Invitation to Tender for modelling and report on ‘least regrets’ system flexibility in GB energy system

Technical Proposal

Tender reference no. 1076/10/2015

October 2015

1- Introduction

The Carbon Trust, supported by Imperial College London (Imperial), have thought carefully about the requirements of this project and created a partnership model which we believe most effectively meets DECC's needs. We are delighted to submit this proposal to DECC to undertake modelling and report on 'least regrets' system flexibility in GB energy system.

Our consortium

The Carbon Trust and Imperial have enjoyed a productive collaborative relationship and have worked together on a number of formally contracted projects for DECC and other clients, encompassing a wide range of innovation areas in low carbon energy and combining Imperial's expertise in energy system modelling and the Carbon Trust's interpretation of where and how to intervene to accelerate the development of technology.

The Carbon Trust and Imperial are currently working together on a *Technology Innovation Needs Assessment project for Electricity Networks and Storage* and a *Storage Joint Industry Project* (STORJIP), which utilise Imperial's modelling and knowledge and a whole systems approach to provide strategic recommendations on innovations in this sector. These projects are discussed in detail later in the proposal.

As a result of our longstanding relationship, we are confident of our ability to work together to deliver this project to time and budget. Both the Carbon Trust and Imperial will have a project manager and a project director leading their contributions to the project, with the Carbon Trust having overall responsibility and control. The Carbon Trust will be the lead contact for DECC for the project.

The Carbon Trust

The Carbon Trust is a not-for-profit company with the mission to accelerate the move to a sustainable, low carbon economy. We provide specialist support to business and the public sector to help cut carbon emissions, save energy and commercialise low carbon technologies. By stimulating low carbon action we contribute to key goals of lower carbon emissions, the development of low carbon businesses, increased energy security and associated jobs.

Our work spans three areas:

- **Advice:** We advise businesses, governments and the public sector on their opportunities in a sustainable, low carbon world;
- **Technology:** We help develop and deploy low carbon technologies and solutions, from energy efficiency to renewable power; and
- **Footprinting:** We measure and certify the environmental footprint of organisations, products and services.

We offer three distinct attributes:

- **Experience:** We have been working in the climate and sustainability sector for over ten years. We understand what does and doesn't work and most importantly why;
- **Impartiality:** As a bridge between business and government we had to be impartial. Today this underpins the effectiveness and impact of all our work and our reputation as a trusted partner; and
- **Rigour:** We work in a sector where much is new, unknown and open to opinion. We make the case for change and investment based on evidence and facts.

Through our work to date, we have helped our customers achieve energy cost savings of £5bn and reduce their CO2 emissions by 53.5 MtCO2e tonnes.

Imperial College London

Imperial is a world class science-based institution with an international reputation for excellence in teaching and research. Consistently rated amongst the world's best universities, Imperial is a multidisciplinary space for education, research, translation and commercialisation, harnessing science and innovation to tackle global challenges. Since its foundation in 1907, Imperial has maintained a focus on conducting internationally competitive research across a wide range of topics, targeting both fundamental advances and practical applications of science and technology. Imperial has worked with a wide range of clients from small local businesses, to international corporations, across a wide range of industries, governments and charities and has innovative approaches and expertise within several different areas of energy systems, advanced modelling and analysis.

Structure of this proposal

The remainder of this proposal is structured as follows:

- Section 2 – Understanding Requirements
- Section 3 – Methodology
- Section 4 – Skills and Expertise
- Section 5 – Management and Delivery
- Section 6 – Development of DECC's Capability

2- Understanding requirements

The changing UK electricity system and the need for greater flexibility

Maintaining a resilient, secure and affordable electricity system, as the generation mix and sources of demand change between now and 2050 will pose various challenging investment decisions for the UK. To achieve the UK's decarbonisation targets, the electricity sector will take on its share of mitigation by integration increasing amounts of intermittent renewable generation whilst enabling the electrification of the heat and transport sectors through increasing penetration of electric vehicles (EVs) and heat pumps.

At the same time traditional sources of flexibility, such as coal and gas fired generation, will reduce in capacity and new sources of flexibility will be needed to ensure system stability and to adequately meet demand. Previous analysis by Imperial College for DECC on "understanding the balancing challenge" highlighted the significant additional investment which will be needed across the electricity system from generation to network assets if alternative providers of flexibility are not planned for. Other studies have shown the positive impact of greater flexibility on more cost effectively meeting emission targets and also maintaining security of supply.

There are several technologies that can provide flexibility

There are a host of potential solutions that can increase flexibility in the system and these range from those on the demand side such as controllable consumer loads including EVs and heat pumps, storage – from distributed batteries to large pumped hydro or compressed air systems that can help firm renewables output, interconnectors – that can move electricity between countries to minimise demand/supply imbalances and flexible gas generators that can be more effectively turned up/down to provide system services for flexibility. It is envisaged that a portfolio of such providers of flexibility will emerge rather than a single provider owing to their different stages of development and suitability for different "types" of flexibility in terms of delivering over a range of time scales and speed of response[1].

Given that the solutions offering flexibility are vastly different, it is important to better understand the feasibility, scale of provision and also the associated costs and benefits across a range of potential energy futures for these different solutions. As retaining flexibility has a cost as well as an impact on the wider electricity system in terms of the requirement for generation, transmission and distribution network assets, effective strategic planning to create and retain a portfolio of such solutions offers a significant opportunity to streamline and reduce the costs of the UK's electricity system.

This strategic planning while providing the opportunity to reduce long term costs of the energy systems is however far from straightforward given the range of uncertainties in many key variables such as:

[redacted]

[1] Climate Change Institute (2010) Options for low-carbon power sector flexibility to 2050

[redacted]

How to plan for flexibility when the future is uncertain

In this context of uncertainty, adhering to a deterministic framework for system planning entails the risk of inefficient investments and stranded assets. Capital intensive decisions made in the present may prove unnecessary in the future, while opportunities that were deemed unattractive may turn out to have brought significant economic benefits but are no longer implementable. In this context, new planning frameworks are required to account for uncertainty in future development and identify investment strategies that are cost-efficient under all possible future realisations. Given the capital-intensive and irreversible nature of generation and network investments, decision makers are generally interested in minimising the risks associated with the planning decisions.

This approach for planning under uncertainty is strengthened by the ability to look across the whole electricity system rather than just at one part. E.g. [redacted].

Applying a minimised-regret approach

Moving from using traditional methods of identifying optimal investments such as least cost to something that allows to account for a wide range of potential energy futures help with addressing the inherent uncertainty. Here, a "least-regret" metric usefully complements least cost as it helps identifying investment into flexibility options that are low cost and low risk across a range of future energy scenarios. Estimating a "regret" of investing into a certain type of flexibility and optimising to minimise the forecasted regret across scenarios helps identifies a set of technology or solutions that is comparatively low cost for the electricity consumers regardless of which energy future materialises.

Summary of DECC's requirements

We aim through this project to provide DECC with:

- An investment profile for a portfolio of flexible technologies annually to 2050 for each of the core scenarios without considering the uncertainty associated with the varied energy futures
- An investment profile for a portfolio of flexible technologies annually to 2050 where the investment will be "least regret" given the uncertainties of four potential energy futures
- Insights into the role of innovation in reducing the cost and risk of "least regret" solutions
- High quality cost and performance projections for flexibility options, shared and consolidated through this project, to improve DECC's in house modelling capability of the future UK electricity system

3- Methodology

Imperial College has developed a set of novel tools for optimal planning under uncertainty, based on a minimum-maximum (min-max) regret decision making framework. This approach has been successfully applied in two Low Carbon Network Fund projects (in collaboration with SSE and UKPN) and in the case of North Sea Grid (conducted in collaboration E3G).

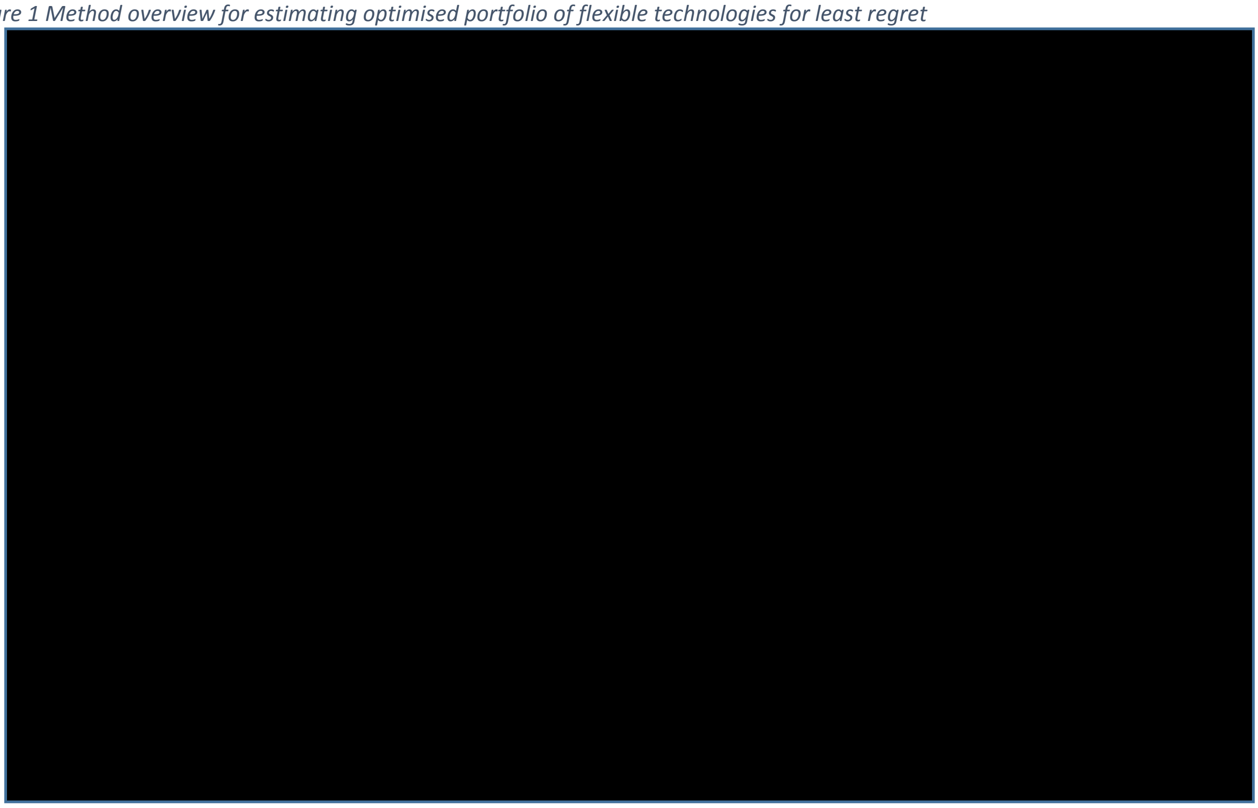
A network investment plan that is optimised for scenario X will tend to be sub-optimal in scenario Y, meaning that it contains avoidable costs relative to the optimal investment plan for scenario Y. In this context the 'regret' is the amount of avoidable cost incurred. The same investment plan optimised for scenario X might lead to even more regret in scenario Z. The min-max regret framework identifies robust network plans by minimising, across multiple future scenarios, the maximum regret that the planner (decision maker) might feel after the materialisation of the uncertain future. In a sense, the developed approach produces a plan that minimises the cost of uncertainty under the most unfavourable future realisation.

In power system planning problems, the min-max regret approach optimally balances two sources of regret: a) the regret of stranded assets, encountered when more generation or network capacity is procured than is actually required in the future and b) the regret of corrective actions (e.g. shedding demand, high reliance on inefficient backup plant, constraining low carbon generation, upgrading the same assets multiple times etc.), encountered when less generation or network capacity is procured than is actually required in the future.

Analysis carried out with the min-max regret approach by Imperial group has demonstrated the significant value of flexible low-carbon technologies (demand response, storage, controllable micro-generation, advanced network technologies) in limiting the regret experienced by the planner. This value lies in their ability to postpone capital-intensive generation and network upgrade decisions, until the investment can be made with more certainty. In other words, they provide interim solutions “buying time” until uncertainty is partially/fully resolved, maintaining the performance of the network while allowing a “wait-and-see” strategy that reduces investment risks.

Attempts to quantify the value of and requirement for flexibility options using deterministic planning approaches that do not recognise the cost of uncertainty and the need to minimise regret tend to underestimate the role of flexibility. Instead they tend to favour large-scale generation and network upgrades exactly timed to meet the increasing requirements of the system.

Figure 1 Method overview for estimating optimised portfolio of flexible technologies for least regret



Stage 1

Imperial’s Whole-electricity System Investment Model (*WeSIM*) is a comprehensive electricity system analysis model that simultaneously balances long-term investment decisions against short-term operation decisions, across generation, transmission and distribution systems, in an integrated fashion[2]. When considering development of future low carbon electricity systems, including application of alternative smart flexible technologies such as DSR, distributed energy storage, flexible network technologies and emerging designs of

[2] Pudjianto D, Aunedi M, Djapic P, Strbac Gclose, 2014, Whole-Systems Assessment of the Value of Energy Storage in Low-Carbon Electricity Systems, IEEE Transactions nn Smart Grid, Vol: 5, Pages: 1098-1109

flexible generation technologies, it is important to consider two key aspects:

- **Different time horizons**: from long-term investment-related time horizon to real-time demand-supply balancing on a second-by-second scale (Figure 1); this is important as, for example, alternative smart technologies can impact system investment and operation cost (and carbon) performance simultaneously.
- **Different assets in the electricity system**: generation assets (from large-scale to distributed small-scale), transmission network (national and interconnections), and local distribution network operating at various voltage levels. This is important as alternative technologies may be located at different sites in the system and at different scales.

[redacted]

We propose to use *WeSIM* to cost optimise DECC's four core scenarios but first under the assumption of perfect future information. *WeSIM* is a holistic model that enables optimal decisions for investing into generation, network and/or storage capacity (both in terms of volume and location), in order to satisfy the real-time supply-demand balance in an economically optimal way, while at the same time ensuring required levels of security of supply. The output of the analysis will provide insight on the key challenges encountered in each scenario, for example, [redacted]

The identified challenges will be compared across all scenarios to determine the common challenges and those which are specifics to certain scenarios. From this analysis, we will identify possible options and opportunities to address both the common and specific challenges and to improve the system efficiency in terms of capital investment and operation cost and also the emissions levels through improved flexibility in the system. A set of improvement targets (e.g. reinforcing the emissions target, reliability of supply) will be devised to enable determination of optimal investment and operation strategy in flexible technologies.

Stage 2

Now, based on the range of targets set in the previous task, we will apply WeSIM to identify the portfolio of flexible technologies that would optimise cost, security and emissions performance of each of the Core scenarios. WeSIM will minimise the total cost of the investment while optimising the system operation across the time span of scenarios (2015 – 2050). Some of the technologies we propose to include into our flexible portfolio are:

[redacted]

Additional to the above, Imperial's detailed Distribution Planning model (DistPlan) will be used as it aids in modelling distribution networks with different characteristics such as urban, semi-urban, semi-rural and rural networks and brings these together under different load densities and customers to accurately represent GB electricity distribution networks and for the Transmission network, the Dynamic Transmission Investment Model (DTIM) would be employed to estimate benefits of network technologies that lower reinforcements and balancing costs. DTIM has been used to support the fundamental review of the historic transmission network operation and planning standards in the UK. Using the combination of these two network based models, will allow us to evaluate other "smart" technologies that help minimise costs and risks across the system in addition to those that provide flexibility at the system level – **most analytical approaches would not allow this**. The advantage of this approach is that it allows us to create a potentially wider set of flexible technologies that aid in further minimising regret across a range of uncertain future energy scenarios. Examples of the additional technologies we will potentially consider are:

[redacted]

We will then compare the strategies devised by WeSIM across all scenarios to determine the common and specific deployment of considered flexible technologies. A set of scenarios will be developed either by selecting the optimal deployment of flexible technologies for a specific scenario or by combining the results from different scenarios based on the expert analysis. There is also a possibility to develop new scenarios (e.g. by sensitivity analysis) as a 'sanity check' to ensure that the results obtained previously are really optimal.

Stage 3

We will evaluate the cost and effectiveness of alternative flexibility investment strategies using the portfolio established in 'stage 2' across all Core scenarios and calculate the regret costs by comparing the system performances (economics and environmental) with the scenario-specific optimal results as references. It is important to highlight that a specific flexibility-reinforcement scenario may be optimal for one (or more) scenario but it may not be optimal for others.

For example, [redacted]

Through the sensitivity analysis we will identify a portfolio of flexibility technologies / solutions that would produce "least regret" across all possible scenarios. To obtain an optimised portfolio of flexible solutions, we propose to use an iterative approach based on expert judgement and rerun the model until a robust and satisfactory result is obtained which minimises least-regret.

Stage 4

[redacted]

4- Skills and expertise

Imperial and the Carbon Trust have a strong and well-established working relationship in this technical area. We are currently working together on 2 other projects related to energy system design and flexibility options, the Electricity Networks and Storage (EN&S) TINA and the Storage Joint Industry Project (STORJIP). National Grid scenarios have been used to estimate storage's value under different future energy scenarios and the project also used extensive expert interviews for calibrating current and future costs of energy storage and conventional and renewable energy generators. Additionally, the project examines the commercial case for storage for 2 specific case studies at the transmission and distribution level. In STROJIP we apply least-regrets analysis to making choices under uncertainty and look at opportunities for storage, not only across a range of scenarios but also across a range of price sensitives (gas, nuclear) to determine the business case for investing in storage now, given the uncertainties. Our individual experiences and our ability to work together provides us, as a consortium, with a high level of expertise and understanding which we could bring to this project to most effectively meet DECC's needs.

Expertise in current electricity market and policy landscape

The Carbon Trust has been a trusted advisor to the UK government for over 10 years, analysing and shaping numerous energy policies including the Feed in Tariff (FiT), the Renewable Heat Incentive (RHI), the Green Deal, Contracts for Difference (CfD) and the Climate Reduction Commitment (CRC). We have been working for the UK government on innovation in energy technologies continuously since 2010, including through the Technological Innovation Needs Assessments (TINA) projects, which require a detailed understanding of energy policy and the UK energy system. We work closely with UK energy companies and one of the proposed Expert Contributors, Andrew Lever, worked at E.On, the world's largest investor owned utility, for 8 years before joining the Carbon Trust in 2014. Whilst at E.On Andrew held a number of roles including head of Innovation Europe, Head of UK Retail Strategy, Head of UK Energy Services Strategy and Head of UK Generation Strategy. He brings a wealth of knowledge and experience to the project in this area. The Carbon Trust also advises other governments around the world based on our experience of the current UK electricity market and policy landscape. The Carbon Trust recently has been working on a series of projects relating to the smart grids policy particularly focussing on the UK's experience in formulating policy and regulation in the sector.

Expertise in 'least regrets' analysis and making choices under uncertainty

Imperial has a breadth of knowledge and extensive experience in 'least regrets' analysis and has conducted a number of projects which involved application of min-max regret (least-worst regret) modelling. One project focused on the *Strategic Development of North Sea Grid Infrastructure to Facilitate Least-Cost Decarbonisation*. This aimed to support the development of policy which will deliver multiple objectives in an uncertain and evolving world and help the UK to manage unforeseen risks. The extent of future deployment of offshore renewable resources in the North Sea is an issue of great uncertainty with consequences for network planning. The undersea cables used to connect offshore renewable generation to the mainland grid are expensive, and this cost can be minimised by installing only the capacity required. However there is a large fixed component to the installation cost meaning that additional capacity, beyond the expected requirement, could be installed at the same time at a far lower cost than if the expectation is wrong and the connection has to be upgraded in future years. Imperial applied leading edge modelling techniques to explore whether the current approach to the design of the offshore grid network represents a good policy or whether alternative approaches are more appropriate given the potential importance of offshore resources.

Imperial also used 'least regrets' analysis in a project to address the impact of uncertainty in distribution network planning and the risks associated with capital-intensive network reinforcement decisions. This approach identified robust planning solutions – including conventional and smart in the form of DSR – by minimising the maximum (across all scenarios) regret that the Distribution Network Operator will feel after the materialisation of the uncertain future. This is carried out by balancing the two risks of building capacity that is stranded due to lower than anticipated demand and increased cost of network upgradation due to under sizing assets, particularly those with a large fixed cost component (e.g. underground cables).

Imperial has a demonstrated wealth of knowledge and a deep understanding of 'least regrets' analysis and making choices under uncertainty, evidenced in a number of other projects. These include (but are not limited to):

- D Pudjianto, P Djapic, S Kairudeen, G Strbac "Flexible Plug and Play - Strategic Investment Model for Future Distribution Network Planning", December 2014 (work with UK Power Network - LCNF project).

- P Djapic, M Kairudeen, M Aunedi, J Dragovic, D Papadaskalopoulos, I Konstantelos, G Strbac"Low Carbon London - Design and real-time control of smart distribution networks - Risk-constrained distribution network planning under Uncertainty", January 2015 (work with UK Power Networks, LCNF project)
- D Papadaskalopoulos, M Aunedi, G Strbac, "Role and benefits of ADR in distribution network planning uncertainty", March 2015, (with SSE LCNF project).

Technical expertise and capabilities

Summary of each proposed team members experience and capabilities

The project team in this proposal has both excellent degrees, from world-leading universities in relevant technical areas, and real world experience of least regrets analysis, energy systems, modelling and analytics. Each team member has the high level expertise in modelling and analytics required to deliver the project to DECC's standards. Below is a summary of each proposed team member and their experience and capabilities.

Carbon Trust (CT) Team

James Wilde (proposed Quality Assurance Lead) leads two of Carbon Trust's business units, Policy & Markets and Innovations. James has in-depth expertise in climate change related issues gained from 11 years work at the Carbon Trust – from renewable energy to energy efficiency. James has worked extensively on engaging and informing senior business and Government stakeholders on business opportunities and the risks associated with climate change. He has authored over 30 policy publications and led projects which have resulted in fundamental changes to both the UK and international policy and market landscapes. Prior to joining the Carbon Trust, James was a senior associate at McKinsey & Co where he established an excellent grounding in a wide range of sectors. He holds a PhD in Nanostructured Material from the University of Cambridge and a MEng in Metallurgy and Science of Materials from the University of Oxford.

David Sanders (proposed Project Director – CT) has over 25 years' experience in strategy consultancy, corporate advisory and as a technology entrepreneur, with core expertise in carbon, energy and corporate strategy. Prior to joining the Carbon Trust, David spent 12 years running businesses that provided both strategic consultancy to large corporates and also commercialisation support. David has a track record of success, with achievements including the launch of a €40 carbon fund focused on energy efficiency projects in emerging markets for a European utility. At Carbon Trust David leads the joint industry project on energy storage providing strategic guidance and critical linkage to wider storage industry.

Alex Hart (proposed Project Manager) is a manager in the policy and markets team at the Carbon Trust, with a focus on technologies related to alternative energy vectors. He has extensive knowledge of the strategic challenges in the application and commercialisation of new technologies with particular expertise in commercialising disruptive low carbon technologies in the energy sector. Alex has led projects for the UK Department of Energy and Climate Change (DECC) with large modelling components and has also led projects for government departments in Brazil on how to support innovation in energy technologies. He also has a wealth of experience supporting various projects on energy technology innovation for the private and public sector. Alex holds an MBA from Cranfield University and a MChem from Oxford University.

Manu Ravishankar (proposed Project Associate) has a wide range of expertise from conducting detailed corporate carbon audits to conducting techno-economic assessment of novel low carbon technologies. Manu's area of expertise is Smart Grids and energy storage in the UK, both in terms of policy development for flexible energy systems as well as identifying innovation priorities for public and private sector investment. He is currently working on a joint industry project to identify and quantify systems benefits from energy storage for a future UK low carbon energy system and has expertise in modelling and analytics. Prior to joining the Carbon Trust, Manu worked for a managed services company employing novel Machine-2-Machine (M2M) technology, carrying out large-scale energy management programmes for over 2 years which provided him with an insight into the evolving role of technology in the sustainability and resource management sector. Manu brings a rich academic background in climate change science, sustainability and biotechnology, having gained a distinction in MSc Carbon Management from the University of Edinburgh, an MSc in Managing Environmental Change from the University of St Andrews and a first class BTech in Biotechnology from SRM University, India.

Andrew Lever (proposed Expert Contributor) has 16 years of experience focusing on renewable/low carbon energy generation, energy efficiency and smart grid. At Carbon Trust, Andrew leads the Innovation activities in Scotland to support renewable low carbon energy and energy efficiency. Andrew works closely with Scottish

Government, Scottish Enterprise and UK Government to support the development of renewable low carbon energy, energy efficiency and smart grid solutions. Andrew's core expertise is in low carbon technology strategy development and smart grid/meter technology innovation. Prior to joining the Carbon Trust, Andrew worked internationally with E.ON SE, the world's largest investor owned utility. He held a number of roles including Head of Innovation Europe, Head of UK Retail Strategy, Head of UK Energy Services Strategy and Head of UK Generation Strategy. Andrew holds an MBA from Warwick, a Masters in Energy and Environmental Systems from Glasgow Caledonian University and a Bachelor of Engineering from Strathclyde University.

Nils Lehmann (proposed Expert Contributor) is a manager in the Carbon Trust's Innovation Team, focusing on technology innovation strategy and venturing activities. Nils has worked extensively with technology start-ups, corporates, investors and government to successfully commercialise low carbon technologies. His particular expertise is in supporting clients in developing and realising novel business models in a low carbon economy and he leads the development of the Carbon Trust's client facing innovation support offering for smart energy systems. Nils has previously worked as a project manager to develop recommendations for realising system benefits from energy storage for the UK. Prior to joining the Carbon Trust, Nils was a senior consultant at McKinsey & Company, focused on low carbon strategy work across industries. He holds an MSc in Mathematics with Physics from McGill University.

Imperial Team

Goran Strbac (proposed Project Director – Imperial) is a Professor of Energy Systems, with extensive experience in modelling and analysis of operation, planning, investment and economics of electricity systems. He led the development of novel advanced whole system based approaches and methodologies that have been extensively used to inform electricity industry, governments and regulatory bodies about the system integration costs, role and value of emerging new technologies and systems in supporting effective evolution to smart low carbon future. He is a member of the Steering Committee of the SmartGrids European Technology Platform, Member of DECC Panel of Technical Experts for EMR implementation, Co-chair of Sustainable Districts & Built Environment of the EU Smart Cities and participates in working groups and committees within CIGRE, CIRED IET, IEEE and IEA. He has co-authored 4 books and published over 180 technical papers.

Danny Pudjianto (proposed Project Manager – Imperial) has expertise in power system modelling, analysis and optimisation, power system economics, regulation, system operation, strategic planning, system security and technology integration from power system perspective including smart grids, active network management, demand response, distributed generation, energy storage, and energy networks. He has more than 10 years' experience with public and private sector research projects at the international level. He led the development of the Whole Electricity System Investment Model (WESIM) that has been applied in a number of recent projects. His research interests include impact assessment of implementing alternative network design, standards and operation strategies, e.g. active network management, demand response and network control technologies on the system performance. He has published more than 55 technical papers.

Marko Aunedi (proposed Researcher) is a Research Associate at the Control and Power research group at Imperial College London. His research interests cover generation scheduling under uncertainty, system operation with high penetration of renewable and less flexible generation and the impact of flexible technologies on power system operation. He has almost 15 years of research experience in energy systems modelling analysis and optimisation and has been involved in a number of European and UK-based research projects. He also contributed significantly to a number of studies on the transition towards the low-carbon electricity system. As part of his project work, he has developed and applied models to study the contribution of smart grid technologies to power system operation and design. He has published a number of scientific publications as well as delivered invited lectures on benefits of smart grid and energy storage in many events throughout the world.

Predrag Djapic (proposed Researcher) is a Research Associate at Imperial College London. He has more than 20 years of experience in distribution network analysis, operation and planning, including security, reliability, investment, active management and losses, and development of techniques to guide optimal network design strategies. He has a particular specialisation in power network security and planning, and in the integration of new smart grid technologies into the electricity network to support integration of low carbon technologies. His recent relevant work includes contribution to review of distribution network security standards, evaluation of GB distribution network reinforcement cost driven by uptake of low carbon technologies, development of models to estimate load related expenditure, development and evaluation of alternative distribution network design strategies.

Allocation of resources to responsibilities

The table below shows the role, grade and key activities for each proposed team member and the allocation of days. The project manager and quality assurance lead are highlighted in bold. The activities of Imperial are concentrated in Workstream 2- Analysis. The allocation of effort by task is shown in the Project Plan in the Management and Delivery section.

Team members and key activities

Name	Role	Grade	Firm	Key activities	Days
James Wilde	**Quality Assurance Lead**	Managing Director	Carbon Trust	Independent quality assurance of all deliverables and numerical analysis	[redacted]
David Sanders	Project Director	Director	Carbon Trust	High level direction and oversight of the project	[redacted]
Alex Hart	**Project Manager**	Strategy Manager	Carbon Trust	Day to day project leadership and management, structuring of analysis, drafting of deliverables, regular customer interface	[redacted]
Manu Ravishankar	Associate	Associate	Carbon Trust	Leading the research and analysis of the Carbon Trust	[redacted]
Andrew Lever	Expert Contributor	Director	Carbon Trust	Provide expert input on the electricity market, particularly from a supplier's perspective	[redacted]
Nils Lehmann	Expert Contributor	Manager	Carbon Trust	Provide expert input on smart energy systems	[redacted]
Goran Strbac	Project Director (Imperial)	Professor	Imperial	Oversight, direction and quality assurance for all of Imperials analysis	[redacted]
Danny Pudjianto	Project Manager (Imperial)	Research Fellow	Imperial	Day to day project management and guidance of Imperial's activities	[redacted]
Marko Aunedi	Researcher (Imperial)	Research Associate	Imperial	Leading the modelling and analysis of Imperial	[redacted]
Predrag Djapic	Researcher (Imperial)	Research Associate	Imperial	Provide expert input on optimal network design strategies	[redacted]

5- Management and delivery

Project management

Our reputation is built, in part, upon our ability to manage, direct and ensure coherency of our experts' inputs on all of our assignments. We apply the **highest project management standards** to our work by:

- Maintaining an open and transparent relationships with our clients and partners;
- Quality assuring all of our deliverables;
- Delivering project outputs on-time or ahead of schedule;
- Utilizing a flexible range of formal project management approaches, drawing on elements of the PRINCE 2 project management methodology and our own practical project experience;
- Maintaining a robust financial management system that ensures accuracy and timeliness in financial reporting to clients, and rapid payments to partners; and
- Following the ISO 9001 2008 standards in quality assurance and project management.

Quality at the Carbon Trust

The Carbon Trust has a corporate wide commitment to quality, articulated in our policy which aims to provide our customers with high quality services which meet their requirements and are fit for their purpose. To this end we operate the business to the systems required by ISO9001: 2008, including:

- Providing our customers with high quality services which meet their requirements and are fit for their purpose
- Ensuring all staff are engaged in and committed to our mission and strategy
- Making full use of all of our staff's skills and expertise and bringing the best of the Carbon Trust to every project
- Promoting best practice project and quality management processes across all aspects of our work
- Implementing a systems approach to managing our business including regular meetings and feedback loops across all levels of the organisation to monitor progress and promote continuous improvement
- Promoting a root cause analysis approach to any issues that arise
- Enhancing the skills of management and staff through review and actively pursuing an on-

Managing quality

Within this sector both the Carbon Trust and Imperial maintain outstanding reputations for achieving results. Quality management is fundamental to all of our work at the Carbon Trust— our core values of objectivity, collaboration, creativity, and straightforwardness allow us to deliver high quality and high impact outputs. We do not simply deliver a list of tasks against a ToR — we aim to deliver quality. As a result of our commitment to quality, we have built a reputation for robust analysis and well-articulated reports that can withstand scrutiny by the harshest of critics. For the past 12 years our reports have been widely published and distributed and have informed policy developments on key areas of energy, innovation and carbon policy.

In order to maintain our high standards for quality:

- We ensure we **resource the most capable and qualified staff** on our engagements. We also use the planning stage to manage our "bandwidth" both within projects and across projects to ensure the teams we propose to clients are available to undertake the project once it is underway.
- We **develop a quality management plan** during the project start-up which identifies the quality standards that are relevant to the project. The quality standards identified are communicated to the project team. It is the responsibility of the Project Manager to deliver work in draft in good time both for review and for any necessary downstream revisions to be completed before the delivery deadline.
- We **execute our quality management plan** by instituting regular quality assurance checks at key project junctions. The quality assurance checks are undertaken by our managing director – James Wilde - to ensure the project is delivering at the quality level expected, and the deliverables are aligned with the agreed objectives and specifications laid out with the client. On all of our projects we hold reviews with the appropriate senior experts within the organization to quality assure key deliverables.
- **We learn** from our quality assurance checks and adjust our quality management plan accordingly to minimize future divergences from quality targets.

- We **keep our clients informed**. Our approach to liaison and reporting strikes a balance between keeping the client briefed on major elements of the project whilst seeking to ensure they are not overwhelmed by information overload. Ensuring the client understands how the project is moving along enables us to identify and solve issues early on.

Project plan

Gantt Chart of project plan

[redacted]

We will execute our work plan to ensure that we have results from this flexibility work early in the new year and deliver outputs according to DECC's timeline.

Quality Assurance

We will appoint a senior member of the Carbon Trust to be the 'Quality Assurance Lead' who will be responsible for all quality assurance on the project. This person will otherwise be completely independent of the analysis in the project. They will only interact with the project at specific points to maintain their independence. They will review:

[redacted]

Risk Management/Identification

This project will be carried out to a tight deadline. It will therefore be essential that risks and issues are identified as soon as they arise, and targeting mitigation actions are proposed and agreed. The Carbon Trust takes a proactive organisation-wide approach to risk management, running bi-monthly risk management reviews for each area of the business/programme, and maintain a risk register which prioritises the results with a red/amber/green rating system. Mitigation actions are agreed and implementation of these is monitored at director level.

For individual projects the Project Director maintains a risks/actions/issues/decisions (RAID) log compiled in conjunction with the project team. For this project, we will record strategic (e.g. financial, stakeholder support, reputational, commercial) and operational risks (e.g. project delivery, deliverable quality, etc.) and on a monthly basis these will be reviewed with the Director. The Project Director will implement a mitigation strategy proportional to the likelihood/impact. He will feed issues in to DECC's wider risk management process where their impact extends beyond delivery of this specific project.

For this project, we have identified the following key risks:

[redacted]

Initial Risk Register

Risk	Impact L/M/H	Probability L/M/H	Mitigation
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

* Risks with potential to delay the final report have 'high' impact reflecting the importance to DECC of receiving the results from this flexibility work early in the New Year.

Deliverables

We will have meetings with DECC every two weeks, attended by a project manager. We will update DECC via a weekly phone call or e-mail. All written deliverables will be drafted by the project manager, with guidance from the project director and content provided by the project team. Guidance given to DECC modellers on the functionality of the models and analytical methods will be delivered by the Imperial team.

Project deliverables will be synchronised with update meetings, so that they can be presented and discussed at these meetings. Where appropriate weekly progress updates will be used to verbally discuss aspects of deliverables as they are being developed. Large deliverables, such as the summary report, will be drafted in stages, starting with a skeleton outline of the key points for early discussion with DECC, with the detail added once the outline has been agreed.

We have identified 3 deliverables in the ITT which have associated delivery dates. The table below shows how we propose to group these outputs and the update meetings at which we expect to present them (how these deliverables relate to other activities, including quality assurance, is shown in the work plan).

Deliverable	**Expected Delivery Date**	**Associated meeting**
(1) Interim findings report	4th January 2016	5th Update Meeting with DECC
(2) Draft Final Report	11th March 2016	Penultimate Update Meeting with DECC
(3) Final Report	18th March 2016	Final Update Meeting with DECC

6- Development of DECC's capability

Input data relating to the smart technologies that provide flexibility will be consolidated and updated over the course of this project as inputs to the modelling and these will be shared with DECC. The Carbon Trust and Imperial already hold a large share of the data required on current and future technology cost and performance due to recent collaborative projects such as the EN&S TINA and STORJIP. Further research in this project will build on this, filling knowledge gaps and reducing certainty, particularly around key technologies. Some of the technology costs we currently have updated from previous work are those relating to

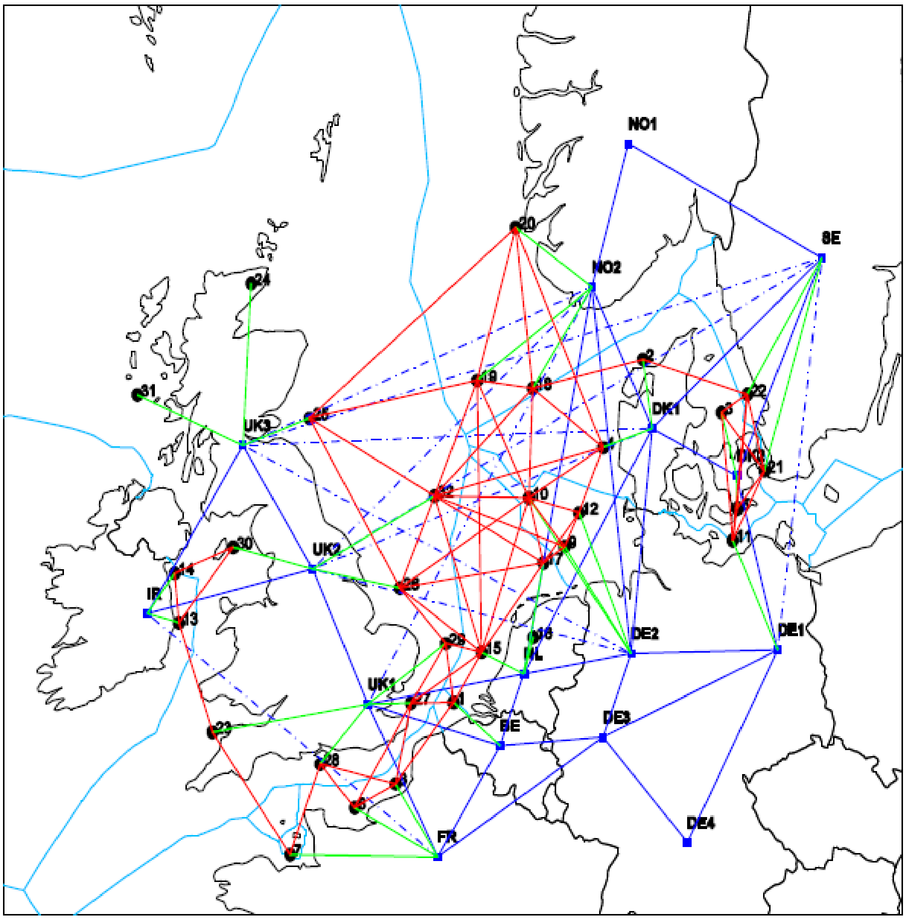
[redacted]

Through the project we will aim to update the extensive datasets of technology costs so that we will be utilising the most updated and available costs for modelling the investment costs into their technologies and benefits they unlock. Importantly, we will be sharing all of the datasets utilised in this exercise with DECC, along with relevant sources so that this can be used across all other modelling work DECC chooses to undertake.

The energy system models and analytical approaches Imperial will use in this project sit within a conceptual framework which facilitates experimental design, interpretation of results and the integration of new tools. Early in the project we will explain this framework to DECC modellers as a way to frame the discussion of the results of the analysis. We will then discuss how Imperial's framework relates to the frameworks DECC uses for its own models. Where this discussion highlights potential improvements to DECC's frameworks we will suggest practical steps DECC could take to develop their in-house capabilities. Potential improvements might include: [redacted].

European energy prices are a crucial element in determining the optimal capacity and utilisation of interconnection and are necessary to determine the flow of energy across interconnectors and hence the economics of such assets. WeSIM contains an integrated European energy market model based on marginal cost pricing theory. It will generate half-hourly profiles of European wholesale energy prices, out to 2050, at the point of interconnection. The prices profiles generated depend primarily on the mixes of European generating fleets, weather profiles, fuel and carbon prices, interconnection capacities and the availability of flexible technologies.

Representation of the European interconnections modelled within WeSIM



These datasets that will be generated will also be further refined over the course of the project and will be shared with DECC along with the other information described above. We propose to run a formal dissemination event specifically for the modellers at DECC to provide detailed information on our approach, assumptions and also the key sensitivities we utilised and the insights that emerged from those model runs so that they will have a better context and understanding of the results and its application.

Section 4

Declarations to be submitted by the Tenderer

Invitation to Tender for modelling and report on 'least regrets' system flexibility in GB energy system

Contents

Declaration 1: Statement of non-collusion

To: The Department of Energy and Climate Change

1. We recognise that the essence of competitive tendering is that the Department will receive a bona fide competitive tender from all persons tendering. We therefore certify that this is a bona fide tender and that we have not fixed or adjusted the amount of the tender or our rates and prices included therein by or in accordance with any agreement or arrangement with any other person.

2. We also certify that we have not done and undertake not to do at any time before the hour and date specified for the return of this tender any of the following acts:

(a) communicate to any person other than the Department the amount or approximate amount of our proposed tender, except where the disclosure, in confidence, of the approximate amount is necessary to obtain any insurance premium quotation required for the preparation of the tender;

(b) enter into any agreement or arrangement with any other person that he shall refrain for submitting a tender or as to the amount included in the tender;

(c) offer or pay or give or agree to pay or give any sum of money, inducement or valuable consideration directly or indirectly to any person doing or having done or causing or having caused to be done, in relation to any other actual or proposed tender for the contract any act, omission or thing of the kind described above.

3. In this certificate, the word “person” shall include any person, body or association, corporate or unincorporated; and “any agreement or arrangement” includes any such information, formal or informal, whether legally binding or not.

…………………………………………………………………………………….
Signature (duly authorised on behalf of the tenderer)

…………………………………………………………………………………….
Print name

…………………………………………………………………………………….
On behalf of (organisation name)

…………………………………………………………………………………….
Date

Declaration 2: Form of Tender

To: The Department of Energy and Climate Change

1. Having considered the invitation to tender and all accompanying documents (including without limitation, the terms and conditions of contract and the Specification) we confirm that we are fully satisfied as to our experience and ability to deliver the goods/services in all respects in accordance with the requirements of this invitation to tender.

2. We hereby tender and undertake to provide and complete all the services required to be performed in accordance with the terms and conditions of contract and the Specification for the amount set out in the Pricing Schedule.

3. We agree that any insertion by us of any conditions qualifying this tender or any unauthorised alteration to any of the terms and conditions of contract made by us may result in the rejection of this tender.

4. We agree that this tender shall remain open to be accepted by the Department for 8 weeks from the date below.

5. We understand that if we are a subsidiary (within the meaning of section 1159 of (and schedule 6 to) the Companies Act 2006) if requested by the Department we may be required to secure a Deed of Guarantee in favour of the Department from our holding company or ultimate holding company, as determined by the Department in their discretion.

6. We understand that the Department is not bound to accept the lowest or any tender it may receive.

7. We certify that this is a bona fide tender.

…………………………………………………………………………........
Signature (duly authorised on behalf of the tenderer)

………………………………………………………………………………
Print name

………………………………………………………………………….
On behalf of (organisation name)

………………………………………………………………………….
Date

Declaration 3: Conflict of Interest (Carbon Trust)

I wish to declare the following with respect to personal or professional interests related to relevant organisations*;

- The Carbon Trust has run numerous UK government funded technology programmes (across a spectrum of SMEs, large corporates and investors generally) in which we have advised, incubated, provided seed funding to, and, on occasion, founded companies active in the clean technology sector – including innovative energy related companies. Within these activities it is not unusual for us to need to manage conflicts of interest. Certain of these companies could potentially seek to access the Programme.
- Specifically, we have an ownership interest in *open energi,* whose vision is to build the world's first demand-side power station. They help organisations across the public and private sector to commercialise their energy loads, improve their energy management and support their sustainability goals.

Where a potential conflict of interest has been declared for an individual or organisation within a consortia, please clearly outline the role which this individual or organisation will play in the proposed project and how any conflict of interest has or will be mitigated.

The following policies and structures will be put in place to ensure the Carbon Trust can actively manage the conflicts identified:

- Individuals from Carbon Trust that will manage the DECC programme will have complete separation from (a) any investee company involved in the Competition or any Carbon Trust staff dealing with any investee company involved in the Competition and (b) any non-investee company involved in the Competition for which there is deemed to be a conflict due to on-going Carbon Trust activity - i.e. a rigid Chinese wall would be in place.
- There will be security controls put in place around access to information, so that only the Carbon Trust staff managing the DECC programme will have access to Competition related information (i.e. any staff members dealing with investee companies involved in the Competition will be strictly precluded from such access). Similarly, the Carbon Trust staff managing the DECC programme will be strictly precluded from accessing any information related to investee companies involved in the Competition or non-investee companies where there is a deemed conflict.
- All investments in investee companies are held through Carbon Trust subsidiaries. This embeds the Chinese wall into the very structure of the Carbon Trust's operations.

- We will regularly monitor, revisit and update DECC on programme conflicts and conflict management, including after each stage of the competition completes.

Signed ……………………………………….

Name ……………………………………….

Position ……………………………………….

Declaration 3: Conflict of Interest (Imperial)

I have nothing to declare with respect to any current or potential interest or conflict in relation to this research (or any potential providers who may be subcontracted to deliver this work, their advisers or other related parties). By conflict of interest, I mean, anything which could be reasonably perceived to affect the impartiality of this research, or to indicate a professional or personal interest in the outcomes from this research.

Signed

Name Goran Strbac

Position *Professor of Energy System, Imperial College London*

Please complete this form and return this with your ITT documentation - Nil returns **are** required.

***** These may include (but are not restricted to);

- A professional or personal interest in the outcome of this research
- For evaluation projects, a close working, governance, or commercial involvement in the project under evaluation
- Current or past employment with relevant organisations
- Payment (cash or other) received or likely to be received from relevant organisations for goods or services provided (Including consulting or advisory fees)
- Gifts or entertainment received from relevant organisations
- Shareholdings (excluding those within unit trusts, pension funds etc.) in relevant organisations
- Close personal relationship or friendships with individuals employed by or otherwise closely associated with relevant organisations

All of the above apply both to the individual signing this form and their close family / friends / partners etc.

If your situation changes during the project in terms of interests or conflicts, you must notify DECC straight away.

A DECLARATION OF INTEREST WILL NOT NECESSARILY MEAN THE INDIVIDUAL OR ORGANISATION CANNOT WORK ON THE PROJECT; BUT IT IS VITAL THAT ANY INTEREST OR CONFLICT IS DECLARED SO IT CAN BE CONSIDERED OPENLY.

Declaration 4: Questions for tenderers

In some circumstances the Department is required by law to exclude you from participating further in a procurement. If you cannot answer 'no' to every question in this section it is very unlikely that your application will be accepted, and you should contact us for advice before completing this form.

Please state 'Yes' or 'No' to each question.

Has your organisation or any directors or partner or any other person who has powers of representation, decision or control been convicted of any of the following offences?	**Answer**
(a) conspiracy within the meaning of section 1 or 1A of the Criminal Law Act 1977 or article 9 or 9A of the Criminal Attempts and Conspiracy (Northern Ireland) Order 1983 where that conspiracy relates to participation in a criminal organisation as defined in Article 2 of Council Framework Decision 2008/841/JHA;	No
(b) corruption within the meaning of section 1(2) of the Public Bodies Corrupt Practices Act 1889 or section 1 of the Prevention of Corruption Act 1906; where the offence relates to active corruption;	No
(c) the offence of bribery, where the offence relates to active corruption;	No
(d) bribery within the meaning of section 1 or 6 of the Bribery Act 2010;	No
(e) fraud, where the offence relates to fraud affecting the European Communities' financial interests as defined by Article 1 of the Convention on the protection of the financial interests of the European Communities, within the meaning of:	No
(i) the offence of cheating the Revenue;	No
(ii) the offence of conspiracy to defraud;	No
(iii) fraud or theft within the meaning of the Theft Act 1968, the Theft Act (Northern Ireland) 1969, the Theft Act 1978 or the Theft (Northern Ireland) Order 1978;	No
(iv) fraudulent trading within the meaning of section 458 of the Companies Act 1985, article 451 of the Companies (Northern Ireland) Order 1986 or section 993 of the Companies Act 2006;	No
(v) fraudulent evasion within the meaning of section 170 of the Customs and Excise Management Act 1979 or section 72 of the Value Added Tax Act 1994;	No
(vi) an offence in connection with taxation in the European Union within the meaning of section 71 of the Criminal Justice Act 1993;	No

(vii) destroying, defacing or concealing of documents or procuring the execution of a valuable security within the meaning of section 20 of the Theft Act 1968 or section 19 of the Theft Act (Northern Ireland) 1969;	No
(viii) fraud within the meaning of section 2, 3 or 4 of the Fraud Act 2006; or	No
(ix) making, adapting, supplying or offering to supply articles for use in frauds within the meaning of section 7 of the Fraud Act 2006;	No
(f) money laundering within the meaning of section 340(11) of the Proceeds of Crime Act 2002;	No
(g) an offence in connection with the proceeds of criminal conduct within the meaning of section 93A, 93B or 93C of the Criminal Justice Act 1988 or article 45, 46 or 47 of the Proceeds of Crime (Northern Ireland) Order 1996; or	No
(h) an offence in connection with the proceeds of drug trafficking within the meaning of section 49, 50 or 51 of the Drug Trafficking Act 1994; or	No
(i) any other offence within the meaning of Article 45(1) of Directive 2004/18/EC as defined by the national law of any relevant State.	No

Signed ……………………………………….

Name ……………………………………….

Position ……………………………………….

Declaration 5: Code of Practice[3]

I confirm that I am aware of the requirements of the DECC Code of Practice[4] for Research and, in the proposed project, I will use my best efforts to ensure that the procedures used conform to those requirements under the following headings[5]:

- Responsibilities
- Competence
- Project planning
- Quality Control
- Handling of samples and materials
- Facilities and equipment
- Documentation of procedures and methods
- Research/work records

I understand that DECC has the right to inspect our procedures and practices against the requirements of the Code of Practice, and that I may be asked to provide documentary evidence of our working practices or provide access and assistance to auditors appointed by DECC.

(There is some flexibility in the application of the Code of Practice to specific research projects. Contractors are encouraged to discuss with DECC any aspects that cause them concern, in order to reach agreement on the interpretation of each requirement.)

Signed ……………………………………

Name ……………………………………

Position ……………………………………

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[3] Please note that this declaration applies to individuals, single organisations and consortia.

[4] The Code of Practice is attached to this ITT as Annex C

[5] Please delete as appropriate

Annex A: Pricing Schedule

Part A – Staff/project team charges

Set up Costs – please specify	[redacted]
Expenses	No more than [redacted]

*Grade / level of staff	Daily rate (ex VAT)	No. days offered over course of contract	Tasks to be undertaken on this project	Total price offered per grade (before discount)	Contribution in kind	Total price offered per grade (after discount)
Director	[redacted]	[redacted]	Project director, expert input and QA lead	[redacted]	[redacted]	[redacted]
Manager	[redacted]	[redacted]	Project manager and expert input	[redacted]	[redacted]	[redacted]
Associate	[redacted]	[redacted]	Analysis	[redacted]	[redacted]	[redacted]
Professor	[redacted]	[redacted]	Project director (Imperial)	[redacted]	[redacted]	[redacted]
Research Fellow	[redacted]	[redacted]	Project Manager (Imperial)	[redacted]	[redacted]	[redacted]
Research Associate	[redacted]	[redacted]	Researcher (Imperial)	[redacted]	[redacted]	[redacted]
Sub-total				[redacted]		**£104,720**

[*Suppliers should also include sub-contractors]

Part B – Non-staff/project team charges

Item	**No. of items**	**Price per item (ex VAT)**	**Total price per offered**
		£	£
		£	£
		£	£
		£	£
		£	£
Sub-total			**£0**

Part C – Full price offered

Sub-total (Part A + Part B)	**£104,720**
VAT	**£20,944**
TOTAL (Sub-total + VAT)	**£125,664**