Institution: Queen Mary University of London		
Unit of Assessment: 10		
Title of case study: Bringing cost savings and customer benefits at Electricity North West Ltd		
Period when the underpinning research was undertaken: 2016 – 2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): John Moriarty	**Role(s) (e.g. job title):** Professor of Mathematics	**Period(s) employed by submitting HEI:** Sep 2015—present
Period when the claimed impact occurred: 2016 - 2020		
Is this case study continued from a case study submitted in 2014? N		

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

Traditional methods of cost-benefit analysis (CBA) under-value investment in 'smart' technologies. To overcome this challenge, Queen Mary's Prof. Moriarty developed a new Real Options CBA model, a decision-making process, and software in collaboration with Electricity North West Ltd. (ENWL), the electricity distribution network for north-west England. ENWL has incorporated Moriarty's software tools to benefit 102,396 customers across 14 projects. ENWL has now integrated these tools as part of their business practice to compare flexible and inflexible capital investments. This change has enabled the network to provide better-value electricity for 2,400,000 homes and informed National Grid policy on the use of Real Options in cost-benefit analyses.

2. Underpinning research (indicative maximum 500 words)

Research by Queen Mary's Prof. Moriarty has played an instrumental role in overcoming the challenges of cost-benefit analysis (CBA) for electricity distribution networks. Traditional methods of CBA are deterministic: they do not account for the value of uncertainty and flexibility, such as the ability to delay, expand, or scale back an investment, in energy networks. As a result, they under-value new 'smart' technologies such as demand-side response, a method that aims to reduce and redistribute peak-time energy usage to mitigate strain and use resources more efficiently. Instead, they favour inflexible and capital-intensive infrastructure (e.g. transformers, overhead lines). This makes it highly challenging for networks to compare flexible and inflexible network investments fairly, to justify 'smart' network upgrades, and to obtain best value for money by investing in energy-use innovation.

Moriarty's research uniquely demonstrates how a probabilistic approach, which accounts for randomness and flexibility, can be applied to investments in electricity distribution networks. His work (for example, [3.1]) builds on Real Options Analysis (ROA), a principled framework by which to calculate and compare the value of both flexible and inflexible investments. Moriarty first worked on developing a prototype spreadsheet implementation of ROA in collaboration with Dr. Pierluigi Mancarella (University of Manchester).

In 2016, he collaborated again with Mancarella and Dr. Rita Shaw at Electricity North West Ltd. (ENWL) [3.2] to develop and justify a novel stochastic model for how the inherently random (stochastic) process of peak network loads evolves over time. Moriarty's unique contribution was to develop a 'Real Options Cost Benefit Analysis' (RO CBA) tool which does not require the assumption of geometric Brownian motion, an approach that is commonplace in mathematical finance, but one which has not been justified as a way of modelling electricity demand [3.3]. Instead, Moriarty's approach develops the network operator's own long-term demand forecasts into a probabilistic framework for investment decision-making. In addition, it provides an objective approach to quantifying appropriate demand-side response compensation (customers participating in demand-side response require compensation, as such schemes rely upon customers temporarily reducing their demand) [3.4].

After developing and refining this model in work commissioned by ENWL, and adding a new metric ('least worst regret'), Moriarty supported the electricity distribution network in extending and refining the prototype into a business-as-usual tool with which to evaluate the value and impact of network investments.

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

[3.1] De Angelis, T., Ferrari, G., Martyr, R., & Moriarty, J. (2017). Optimal entry to an irreversible investment plan with non-convex costs. *Mathematics and Financial Economics*, *11(4),* 423–454. https://doi.org/10.1007/s11579-017-0187-y

[3.2] Schachter, J., Mancarella, P., Moriarty, J., & Shaw, R. (2016). Flexible investment under uncertainty in smart distribution networks with demand side response: Assessment framework and practical implementation. *Energy Policy, 97*, 439-449. https://doi.org/10.1016/j.enpol.2016.07.038

[3.3] Moriarty, J., & Palczewski, J. (2017). Real option valuation for reserve capacity. *European Journal of Operational Research, 257*, 251–260. https://doi.org/10.1016/j.ejor.2016.07.003

[3.4] Mijatovic, A., Moriarty, J., & Vogrinc, J. (2017). Procuring load curtailment from local customers under uncertainty. *Philosophical Transactions of the Royal Society* A, *375 (*20160311*).* https://doi.org/10.1098/rsta.2016.0311

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

Moriarty's research and 'Real Options Cost Benefit Analysis' (RO CBA) tool set a precedent for its successful use in an electricity distribution network context, and generated three key impacts. It has:

1. Provided access to better-value electricity for 5,000,000 people across 2,400,000 million homes
2. Informed strategic investment decision-making at ENWL
3. Influenced guidelines on cost benefit analyses for national network investments and prevented potential losses

Providing access to better-value electricity for 5,000,000 people across 2,400,000 million homes

ENWL is one of 14 electricity distributors in the UK and serves 2,400,000 of the UK's ~30,000,000 customers, in the north-west of England (area of service highlighted in Figure 1). It owns, operates, maintains and upgrades 13,000km of overhead lines, 44,000km of underground cables, and related transformers and switchgear.

Figure 1: Map of the UK with the area served by ENWL highlighted in blue

Moriarty's RO CBA tool has been adopted by ENWL to compare investment strategies using a set of long-term demand forecasting scenarios. It has been used to make 14 investment decisions, with 102,396 customers directly benefiting from local upgrades across the 14 projects. By using the tool, ENWL has improved the cost-effectiveness of their electricity supply for 5,000,000 people across 2,400,000 homes according to Flexibility Solutions Manager Lois Clark, as the financial saving "is passed back to all 2.4 million of our customers in the form of reduced electricity bills. We recover our costs by charging electricity suppliers for the use of our network, which for domestic customers equates to about 16% of their average electricity bill" [5.1]. Moriarty's tool provides a much improved method of risk assessment over the company's prior process, as "previously this was a time-consuming task performed by hand, which did not identify an optimal strategy and lacked additional decision metrics (e.g. risk assessments) that the RO CBA model provides. The RO CBA model enables us to quantify the impact of each strategy, to ensure that the most cost-effective and risk-averse investments are made" [5.1].

Informing strategic investment decision-making at ENWL
The RO CBA tool has found multiple applications within ENWL beyond its intended purpose, for example planning asset replacement schemes [5.1]. Across its network, ENWL faces two key issues: insufficient network capacity (requiring network reinforcement), and poor network health (requiring asset replacement). While the "RO CBA tool was originally developed with the intention of comparing traditional network reinforcement strategies against innovative demand side response solutions to address network capacity issues, the model is also now being applied to asset replacement schemes in order to determine the most cost-effective replacement option. This further application of the model has greatly expanded its reach and usefulness within ENWL, as there is approximately triple the number of replacement versus reinforcement schemes," according to ENWL's Ms. Clark [5.1].

Influencing guidelines on cost benefit analyses for national network investments and preventing potential losses
National Grid plc, which owns and operates the UK's national transmission network, uses Network Options Analysis (NOA) methodology to make recommendations for national network investments based on a set of future demand scenarios. In September 2016, industry regulator Ofgem requested a review of NOA due to concerns over its ability to make efficient investment recommendations, and, in 2017, the review was completed with notable and acknowledged input from Moriarty and ENWL [5.2]. Moriarty and his work with ENWL were "instrumental in influencing the methodological review and its resulting recommendations, which formed the basis of guidance on National Grid's use of Real Options Analysis", according to Adam Hutchinson, Head of Analytical Quality at Ofgem [5.3]. According to the report, "our ideas for how Real Options Analysis can be embedded within the NOA are based on the Electricity North West Ltd RO CBA model, and as such there is a precedent for this type of model being implemented in an electricity network context" [5.2].

Moriarty's research saved National Grid plc from potential financial losses stemming from unwise investments in network infrastructure. Dr. Hutchinson confirms that Moriarty "demonstrated that implicit assumptions within the Black-Scholes framework were not appropriate to the network reinforcement context. As a result, I was able to advise National Grid that this approach not be taken forward. This prevented National Grid from implementing the NOA methodology which could have led to unwise network recommendations, costing consumers money. The methodology effectively modelled network investment risk and used Real Options Analysis in a more appropriate way than I had seen previously. The implementation of this methodology at ENWL, which improved performance and saved customers money, set a precedent for how we could effectively address parallel considerations at National Grid. This demonstrable value led me to recommend the approach as best practice in the NOA methodology review" [5.3]. Moriarty's RO CBA model has set a precedent for its successful use in a UK electricity distribution network context and, as a result, has influenced related national guidelines.

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

[5.1] L Clark. Flexibility Solutions Manager. *Electricity North West Limited* (testimonial letter, 18 June 2020). [Corroborator 1]

[5.2] National Grid Plc (2017). *Network Options Assessment Methodology Review*.

[5.3] A Hutchinson. Head of Analytical Quality. *Ofgem* (testimonial letter, 30 May 2020). [Corroborator 2]