Institution: University College London (UCL)

Unit of Assessment: 10 – Mathematical Sciences

Title of case study: Improved decision making by the power sector and energy saving by consumers

1. Summary of the impact

Financial engineering and optimisation provide both power companies and consumers with better decision support in deregulated energy sectors. UCL research has delivered the following benefits to decision makers: (i) a clearer understanding of the role of statistical analysis in imputing missing data on wind speeds and (ii) reduction in energy costs by optimised scheduling of energy technologies. Other benefits have been (i) investment in follow-up research projects by industrial companies and (ii) knowledge transfer via workshops.

2. Underpinning research

Since 2005, UCL's Department of Statistical Science has been involved with three research projects that have addressed real-world problems: **(a)** ELDEV (funded by the Mid-Norway Business Research Fund) focused on using financial engineering to improve business practices at power companies; **(b)** The Distributed Energy Resources Customer Adoption Model, or DER-CAM, (funded by the US Department of Energy and the California Energy Commission) used optimisation to devise investment and operational strategies for users of small-scale on-site power generation; and **(c)** "An Options Approach to UK Energy Futures" (funded by the Natural Environment Research Council) took a more qualitative perspective to illustrate the consequences for UK energy policy of incorporating real options, i.e., managerial discretion over investment timing/sizing or technology choice. Thus, all problems have directly addressed real-world decision making in deregulated energy sectors in Norway, the US, and the UK.

(a) To assess the likely generating capacities of wind farms at promising sites, power companies use anemometers to measure the wind speed at those locations. However, these instruments tend to freeze in the winter, resulting in the systematic loss of data. Since wind speeds are highest in the winter, ignoring these missing data or using a naïve correction adversely affects the value of new wind farms. A new methodology to correct for missing wind speed data from anemometers was developed during 2008 and 2009 by UCL researcher Afzal Siddiqui (Lecturer in Statistics 2005-2010; Senior Lecturer 2010-present) together with Agder Energi employee Klaus-Ole Vogstad [1]. This work was conducted as part of the ELDEV project.

The seasonality-based approach that was developed is novel in that it preserves the autocorrelation structure of wind speeds and directions while modelling electricity prices accurately via a mean-reverting jump-diffusion (MRJD) process. Using artificially removed data from the Geitvassfjellet site, the researchers demonstrated that the proposed methodology is able to restore accurately the probability density function of the annual revenues from a proposed wind turbine [1]. UCL's specific contribution was in the form of stochastic models for electricity prices and a statistical procedure for imputing wind speeds.

(b) Greater deregulation of the energy sector is likely to lead to more decentralised decision making by energy producers and consumers alike. While large power companies have the resources to manage such a transition, consumers often lack the expertise in optimisation and computation to do so. DER-CAM has been developed to help consumers with this problem; it enables them to minimise emissions or the cost of operating their energy system by assessing their energy profile, prevailing market information, and information on their distributed energy resources technology. A large number of resources (both for energy production and storage) can be handled, as well as flexible demand and details of building thermodynamics. DER-CAM can determine which on-site power generation and combined heat and power systems a user should install, and how and when they should be operated in order to minimise energy bills.

DER-CAM has been developed jointly by Siddiqui and researchers from Berkeley Lab since 2000.

Since joining UCL in 2005, Siddiqui has made significant mathematical contributions to the current version of DER-CAM, including the incorporation of complex thermodynamic constraints [2]. This improvement to DER-CAM was implemented so that the University of New Mexico (UNM) could use the model to optimise their cooling equipment scheduling.

(c) Most models used for energy policy assume perfect foresight and price-taking behaviour by decision makers. The work in the "An Options Approach to UK Energy Futures" project – conducted by Siddiqui together with Derek Bunn and Michail Chronopoulos from the London Business School (LBS) – showed that, in contrast to this assumption, managerial discretion over investment timing/sizing or technology choice is actually affected by uncertainty and imperfect competition.

The project, conducted during 2011 and 2012, involved the development of a high-level framework for illustrating the principal features of optionality in the energy sector. In particular, the theory of real options was used to illustrate how uncertainty, competition, and power companies' flexibility to delay investment decisions lead to vastly different outcomes than those predicted by traditional models [3]. This finding indicates that policymakers need to adjust how their support schemes or market designs are implemented. Taking a UK example, it was shown how a CO_2 price floor would subvert the incentive of a fossil-fuel power plant to be the industry leader by removing the operational flexibility that makes it preferable to a renewable-energy plant. UCL's specific contribution was in Siddiqui's review of real options models to showcase their policy relevance, assistance with positioning the paper, delivery of tutorials on options pricing, and numerous presentations.

Much of the theoretical background to this project, concerning the value of flexibility and strategic interactions, was conducted by Siddiqui working with Stein-Erik Fleten from the Norwegian University of Science and Technology [4] and Ryuta Takashima from the Chiba Institute of Technology [5]. UCL's contribution was central: in both papers, Siddiqui formulated the problem, solved the models numerically where necessary, and formalised the analytical propositions. Siddiqui and Fleten [4] examined mutually exclusive investment opportunities in either a readily available renewable energy technology or a more ambitious one that needs further R&D to bring down its cost for subsequent commercialisation. The main result was a valuation of the option to conduct R&D in the ambitious technology. Surprisingly, it was found that a high level of uncertainty in the electricity price reduced this option value as long as the learning rate was low because higher expected prices made even a rudimentary ambitious technology attractive. Siddiqui and Takashima [5] took a strategic real options approach to investigate how staged investment under uncertainty is affected by the presence of a rival. Such discretion over not only investment timing but also modularity is a hallmark of most infrastructure industries including energy and telecommunications. It was found that a modular investment strategy is worth relatively more to a duopolist than to a monopolist because the former is partially able to offset the loss in market share. Moreover, it was also shown analytically that a duopolist's disadvantage relative to a monopolist worsens as volatility increases only if its loss in market share from the entrance of a rival is relatively high.

3. References to the research

[1] The effect of missing data on wind resource estimation, A. Coville, A. S. Siddiqui and K. Vogstad, *Energy*, 36(7), 4505-4517 (2011) doi:10.1016/j.energy.2011.03.067

[2] Applications of optimal building energy system selection and operation, C. Marnay, M. Stadler, A. S. Siddiqui, N. DeForest, J. Donadee, P. Bhattacharya and J. Lai, *Journal of Power and Energy*, 227(1), 82-93 (2013) doi:10.1177/0957650912468408

[3] The value of capacity sizing under risk aversion and operational flexibility, M. Chronopoulos, B. De Reyck and A. Siddiqui, *IEEE Transactions on Engineering Management*, 60, 272-288 (2013) doi:10.1109/TEM.2012.2211363

[4] How to proceed with competing alternative energy technologies: A real options analysis, A. S. Siddiqui and S.-E. Fleten, *Energy Economics*, 32(4), 817-830 (2010) doi:10/bvffnf

[5] Capacity switching options under rivalry and uncertainty, A. S. Siddiqui and R. Takashima, *European Journal of Operational Research*, 222(3), 583-595 (2012) doi:10/nt3

References [1], [4] and [5] best indicate the quality of the underpinning research.

Selected research grants:

(i) Financial Engineering Analysis of Electricity Spot and Derivatives Markets (ELDEV); PI: Sjur Westgaard (Trondheim Business School), co-I: Stein-Erik Fleten (NTNU) and Afzal Siddiqui (UCL); sponsor: Mid-Norway Business Research Fund, Trønder Energi, and Trondheim Energi; 2008-2011; value: NOK 10 million (of which £93,000 was UCL's share)

(ii) An Options Approach to UK Energy Futures; PI: Derek Bunn (London Business School), co-I: Afzal Siddiqui (UCL); sponsor: NERC NE/GOO7748/1 (via the UK Energy Research Centre's Third Round Research Fund); 2011-2012; value: £130,000 (of which £30,000 was UCL's share)

4. Details of the impact

The research on wind resource estimation (project **(a)**, above) has improved the understanding of wind power production estimates at the Norwegian power company Agder Energi, whose wind mast data were used in the research. The finding that missing wind speed data caused by frozen wind masts can introduce bias into wind power production estimates and profitability assessments, and the new method for imputing the missing data that was developed, raised awareness in the Wind & Site division at Agder Energi in 2008 about the extent of the problem with missing data from wind measurements and the need to employ more suitable statistical methods for dealing with this problem than those that are currently used within the company [A].

Specifically, the research made a two-fold direct contribution: (i) highlighted how Agder Energi's matrix approach is not as stable as their sectoral regression one in dealing with missing data; and (ii) developed a methodology to assess the economic impact of missing data both in terms of expected revenues and the distribution of revenues. Although these knowledge transfers cannot yet be quantified, they have provided valuable insights about the suitability of alternative approaches for correcting for missing data.

DER-CAM (project **(b)**, above) is enabling energy consumers to manage their energy resources better and minimise energy costs. It is also having an environmental impact since the use of energy resources is being managed more efficiently. DER-CAM has been deployed at sites including the Segundo Dining Commons building at the University of California at Davis (in 2011), the Santa Rita Jail in Alameda County, California (in 2012), and the Mechanical Engineering building at UNM (in 2012) [B].

DER-CAM was installed at UNM to manage the operation of chilled water storage tanks and an absorption chiller powered by hot water from a solar array. The building required an automated procedure for forecasting cooling demand, scheduling optimal dispatch of the absorption chiller, and charging-discharging storage units optimally, operations which could not be handled by relying on simple rules of thumb or heuristics. The university reports that "DER-CAM proved to be the most effective solution" for managing their systems optimally and that the use of DER-CAM has resulted in tangible cost savings that are "especially significant over the shoulder season" [C]. Thus, they are realising significant reductions in their energy bill by using solar power for cooling via storage in an automated way. UNM also benefits from the ease of use of DER-CAM; they informed us that "one of the principal advantages of using DER-CAM is that, once set up, it does not require user intervention to set system parameters" [C].

UCL research has also improved knowledge and understanding of the power sector and options pricing among industry professionals and policymakers through the following knowledge transfer events:

(1) Two ELDEV workshops, underpinned by the UCL research in project **(a)**, above, in addition to other UCL research conducted as part of the ELDEV project, were held in Trondheim, Norway,

during 2009 and 2010, and were attended by numerous power companies. For example, Agder Energi, Statkraft, and Trønder Energi represented the Norwegian power sector, which faces issues about valuing renewables and transmission investment. Participants gained an improved understanding of the factors involved in making decisions under uncertainty, e.g., modelling energy prices, hedging risk exposure via financial and physical positions, and investment appraisal. In addition, their increased awareness of the issues raised by the ELDEV project stimulated industrial companies in Norway to co-fund subsequent research projects. For example, ELCARBONRISK (2010-2014, NOK 13.5 million with participation of power companies Eidsiva Energi and Tafjord Karft) and PURELEC (2011-2014, NOK 8.5 million with involvement of power companies NTE and SAE Vind) are both focusing more on modelling energy prices and analysing investment in renewables, two issues that were highlighted in ELDEV.

(2) Two workshops sponsored by the UK Energy Research Centre (UKERC) in 2008 and 2009 on financial methods, underpinned by the UCL research in references [4] and [5] in project **(c)**, have transferred knowledge from UCL academics to industry and policymakers. The 2008 workshop had around 35 attendees, including representatives from power companies (including EDF Energy), consulting firms and ministries (including the Ministry of Energy, Mexico) [D]. The 2009 UKERC workshop was hosted by the Department of Energy and Climate Change (DECC) with about fifty participants. This exchange allowed UK policymakers to gain a better understanding of the benefits and limitations of using financial methods. Furthermore, the 2009 workshop counted as part of DECC's economics training for the year.

(3) The findings of the optionality research conducted in project **(c)**, above, during the "An Options Approach to UK Energy Futures" project were disseminated to the public and private sector via two events held at the LBS: "Decision Analysis and Real Options for Energy" (24 April 2012) and "Climate Policy, Risk and Energy Investment" (2-3 May 2012). The knowledge transfer facilitated by these events, which had around 20 and 80 attendees respectively, has enabled companies active in the power sector to advise managers and clients better about financial fundamentals and the propagation of risk. An attendee (of both events), from the PR firm Ketchum, reported that "The workshop really helped us to understand the energy market dynamics and investment options much better, including the risks and inherent optionality involved in capex-related corporate decision-making process" and that "For us as communication consultants, this knowledge and increased understanding of the underlining financial and business fundamentals of the energy infrastructure investment has enabled us to advise our clients much better in terms of both the corporate positioning and strategic communications - especially given the challenging and rather uncertain operating environment" [E].

5. Sources to corroborate the impact

[A] Supporting statement from former Head of Wind & Site at Agder Energi (employed by Agder Energi at the time of the impact) – corroborates the impact of research **(a)** on Agder Energi. Available on request.

[B] DER-CAM website: http://der.lbl.gov/der-cam – corroborates deployment of DER-CAM at sites including Santa Rita Jail (http://der.lbl.gov/microgrids-lbnl/santa-rita-jail) and University of California at Davis (http://der.lbl.gov/sites/der.lbl.gov/files/davis_report_w_cover_LBNL-4285E.pdf).

[C] Supporting statement from Professor of Mechanical Engineering at the University of New Mexico (UNM) – corroborates the impact of DER-CAM **(b)** on the Mechanical Engineering building at the UNM, including energy cost savings. Available on request.

[D] A webpage about the 2008 UKERC workshop is available at: http://www.ukerc.ac.uk/support/tiki-index.php?page=0807FinancialMethods. The number and types of attendees are corroborated by the 'Attendee List' (http://bit.ly/1aG6zNf).

[E] Supporting statement from Account Director at Ketchum – corroborates the claim that the two events in (3) led to increased knowledge and understanding at Ketchum and enabled them to advise clients better. Available on request.