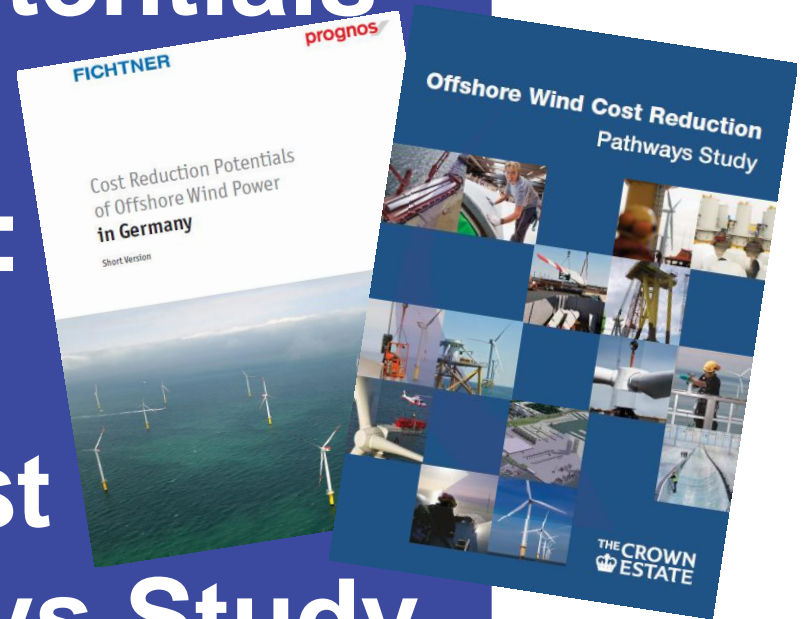


Cost Reduction Potentials of Offshore Wind Power in Germany: comparison with Offshore Wind Cost Reduction Pathways Study



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Revision	Purpose and description	Originated	Checked	Authorised	Date
A	Draft for customer review	BAV	JJW	BAV	10-12-13

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Agenda

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Context and objectives

- In June 2012, The Crown Estate published the *Offshore Wind Cost Reduction Pathways Study*, the most comprehensive examination of current and future cost of energy in offshore wind to date. The study involved significant engagement across the European industry, but with reference to typical UK projects. BVG Associates led the Technology work stream, the source of the majority of cost reductions, and participated in the integration of results from the Supply Chain and Finance work streams.
- In August 2013, German Stiftung Offshore-Windenergie published a similar study, *Cost Reduction Potentials of Offshore Wind Power in Germany*, focussed on the German market, again involving significant industry engagement.
- For both studies, the purpose was to capture industry intent to reduce cost of energy to help focus on priorities and assist in dialogue with government about national support for the sector.
- The Crown Estate asked BVG Associates to compare the two studies in order to capture learning, especially by understanding what underpins any significant differences in results.

Guidance for reading presentation

- Information relating to the Stiftung study is highlighted in green; for The Crown Estate, in dark blue.
- There are a number of differences in terminology between the two reports. throughout, this comparison, the terminology of The Crown Estate study is used, including annual energy production (AEP), levelised cost of energy (LCOE) and weighted average cost of capital (WACC).

Output

- Output is provided in terms of:
 - Comparison of assumptions.
 - Comparison of results, at detail level.
 - Comparison of overall results.
 - Exploration of differences and learning to be captured.
 - Recommendations to take benefit from the German study.

Study comparison

Methodology and element definitions

Methodology

- This presentation provides a robust comparison between the two studies, first by comparing definitions then defining rational cases to compare.
- It then goes on to compare these in terms of capital and operational costs (CAPEX and OPEX), annual energy production and financing cost. Comparing at detail level enables the differences to be clearly seen, a number of which cancel out at a higher level but in themselves are of importance.
- Finally, a comparison of levelised cost of energy is provided, both presenting results directly from the two studies and presenting cost of energy results where arbitrary differences between the studies are removed.
- A summary of learning and recommendations is then provided.
- Most of the work in this comparison has related to understanding the two studies and manipulating results, but we also engaged directly with Stiftung and Stiftung's consultant in order to receive a range of clarifications.

Element definitions: comparison

In general, the Stiftung study follows the definitions of The Crown Estate study in terms of scope if not naming, with the following differences:

- Development and consent:
 - Slight difference in sub-element split, but comparison not carried out at this level.
- Installation
 - Installation of offshore substation is included in the Stiftung study, but it is itemised separately and so removed for this comparison. Likewise, the supply of the offshore substation itself is itemised and hence removed for this comparison.
- Decommissioning
 - Resale of relevant components (eg. steel scrap) is assumed in the Stiftung study. This noted but not quantified in The Crown Estate study. No adjustment is made in this comparison to account for this, as the discounted end-of-life impact is relatively small.
- Aerodynamic array losses
 - Wake losses due to neighbouring wind farms are modelled. These are not considered in The Crown Estate study due to the wider geographical spread of wind farms, though action is recommended in this area.
- Electrical array losses
 - The Stiftung study also includes substation losses. These are removed via a 1% adjustment in this comparison.

Study comparison

Wind farm sites

Comparison

- Sites Types are compared below.

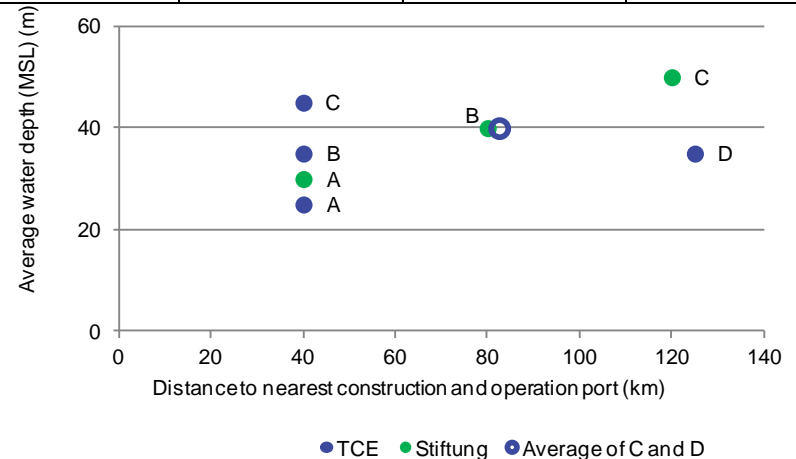
TCE Site Type	Average water depth below MSL (m)	Distance to nearest construction and operation port (km)	Average wind speed at 100m above MSL (m/s)	Stiftung	Average water depth below MSL (m)	Distance to port (km)	Wind speed at 100m height (m/s)
A	25	40	9	A	30	40	9.9
B	35	40	9.4				
C	45	40	9.7	B	40	80	10
D	35	125	10				
				C	50	120	10.1

- There is no combination of Stiftung sites that correspond to any given Site Type in The Crown Estate study.
- The primary Stiftung site is B. This corresponds well to an average of The Crown Estate Site Types C and D, so all results for The Crown Estate study presented in this comparison are an average from these two Site Types.
- This comparison focuses solely on Stiftung site B, as there seem to be no significantly different trends for the other Stiftung sites.

Sizes of sites are compared below.

Year of FID	TCE wind farm size (MW)	Stiftung
2011	500	320
2014	500	450
2017	500	450
2020	500	450

- The Stiftung site size varies over time and is smaller. This is due to the constraint of a maximum of 80 turbines per site. No adjustment is made in this comparison to account for this.
- Stiftung has higher wind shear exponent (0.14, typical for onshore; rather than 0.12, typical for offshore), thereby increasing benefit of large turbines, but impact was checked to be almost negligible. Although not documented, Stiftung confirms that mean wind speeds stated are defined as at 100m above MSL and depths are below MSL, as for The Crown Estate study.
- Stiftung uses annual wind speed distribution shape factor 2.25 whereas TCE uses 2.2. The impact of the higher shape factor (more 'peaky' wind speed distribution) assumed by Stiftung is to increase gross AEP by about 3%. Offsetting this, Stiftung does not consider increased air density due to average temperature being less than standard, which decreases its AEP by 1%. A net 2% adjustment is applied to account for these differences, as neither are likely to be an actual material difference between the two markets.



Study comparison

Years, Industry Stories and Turbine Sizes

Comparison

- The studies use different definitions of years. Stiftung refers to year of initial operation and The Crown Estate refers to year of FID. As there is typically three years between these two milestones for a given project, the following is assumed.

TCE year	= Stiftung
2011	2013
2014	2017
2017	2020
2020	2023

- The studies also use different terminology and description of industry scenarios, summarised below in terms of installed capacity.

TCE Industry Story name	TCE EU installed capacity by end 2020 (GW)	Stiftung name	Stiftung EU installed capacity by end 2020 (GW)
1 'Slow progression'	31	Scenario 1	>20
2 'Technology acceleration'	36		
3 'Supply chain efficiency'	36		
4 'Rapid Growth'	43	Scenario 2	> 40

- For the rest of this comparison, the following best fit of Industry Stories is used. Due to some significant difference in trends between Stiftung Scenarios 1 and 2, both are considered here.

TCE Industry Story name	= Stiftung name
1 'Slow progression'	Scenario 1
4 'Rapid Growth'	Scenario 2

- A summary of the total European market sizes and turbine sizes used in the comparison is shown below. Turbine sizes used can be seen to match perfectly due to the matrix of turbine sizes available from The Crown Estate work.

Scenario 1, Site B	2013	2017	2020	2023
Europe (GW)	6	13	20	>20
Turbine rating (MW)	4	6	6	6
TCE equivalent (average of)	4-11-C-1 & 4-11-D-1	6-14-C-1 & 6-14-D-1	6-17-C-1 & 6-17-D-1	6-20-C-1 & 6-20-D-1
Europe (GW)				31
Turbine rating (MW)	4	6	6	6

Scenario 2, Site B	2013	2017	2020	2023
Europe (GW)	6	25	40	>40
Capacity WTG	4	6	8	8
TCE equivalent (average of)	4-11-C-1 & 4-11-D-1	6-14-C-1 & 6-14-D-1	8-17-C-1 & 8-17-D-1	8-20-C-1 & 8-20-D-1
Europe (GW)				43
Turbine rating (MW)	4	6	8	8

Study comparison

Turbine parameters: Stiftung scenario 1

Comparison

- The following table compares turbines for primary Stiftung site (site B). The upper (green) rows describe the Stiftung turbine.

Scenario 1, Site B	2011	2014	2017	2020
Turbine rating (MW)	4	6	6	6
Hub height above MSL (m)	90	105	105	105
Hub height above MHWS (m)*	88	103	103	103
Rotor diameter(m)	120	145	154	164
Tip clearance above MHWS (m)	28	30.5	26	21
Specific rating (W/m ²)	354	363	322	284
Hub height mean wind speed (m/s)	9.92	10.07	10.07	10.07
Wind farm average spacing	8.5D x 4.5D	8.4D x 4.4D	8.1D x 4.3D	7.6D x 4.0D
Foundation type	jacket	jacket	monopile	monopile
TCE equivalent (average of)	4-11-C-1 & 4-11-D-1	6-14-C-1 & 6-14-D-1	6-17-C-1 & 6-17-D-1	6-20-C-1 & 6-20-D-1
Turbine rating (MW)	4	6	6	6
Hub height above MSL (m)	84.0	98.1	99.4	100.7
Hub height above MHWS (m)	82.0	96.1	97.4	98.7
Rotor diameter (m)	120.0	148.3	150.8	153.4
Specific rating (W/m ²)	354	347	336	325
Tip clearance above MHWS (m)	22	22	22	22
Hub height mean wind speed (m/s)	9.65	9.83	9.84	9.86
Wind farm average spacing	9D x 6D	9D x 6D	9D x 6D	9D x 6D
Foundation type	jacket	jacket	jacket	jacket

- The trend in rotor diameter is quite different, from identical start points, end points are 7% different. Turbine rotor diameters for The Crown Estate study are calculated taking into account how much of rotor size innovation has been commercialised in given year for the given turbine size.
- Stiftung hub height has a step change then remains consistent despite changes in rotor diameter. Note that Stiftung consultant advises 105m hub height as shown above for 6MW turbine whilst report states 100m. As rotor diameter increases, Stiftung tip clearance to MHWS decreases to just below the UK limit of 22m, assuming 2 m between MHWS and MSL. The Crown Estate assumes minimum allowable hub height throughout.
- Turbine spacing is constant with rated power for the Stiftung study but constant with rotor diameter for The Crown Estate study. This is because of restrictions placed on German project areas.
- With 40m water depth (MSL), Stiftung study moves to using monopiles for 2017 and 2020. The Crown Estate study remains with Jackets throughout.

Study comparison

Turbine parameters: Stiftung Scenario 2

Comparison

- The following table repeats the comparison for Scenario 2.

Scenario 2, Site B	2011	2014	2017	2020
Turbine rating (MW)	4	6	8	8
Hub height above MSL (m)	90	100	110	115
Hub height above MHWS (m)*	88	98	108	113
Rotor diameter(m)	120	145	164	178
Tip clearance above MHWS (m)	30	27.5	28	26
Specific rating (W/m ²)	354	363	379	321
Hub height mean wind speed (m/s)	9.92	10.07	10.20	10.27
Wind farm average spacing	8.5D x 4.5D	8.4D x 4.4D	8.2D x 4.3D	7.7D x 4.1D
Foundation type	jacket	jacket	jacket	jacket
TCE equivalent (average of)	4-11-C-1 & 4-11-D-1	6-14-C-1 & 6-14-D-1	6-17-C-1 & 6-17-D-1	8-20-C-1 & 8-20-D-1
Turbine rating (MW)	4	6	8	8
Hub height above MSL (m)	84.0	99.4	111.3	111.8
Hub height above MHWS (m)	82.0	97.4	109.3	109.8
Rotor diameter (m)	120.0	150.8	174.5	175.6
Specific rating (W/m ²)	354	336	334	330
Tip clearance above MHWS (m)	22	22	22	22
Hub height mean wind speed (m/s)	9.65	9.84	9.98	9.98
Wind farm average spacing	9D x 6D	9D x 6D	9D x 6D	9D x 6D
Foundation type	jacket	jacket	jacket	jacket

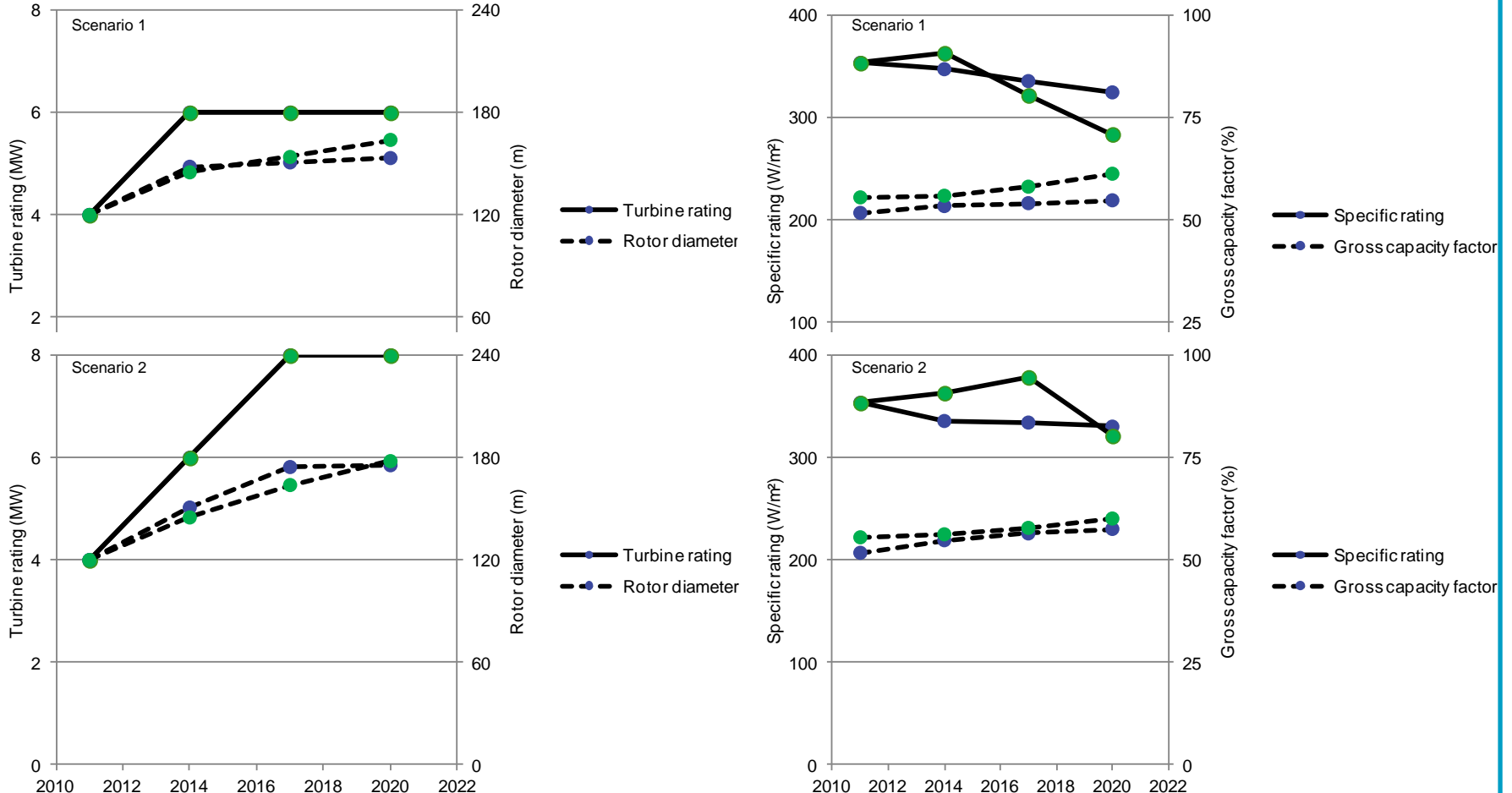
- Comments on rotor diameter, turbine spacing and annual energy production from the previous sheet apply. All turbines are on jacket structures.

Study comparison

Turbine parameters: Summary

Comparison

- The following charts show key turbine parameters and gross capacity factor under the two scenarios. Where only Stifting values are shown, this is because values for The Crown Estate are identical.



Study comparison

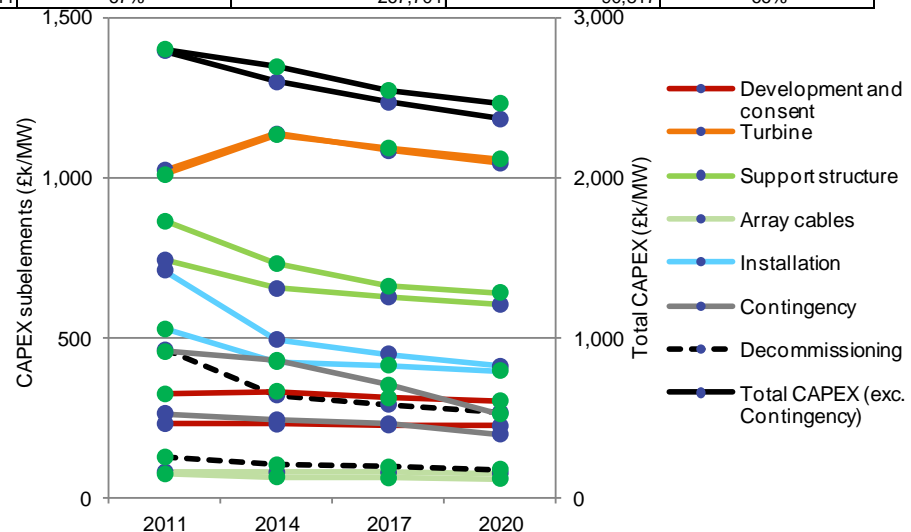
CAPEX: Stiftung scenario 1

Comparison

Scenario 1, Site B	2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
Development and consent	232,512	325,428	40%	230,791	333,837	45%
Turbine (exc. tower)	1,024,474	1,009,921	-1%	1,136,839	1,135,215	0%
Support structure (inc. tower)	743,704	864,445	16%	654,455	732,424	12%
Array cables	82,123	75,681	-8%	80,713	66,431	-18%
Installation	712,088	528,085	-26%	495,588	426,336	-14%
Contingency	264,992	457,450	73%	244,894	430,541	76%
Total CAPEX (exc. Contingency)	2,794,900	2,803,561	0%	2,598,386	2,694,244	4%
DECEX	462,858	128,658	-72%	322,132	104,272	-68%

2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
228,322	312,815	37%	225,852	304,406	35%
1,084,478	1,093,170	1%	1,045,865	1,059,534	1%
628,012	661,788	5%	604,857	642,448	6%
79,593	63,068	-21%	78,456	61,386	-22%
450,826	415,405	-8%	411,852	398,587	-3%
232,432	353,178	52%	200,026	263,202	32%
2,471,230	2,546,245	3%	2,366,883	2,466,360	4%
293,037	97,544	-67%	267,704	90,817	-66%

- Discussion is provided overleaf. Total CAPEX is presented on the RH axis; all other values on LH axis.



Study comparison

CAPEX: Stiftung scenario 1

Comparison

- Overall:
 - Agreement is very close. CAPEX in 2011 is identical to within 0.3%. By 2020, Stiftung is 4% higher.
- Development and consent:
 - Stiftung has about 40% higher cost throughout. The Stiftung consultant confirms that the scope matches The Crown Estate study. The Stiftung consultant advises “Included are all costs necessary for all relevant BSH approvals, for the certification etc. The costs to meet German regulatory standard (Bundesamt für Seeschifffahrt und Hydrographie (BSH), BAM etc.) additionally the certification bodies like GL/DNV seem to be higher in Germany for the time being.” There also seems at times to be lack of continuity in what is allowed by certification bodies. Typically, UK imposes less regulations and as The Crown Estate study assumes balance sheet financing, project certification and related 3rd part evaluation is substantially less. The difference in cost between UK and Germany for a 500MW project however is £40-50 million which is significant. The UK assessment also replaces actual project development costs to FID with a market rate for projects at this point, to reflect the fact that some projects do not reach FID. This means that for a project that does reach FID, the difference would be even greater. It is recommended that as UK moves towards more project finance, a more thorough examination of the differences between German and UK costs and causes of costs is carried out.
- Turbine:
 - Agreement over the whole period is very close, suggesting that the starting point for Stiftung engagement may have been The Crown Estate costs. This is agreement is despite the fact that there are significant differences in rotor diameter, Stiftung having 7% greater rotor diameter in 2020.
- Support structure:
 - Stiftung has 16% higher cost than The Crown Estate in 2011, decreasing to 6% higher in 2020 (hence steeper reduction in cost). No specific evidence is provided to justify this.
- Array cables:
 - Stiftung has somewhat lower costs that drop slower over time than The Crown Estate, the contribution to total CAPEX is small.

Study comparison

CAPEX: Stiftung scenario 1

Comparison

- Installation:
 - Stiftung has 26% lower cost than The Crown Estate in 2011, moving to only 3% lower cost in 2020. Again, no specific evidence is provided to justify this. Trends at element level looked quite different but on discussion, Stiftung has re-issued its report, interchanging turbine and support structure installation costs, throughout. This brings costs roughly in line with The Crown Estate. A comparison in 2011 is shown below.

Scenario 1, Site B	2011	2011	2011	2011	Stiftung vs TCE
Turbine installation	120	17%	158	25%	32%
Foundation installation	443	62%	350	56%	-21%
Cable installation	150	21%	120	19%	-20%
Total	712	100%	628	100%	-12%

- Combined with support structure costs, the different trends between the two studies partly cancel each other out, but with greater combined reductions for The Crown Estate study.
- Contingency:
 - Stiftung has a far larger reduction than The Crown Estate, but it is not used directly in LCOE calculations by The Crown Estate, rather, it is taken into account in changing WACC over time.
- Decommissioning:
 - Stiftung has much lower costs, though Stiftung includes benefit of resale/scrap value which was noted but ignored in TCE work. Value of scrap so far in the future is not known, but is likely to become more significant.

Study comparison

CAPEX: Stiftung scenario 2

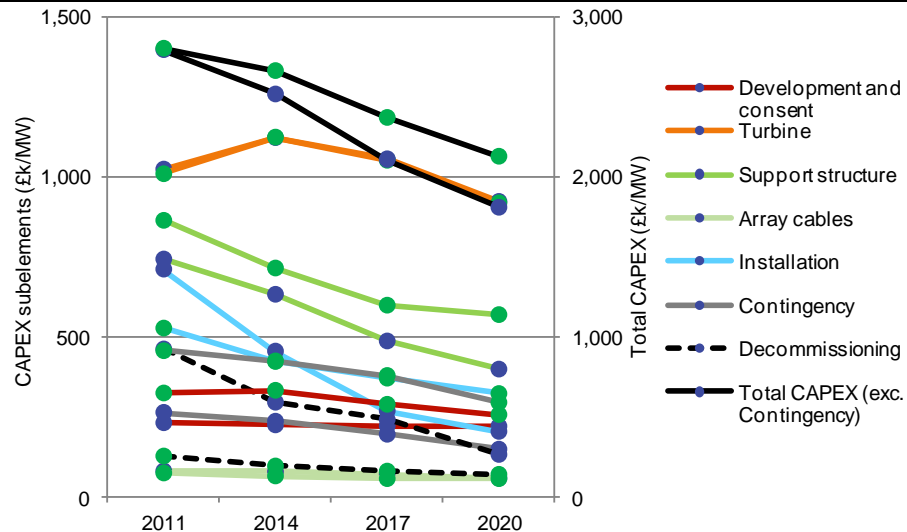
Comparison

Scenario 2, Site B	2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
Development and consent	232,512	325,428	40%	225,852	333,837	48%
Turbine (exc. tower)	1,024,474	1,009,921	-1%	1,122,715	1,124,283	0%
Support structure (inc. tower)	743,704	864,445	16%	633,563	715,606	13%
Array cables	82,123	75,681	-8%	79,594	66,431	-17%
Installation	712,088	528,085	-26%	456,255	423,814	-7%
Contingency	264,992	457,450	73%	237,361	425,495	79%
Total CAPEX (exc. Contingency)	2,794,900	2,803,561	0%	2,517,979	2,663,971	6%
DECEX	462,858	128,658	-72%	296,566	97,544	-67%

2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
222,628	290,111	30%	221,814	258,156	16%
1,056,604	1,051,966	0%	923,545	919,104	0%
487,825	599,562	23%	400,026	570,130	43%
71,953	58,022	-19%	59,636	58,022	-3%
269,899	371,678	38%	205,514	323,747	58%
196,498	380,087	93%	150,106	295,997	97%
2,108,910	2,371,338	12%	1,810,535	2,129,159	18%
242,643	81,567	-66%	133,584	71,477	-46%

Overall:

- Trend is similar to scenario 1, but there is larger divergence. By 2020, Stiftung has 18% higher CAPEX due to smaller reductions in support structure and especially installation costs.
- The main reason for smaller reductions is that Stiftung has a 39% reduction in installation costs, moving from 4MW turbine in FID 2011 to 8MW turbine in FID 2020, whilst The Crown Estate has a 71% reduction, with 42% coming just from the change in turbine size.



Study comparison

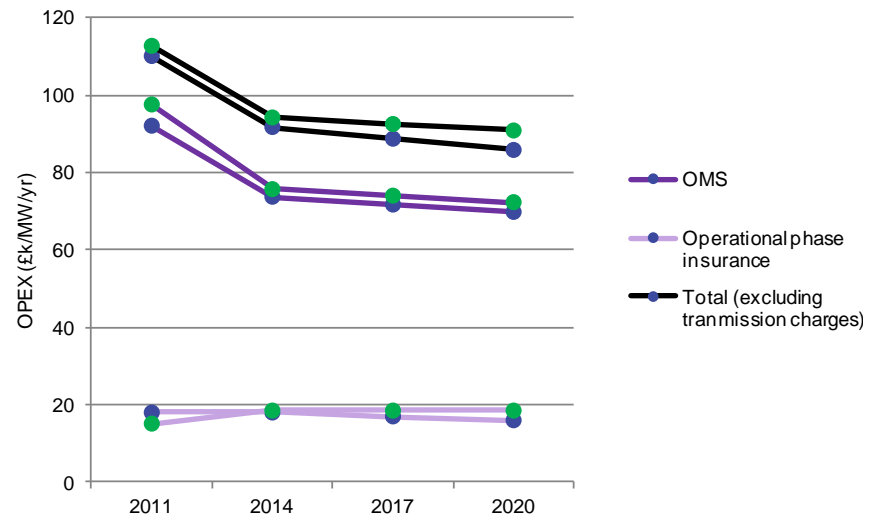
OPEX: Stiftung scenario 1

Comparison

Scenario 1, Site B	2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
OMS	92,058	97,544	6%	73,722	75,681	3%
Operational phase insurance	18,000	15,136	-16%	18,000	18,500	3%
Transmission charges	101,012	101,012	0%	101,475	101,475	0%
Total annual OPEX	211,070	213,693	1%	193,197	195,656	1%

	2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
	71,697	73,999	3%	69,802	72,317	4%
	17,000	18,500	9%	16,000	18,500	16%
	95,213	95,213	0%	89,566	89,566	0%
	183,910	187,712	2%	175,368	180,383	3%

- Trends in OPEX (excluding transmission charges) are very similar. Socialisation of transmission charges reduces LCOE by about 20%, depending on the case.
- For the purposes of this study, UK transmission charges are added to Stiftung OPEX in deriving an LCOE comparable to results from The Crown Estate (see red values above).



Study comparison

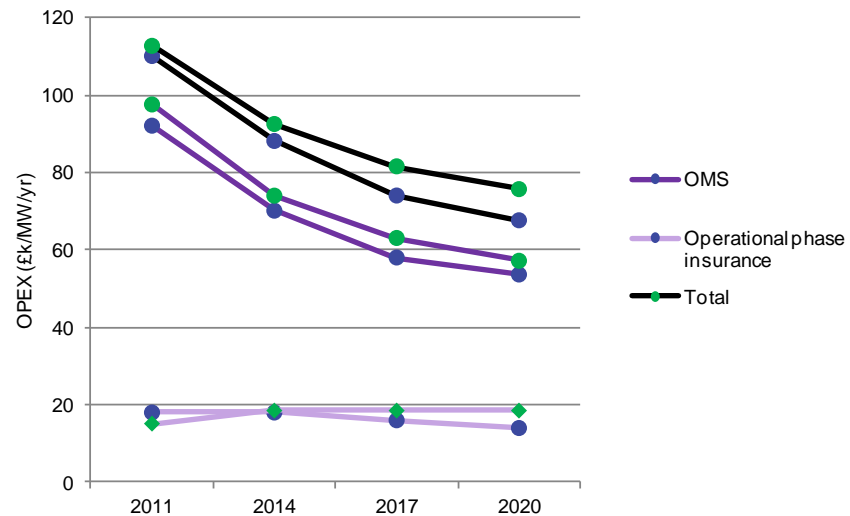
OPEX: Stiftung scenario 2

Comparison

Scenario 2, Site B	2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
OMS	92,058	97,544	6%	70,119	73,999	6%
Operational phase insurance	18,000	15,136	-16%	18,000	18,500	3%
Transmission charges	101,012	101,012	0%	101,475	101,475	0%
Total annual OPEX	211,070	213,693	1%	189,594	193,974	2%

	2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
	58,031	63,068	9%	53,634	57,181	7%
	16,000	18,500	16%	14,000	18,500	32%
	95,213	95,213	0%	89,566	89,566	0%
	169,243	176,780	4%	157,200	165,247	5%

- Trends are similar to Stiftung scenario 1.



Study comparison

AEP: Stiftung scenario 1

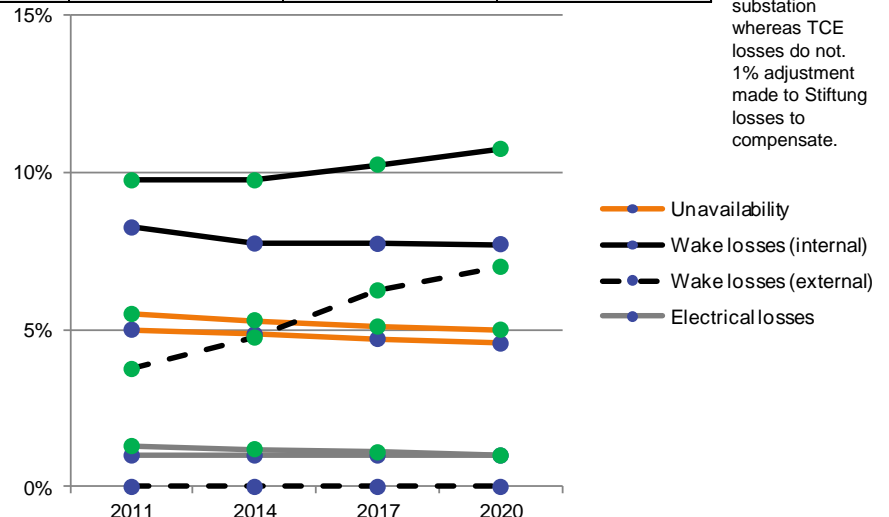
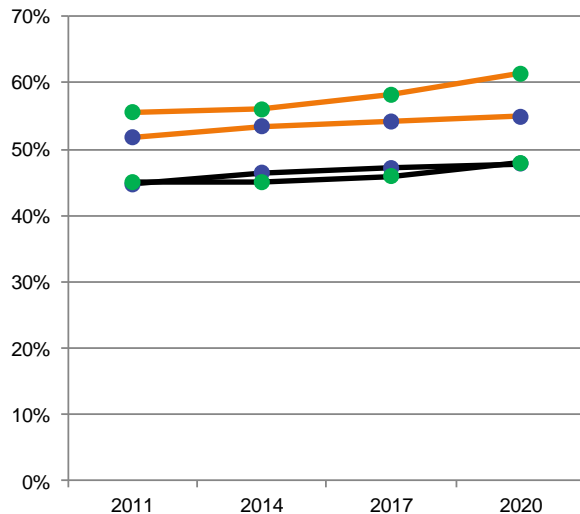
Comparison

Scenario 1, Site B	2011	2011**	Stiftung vs TCE	2014	2014**	Stiftung vs TCE
Turbine annual energy production*	4,540	4,871	7%	4,685	4,907	5%
Net energy production **	3,917	3,947	1%	4,072	3,946	-3%
Gross capacity factor	51.8%	55.6%	7%	53.4%	56.0%	5%
Unavailability	5.0%	5.5%	10%	4.9%	5.3%	9%
Wake losses (internal)	8.3%	9.8%	18%	7.7%	9.8%	26%
Wake losses (external)	0.0%	3.8%	N/A	0.0%	4.8%	N/A
Electrical losses***	1.0%	1.3%	30%	1.0%	1.2%	20%
Net capacity factor	44.7%	45.0%	1%	46.5%	45.0%	-3%

* includes other turbine losses (assumed = Stiftung 'other losses'); adjusted for difference in shape of wind speed distribution and air density correction.
 ** derived by applying losses multiplicatively; Stiftung study adds wake losses.
 *** Stiftung electrical losses include substation whereas TCE losses do not. 1% adjustment made to Stiftung losses to compensate.

- Discussion is provided overleaf.

	2017	2017**	Stiftung vs TCE	2020	2020**	Stiftung vs TCE
	4,747	5,100	7%	4,809	5,378	12%
	4,133	4,028	-3%	4,193	4,198	0%
	54.2%	58.2%	7%	54.9%	61.3%	12%
	4.7%	5.1%	8%	4.6%	5.0%	10%
	7.7%	10.3%	33%	7.7%	10.8%	39%
	0.0%	6.3%	N/A	0.0%	7.0%	N/A
	1.0%	1.1%	10%	1.0%	1.0%	0%
	47.1%	45.9%	-3%	47.8%	47.9%	0%

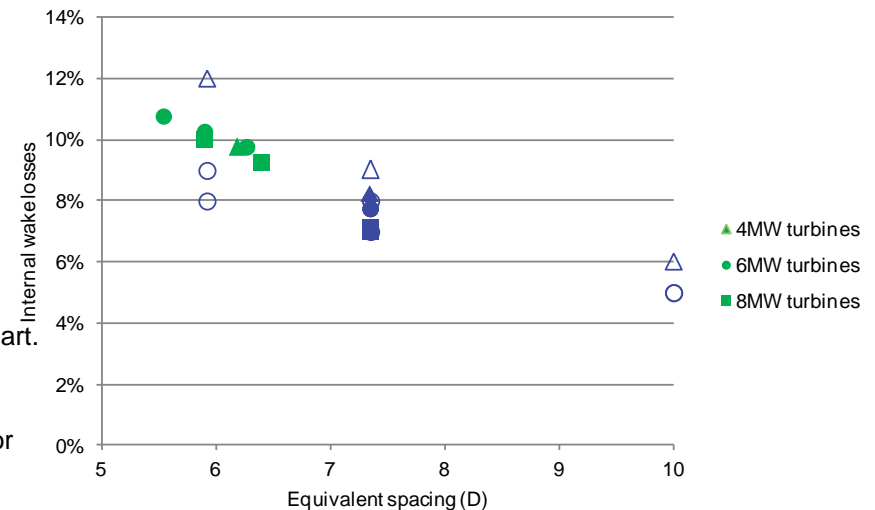


Study comparison

AEP: Stiftung scenario 1

Comparison

- Stiftung consultant advises that "calculation is based on various power curves from different offshore WTG know to us from projects we have been involved". Actual power curves used in the Stiftung study however are not available. Mean wind speeds at 100m height on study sites in Germany are somewhat higher. Coupled with increased hub heights to account for larger rotors and the larger rotors themselves gives an anticipated 5% higher AEP than The Crown Estate in 2011 (actual 7%), growing to anticipated 10% (actual 12%), suggesting around a 2% higher gross energy calculation. Losses to account for hysteresis, power curve degradation etc. are stated by Stiftung to be around 2%, around 2.5% less than assumed in The Crown Estate study, which may explain this difference.
- Stiftung gross capacity factor is higher and increases faster. This is because of the above and Stiftung assumes 10m larger rotor increase by 2020 (to 164m) than The Crown Estate. None of these effects are anticipated to be different between the two markets looking to 2020.
- Stiftung net capacity factor is similar throughout due to higher wake losses, increasing with time. This is both to higher internal wake losses within the wind farm and the consideration of external wake losses due to the interaction between wind farms.
- Internal wake losses, when plotted against an equivalent spacing (eg. square root of 54 for 9D x 6D spacing), ignoring turbine rating, show reasonable consistency between Stiftung, The Crown Estate and other input data received by The Crown Estate, as shown below. Note that Stiftung data shows minimal differentiation with turbine rating, unlike data for The Crown Estate. The difference in wake effects therefore relates to the constraints in spacing imposed on German wind farms, rather than different assumptions about wake losses. This means that larger rotors on turbine with the same rating drive an increase in wake effects as actual spacing is unchanged, rather than an increase in CAPEX and OPEX due to turbines further apart.
- Looking at internal wake losses, the trend for Stiftung is upward due to decreased spacing relative to rotor diameter, whilst the trend for The Crown Estate is downward due to constant spacing relative to rotor diameter but increased turbine size.
- External wake losses are not considered in The Crown Estate study, due to the flexibility in locating wind farms within zones, through recent evidence is that some future wind farms may be located relatively close together.
- Although there is a strong trend of increasing external wake losses with time in the Stiftung study, in reality, earlier German wind farms may become more wake affected in time when new wind farms are constructed. We understand that this is not considered in the Stiftung study.



Study comparison

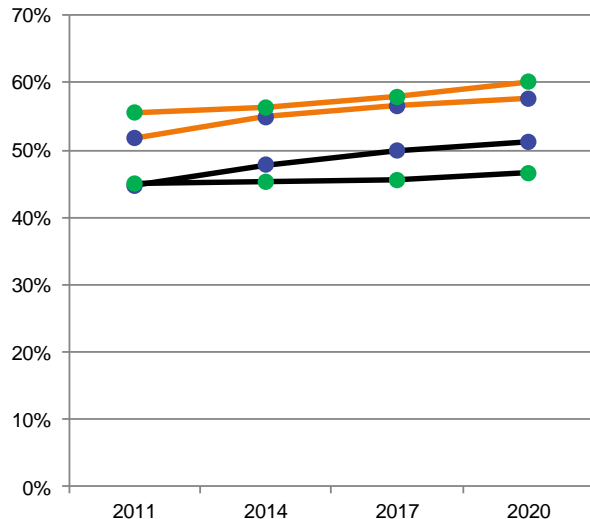
AEP: Stiftung scenario 2

Comparison

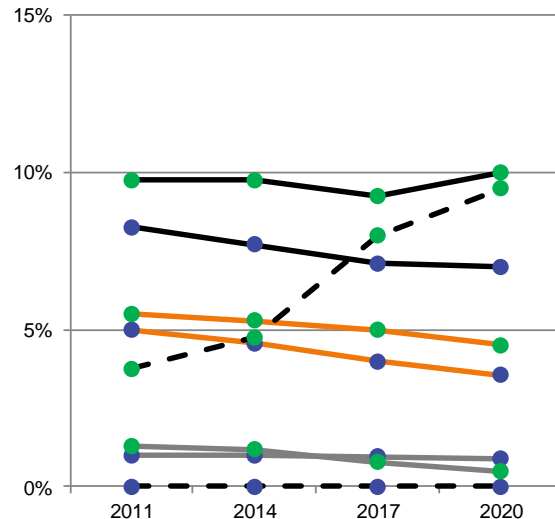
Scenario 2, Site B	2011	2011**	Stiftung vs TCE	2014	2014**	Stiftung vs TCE
Turbine annual energy production*	4,540	4,871	7%	4,809	4,935	3%
Net energy production	3,917	3,947	1%	4,193	3,970	-5%
Gross capacity factor	51.8%	55.6%	7%	54.9%	56.3%	3%
Unavailability	5.0%	5.5%	10%	4.6%	5.3%	16%
Wake losses (internal)	8.3%	9.8%	18%	7.7%	9.8%	26%
Wake losses (external)	0.0%	3.8%	N/A	0.0%	4.8%	N/A
Electrical losses***	1.0%	1.3%	30%	1.0%	1.2%	20%
Net capacity factor	44.7%	45.0%	1%	47.8%	45.3%	-5%

	2017	2017**	Stiftung vs TCE	2020	2020**	Stiftung vs TCE
	4,954	5,073	2%	5,050	5,273	4%
	4,376	3,991	-9%	4,489	4,081	-9%
	56.5%	57.9%	2%	57.6%	60.2%	4%
	4.0%	5.0%	26%	3.6%	4.5%	26%
	7.1%	9.3%	30%	7.0%	10.0%	43%
	0.0%	8.0%	N/A	0.0%	9.5%	N/A
	1.0%	0.8%	-18%	0.9%	0.5%	-45%
	49.9%	45.5%	-9%	51.2%	46.6%	-9%

* includes other turbine losses (assumed = Stiftung 'other losses'); adjusted for difference in shape of wind speed distribution and air density correction.
 ** derived by applying losses multiplicatively; Stiftung study adds wake losses.
 *** Stiftung electrical losses include substation whereas TCE losses do not. 1% adjustment made to Stiftung losses to compensate.



— Gross capacity factor
 — Net capacity factor



— Unavailability
 — Wake losses (internal)
 — Wake losses (external)
 — Electrical losses

Study comparison

AEP: Stiftung scenario 2

Comparison

- The growth in rotor diameters is more similar for Scenario 2, and this is reflected in the increased consistency in trend of gross energy production.
- As for scenario 1, availability is somewhat lower than for The Crown Estate study, but the trend in availability is similar.
- Internal array losses are relatively level for Stiftung, due to a smaller changes in specific rating. Internal losses for The Crown Estate reduce more with time than in Scenario 1, due to the greater increase in turbine rating.
- External array losses for Stiftung increase faster than in scenario 1 due to increased deployment of neighbouring wind farms. Again, no external losses are modelled for The Crown Estate.
- Net capacity factor in the Stiftung study does not increase nearly as much as for The Crown Estate due to the higher wake losses, giving an eventual 9% reduction in in annual energy production relative to The Crown Estate for FID 2020.

Study comparison

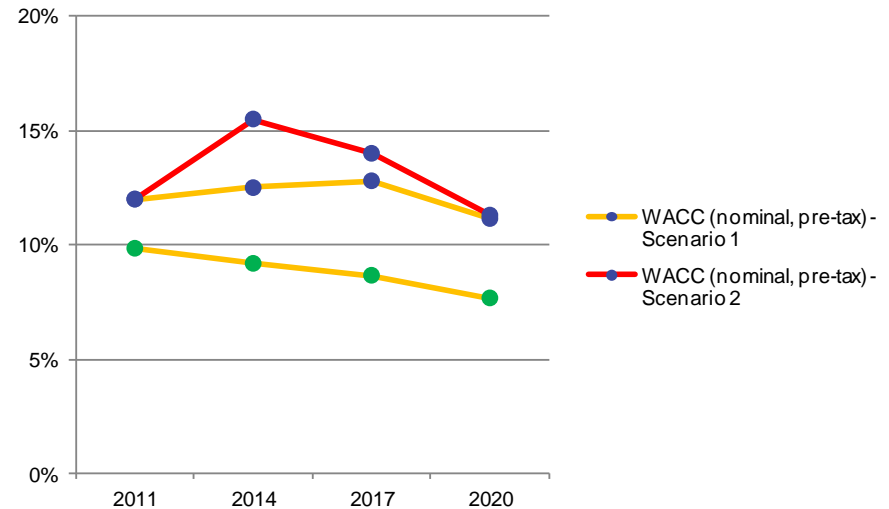
WACC

Comparison

Scenario 1, both sites		2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
WACC (nominal, pre-tax)		12.00%	9.85%	-18%	12.50%	9.19%	-26%
		2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
		12.80%	8.67%	-32%	11.15%	7.68%	-31%

Scenario 2, both sites		2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
WACC (nominal, pre-tax)		12.00%	9.85%	-18%	15.50%	9.19%	-41%
		2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
		14.00%	8.67%	-38%	11.30%	7.68%	-32%

- Stiftung study does not differentiate between the two scenarios and shows a smoothly decreasing trend as investment risk is reduced through experience installing and operating wind farms.
- The Crown Estate study assumes an increase in cost of capital due to concerns about availability of supply, especially in scenario 2, where the demand is higher. We remain sceptical about the justification for this trend.
- There is also a significant offset of 2% in WACC. Although both studies are believed to use compatible definitions. The UK finance community is known for having higher rates, though EU finance community has access to the UK offshore market (though possibly with exchange rate risk). It is recommended that this area be explored in more detail. A 2% change in WACC corresponds to about a 10% change in LCOE.



Study comparison

LCOE: Stiftung scenario 1

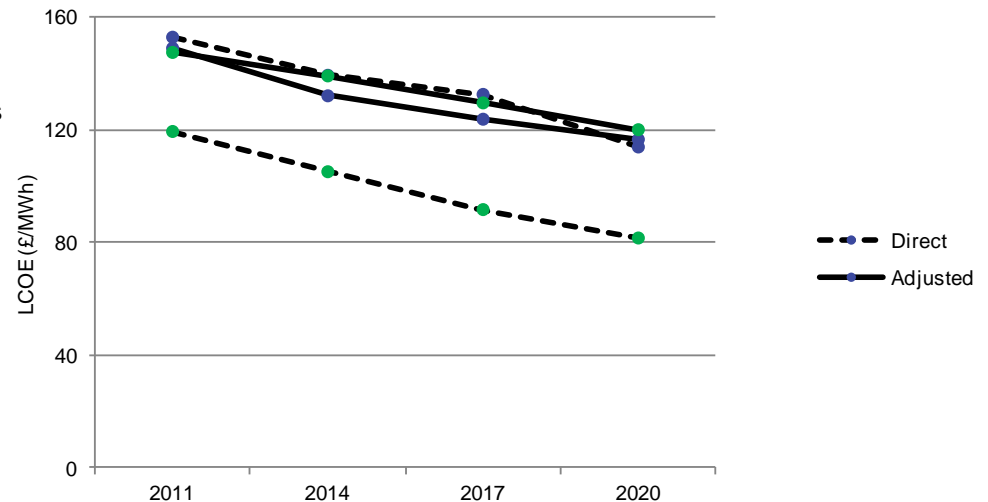
Comparison

Scenario 1, Site B	2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
Total CAPEX (exc. Contingency)	2,794,900	2,803,561	0%	2,598,386	2,694,244	4%
Total annual OPEX	211,070	213,693	1%	193,197	195,656	1%
Total DECEX	462,858	128,658	-72%	322,132	104,272	-68%
Net AEP	3,917	3,947	1%	4,072	3,946	-3%
WACC	12.0%	9.9%	-18%	12.5%	9.2%	-26%
LCOE (as stated in study)	153	119	-22%	139	105	-25%
LCOE (offset to correspond to TCE*)	149	147	-1%	132	139	5%

* WACC(real, pre-tax) set to 10% for both studies; transmission costs from TCE incorporated for Stiftung; substation and substation installation removed from Stiftung costs.

2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
2,471,230	2,546,245	3%	2,366,883	2,466,360	4%
183,910	187,712	2%	175,368	180,383	3%
293,037	97,544	-67%	267,704	90,817	-66%
4,133	4,028	-3%	4,193	4,198	0%
12.8%	8.7%	-32%	11.2%	7.7%	-31%
133	92	-31%	114	82	-28%
124	130	5%	117	120	3%

- A direct comparison of LCOE results stated in the studies shows Stiftung LCOE is 20-30% lower. This is due mainly to socialisation of transmission costs and differences in WACC. Generally, differences in CAPEX (adjusted to exclude transmission system cost), OPEX (adjusted to include transmission cost) and AEP are all less than 5%. With WACC adjusted to be constant for both studies, the Stiftung LCOE moves from being marginally lower to marginally higher by 2020, reflecting a trend of marginally higher CAPEX and OPEX and marginally lower AEP.
- No attempt is made to compare the LCOE calculation process in the two studies using exactly the same input data, as a working version of the model used in the Stiftung study is not available.



Study comparison

LCOE: Stiftung scenario 2

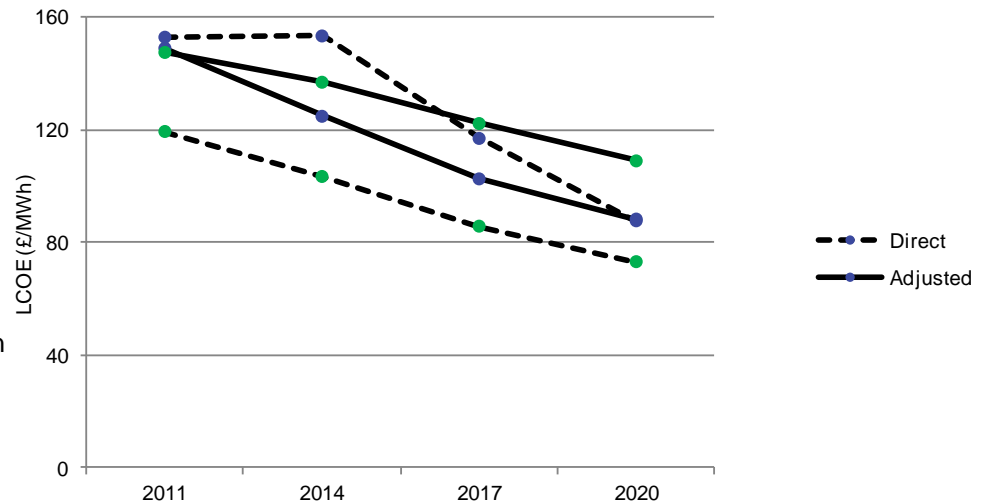
Comparison

Scenario 2, Site B	2011	2011	Stiftung vs TCE	2014	2014	Stiftung vs TCE
Total CAPEX (exc. Contingency)	2,794,900	2,803,561	0%	2,517,979	2,663,971	6%
Total annual OPEX	211,070	213,693	1%	189,594	193,974	2%
Total DECEX	462,858	128,658	-72%	296,566	97,544	-67%
Net AEP	3,917	3,947	1%	4,193	3,970	-5%
WACC	12.0%	9.9%	-18%	15.5%	9.2%	-41%
LCOE (as stated in study)	153	119	-22%	153	103	-33%
LCOE (offset to correspond to TCE*)	149	147	-1%	125	137	10%

* WACC(pre-tax, nominal) set to 11% for both studies; transmission costs from TCE incorporated for Stiftung; substation and substation installation removed from Stiftung costs.

2017	2017	Stiftung vs TCE	2020	2020	Stiftung vs TCE
2,108,910	2,371,338	12%	1,810,535	2,129,159	18%
169,243	176,780	4%	157,200	165,247	5%
242,643	81,567	-66%	133,584	71,477	-46%
4,376	3,991	-9%	4,489	4,081	-9%
14.0%	8.7%	-38%	11.3%	7.7%	-32%
117	86	-27%	88	73	-17%
103	122	19%	88	109	23%

- In this scenario, LCOE for The Crown Estate is high in 2014 due to the high increase in WACC. Once WACC and transmission costs are adjusted, LCOE for Stiftung does not fall nearly as steeply as for TCE, with LCOE for Stiftung eventually 23% higher than for TCE. This is due to less progress on both AEP and CAPEX.
- Note also that the difference between Stiftung scenarios in 2020 is only about 10%, whereas the difference between Industry Stories in The Crown Estate study is over 20%. The Stiftung consultant advises that cost of energy reduction to FID 2020 is relatively small due to the early lock-in of costs; it expects a larger difference between the two scenarios beyond FID 2020.

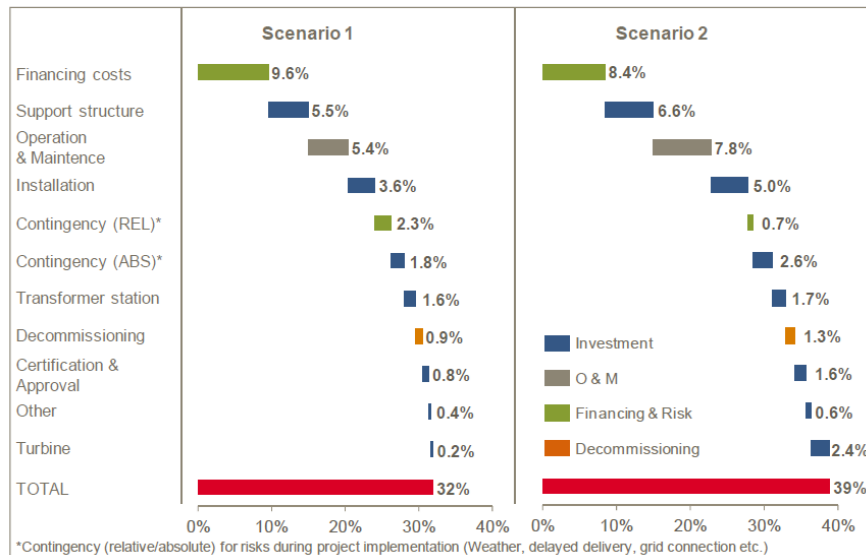


Study comparison

Key areas for cost of energy reduction

Comparison

- Although both studies incorporate a waterfall plot showing the impact of innovations, the Stiftung chart relates to the savings in the given element, whereas The Crown Estate chart relates to innovations in the given element that may impact LCOE through savings in other elements. This means that it is not possible to compare accurately the relative importance of innovation in different elements.
- Generally also, the Stiftung study does not define specific innovations, though one difference between the two studies is that Stiftung study flags the importance of shared offshore operation, maintenance and service infrastructure for projects that are located close together, even if different suppliers of turbines are used.



Study comparison

Learning and recommendations

Learning

- The comparison suggests that German offshore wind risks being up to 10% less cost effective than UK due to wake effects, both internal within wind farms due to lower spacing than planned in UK and also external, due to wake effects between wind farms. The latter was not modelled in The Crown Estate study but may become significant in future, depending on layout of wind farms within zones.
- The comparison shows that:
 - German development and consenting costs are about 40% higher than in UK. If this is a real effect, it is important to understand whether this is for good reason (rational additional levels of environmental and personnel protection, statutory regulation and front-end engineering design) or not. Any differences in regulation offer the opportunity for harmonisation leading to cost of energy reduction across the EU market.
 - Parameters locked-in early in the project development lifecycle can have a significant impact on cost of energy – for example where at leasing stage, if too small an area is allocated for the wind farm, as turbine rotor sizes continue to evolve then this drives excessive wake effects.
 - Financing costs seem significantly lower in Germany, though there is no structural reason why the difference should be so great.
 - The Stiftung study is significantly less optimistic about installation cost reduction than The Crown Estate study.
- The German sector expects to take benefit from shared operation, maintenance and service infrastructure between wind farms, even operating turbines from different wind turbine manufacturers.

Recommendations

It is recommended that:

- Differences between historical and anticipated financing costs between the two markets are thoroughly explored and barriers to reduction in financing costs for UK projects be addressed. There is an opportunity to impact LCOE by up to about 5%.
- Anticipated spacing both within and between planned wind farms and resulting wake effects on UK projects be surveyed and both trends and outliers investigated. Based on the Stiftung study, there is an opportunity to avoid LCOE penalties of up to about 5% through avoiding excessive wake losses, that are not in any case expected to approach those anticipated in Germany.
- Collaborative innovations such as sharing of operation, maintenance and service infrastructure between projects be further encouraged.
- Development and consenting costs and practices be compared between Germany and UK. Renewable is currently carrying out a study to understand whether regulatory requirements for consenting and construction are adding to costs and timelines, and if so to what extent. It may be that work can build on the output of this study, though it is recognised that relative benefits of such work are likely to be greater for the German rather than UK market.
- Closer links be established between The Crown Estate and German Stiftung Offshore-Windenergie.