Technology Innovation Needs Assessment (TINA)

Offshore Wind Power
Summary Report

February 2012

Background to Technology Innovation Needs Assessments

The TINAs are a collaborative effort of the Low Carbon Innovation Co-ordination Group (LCICG), which is the coordination vehicle for the UK's major public sector backed funding and delivery bodies in the area of 'low carbon innovation'. Its core members (at the time of this document's completion) are the Department of Energy and Climate Change (DECC), the Department of Business, Innovation and Skills (BIS), the Engineering and Physical Sciences Research Council (EPSRC), the Energy Technologies Institute (ETI), the Technology Strategy Board, and the Carbon Trust.

The TINAs aim to identify and value the key innovation needs of specific low carbon technology families to inform the prioritisation of public sector investment in low carbon innovation. Beyond innovation there are other barriers and opportunities in planning, the supply chain, related infrastructure and finance. These are not explicitly considered in the TINA's conclusion since they are the focus of other Government initiatives, in particular those from the Office of Renewable Energy Deployment in DECC and from BIS.

This document summarises the Offshore Wind Power TINA analysis and draws on a much more detailed TINA analysis pack which will be published separately.

The TINAs apply a consistent methodology across a diverse range of technologies, and a comparison of relative values across the different TINAs is as important as the examination of absolute values within each TINA.

The TINA analytical framework was developed and implemented by the Carbon Trust with contributions from all core LCICG members as well as input from numerous other expert individuals and organisations.

DEPARTMENT OF ENERGY & CLIMATE CHANGE

BIS Department for Business Innovation & Skills

Research Councils UK Energy For a Low Carbon Future

CARBON TRUST

energy technologies institute

Technology Strategy Board Driving Innovation

Key findings

Offshore wind has tremendous potential to replace aging power plant, reduce reliance on imported gas, and meet GHG emissions and renewable energy targets. Innovation is critical to enabling the deployment and cutting the cost of offshore wind, with an estimated saving to the energy system of £18-89bn[1] to 2050. Innovation can also help create UK based business opportunities that could contribute an estimated £7-35bn to GDP to 2050. Significant private sector investment in innovation, catalysed by public sector support where there are market failures, is needed to unlock these opportunities.

Potential role in the UK's energy system	• The UK has a large natural resource of wind power around its coast, and offshore wind power is a commercially available, proven technology to capture this resource. • Over the next decade, offshore wind has the potential to replace much of the UK's aging power plant whilst helping to meet our GHG emissions and renewable energy targets and reducing reliance on gas and fuel imports. Offshore wind can be rapidly deployed at scale with fewer planning constraints than onshore wind, has a quicker development time than nuclear power and, unlike CCS, has already been proven at scale. • By 2050 sensitivity analysis suggests offshore wind could deliver c.20-50% of total UK electricity generation. This depends primarily on the constraints (economic, technical or public acceptance) to alternatives (onshore wind, nuclear, and CCS), and on the overall energy demand.
Cutting costs by innovating	• However, offshore wind power is currently a relatively high cost source of energy. How much and how quickly it is deployed will depend on how successful innovation is in reducing costs. • Innovation has the potential to drive down the costs of offshore wind by 25% by 2020 and 60% by 2050. Together with savings in the supply chain and financing, this could reduce the cost of energy to about £100/MWh by 2020 and £60/MWh by 2050. Such improvements would enable large deployment potential, and greatly reduce energy system costs. • Successfully implementing innovation would save the UK in the range of £18–89bn to 2050.
Green growth opportunity	• The UK could become one of the leaders in a global offshore wind market, with a 5-10% share of a market with potential cumulative gross value-added of between £200 - 1,000bn up to 2050. • If the UK successfully competes in a global market to achieve the market share above, then the offshore wind industry could contribute £7 – 35bn to UK GDP up to 2050 (cumulative).
The case for UK public sector intervention	• To unlock this opportunity there is a strong case for targeted public sector intervention to catalyse private sector investment – there are significant market failures to innovation and the UK cannot exclusively rely on other countries to develop the technologies within the required timescales. – There are on-going market failures, including demand uncertainty (*negative externalities),* a lack of shared test facility and other infrastructure requirements (*public goods),* insufficient payback on early stage R&D and insufficient coordination and sharing of data (*positive externalities/IP spillover*). Other potentially short-term market failures include limited competition in some areas, notwithstanding expected new entry into this industry, and a constraint on capital availability. – The UK has an earlier and greater need for offshore wind than other countries, and UK farms are further out to sea and in deeper water than other earlier adopters.

[1] Cumulative (2010-2050) present discounted values for low-high scenarios. Depending on counterfactual methodology (see below), these values could be ~65% lower (i.e., roughly £6-32bn)

Potential priorities to deliver the greatest benefit to the UK	• Innovation areas with the biggest benefit to the UK are: – Test sites and drive train and blade testing facilities to support development of high yield/reliability turbines – Novel/innovative designs of: high yield/reliability turbines, foundations for depths of greater than 30m, cabling concepts, installation techniques that are fast, low cost and can access deep water and O&M vessels/access systems – Developing serial manufacturing/production of foundations – Measurement and sharing of test data • The LCICG is already delivering a number of publically supported innovation programmes that are working on addressing most of these innovation areas. Substantial further UK public sector investment is planned, with the LCICG members together expected to invest in excess of £100m of funding over the next 3-4 years, leveraging up to three times that from the private sector. • To realise the full benefit from innovation over the following 4-10 years will require on-going support to existing areas, scaling up a subset as they move from design to demonstration, as well as adding a prioritised set of new programmes. • Supporting *all* the prioritised innovations would require a significant increase in public sector funding to UK projects in future funding periods. Resources will therefore need to be targeted on particular areas but material impact can be achieved by doing so.

Chart 1 Offshore wind TINA summary

Sub-area	Focus	Value in meeting emissions targets at low cost £bn[2]	Value in business creation £bn[3]	Key needs for public sector innovation activity/investment
Turbines	High yield / reliability turbines	11 (5 – 19)	4 (1 – 7)	• Funding for demonstration sites (both on wind farm extensions and at national centres); accelerated consenting to enable testing of innovative designs • Drive train and blade testing facilities • Coordinated pooling and dissemination of reliability data • Funding to develop novel components and demo turbines for testing new components • Product and process development – not core to innovation support, but critical *complementary* support to the creation of competitive advantage
	High yield arrays	6 (2 – 10)		• Funding wake effects measurement and modelling
Foundations	<30m	4 (2 – 3)		• Development of serial manufacturing processes
	30-60m	6 (2 – 6)	3 (1 – 5)	• Development of novel foundation designs – concept development, detailed design and demonstration of foundations tailored for larger turbines in 30-60m water depths • Development of serial manufacturing processes and potentially fabrication facilities
	60-100m	0 (0 – 13)		• Development and demonstration of new concepts such as floating foundations
Collection & Transmission	Improved intra-array connections	4 (2 – 8)	1 (0.3 – 2)	• Design and test innovative cabling concepts – including higher voltage AC, DC arrays and integration with national and supergrid • Develop, design and test centralised power clean-up
Installation	Increased installation rate/deep water	7 (3-17)	2 (1 – 4)	• Design and test new installation vessels, float-out concepts and other installation innovations (e.g. cranes for feeder concepts)
O&M	Improved access technologies	5 (1 – 9)	9 (3 – 16)	• Design and test novel vessels and transfer systems
	Remote monitoring/ O&M planning	2 (1 – 4)		• Coordinate the installation and usage of condition monitoring equipment in all offshore wind turbines and the dissemination of this pooled data set
Total	**Value:**	**£45bn (18 – 89)**	**£18bn (10 – 35)**	**5-10 year investment in the hundreds of millions of GBP (programmes of material impact in individual areas in the millions to tens of millions of pounds)**

Benefit of UK public sector activity/investment[4]	
	High
	Medium
	Low

Source: DECC '2050 Pathways Analysis' (2010); UKERC 'Great expectations: The cost of offshore wind in UK waters' (2010); expert interviews; Carbon Trust analysis

[2] 2010-2050 Medium deployment / High improvement (L/H – H/H)
[3] 2010-2050 with displacement
[4] Also taking into account the extent of market failure and opportunity to rely on another country but without considering costs of the innovation support

Offshore wind has an important role to play in the UK energy system

Offshore wind has large resource potential, and although it is more expensive than onshore wind, it is more scalable and is dealt with as major infrastructure in planning terms. Moreover, while its cost-competitiveness against nuclear and CCS is still uncertain, it is currently deployable sooner and faster than either of these. This means that it is a low carbon alternative to CCGT that can be deployed at the required scale to replace aging power plant ready for decommissioning.

Nevertheless, how much and how quickly offshore wind is deployed (especially in the medium to long run) will depend on how successful innovation is in reducing costs. The improvement potential from innovation is very large (detailed below), and various energy system modelling exercises suggest that offshore wind could cost-effectively deliver c.20-50% of total electricity generation by 2050.

While innovation will play an important role in ensuring offshore wind is deployed at large scale, the overall capacity installed also depends significantly on key “exogenous” factors, especially the cost of alternative generation technologies, the degree of public acceptability of onshore wind and nuclear, the (relative) technical success of CCS, the availability of biomass for energy use, the overall energy/electricity demand, and the success of energy efficiency and demand reduction measures.[5]

We have considered 3 indicative deployment levels of offshore wind, aligned to different beliefs about the exogenous factors affecting the future energy system (these scenarios aim to capture the full range of feasible deployment scenarios, and are neither forecasts for the UK nor targets for policy makers[6]):

- **Low scenario** (8GW by 2020, 20GW by 2050) if there are few constraints on nuclear, CCS and onshore wind, energy demand is relatively low (through successful energy efficiency and demand reduction measures), large amounts of biomass are available for energy needs, and electrification of heat and transport is relatively limited
- **Medium scenario** (18GW by 2020, 45GW by 2050) if there are moderate constraints on nuclear, CCS and/or onshore wind, energy demand is moderate (owing to only partial success of reduction measures), and electrification occurs extensively in heat or transport
- **High scenario** (29GW by 2020, 100GW by 2050) if there are strong constraints on nuclear, CCS and onshore wind, biomass availability is limited, or energy/electricity demand is relatively high

These deployment scenarios were generated based on CCC MARKAL runs for the fourth carbon budgets, DECC 2050 calculator scenarios, and customised runs of the ESME model for this work. ESME determines how much capacity is required across the generation mix to meet energy demand and emissions reduction targets at lowest cost based on the constraints outlined above.

Whilst all scenarios meet energy demand and carbon emission constrains, it is unlikely that the low 8GW 2020 scenario would meet renewable energy targets without significant trading.

The medium 18GW by 2020 and 45GW by 2050 is used as the central scenario for the following analyses.

[5] Successful deployment of offshore wind will also depend on other factors affecting the energy system such as the grid upgrades and connections. Our analysis of deployment potential took those factors (and their cost) into account, including ensuring that the proportion of variable offshore wind generation was feasible within an optimised energy system, but this TINA does not look at the innovation and other challenges related to these developments.

[6] By trying to capture the full range of uncertainty over the mid to long term to inform innovation policy, these indicative deployment levels were not precisely aligned with UK government short and mid-term targets.

Cutting costs by innovating

Current costs

Offshore wind power currently costs about £3.1m/MW and over £140/MWh[7] for a typical Round 2 site. However, the costs are very site-specific, driven by water depth, distance to shore, and wind speed. Round 3 sites are typically deeper and further from shore, which means costs are likely to be higher all other things being equal. Compared to typical near-shore shallow-water site, moving to water depth of 40-60m can increase the cost of energy by 15-20%, and moving beyond 100km offshore can increase cost of energy by another 15-20%. However, this can be compensated for by higher wind speeds which improve the capacity factor – cost reductions of up to 20% can be achieved if the site is in a high-wind speed regime.

Therefore innovation must tackle not only the cost challenges of shallow-water near-shore sites, but also deliver new technologies for Round 3 and beyond which will reduce the sensitivity of cost to water depth and distance-to-shore.

Offshore wind systems can be split into five major technology sub-areas: the turbine and their integration into arrays, foundations, collection & transmission, installation and operation & maintenance. The turbines constitute the largest share of cost of energy (28%) followed by the foundation, installation and O&M (about 20% each) with connect & transmission the lowest cost element (13%) as detailed in Chart 2.

Chart 2 Overview of offshore wind sub-areas

Sub-area	Descriptions	% COE
Turbines	• Current turbines are less than or equal to 5-6 MW, with 3 blades on a horizontal axis, and most designs use gearboxes to drive the generator • Turbines are installed in arrays to create large wind farms	28%
Foundation	• <30m foundations are usually simple steel tubes e.g. monopiles, although larger turbines may use more sophisticated foundations • Foundations suited for 30-60m water depth are more sophisticated than monopiles and are fixed to the sea floor e.g. concrete gravity bases, tripods or jackets • Floating platforms could potentially be used in 60-100m depths – for example, tension leg platforms; various spar buoy concepts are being developed outside of the UK for depths >>100m	19%
Collection & Transmission	• Currently high voltage AC (HVAC) cables are used to link turbines to an offshore substation, with power clean-up at each turbine • HVAC cables are also used to transmit power to the onshore substation as current wind farms are relatively close to shore within (60-80km)	13%
Installation	• Currently oil & gas vessels that jack-up from the seabed to install the foundation and turbine. Dynamic positioning (DP2) vessels have also been used to a certain extent, but this is not yet the norm	22%
O&M	• Current access technologies involve helicopter transfers and direct boat access from shore which works best in calm seas • Limited remote condition monitoring	18%

Source: Carbon Trust ‘Offshore Wind: Big Challenge, Big Opportunity’ (2008), BVG Associates, Expert interviews

[7] Offshore wind costs (and those of other generation technologies) depend critically on factors such as the level of competition in the supply chain, efficient financing mechanisms, world commodity prices, and the value of the Pound. For example, the cost of offshore wind is believed to be about 50% higher than it might have been had the Pound held its value of 3 years ago, and commodity prices not risen. This analysis holds those other factors constant, focussing instead on the impact of innovation. As such, the anchor costs of £140/MWh does not necessarily represent the actual costs, but rather a reasonable base cost from which to assess the potential for innovation improvements.

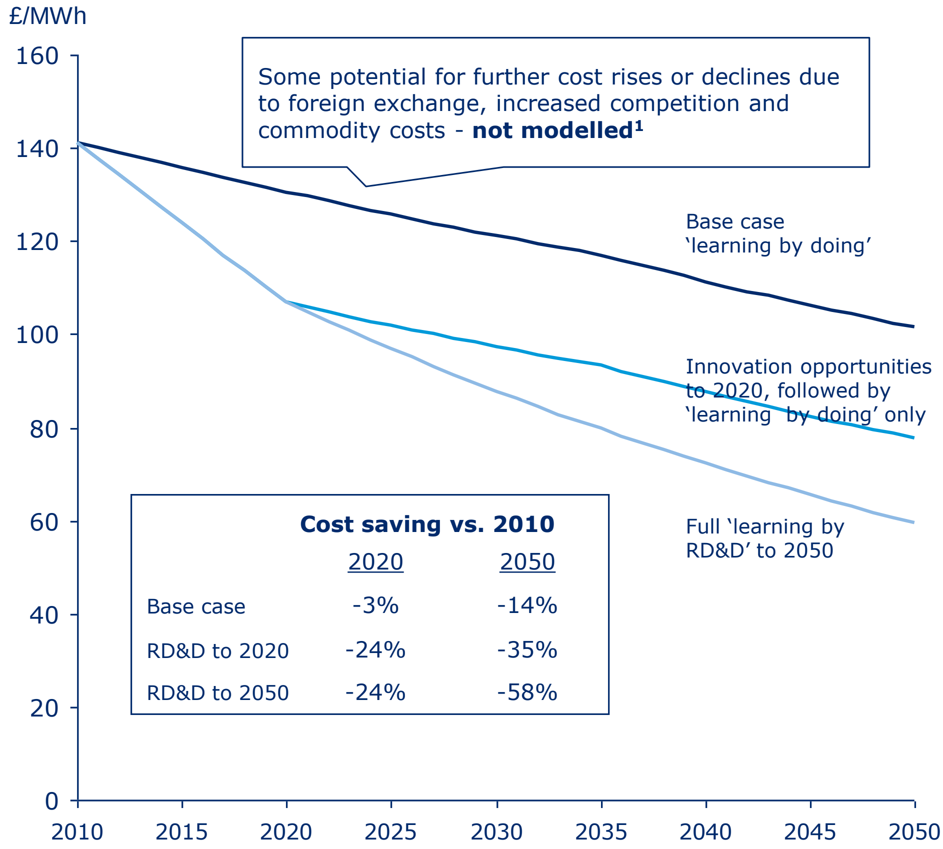
Cost savings through economies of scale and innovation

Offshore wind power is a relatively nascent technology compared to the gas, coal and nuclear technologies that make up the majority of our current generation mix. Offshore wind power has been deployed at scale since 2002. It has been proven to operate in harsh offshore conditions. Nevertheless technologies are largely based on modified onshore wind turbines and oil/gas foundations. Further innovation is required at both a system level and in each sub-area to reduce costs and enable deployment in deeper water, further offshore.

Innovation opportunities over the next 10 years can bring down the deployment costs of offshore wind by up to ~25%, with further savings after 2020 likely to bring down costs even further (up to c.60% by 2050).

Cost savings are also possible in the supply chain and financing. Combined with a high level of innovation, the cost of energy from offshore wind power would be about £100/MWh by 2020[8] and £60/MWh by 2050 (see Chart 3).

Chart 3 Potential impact of innovation on levelised costs of an example offshore wind site



1 Such factors were taken as independent of innovation improvement potential, and its value. Hence the analysis normalises for these factors (i.e. holds them "constant"). For this reason today's levelised costs estimate of ~£140/MWh may be somewhat lower than current estimates. This has no impact on our main conclusions.

Source: Carbon Trust 'Offshore Wind: Big Challenge, Big Opportunity' (2008); DECC '2050 Pathways Analysis' (2010): ETI ESME; UKERC 'Great expectations: The cost of offshore wind in UK waters' (2010); Carbon Trust 'Focus for success' (2009); expert interviews; Carbon Trust analysis

[8] The Crown Estate and DECC have created the Offshore Wind Taskforce to look at how we can reduce the cost of offshore wind to £100MWp/h by 2020

The scenario 'Innovation opportunities up to 2020' is based on a bottom-up assessment of highest potential cost and yield improvements identified and potentially commercialisable by ~2020 as shown in Chart 4. Full innovation until 2050 is a top-down assessment of the long term potential for cost reduction and yield improvement, with c. 50-60% reductions in CAPEX and OPEX.

These estimates include maximum innovation potential, combining 'learning by research' (driven by RD&D spending)[9] and 'learning by doing' (achieved through the incremental learning associate with increased deployment alone)[9] – the bottom path in Chart 3. This path is steeper than a base case scenario with only 'learning by doing' (without focussed RD&D activity). The path in-between these in Chart 3 incorporates the maximum innovation opportunities to 2020, followed by 'learning by doing' only.

Chart 4 Potential cost savings from innovation by sub-area

Sub-area	Type	Foreseeable innovation impact potential[1] (by ~2020)	Innovation impact potential by 2050 (levelised cost)	What is needed (source of improvement potential)
Turbine	High yield / reliability turbines High Yield arrays	8% yield increase 4% yield increase	c.50%	▪ Series of innovations in turbines, blades and generators will increase yield and reliability ▪ Better array layout designs to optimise wind farm yields. For example, to limit wake effects ▪ Increase scale, greater reliability and optimised designs give scope for further cost reduction
Foundation	<30m 30-60m 60-100m	40% capex reduction 40% capex reduction 60% capex reduction	c.70%	▪ New design structures for 30-60m (e.g. improved jackets, gravity base or suction buckets) will lower material and construction costs as will serial production techniques. These structures and manufacturing processes will likely also provide cheaper alternative for shallower water ▪ Floating foundations, once proven, will lower costs (60% capex reduction foreseeable)
Collection & Transmission	Intra-array and to-shore connections	2% yield increase	c.50%	▪ Higher voltage intra-array cabling will reduce transmission losses ▪ Longer term improvements may result from centralised power clean-up
Installation		40% increase in installation rate	c.60%	▪ Newly designed higher efficiency installation vessels, float out concepts and/or other innovations will reduce the installation costs or large scale farms, far from shore
Operation & Maintenance	Access O&M planning	4% yield increase 1.5% yield increase	c.55%	▪ New technologies enabling access to turbines in rougher sea conditions will reduce down time for far from shore turbines and increase yield ▪ Better O&M planning by using data from monitoring devices smartly will reduce down time from turbines
Total (Levelised cost)		c.25%	c.60%	

[1] The innovation impact potential represents what experts deem to be "aspirational but feasible", and will form the central scenario for our modelling, our innovation goals, and our value assessments. Project development cost are smeared over the components of the system and re-powering is excluded

Source: Carbon Trust 'Offshore Wind: Big Challenge, Big Opportunity' (2008); Carbon Trust 'Focus for success' (2009); expert interviews

[9] As defined in Jamasb, T. (2007). Technical Change Theory and Learning Curves: Patterns of Progress in Energy Technologies, The Energy Journal, Vol. 28, Issue 3, 45-65.

Value in meeting emissions and energy security targets at lowest cost

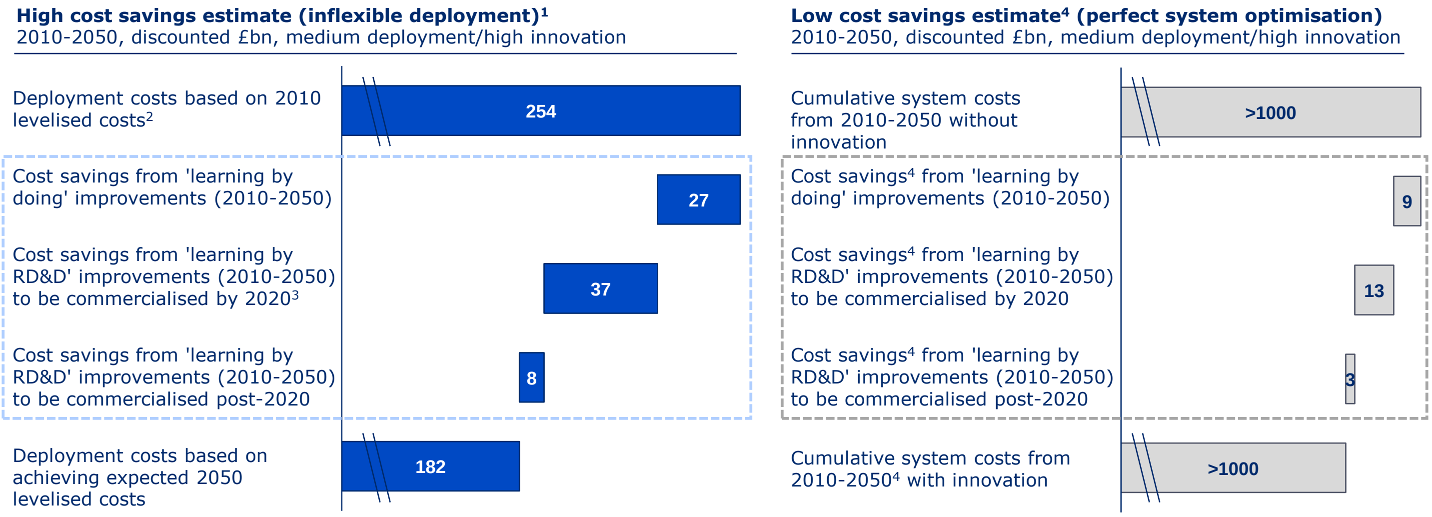
Based on our cost and efficiency improvements, and our scenarios for deployment (taking into account emissions and energy security constraints), we calculate the potential savings in energy system costs through innovation.

In our medium scenario, the identified innovation opportunities lead to a saving of £45bn in deployment costs over 2010-2050. As shown in the left hand side of Chart 5 below, the majority of this, £37bn, is from ‘learning by research’ improvements achievable by 2020. An additional £8bn is saved from ongoing ‘learning by research’ post 2020. The £45bn cost saving from RD&D is in addition to the base case £27bn cost saving from ‘learning by doing’. These savings estimates use an ‘inflexible deployment’ counterfactual, which is most appropriate if we believe the feasibility of substitute technologies is low and/or deployment incentives are inflexible to changes in the relative cost-effectiveness of different technologies. This is a high cost saving estimate.

An alternative counterfactual was also used assuming ‘perfect system optimisation’ whereby offshore wind deployment could adjust significantly if cost improvements are not achieved, which is more appropriate when least cost alternatives are readily available and easily substitutable and deployment incentives adjust perfectly to changes in the relative cost-effectiveness. Under this counterfactual, our savings estimate would be about 65% lower. The right hand side of Chart 5 illustrates the implied cost savings under perfect system optimisation. The actual cost savings are likely to be somewhere in between the inflexible deployment and the perfectly optimised system scenarios. We have shown the former estimates throughout this paper to give a clear indication of the upper limit of our estimates.

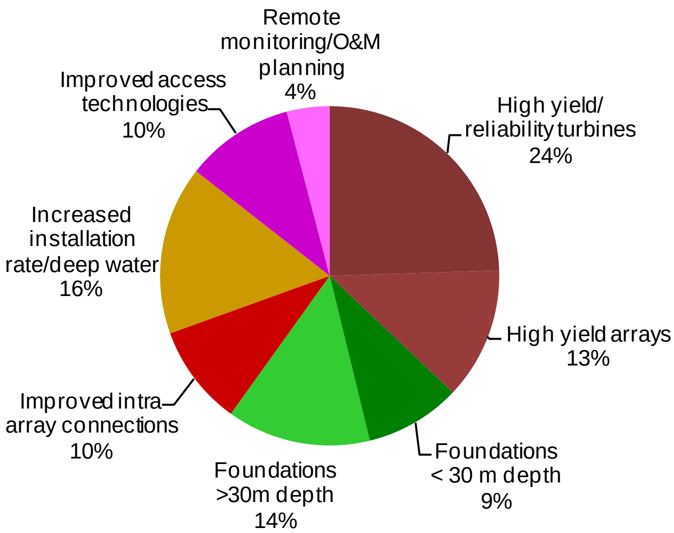
The savings opportunity can be further broken down by each sub-area, as shown in Chart 6. The greatest cost savings are from high yield/reliability turbines (and feedback suggests this is a conservative estimate). The next highest cost savings are from foundations and increased installation rate/in deep water.

Chart 5 Potential cost savings from 2010 to 2050 – assuming inflexible deployment (left-hand chart) or perfect system optimisation (right-hand chart)



[1] Cumulative levelised cost of offshore wind capacity installed between 2010 and 2050 discounted to 2010 using the social discount rate
[2] £254bn is the total actual cost of deployment (medium scenarios), it does not represent the additional cost over the best high-carbon alternative
[3] About £2bn of the 2020 deployment cost saving will be delivered by 2020, equivalent to about £4bn of capex between 2010-20
[4] Cumulative system costs and savings are as calculated by running one representative scenario in the ESME model (with TINA-specific assumptions) without cost improvements. Model assumes ~80% reduction in greenhouse gas emissions by 2050; The total cumulative system costs are highly sensitive to all assumptions in the model, and to avoid “false precision” we do not provide a precise figure; for similar reasons cost savings estimates are also highly sensitive.
Source: DECC ‘2050 Pathways Analysis’ (2010); UKERC ‘Great expectations: The cost of offshore wind in UK waters’ (2010); expert interviews; Carbon Trust analysis

Chart 6 Potential cost savings from 2010 to 2050 by sub-area (medium deployment scenario)



Source: Expert interviews (including input from ETI, RPS, GL Garrard Hassan, RUK, and developers), DECC, UKERC, Carbon Trust analysis

Green growth opportunity

A large global offshore wind market

A large amount of offshore wind power is required globally as well as in the UK, with IEA estimates ranging widely from around 100GW to over 1,000GW by 2050:

- **Low scenario** (32GW by 2020, 119GW by 2050) if the world fails to remain on a path to 2 degrees Celsius and/or few constraints on nuclear and CCS, and/or electricity demand is low, relatively
- **Medium scenario** (86GW by 2020, 439GW by 2050) the world keeps on a 2 degrees path and few constraints of nuclear and CCS
- **High scenario** (118GW by 2020, 1142GW by 2050) the world keeps on a 2 degrees path and there are strong constraints on nuclear and CCS

Across the low-medium-high scenario, the global market turnover by 2050 could grow to £16bn – £168bn (£56bn in medium scenario) (undiscounted). In the medium scenario, this represents potential cumulative, discounted GVA between 2010 and 2050 of £526bn.

The UK could be one of the market leaders

The UK is well positioned to become one of the leaders in the global offshore wind market, achieving a market share of 5-10% in 2050. It can leverage its capabilities from the offshore oil and gas, maritime, aerospace and other sectors which allow the UK to create a strong position in turbines, foundations, installation and O&M.

Market shares will vary by each sub-area (turbine, foundation etc.), from 3% in turbine components, competing against established foreign competitors, to 15% in installation, leveraging the UK's skills from the North Sea oil & gas industry.

£10 – 35bn net contribution to the UK economy

If the UK successfully competes in a global market to achieve the market share above, then offshore wind could contribute c.£2.6bn (£0.8 – 7.4bn)[10] in GVA per annum by 2050, a cumulative contribution[11] of c.£37bn (£14 – 69bn)[10] to 2050.

It may be appropriate to apply an additional displacement effect since part of the value created in the export market will be due to a shift of resources and thus partly cancelled out by loss of value in other sectors. Expert opinion has roughly assessed this effect to be between 25% and 75%, so we have applied a flat 50%. Including this displacement factor, offshore wind would still make a net contribution of £1.3bn (£0.4 – 3.7bn)[10] in GVA per annum by 2050, a cumulative contribution of c.£18bn (£7 – 35bn)[10] to 2050.

[10] Medium (Low – High) deployment scenarios

[11] Discounted at 3.5% to 2035, and 3.0% between 2035 and 2050, in line with HMT guidelines

The case for UK public sector intervention

Public sector activity is required to unlock this opportunity – both the £45bn reduction in the costs to the energy system from learning by research, and the c.£18bn net contribution to UK GDP from new business creation.

Market failures impeding innovation

A number of overall market failures inhibit innovation in offshore wind, especially critical failures in market demand (externality effects) and infrastructure conditions (public good effects). Significant failures in supply conditions (e.g. oligopoly power and constraints on capital availability) also exist, but are expected to be ameliorated in the future.

Within the value chain, the critical market failures have most impact on:

- turbine and foundations
    - test sites / facilities
    - associated monitoring and pooling of reliability data
    - development of novel/innovative concepts
- sharing wind farm wake effects data
- innovative installation methods and vessels

These are further detailed in Chart 7 below.

The UK cannot rely on other countries to drive innovation with the required focus and pace

For most offshore wind technologies, the UK cannot wait and just rely on other countries to intervene in tackling these market failures, and in driving innovation with the focus, and at the pace, required for UK value creation.

Overall, the UK has an earlier and greater need than other countries:

- Offshore wind comprises a much larger share of UK renewable resource than in most other countries
- The UK lags behind its European peers on renewable deployment with only 4% of electricity demand compared to a 15% EU average. Germany and China both have ambitions to deploy double-digit GWs of offshore wind capacity, but have fewer pressing requirements driving for significant deployment by 2020
- UK RD&D programmes have been among a handful of leaders in offshore wind, and there would be some time lag before other major programmes were able to catch up and supersede UK efforts given that they start from a lower base

Finally, the UK has specific needs in the technology sub-areas:

- Foundations – the UK has a greater need than most others for 30-60m foundations and a potential specific need for 60 - 100m foundations; it could potentially rely on others for very deep water (100m+) foundations
- Installation and O&M – to meet ambitions some UK farms will have to be in deeper water and further out to sea than other earlier adopters
- O&M – UK farms have larger arrays and some are in tougher wave climates[12] and further out to sea than other earlier adopters

[12] The Dogger Bank and west coast of Scotland have particularly tough wave climates

Chart 7 Market failures in offshore wind innovation areas

Sub-area	What market failures exist?	Assessment
Turbines - High yield/ reliability turbines	1. **Test sites and facilities lacking due to high capital costs, demand uncertainties and private sector coordination failures** • Turbine manufacturers lack the capability to develop their own test sites, and so rely on national centres or developers to provide sites • Developers are reluctant to add risk, cost and complexity to their commercial projects to test new technologies • Where developers do have positions in their wind farms to test new technologies, they may not have a sufficiently broad consenting envelope 2. **Coordination failures (*positive externalities*) including a lack of monitoring and pooling of reliability data** 3. **Barriers to developing novel/innovative concepts** – barriers to entry, risk aversion, long lead times: • High barriers to new entrants – need a track record of operating hours but investment is high to get to this point without an order book • Construction and operating risks can have a catastrophic impact on IRRs, so developers are unlikely to add additional risks to the project therefore • Product lead times are very long (5-10 years) *(i.e. negative externalities)*	*Critical failures*
	4. **Lack of competition may hinder turbine innovation** (i.e. *imperfect competition and high barriers to entry*). The OSW turbine market is currently dominated by a limited number of firms; however, entry by other players are expected soon	*May ameliorate in future*
Turbines - High yield array	5. **Insufficient sharing of array performance data** due to perceived risks of losing competitive advantage (i.e. *positive externalities/coordination failures*)	*Significant failure*
Foundation	See 1 and 3 above impacting **test sites/facilities** and **novel/innovative concepts** (including serial manufacturing processes) and aligning developers, turbine manufacturers, foundation designers and test sites	*Critical failure*
Collection & Transmission	See 1 and 3 above impacting **new solutions**	*Significant failure*
	Similar to 4 above - both switchgear and cabling markets dominated by l large players,) *(i.e. barriers to entry and immateriality)*	*Important failure*
Installation	6. **Uncertainty on future offshore wind demand inhibits investment in innovative installation methods and vessels** - installation vessels are high cost (~£100m), long lead time (3-4 years) items that pay off only over multiple installations *(i.e. negative externalities).*	*Critical failure*
O&M	7. **Uncertainty on future offshore wind demand** has particular effect since investments in new **access and condition monitoring technologies** are substantial for the relatively small O&M play	*Important failure*
	8. There are **barriers for companies to collaborate** as turbine manufacturers do not want to share product warranty data	*Important failure*

Source: Expert interviews, Carbon Trust analysis

Potential priorities to deliver the greatest benefit to the UK

The UK needs to focus its resources on the areas of innovation with the biggest relative benefit to the UK and where there are not existing or planned initiatives (both in the UK and abroad). The LCICG has identified and prioritised these innovation areas.

Innovation areas with the biggest relative benefit from UK public sector activity/investment

The LCICG has identified the areas of innovation with the highest relative benefit from UK public sector activity/investment[13]. These are high yield/reliability turbines and increased installation rate/deep water installation innovations, followed by high yield arrays, deep water foundations (30m+) and improved O&M technologies (see Chart 8).

These have been prioritised by identifying those areas that best meet the following criteria:

- value in meeting emissions targets at lowest cost
- value in business creation
- extent of market failure
- opportunity to rely on another country

Chart 8 Benefit of UK public sector activity/investment by sub-area and technology type

Sub-area	Type	Value in meeting emissions targets at lowest cost £bn[1]	Value in business creation £bn[2]	Extent market failure	Opportunity to exclusively rely on others	Benefit of UK public sector activity/investment (<u>without</u> considering costs)
Turbine	▪ High yield/ reliability turbines	11 (5-19)	4 (1 – 7)	Critical	▪ No due to earlier & greater need	HIGH
	▪ High yield arrays	6 (2-10)			▪ No due to earlier & greater need	MEDIUM-HIGH
Foundation	▪ <30m depth	4 (2-3)	3 (1 – 5) [4]	Significant	▪ Yes for <30m	LOW
	▪ 30-60m depth	6 (2-6)		Critical	▪ No for 30-60m	MEDIUM
	▪ 60-100m depth	0[3] (0-13)			▪ No for 60-100m	MEDIUM
Collection & transmission	▪ Improved inter-array connections	4 (2-8)	1 (0.3 – 2)	Significant	▪ No due to earlier & greater need	LOW-MEDIUM
Installation	▪ Increased installation rate/deep water	7 (3-17)	2 (1 – 4)	Critical	▪ No for deep water	HIGH
O&M	▪ Improved access	5 (1-9)	9 (3 – 16)	Significant	▪ No for larger sites and for sites with a tough wave climate	MEDIUM-HIGH
	▪ Remote monitoring/ O&M planning	2 (1-4)				
TOTAL		**45 (18 – 89)**	**18 (7 – 35)**	**Significant -Critical**		**HIGH relative to other technology families**

1 These values are potentially 65% lower according to alternative "perfect system optimisation" counterfactual;
2 After displacement effects
3 Innovation (e.g. floating foundations) may unlock economical high wind speed sites in +60m deep water, creating value in meeting emissions targets under the medium deployment scenario
4 Value in business creation is not split by different depths. Data on the market sizes for different depths of foundation was not available.

Source: Expert interviews, Carbon Trust analysis

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13 Without considering costs – these are considered in the final prioritisation).

Existing innovation support

The UK is supporting many of the areas highlighted above. This is through a combination of policies to incentivise demand, supply-side innovation programmes to 'push' technology and support for enablers (Chart 9).

Potential priorities for public sector innovation support

In the sections above, we identified the key innovation needs and the market barriers hindering these innovations. This analysis points to a number of priorities for public sector innovation support:

- Test sites and drive train and blade testing facilities to support development of high yield/reliability turbines – funding and accelerated consents
- Novel/innovative designs of high yield/reliability turbines, foundations for depths of greater than 30m with low material costs, cabling concepts, installation techniques with increased utilisation/rates, lower costs and ability to access deep water and vessels/access systems – funding and coordination
- Developing serial manufacturing/production of foundations – funding
- Measurement and sharing of data – funding and incentives to share and/or coordination

Chart 9 Summary of current/recent UK public sector activity/investment

Market pull (demand side)	**Technology push** (supply side)	**Enablers**
▪ **Levy Exemption Certificates (LECs)** – As a renewable energy source offshore wind energy qualifies for LECs ▪ Revenue support through **Banded Renewables Obligation** - 2009 to 2017, offshore wind currently eligible for 2 ROCs/MWh*. CfD FiT expected 2017 onwards ▪ Carbon price, via the **EU Energy Trading Scheme (ETS)**	– **Offshore Renewable Energy Catapult** – from summer 2012; up to £10m per annum over five years (£50m) from the Technology Strategy Board. To be set up by a consortium of the Carbon Trust, Narec and Ocean Energy Innovation, headquartered in Glasgow with an operational centre in the North East of England (Northumberland) – **Supergen 2** – 2010 to 2014; £5.8m; Research Council led funding to undertake research to achieve an integrated, cost-effective, reliable & available Offshore Wind Power Station – **Carbon Trust Offshore Wind Accelerator**– 2008 to 2014; c£30m fund to accelerate cost reduction and increase reliability and yield in a consortium with eight major developers – **ETI Offshore Wind Programme**; funding for the design and demonstration of novel offshore systems and improvement of existing technologies – **ETF Third Demonstration Call** – 2010-2011; up to £8m; capital grant funding for component / technology development There have also been a number of programmes funded by RDAs including ONE, NWDA, EMDA and SEEDA	Testing sites: – **Narec** – National Renewable Energy Centre; Narec operates the only full-scale and independent blade testing facility in the UK (since 2005). A second 100m+ blade test facility, a 15MW drive train test facility, and an offshore wind test site are under development (to be operational in 2012/13) – **AREG** – Aberdeen Renewable Energy Group is developing the European Offshore Wind Deployment Centre – an offshore wind test facility off the coast of Aberdeen – in a joint venture with Vattenfall, using an EC grant of up to €40m Permitting regime: – **Crown Estate** – has leased sites with the aim of installing 25GW by 2020 Non-technology bottlenecks: – RenewableUK and Scottish Enterprise are working on, amongst others, health and safety issues and skills shortages – DECC ports & infrastructure funding Centres for doctoral training (EPSRC)

N.B. In addition the Devolved Administrations have a number of active programmes and EU funding is being invested in offshore wind in the UK

Source: TSB (Energy and Supply KTN), Carbon Trust, ETI, NaREC, Crown Estate, AREG

*Renewables Obligation banding for 2013-17 in England and Wales currently under consultation

Chart 10 outlines how the potential innovation priorities align against each technology sub-area, the scale of public funding for each, the current activities/investment in each area and potential, future activities.

The LCICG's existing and planned innovation programmes span almost all the innovation priorities. Its members expect to commit over a hundred million GBP of public sector funding to these programmes over the next 3-4 years (leveraging up to three times that from the private sector).

To realise the full benefit from innovation over the following 4-10 years will require on-going support to existing areas, scaling up a subset as they move from design to demonstration, as well as adding a prioritised set of new programmes. Supporting *all* the prioritised innovations would require a significant increase in public sector funding to UK projects in future funding periods. The UK government will need to balance its own investment, and any funding secured from European Union programmes, with the risk of relying on developments in other countries. Resources may need to be targeted on particular areas but material impact can be achieved by doing so. The public sector investment required however is a fraction of the value that offshore wind innovation could bring to the UK economy, including helping to unlock £45bn (18 – 89) savings in meeting energy and emissions targets at lowest cost, and the £18bn (10 – 35) value add creation to UK GDP[14].

A more detailed overview of ongoing requirements is given in the call out box below for the four priorities: test sites and facilities, novel/innovation designs, serial manufacturing/production of foundations and measurement and sharing of data.

As well as supporting innovation in each of the individual areas above, public intervention can help collaboration and integration across them. It can also facilitate the commercialisation of innovative concepts created by research institutes and small companies through entrepreneurial support programmes (generally across many technology areas). Finally, it can join up innovation programmes with supply chain and infrastructure development. Where appropriate this includes helping to focus activity into centres of excellence where there are colocation benefits. The recently announced Offshore Renewable Energy Catapult will help capitalise on this opportunity.

Summary of on-going LCICG innovation priorities

Test sites and facilities

Accelerating the achievement of high yield and reliable turbines requires a scale up of testing on existing and/or new sites and site consenting to enable testing of innovative designs. The new test sites and associated infrastructure that are already being planned by Narec and AREG are a significant step in this direction. More sites (both onshore and offshore) will be needed to test a sufficient number of innovative new turbine designs.

Testing need not only occur in new/virgin test sites, it can also occur in existing sites. However, developers' consents are currently limited to existing designs. These will need to be changed if innovative designs are to be tested on these sites. Furthermore, developers may need to be incentivised to overcome additional risks.

Test facilities are also required. The Narec drive train centre has recently been funded, complimenting the Narec blade test facility.

Novel/innovative designs

The LCICG is supporting the concept design of novel/innovative designs across all the sub-areas, especially foundations, installation and O&M. Continued support is required through the technology lifecycle up until they are commercial. In most cases, the next step would be supporting the full development and build of prototypes that can then be tested.

Support could also be provided for additional novel design concepts with radical cost reduction potential, although the extent of such opportunities is hard to predict ahead of time.

Serial manufacturing/production of foundations

To manufacturer thousands of foundations in the next ten years cost effectively will require the manufacturing process to transition from low volume batch processes to serial production. This would require funding to develop these processes and to implement serial production methods. This may be out of scope for the mandate of some/most of the LCICG members, but should be considered as part of broader support.

Measurement and sharing of data

The LCICG's programmes in foundations and condition monitoring are promoting the sharing of data. New programmes to measure and share turbine reliability data would benefit innovation at relatively low cost.

[14] 2010-2050 with displacement

Chart 10 Potential offshore wind innovation priorities and support

	Potential innovation priorities	Indicative scale of public funding[1]	Current activities/investments	Future potential activities
Turbine ▪ High yield / reliability turbines	▪ Test sites and incentives to test at those sites	▪ High tens of millions of pounds	▪ Planned Narec & AREG offshore test sites ▪ SSE's planned test site	▪ Expand existing and support new sites.
	▪ Drive train and blade testing facilities		▪ Narec drive train & blade testing facilities ▪ ETI 90m+ blade project	
	▪ Monitoring and pooling of test data	▪ Millions of pounds	▪ *None*	▪ New programmes to coordinate and provide incentive for sharing
	▪ RD&D for components & novel concepts	▪ Tens of millions of pounds	▪ Scottish Enterprise call for novel turbine concepts ▪ DECC-TSB OSW Component Technologies Development and Demonstration Scheme.	▪ Additional support for novel concepts and turbines for testing
▪ High yield array layouts	▪ Model, measure and monitor of wake effects	▪ Millions of pounds	▪ Carbon Trust Offshore Wind Accelerator wake effects programme (modelling)	▪ Funding and coordination of measurement and monitoring
Foundation ▪ 30-60m	▪ Programme to develop, demonstrate, test and monitor novel designs and serial manufacturing processes	▪ Tens of millions of pounds	▪ Carbon Trust Offshore Wind Accelerator - supporting 7 foundation designs ▪ DECC-TSB OSW Component Technologies Development and Demonstration Scheme	▪ Support full demonstration with turbines (post-2014) including installation
▪ 60-100m	▪ Programme to develop new concepts, with potential demo and testing later	▪ Tens of millions of pounds	▪ ETI floating foundation concept programme	▪ Support a demonstration upon successful completion of first stage
Collection & Transmission	▪ Design and test novel cabling concepts ▪ Develop, design and test central power clean up	▪ Millions of pounds	▪ Carbon Trust Offshore Wind Accelerator - high voltage array design ▪ ETI transmission to shore project ▪ DECC-TSB OSW Component Technologies Development and Demonstration Scheme	▪ Additional support for testing
Installation	▪ Programme to design, build and test new vessels / barges, float-out concepts and other installation innovations	▪ Tens of millions of pounds	• Carbon Trust Offshore Wind Accelerator funding design work for new installation vessel • DECC-TSB OSW Component Technologies Development and Demonstration Scheme	• Additional support for design • Support for building and testing
O&M ▪ Access technologies	▪ Programme to design, build and trial novel vessels / access systems	▪ Tens of millions of pounds	▪ Carbon Trust Offshore Wind Accelerator is funding design work for access technologies. ▪ DECC-TSB OSW Component Technologies Development and Demonstration Scheme	▪ Support to build and test novel vessels / barges and access systems
▪ Remote monitoring/ O&M planning	▪ Condition monitoring technologies – support the installation and usage of whole system equipment and coordinate data sharing	▪ Millions of pounds	▪ ETI Condition Monitoring programme ▪ DECC-TSB OSW Component Technologies Development and Demonstration Scheme	▪ Increased support and coordination to promote data sharing

N.B. In addition the Devolved Administrations have a number of active programmes and EU funding is being invested in offshore wind in the UK

Source: Expert interviews, Carbon Trust analysis 1 Provides an order of magnitude perspective on the scale of public funding (existing and future) potentially required over the next 5 to 10 years to address each need.

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