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Levelised Cost Analysis Update 2018

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Acknowledgement The authors are grateful to Keith Burns for his assistance with the nuclear worksheet.

9 January 2018

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'This document has been prepared in good faith, and endeavours have been made to make it as objective as possible using the authors' expertise together with reference to other documents. However, the results are for a specific set of input data chosen by the authors, and IESIS and the authors accept no liability for any loss or damage to others as a result of relying on information in this paper.'
November 2017

Contents

Role of levelised cost estimates

It should be borne in mind that Levelised Cost Studies should not be used as a planning tool. Planning should be done using Total System Cost analysis which would take account of the characteristics of the particular system e.g. the shape of the load curve, the existing and follow-on generation plant, the existing transmission system etc.

The levelised cost methodology was developed to inform long-term strategic discussions on the relative costs of various types of generating plant. All the costs to the customer of a type of plant should be included e.g. System Integration Costs. The studies should be done at current prices, but with any forecast 'real' cost changes included. Re-financing could be considered if the riskiness of the project is forecast to change over its life. It is not necessary to include 'general inflation' since this could vary over the life of a project and is 'unknown' on long timescales. Also, changes to the discount rate used over the life would be required.

Summary

The first version of the IESIS levelised cost spreadsheet was published in 2011 Since that time we have seen a rapid expansion of UK electricity generation using wind turbines and solar panels. A similar expansion of generation using roof-top and ground mounted solar panels has occurred. Further, papers have been written studying the ageing of both technologies and its impact upon production. In 2016 we published a revision that responded to these changes by including

1. An analysis of historic onshore and offshore wind farm capital costs and capacity factors,
2. A new analysis of the levelised costs for solar generation, and
3. Inclusion of reported ageing effects on both wind and solar generation.
4. Creation of a new coal with carbon capture analysis sheet in which progress at the Boundary Dam (and other) project is considered.

The 2016 levelised cost paper standardised the calculation method and presentation for all fossil fuel generators, and improved the macro analysis tool so that users could explore the sensitivity of the levelised cost calculation to various parameters.

This 2017 version includes the contribution of decommissioning costs and income within the levelised cost of electricity calculation.

System integration costs can be included for all technologies as appropriate. These costs have three components:

1. The capital cost of any new or modified transmission required to support the technology connection to the transmission grid. Extra costs for maintenance are not included.
2. The cost of planning reserve plant required to address technology intermittency problems, and
3. The cost of system integration charges required from an external service provider if the generator cannot provide response, frequency control, and other grid services.

Marginal system line losses that are not included in the estimates could be significant.

A sensitivity analysis can be performed for each of these charges - see Section 2

The four variants of coal generation in the previous version of the spreadsheet have been reduced to two: with and without carbon capture. The Severn Barrage scheme has also been dropped (it is still included in the 2011 spreadsheet if required).

Other small modifications have been made to the gas and nuclear generation sheets.

In Sections 5 to 11 of this document we describe some of the settings for the values of input variables used in the published version of the spreadsheet, with supporting evidence for their choice.

1 Definitions

1.1 Levelised Cost

A description and validation analysis for levelised cost is given in Section 16.

LCOE (cell O15) is the 'Levelised Cost of Electricity' i.e. the cost of production of energy by a particular method.

System Integration Costs (Cell O23) are defined in Section 12.

Total System Cost (Cell P24) is the sum of LCOE and the System Integration Costs.

1.2 Financial variables

Overall borrowing rate (D14) = Debt discount rate(D13) x Gearing(D12) + Equity return(D11) x (1 – Gearing(D12))

The gearing (or gearing ratio) is the proportion of the finance that is provided by debt relative to the total finance provided. For example, if the gearing ratio is 0.4 then 40% of the funding is from debt and 60% is from equity.

The financial method used is based on 'real' costs and therefore neither tax nor inflation is included in the calculation. However, the cost of debt assumes the developer receives tax relief.

1.3 Load Factor

For the purposes of the spreadsheet the load factor is defined as:

Load Factor = plant availability x availability of the prime source of energy

'Plant availability' is a factor that represents the average time that plant will be available to generate taking account of time when the plant may be shut down for maintenance.
The 'availability of the prime source of energy' is expressed as a factor on installed capacity.

Thermal generation: The availability of the prime source of energy is taken as 1.0 for thermal plant (assuming that there is sufficient fuel storage on site). Therefore the value of the load factor used in data cell D15 for thermal plant represents the plant availability. This results in a minimum cost prediction for these types of generation in relation to load factor. If the levelised cost is used in further calculations, say, to provide an approximation of Total System Costs for a particular power system, the estimate of levelised cost would be modified at that point for that circumstance. For example, preferential running for renewables or nuclear would modify the estimated load factors for other types of thermal generation and hence would predict higher values of cost .

Wind and solar generation: The plant availability is taken as 1.0 in year zero but is modified by an ageing factor – see Section 1.4.

The availability of the prime source of energy for wind and solar are both weather related. Therefore the availability factor will be different every time it is estimated. Predictions can be made (references 1,2) or the factor can be based on observations of output from generators.

1.4 Ageing discount factor

This factor is a measure of the rate of reduction of production of a generator with time.

The data value in Cell D22 is for the per annum rate of reduction as a proportion of the plant availability.

For wind and solar generation the values of ageing factor used are discussed in Sections 10.2 and 11.3

For thermal generators it is assumed that sufficient O&M cost is included to ensure zero ageing effect - hence an ageing factor of zero is used.

2 Technology sheets overview

2.1 Layout

All of the sheets have the same layout and calculation method apart from the nuclear sheet which has some variation to deal with fuel cost and fuel waste handling.
Each sheet has six main calculation areas (Figure 1), each with different coloured backgrounds.

a. Development of Levelised Cost of Electricity LCOE (Green background).
b. Transmission costs (Blue)
c. Planning Reserve Costs (Brown)
d. Decommissioning Costs and Income (Purple)
e. System Response Charges (Buff Green – see cell G22)
f. Macro Calculation Area (Grey)

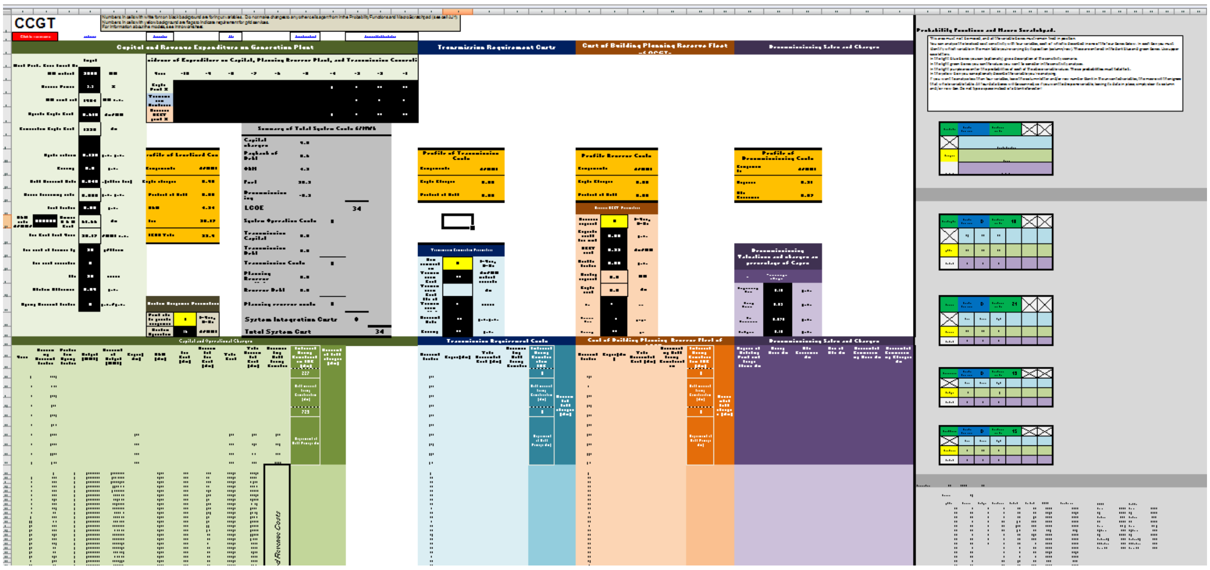

Figure 1 Overview of the LCOE calculation sheets

A description of incidence of expenditure is required for capital, transmission reinforcement, and reserve OCGT; this common area is G4:Q8.

All cells with a black background and white text are user input parameters which users can change as required. The incidence of expenditure boxes (H6: Q8) are so coloured as they can be set by the user, provided they sum to 100.

The nuclear sheet has two additional parameters for the LCOE calculation. These deal with waste handling charges. See cells D23:24.

There are three cells with black text upon a pale yellow background – H23, S19, Y16. Each can be set to either 0 or 1. These are flags which the user must set to indicate whether the costs are to include transmission, reserve or response charges.

Each sheet has two types of calculation result tables, separately coloured:

a. Calculation results for each separate cost area coloured (Dark Yellow). There are four of these: G11:I16, R11:T14, X11:Z14, AD11:AD14,
b. Levelised Costs with System Integration Costs (Dark Grey) – K9:P24 LCOE is 'Levelised Cost of Energy' i.e. the cost of producing the energy. The System Integration costs are defined in Section 12.

2.2 Calculation methods

There are two ways of calculating levelised cost:

a. Change input parameters (white font on black) gives immediate estimates of levelised cost.
b. Exploring the sensitivity of levelised costs to changes in input parameters.

The spreadsheet includes a facility that allows the user to explore the sensitivity of the levelised cost to varying parameter costs, each with a different probability. Up to four parameters can be selected for inclusion in this sensitivity analysis. The facility takes the form of an Excel macro that is initiated by a macro button (cell A2) on each worksheet), and a macro scratchpad area. Use of this sensitivity analysis macro is optional.

The macro scratchpad area (Cols AJ:AZ):

a. is headed with a description of how to use the scratchpad
b. allows the user to configure the parameter values and probabilities. The user can enter a range of up to six pairs of data and probability values for any four of the input parameters
c. displays the results of the macro calculations.

2.3 Sensitivity analysis: an example

We wish to determine the sensitivity of CCGT costs to

a. Fuel prices
b. Efficiency
c. Fuel cost escalation
d. Load factor

In the scratchpad data entry areas we configure each of these parameters with a range of values each with a corresponding probability, as shown below (Figure 2).

Fuel Cost p/therm	Variable Column letter	D	Variable row number	18		
	P1	P2	P3			
p/Therm	25	35	45			
Probability	0.2	0.4	0.4			

Efficiency	Variable Column letter	D	Variable row number	21		
	Low	Central	High			
Efficiency	0.58	0.59	0.6			
Probability	0.3	0.4	0.3			

Fuel escalator	Variable Column letter	D	Variable row number	19		
	Low	Central	High			
Esc% pa	-0.02	0	0.01			
Probability	0.3	0.5	0.2			

Load Factor	Variable Column letter	D	Variable row number	15		
	Low	Central	High			
Load factor	0.8	0.85	0.9			
Probability	0.2	0.6	0.2			

Figure 2 Macro parameter/probability dada entry boxes

Note that the probabilities in each table have to sum to 1. If they don't, a warning box appears to the right of the table.

The macro runs through the calculation of levelised cost for each and all of the combinations of these parameters and calculates the corresponding combined probabilities. In this example, there will be 3^4 results, which will be listed in ranked order of levelised and total system cost. The probability of each resultant LCOE, and the cumulative probability are also shown see Figure 3.

p/Therm	Efficiency	Esc% pa	Load factor	Probability	Cum Prob	LCOE	Total System cost
25	0.6	-0.02	0.9	0.0036	0.0036	24.93	24.93
25	0.59	-0.02	0.9	0.0048	0.0084	25.14	25.14
25	0.58	-0.02	0.9	0.0036	0.012	25.35	25.35
35	0.58	0	0.9	0.012	0.36	33.30	33.30
35	0.6	0	0.85	0.036	0.396	33.37	33.37
35	0.59	0	0.85	0.048	0.444	33.70	33.70
35	0.58	0	0.85	0.036	0.48	34.05	34.05
35	0.6	0	0.8	0.012	0.492	34.21	34.21
45	0.58	0.01	0.85	0.0144	0.9888	42.17	42.17
45	0.59	0.01	0.8	0.0064	0.9952	42.53	42.53
45	0.58	0.01	0.8	0.0048	1	43.01	43.01

Figure 3 Macro sensitivity analysis results

Note: if the probabilities of each variable have not summed to 1, then the cumulative probability value at the bottom of the table will not be 1.

During the sensitivity analysis the macro finds the scenario with the highest probability, and at the end of the calculations it will load the spreadsheet with the component parameters that generate this result. If there are two or more such results, the lowest LCOE result will be selected.

When the spreadsheet is downloaded from the IESIS website the parameters will have been set with reference to previous surveys of historic data and by operation of a sensitivity analysis determined by the authors of this work.

2.4 Charts

Three charts are derived from the macro analysis and appear in each worksheet in the cell range A108:U136, see Figure 4.

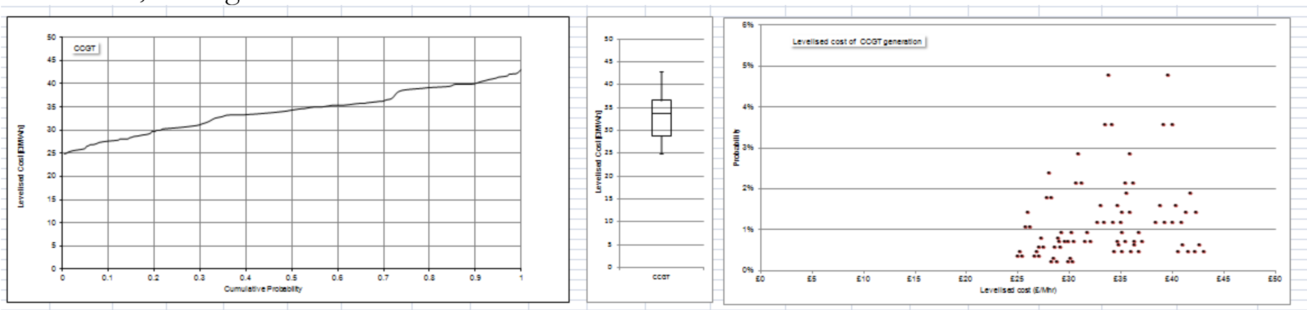

Figure 4 Overview of the charts area on each calculation sheet

2.4.1 Total System Cost versus cumulative probability

This chart can be interpreted as follows:

- For a point on a curve with value of levelised cost C and probability P, P is the probability that the cost will be not less than C
- Examples:
  At P = 0.1 there is a 10% chance that the cost will be less than the chart value - and hence a 90% chance that the cost will be greater than this value.
  At P = 0.5 there is a 50% chance that the cost will be less than the chart value.
  At P = 0.9 there is a 90% chance that the cost will be less than the chart value - and hence there is a 10% chance that the cost will be greater than the chart value.
- The slope of the curve is a measure of the degree of uncertainty in the predictions. Flat slopes infer low uncertainty. Steep slopes infer high uncertainty.

2.4.2 Plots of levelised and total system cost against probability

The horizontal axis is the levelised cost (i.e. the Total System Cost) from the column below AR46. The vertical axis is probability from the column below AO46. For the wind and solar charts the values for LCOE are also plotted (red dots).

2.4.3 Whisker charts

These charts, also known as 'box and whisker', relate only the values of total system cost and do not use the values of probability. The data is the set of values of levelised cost starting in Cell AR46.

Figure 5 shows the definitions of the lines in the whisker diagram.

The *quartiles* are the value of the numbers in the set that divides the set into quarters. How the quartiles are defined depends on the function used. The macro calls a user defined function *quantile*. This function is explained here. The calls on *quantile* in the macro are for Method 8.

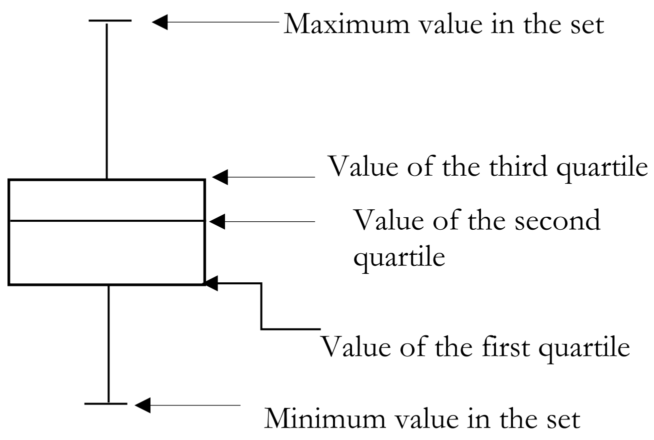

Figure 5 Explanation of the whisker plots

3 Intro worksheet

This provides background information for the spreadsheet and a list of amendments.

4 Main Charts worksheet

This worksheet shows charts for comparison of costs against cumulative probability for (a) renewable generation, (b) thermal generation and (c) coal options.

Also included in this sheet are whisker diagrams for costs for the different types of generation.

5 Coal1 worksheet (no carbon capture)

This worksheet is provided so as to be able to assess the extra cost of Coal with Carbon Capture and Storage (CCS)

5.1 Capital cost

Capital Costs from Reference 3 for a NOAK of £1768/kW are used

5.2 O&M cost

The central figure for O&M of £102.8m/year (including insurance, excluding transmission) was taken from Reference 3

5.3 Fuel costs

Reference 3 uses Fuel Costs supplied by DECC and takes the average of these over the period 2015 to 2030. This study uses a different approach: it takes the average central forecast cost for these 15 years of $80/t as the cost in Year 0 then escalates this at 3% p.a. The Year 0 Cost is equivalent to 20p/therm or £17.3/MWh s.o. (sent out)

6 CoalCCS worksheet   (Coal with carbon capture and storage)

The Canadian Boundary Dam project (ref 4) gives us firm figures for capital costs and production levels of the operational carbon capture station. There are also projections for future developments and costs (lower and higher) which can be taken into account, see Table 1.

	Possible future carbon capture capital costs			
Capex (£m/MW)	£11.8	£9.45	£12.66	£8
Probability	20 %	30 %	30 %	20 %

Table 1 Possible carbon capture capital costs.

7 CCGT and OCGT worksheets (Gas generation)

7.1 Gas price

The current price (October 2017) of gas on NYMEX Henry Hub is 3.02 USD/ MBTU i.e. 23p/therm, see Figure 8.1. The 50 week average (red) suggests a central price of 3.2 USD/MBTU (25p/therm) with a probability of 52%; a low figure of 3USD/MBTU (23p/therm) with a probability of 24%; and a high figure of 3.4 USD/MBTU (26p/therm) with a probability of 24%. These prices are for a market supplied with gas extracted by fracking.
The UK wholesale gas price is currently (October 2017) 44 p/therm. Inspecting the last two years of gas price movements, we have set the fuel cost probabilities as shown in Table 2. These gas prices will also apply to the OCGT technology sheet.

	Possible gas prices		
Gas price (p/therm)	25	35	45
Probability	0.2	0.4	0.4

Table 2   Expected UK gas prices (p/therm).

(These observations suggest that if UK gas extraction using fracking is a success, the cost of CCGT and OCGT could fall by 25-30 %.), see Figure 6.

Figure 6 Nymex gas prices

7.2 Gas price escalation

We have set probable gas price escalation factors as shown in Table 3.

	Future gas price future escalation		
Escalation (%) per annum	-2 %	0 %	1 %
Probability	20 %	60 %	20 %

Table 3 Possible gas price escalation.

Extraction of gas by fracking is expanding worldwide, dispelling past concerns that gas prices would surge. The OCGT sheet carries the same gas price escalation profile.

7.3 CCGT and OCGT load factors

CCGTs are assumed to run mainly as baseload, Table 4.

	CCGT load factor		
Load factor	80 %	85 %	90 %
Probability	20 %	60 %	20 %

Table 4 Possible CCGT fleet load factor.

OCGTs are assumed to run mainly as reserve and response plant and have lower load factors, Table 5.

	OCGT load factor		
Load factor	40%	55 %	60 %
Probability	20 %	60 %	20 %

Table 5 Possible OCGT fleet load factor.

7.4 Capital and O&M costs

The Capital and O&M costs are from reference 5.

8 Biomass worksheet

The costs are based on new-build biomass. Capital cost and O&M data are from Table 20 in Reference 5.

9 Nuclear worksheet

9.1 Nuclear capital costs

The Capex sensitivity analysis reflects a range from Mott MacDonald 2010 estimates for NOAK build (£2.4m/MW to £3.3m/MW and Hinkley C FOAK at around £5.8m/MW, see Table 6

	Possible nuclear capital costs				
Capex (£m/MW)	4.5	3.75	2.5	2.8	2.9
Probability	0.1	0.35	0.1	0.2	0.25

Table 6 Possible nuclear capital costs.

9.2 Nuclear O&M costs

Operation and Maintenance costs for nuclear vary from £78,000/MWh/yr (FOAK) down to £61,500/MWh/yr (NOAK), (reference 6). We have constructed a distribution around the NOAK costs, see Table 7.

	Nuclear O&M costs		
O&M (£/MW/yr)	55000	61500	65000
Probability	0.25	0.5	0.25

Table 7 Possible nuclear O&M costs..

9.3 Other nuclear costs

Waste storage: The on-site waste storage cost (D23) is set at £2.41/MWh s.o. (sent out) (calculated annually) from reference 6

Fuel disposal: The Final fuel disposal cost (D24) is set at £0.45/MWh s.o. (calculated at end of station life) from reference 6.

Decommissioning The worksheet shows that in present value terms, the cost of nuclear decommissioning is a very small proportion of the levelised cost. This implies that appropriate financial planning is needed to cover the cost of decommissioning e.g. via a liabilities fund.

10 Onshore (Ons) and Offshore (Offs) worksheets (Wind generation)

10.1 Capital costs

Offshore wind: The capital costs of UK offshore wind farms is well reported and a simple Wikipedia query gives all the information we require. This is graphed in the 'Offshore wind capex' worksheet.

In reference 8 this survey is extended to include 76 offshore wind farms in European waters, indexing costs to 2012. Indexing the costs to 2017 the offshore wind capital cost in the 'Offs' worksheet is represented as shown in Table 8.

	Possible future offshore wind farm capital costs					
Capex (£m/MW)	1.6	2.2	2.8	3.4	4	4.6
Probability	0.01	0.05	0.24	0.4	0.24	0.06

Table 8 Possible capital costs for offshore wind farms

Onshore wind: Although details of onshore wind farm size, likely production, benefits to the community and carbon dioxide savings are well documented, it is rare for the build cost to be published. But from time to time these figures are reported, and given the number of wind farms, we now have adequate data as shown in the 'Onshore Capex' worksheet

These are represented in the 'Ons' worksheet as a range of likely costs as given in Table 9.

	Possible future onshore wind farm capital costs				
Capex (£m/MW)	1.20	1.30	1.50	1.60	1.80
Probability	0.06	0.24	0.41	0.24	0.05

Table 9 Possible capital costs for onshore wind farms

10.2 The effect of ageing on offshore and onshore wind farms

Two papers (Gordon Hughes: *The Performance of Wind Farms in the United Kingdom and Denmark*, REF, 2012, and I Staffel and R Green: *How does wind farm performance decline with age*? Renewable Energy 2014) have attempted to detect and quantify the drop of performance of the UK onshore wind fleet over time. Both agree there is a decline but differ in its magnitude. Staffel and Green report 1.6 +/- 0.2 % per annum, Hughes 5 to 13 % per annum; Staffel and Green also report a doubling of the decline rate after year 16. Either viewpoints of performance ageing will increase the levelised cost of these generation methods, but since there is no way at present of separating their likelihood they are both included with equal probability in the sensitivity analysis for levelised cost. Staffel and Green's acceleration at year 16 is included for both possible scenarios (see calculation method in the column headed ageing factor). Table 10 shows the range of parameters used in the onshore wind cost sensitivity analysis.

	Possible onshore wind farm ageing factors					
	Staffel & Green Low	Staffel & Green Central	Staffel & Green High	Hughes Low	Hughes Central	Hughes High
Ageing p.a.	0.014	0.016	0.018	0.05	0.09	0.13
Probability	0.075	0.35	0.075	0.075	0.35	0.075

Table 10 Possible ageing factors for onshore wind farms

Only Hughes analysed offshore wind, and was hampered by lack of data. It is likely that the ageing effect offshore will be worse than onshore because of poor maintenance access. We have increased the observed onshore ageing effects by 30% to represent this accelerated ageing for offshore wind, see Table 11.

	Possible offshore wind farm ageing factors					
	A	B	C	D	E	F
Ageing p.a.	0.018	0.021	0.023	0.065	0.12	0.17
Probability	0.075	0.35	0.075	0.075	0.35	0.075

Table 11 Possible ageing factors for offshore wind farms

The ageing effect is incorporated by multiplying the load factor by the ageing factor.

10.3 Wind load factors

We have set the probable load factors for offshore wind farms as shown in Table 12.

	Possible offshore wind farm load factors				
Load factor (p.u.)	0.3	0.35	0.39	0.41	0.43
Probability	0.05	0.1	0.45	0.35	0.05

Table 12 Possible load factors for offshore wind farms

(In 2016 5,344 MW of installed offshore wind generation delivered 13,525 GWh, a load factor of 29 %.–reference 9.

We have set the probable load factors for onshore wind farms as shown in Table 13.

	Possible onshore wind farm load factors				
Load factor (p.u.)	0.20	0.24	0.25	0.26	0.28
Probability	0.15	0.3	0.4	0.1	0.05

Table 13 Possible load factors for onshore wind farms

(In 2015 9,085 MW of installed onshore wind generation delivered 22,423 GWh, a load factor of 25 %.–reference 9.

11 Solar worksheet

This is a new worksheet. The levelised cost method is unchanged. Three main sensitivities are considered: load factor, capital cost and ageing.

11.1 Load factor

Table 14 shows a range of observed solar capacity factors, together with possible probabilities. These are load factors seen at the terminals of the local grid transformer (ground–mounted) or the consumers meter terminals (roof-top); further losses in the distribution system could decrease delivery to the transmission system. depending on the distribution load when solar is generating. Of course, renewable generation embedded in the distribution system could 'back-off' the distribution load).

	Possible solar load factors				
Load factor (p.u.)	0.08	0.085	0.09	0.11	0.13
Probability	0.15	0.3	0.4	0.1	0.05

Table 14 Possible capacity factors for solar farms

11.2 Capital cost

Based on figures extracted from the report produced by KPMG–reference 12. Table 15 shows likely capital cost.

	Possible solar capital costs		
Capex (£m/MW)	£0.91	£0.84	£0.77
Probability	0.2	0.6	0.2

Table 15 Possible capital cost of solar farms. See

11.3 Ageing factor

Based on reference 13, Table 16 shows the likely ageing factors per annum for solar generation used in this study.

	Possible solar ageing factors		
Ageing factor (% per annum)	0.5 %	1 %	2 %
Probability	0.1	0.6	0.3

Table 16 Possible ageing factors for solar farms.

12 Integration costs

The information in this section is relevant to Onshore Wind, Offshore Wind and Solar generation.

Balancing costs We have not been able to make our own estimates of extra generation revenue costs so reliance has been placed on a Parsons Brickerhoff paper of some years ago (reference 10) which gives an extra levelised cost of £16/MWh. These are the costs of flexing fossil-fuelled and hydro plant to accommodate variations in the output of intermittent plant, without which unacceptable variations in frequency would occur. This would include part load running of fossil and hydro plant, cold, warm and hot start-ups etc. Total system cost studies using a daily load curve program like GOAL are required to give reasonable confidence in a figure for the GB system, but these are beyond he scope of the present study work.

However, assuming the £16/MWh in 2011 was a reasonable estimate, adjusting for fuel cost would reduce this to between £10/MWh and £12/MWh. This was calculated on the basis that with coal at 25p/therm and gas at 68p/therm assumed in 2011, and that between 25% and 50% of the flexibility would be provided by coal. Looking at a NOAK in 2030, say, there would be no coal stations and gas would be costed at 35p/therm, so the costs of fuel would be reduced by between 25% and 40%.

No account has been taken of the costs of the increase in renewable penetration forecast in FES17 (reference 11) for future years. At low penetrations, much of the flexibility could be provided by governor action at fossil-fuelled generation. As the percentage of flexible generation reduces, there will be an ever greater need for part loading, and hot, warm, and cold starts, and less than optimal use of pumped storage.

Also, no account has been taken of extra maintenance costs that will be incurred by flexing fossil-fuelled plant.

A figure of £10/MWh (Cell H24) has been used in the 2017 studies for extra generation revenue costs, but it should be recognized that this figure could be significantly higher if these other costs mentioned above could be estimated.

Back-up generation The same level of contribution as thermal plant to Security of Supply is assumed to be provided by OCGTs costing £0.32m/MW of Capex. Wind generation was given a credit of 8% installed capacity as in the EOn submission to the House of Lords Inquiry. Only capital charges are included. This is the same as on-shore wind.

Transmission The extra cost of transmission to connect generation in the north of Scotland to the main load centres in the south of England is taken to be the same as for on-shore. That is, the capital cost of off-shore transmission is contained within the total capital cost of the project.

13 Onshore wind capex and Offshore wind capex worksheets

The worksheets *Ons* and *Offs* give data tables and charts for capital costs of wind generation.

14 Load factor cost impact worksheet

This worksheet gives data and a chart for the effect on levelised cost of changes in load factor.

15 Calibrate worksheet

This worksheet compares levelised cost values from a 2013 DECC report with values from the IESIS spreadsheet using the same input data - Worksheet Table 1. This shows close correlation indicating that the basic algorithms used are similar. Worksheet Table 2 makes a comparison between DECC and IESIS values with modified input in the later spreadsheet. This worksheet has not been altered since its original issue in 2016.

16 Validation analysis for the levelised cost estimates

16.1 Basic definition of levelised cost

The levelised cost is a discounted average cost per unit of energy over an investment period.

The levelised cost of energy–*LCOE* is calculated using Expression (1):

$$LCOE = \frac{\sum_{i=1}^{n} \frac{I_t + M_t + etc}{(1+r)^t}}{\sum_{i=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (1)$$

where:
n is the number of years of the investment period
t is one of the years during period *n*
I_t is the cost of the investment in year *t*
M_t is the cost of operation and maintenance in year *t*

etc represent costs from other sources in year *t* e.g. fuel cost, cost of backup generation
E_t is the number of Megawatt hours generated by the facility during year *t*
r is the discount rate

That is, for each year of the investment period the costs are calculated and discounted. The sum of the costs for all years is then established. This is divided by the sum of the energy generated over the *n* years also discounted to present value. The discounting of the energy takes account of the change in value of the energy over the period.

The following process was used to calculate the cost probabilities:

1. A selection of the input variables were chosen as being dominant.
2. Values for each of these variables representing low, central and high estimates were defined and corresponding probabilities assigned to them.
3. The number of combinations *N* of variables and probability is:
   $N = n_p^v$ where n_p is the number of probabilities per variable and *v* is the number of variables.
4. For example with 4 variables and 3 probabilities per variable $N = 3^4 = 81$
5. The levelised cost for each combination is calculated
6. Each of the combinations is associated with *v* probabilities. Say with 4 variables there would be four probabilities p_1, p_2, p_3, p_4 The combined probability p_v for a combination of variable values is calculated as: $p_v = p_1 \times p_2 \times p_3 \times p_4$
7. The *N* values of levelised cost and corresponding p_v probabilities are set up in an ordered list from lowest to highest cost.
8. The cumulative probability for each item in the ordered list is calculated as the sum of the probabilities for all the costs less than and equal to the item.
9. Levelised cost against cumulative probability is then plotted.

16.2 General validity of the levelised cost model

There are many limitations to the use of Equation (1). It is a useful approximate method of comparing the costs of different types of generation assuming that the generation can be run at its maximum possible load factor i.e. it is not constrained by the load curve or the running of other plant. A more thorough method of comparing types of generation and plant mix is to run Total System Cost studies for various combinations of plants.

16.3 The individual cost items (I_t M_t *etc.*)

It is most important that the all contributory costs are included when using Equation (1). As noted in Section 12, the DTI and Parsons Brinkerhoff estimates do not appear to include all cost items in their final figures, although the existence of these costs is recognised in the text. There is some confidence that the estimates from the spreadsheet do include all the main costs but there is much uncertainty about the values used for the cost items.

16.4 Validity of the probability approach

A significant amount of judgement was used to establish the values of probability and in choosing the key variables used. In principle, accuracy of prediction could be improved by increasing the numbers of key variables and probabilities but, in view of the shortage of data for establishing the values of the data variables and the probabilities, such refinement may not achieve better outcomes.

16.5 Overall validation assessment

Because of the limitations of the levelised cost approach and uncertainty about the data, the cost predictions presented here will tend to give only broad indication of trends rather than accurate predictions. The important feature of the model is that an attempt has been made to include all the factors that affect the cost of generation

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