Institution: University College London		
Unit of Assessment: 13 – Architecture, Built Environment and Planning		
Title of case study: Developing the UK TIMES model to underpin the UK Government's decarbonisation strategy across all sectors of the economy		
Period when the underpinning research was undertaken: 2009-2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Paul Dodds	Professor of Energy Systems	2011-present
Paolo Agnolucci	Associate Professor in Resources and Environmental Economics	2012-present
Neil Strachan	Professor in Energy Economics and Modelling	2009-present
Steve Pye	Associate Professor in Energy Systems	2011-present
Birgit Fais	Research Associate in Energy-Economic Modelling	2013-2016
Hannah Daly	Research Associate in Energy Systems	2012-2015
Period when the claimed impact occurred: 2015-2020		
Is this case study continued from a case study submitted in 2014? Y		

1. Summary of the impact (indicative maximum 100 words)

The Department of Business, Energy and Industrial Strategy (BEIS) uses UK TIMES as its principal in-house model to generate energy scenarios for policy-making. Bartlett researchers developed UK TIMES to identify pathways to meet the UK's 2050 net-zero emissions target at the lowest possible cost by showing which sectors should be decarbonised first, and how fast. Through engagement with policy-makers, consultation, training and co-creation, this model and its supporting research: i) have become the core mechanism by which BEIS is transitioning UK energy policy to net-zero emissions; and, ii) underpin industrial sector policies for competitive decarbonisation by 2050.

2. Underpinning research (indicative maximum 500 words)

Achieving the UK's target of net-zero emissions by 2050 requires overhauling the energy system. The UK government aims to avoid greenhouse gas emissions whilst simultaneously meeting growing energy demands in a cost-effective manner. Researchers (including Dodds and Pye) in the Bartlett School of Energy, Environment and Resources have developed a novel energy system cost-optimisation model, and collaborated with government to inform policies that balance cost and decarbonisation needs.

Modelling CO2 emissions and sequestration technologies

The UK MARKAL (acronym for MARKet ALlocation) energy system model was developed in the UK Energy Research Centre in 2005 to identify how the UK might transition to a low-carbon economy. It minimised the total discounted energy system cost to 2050, subject to a wide variety of physical and policy constraints. It included costs and characteristics of resources, infrastructures, new technologies, and energy conservation measures to meet energy service demands. The model and its research base moved to UCL in 2009.

Modelling all greenhouse gas emissions and all sequestration options in all sectors

In 2012, Bartlett researchers created the UK TIMES (The Integrated MARKAL-EFOM System) model to replace UK MARKAL. Working with the UK Energy Research Centre (UKERC, EP/L024756/1) and the Whole Systems Energy Modelling Consortium (wholeSEM, EP/K039326/1), UK TIMES went beyond the CO_2 emissions and sequestration options in UK MARKAL to simulate all UK greenhouse gas emissions and mitigation options. UK TIMES is a bottom-up, partial equilibrium, cost-optimisation model of the whole UK energy system ('bottom-up' as it describes a large number of existing technologies and energy commodities, and their interactions; 'partial equilibrium' as it covers only the energy system and other parts

of the economy producing greenhouse gas emissions, and not the whole economy). All emissions and their mitigation options outside the energy system were modelled for the first time, including those from agriculture, land use, refrigerants, and waste.

The research, led by Dodds, developed UK TIMES to represent more than 50 energy service demands and 1,000 energy technologies. Based on insights from the UKERC 'Industrial Energy Use from a Bottom-up Perspective' project (with the University of Bath), low-carbon processes for sectors like iron, steel and chemicals were represented **[a]**. UK TIMES was also unique in its inclusion of six local air pollutants (e.g. NO_x, PM2.5).

Developing a new industrial energy demand model

UK TIMES relies on projections of future energy demands for heating, lighting and transport, related to GDP, population and other key determinants, from econometric models such as the UK government's Energy Demand Model (EDM).

Analysis, led by Agnolucci, showed that aggregation of EDM projections had overestimated by about 10% the future energy demands for the industrial sector as a whole, and in particular, for some energy-intensive sectors. Tackling these sub-sectors for the first time, the research allocated energy consumption by fuel (gas, electricity, oil and coal) to determine more accurate CO_2 emissions **[b]**. The research led to a new industrial energy demand model, which contributes future demand projections to UK TIMES.

Modelling climate-change strategies for the UK

A series of novel scenario-based studies focusing on climate change strategies have been underpinned by UK TIMES. One explored the potential for the UK to adopt a net zero emissions target, and this target was adopted by the UK Parliament in 2019 after first being analysed on an economy-wide scale using UK TIMES **[c]**.

There are substantial uncertainties about the cost and performance of some low-carbon technologies, and research has shown how this affects decarbonisation pathways **[d]**. By linking UK TIMES to a global input–output economic model (University of Leeds), research accounted for indirect CO_2 emissions from overseas in addition to direct UK emissions **[e]**. The research also tested removing the 'perfect foresight' model assumption (enabling UK TIMES scenarios to account for a deeply uncertain future), finding that renewable energy generation would be more competitive than previously thought **[f]**.

3. References to the research (indicative maximum of six references)

a) Strachan, N., B. Fais and H. Daly, *Reinventing the energy modelling–policy interface*, Nature Energy 1:16012 (2016). https://doi.org/10.1038/nenergy.2016.12

b) Agnolucci, P., V. De Lipsis and T. Arvanitopoulos, *Modelling UK sub-sector industrial energy demand*, Energy Economics 67:366-374 (2017). https://doi.org/10.1016/j.eneco.2017.08.027

c) Pye, S., F. G. N. Li, J. Price and B. Fais, *Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era*, Nature Energy 2:17024 (2017). https://doi.org/10.1038/nenergy.2017.24

d) Fais, B., I. Keppo, M. Zeyringer, W. Usher and H. Daly, *Impact of technology uncertainty on future low-carbon pathways in the UK*, Energy Strategy Reviews 13-14:154-168 (2016). https://doi.org/10.1016/j.esr.2016.09.005

e) Daly, H. E., K. Scott, N. Strachan and J. Barrett, *Indirect CO2 Emission Implications of Energy System Pathways: Linking IO and TIMES Models for the UK*, Environmental Science & Technology 49(17):10701-10709 (2017). https://doi.org/10.1021/acs.est.5b01020

f) Nerini, F. N., I. Keppo and N. Strachan, *Myopic decision making in energy system decarbonisation pathways. A UK case study*, Energy Strategy Reviews 17:19-26 (2017). https://doi.org/10.1016/j.esr.2017.06.001

4. Details of the impact (indicative maximum 750 words)

Bartlett researchers have developed and used models that combine engineering and economics to enable policy-makers and industry to understand potential pathways to decarbonisation, as well as implications for affordability and energy security.

4.1 Shaping UK climate policy on net-zero emissions

The Climate Change Act 2008 requires the UK government to reduce UK greenhouse gas emissions by 80% by 2050 compared to 1990 levels. In July 2019, the UK adopted a more ambitious net-zero emission target to meet its Paris Agreement commitment. Building on its underpinning research, UK TIMES is the principal model within the UK government for generating long-term energy scenarios, and it directly contributed to the decision to adopt a net-zero target.

Co-creating UK TIMES with BEIS to enable their climate policy analyses

In 2013, The Department for Business, Energy and Industrial Strategy (BEIS; then the Department for Energy and Climate Change) appraised then adopted an early version of UK TIMES for energy scenario development. BEIS signed a Memorandum of Understanding with UCL to co-develop the model. Cross-government reviews examined each part of UK TIMES to build consensus around its use. BEIS then used UK TIMES to create a range of internally consistent scenarios that met emission targets, and each part of those scenarios was then reviewed by the appropriate expert team in BEIS or elsewhere in government. This helped BEIS to coordinate its various teams around a more coherent decarbonisation strategy. The importance of using the model to improve communication across government is evident in the testimonial from BEIS's Deputy Director of Central Modelling: "UK TIMES [is] the focal point for developing long term decarbonisation strategy. We work with teams within BEIS, DEFRA [Department for Environment, Food and Rural Affairs] and DfT [Department for Transport]…to produce analysis that has been validated and verified by our stakeholders. The role of UK TIMES in improving communication within and across government departments is evident in the Clean Growth Strategy and our recent Energy White Paper which also sets out our long-term commitments on using UK TIMES" **[1]**.

The UK TIMES user group now meets annually and includes BEIS and the Scottish Government, government agencies (Climate Change Committee, National Infrastructure Commission, Energy Systems Catapult), universities, and companies (e.g. National Grid).

Providing the evidence for the UK's Fifth Carbon Budget and Clean Growth Strategy

In June 2015, the UK government used UK TIMES to provide evidence in its decision to accept the advice of the Climate Change Committee (CCC) on the level of the UK's Fifth Carbon Budget for 2028-2032 **[2]**. The advice used UK TIMES scenarios to explore potential decarbonisation pathways **[3]**, and was supported by UK TIMES analysis by Dodds that explored the potential roles of hydrogen for decarbonising road transport, industry, and heating houses and offices in a future low-carbon energy system **[4]**.

In 2015, the Scottish Government created a Scottish TIMES model from UK TIMES by replacing UK data with Scottish data. As noted in the testimonial from the Scottish TIMES lead at the Scottish Government: "Much of the other information, for example the assumptions about future energy technologies, remained largely unchanged [from UK TIMES]. The Scottish TIMES model was first used to provide evidence for the 2018 Climate Change Plan as well as supporting parliamentary debate around earlier draft plans. Scottish TIMES has since been used for a draft update to the Climate Change Plan which is consistent with [Scottish] revised 'net-zero' targets. This is currently progressing through the Scottish Parliament" **[5]**. The value of the model to the policy process is explained in the 2018 Climate Change Plan as "[helping] us to define policy outcomes in each sector in terms of real life,

tangible changes in technologies, fuels and other measures, allowing us to visualise the low carbon economy of the future" **[6, p.10]**.

Informing the Paris Agreement through the Deep Decarbonisation Pathways Project

In advance of COP21, the Deep Decarbonization Pathways Project (DDPP), a collaboration of researchers from 16 countries, identified practical national pathways to deeply reduce greenhouse gas emissions. UK TIMES was used to produce the first national Deep Decarbonization Pathways Project appraisal **[7]**. Built on a rigorous accounting of national circumstances, the project defined pathways to support decarbonisation of energy systems, while respecting national political economy and domestic development priorities **[8]**. The DDPP contributed to the evidence base needed to support Article 4.19 of the Paris Agreement, which urged countries to establish long-term, low-emission development strategies **[9]**.

Identifying pathways to curb emissions

In October 2017, BEIS published the Clean Growth Strategy, which set out how the government plans to meet the Fourth and Fifth Carbon Budget commitments **[10]**. BEIS used UK TIMES to explore scenarios for the energy system, and identify key energy technologies that could contribute to decarbonisation and provide growth opportunities.

In March 2018, UCL was approached by the CCC to carry out analyses of industrial emissions projections. This analysis contributed to the CCC's 'Reducing UK emissions' report to Parliament, which showed that although progress had been made in reducing emissions from electricity generation, reductions in other sectors had stalled **[11]**.

4.2 Supporting competitiveness in the UK industrial sector

The cost of transitioning to a low-carbon energy system has been estimated as 1%-2% of GDP, and would be higher if the combination of low-carbon technologies was chosen poorly. Bartlett research is underpinning UK energy transition cost and demand analysis.

Underpinning National Grid Future Energy Scenarios

National Grid adopted UK TIMES in 2017 and used it to inform its 2018 Future Energy Scenarios, which are used by the UK electricity and gas system operators, the wider energy industry, and academia. Bartlett researchers trained and supported National Grid staff during scenario development, leading to the 2018 publication that used UK TIMES to calculate detailed greenhouse gas emission profiles and compare the costs of Future Energy Scenarios for the first time **[12]**.

This was further developed in Future Energy Scenarios 2020, which shows how UK TIMES underpins National Grid's net zero scenarios, and that it "is used to provide guidance for the scenarios that meet the 2050 decarbonisation target" and "to determine the emission level within the scenario" **[13]**.

Improving the accuracy of the industry energy demand model

The UK government publishes annual Energy and Emission Projections based on its Energy Demand Model (EDM). These are required for international reporting to the UN Framework Convention on Climate Change, as well as to inform the Climate Change Programme, fiscal policy and clean growth strategy, the Climate Change Committee, and to set carbon budgets as required by the Climate Change Act 2008.

In 2015, UK government grew concerned that the EDM industry model overestimated industrial demand for energy. Agnolucci carried out an econometric analysis that confirmed this concern **[b]**, and used this analysis to create a new industry model for the EDM. Researchers worked closely with BEIS, with an estimated contact time of 160 hours, including facilitating two workshops attended by around 40 policy-makers. This approach increased BEIS's understanding of the industry sector and raised confidence in the EDM projections.

Based on BEIS's internal analysis, use of the new UK TIMES model resulted in a reduction of 20 megatonnes of CO_2 emissions for carbon budget periods 3 and 4, which represents 5.5% of the whole CO_2 emissions reduction envisaged for that period **[14]**. BEIS officials testified to the usefulness of these workshops, indicating that since the workshops, "the revised industry model was incorporated into the EDM in 2017 and has, with some modifications, been used ever since to produce the BEIS Energy and Emissions Projections" **[1]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Testimonial: BEIS Deputy Director, Central Modelling.
2. DECC, *Impact Assessment for the level of the fifth carbon budget*, Department of Energy and Climate Change, London, UK (2016.) https://bit.ly/2P2hQWc. See pages 9, 30, 81.
3. Committee on Climate Change, *The Fifth Carbon Budget: The next step towards a low-carbon economy*, London, UK (2015). https://bit.ly/3eNcJnK. See page 58.
4. Hart, D., J. Howes, F. Lehner, P. E. Dodds, N. Hughes, B. Fais, N. Sabio and M. Crowther, *Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target*, London, UK (2015). https://bit.ly/2QdpcXI. See page 147.
5. Testimonial: Scottish Government statistician, Climate Change Statistics and Modelling
6. Scottish Government, *Climate Change Plan: The Third Report on Proposals and Policies 2018-2032*, Edinburgh, UK (2018). https://bit.ly/3bWIMAM. See pages 10, 57.
7. Pye, S., Anandarajah, G., Fais, B., McGlade, C., Strachan, N., *Pathways to deep decarbonization in the United Kingdom*, SDSN - IDDRI (2015). https://bit.ly/3rXvmZN.
8. Deep Decarbonization Pathways Project (2015). Pathways to deep decarbonization 2015 report, SDSN - IDDRI. https://bit.ly/3qVRO4q
9. Waisman, H. *The Role of Modeling and Scenario Development in Long-term Strategies*. 2018. https://bit.ly/3cKC5jo.
10. BEIS, *The Clean Growth Strategy*, Department for Business, Energy & Industrial Strategy, London, UK (2017). https://bit.ly/38QTMg9. See page 151.
11. Committee on Climate Change, *Reducing UK emissions: 2018 Progress Report to Parliament* (2018). https://bit.ly/3qPmEeU. See page 3.
12. National Grid, *UK Future Energy Scenarios*, Warwick, UK (2018) PDF provided. See page 42.
13. National Grid, FES Modelling Methods (2020). https://bit.ly/3ttiUkT. See page 27.
14. BEIS, *Updated Energy and Emissions Projection* (2016) https://bit.ly/30SrTjy. See page 2.