Institution: University of Strathclyde		
Unit of Assessment: B12 - Engineering		
Title of case study: Reduced cost of generation and greater flexibility of low carbon electricity supply from UK wind farms		
Period when the underpinning research was undertaken: 2013-2018		
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:**
Dr David McMillan	Senior Lecturer	01/07/2008 – present
Dr Kerem Akartunali	Professor	01/02/2010 – present
Dr Euan Barlow	Senior KE Fellow	02/11/2009 – present
Prof Keith Bell	Professor	10/08/2005 – present
Period when the claimed impact occurred: 2014 – July 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Multidisciplinary research led to the development of modelling tools for use in planning, installation and construction of offshore wind farms. Used in major UK offshore wind farm projects from 2014 by Scottish and Southern Energy, Iberdrola and its subsidiary Scottish Power Renewables, the modelling tools reduced a wide range of costs. Research also led to a change in strategy by National Grid ESO to enable renewable energy suppliers to provide reactive power to the grid, opening a new revenue stream for all windfarms from 2019. Electricity generation from offshore wind has become more economic, leading to further investment by SSE and SPR, and a boost to local economies. Offshore wind generation is increasingly adding to the energy mix available to consumers, assisting the renewables industry to meet UK Government low carbon targets.

2. Underpinning research

Through the Climate Change Act (2008), the UK government has committed to reduce carbon emissions by at least 100% of 1990 levels (net zero) by 2050. In line with these policy drivers, there has been a huge expansion in both onshore and offshore wind developments in the UK. There is also ongoing governmental pressure to reduce the cost of electricity generation from renewables and reduce government subsidy levels. This is a particular problem for offshore wind projects which have huge additional logistical challenges and associated costs in comparison with any onshore project. Against this background, in 2012-2013, a series of workshops were held at the University of Strathclyde with future industrial partners including Scottish and Southern Electricity (SSE) and Scottish Power Renewables (SPR). This led to a programme of projects to tackle key renewables industry challenges such as the high cost of offshore installation and maintenance, and the need for renewable energy suppliers to be more competitive in the electricity market.

Key findings: Researchers in the fields of Electronic and Electrical Engineering, Naval and Marine Engineering, Management Science and Civil Engineering used advanced engineering and mathematical models to develop software tools to support quick and reliable decision-making in the planning, installation and operation of offshore wind farms, with the aim of driving down costs and improving efficiency. Methodology was developed for complex data analysis of many factors, crucially weather, built into an **Operational Expenditure (OpEx) tool** to analyse the technical and economic implications of any given installation strategy. This cost control tool balanced technical requirements with optimal cost of installation [**R1**] and could be used many years ahead of actual construction. The core weather model was then adapted to examine installation risks, **to model the logistics of the offshore installation process** and identify vessels and operations most sensitive to weather delays. These operations were explored to identify the impact of technological or operational advances with respect to weather delays and the resulting installation duration under different levels of weather severity. The result was another decision support tool specifically **to optimise contractual strategies for the installation phase** of wind turbine foundations, cables and turbines. This 'installation support tool' was further refined in a project to develop a simulation and optimisation tool to facilitate the **minimum cost scenario** of installations at offshore wind farms [**R2**, **R3**]. A further project advanced this modelling to deal with a 24-hour planning horizon, for dynamic decision support actively updated as foundations are piled, turbines planted, and cables installed [R4, R5]. This allowed **modelling of installation costs in real time**, on a day-to-day basis during the installation phase of major OWF projects.

Ancillary services are the 'responsive' transmission services, delivered intermittently or at times of peak demand for electricity. This ensures power is delivered reliably, securely and efficiently to support the continuous flow of electricity, so that supply continually meets demand (known as balancing). In collaboration with SSE and SPR, the Wind-03 project [R6] identified **commercial opportunities for wind farms to provide ancillary services** to the UK National Grid and looked at associated technical and financial aspects. The ancillary services considered in the analysis included frequency response (the ability to regulate rotor speed of turbines to generate additional energy for the Grid), reactive power services, inter-trip and the potential for added value of distributed storage. This project provided an analysis of existing and future commercial opportunities for wind farms to generate revenue from the provision of ancillary services, which can provide new revenue streams for wind farms beyond selling of active power.

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **Dinwoodie, I.** and **McMillan, D.** (2014) Operational strategies for offshore wind turbines to mitigate failure rate uncertainty on operational costs and revenue. *IET Renewable Power Generation, 8(4)*, 359-366. https://doi.org/10.1049/iet-rpg.2013.0232 [REF2]

R2 **Barlow, E.**, **Tezcaner Öztürk, D.**, **Revie, M.**, **Boulougouris, E.**, **Day, A.H.**, **Akartunali, K.** (2015) Exploring the impact of innovative developments to the installation process for an offshore wind farm. *Ocean Engineering, 109*, pp. 623-634. https://doi.org/10.1016/j.oceaneng.2015.09.047

R3 **Barlow, E.**, **Tezcaner Öztürk, D.**, **Revie, M.**, **Akartunalı, K.**, **Day, A.H.**, **Boulougouris, E.** (2018) A mixed-method optimisation and simulation framework for supporting logistical decisions during offshore wind farm installations. *European Journal of Operational Research, 264(3)*, 894-906. https://doi.org/10.1016/j.ejor.2017.05.043

R4 **Dalgic, Y.**, **Lazakis, I.**, **Dinwoodie, I.**, **McMillan, D.**, **Revie, M.** (2015) Advanced logistics planning for offshore wind farm operation and maintenance activities. *Ocean Engineering, 101,* 211-226. https://doi.org/10.1016/j.oceaneng.2015.04.040

R5 **Dinwoodie, I.**, Endrerud, V.O-E., Hofmann, M., Martin, R., & Sperstad, I.B. (2015). Reference Cases for Verification of Operation and Maintenance Simulation Models for Offshore Wind Farms. *Wind Engineering, 39(1)*, 1–14. https://doi.org/10.1260/0309-524X.39.1.1

R6 **Nedd, M.**, **Bell, K.**, and **Booth, C.** '*Containing Loss Risk in a Low Inertia GB Power System*'. 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe, Palermo, 2018, 1-6. https://doi.org/10.1109/EEEIC.2018.8494455

Notes on the quality of research: The above outputs have all been subject to rigorous peer review, including the IEEE conference presentation. Research was supported by funding from SSE and SPR among others, as part of the Technology and Innovation Centre Low Carbon Power and Energy Programme at the University of Strathclyde. Total funding was GBP3,600,000 in phase one 2012-2018, with a further GBP1,800,000 for projects in Phase 2 from 2018 – 2021.

4. Details of the impact

Development of decision-making tools and an analysis of commercial opportunities for renewable energy operators were conducted by researchers at Strathclyde in collaboration with industrial partners Scottish & Southern Energy (SSE) and Scottish Power Renewables (SPR) from 2013-18. Collaborative projects were aimed at solving industry problems, and the organisations became the immediate users of any data analysis or software tools developed for planning and construction of Offshore Wind Farm projects. These research projects have enabled the UK energy industry to respond to the challenge of low carbon targets; examples are provided below, with benefits to:

- SPR, part of the Iberdrola Group, one of the world's largest integrated utilities, and SSE Energy, a major UK renewable energy company, which have both achieved cost reductions in planning and installation stages of major OWF projects. These efficiencies were a factor in the success of these companies in gaining an increased share of the UK low carbon electricity market. This success led to increased focus on generation of energy from Offshore Wind as part of SPR and SSE business strategies. Cost reductions have also enabled these renewables providers to make considerable progress towards meeting UK Government low carbon targets.

- National Grid (NG ESO) the electricity system operator for Great Britain, who used research findings to ensure that, from 2019 onwards, wind farms can play an increasing role in supplying electricity to the UK Frequency Response market, delivering energy to the grid intermittently or at times of peak demand, and giving NG ESO greater security and flexibility of supply.
- Supply chains and local economies, which have gained from investment and employment as a direct result of major offshore wind farm construction and ongoing maintenance. UK consumers have also been able to purchase low carbon energy at a more economic cost.

Efficiency savings in planning and installation of major offshore wind farm projects: The World Forum Offshore Wind places the UK as number one for offshore wind capacity, with an actual grid connected capacity of 9.9GW at the end of 2019 [S1]. This represents 45% of all grid connected capacity in Europe. Installation and associated contingency have been estimated at 20% of total capital expenditure in any OWF project [S1], with this aspect dominated by transport vessel costs. Installation involves a complex sequence of tasks, with a range of shipping vessels required to install cabling, offshore electrical systems, masts and turbine foundations. For each activity there is a choice of available vessels with different capabilities and costs. Data to inform decisions on when and where to employ these vessels in 'windows' of favourable weather is a major benefit of the Strathclyde modelling, together with accurate estimation of time and cost of various installation scenarios.

Modelling tools were implemented by SSE and SPR across some of the largest and most expensive offshore wind projects in the UK, summarised in the table below:

OWF project	Operator	Construction from	Operational from	Capacity	
				MW	Homes
Beatrice	SSE	April 2017	June 2019	588	450,000
East Anglia One	Iberdrola/SPR	May 2017	July 2020	714	630,000
Seagreen	SSE	Autumn 2020, planning consent 2017	2022/2023 (expected)	1500	1,200,000
Dogger Bank	SSE/Equinor	Jan 2020, planning consent 2015	2023 (expected)	3600	4,500,000

The operational expenditure and installation modelling tools were used to reduce costs through:

- **Improved logistics, planning and strategy:** The Director of Engineering and Innovation at SSE [S2] confirms that the Strathclyde data modelling '*has helped to optimise the logistics strategy for Seagreen, given the site conditions, layout and available vessel options. ... It enabled rapid logistics optioneering studies to be carried out and demonstrated the impact of failure rate uncertainty on project performance. The impact will undoubtedly be an uplift in wind farm energy-based availability in the region of 1.0%.'* [Text removed for publication] SSE confirm that the OpEx modelling tool has successfully reduced operational costs and '*This model is now used as part of our business as usual processes* [Text removed for publication] *As our offshore wind capacity continues to increase, we expect these benefits to also continue to grow.'* [S2]

  The Head of Innovation, Sustainability and Quality (SPR) also confirms that '*The operations and maintenance teams on the East Anglia One project used Strathclyde data modelling (OpEx) to estimate time and costings of various installation scenarios, and this was an asset in planning and contract negotiations before and during construction*'. Highlighting the benefits of this, they stated: '*accurate modelling was part of an overall effort to bring down costs across a range of offshore wind projects and was of particular value in planning the timing of vessel use in construction and maintenance'* [S3].

- **More effective negotiations with suppliers*:*** The OpEx model was used to make decisions on personnel and vessel numbers, and data from installation scenarios was used to challenge quotes from suppliers. [Text removed for publication] SSE were able to negotiate with suppliers from a stronger position, backed up by data. They confirm that '*The benefits depend on the operating environment; however, significant value was delivered by supporting offshore package and project control managers with proofing offshore installation contractor schedules'* [Text removed for publication] [**S2**]. [Text removed for publication] SPR also confirm that the modelling data '*benchmarked our collaborative approach against commercial offerings... demonstrating significant benefits*' [**S3**].

Increased share for wind energy in the UK low carbon electricity market: Cost reductions achieved by renewables generators, together with increased flexibility and levels of supply to the grid are factors which have contributed to more low carbon electricity from wind farms becoming available to the consumer. This process includes:

- **Success in Contracts for Difference (CfD) scheme:** Eligible UK renewable generators bid every 2 years for a share of the UK low carbon electricity market under the CfD scheme; the Government decides how many long term (15 year) contracts to award and can limit the level of spend in a given year. 'Sealed bids' are submitted, offering a cost price per Megawatt/hour (MWh) of electricity. The strike price agreed is the cost the government will pay the provider per MWh of energy. Where the strike price agreed is higher than the wholesale price of energy the government is in effect providing a subsidy. OWFs which applied Strathclyde modelling to reduce costs have been successful in CfD auctions. In February 2015 East Anglia One/SPR were successful bidders, gaining a contract with a strike price of £119.89/MWh [**S4**]. In the May 2019 CfD auction, SSE successfully secured strike prices of £39.65/MWh and £41.61/MWh for Dogger Bank and Seagreen, [**S4**] stating in their announcement '*The strike prices … show that offshore wind in particular is now one of the cheapest forms of electricity generation in the UK'* [**S5**]. In 2019 strike prices for Offshore Wind generation fell below the wholesale price for the first time, and it became competitively priced in comparison with coal and nuclear energy in the UK (e.g., a strike price of £92.50/MWh was awarded in October 2013 to Hinkley Point C).
- **Change in NG ESO strategy allowing wind farms to provide reactive power to the grid**: The provision of reactive or 'ancillary' services in response to fluctuations in electricity demand is known as the Frequency Response market and is worth GBP100,000,000 per annum. Collaborative research on reactive power services [**R6**] led to an invitation in 2019 to Strathclyde researchers to join the Power Available (PA) Working Group, chaired by National Grid ESO. Strathclyde researchers lobbied for wind farms to contribute to ancillary services and were commissioned by NG ESO to review the reliability of the PA signal across UK.

  In February 2019 NG ESO began trialling a weekly auction to procure a proportion of their frequency response requirements from renewables. NG ESO confirm that the '*analysis undertaken by Strathclyde University has supported the ESO's development of a Quality Standard methodology for determining the acceptable error tolerance for Power Available data and the implications for submitting inaccurate PA*' published in March 2020 [**S7** p15]. This allows wind farm operators to react to fluctuations in demand and reduces the chance of either overloading parts of the network or creating situations where frequency response requirements are not met. SSE note that the collaborative study [**R6**] *'provided a fact based argument for the future need for ancillary services and enabled wider industry conversations with National Grid. This ultimately stimulated the creation of a new frequency response category*.' [**S2**]

  SPR has now moved its focus towards providing ancillary services from all its windfarms, stating that '*Windfarms are displacing coal in the Mandatory Frequency Response and SPR has accessed a new revenue stream … during 2019. SPR's current pricing methodology has been designed on the basis of the work with Strathclyde'* [**S6**]. In May 2020, NG ESO integrated the PA signal from over 90 renewable generators, stating: '*Through innovations like the PA project our electricity system is becoming smarter, more flexible and – since wind power is often a cost-effective option when it comes to real time frequency response – delivers increased value to consumers'*. [**S8**]

Investment in offshore wind; with economic benefits for supply chains and local economies: Large OWFs require significant planning and financing over the lifetime of the project; East Anglia One/SPR had a total GBP2,500,000,000 investment, and Seagreen/SSE a total GBP3,000,000,000. SSE and SPR have both gained experience in use of data modelling to lower costs and drive efficiency in these complex multimillion pound offshore projects. They have both changed their business strategy to include a higher proportion of energy from offshore wind. SSE Renewables [**S2**] note that the Strathclyde modelling allowed them '*to seize opportunities for efficiency and innovation*' and to meet '*challenges which go beyond industry's ability to solve ... the collaboration with Strathclyde has given SSE Renewables access to knowledge and expertise to complement our own and come to more effective solutions*.'

Scottish Power has confirmed that as part of its GBP6,000,000,000 investment plan it is actively pursuing future offshore wind projects in England and Scotland. In March 2019, the Chief Executive, Scottish Power stated: '*we've worked tirelessly to bring down costs and, having transitioned to 100% renewable energy, will be building more windfarms to help the UK shift to a cleaner electric economy. Two of our offshore windfarms in East Anglia will replace all of the old thermal generation we've sold*' [**S9**].

Industry confidence in OWF developments translates to employment in the supply chain, in construction and installation of components, infrastructure and skilled maintenance jobs once operational. SPR co-invested GBP5,000,000 in Great Yarmouth and GBP25,000,000 in a new operations and maintenance base at Lowestoft Port, opened in 2019, and brought in nearly 3500 jobs during the East Anglia ONE construction phase 2017 - 2020 [**S9**]. SSE invested GBP20,000,000 in Wick and will employ 90 staff through the 25-year lifetime of the Beatrice project [**S9**]. The Seagreen project will create around 400 skilled construction jobs in Montrose Port [**S9**].

Cost reductions enable renewables industry to meet the challenge of low carbon targets: The Director of Engineering and Innovation at SSE Renewables notes that *'renewable energy and offshore wind is critical to delivering the UK's net zero targets ... Notable value has been derived from the work carried out with Strathclyde University which has supported a reduction in the cost of offshore wind*' [**S2**]. SSE claim, with respect to Dogger Bank and Seagreen OWFs: '*Once completed these projects will generate over 20TWh of green energy annually, equivalent to nearly 7% of the UK's current energy demand, making a significant contribution to the UK's net zero climate change targets*' [**S5**]. SPR also confirm the collaboration with Strathclyde researchers led to '*immediate, and commercially significant benefits to the levelised cost of energy from our sites, and hence the UK electricity consumer*', and that '*exploring the potential for cost reductions in offshore wind can assist us in in supporting the UK Government's 2050 Net Zero ambitions and therefore is very much of interest*.' [**S3**].

The Grid and Regulation Analyst at Scottish Power also confirms that '*the expertise provided by Strathclyde University has built the industry's confidence for tackling the challenges we are facing, managing to put us in the forefront of creating alternatives to run a resilient and secure system. It's clear that without Strathclyde University, Scotland and therefore, GB, wouldn't be the Renewables Hub that currently is.*' [**S6**]

5. Sources to corroborate the impact

S1 Crown Estate (2020). Offshore wind operational report.
S2 Factual statement from Director of Engineering and Innovation, SSE Renewables (18/02/2020).
S3 Factual statement from Head of Innovation, Sustainability & Quality, Scottish Power (12/02/2021).
S4 Gov.uk. Contracts for Difference Allocations for Round One (February, 2015; https://bit.ly/3l5m2Ap) and Round Three (October 2019, https://bit.ly/3rBR9WL).
S5 SSE Renewables secures 2.2GW of new offshore CfD contracts. https://bit.ly/3epnmgr
S6 Factual statement from Grid and Regulation Analyst, Scottish Power.
S7 Power Park Module Signal Best Practice Guide. National Gird ESO Report. https://bit.ly/3qAmpV5
S8 Power Available: Unlocking renewables' potential to help balance the electricity system. National Grid ESO News Article. https://bit.ly/3euHFJg
S9 Press releases relating to investment in offshore wind and local economies.