Impact Objectives

- Establish a realistic and concrete pathway to ultimately achieving independence from fossil fuels by harnessing the latent flexibility of the integrated energy system
- Develop methodologies and ICT solutions for the analysis, operation and development of fully integrated urban energy systems
- Educate a new generation of academics, engineers and entrepreneurs on the added value and necessity of considering the energy system as a whole
- Identify and establish solutions which can form the background for commercial opportunities for intelligent energy systems, with a focus on the smart cities environment

Working towards a fossil-free future

***Henrik Madsen**, head of the **CITIES (Centre for IT-Intelligent Energy Systems in cities)** project, and his team of pioneering researchers are passionate about progressing Denmark to a fossil-fuel free future. His vision is of a fully integrated, intelligent energy system supported by a restructured regulatory system which facilitates a smart and flexible energy system powered by the smart use of data*

Can you share the background to the CITIES project?

A wide range of research projects have been conducted to support European and national targets towards fossil-free energy systems. The Danish target is that by 2035 all of Denmark's energy demands in electricity and heating will be met by renewable energy – and, by 2050, all energy will be fossil-free. Most projects focus on the individual aspects of the energy system and overlook the possibilities provided by an integrated approach that facilitates flexibility in the integrated energy system. CITIES is the first research project using an integrated and intelligent energy systems approach, in which smart use of data, models, forecasting and control optimisation enables efficient and flexible energy systems. The CITIES project is funded by the Danish Council for Strategic Research. Today about 50 people are working at the Centre, including 15 PhD students and six postdoctoral fellows. Some researchers are working part time on CITIES while also working at companies, research laboratories or universities.

What is your own career background and what led to your interest and involvement in this project?

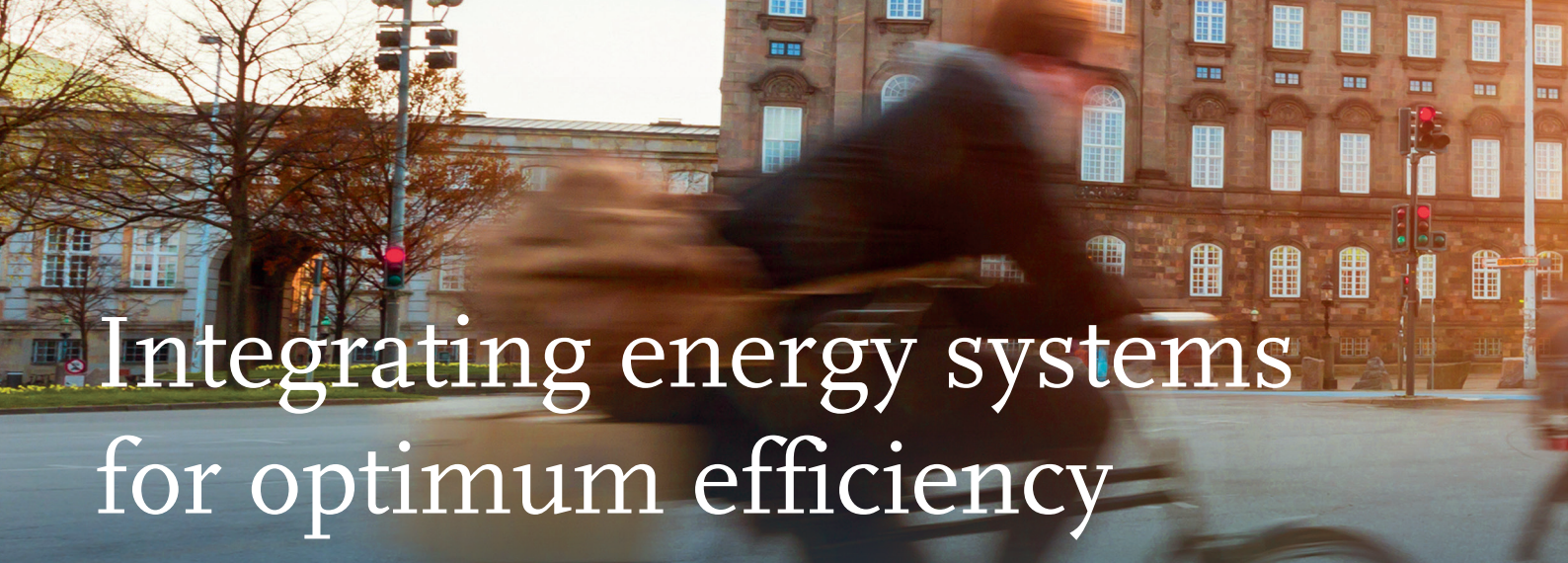
I'm a professor in mathematical statistics and stochastic dynamical systems. I have co-authored about 500 papers and 12 books, and even though many of those books are linked to my position as a professor in statistics, most of my scientific work deals with modelling, forecasting and control of energy systems. Future energy systems represent a challenge which calls for intelligent use of data in a complex network of coupled stochastic systems.

What does the Danish energy infrastructure currently look like?

The Danish energy system is characterised by efficient power, gas and thermal networks. Consequently this system constitutes the ideal setup for tests of future integrated energy solutions. Today almost 50 per cent of the power load is covered by renewable energy sources, and three large offshore wind farms play an important role here. The plan for the near future is to build two additional large offshore wind farms. By the future use of intelligent and integrated energy solutions developed in projects like CITIES, it is expected that Denmark will be close to fulfilling its 100 per cent fossil-free energy goal in 2035 for heating and power systems.

In a perfect world, what would you like Denmark's energy infrastructure to look like in 20 years' time?

I would like it to be 100 per cent fossil-free. The solution will take advantage of intelligent use of data, the Internet of Things, Big Data analytics and cloud computing – these are exactly the technologies we are developing and using within the CITIES projects. The planning, however, has to be more diverse than now – we need a spectrum of different intelligent and integrated energy solutions. We also need a change in regulatory conditions.



Integrating energy systems for optimum efficiency

*The **CITIES (Centre for IT-Intelligent Energy Systems in cities)** project is developing systems and models to enable Danish cities to optimise energy efficiency, utilise virtual storage within fully integrated energy networks and operate a flexible demand response using future market designs with real-time price-based control of the energy consumption*

Countries around the world have recognised the need to reduce emissions of greenhouse gases in order to combat climate change. Europe is targeting 20 per cent of all energy consumption being from renewable sources by 2020. However, many countries are currently unable to capitalise on the full power generation capabilities of wind and solar, for instance, due to the difficulty of integrating intermittent power sources into national electrical grids. The problem is one of matching supply and demand at any given point in time.

Several projects are already addressing this problem, with most being focused on specific aspects of the energy systems. In contrast, the six-year CITIES project, which is being led by Henrik Madsen, Section Head for Dynamical Systems at the Technical University of Denmark, is taking a more holistic approach, aimed at full integration of the various energy sources and consumers within Denmark. This country has a mix of energy sources including biomass, gas and wind power, plus developed networks for the distribution of district heating, power and gas.

HOLISTIC URBAN ENERGY PLANNING

Denmark is already in the enviable position of producing 50 per cent of its annual electricity consumption from wind power, and is aiming to become fully renewable by 2050. CITIES, funded by the Danish Council for Strategic Research, predicts that full integration of the nation's energy networks, plus intelligent controls, will enable wind power to be fully employed by identifying and exploiting the inherent flexibility within the system. This research, coupled with additional wind power capacity, is expected to propel Denmark to its 100 per cent renewable power generation goal earlier than targeted. CITIES is cooperating with international research agencies which have similar aims, including those in Ireland, South Korea, Spain, the USA, Austria, Germany and Norway.

The initiative is targeted primarily at urban areas which have a high density of consumers and power sources, plus existing communications and energy networks. Also, as pointed out by Madsen, 80 per cent of global energy consumption and emissions are from urban areas, meaning that cities are the ideal targets for energy integration and efficiency savings. 'The scope of the CITIES project is extensive, examining the whole supply chain from generation to appliance, as well as including both short-term control systems and long-term planning and forecasting,' Madsen explains. Detailed consideration of transport and water distribution is excluded from the project, but full note is taken of the need for future integration with these important sectors. The group at DTU is now participating in new projects which focus on the energy-water and energy-transport nexus, respectively.

MODELLING SUPPLY AND DEMAND

CITIES is taking a multifaceted approach to develop intelligent and integrated urban energy systems. Different Work Packages are undertaking extensive research into consumption patterns, energy production, transmission resources, storage solutions and the potential for greater efficiencies. A large quantity of data has been produced, necessitating the development of novel statistical tools for analysis. 'Each component of the energy system is being independently modelled and fed into aggregated models, with a view to producing high level intelligent decision-support software,' says Madsen. 'Good forecasting tools are necessary to plot expected energy production against consumption to reveal where and when demand and supply are mismatched.' CITIES also makes recommendations for restructuring market frameworks to support energy systems integration.

Three years into the project, CITIES has already demonstrated that it is possible for Denmark to establish a 100 per cent fossil-free power system, says Madsen. The team has developed a framework called Smart Energy Operating System (SE-OS) which incorporates solutions for the setup of future power and energy markets and the use of energy integration to provide 'virtual' storage solutions. These two factors, combined with methods for improving energy efficiency, are the solutions to the problem of renewable energy utilisation and will enable a fossil-free power system.

BALANCING ENERGY MARKETS

Traditional energy markets are based on structured bidding and clearing principles and provide an inflexible framework for giving variable targeted pricing signals aimed at provoking an efficient demand response from consumers. Madsen explains that a future energy market will require an overhaul of the regulatory systems and implementation of price-based control of the electricity load, rather than the current system of operators bidding into static markets based on clearing principles. Demand response can be used to balance the fluctuating wind and solar power production with consumption by tuning the usage of large flexible operators such as wastewater and water treatment plants.

Storage has long been identified as an important enabling technology for the use of renewables. CITIES has discovered

that large-scale electrical energy storages (batteries) is not necessary in Denmark, owing to the inherent flexibilities and storage capacity of the district heating and gas networks. In addition, 'the thermal mass of buildings can be used as a "battery" to store energy 5–12 hours ahead,' says Madsen. The district heating network, which is largely based on combined heat and power plants, pumps hot water through high pressure insulated transmission pipelines and features underground storage facilities for the retention of hot water. The entire network therefore constitutes a giant battery for the storage of energy at all relevant time scales is the key reason Danish power systems could support 100 per cent renewables.

Much research within CITIES has been focused on improving efficiency at all levels of the system. Data has been collected from smart meters which link energy consumption patterns with the type of building being monitored. Careful analysis of this data has led to the development of models which calculate the best means of renovating buildings to make them more energy efficient. In addition, smart controllers have been developed for use inside buildings, which are networked into the Internet of Things and maximise flexibility and efficiency within the home and office.

However, the team do not see the need for each building to incorporate solar panels or be carbon neutral in itself. Rather, the CITIES researchers believe the focus should be on energy balancing at a district, national or even regional level, to enable the full utilisation of renewable energy generation. Indeed, some of the solutions tested have led to greater use of energy, but at times when wind power was high and the alternative would have been to stop the turbines. As Madsen points out, the overall aim is 'emission efficiency rather than merely energy efficiency'. Energy balancing across countries would open up the use of other storage possibilities such as hydro schemes as well as invoking greater emission efficiency savings.

> *"The scope of the CITIES project is extensive, examining the whole supply chain from generation to appliance, as well as including both short-term control systems and long-term planning and forecasting"*

The second three years of the project will focus on further refinements of the mathematical models and implementation and testing of software tools. Testing will be undertaken jointly with the many partners to CITIES, including industry and smart city projects. Commercialisation opportunities will also be sought, although where possible findings from the project will be provided as open source solutions. To facilitate further developments, the CITIES Innovation Centre (http://www.citiesinnovation.org) has been founded, which will form a hub for further novel developments.

Madsen foresees a bright future for Denmark, one which is fuelled 100 per cent by renewable energy sooner rather than later. However, he warns that these advances will be reliant on more diverse planning and redesigned regulatory frameworks, which will need the cooperation and support of governments.

Project Insights

FUNDING
CITIES is supported by the Danish Council for Strategic Research

CONTACT
Henrik Madsen
Centre Manager

T: +45 45253408
E: henrik.madsen@smart-cities-centre.org
W: http://smart-cities-centre.org/

CENTRE MANAGER BIO

Professor Henrik Madsen is the Section Head for Dynamical Systems, Applied Mathematics and Computer Sciences at the Technical University of Denmark (DTU). He received his PhD in Statistics from DTU in 1986 and was appointed Assistant Professor in Statistics in 1986, Associate Professor in 1989, and Professor in Mathematical Statistics with a special focus on Stochastic Dynamical Systems in 1999. Madsen's main research interest is related to analysis and modelling of stochastic dynamics systems. This includes signal processing, time series analysis, identification, estimation, grey-box modelling, prediction, optimisation and control. The applications are mostly related to energy systems, informatics, environmental systems, bioinformatics, biostatistics, process modelling and finance. Madsen has authored or co-authored approximately 500 papers and 12 books.

CITIES
Centre for IT Intelligent Energy Systems

DTU