS tool spatial output view.

Transport options – Stakeholders in Exeter are interested in exploring how the different transport policies they influence could help to reduce air pollution. They set-up three different scenarios to compare to a base case. The first scenario looked at increasing the proportion of electrically driven taxis in the city, the second looked at increasing the proportion of electric buses, the third looked at a modal shift from private vehicles to active travel, such as cycling. The stakeholders were able to understand the likely level of impact that the three different options could have on air pollution. They were also able to understand the impact of the increase in electric vehicles on the electricity consumption within the city.

Development options – Stakeholders in Exeter wanted to compare a scenario of dispersed small development across the city with another scenario of more concentrated development in one area. Within the current tool the user can only input growth scenarios at a city level, the new buildings are then assigned across the city. This type of scenario comparison therefore requires further development to allow new developments to be located spatially by the user.

A key area for development identified through the testing process is the need for scenarios to be compared within the tool itself. The current user interface allows one scenario to be run at a time and results to be exported for comparison across different scenarios. A future development will allow model runs to be saved in order to reduce the run-time of the model and to allow the outputs of previous scenarios to be compared with current scenarios.