



**Modelling energy use in the
global building stock:
a pilot survey to identify
available data sources**

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This is the final report from Tyndall research project T3.11 (Modelling energy use in the global building stock – a pilot survey to identify available data sources). The following researchers worked on this project:

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Tyndall° Centre

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Section 1 Overview of project work and outcomes

Non-technical summary

Highly detailed data about energy use in the UK reveals that about half of the energy used here, together with the resulting emissions of greenhouse gases, is associated with buildings – for heating, lighting, cooling, domestic appliances, business equipment, and so on. Similar findings are anticipated in most industrialised countries. It is therefore essential to include data about the building stock and its energy characteristics in global economic models. This six-week pilot project sought to identify sources of information about the building stock so as to assess the resources needed to build a database of global building stock data that could be used *inter alia* in the E3MG global economic model which is being developed as part of the Tyndall Centre's ETech+ project 'Technology policy and technical change, a dynamic global and UK approach'.

Extensive use was made of the internet for locating data, using a variety of search terms. We began searching for sources of international data on both energy use in buildings and the building stock. If data could be found at this level, there would be no need to continue searching at the regional or national level. Valuable data were located, particularly for residential buildings held by the UN Statistics Division. However, few data were found for non-domestic buildings. The internet search was then continued at the regional level – with the world divided into four regions - USA, Europe, China, and the Rest of the World. Excellent data exists for the USA. The quality of data is more varied in Europe, though at its best it is excellent. Data on the Chinese building stock is published annually as part of the Chinese National Statistics and a 'China Energy Group' in the USA publishes a sourcebook of energy statistics. The availability and quality of data for the Rest of the World varies widely from country to country; broadly the more developed the country the better the information. Gathering data for this region would be the most time-consuming and problematic.

Objectives

The objectives of this short intensive pilot study were:

- to identify what data exists internationally about the size and nature of the global building stock and its energy use characteristics
- to identify the rates of change of the building stock
- to identify the rates of change of its energy use characteristics
- to identify sources of information from which these data may be gathered, including centres of expertise and research teams active in the area

- to identify the resource implications of building a database of the global building stock

Gathering the data and analysing it was deliberately excluded – these activities are the subject of a follow up proposal and project.

Ultimately, the preparation of data for the global building stock will feed in to the Tyndall Centre's Research Theme 1, concerned with the impact of human activities on climate change, and specifically the E3MG economic model in the ETech+ project. This global economic model, which focuses on the EU, USA and China, (and is being developed by the Department of Applied Economics at Cambridge and CROMTEC at the UMIST School of Management) will benefit from data on the building stock and its rate of change. This knowledge will help ensure the model provides a useful comprehensive picture of how global energy demand is changing.

Work undertaken and results obtained

Fionna Holdsworth was appointed as the Research Assistant. She is a Cambridge graduate and architect who has worked for Cambridge Architectural Research recently as a researcher. She was engaged for the period 21 July 2003 to 31 August 2003. One of the Martin Centre Research Associates – Dr Runming Yao - was in China on another project and was able to acquire some information about Chinese building stock data. This pilot was carried out systematically and with excellent records of the outcomes of the internet searches; the project has been extremely successful in meeting its objectives. Tables of the search results have been compiled, listing the websites visited, the organisations that have data, names of any individuals contacted, and details of the datasets and/or publications that are available. A list of the contents of these tables, which are in the form of appendices, is provided at the end of Section 2 - Technical Report. All the appendices are available on CD, though they are not being provided in hardcopy form as part of this report since they are very extensive.

Relevance to Tyndall Centre research strategy

The Tyndall Centre's Research Theme 1 is concerned with Integrating Frameworks - bringing together, advancing and organising climate change information to explore the effects of different choices on future social, economic and climatic conditions. The Centre is taking a lead role in developing a next generation Community Integrated Assessment Model (CIAM) which will ultimately bring together climate models, socio-economic models, models of technological change, transport models, models of social behaviour and decision making, hydrological models, agricultural models, and models of climate change impacts such as biome shifts, human health and extreme weather events. One of the core elements of the CIAM is a macroeconomic model, to enable the simulation of climate change policy and its effects. The economic component of this system will be led by the E3MG model, under development in the ETech and ETech+ projects. This is both multi-national (because climate change is a global problem and therefore an international policy issue) and multi-sectoral (because different industrial sectors have different responses to climate change policies.) In industrialised countries, approximately 50% of energy is used in buildings – household and commercial – so in order to model energy use and GHG emissions, an understanding of the energy used in buildings and the growth of urbanisation are essential. The project has demonstrated that, for the E3MG regions (EU, USA and China) data is available to include a quantitative assessment of energy use in buildings. Therefore, it is feasible for E3MG and hence CIAM to consider long term developments in energy use internationally.

Potential for further work

The obvious further work from this pilot is to actually compile a dataset containing:

- The number and size of both domestic and non-domestic buildings globally
- The rate of increase of buildings
- The energy use characteristics of buildings
- The rate of change of energy use in buildings.

All these are necessary to ensure global economic models contain the most up to date knowledge

about the building stock. In Section 2, we outline the resources needed to collect, collate and analyse and interpret the data at the level of the four global regions. We believe that a research assistant would require six months to prepare a well-founded database containing this information, including collation and analysis. Much of the data is available without charge, but some modest funds would be needed for purchasing certain data sets.

Section 2 Technical Report

Background and objectives

About half of the energy used in the UK, together with the resulting emissions of greenhouse gases, is associated with buildings. A similar relationship almost certainly occurs in most other countries. Data about buildings and their associated energy use are therefore vitally important in any study of global climate change. Energy use in buildings arises from heating, artificial lighting, ventilation, cooling, and air conditioning, together with other end-uses linked to the operation of the building such as cooking, domestic appliances and business equipment.

To build a global model of energy use (including future projections) associated with buildings data is required about the nature and size of the building stock globally, together with regional growth rates, regional energy uses associated with buildings and rates of change of energy use. With this in mind the aim of this short pilot study was to identify what data exists about the global building stock, its energy use characteristics, and rates of change of both buildings and their energy use. The study concentrates on grouping the building stock into four main regions – the USA, Europe (original 15 members), China and the Rest of the World.

Ultimately, any data collected as part of a future project will feed into the Tyndall Centre's Research Theme 1, concerned with the impact of human activities on climate change, specifically the E3MG model in the ETech+ project.

Search methodology

The search for data started at the international level – if data could be found at this level then there would be no need to carry out the more time-consuming search at a regional and national level. However, these more detailed searches were needed.

The internet, now a major source of information, was the main search method used.

Organisations known to be likely sources of data were located using a name search on the internet; and any relevant data found was recorded¹. Further useful websites became apparent during this exercise – these were investigated and relevant data recorded.

'Identifiers'², related to energy and buildings as well as geographical area, were used as the main method of searching the internet³. Interesting websites were saved as 'favorites' and relevant data sources recorded. Any organisations found to be involved in the study of either building stock or energy consumption in buildings were recorded for future reference⁴.

Direct contact was made with those known to be involved in the study of energy and buildings and others were contacted as a result of the internet search in the hope that they would be able to suggest additional sources of data or further contacts⁵.

¹ Data from the search is recorded in Appendices A-E.

² Only English 'identifiers' were used during the search.

³ See Appendix F for the list of 'identifiers' used. The list is not exhaustive, further searches could be carried out given more time.

⁴ See Appendix G for a list of potentially useful research teams.

⁵ See Appendix H for a list of those contacted and resulting correspondence.

In addition Dr R Yao, due to be in China on another project, was able at minimal cost to the project to identify what data was available in China⁶.

Existence of appropriate data sources

The following section outlines the data found for the global building stock and its energy use characteristics. It begins at the International level and then covers each of the four regions: the USA, Europe, China and the Rest of the World.

International Data⁷

Little data was found detailing the energy used in residential and non-residential buildings. However, data was found on both energy consumption and the building stock, and is of use.

i) Energy characteristics

The main sources of energy data at an international level are the UN Statistics Division, the International Energy Agency (IEA) and Enerdata⁸. Data held by these organisations, the World Resources Institute (WRI) and the Energy Information Administration (EIA) are categorised by sector only and do not breakdown consumption into process and end-use energy. Generally the residential data is separated from other sectors though it is sometimes grouped with the commercial/ services sector.

The data found covers a number of years and a wide range of countries (though with varying degrees of completeness) and could be used to estimate trends in energy consumption globally. The data could also be used to form the basis of an approximation of the energy use for both residential and non-residential building stock⁹. For a more precise understanding of the energy use within buildings this data would need to be looked at in conjunction with data at an area or national level.

ii) Building Stock

The UN Statistics Division (UNSD) is the main source for internationally collated data on the residential building stock. The 'Compendium of Human Settlements Statistics 2001'¹⁰ covers 243 countries and includes 'housing' as one of its five main sections.

The UNSD also lists the dates for recent country level housing and population census¹¹ and gives web-links to some of this data¹². It is worth noting that some countries have only carried out population surveys and have not included housing surveys in their census.

Another potential source of information on the residential building stock is Habitat (UNCHS) in its book 'Cities in a globalizing world – global report on human settlements 2001' which contains several tables on households and dwellings for a wide range of countries though this is not complete and does not give a straight forward count of the residential building stock. The data in these tables is from the UN Human Settlements Statistics Questionnaire 1999.

No data was found at the international level for non-residential building stock though some useful information on the number of establishments and employees might be found in the IEA's 'Industrial Structure Statistics' and 'Structural Statistics for Industry and Services'.

⁶ See Appendix I for her findings.

⁷ Potential International data sources are listed in Appendix A.

⁸ Enerdata sources of data include the UN and the IEA.

⁹ See Appendix H for correspondence with Mr L Schipper formerly of the IEA.

¹⁰ A similar Compendium is also available for 1995.

¹¹ This list covers census from 1984 to 2000.

¹² A list of the countries covered by the UNSD can be found in Appendix J.

USA¹³

i) Energy characteristics

There is a good level of data available for the US on energy-use in both residential and non-residential buildings. The main sources found were the Energy Information Administration (EIA) and the Lawrence Berkeley National Laboratory (LBNL).

For residential building stock the EIA data gives energy consumption by end-energy use. It also carries out the 'Residential Energy Consumption Survey' (RECS) periodically, collecting data on the energy consumption in buildings as well as their characteristics for a representative sample of US households. It also carries out Energy Consumption Surveys on a representative sample for both commercial and manufacturing sectors. The surveys are entitled 'Commercial Buildings Energy Consumption Survey' (CBECS) and 'Manufacturing Energy Consumption Survey' (MECS) respectively.

The LBNL, a research group based in California, is very active in all aspects of the energy field. Its 'Residential Energy Databook' includes information on the end-energy use of appliances, the thermal characteristics of housing and baseline housing stock. The LBNL have also carried out a study into the end use characteristics of commercial buildings, entitled 'Energy End-Use Data for Commercial Buildings', which contains detailed tables.

ii) Building Stock

The US Census Bureau is the best source for residential building stock data. They hold data collected during the 'American Housing Survey' and the 'Decennial Housing Census' under the sub-section 'housing' and includes historical data. The Manufacturing, Mining and Construction Statistics division of the Census Bureau holds information about new housing construction and characteristics.

The sources already described for the energy use in non-residential buildings also include some information about the non-residential building stock.

Data from all these major sources covers a number of years (some include forecasts) and will be useful in the assessment of trends in the energy consumption and building stock in the USA.

Europe¹⁴

i) Energy characteristics

There is data at a European level for the energy use within residential and non-residential buildings. Sources of data found comprise EUROSTAT¹⁵, the European Environment Agency and the 'Odyssey Project' managed by Enerdata¹⁶. Initial searches show that for residential and service industry building stock end-energy use data exists, as well as energy use by sector.

In addition to these European sources some data exists at a national level, though its quality varies from country to country¹⁷. For the energy use in non-residential buildings data is likely to only be held for a sample or part of the total stock.

¹³ Potential data sources for the USA can be found in Appendix B.

¹⁴ Potential data sources for Europe can be found in Appendix C.

¹⁵ EUROSTAT: is the statistical office of the European communities

¹⁶ ENERDATA: is a private company that specialises in 3 areas. 1. Information systems on energy, 2. Consulting on energy management, forecasting and demand, and 3. Training

¹⁷ At the time of writing data sources for all 15 countries had not been found, but energy data is likely to exist in some form for all. This difference in quality of data will be transferred to any of the European level data sources.

ii) Building Stock

Both Enerdata in its ‘Odyssey database’, and the UN Economic Commission for Europe (UNECE) in its ‘Human Settlements database’, hold data at a European level for the residential building stock¹⁸. These sources may also contain limited data on non-residential building stock but further investigation would need to be carried out to see if this were the case.

As with the energy use in residential buildings, data for residential building stock is also held nationally. The quality of data held at national level is, in general, of better quality than for energy-use, though it still varies between countries¹⁹. The data is usually held by the National Statistics Offices²⁰. In some cases further research has been done on the national building stock, such as the UK.

Many countries have records of buildings authorised and completed. These look likely to be a possible source of information for the non-residential building stock. Some countries, such as the UK, have carried out more extensive research into their building stock and have used the property tax system to identify the non-residential building stock.

China²¹

i) Energy characteristics

Data and studies on the energy characteristics of China’s residential and non-residential buildings are available. The ‘China Energy Group’ of the Lawrence Berkeley National Laboratory (LBNL) in the USA has carried out a number of studies in conjunction with Chinese partners. It has produced a sourcebook detailing the Energy Statistics available and includes commentary on the strengths and weaknesses of this data.

ii) Building stock

The main source of data on China’s building stock, both residential and non-residential is from the Chinese Government. This data is only in paper format and is best collected by someone who is familiar with the country and language. The data available looks to be adequate for the proposed economic model.

Rest of World²²

As is suggested this region includes every country not included in the previous three. Covering a wide geographic area, numerous climatic conditions and a variety of economic situations it will not be surprising that the availability and quality of data varies greatly. Due to the tight time constraints of this pilot study it has not been possible to look at all the countries included in the ‘rest of the world’ as they number over 200. Where websites were found that might be of use they were recorded as ‘favorites’, however only a few have been investigated in detail. Of the many developing countries only India was studied in any depth²³.

i) Energy characteristics

Data on the energy use within buildings for developed countries such as Canada or Australia is equivalent to that found in Europe but data for developing countries such as the Democratic Republic of the Congo and Cuba is scarce and of limited reliability.

A brief search was carried out on the internet to see what information was available on the energy

¹⁸ In general the European sources of data include additional countries to the original 15 member states, such as Norway.

¹⁹ Data sources for all 15 countries had not been found at the time of writing. However it is likely that these exist.

²⁰ A list of the National Statistics Offices found on the UN website can be found in Appendix K.

²¹ Potential data sources for China can be found in Appendix D.

²² Potential data sources for the ‘Rest of the World’ can be found in Appendix E.

²³ India was chosen as an example because its population forms a significant percentage of the world’s population.

characteristics of India's building stock. The search highlighted several interesting projects and potential data sources for both residential and non-residential buildings. The best sources of data look to be the Energy and Resources Institute (TERI) and the Centre of Energy policy and economics - Swiss institute of federal technology (CEPE).

ii) Building stock

Data on the residential and non-residential building stock for developed countries such as Canada or Australia is equivalent to that found in Europe. It is likely that better data exists for the building stock of developing countries than for energy use.

A brief search of the internet was carried out for India's Building Stock. The last census contains data on the residential building stock, but no information was found for the non-residential building stock.

Resource implications for compilation of a global data set

This section outlines the resources required to collect the data for the economic model. It looks at each region in turn and discusses the accessibility and cost of the data. It goes on to summarise the costs involved and estimates the time required to collect, collate, analyse and report on the data.

International data

In general the international data found can only be accessed once the data has been purchased or a subscription to the relevant database has been made. Detailed prices for each database (where known) is given in Appendix A. Data are available in a number of media, with most of the datasets being available in some form of electronic media as well as in paper.

USA

Data is most complete for the USA and though minor gaps can still be found, the data available should enable reliable figures to be used as inputs into the economic database. The organisations that have been identified as holding data for the USA are listed below. Short notes are given for the accessibility and cost of the data from each organisation.

| Organisation | Accessibility | Cost |
|--|--|--|
| Energy Information Administration (EIA) | Good data available on the web www.eia.doe.gov . Data comes in a variety of electronic formats, including Excel spreadsheets. Contact names given on website. | Data available on the web is free |
| Lawrence Berkeley National Laboratory (LBNL) | Databooks available as downloadable PDFs. Raw data would need to be sourced from the LBNL directly. Contact names given on website. | Data found on the web is free. Other data may cost. |
| Census Office | Most data is available as downloadable PDFs – though these are of scanned documents. Paper copies are also available for order. | Data downloadable from the web is free. Paper versions and data as Excel spreadsheets need to be purchased. A subscription service is available for 'Construction Reports in print', cost varies depending |

| | | |
|--|--|--|
| | | on what is included in the subscription. |
|--|--|--|

The quality and apparent accessibility of the data at a national or area level for the USA suggests that it would be sensible to use this data over and above the cruder international data that is available.

Europe

Data at a European level reasonable for all areas except the non-residential building stock.. Better data can sometimes be found at a national level. In general the data found should give, with some extrapolation, reliable enough figures to be used in the economic model. The organisations that hold data at a European level are listed individually in the table below discussing accessibility and cost – National Statistics Offices are grouped into one category.

| Organisation | Accessibility | Cost |
|---|--|---|
| EUROSTAT | Data is available in either one, or both of the following formats: paper or PDF. The website includes a section entitled 'Data shop services' which explains how to order any documents required. Yearly subscriptions to the database are available. | Some basic data that is not very relevant to our study is free to download. Other data must be purchased. |
| European environment Agency (EEA) | Factsheets on energy consumption are available as PDFs www.eea.eu.int . Underlying data not known or found during project. | Free factsheets. |
| ENERDATA | Data from the Odyssee project is available on a CD-Rom. Application form on website. | Subscription for a University is EUR 700 (exc VAT), and EUR 1400 (exc VAT) for a commercial organisation. |
| Statistics on line Europe and North America (UNECE) | Access to Human Settlements database through search criteria on line. Contact with the Environment and Human Division via a link from the site. | Data free from website. Other data may be available, but is unknown. |
| National Level data | Often via National Statistics Offices – all have websites. Quantity and quality of data available varies. Data for all countries not found during search – but is likely to exist somewhere. Data can be in PDF, Excel or paper. Most have data in own language, with some key statistics in | Data sometimes free, sometimes through subscription or other payment method. |

| | | |
|--|---|--|
| | <p>English.</p> <p>Further data is available through research organisations. Accessibility will depend on their attitude to sharing data.</p> | |
|--|---|--|

Though the data is less accessible than that for the USA²⁴, its level of detail still exceeds the international level data available and it would be worthwhile using this data instead of the international data.

China

Data on China's building stock and its energy use characteristics looks to be surprisingly good. Perhaps the easiest way to collect data is to contact the 'China Energy Group' at the Lawrence Berkeley National Laboratory. If data needs to be collected from China then this would be best done through established contacts within the government.

Rest of the World

For countries with a similar level of economic and industrial development as Europe and the USA the data available looks to be good enough to use in lieu of the international data. Many of the developing countries are covered in some way by the international level statistics, but often with significant gaps in the data. However, there is a general lack of regional or national data²⁵ available for many of these countries for both the energy use in buildings and building stock itself. Finding any data that does exist for these countries is likely to be a lengthy process and will often need the help of a local expert. Translation may also be required once datasets have been collected. As a result other types of data will be needed, together with some careful assumptions to generate the data needed for the economic model.

Some data does exist at an international level, for example population figures, macro-economic indicators and climate data. This information could be used to classify countries which lack data in to a number of 'groups'. Once classified it would be possible to identify the country or countries with the best and most accessible data on the building stock and its energy characteristics in each group. These could then be investigated at a detailed level enabling a series of inferences to be made, which could be used to make reliable extrapolations for the other countries in that group. As only area level data is required for the economic model the results of any investigation would need to be combined into a single figure.

Resource summary

The collection of data on the global building stock is a task where quality of data and cost are directly correlated with one another. From our experience of this pilot study we anticipate that a fair data set could be compiled by a well-motivated Research Assistant under academic supervision in a period of six months. An allowance should be made for the purchase of some data, and for some travel costs. If undertaken by a university, we believe a good deal could be accomplished for about £30,000.

However, we have also given thought to the costs of a more comprehensive approach. In the following table we suggest that the construction of a high quality and reliable data set would take about 22 months of a Research Assistants time, together with about four months of supervision. Local experts may be required for individual countries.

²⁴ Not only does the quality of data vary between EU-15 countries, but also it is likely that some translation will be needed along with the use of a local expert to help pinpoint and collect data.

²⁵ Links have been found to many National Statistics Offices, which may form a useful source of useful data.

| Region | Data and travel costs | Research assistant | Supervisor | Local experts/ translation |
|-------------------|--|---|-------------------|-----------------------------------|
| International | By subscription | 1 month | 0.25 months | |
| USA | Much of the data is available in some form free of charge, however some of the LBNL's data may need to be purchased from them. Cost is unknown. Travel costs may be needed to meet active research groups. | 3 months | 0.25 months | |
| Europe | | 6 months (more countries to cover – collation harder due to number of different systems used by countries to collect data - if gaps are found in European level data) | 1 month | 0.75 month |
| China | | 3 months (less data available? But more time spent searching?) | 0.5 months | 0.5 month |
| Rest of the World | Data costs? Some travel will be required, either to search for data or link up with research groups? | 9 months (collect data that is available?, collect related statistics, form assumptions and extrapolation methods, analyse) | 2 months | 2 months |
| Total | | 22 months | 4 months | 3.25 months |

The following job roles are suggested as necessary:

Research Assistant

In charge of collection and collation of data. Helps analyse the data and write report on results. Quite a significant amount of time can be spent on data entry, so it may be worth paying extra to have data in Excel or similar spreadsheet form.

Supervisor

A more experienced researcher with experience in the development of databases and methods of extrapolation will be needed to oversee the project.

Local experts/translators

Local experts will be needed to help find and collect data in some countries. A translator may also be needed to translate raw data into English.

Conclusions

This pilot study has highlighted that on a global level there is a lack of knowledge on building stock and its energy use characteristics. Some national, and in the case of Europe, regional level studies are being carried out, but a larger scale study has been hampered by a lack of available data.

As expected, it is easiest to find data on the residential building stock. Data on the non-residential building stock is patchy, even in developed countries, and data on energy use characteristics for both residential and non-residential buildings is limited to developed countries (and of varying quality between even these few countries). It is also no surprise that of the four regions the USA, and Europe have the most complete data.

In summary, more than a simple collect and collate exercise is needed to provide an adequate level of data to the proposed economic model – in particular a systematic method of extrapolation is required to provide figures for the ‘Rest of the World’.

Appendices containing the results of the searching

The following appendices have been constructed to record the results of our searches. These have been stored electronically and can be made available on CD if and when the actual construction of a global data set proceeds:

Appendix A: International Data

Appendix B: USA Data

Appendix C: Europe Data

Appendix D: China Data

Appendix E: Rest of the World Data

Appendix F: List of ‘Identifiers’ used in the internet search

Appendix G: List of potentially useful research teams

Appendix H: List of those contacted during the pilot study and resulting correspondence

Appendix I: Dr R Yao’s findings from her trip to China

Appendix J: Countries included in the UN Statistics Division housing and population census table

Appendix K: List of National Statistics Offices, from the UN website.

Appendix L: UN 1999 Energy Yearbook

Appendix M: Member countries of the IEA

The inter-disciplinary Tyndall Centre for Climate Change Research undertakes integrated research into the long-term consequences of climate change for society and into the development of sustainable responses that governments, business-leaders and decision-makers can evaluate and implement. Achieving these objectives brings together UK climate scientists, social scientists, engineers and economists in a unique collaborative research effort.

Research at the Tyndall Centre is organised into four research themes that collectively contribute to all aspects of the climate change issue: Integrating Frameworks; Decarbonising Modern Societies; Adapting to Climate Change; and Sustaining the Coastal Zone. All thematic fields address a clear problem posed to society by climate change, and will generate results to guide the strategic development of climate change mitigation and adaptation policies at local, national and global scales.

The Tyndall Centre is named after the 19th century UK scientist John Tyndall, who was the first to prove the Earth's natural greenhouse effect and suggested that slight changes in atmospheric composition could bring about climate variations. In addition, he was committed to improving the quality of science education and knowledge.

The Tyndall Centre is a partnership of the following institutions:

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- University of Southampton
- University of Cambridge
- Centre for Ecology and Hydrology
- SPRU – Science and Technology Policy Research (University of Sussex)
- Institute for Transport Studies (University of Leeds)
- Complex Systems Management Centre (Cranfield University)
- Energy Research Unit (CLRC Rutherford Appleton Laboratory)

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