OFTO BENCHMARKING
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FINAL REPORT

Prepared by:

Cambridge Economic Policy Associates (CEPA) Ltd

In association with:

Sinclair Knight Merz (SKM)

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EXECUTIVE SUMMARY

CEPA in collaboration with SKM were retained by the Office of Gas and Electricity Markets (Ofgem) to provide support in reviewing information from the first two tender rounds of the Offshore Transmission Owner (OFTO) regime. As part of this review, Ofgem asked CEPA to design a benchmarking approach for ongoing use. In particular Ofgem required the following support:

- perform a thorough check of Ofgem's data in order to determine its suitability for benchmarking;
- undertake data analysis for all Ofgem's data sets (initial, indicative, developer final submissions and final transfer value) including the development of cost drivers that are both correct from a theoretical perspective and statistically robust;
- perform bottom-up cost modelling to assess total project costs and develop a benchmarking process that is fit for purpose; and
- assist Ofgem in the work required to publish a report on benchmarking of offshore transmission assets for public consultation.

In this report we set out our approach to assessing the available data, our assumptions and our testing of bottom-up models that can be used for the purpose of benchmarking offshore transmission assets.

The purpose of the analysis is to assess the feasibility of using the offshore transmission data for benchmarking. The feasibility assessment should be across both its use in assessing past projects, but also to help determine ex ante costs for new OFTO projects.

We note that, while benchmarking is a useful tool for regulators to use to determine efficient costs, data limitations and heterogeneity across projects means that a level of regulatory judgement is needed when using the raw outputs from modelling.

Background

Under the OFTO regime, there are two key models of development; the 'Generator Build' and 'OFTO build' models.

- The 'Generator Build' option involves the generator developer completing preliminary works, designing and constructing the transmission assets. There is then a competitive tender for an OFTO licensee to operate and maintain these assets. After transfer of the asset, the OFTO is awarded a revenue stream for twenty years which is constant in real terms. This revenue stream is based on the Final Transfer Value (FTV) of the asset at the time of asset ownership switching hands and ongoing costs for the OFTO. Ofgem is responsible for setting the FTV based on an assessment of an efficient cost for development and construction of the assets, with this figure enshrined in the commercial agreement between the two parties. Examples of ongoing costs included in the revenue stream will include a cost of capital for financing the purchase, ongoing opex costs and costs for decommissioning.

- The 'OFTO Build' model still requires the generator developer to complete the preliminary works and undertake high level design. However at this stage a competitive tender process occurs and the selected OFTO will construct the asset, as well as operate and maintain it.

The offshore transmission asset regime for construction and operation was designed to be split into a transitional regime and an enduring regime. The Transitional Regime was composed of two Tender Rounds. There were nine projects tendered under Tender Round 1 (TR1) and four projects tendered under Tender Round 2 (TR2). This transitional regime tender process has now been completed for all projects (except for the West of Duddon Sands project which is in the FTV stage at the time of writing). Under the Transitional Regime, every project is operated under a Generator Build model. For the Enduring Regime for subsequent Tender Rounds, both models may be utilised.

Our study involves analysis of data pertaining to 13 Transitional tender round projects. Table E.1 below sets out the summary details for these 13 projects.

Table E.1: List of transitional tender round projects[1]

Tender round	Project	Size (MW)	Ofgem assessed Final Transfer value	Construction commenced^
1	Robin Rigg	180	£65.5m	Jul 2007
1	Gunfleet Sands	173	£49.5m	Feb 2008
1	Barrow	90	£33.6m	Feb 2005
1	Walney 1	184	£105.4m	Oct 2010
1	Ormonde	150	£103.9m	Sep 2009
1	Walney 2	184	£109.8m	Oct 2010
1	Sheringham Shoal	315	£193.1m	Jun 2009
1	Greater Gabbard	504	£317.1m	Sep 2009
1	Thanet	300	£163.3m	Mar 2008
2a	London Array	630	£461.6m	Feb 2011
2a	Lincs	270	£307.7m	Mar 2010
2a	Gwynt y Mor*	576	£346.0m**	Nov 2009
2b	West of Duddon Sands	389	£296.3m**	Feb 2012

^ construction of transmission assets

**The AFTV for Gwynt y Mor has now been determined but it was not available at the time of our analysis.*

** *denotes ITV assessment where AFTV assessment is not available*

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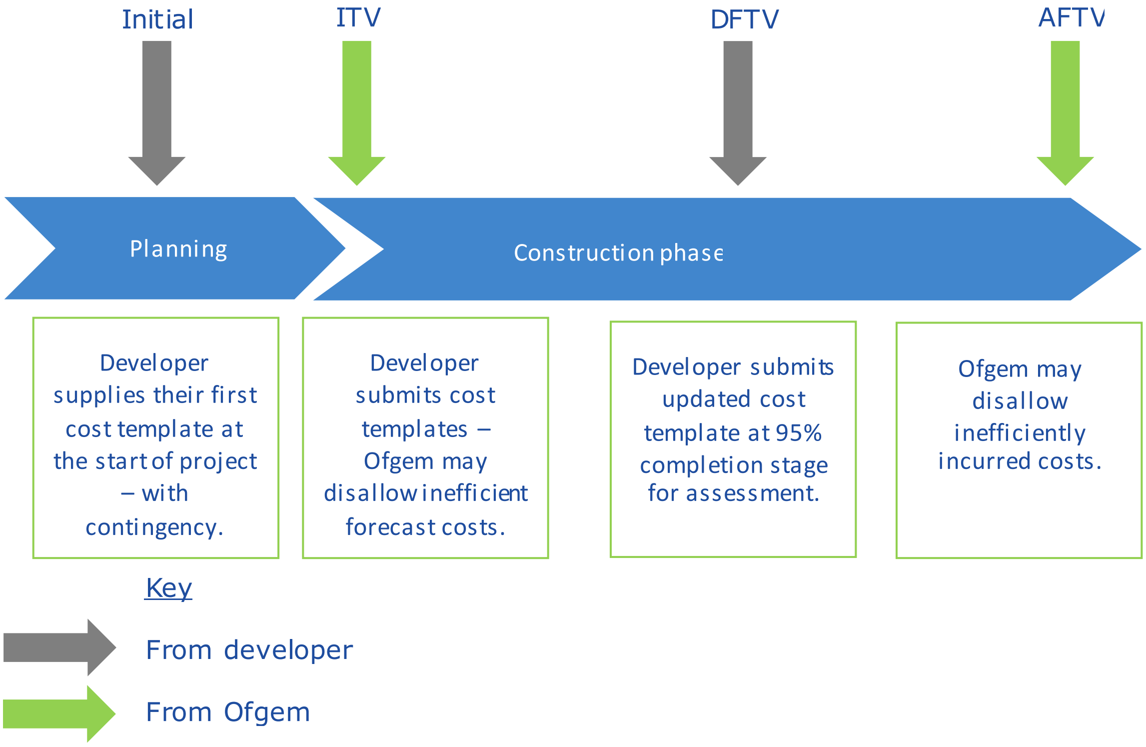
[1] For benchmarking purposes we adjust all costs to 2012/13 prices.

The data used for this benchmarking exercise is drawn from different sources and has been examined to varying degrees - Although primarily relies upon the data collected from developers by Ofgem. Ofgem has collected cost data at a number of different stages throughout the process. Figure E.1 below illustrates when cost estimates (at initial and ITV stages) are made and FTVs are reached and how these costs are constructed.

Figure E.1 – Cost data availability



Developer supplies their first cost template at the start of project – with contingency.

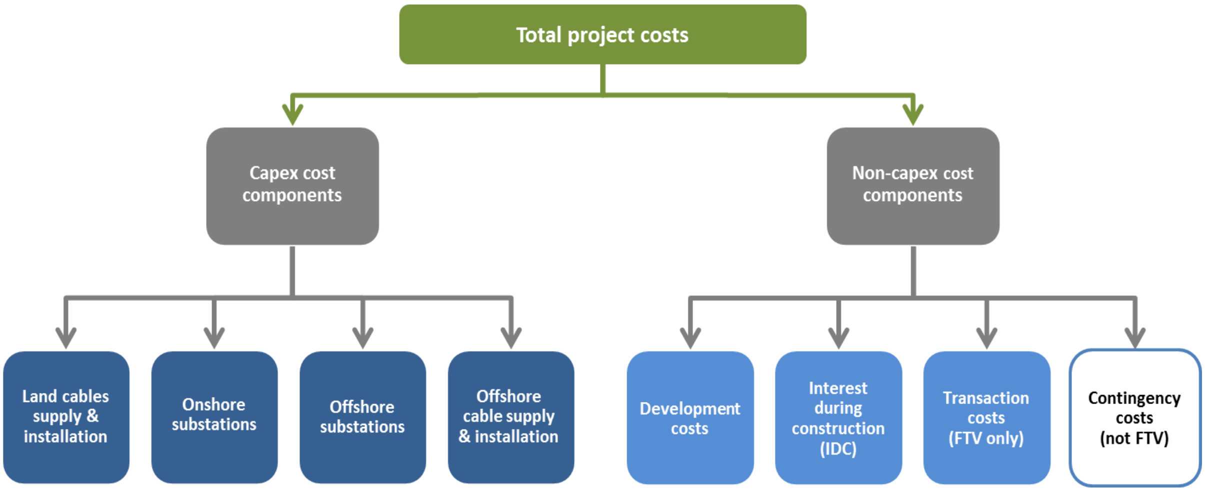
Developer submits cost templates – Ofgem may disallow inefficient forecast costs.

Developer submits updated cost template at 95% completion stage for assessment.

Ofgem may disallow inefficiently incurred costs.

The cost categories can be split into two main types: i) capex costs; and ii) non-capex costs. Figure E.2 below shows the split of costs across the capex and non-capex areas.

Figure E.2 – Cost categories for offshore transmission cost assessment



Note: Contingency costs may be included with capex rather than being allocated to a separate category.

Source: Ofgem, CEPA analysis

For capex costs we have looked at three top-level cost categories for our analysis:

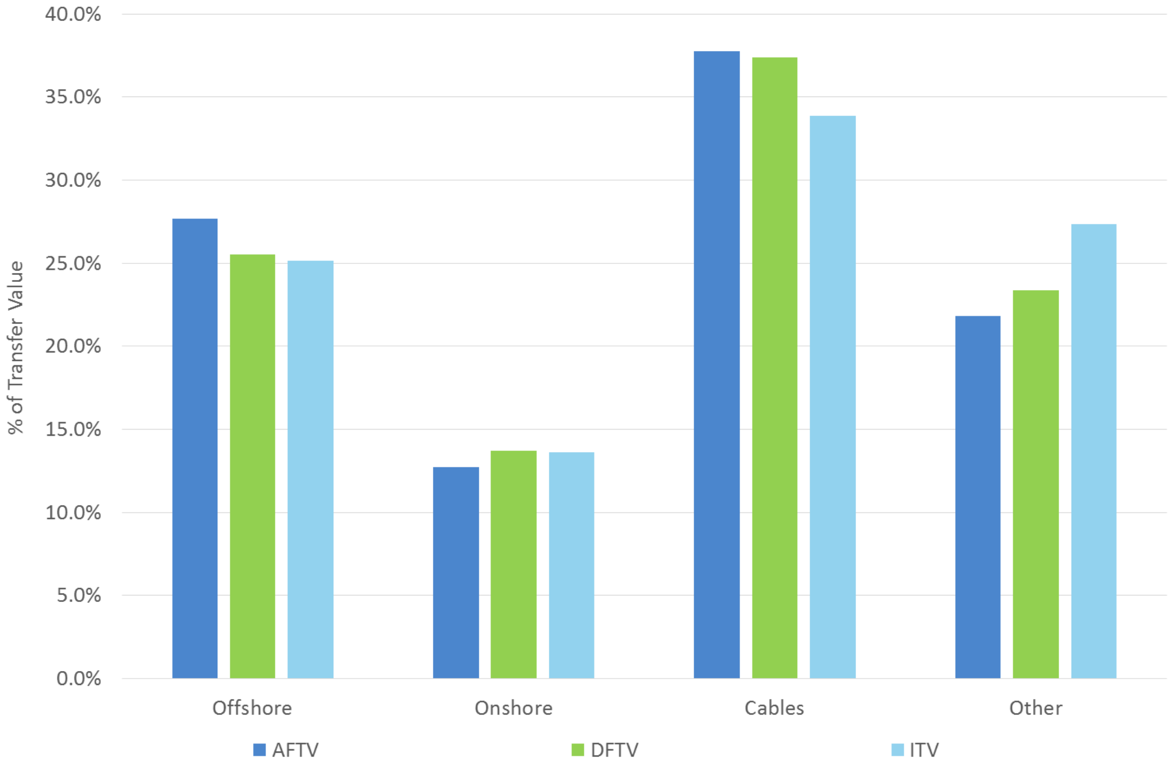
- offshore platform and substation costs;
- onshore substation, equipment and connection costs; and
- cable costs – both land and sea cable.

For non-capex costs, there are four sub-categories:

- development costs (this covers project planning and management costs, plus additional costs that may vary by the size and complexity of project);
- contingency costs (these are included within the ITV stage for increases in costs for unforeseen circumstances and may represent approximately 10% of total capex costs);
- transaction costs (included at the DFTV and AFTV stages only, this relate to legal fees associated with development of a project); and
- IDC (the funding costs incurred by the developer, based on the rate allowed (which is capped) and the cash-flow profile of different projects).

Figure E.3 below shows the proportion of costs across the high level cost categories.

Figure E.3 – Cost proportions at aggregate levels



Source: Ofgem, CEPA analysis

We have not modelled non-capex costs as:

- the IDC rate is dealt with separately by Ofgem and is dependent on cash flow profiles;
- transaction costs are small;
- contingency costs fall away for the Assessed Final Transfer Value (AFTV) phase; and
- development costs are likely to be difficult to model outside of project size.

Note, our analysis looked at the categories from a cost efficiency perspective and does not deal with efficiency of design e.g. it only looks at the cost of a transformer, not whether a transformer was required in the first place.

Approach

Cost drivers

In this report we tested different approaches to benchmarking disaggregated OFTO construction costs. In general we found that econometric approaches tended to perform the best and, as expected, scale or size variables were the best cost drivers.[2] Ideally cost drivers would be outside of companies' control, i.e., MVA required. However, this data may not be available and is likely to be less explanatory in terms of the specific characteristics of the construction requirements. In light of these issues it is common practise to use size or scale variables.[3] Size and scale variables, e.g. weight of platform and size/number of transformers, are reflective of the solution type (in order to meet the output requirements) but are not necessarily reflective of whether the developer has chosen the most cost effective solution (to provide the output).[4] Therefore, in conjunction with cost models, it is best practise to undertake sense checks of projects to ensure that the company is not over engineering ('gold-plating') a project. A further option could be to undertake an *ex post* evaluation of the volume/ size of the work undertaken, i.e. is the final weight of the offshore platform in line with the original engineering plans.

Cost categories benchmarked

For most of the disaggregated cost categories we identified models which, based on the available data set, appear to provide reasonable cost predictions. There were some cost categories for which we were unable to identify robust models, however, these tended to be for smaller cost areas.

Figure E.4 below indicates each of the cost categories which we benchmarked. The percentages indicate the average share of costs for each of the disaggregated categories to next (aggregate) level based on the AFTV stage, e.g., offshore cable supply makes up on

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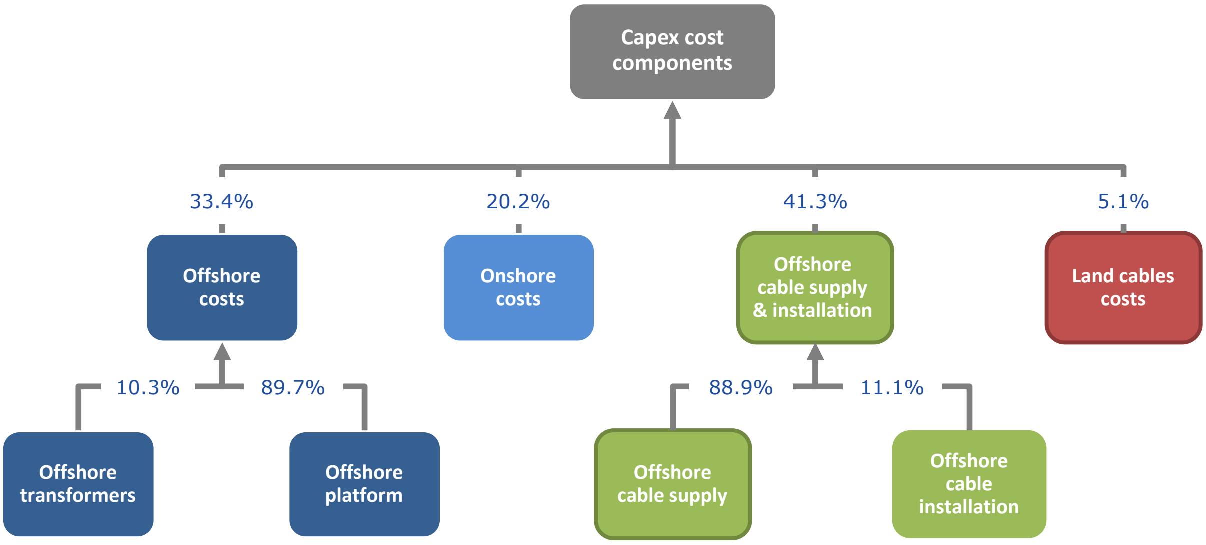
[2] In econometric models, the modeller specifies the functional form of the model.

[3] Ofgem's RIIO price controls tend to rely on scale and size variables (customer numbers, length of network, and volume of assets) for its benchmarking. Likewise, Ofwat's PR14 econometric models rely on length of mains and density explanatory variables.

[4] We would expect there to be a strong correlation between the size/scale of a project and the outputs of the project, e.g. a large cable(s) should reflect a higher capacity requirement of the OFTO.

average 88.9% of total offshore cable costs and total cable costs (offshore and onshore) are 46.4% of capex costs.

Figure E.4 – Modelled cost categories and their aggregation[5]



Source: Ofgem, CEPA analysis

In addition to the disaggregated cost categories benchmarked as set out in Figure E.4 above, we also benchmarked *Onshore transformers* and *Onshore total cost excluding other.*[6] We did identify a robust model for onshore transformers, but not for onshore total costs excluding other.[7] We did not include these in the above diagram as there is not a corresponding model that covers the excluded costs[8] we could not *add* these models to get an aggregate cost estimate.

We focused on modelling at the Initial Transfer Value (ITV) and AFTV stages (we do however also provide the models for the Developer Final Transfer value [DFTV] stage in the Annexes). This is because:

- the ITV provides an estimate which includes a contingency for unanticipated delays and increased costs etc; and
- we believe cost benchmarks based on AFTV, rather than DFTV, set a better cost target as it is adjusted for efficiency (although we would suggest caution should be used by Ofgem if it wished to use an adjusted [e.g. upper quartile] target).

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[5] Note, due to cost allocation issues in the data it was not always clear if developers' had allocated costs to the correct areas. This led to some cost categories not summing to the totals correctly. In most cases this was a relatively small difference.

[6] Onshore total costs excluding other include costs for onshore transformers, onshore reactive equipment, onshore harmonic equipment and onshore connections. See Annex A for data descriptions.

[7] Onshore transformers range from 12% to 65% of the onshore costs excluding other.

[8] Namely the onshore other costs.

We note that as more data becomes available, Ofgem will need to consider how it is used. That is, Ofgem would need to consider what adjusted data to use to avoid any circularity created by using the models' outputs to set targets.

Methodology

In terms of the methodology adopted, we considered using parametric and/or non-parametric (unit cost) approaches. We chose to use parametric approaches for all the models presented in this report. We consider that these are preferable to more simplistic unit cost models as they offer information as to the 'fit' of the model to the data and how well the cost drivers perform given the available data set. We tested both linear and log-linear functional forms and found that in general log-linear models performed better than linear. However, we found some for cost areas both a linear and log-linear form were valid. Text box E.1 below sets out the differences between a linear and log-linear specification.

Text box E.1: linear and log-linear transformations

The main difference between linear and log-linear is that linear regressions assume that marginal costs are constant (e.g. one unit increase in the cost driver will have the same impact on costs regardless of the starting point), while log-linear regressions allow them to vary (e.g. diminishing returns to scale). The log-linear form also allow the simple interpretation of the coefficient as the elasticity of the dependent variable to the cost driver (i.e. the coefficient reflects the percentage change in the costs from a percentage change in the cost driver).

Assessment

In assessing our preference for models, we drew upon three assessment criteria:

1. theoretical correctness;
2. statistical performance; and
3. robustness testing.

In order to assess the models we adopted a 'traffic light' system to indicate how well a model performs against a given criterion i.e. a green light relates to good, an amber light corresponds to acceptable but with a few issues, and a red light means the model is flawed. Note, as part of our assessment we also considered practical implementation and regulatory best practice. We consider that all the estimation methods used in the models presented in the report are in line with regulatory best practice and there are no obvious concerns about their practical implementation.

We did not assign a traffic light for theoretical correctness given the limited range of drivers available in the dataset. Rather we focused on whether the coefficients on the cost drivers had the expected sign and were significant. We therefore only assigned traffic lights for the three categories, i.e. coefficients, statistical test, and robustness checks. We considered whether the model meets a set of criteria for each category, listed by priority in Table E.2 below. The boundary between 'amber' and 'green' depends on whether the model satisfies the top criteria.

Note, a ‘better’ traffic light rating for coefficients in a particular cost model does not necessarily mean the coefficients chosen are better, rather that the statistic performance is better. In other words, a sea cable supply model with length and rating receiving an ‘amber’ for coefficients does not necessarily imply that the combination of these variables is invalid when a sea cable supply model with only length receives a ‘green’ rating for the coefficients. In addition, we have assigned an amber light at most for robustness given the small sample size, however we consider that even the maximum 13 data points is low for being able to generate a robust model.

Table E.2: Traffic light criteria in order of priority

	Coefficients	**Statistical test**	**Robustness check**
R	1. Coefficient signs were not consistent with expectations (i.e. negative when positive expected) and there are no offsetting reasons (e.g. multicollinearity). 2. All coefficients were insignificant and there are no offsetting reasons (e.g. multicollinearity).	1. Failed multiple statistical tests. 2. R-squared is very low (less than 0.6).	1. Sample size very low (i.e. below 7). 2. Very sensitive to sample choice.
G A	1. Coefficient signs were in line with expectations and levels/ elasticities relatively sensible. *If not, given Amber.* 2. All coefficients were significant or there are potentially offsetting reasons (e.g. multicollinearity). *If not, given Amber.*	1. Passed all statistical tests (RESET, normality and White). *If not, given Amber.* 2. Alpha factor close to one (e.g. within 5%). (Log models only.) *If not, given Amber.* 3. Goodness of fit above 0.80. *If not, given Amber.*	The small sample size available means that the robustness of any models assessed is likely to be low. Therefore we expected to give few ‘green’ lights in this category. 1. Not very sensitive to sample choice (i.e. not much difference between ITV and AFTV, removal of projects). *If not, given Amber.*

Models

In Tables E.3, E.4 and E.5 below we list out each of the model specifications which we identified as being plausible for, respectively, offshore, onshore and cabling costs. The traffic light rating is in line with our assessment approach set out in Section 3.6.[9]

Table E.3: Offshore costs

Cost	Model reference and specification[10]	Coefficients	Statistical tests	Robustness
Offshore transformers – ITV only	(OffTrlin6) Linear - Offshore transformer capacity.	G	A	A
	(OffTrlog1) Log - Number of offshore transformers, offshore transformer capacity	A	G	A
	(OffTrlog6) Log - Offshore transformer capacity.	G	G	A
Offshore platform excluding transformers	(OSPlog3) Log - Weight of offshore platform, distance from shore, total weight of offshore platform squared.	G	G	A
	(OSPlog4) Log - Weight of offshore platform	G	G	A
Total offshore costs	(OffTotlog1) Log – Total weight of offshore platforms, total offshore transformer capacity	A	A	A
	(OffTotlog2) Log – Total weight of offshore platform, total offshore transformer capacity, distance from shore	A	A	A

For offshore transformers we had relatively few observations, around eight, and this impacted on the robustness of these models. In addition, for offshore transformers we found that the model using AFTV was heavily influenced by one observation, which meant a poor robustness score for the AFTV models. We did however consider the ITV stage based modelling to be relatively robust (taking into account the small number of observations) and believe the models would be reasonable predictors of average costs for offshore transformers.

The offshore platform excluding transformer models performed relatively well, with the robustness reflecting the small number of observations (10-12 depending on the stage). The

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[9] The method of assessment using our traffic light approach is shown in Table 3.1. Green represents an appropriate model to use, whilst red means the model is not suitable based on that criterion.

[10] The independent variables within these tables represent totals i.e. total offshore transformer capacity, not on a per unit basis, i.e. the average offshore transformer capacity.

models for total offshore costs did not perform as well as the more disaggregated models. This may be a reflection of using a combination of transformer and platform drivers.

Table E.4: Onshore costs

Cost	**Model reference and specification**	**Coefficients**	**Statistical tests**	**Robustness**
Onshore transformer (OnTrlog3)	(OnTrlog3) Log - Onshore transformer capacity	G	A	A
Onshore total cost	(OnTotlog4) Log – Generation capacity	G	A	A

As noted above, we identified a relatively robust model for onshore transformers relating to transformer capacity. However we did not identify model(s) for the remaining costs (e.g. reactive capacity). These are needed in order to form an aggregate view of total onshore costs. Therefore we focused on total onshore costs models.

Table E.5: Cabling costs

Cost	**Model reference and specification**[11]	**Coefficients**	**Statistical tests**	**Robustness**
Sea cable supply	(SCsuplin3) Linear - Sea cable length	G	A	A
	(SCsuplog1) Log - Sea cable length, sea cable conductor size	G	A	A
	(SCsuplog3) Log - Sea cable length	G	G	A
	(SCsuplog7) Log - Sea cable length, sea cable rating	A	G	A
Sea cable installation	(SCinslog1) Log - Sea cable numbers (above 1[12]), Sea cable length	G	A	A
	(SCinslog3) Log - Sea cable length	G	A	A
	(SCinslog5) Log - Sea cable length, sea cable conductor size	G	A	A
Sea cable total costs	(SCTotlog1) Log - Sea cable length	G	G	A
	(SCTotlog3) Log - Sea cable	G	A	A

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[11] Both land and sea cable conductor sizes and sea cable rating are averages rather than totals if multiple sea cables are used.

[12] The starting point for the modelling is assuming one cable as there would zero costs in the absence of any sea cable.

Cost	Model reference and specification[11]	Coefficients	Statistical tests	Robustness
	rating, sea cable conductor size			
Land cables total costs	(LCTotlin7) Linear - Land cable length, land cable conductor size	A	A	R

We identified a number of models for each of the disaggregated areas aside from land cable costs. For land cable costs we had much more difficulty identifying a robust model, we believe that this is mainly due to the different level of civil works which may be required for connection to the grid for which we did not have any cost drivers. We have included one of the better models in the table above to allow aggregation up to the total capex level and it should be noted that land cables only make up on average 5.1% of capex at the AFTV stage so the overall impact from this model on predictions of total project costs is likely to be small.

Aggregation

In most cases we identified more than one suitable model for each of the cost categories. We do not consider that there is a robust and objective way to choose between these models. Therefore we propose that at each cost level the predictions could be averaged across the models. This takes into account the difference between the models, allowing multiple cost drivers or functional forms to be considered (which may provide alternative results), without assigning specific weights to any one model (i.e., all the models are given the same weights). We consider that an averaging approach mitigates the risk of choosing a single model which, for any project, may have a large variance between the estimate and the ‘correct’ answer.[13]

In addition, the disaggregated cost models can be combined and then averaged with the next aggregation level, e.g., offshore transformer predictions *plus* offshore platform (excluding transformers) averaged with offshore platform total. Figure E.5 below illustrates our proposed aggregation process for total offshore costs.

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[13] Ofgem, in its RIIO price controls, has weighted together different modelling approaches using equal/average weights, for example in its RIIO-ED1 draft determinations it applied a 50/50 weight across two totex models before averaging with the result with its disaggregated models. Ofwat, during PR14, has averaged across models at the same aggregation levels.

Figure E.5 – Illustration of averaging and aggregation process

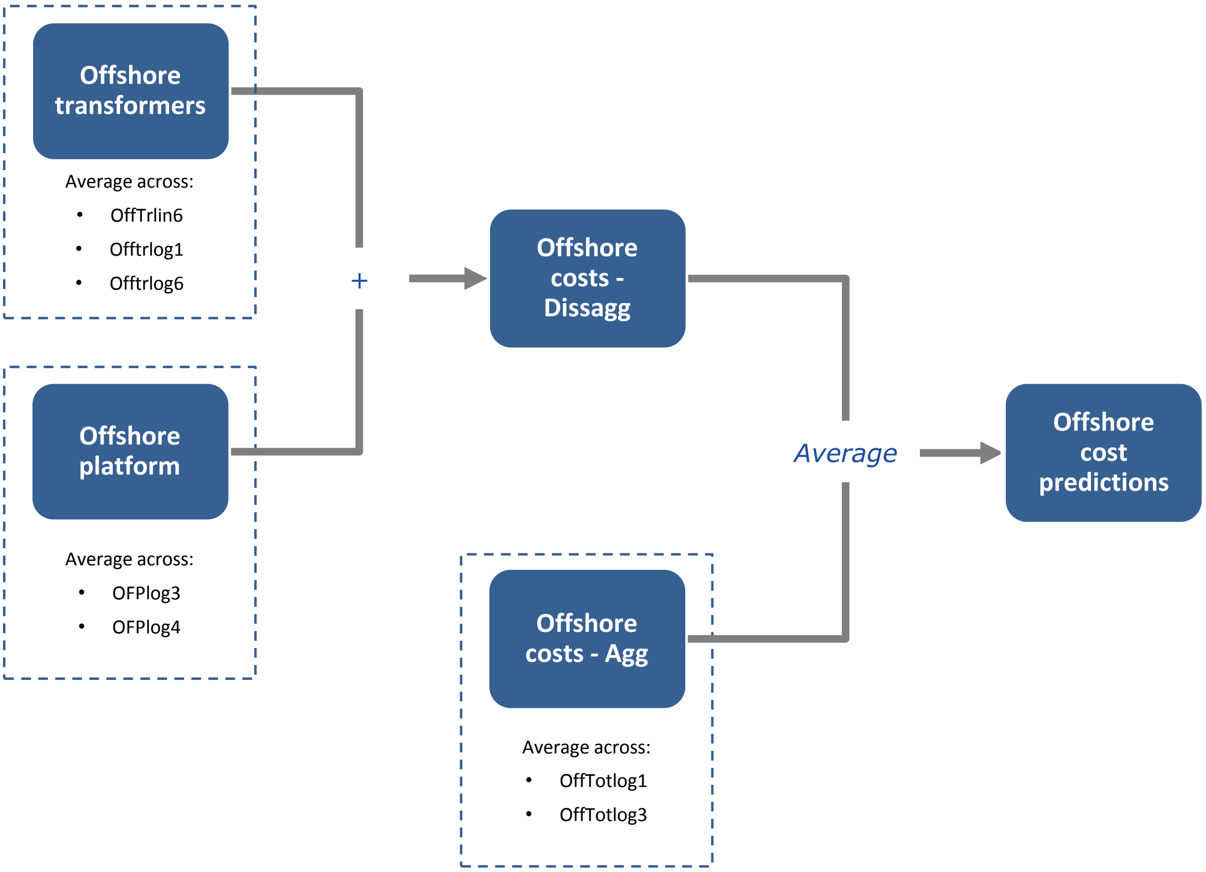

Figure E.6 below provides the overall difference between developers' total actual capex and the predicted costs. A positive percentage means the predicted value is above the actual.

Figure E.6 – Predicted versus actual total capex[14]

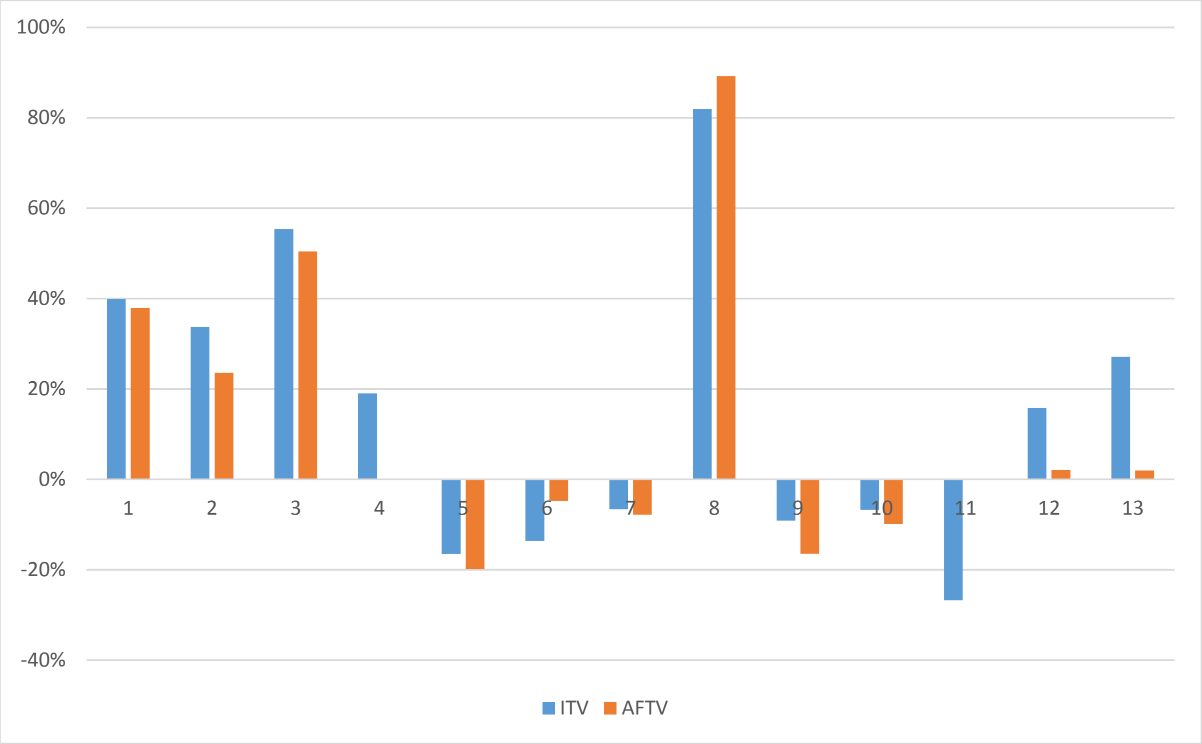

Figure E.6 shows that there is significant variation between the predictions and the actual capex for some projects. We note that the largest variations relate to the early TR1 projects where the cost reporting was done retrospectively.

For the projects where the percentage difference is much smaller, it is worth noting that the magnitude of the difference can still be quite large. This would raise questions around the use of these models to arrive at an exact estimate of costs. However, the overall degree of accuracy observed above may be acceptable for certain uses of benchmarking, for example, assessing the cost efficiency of future projects in broad terms (i.e., whether a proposed project appears efficient or inefficient).

Conclusion

As noted, we were able to identify some plausible models at varying levels of aggregation of capex. For some models we identified large differences between the modelled and actual costs. We do not believe that these are solely down to efficiency differences between the projects[15]. Instead we believe there are a number of additional factors driving the observed differences between modelled and actual costs. These are as follows:

- Predominately for earlier projects, we had a lack of certainty over cost allocation and missing data in certain cost categories.

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[14] To ensure confidentiality we have removed or anonymised that data throughout this report.

[15] In theory, the difference between actual and modelled costs in benchmarking models are down to efficiency differences alone if there are no measurement errors and operating environment differences are accounted for.

- We also found the level of data granularity available for individual project components were not as detailed at the ITV stage compared to the AFTV stage. This is because costs are more likely to be estimates at ITV stage whereas more detailed cost information is available for assets at the AFTV stage.
- There is reasonable heterogeneity between projects for which there are insufficient cost drivers and/or observations to model adequately.
- For some projects there were additional costs due to delays, etc in high cost areas, e.g. sea cable installation.

However, even with these issues/limitations we believe that the benchmarking is a useful tool to look at the level of costs for OFTO projects and identify potential cost outliers. The models may be useful for assessing the costs of future projects, although at this stage with the current data set and given the variation in modelled estimates to actual costs, we consider that the data does not support the introduction of a strong ex-ante target cost incentive mechanism.

GLOSSARY

Term	Description
Alpha factor	An adjustment factor to convert log values into linear when regressions are used to predict costs.
Assessed Final Transfer Value (AFTV)	Ofgem's final assessment of economic and efficient costs, which will be used as the transfer value for the transferring of assets under the OFTO regime.
Capex	Capital expenditure.
Correlation	A correlation coefficient is the measure of interdependence between two variables. The value ranges from -1 to 1, with -1 indicating a perfect negative correlation and 1 indicating a perfect positive correlation. Zero indicates the absence of correlation between the variables.
Cost drivers	These are factors that drive costs. The term is used interchangeably with explanatory variables.
Developer Final Transfer Value (DFTV)	The developer's submission when almost all of costs have been incurred for the asset.
Elasticity	The degree (sensitivity) of one variable to changes in another.
Enduring Regime	OFTO projects that have qualified after 22 February 2013.
Explanatory variables	These are variables which help explain differences in costs i.e., environmental differences. This is generally the term given to these variables once they have been included in an econometric model. These are the same as cost drivers and the term is used interchangeably.
Generator build	The 'Generator Build' option involves the generator developer completing preliminary works, designing and constructing the transmission assets under the OFTO regime.
Heterogeneity	A state of being heterogeneous, i.e., diverse or dissimilar.
Heteroskedasticity	When sub-population (sample) have different variability from others in the population (sample).
Homoskedastic	When sub-population (sample) have equal variance from others in the population (sample).
Indicative Transfer Value (ITV)	Ofgem assessment (aided by technical advisers) on their view of economic and efficient costs, to aid in the tender process for the OFTO.
Initial Transfer Value	Initial developer submission on economic and efficient costs of developing the transmission assets.
Interest During Construction (IDC)	Interest to cover the capital costs of cash flows incurred during the construction phase by the developing. The rate is capped by Ofgem.
Log-linear model	Log-linear models allow marginal costs to vary, which is not the case in the standard OLS regression.

Term	Description
Multi-collinearity	When two or more explanatory variables are highly correlated with each other. This may mean that in a multiple regression model the coefficients on the correlated variables may not be valid, but the overall predictive power of the model is not reduced (only the ability to use the coefficients individually).
Multivariate	Involving more than one variable.
Normality	A linear regression assumes a normal distribution of the error term. The error distribution may however be skewed by the presence of a few large outliers, usually more than three standard deviations away from the mean.
Offshore Transmission Owner (OFTO)	The successful bidder in the tender process, that takes ownership of the transmission asset from the developer.
OFTO build	The 'OFTO Build' model still requires the generator developer to complete the preliminary works and undertake high level design. However at this stage a competitive tender process occurs and the selected OFTO will construct the asset, as well as operate and maintain it.
Ordinary Least Squares (OLS)	OLS is a method by which linear regression analysis seeks to derive a relationship between company performance and characteristics of the production process. This method is used when companies have relatively similar costs. Using available information to estimate a line of best fit (by minimising the sum of squared errors) the average cost or production function is calculated and companies are benchmarked against this.
Opex	Operating expenditure.
Parametric	In these models, the statistician specifies the functional form of the model. This is not the case in non-parametric models.
Quadratic	This uses a squared term for cost drivers. This can take into account different returns to scale – e.g. economies of scale if the coefficient on the squared term is negative. Such terms provide further flexibility to the cost curve but they reduce the degrees of freedom of the regression, which can in turn affect statistical testing and robustness.
R-squared	Tests how much of the variation in costs is explained by variation in the driver. A figure of 1 indicates that all variation is explained, whilst a figure of zero indicates that no variation is explained by the model. The adjusted R2 value adjusts for the number of explanatory variables included in the model.
Ramsey RESET test	The Ramsey Regression Specification Error Test (RESET) is a general misspecification test for the linear regression model which tests whether non-linear combinations of the variables help improve the explanatory power of the model. A low probability value (i.e. <0.05 or 5%) means we cannot reject the null hypothesis, therefore there could be non-linear specifications of the explanatory variables that could improve

Term	Description
	our model. Conversely a higher probability value means we can reject the null hypothesis therefore the linear specification is the correct functional form for the model.
Robustness	This is the extent to which a model is in the correct functional form, has the correct selection of variables (no omitted or unnecessary variables included), does not suffer from heteroskedasticity and that a normal distribution is an appropriate assumption for the cost.
Tender Revenue Stream (TRS)	The fixed stream of revenue that the OFTO receives over a twenty year period – this is based upon the final value.
Tender Round 1	The first round of OFTO projects (there are 9 projects in total at this phase).
Tender Round 2	The second round of OFTO projects, split into two parts (there are 4 projects in total at this phase).
Tender Round 3	The third round of OFTO projects (coming under the Enduring Regime). This is the current tender round.
Third Package	An EU requirement to split ownership of generation and transmission assets.
Total Transfer Value	The transfer value of all cost categories.
Transitional Regime	The OFTO regime for projects qualifying prior to 22 February 2013.
Univariate	Involving one variable.
White test	White's test checks for heteroskedasticity in a regression. OLS regressions work on the assumption that the variance of the error term is constant (homoskedastic). Heteroskedasticity refers to the situation when the variance of the error term in a regression is not constant. This may occur for example when the error terms increase as the value of the variables increase.

1. INTRODUCTION

1.1. Aim of study

CEPA in collaboration with SKM were retained by the Office of Gas and Electricity Markets (Ofgem) to provide support in reviewing information from the first two tender rounds of the Offshore Transmission Owner (OFTO) regime. As part of this review, Ofgem asked CEPA to design a benchmarking approach for ongoing use. In particular Ofgem required the following support:

- perform a thorough check of Ofgem's data in order to determine its suitability for benchmarking;
- undertake data analysis for all Ofgem's data sets (initial, indicative, developer final submissions and final transfer value) including the development of cost drivers that are both correct from a theoretical perspective and robust statistically;
- perform bottom-up cost modelling to determine total project costs and develop a benchmarking process that is fit for purpose; and
- assist Ofgem in the work required to publish a report on benchmarking of offshore transmission assets for public consultation.

In this report we set out our approach to assessing the available data, our assumptions and our testing of bottom-up models that can be used for the purpose of benchmarking offshore transmission assets.

1.2. Objectives

The purpose of the CEPA analysis is to assess the feasibility of using the offshore transmission data in benchmarking. The feasibility assessment should be across both its use in assessing past projects, but also to help determine ex ante costs for new projects.

We note that, while benchmarking is a useful tool for regulators to use in determining efficient costs data limitations and heterogeneity across projects means that a level of regulatory judgement is needed when using the raw outputs from the models.

1.3. Background

Under the OFTO regime, there are two key models of development; the 'Generator Build' and 'OFTO build' models.

- The 'Generator Build' option involves the generator developer completing preliminary works, designing and constructing the transmission assets. There is then a competitive tender for an OFTO licensee to operate and maintain these assets. After transfer of the asset, the OFTO is awarded a revenue stream for twenty years which is constant in real terms. This revenue stream is based on the Final Transfer

Value (FTV) of the asset at the time of asset ownership switching hands and ongoing costs for the OFTO. Ofgem is responsible for setting the FTV based on an assessment of an efficient cost for construction of the assets, with this figure enshrined in the commercial agreement between the two parties. Examples of ongoing costs will include a cost of capital for financing the purchase, ongoing capex costs, ongoing opex costs and costs for decommissioning.

- The 'OFTO Build' model still requires the generator developer to complete the preliminary works and undertake high level design. However at this stage a competitive tender process occurs and the selected OFTO will construct the asset, as well as operate and maintain it.

The offshore transmission asset regime for construction and operation was designed to be split into a transitional regime and an enduring regime. The transitional regime was composed of two Tender Rounds. There were nine projects tendered under Tender Round 1 (TR1) and four projects tendered under Tender Round 2 (TR2). This transitional regime tender process has now been completed for all projects except for the West of Duddon Sands and Gwynt-y-Mor projects which at the time of writing this report were both at the FTV stage. Under the Transitional Regime, every project is operated under a Generator Build model. For the Enduring Regime, both models will be utilised.

- Tenders under the Transitional Regime were governed by the "2010 Regulations",[16] which applied for projects that met the qualifying requirements by 31 March 2012. Of TR1 and TR2 projects, only the West of Duddon Sands project is already governed by the "2013 Regulations"[17] which apply for the tenders under Enduring Regime, i.e. for all projects that qualify after 22 February 2013.
- The Enduring Regime is expected to cover up to 30GW and investments of several billion pounds over the next decade. The competitive tenders under the Enduring Regime will thus govern more projects and larger installations than the two tender rounds under the Transitional Regime.

Although there have been changes to the Transitional Regime, the majority of these did not affect the transfer value. Such changes include the OFTO choosing the degree of revenue indexation, a refinancing gain share and capacity weighting of the availability incentive.[18] The enduring regime no longer includes the guarantee of 75% of the Indicative Transfer Value (ITV) being allowed, but this guarantee had not been utilised under the transitional regime as it was below the entirety of economic and efficient costs incurred. Therefore the cost assessment process under the first two Tender Rounds should be direct experience of a process that can be refined for the enduring regime.

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[16] Electricity (Competitive Tender for Offshore Transmission Licences) Regulations 2010

[17] Electricity (Competitive Tenders for Offshore Transmission Licences) Regulations 2013

[18] Ofgem, *Offshore Electricity Transmission: Statement on future generators build tenders*, July 2013.

Our study involves analysis of data pertaining to 13 Transitional tender round projects. Table 1.1 below sets out the summary details for these 13 projects.

Table 1.1: List of transitional tender round projects

Tender round	Project	Size (MW)	Ofgem assessed Final Transfer value	Construction commenced^
1	Robin Rigg	180	£65.5m	Jul 2007
1	Gunfleet Sands	173	£49.5m	Feb 2008
1	Barrow	90	£33.6m	Feb 2005
1	Walney 1	184	£105.4m	Oct 2010
1	Ormonde	150	£103.9m	Sep 2009
1	Walney 2	184	£109.8m	Oct 2010
1	Sheringham Shoal	315	£193.1m	Jun 2009
1	Greater Gabbard	504	£317.1m	Sep 2009
1	Thanet	300	£163.3m	Mar 2008
2a	London Array	630	£461.6m	Feb 2011
2a	Lincs	270	£307.7m	Mar 2010
2a	Gwynt y Mor*	576	£346.0m**	Nov 2009
2b	West of Duddon Sands	389	£296.3m**	Feb 2012

^ construction of transmission assets

**The AFTV for Gwynt y Mor has now been determined but it was not available at the time of our analysis.*

***denotes ITV assessment where AFTV assessment is not available*

1.3.1. Offshore transmission cost assessment process

In December 2013, Ofgem put forward development proposals for offshore transmission cost assessment.[19] This document referred only to the Generator Build model and Ofgem noted their experience so far identifying economic and efficient costs of the developer and then estimating the transfer value of the offshore transmission assets. This transfer value is also used by National Grid in setting charges for use of the transmission system by generators. The cost assessment process has been used to determine the transfer values for offshore transmission assets worth £1.1bn for TR1 alone.

Table 1.2 below gives a high-level overview of the different stages of the cost assessment process and how they fit into the tender process.

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[19] Ofgem, *Offshore transmission cost assessment: development proposals*, 2013.

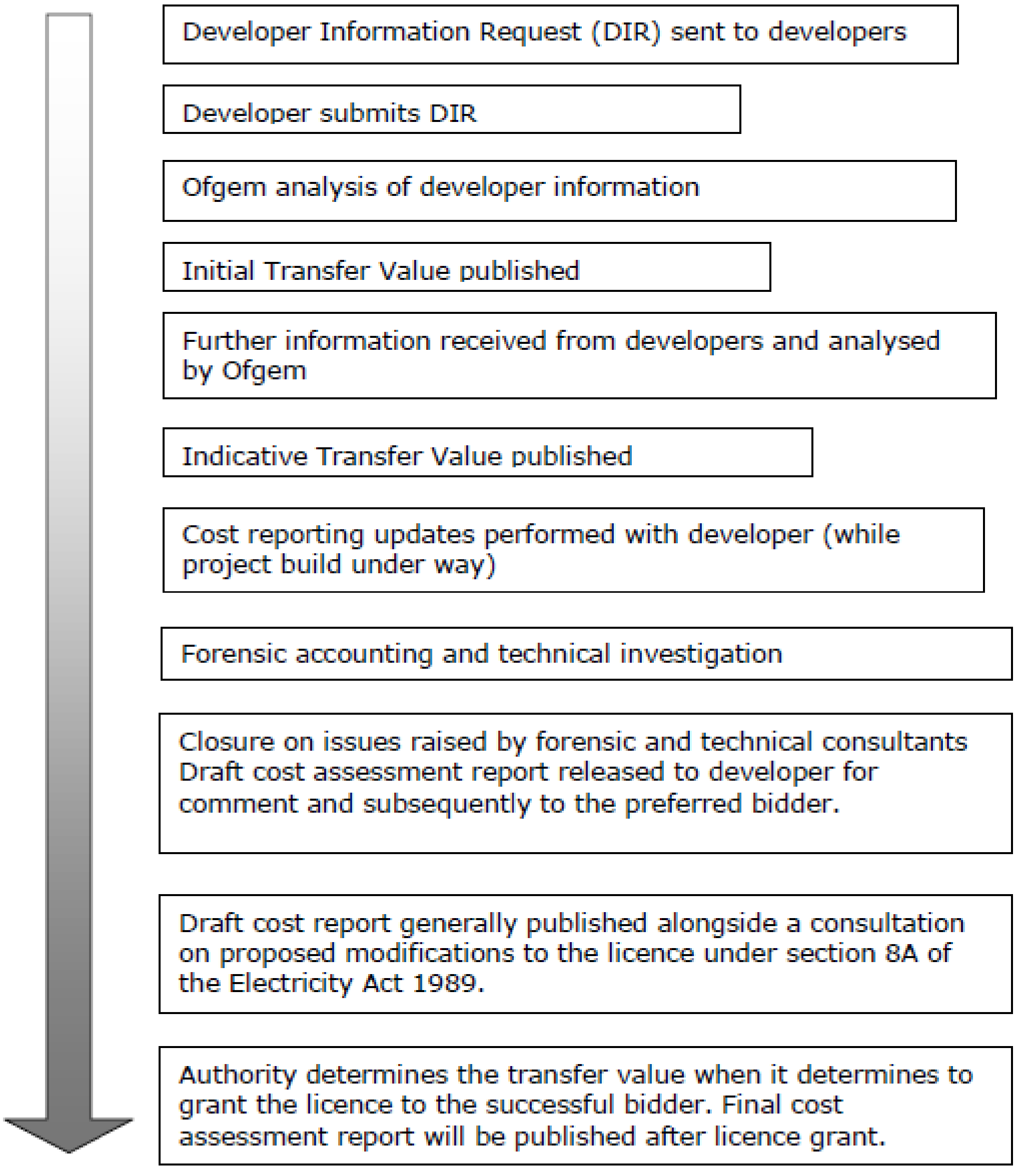
Table 1.2: Overview of stages in the cost assessment process

Stage	Description	Role in the tender process
Initial transfer value	Initial estimate by the developer of how much the offshore transmission asset will cost to develop and construct	Forms part of the preliminary information memorandum published by Ofgem at PQ stage of the tender exercise. It gives bidders a reasonable indication of the size and value of the project
Indicative Transfer Value (ITV)	Developer submits updated cost information which Ofgem uses to carry out a forensic accounting and technical analysis (where necessary). This involves a review of the contracts, amongst other things, for the development and construction of the assets. Cost submissions are compared to both costs from other transmission projects and the cost data held by Ofgem advisers. Some of the costs submitted at this stage are estimates rather than exact values and may change at later submissions	ITV published at the start of the ITT stage of the tender process – used as an assumption of the tender revenue stream which OFTO can expect
Final Transfer Value	Assessment of costs once approximately 90-95% of the project costs have been incurred. Ofgem conducts both accounting and technical review (if required) of the developer final transfer value (DFTV). Ofgem produces a draft cost assessment report containing the assessed transfer value (AFTV)	Used to assess the transfer value for the transmission assets

We understand that benchmarking has formed part of the cost assessment process thus far. For the transitional tender round projects, due to a lack of comparable data, Ofgem stated that benchmarking was only used for certain cost components such as development cost and Interest During Construction (IDC). Ofgem also used benchmarking more as an initial investigation tool highlighting which cost areas might be investigated further.

We set out how the Transfer Value estimates fit into the broader timeline around the Generator Build option.

Figure 1.1 – Timeline for the cost assessment process



Developer Information Request (DIR) sent to developers

Developer submits DIR

Ofgem analysis of developer information

Initial Transfer Value published

Further information received from developers and analysed by Ofgem

Indicative Transfer Value published

Cost reporting updates performed with developer (while project build under way)

Forensic accounting and technical investigation

Closure on issues raised by forensic and technical consultants
Draft cost assessment report released to developer for comment and subsequently to the preferred bidder.

Draft cost report generally published alongside a consultation on proposed modifications to the licence under section 8A of the Electricity Act 1989.

Authority determines the transfer value when it determines to grant the licence to the successful bidder. Final cost assessment report will be published after licence grant.

Source: Ofgem

The Transfer Value has both increased and decreased across projects as the costs become more certain. Ofgem can disallow inefficient costs when the requirements become more certain. The National Audit Office report[20] notes that £22m (or 8% of spend) was disallowed from the transfer value of the first four projects. The report also recommended that information should be used to set target costs for new assets earlier. This would have been more difficult for the transitional regime given that construction was underway on several projects and key decisions had been made, but it will be increasingly important for the enduring regime. The passing of time will mean that further information both from onshore and from offshore projects should be available for benchmarking purposes.

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[20] National Audit Office, *Offshore Electricity Transmission – a new model for delivering infrastructure*, 2012.

The table below shows how transfer values developed by project and the relationship with the transmission asset size.

Table 1.3: Details of TR1 and TR2 projects

Project	Size (MW)	ITV (£m)	DFTV (£m)	AFTV (£m)
Barrow	90	36.5	34.8	33.6
Robin Rigg	180	57.3	65.5	65.5
Sheringham Shoal	315	182.2	196.2	193.1
Ormonde	150	101.1	108.9	103.9
Gunfleet Sands	173	48.2	51.6	49.5
Greater Gabbard	50	316.6	323.7	317.1
Walney 1	184	101.8	112.5	105.4
Walney 2	184	105.0	116.7	109.8
Gwynt-y-Mor	576	346.0	-	-
Lincs	270	281.6	335.2	307.7
London Array	630	428.4	475.5	461.6
West of Duddon Sands (WODS)	389	296.3	-	-

Source: Ofgem cost assessment reports

1.3.2. Benchmarking

On average, the AFTV is 3.5% lower than the initial transfer value, but 7.1% higher than the indicative transfer value. Benchmarking has been used by Ofgem to determine what can be reasonably expected from an 'average' or 'top' performer in a comparator group and to identify potential outliers in terms of project (unit) costs.

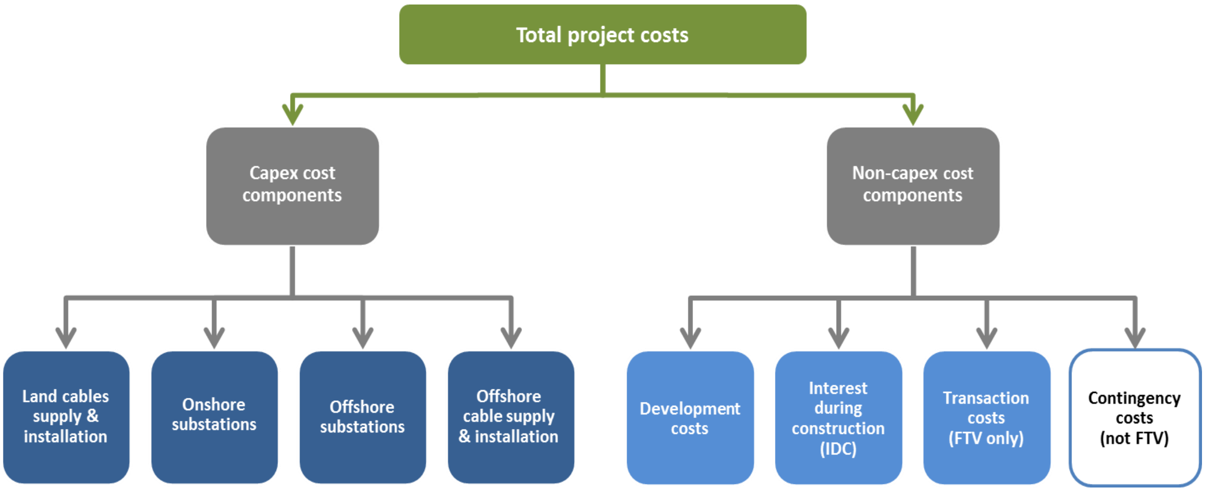
Benchmarking of project costs has been done by considering either:

- total project costs (top-down benchmarking); or
- individual cost categories (bottom-up benchmarking).

Whichever approach is employed, benchmarking requires the identification of suitable cost driver(s) as well as the relationship between the cost driver and actual costs. The choice of benchmarking approach needs to take into account the dataset available (or scope for future data).

Ofgem have identified different cost categories for establishing economic and efficient costs. These are shown in Figure 1.2 below.

Figure 1.2 – Cost categories for offshore transmission cost assessment



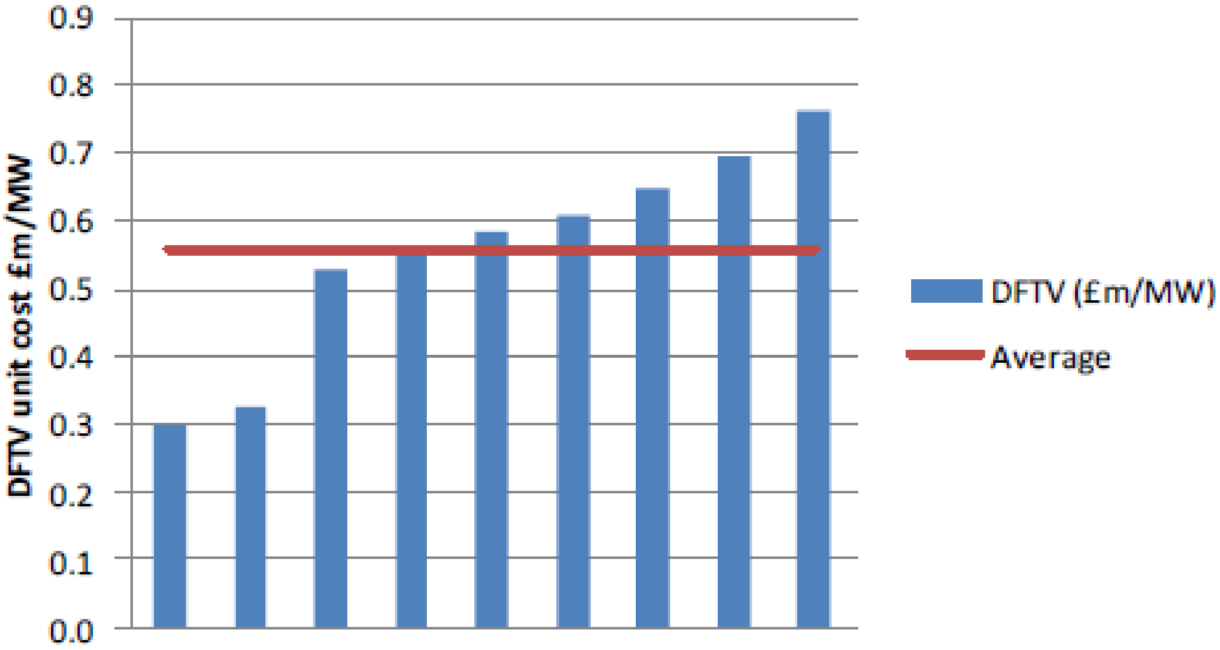
Note: Contingency costs may be included with capex rather than being allocated to a separate category.

Source: Ofgem, CEPA analysis

Total cost benchmarking

This approach involves setting total project costs based on overall cost drivers such as total generation capacity or generation capacity multiplied by length of cable. This is a simple approach to implement, but more adjustments will become necessary as project characteristics (e.g. distance from shore) vary more for future projects. Additional characteristics can be taken into account in an econometric (or non-parametric) approach, however a greater number of observations are required as the number of explanatory variables in a model are increased (we discuss this further in the Methodology section). Figure 1.3 below shows the unit cost of transitional round projects.

Figure 1.3 – Unit costs based on DFTV



Source: Ofgem

Individual cost benchmarking

An alternative approach is to benchmark individual cost components and use this to build up a total project cost.

In its cost assessment consultation,[21] Ofgem presented a benchmarking approach involving single cost drivers (such as length of cable) appropriate to each cost component and only considered linear relationships between cost and drivers without fixed costs. Using this approach, Ofgem's illustrative assessment on the use of cost drivers for the various cost components is presented in Table 1.4.

Table 1.4: Ofgem current view of individual cost components and associated cost drivers

Cost component	Cost driver	Goodness of fit	Comments
Land cable supply and installation	Cable length (km)	0.744[22]	Unit costs similar to onshore rural land cables. Economies of scale may be at play
Onshore substations	Installed capacity (MW) + project specific element	0.636	Costs of onshore substations similar onshore price-control data but there is a need to account for additional costs related to greenfield infrastructure sites
Offshore	Installed capacity (MW) +	0.824	As project characteristics begin to

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[21] Ofgem, *Offshore transmission cost assessment: development proposals*, 2013.

[22] This assessment was for land cables under 10km.

Cost component	Cost driver	Goodness of fit	Comments
substations	project specific element for platform installation costs		vary more, project specific elements will need to evolve to take this into account
Offshore cable supply	Cable length (km)	0.941	Cost driver suitable as submarine cables used until now have been similar. Other factors such as load carrying capability will have to be incorporated
Offshore cable installation	Cable length (km)	0.578	Most testing part of the construction process resulting in costs increasing more than any other component from initial cost estimate to final value. Weak regression coefficient in Ofgem analysis suggests low predictive power
Development costs	Proportion of project capex costs	0.888	Costs tend to escalate if there are issues with one of the capex component costs
IDC	Total costs (capped at 8.5%)	n/a	IDC allowed only related to capex costs deemed economic and efficient Approach currently under review

A total project cost can be derived from benchmarking analysis of individual component costs. For the TR1 projects, there has been a difference in the total predicted costs for the projects and the actual costs of projects, in one case reaching circa 15%. The majority however differ by +/- 5%. The current approach appears to be working relatively well, so scope for improvement may be limited.

1.4. Structure of the report

Our report has the following sections:

- Section 2 looks at the data available and sets out our choice between parametric and non-parametric approaches;
- Section 3 sets out our criteria for assessing our models;
- Section 4 sets out our models for offshore costs, including our rationale behind our choice of costs driver and assessment of the more promising models;
- Section 5 sets out our models for onshore costs, including our rationale behind our choice of costs driver and assessment of the more promising models;
- Section 6 sets out our models for cabling costs, including our rationale behind our choice of costs driver and assessment of the more promising models; and

- Section 7 includes provides our view on bring the benchmarking together and overall conclusions from this benchmarking project.

There are also annexes which give further detail on items included within our modelling.

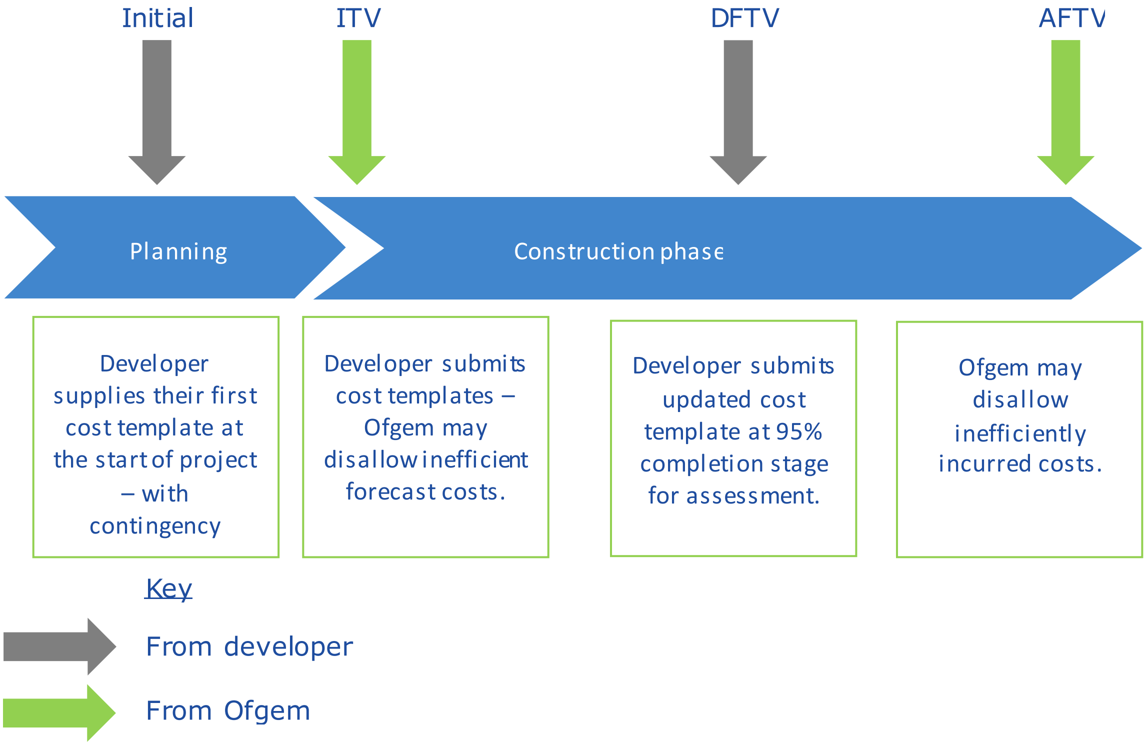
2. AVAILABLE DATA AND METHODOLOGY

2.1. Introduction

Primary data sources

The data used for this benchmarking exercise is drawn from different sources and has been examined to varying degrees. As set out in Section 1.3.1, cost data is available at a number of different stages throughout the process. Figure 2.1 below illustrates when each of the cost estimates are made and how they are constructed.

Figure 2.1 – Cost data availability



Developer supplies their first cost template at the start of project – with contingency

Developer submits cost templates – Ofgem may disallow inefficient forecast costs.

Developer submits updated cost template at 95% completion stage for assessment.

Ofgem may disallow inefficiently incurred costs.

The initial costs are based on those submitted by developers and then analysed by Ofgem's consultants who assist Ofgem in making a decision on the economic and efficient costs for the ITV stage. The developer then submits further cost information in the Ofgem data template for the DFTV stage. This data is also scrutinised by external consultants to help Ofgem make a decision for the cost values for the AFTV stage. Ofgem have included this information from all stages in a spreadsheet which is used for their Transmission Assets Model. ANNEX D shows which projects we have data for at each stage.

Text box 1: Sample size

There are no specific rules, aside from having a least one degree of freedom, around the required number of observations for a robust model. With the small dataset available, maximum 13 observations, we assess each model based on the number of observations, number of variables used and the sensitivity of the model to the removal of observations. While we may conclude that a model appears suitable based on the available data set, in the future as more data becomes available the models would need to be reassessed to determine the impact of the increase in observations.

Cost categories

We analysed this data at different levels of disaggregation to test appropriate allocation between cost categories and check whether the data is robust. Our first step in the process was to observe any differences in costs between project stages and see whether the magnitude of such changes or changes in similar categories suggested that it was allocation rather than a change of estimate that was driving this difference.

We have also verified that where there is missing data or a zero value is given that this is appropriate. For some projects, certain equipment may not be required e.g. transformers or harmonic filters, so it is correct that there is a zero cost given for that category. Other projects may have relied upon pre-existing equipment for their infrastructure.

Our cost categories can be split into two main types: i) capex costs; and ii) non-capex costs. This will look at the categories from a cost efficiency perspective and does not deal with efficiency of design e.g. it only looks at the cost of a transformer, not whether a transformer was required in the first place.

For capex costs we have looked at three top-level cost categories for our analysis:

- offshore platform and substation costs;
- onshore substation, equipment and connection costs; and
- cable costs – both land and sea cable.

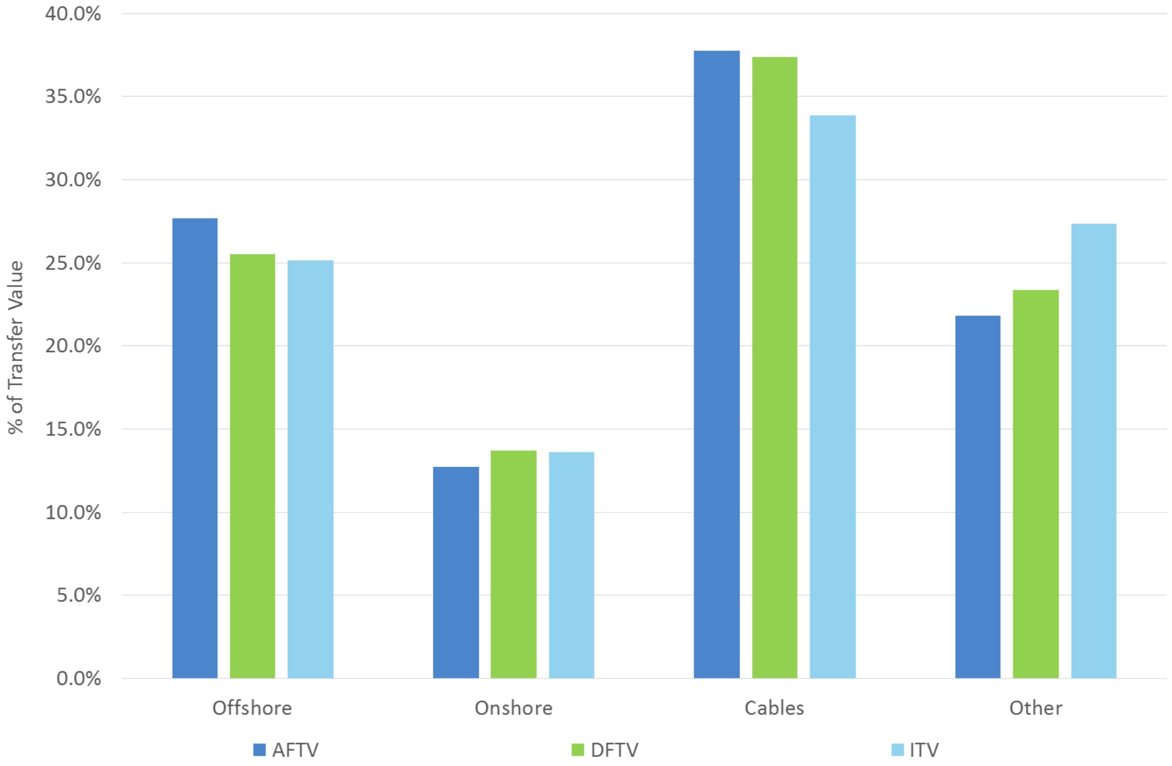
For non-capex costs, there are four sub-categories:

- development costs (this covers project planning and management costs, plus additional costs that may vary by the size and complexity of project);
- contingency costs (these are included within the ITV stage for increases in costs for unforeseen circumstances and may represent approximately 10% of total capex costs);
- transaction costs (included at the DFTV and AFTV stages only, this relate to legal fees associated with development of a project); and

- IDC (the funding costs incurred by the developer, based on the rate allowed (which is capped) and the cash-flow profile of different projects).

Our focus is on the capex costs as these represent the majority of costs and can be modelled in some cases at a more granular level. The IDC rate is dealt with separately by Ofgem and is dependent on cash flow profiles, whilst transaction costs are small, contingency costs fall away for the AFTV phase and development costs are likely to be difficult to model outside of project size. Figure 2.2 below shows the proportion of cost across the high level categories.

Figure 2.2 – Cost proportions at aggregate levels



Source: Ofgem

Under the transitional regime, the cost categories collected by Ofgem are generally backed by actual contracts. For example, it is our understanding that land cable generally comes packaged together with supply and installation, whereas sea cable packages are generally split between supply and installation. As such, the cost category for land cables is presented as a combined cost whilst the sea cable costs are split into supply and installation respectively.

A further issue with our data is the availability of information for earlier projects that pre-dated the TR1 transitional regime in their construction. When these earlier projects were completed, the cost allocation and apportionment ended up being arbitrary and Ofgem was unable to determine the costs for transmission assets as these had been included with the costs of developing the generation assets. However given the small number of existing data points, we have decided against removing the data pertaining to these projects.

Benchmarking relies upon good quality data and as large a sample as possible. We are concerned about the small sample size, and possible cost allocation issues, particularly as it means that outliers may have a significant effect on results.

Cost drivers

In terms of the cost driver information, as project design comes prior to construction there is practically no change in cost driver information between project stages. However, there is generally variation across projects depending on which category is chosen. Only one project has utilised a turnkey contract and all projects apart from two used 132kV sub-sea cables, meaning there are a few cost drivers where there is little variation.[23] One project also varied in terms of not using 33kV to 132kV electrical equipment. In terms of the applicability of our modelling going forward, we can be more confident in our assessment of costs if the design of the upcoming project is consistent with what was observed for TR1 and TR2 projects, but less confident if the design is more novel.

The cost driver information is restricted in many cases to common information that Ofgem has collected. For effective modelling we need accuracy in both our cost category and cost driver information, which for a small sample has sometimes been difficult.

Data quality

Overall we found that data experienced some cost allocation issues, particularly for earlier projects. This would impact more on the disaggregated level models rather than the more aggregated ones. The small data set would also affect the robustness of our modelling. Ofgem had introduced standardised cost reporting, but this was after the earlier projects had reported costs. We worked with Ofgem to improve the data where possible, but we note that data robustness impacted our modelling and as such reduced our confidence in the robustness of the models.

Secondary data sources

There is also additional data that we have used as a cross-check for our benchmarking analysis. This includes an internal database maintained by SKM, but also RIIO cost data. The extent to which this data is directly comparable is an important consideration in our analysis. For example, land cables used by National Grid onshore are a different voltage to the projects so the cost data is not directly comparable.[24]

2.2. Modelling different stages

Our data set includes cost data for three stages of the cost assessment process for transitional tender round projects. There are different approaches that we can take in our approach to modelling. We have run models comprised of three different sets of data.

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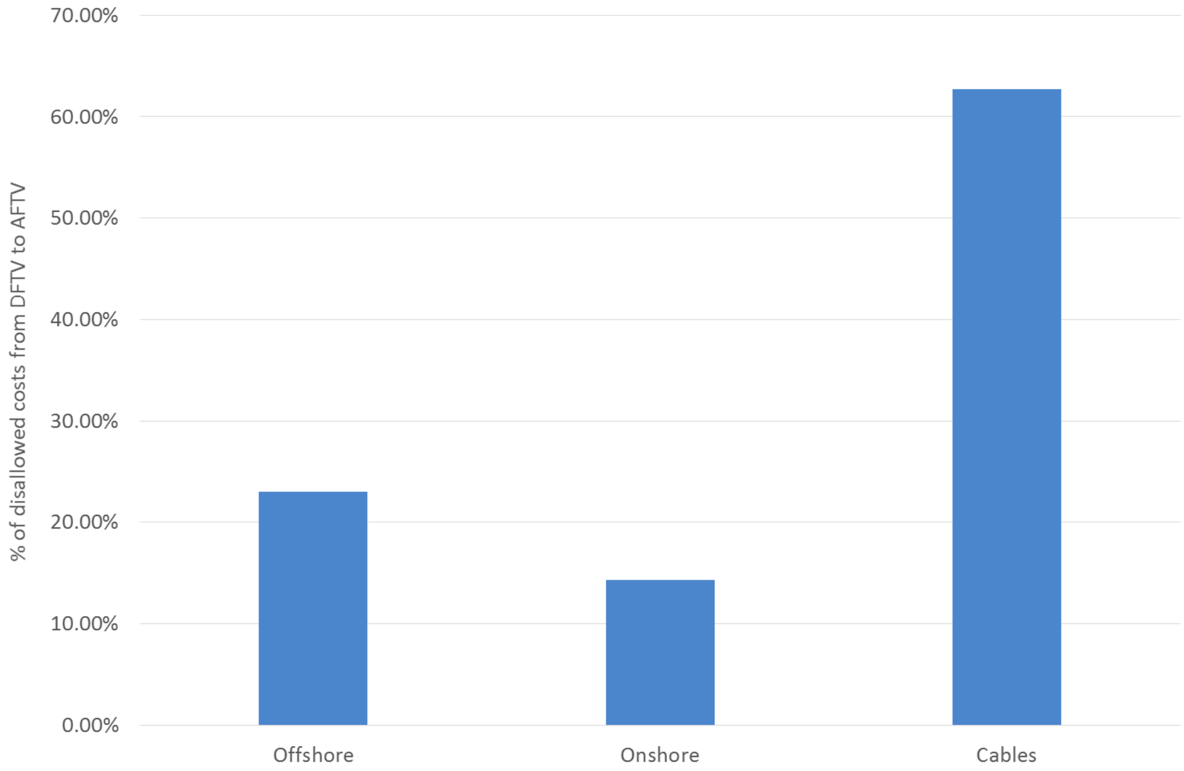
[23] Ofgem, *Preliminary Information Memorandum: Greater Gabbard Offshore Transmission Assets,* July 2009.

[24] SHETL and SPTL do use the 132kV cables, similar to the OFTO projects, but then may differ due to other circumstances, such as the terrain on/under which they are installed.

The first of these is done at the AFTV level. This is the final stage of the project and reflects Ofgem's views of economic and efficient costs. At the time of our analysis, the AFTV was available for 11 of the 13 TR1 and TR2 projects. In addition, although it represents economic and efficient costs, these have been made after consideration was given to project specific circumstances which, as noted earlier, may incorporate costs associated with delays etc.

The DFTV has additional information on one project and there are several disaggregated categories where costs were not revised between the AFTV and DFTV stage. However, the DFTV data provided to us does not include the corrections for errors and misallocations, which Ofgem makes to the AFTV data, and is based only on 90-95%[25] of the costs (although the forecast for the remaining 5% should be robust).[26] The drawbacks may therefore not outweigh the benefits of an additional data point with our small sample size. Figure 2.3 below shows the percentage of costs disallowed between the DFTV and AFTV stages.

Figure 2.3 – Source of disallowed costs from DFTV to AFTV stages



Source: Ofgem

Another alternative is to use the ITV data. Although it is an estimate reached at an early point within the construction phase, the ITV data will likely be made in the absence of any unforeseen costs. There is also a complete dataset i.e. we have data on all 13 projects. From a modelling perspective, the aforementioned unforeseen costs that may have been caused

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[25] Ofgem, *Offshore transmission cost assessment: development proposals*, December 2013, page 11.

[26] In its *Offshore transmission cost assessment* consultation, Ofgem refers to 'corrected DFTV' however this data is combined directly with Ofgem efficiency adjustments and forms the AFTV stage data and there is no separate 'correct DFTV' data.

by delays or physical characteristics of construction are likely to not have been captured in the econometric models. This may therefore end up showing a better goodness of fit. On the other hand, there is a risk that this may become circular if the ITV is based on Ofgem's benchmarking data to begin with and that by running the model at the ITV stage, this viewpoint is reinforced.

The information at different cost assessment stages may serve different purposes. AFTV data includes a view from Ofgem on efficient costs. This may make a model using AFTV data more appropriate for setting costs targets for future projects, however it creates the risk of some circularity if similar cost models were used to determine efficient costs.

Within the main body of this report we have focused on modelling at the ITV and AFTV stages (we provide results for the DFTV stage in the Annexes). This is because:

- the ITV provides an estimate which includes any unanticipated delays, etc; and
- we believe cost benchmarks based on AFTV, rather than DFTV, sets a better cost target as it is adjusted for efficiency (although we would suggest caution should be used by Ofgem if it wished to use an adjusted [e.g. upper quartile] target).

We note, that as more data becomes available, Ofgem will need to consider how it is used in order to avoid any circularity created by using the models' outputs to set targets.

2.3. Cost breakdown

Our proposed approach is to start at the most disaggregated level for our analysis. With these disaggregated costs and models, we can then aggregate different categories if it is possible to do so. Disaggregation however is only possible where we are confident that the costs are comparable across projects and if this is not the case, we have aggregated to a level where we are confident that this is the case.

2.3.1. Offshore

This cost category relates to all the transmission assets located offshore i.e. the offshore platforms, foundations, topsides and electrical equipment with the exception of the sea cable. Our ideal cost breakdown for the offshore substation would be to have cost and cost driver information for the different components of the offshore platform. This includes the non-electrical items such as the topside, the jacket, the foundations and the installation of the offshore platform as well as the electrical items at a disaggregated level i.e., offshore transformers and other electrical costs relating to the offshore platform. However, this information was not available at this level of disaggregation. The most granular level of cost data splits these costs into offshore platform electrical, offshore platform non-electrical and offshore transformers.

Table 2.1: Ideal list of cost disaggregation for offshore platforms

Cost level	Available
Offshore substation topside (not electrical)	No
Offshore substation jacket	No
Offshore substation foundations	No
Offshore substation installation	No
Offshore Transformer(s)	Yes
Offshore Substation(s) other electrical	No
Total offshore platform costs	Yes

2.3.2. Onshore

For onshore assets, there are several items and pieces of equipment that would be useful to model at a disaggregated level. This includes the onshore transformer, reactive and harmonic costs, total substation costs (including transformers, reactive, harmonic, and substation other costs) and onshore connection costs[27].

This information is available at these levels for some projects, but in most cases the information is limited to less than half of our overall sample. There is also an 'Onshore – other' category captured in the data set which represents a high proportion of overall onshore costs. Onshore other costs include a variety of non-equipment costs which may include a proportion of onshore civils costs, project management costs and insurance.

Table 2.2: Ideal list of cost disaggregation for onshore costs

Cost level	Available
Onshore transformer	Yes*
Onshore reactive	Yes*
Onshore harmonic	Yes*
Onshore substation other	Yes*
Onshore connection	Yes*
Total onshore substation costs	Yes

** Information available is limited to few projects*

2.3.3. Cabling (supply and installation)

We would expect total sea cable costs to be greater than land cable costs for cables of equivalent size and length. For cable supply (i.e. obtaining the cable), this is due to the greater complexity of cable with greater insulation, fibre optic materials and multiple layers given the more exposed environment that they face. We would expect greater costs at the

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[27] Namely costs to connect into the electricity grid.

installation phase as well with higher costs from transporting the cable and then installing this at sea. Although the land cable installation costs may also be high when dealing with brownfield sites or sites with difficult access.

Although a breakdown of land cable costs is not available whilst it is for sea cables (as discussed at the start of this section), we can compare land cables to sea cables at the total costs level. Perhaps not surprisingly, given that sea cables are typically of much greater length than land cables and as such the installation costs are spread over a longer length of cable, we observed that per km cable costs are generally higher for land cables.

Table 2.3: Ideal disaggregation of cable costs

Cost level	Available
Sea cable supply	Yes
Sea cable installation	Yes
Total sea cable	Yes
Land cable supply	No
Land cable installation	No
Total land cable	Yes

Source: Ofgem

2.4. Cost adjustments

The data provided in Ofgem's estimates of transfer value are provided in nominal terms and without adjustment for changes in particular project costs. To be able to benchmark effectively, we require data which is comparable. As such, we have adjusted the nominal costs at an individual cost category level.

This question is more difficult than it may first appear, because:

- different cost categories will have changed in price by different amounts;
- purchases of different items occurred at different times within a project;
- payment for items may be made in instalments;
- technological changes in the value of items; and
- choosing a central inflation estimate that is applicable – CPI or RPI or other?

There are certain items which are difficult to model to ensure comparative figures are obtained across projects. An example of this would be technological change. For this parameter, we do not make an adjustment for technology given that the projects were constructed in a relatively similar time period.

For different cost categories, we will see if there is a key driver that may be used to explain some of the cost variation that currently sits outside our model. An example of this is for sea cables, where each of the cables are made from copper, thus an adjustment for copper prices may be applicable.

In terms of purchases occurring at different times and payments made in instalments, although the construction period is meant to last around three years, in some cases this has been over five years and there are seasonal effects as projects can only do some construction activity in summer months. This information is not available on a consistent basis across our projects and thus it is difficult to ascertain the dates that contracts were entered into and the dates to which these contracts become effective. For future benchmarking, obtaining data at this level of detail would help a greater level of precision in benchmarking, though the degree to which this is necessary depends on the purpose of the benchmarking. If this is to identify outliers only, then the absence of such information may not be a big issue, however if it is to set ex-ante allowances in future then this takes on greater significance.

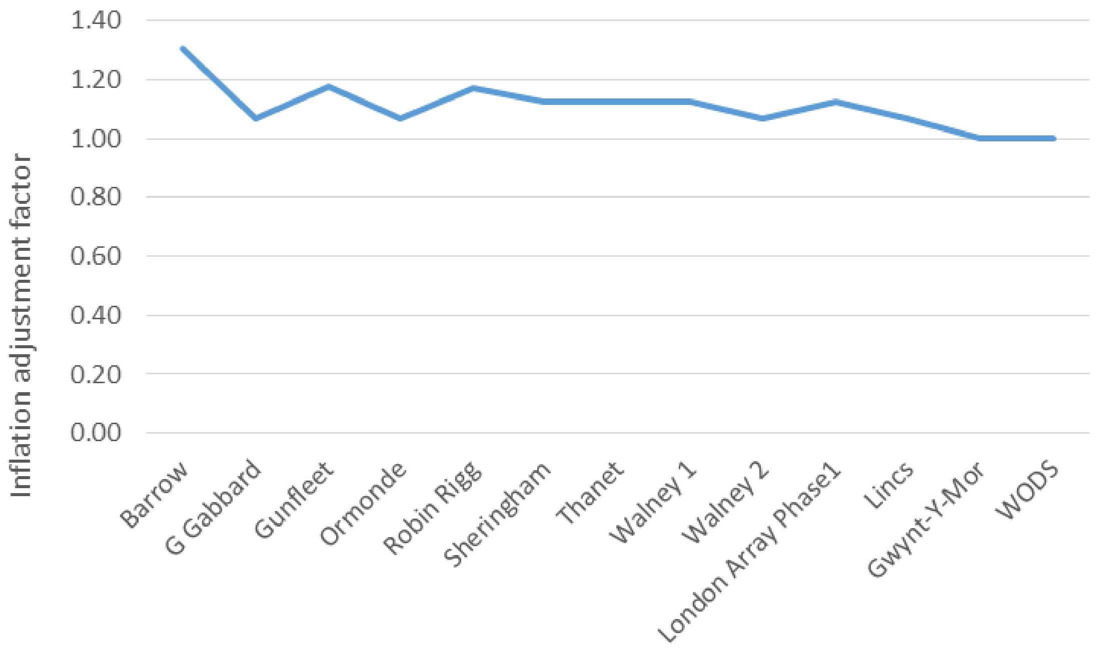
Adjustment to convert to real prices

Any adjustment that is made to nominal prices must be robust. Given the points noted above, we cannot be precise about when the contracts were entered into, to what degree the prices in these contracts included an estimate of inflation and when the product was utilised within the construction period. As such, we think that taking a monthly inflation figure is attempting to gain a spurious degree of accuracy. Consequently we have used the annual RPI index figure for the end of the financial year and applied this to the project.

A further question is when to start inflating the costs to a common base year. We have the dates for both the start of construction and the end of construction for each project. As we understand that contracts are entered into by the start of the construction period, one approach would be to use inflation assumptions to make a judgement on the inflation built into the price. However, this is likely to be unrepresentative of the treatment of inflation by contracted parties and will obtain a spurious degree of accuracy. Instead our approach is to assume that delivery of materials is spread across the construction period, with approximately half of the costs incurred by the mid-point of the construction period. As such, we start adjusting to a common base year from the middle of the construction period. Where a project has not finished construction, we do not make any adjustment for inflation at that stage. As a base year, we take the end of the financial year 2012/13 as at the time of writing we do not have the figure for the 2013/14 financial year.

Figure 2.4 below show the inflation adjustment we apply to each of our project costs.

Figure 2.4 – RPI inflation conversion



Source: ONS

Many of the projects are grouped in the latter years of this analysis and thus our adjustment does not have a significant effect. For earlier projects where construction started approximately eight years ago, we think that an inflation adjustment is required. This applies to each sub-cost category and allows for comparability across our benchmarking analysis.

We considered making an adjustment to cable supply costs based on the price of copper or aluminium. However, this would have required information on the proportion of costs that copper/ aluminium make-up of the entire cable cost. The information was not available at this level of detail[28], and as such we considered that adjusting on an RPI basis would be acceptable.

2.5. Methodology

In deciding on the appropriate models to use, we considered both parametric (econometric) and non-parametric (unit cost) approaches. A detailed explanation of these two approaches are set out in ANNEX C. In Table 2.4 below we provide a summary comparison of the pros and cons of parametric and non-parametric approaches. In general, we believed that parametric approaches were preferable to more simplistic unit cost models. The main reason being is that parametric approaches offer information as to the ‘fit’ of the model to the data and how well the cost drivers perform given the available data set.

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[28] For modelling purposes we felt that the use of an assumption on this cost category could be misleading.

Table 2.4: Comparison of parametric and non-parametric (unit cost) approaches

	Pros	**Cons**
Parametric	• Allows for more flexibility in the functional form, which can vary for cost categories depending on the expected cost curve. • Parametric approaches allow for various statistical tests to be conducted for model robustness and to compare model robustness. • Can account for fixed and variable costs where appropriate. • Linear OLS models are conventional enough and widely understood.	• In small samples, parametric approaches are not more robust than simple unit costs/non-parametric approaches. • Some of the estimation methods are more complex than and not as transparent as simple unit cost ratios. • Some of the flexibility that the parametric approaches provide (e.g. log-linear functional form) may sometimes be offset by large adjustment factors (e.g. alpha factor).
Non-parametric	• Unit cost models do not require any assumptions around the technology or cost / production function (unlike econometric models where the functional form must be specified). • The methodology is quick and straightforward to implement, with simple calculations. Therefore analysis can be undertaken using Excel, as opposed to more specialist econometric software. • Simplistic approach also means that project developers are more able to understand underlying approach / calculations and can cross-check regulatory results. • It can generally be implemented on a small dataset. Although the power to differentiate projects/companies diminishes as the sample size falls, results are still meaningful to a degree. Regression analysis tends to require a larger sample size.	• The efficiency scores tend to be sensitive to the choice of input and output variables. For example, if the denominator is poorly chosen, it may produce misleading results. • No information on statistical significance or confidence intervals is provided. • Results can be overly simplistic e.g. where unit costs are based on a single output variable that does not take account of the range of outputs provided.

3. MODEL ASSESSMENT CRITERIA

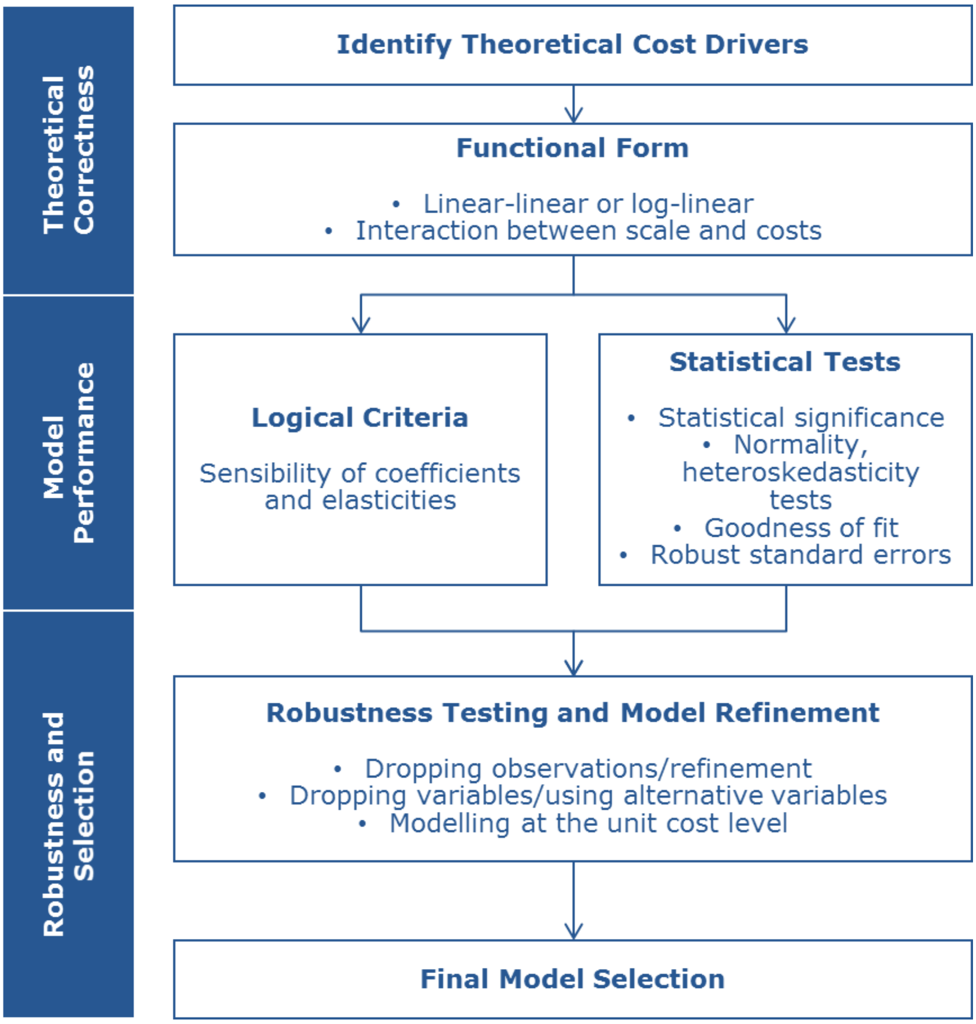
3.1. Introduction

In assessing our preference for models, we drew upon four assessment criteria:

1. theoretical correctness;
2. statistical performance;
3. practical implementation issues; and
4. robustness testing.

Figure 3.1 briefly illustrates our logic in applying the model selection criteria. There are going to be trade-offs between models, which may mean that we recommend more than one model for use in cost assessment. In terms of practical implementation and regulatory best practice, this is not included in Figure 3.1 below but as our proposed models used common regulatory modelling approaches we consider that all of our models are in line with regulatory best practice and relatively easy to implement.

Figure 3.1 – Model selection process



3.2. Theoretical correctness

This is a critical first step to the modelling process, identifying what key drivers would be based on issues set out in Section 2. There is a useful starting point in the work Ofgem has done to date, which we sought to build upon with advice from engineers. In addition to identifying the cost drivers, it is important that any model reflects the true functional form of the relationship such that the model is theoretically correct.

Ideally cost drivers would be outside of companies' control, i.e., MVA required. However, this data may not be available and is likely to be less explanatory in terms of the specific characteristics of the construction requirements. In light of these issues it is common practise to use size or scale variables.[29] Size and scale variables, e.g. weight of platform and size/number of transformers, are reflective of the solution type (in order to meet the output requirements), but may not necessarily reflect whether the developer has chosen the most cost effective solution (to provide the outputs required).[30]

Based on these relationships we can identify the appropriate functional form. If there are economies of scale expected for certain cost items, a linear OLS regression is likely to not be representative from a theoretical correctness perspective. This leads into statistical performance, which is important given that the model does represent some abstraction from reality.

3.3. Statistical performance

In reviewing our preferred models, we looked for the following aspects:

- *Significance of variables*: There should be a rationale behind the choice of the independent variable and we would like there to be statistical significant at the 1% confidence level.
- *Expected sign*: If the variable is significant and selected based on a well-thought out rationale, we would expect the sign of the coefficient to match the expectations around the direction of the theoretical relationship.
- *Adjusted R^2*: Although not a primary measure of our model's predictive strength, it does give an indication of goodness of fit under an OLS model.
- *Robustness*: In running tests on our model, we tried to ensure that the model itself is robust – by this we mean that it is in the correct functional form, has the correct selection of variables (no omitted variables or unnecessary ones included), does not

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[29] Ofgem's RIIO price controls tend to rely on scale and size variables (customer numbers, length of network, and volume of assets) for its benchmarking. Likewise, Ofwat's PR14 econometric models rely on length of mains and density explanatory variables.

[30] We would expect there to be a strong correlation between the size/scale of a project and the outputs of the project, e.g. a large cable(s) should reflect a higher capacity requirement of the OFTO.

suffer from heteroskedasticity and that a normal distribution is an appropriate assumption for the cost.

- *Alpha factor*. While not a test *per se* we expected an alpha factor to be close to one, if it is significantly greater than one this would indicate an issue with the regression or sample (i.e. a large outlier).

3.4. Robustness testing

We carried out robustness testing in our cost assessment analysis. This involved testing with different variables, different functional forms, removing observations and statistical testing. Given our small sample size, the inclusion of many dependent variables would not be appropriate and as such we have tended to use a variety of models rather than refine a model that started out with many independent variables.

Based on our statistical testing above, we also ran models using different functional forms and then tested the sensitivity of outputs by dropping observations. This is especially relevant for cases where we are not confident whether the cost allocation is entirely comparable across projects for certain categories. In removing observations, we looked at unit costs and how the costs fit in to overall transfer value, understanding that there are differences in projects that are in different locations, have different specifications and were constructed at different times. In relating this back to our model selection, we note a preference for models that are less sensitive to the removal of any potential outliers.

3.5. Practical implementation issues

Any proposed cost models should be transparent, replicable and stable. The nature of our data set means that the models are not likely to be too complex, although the current sample size and data availability may not be preferable from an accuracy and theoretical correctness perspective. All our models can be implemented using standard econometric methods and software.

3.6. Results coding

There is no single metric or method to assess the models mechanistically. Therefore, in order to assess the models we have adopted a ‘traffic light’ system to indicate how well a model performs against a given criterion i.e. a green light relates to good, an amber light corresponds to acceptable but with a few issues, and a red light means the model is flawed.

In this sub-section we describe the method of assigning traffic lights to a short-list of models. The selection of traffic lights is based on the conclusions for each model summarised in the templates set out in ANNEX E for offshore, ANNEX G for cabling and ANNEX F for onshore costs.

As we mentioned earlier in the report, we consider that all the estimation methods used in the models presented in the following sections are in line with regulatory best practice and there are no obvious concerns about their practical implementation.

We did not assign a traffic light for theoretical correctness given the limited range of drivers available in the dataset. Rather we focused on whether the coefficients on the cost drivers had the expected sign and were significant. Our traffic light criteria are set out in below. We therefore only assigned traffic lights for the remaining three categories, i.e. coefficients, statistical test, and robustness checks. We considered whether the model meets a set of criteria for each category, listed by priority in Table 3.1 below. The boundary between Amber and Green depends on whether the model satisfies the top criteria.

We considered that any model that received a red light (in any category) should not be used to set cost benchmarks/ baselines.

Table 3.1: Traffic light criteria in order of priority

	Coefficients	Statistical test	Robustness check
R	1. Coefficient signs were not consistent with expectations (i.e. negative when positive expected) and there are no offsetting reasons (e.g. multicollinearity). 2. All coefficients were insignificant and there are no offsetting reasons (e.g. multicollinearity).	1. Failed multiple statistical tests. 2. R-squared is very low (less than 0.6).	1. Sample size very low (i.e. below 7). 2. Very sensitive to sample choice.
G A	1. Coefficient signs were in line with expectations and levels/ elasticities relatively sensible. *If not, given Amber.* 2. All coefficients were significant or there are potentially offsetting reasons (e.g. multicollinearity). *If not, given Amber.*	1. Passed all statistical tests (RESET, normality and White). If not, given Amber. 2. Alpha factor close to one (e.g. within 5%). (Log models only.) If not, given Amber. 3. Goodness of fit above 0.80. If not, given Amber.	The small sample size available means that the robustness of any models assessed is likely to be low. Therefore we expected to give few 'green' lights in this category. 1. Not very sensitive to sample choice (i.e. not much difference between ITV and AFTV, removal of projects). *If not, given Amber.*

4. OFFSHORE COSTS

4.1. Introduction

In this section we set out our modelling approaches for offshore costs (excluding cables). As set out in Table 2.1, disaggregated cost data was only available for:

- offshore transformers; and
- other offshore platform costs.

For most of the disaggregated costs the ITV exclude some projects for which there is AFTV data, and vice-versa, which means the models regress different samples depending on whether the ITV or AFTV is used. We chose not to align the two samples due to the small number of observations. Where there are significant differences between the results for a given model specification we conducted sensitivity testing with the two samples aligned and have incorporated this in our assessment.

As mentioned in the preceding section we have adopted an approach based on a 'traffic-light' system to indicate how well the model performs against a given criterion, i.e., a 'green light' corresponds to 'good', 'amber light' corresponds to 'acceptable but with a few issues', and a 'red light' means that the model is flawed.

We set out our rationale behind each of the cost drivers, for each cost category, in the sections below. We have developed this rationale in conjunction with our engineering support and in ANNEX D we set out a list of other drivers for which data was unavailable. For reasons discussed in Section 2.2 we have focused on ITV and AFTV costs. However, we provide results for ITV, AFTV and DFTV in ANNEX E.

4.2. Offshore transformer costs

Definition:- Offshore transformer costs refer to the supply and installation of offshore transformers, devices which take one voltage and convert it into another voltage.

4.2.1. Data and cost drivers

There are only eight observations available in the ITV and AFTV stages. Given the number of observations and our comments in Section 2 on cost allocation, we were not always clear on the exact costs included in this category, e.g. if all installation costs had been included. In addition, given the small number of observations, we limited the number of variables included in each model.

Table 4.1 below details our understanding of the cost category and our rationale for including potential cost drivers for offshore transformer costs.

Table 4.1: Cost drivers for offshore transformer (identifier in italics)

Cost driver	Rationale
No of offshore transformers - *OfftransNo*	The costs will increase given a higher number of transformers. Multiple transformers with the same total capacity and voltage as a single transformer will have increased costs due to additional installation and connections costs.
Offshore transformer capacity (MVA) - *OfftransCap*	Greater capacity will lead to increased costs due to increased materials and size of the transformer. As voltage does not vary greatly across the projects, we consider that capacity is likely to be the stronger explanatory variable.
Offshore transformer voltage (kV) - *OfftransVolt*	Greater voltage for the same capacity, may lead to reduced costs (reduced windings). For TR1 and TR2 projects, most of the transformers are of the same voltage (while capacity varies). This reduces the explanatory power of voltage when not used in conjunction with capacity.
Constant	*Depending on which variables are included. This can be excluded to allow the number of transformers to reflect the fixed costs.*

As can be seen from Table 4.2, there is unsurprisingly a strong correlation between the number of offshore transformers and the total capacity of these transformers. This suggests that caution is required when using both explanatory variables together. A possible approach to avoid issues of multicollinearity, is to model at the unit level i.e., divide the costs by the number of transformers.

Table 4.2: Correlation between cost drivers for offshore transformers

	OfftransNo	OfftransCap	OfftransVolt
OfftransNo	1.0000		
OfftransCap	0.8109	1.0000	
OfftransVolt	0.0795	0.4263	1.0000

We note that, from the sample available only one project has a voltage for its transformer different from 132kV. This means that the explanatory power of this variable is likely to be quite low as it will only pick up some cost difference (if it exists) between the single project and the rest of the sample. As such we do not run models only using transformer voltage as an explanatory variable.

In addition, while transformer numbers are a key driver of costs by itself this explanatory variable does not provide a great deal of additional information of the differences in costs between transformers. Therefore, in our model selection we did not choose models using only transformer numbers as an explanatory variable.

A plot of total costs excluding offshore other costs revealed a strong linear relationship between cost and capacity. It also indicates that there are some significant differences in the samples (ITV and AFTV) which are likely to lead to different results.

We have used a squared term for capacity to test whether the data indicates an existence of varying economies of scale in constructing transformers with higher capacity. A negative coefficient on the squared term would indicate that as weight increased cost per tonne would fall.

Given the uncertainty around the cost allocation in this category we have run sensitivity testing to exclude the data points over which we have a concern.

4.2.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. ANNEX E contains the full output from these models and a summary of each model's performance against our assessment criteria. We ran each model specification in both a linear and log-linear form.[31]

Table 4.3: Offshore transformer models

Explanatory variables	Model identifier						
	1	2	3	4	5	6	7
OffTransNo	✓	✓	✓				
OffTransCap	✓	✓		✓	✓	✓	✓
OffTransVolt			✓	✓	✓		
OffTransCap_sqrd					✓		✓
Constant	✓		✓	✓	✓	✓	✓

In addition to the models set out in Table 4.3 we also ran a series of models dividing through by the number of transformers i.e. the dependent variables is cost per transformer, and the explanatory variable of capacity is capacity per transformer. We did not divide transformer voltage by transformer numbers. The 'per transformer' models are shown in Table 4.4 below.

Table 4.4: Offshore per transformer models

Explanatory variables	Model identifier			
	1	2	3	4
OffTransCap per transformer	✓	✓	✓	✓
OffTransVolt	✓	✓		
OffTransCap_sqrd per transformer		✓		✓
Constant	✓	✓	✓	✓

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[31] We used a unique identifier for each model. The first part of the identifier 'OffTr' reflects the cost category, 'lin' or 'log' reflects the transformation (linear or log-linear) and the number reflects the model number used to identify which explanatory variables were included.

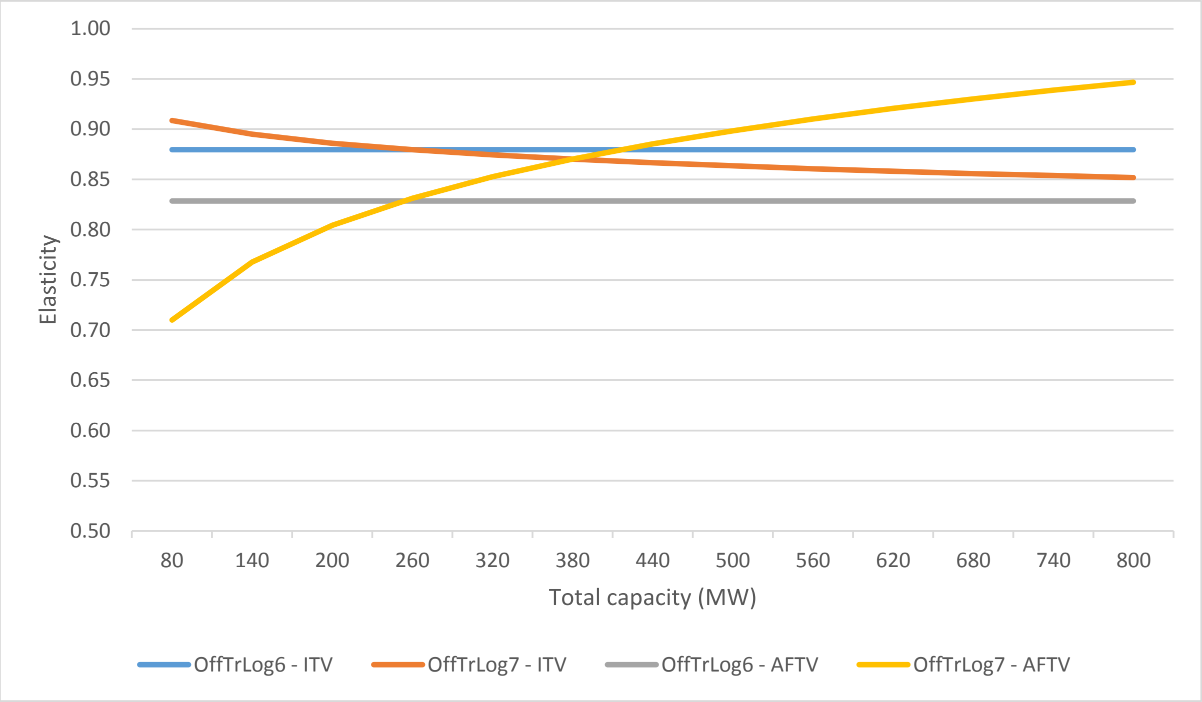
In the section below, we have provided our assessment of the more plausible models.

4.2.3. Assessment

The models that we ran indicated that:

- There are economies of scale in transformer capacity i.e., the coefficient in the log form models are less than 1.[32]
- There was no strong evidence of increasing or decreasing economies of scale cost related to transformer capacity. We might have expected that as capacity increased the marginal cost would decrease. In fact we found that the ITV stage data indicated increasing economies of scale while the AFTV stage data indicated decreasing economies of scale. This is illustrated in Figure 4.1 below. Individually the coefficients on the capacity variables are not significant, however they are jointly significant at the 5% level.

Figure 4.1 – Elasticity of costs to transformer capacity



- Overall it appears that the log models worked better than the linear models. Only one linear model performed well against our assessment criteria as shown in Table 4.5 below. This was mainly due to coefficients having the wrong expected sign (i.e., negative) or being insignificant.

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[32] A coefficient of 1 indicates that a 1% increase in capacity would lead to a 1% increase in costs. Therefore, if the coefficient is 0.9, this indicates a 1% increase in capacity would lead to a 0.9% increase in costs.

- In most cases there is a significant difference in the results of the ITV and AFTV stage. Most notable is that the R-squared for models using ITV data are generally higher. Two related reasons for this may be that the calculation of the cost for the ITV follows a more systematic approach while the AFTV reflects actual costs adjusted by Ofgem for efficiency. Secondly, the actual costs are likely to include unforeseen costs e.g., delays, which may increase certain project's costs.
- All the models are sensitive to the sample used (our sensitivity testing included removing certain observations and then comparing the resulting coefficients/ statistics against the models using the full sample). This means we have less confidence in the robustness of the models.

We set out our assessment of the more plausible models (we have excluded any which received a 'red' light) against our criteria in Table 4.5. We found that the AFTV results were heavily influenced by one project as such this indicated the model was relatively sensitive to the available data. We have therefore only provided an assessment of plausible models using the ITV stage data in Table 4.5 below.

Table 4.5: Offshore transformer model assessment, ITV

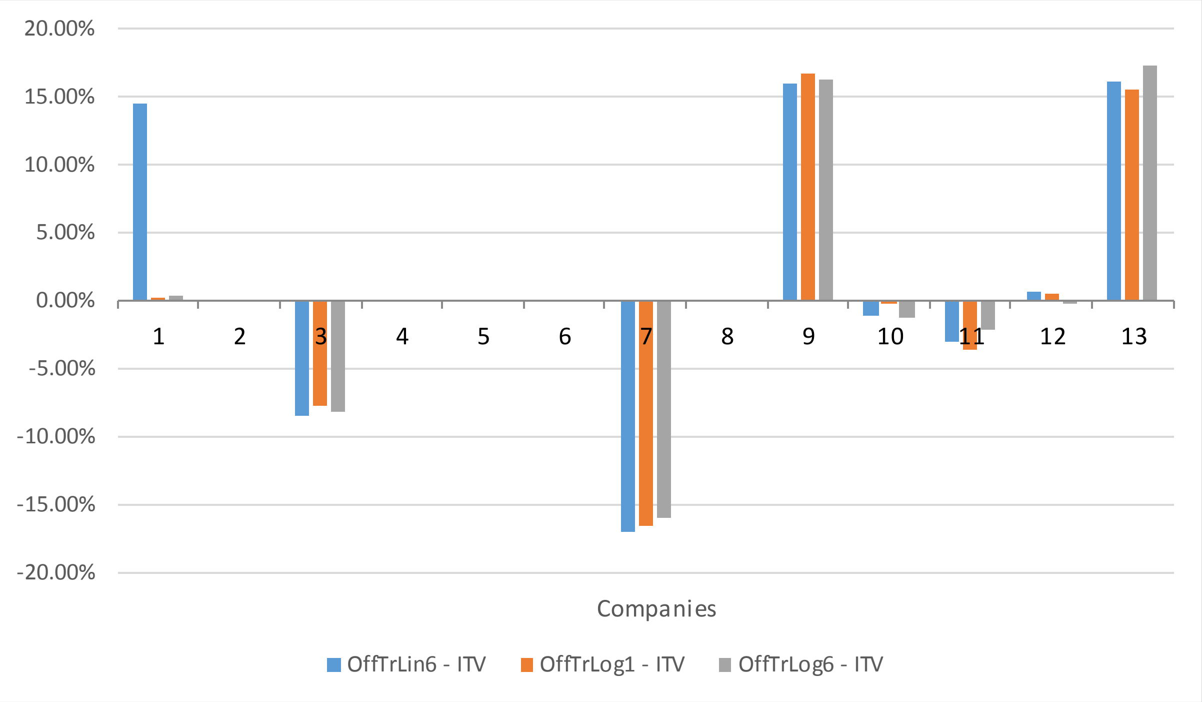
Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrlin6	Offshore transformer capacity.	G	A	A
		Transformer capacity significant at 5%.	Adjusted R2 = 0.95. Passes Reset and White's tests, fails normality.	Stable and significant coefficient, R-squared greatly increased. Normality test incalculable.
OffTrlog1	Number of offshore transformers, offshore transformer capacity	A	G	A
		Transformer capacity significant at 5%.	Adjusted R2 = 0.95. Passes Reset, Normality, and White's tests. Alpha factor close to 1.	ITV sensitivities show relatively small changes in coefficients. Normality not calculable.
OffTrlog6	Offshore transformer capacity.	G	G	A
		Transformer capacity significant at 5% and reasonable value.	Adjusted R2 = 0.96. Passes Ramsey Reset, normality and White's tests. Alpha factor close to 1.	Relatively small change in capacity coefficient (still significant at 5%). Normality not calculable.

The ‘per transformer’ models did not produce any robust results for both ITV and AFTV. This could have been due to a level of fixed costs related to the installation of the transformers.

We did not find many models which passed the robustness test. For those that did, we found significant differences between the results for the ITV and AFTV data. We believe this difference is mainly driven by one project which is included in the AFTV, but was excluded from the ITV, and has a significantly higher cost for the capacity installed than other similar sized projects.

Overall, our modelling, based on the available dataset, indicated that a linear or log transformed model using a capacity driver, with or without the number of transformers in the case of the log model, performed best. The differences between the models’ predictions and the actual values are shown in Figure 4.2 below. A positive percentage means the predicted value is above the actual.

Figure 4.2 – Offshore transformer model predictions compared to actuals



We would expect differences between these values as the predicted value is an average, while the actual value includes any efficiencies or inefficiencies as well as any differences not captured by the cost drivers.

4.3. Offshore platform (excluding transformers) costs

Definition:- Offshore platform (excluding transformers) costs refers to the supply and installation of all the structural components (foundation, jacket and topside) and electrical equipment on the offshore substation excluding the transformer supply and installation costs.

4.3.1. Data and cost drivers

There are 12 observations available in the ITV stage and 10 in the AFTV stage.

Table 4.6 below details our understanding of the cost category and our rationale for including potential cost drivers for offshore platform (excluding transformer) costs.

Table 4.6: Cost drivers for offshore platforms (excluding transformers) (identifier in italics)

Cost driver	Rationale
No. of offshore platforms - *OSPno*	Multiple platforms will require additional foundations, jackets and topsides plus additional electrical equipment so costs are expected to increase as the number of platforms increase. There may be economies of scale in terms of installation costs, as there may be certain pre-construction work (e.g. permits and surveys), but also potential scale benefits in installation.
Offshore platform weight (tonnes) - *OSPtotwt*	A greater weight will require a greater amount of material and construction time and thus increase costs. The requirement for 'heavier' platform will relate to the location of the platform, the number/size of the transformers as well as any equipment housing. Without additional information, we assume that the materials used and construction time remain proportionate for different weights i.e. the same proportions of concrete and steel are required for different platform weights. There are possible economies of scale in relation to the construction of the offshore platforms.
Platform distance from shore (km's) - *OSPshore*	There may be initial set up costs from being located further from shore. Being located further from shore may be representative of larger waves or deeper water, which impose additional costs. (We attempted to have water depth as its own variable, but were not able to do so. Even if this does not vary, there will be costs as a result of the additional time required to get to the platform. This will result in higher costs in labour, fuel and equipment hire.)
Constant	*We would expect a constant given that there will be project costs associated with setting up any offshore platform and other fixed costs.*

There are positive correlations between the number of platforms and total weight, as outlined in Table 4.7 below. There is also a strong positive correlation between distance from shore and total weight. This indicates that as the distance from shore increases so too does the weight of the platform(s).

Table 4.7: Correlation between cost drivers for offshore platform (excluding transformers)

	OSPno	OSPtotwt	OSPshore
OSPno	1.0000		
OSPtotwt	0.8027	1.0000	
OSPshore	-0.0053	0.248	1.0000

While platform numbers are a key driver of costs by itself this explanatory variable does not provide a great deal of additional information on the differences in costs between projects.

Therefore, in our model selection we did not choose models using only platform numbers as an explanatory variable.

We have used a squared term for weight to test whether the data indicates an existence of economies of scale in the construction of platforms. A negative coefficient on the squared term would indicate that as weight increased cost per tonne would fall.

A plot of offshore platform costs against weight (at both the ITV and the AFTV stages) revealed a strong relationship between cost and weight. The differences between the costs in the ITV and AFTV stages do not appear as significant for offshore platform costs as for offshore transformers, however the difference in the samples (ITV and AFTV) may lead to differences in results.

As noted in the section on offshore transformers, there is uncertainty around offshore costs that we do not have data available for at a sufficiently granular level to re-allocate costs or be certain that excluding costs is the correct method to adopt. Therefore we have undertaken sensitivity analysis on the models.

4.3.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. ANNEX E contains the full output from these models and a summary of each model's performance against our assessment criteria. We ran each model specification in both a linear and log-linear form.

Table 4.8: Offshore platform (excluding transformers) models

Explanatory variables	Model identifier				
	1	2	3	4	5
OSPno	✓				
OSPtotwt	✓	✓	✓	✓	✓
OSPshore		✓	✓		
OSPtotwt_sqrd			✓		✓
Constant	✓	✓	✓	✓	✓

We did not divide through by the number of OSPs to create a 'per platform' dependent variable as we found that OSP weights differ within projects. Therefore dividing weight by the number of platforms would not be a true reflection of the cost driver.

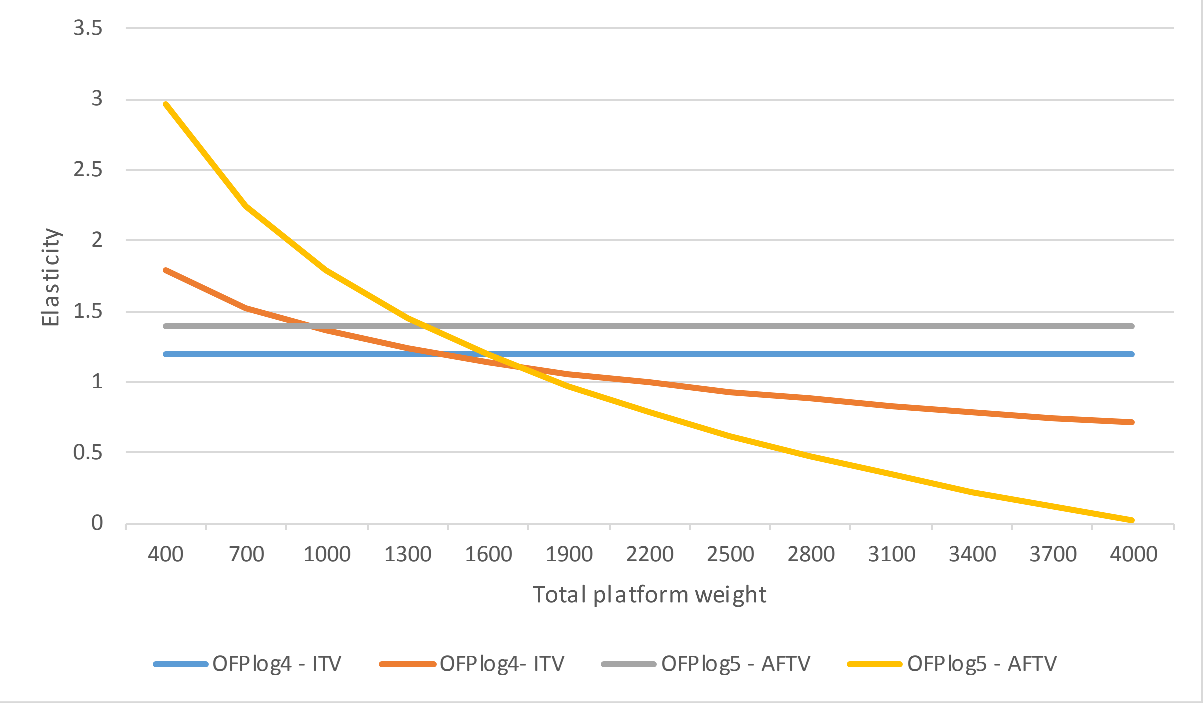
In the section below we have provided our assessment of the more plausible models.

4.3.3. Assessment

The models that we estimated indicated that:

- There appears to be slight diseconomies of scale in platform weight. This is shown through the coefficients on the log transformed weight being above 1 in most models. The models with squared terms included do however indicate that there are varying economies to scale, in this case all the projects had economies of scale (i.e. as the weight increases the marginal cost decreases). This is shown in Figure 4.3.

Figure 4.3 – Elasticity of costs to platform weight



- The models' results were relatively consistent across the ITV and AFTV datasets.

We set our assessment of the more plausible models (we excluded any which received a 'red' light) against our criteria in Table 4.9. As there were relatively small differences in the results for the ITV and AFTV we jointly assessed the results from these two stages.

Table 4.9: Offshore platform (excluding transformers) model assessment

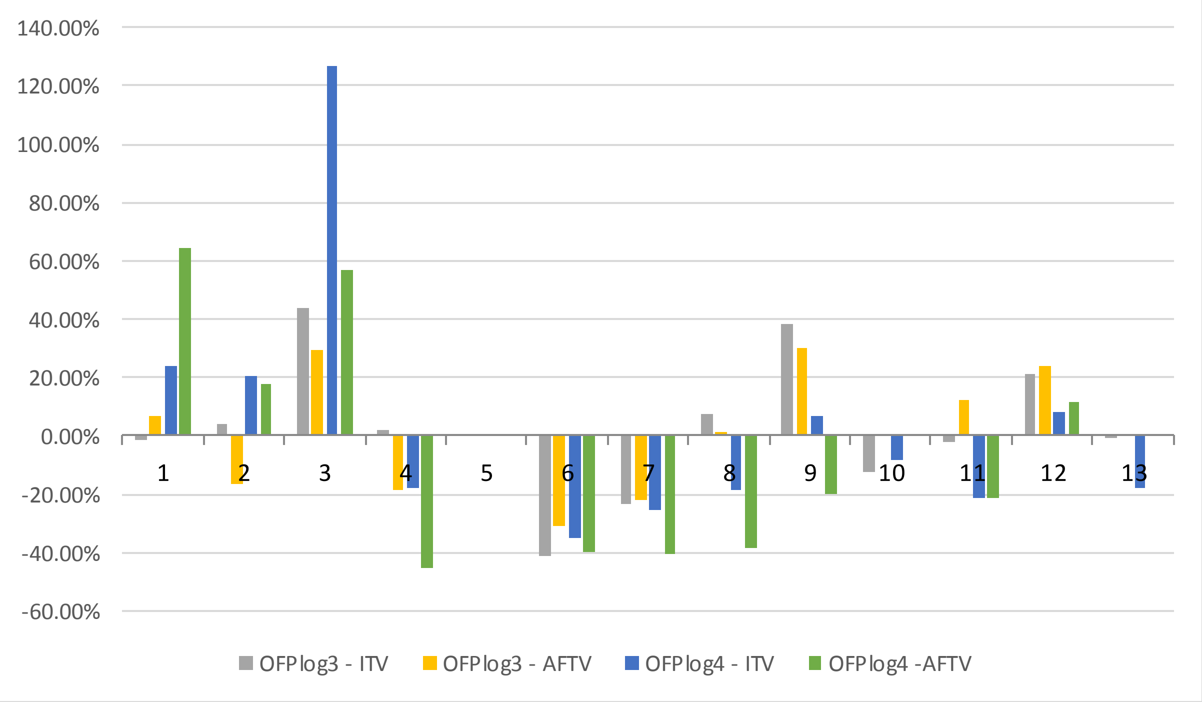
Model reference	**Explanatory variables**	**Coefficients**	**Statistical test**	**Robustness**
OSPlog3	Weight of offshore platform, distance from shore, total weight of offshore platform squared	G	G	A
		Coefficients significant between the 5% and 10% level for DFTV and AFTV. Weight elasticities become negative at greater weigths (likely due to correlation with distance).	R-squared = 0.854 (ITV), 0.901 (AFTV) Passes all tests. Alpha factor around 1.	Jumps in coefficient between ITV and AFTV.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OSPlog4	Weight of offshore platform	G	G	A
		Weight coefficient significant at the 1% level. Constant significant at at least the 5% level.	R-squared = 0.780 (ITV), 0.762 (AFTV) Passes RESET and White test. Only ITV fails normality test.	Some movement in coefficients, but not excessively so.

The small sample size meant that assigning a ‘green’ light for robustness is unlikely. Overall our modelling, based on the available dataset, indicated that a linear or log transformed model using only the weight driver performed best. A log model including all the explanatory variables, expect OSP numbers, performed well with a high R-squared, and passes on each of our statistical tests (although this could be influenced by the high number of variables included relative to the sample size).

The differences between the models’ predictions and the actual values are shown in Figure 4.4 below. A positive percentage means the predicted value is above the actual.

Figure 4.4 - Offshore platform (excluding transformers) model predictions compared to actuals



The differences are significant for a number of the projects. In one case, the prediction error is almost 1.3 times the actual. The best performing model appears to be OFTlog4 (particularly using the AFTV data). Given these results we would be much more cautious in recommending an offshore platform model for use as part of Ofgem’s cost assessment toolkit.

4.4. Offshore platform total costs

In addition to our analysis above, we also considered total platform costs i.e., the cost relating to constructing the platform (foundation, jacket and topside) and the supply and installation of electrical equipment including transformers. The models utilise a combination of the same cost drivers noted above. We excluded some cost drivers which were not consistently significant in the disaggregated cost level models.

4.4.1. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. The correlation between offshore platform weight and capacity is very high at 0.81. We only ran models including both offshore platform weight and transformer capacity as these two variables were the primary drivers of costs at the disaggregated cost level. On average, transformer cost only makes up 13% of total offshore platform costs so we would expect weight to be the more significant driver of costs.

ANNEX E contains the full output from these models and a summary of each model's performance against our assessment criteria. We ran each model specification in both a linear and log-linear form.

Table 4.10: Offshore platform total cost models

Explanatory variables	**Model identifier**	
	1	**2**
OSPtotwt	✓	✓
OSPshore		✓
OSPtotwt_sqrd		
OffTransCap	✓	✓
Constant	✓	✓

In the section below, we have provided our assessment of the more plausible models.

4.4.2. Assessment

The models that we ran indicated that:

- The correlation between weight and capacity likely impacted on the significant level of the coefficients. However for both models the signs of the coefficients were as expected and both indicated economies of scale (coefficients below 1).
- The R-squared was generally lower than the for transformer models, but marginally higher than in the offshore platform models.

- Log models performed slightly better than linear, in line with the transformer and offshore platform models.

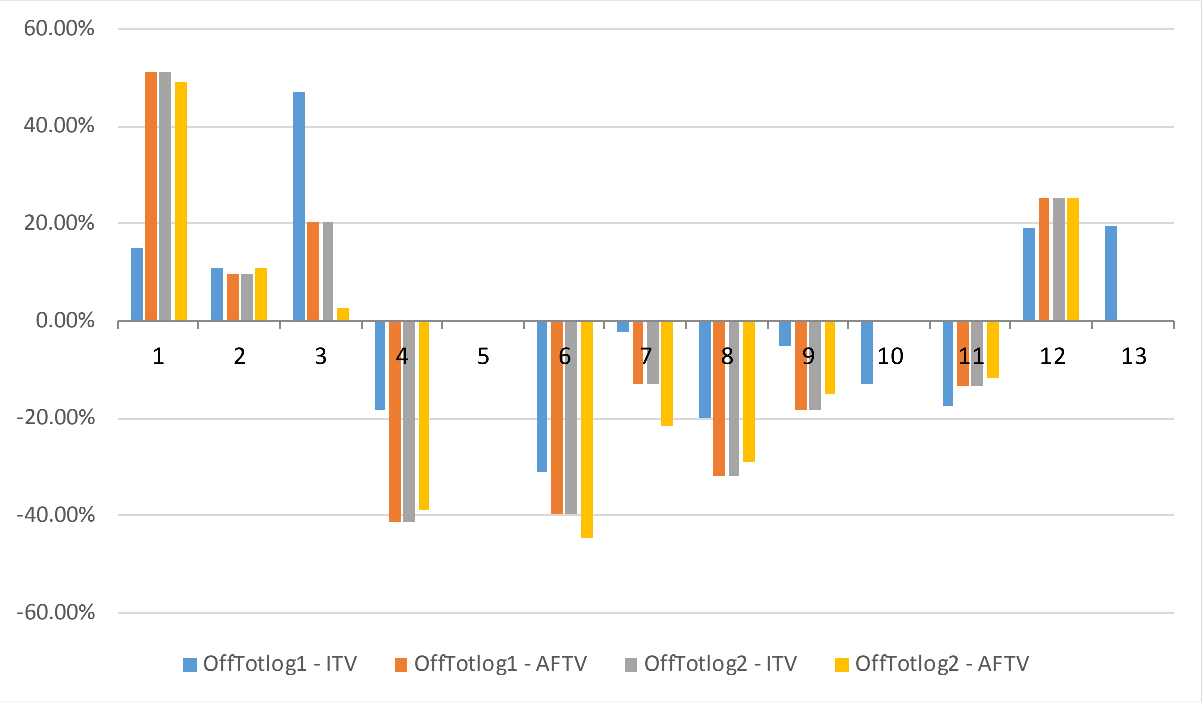
We set our assessment of the more plausible models (we excluded any which received a 'red' light) against our criteria in Table 4.11 below. As there were relatively small differences in the results for the ITV and AFTV we have jointly assessed the results from these two stages.

Table 4.11: Offshore platform total cost assessment

Model reference	**Explanatory variables**	**Coefficients**	**Statistical test**	**Robustness**
OffTotlog1	Total weight of offshore platform, offshore transformer capacity	A Signs are as expected. Elasticities appear reasonable. Only constant and one capacity coefficient are significant, however likely multicolinearity issue between weight and capacity.	A Adj R-squared = 0.885 (ITV), 0.832 (DFTV), 0.794 (AFTV). Passes normality, RESET, and White. Alpha factor not close to 1 (mainly for AFTV).	A Coefficient relatively stable from ITV to the AFTV.
OffTotlog2	Total weight of offshore platform, distance from shore, offshore transformer capacity	A Signs are as expected. Elasticities appear reasonable. Only constant and one capacity coefficient are significant, however likely multicolinearity issue between weight and capacity.	A Adj R-squared = 0.893 (ITV), 0.819 (DFTV), 0.771 (AFTV). Passes normality, RESET, and White. Alpha factor not close to 1.	A Coefficient relatively stable from ITV to the AFTV. Although coefficient on weight almost doubles.

The differences between the models' predictions and the actual values are shown in Figure 4.5 below. A positive percentage means the predicted value is above the actual.

Figure 4.5 - Offshore platforms total cost predictions compared to actuals



Overall we had slightly less confidence in this aggregate level model than the two disaggregated models. However, the aggregate level model would provide a good cross check to the two disaggregated models, especially given the great volatility in the platform weight model.

5. ONSHORE COSTS

5.1. Introduction

In this section we set out our modelling approaches for onshore costs (excluding cables). As set out in Table 2.2, disaggregated cost data was available for:

- onshore transformers;
- onshore reactive costs; onshore harmonic costs;
- onshore substation other; and
- onshore connection.

The reactive cost, harmonic cost, and connection cost categories had a limited number of observations and in our modelling we have not arrived at any plausible models to analyse these specific disaggregations. Therefore we focus on the other categories and consolidated cost categories.

As mentioned in the preceding section we have adopted an approach based on a 'traffic-light' system to indicate how well the model performs against a given criterion, i.e., a 'green light' corresponds to 'good', 'amber light' corresponds to 'acceptable but with a few issues', and a 'red light' means that the model is flawed.

For these cost categories, below we set out our rationale behind each of the cost drivers. We have developed this rationale in conjunction with our engineering support and in ANNEX D we set out a list of other useful cost drivers for which data was not available. For reasons discussed in 2.3.2 we have focused on ITV and AFTV costs. However, we provide results for ITV, AFTV and DFTV in ANNEX F.

5.2. Onshore transformer costs

Definition:- Onshore transformer costs refer to all costs related to the supply and installation of transformers onshore. The transformers convert one voltage to another.

5.2.1. Data and cost drivers

There were only seven observations available in the ITV stage and only five in the AFTV stage. Some projects did not have onshore transformers amongst the transmission assets relating to the project. Given the very small number of observations, from the outset of our models we had concerns for the robustness of any models we estimated.

Table 5.1 below details our understanding of the cost category and our rationale for including potential cost drivers for onshore transformers.

Table 5.1: Cost drivers for onshore transformers (identifier in italics)

Cost driver	Rationale
No of onshore transformers - *OnTransNo*	The costs will increase given a higher number of transformers. Multiple transformers with the same total capacity and voltage as a single transformer will have increased costs due to additional installation and connection costs.
Onshore transformer capacity (MVA) - *OnTransCap*	Greater capacity will lead to increased costs as the construction of the transformer will require more material and a larger sized transformer. The larger sized transformer may in itself lead to higher installation costs.
Onshore transformer voltage (kV) - *OnTransVolt*	Greater voltage for the same capacity may lead to reduced costs (reduced windings).
Constant	*Depending on which variables are included, we may expect no constant given that the first variable takes into account fixed costs.*

As with the offshore transformers it is unsurprising that there is a strong correlation between the number of offshore transformers and the total capacity of these transformers (see Table 5.2). This suggests caution is required when using both explanatory variables together.

Table 5.2: Correlation between cost drivers for sea cable supply

	OnTransNo	OnTransCap	OnTransVolt
OnTransNo	1.0000		
OnTransCap	0.6731	1.0000	
OnTransVolt	0.3015	0.7663	1.0000

We can also see that there is a strong correlation between capacity and voltage. However, we had at most eight projects with onshore transformers.[33] In addition, the range of projects' transformer voltages was very minimal with the voltages being either 132kV or 400kV (evenly split at four apiece). This small variation indicates that the transformer voltage is unlikely to explain the variation in costs between the different projects as a sole explanatory variable in the models.

While transformer numbers are a key driver of costs, like voltage, by itself this explanatory variable does not provide a great deal of additional information of the differences in costs between transformers. Therefore, in our model selection we did not choose models using only transformer numbers as an explanatory variable.

We observed that, while there are only a few observations where there is data available for both capacity and onshore transformer costs, there is a strong relationship between cost and capacity. There is a significant gap between the smallest total capacity and the next

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[33] We had more observations with transformers voltages than costs, therefore the difference between the maximum number of cost observations (seven) and transformer voltages (eight).

largest. This difference is likely to have a reasonable influence on both the scope and intercept (constant).

5.2.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate form. These models are set out in Table 5.3 below. Given our discussion in the preceding section around transformer numbers and voltage, the majority of the models we estimated included capacity. We ran each model specification in both a linear and log-linear form.

ANNEX F contains the full output from these models and a summary of each model's performance against our assessment criteria.

Table 5.3: Onshore transformer models

Explanatory variables	Model identifier						
	1	2	3	4	5	6	7
OnTransNo	✓	✓			✓		✓
OnTransCap		✓	✓	✓	✓	✓	✓
OnTransVolt	✓			✓	✓		
OnTransCap_sqrd						✓	✓
Constant	✓	✓	✓	✓	✓	✓	✓

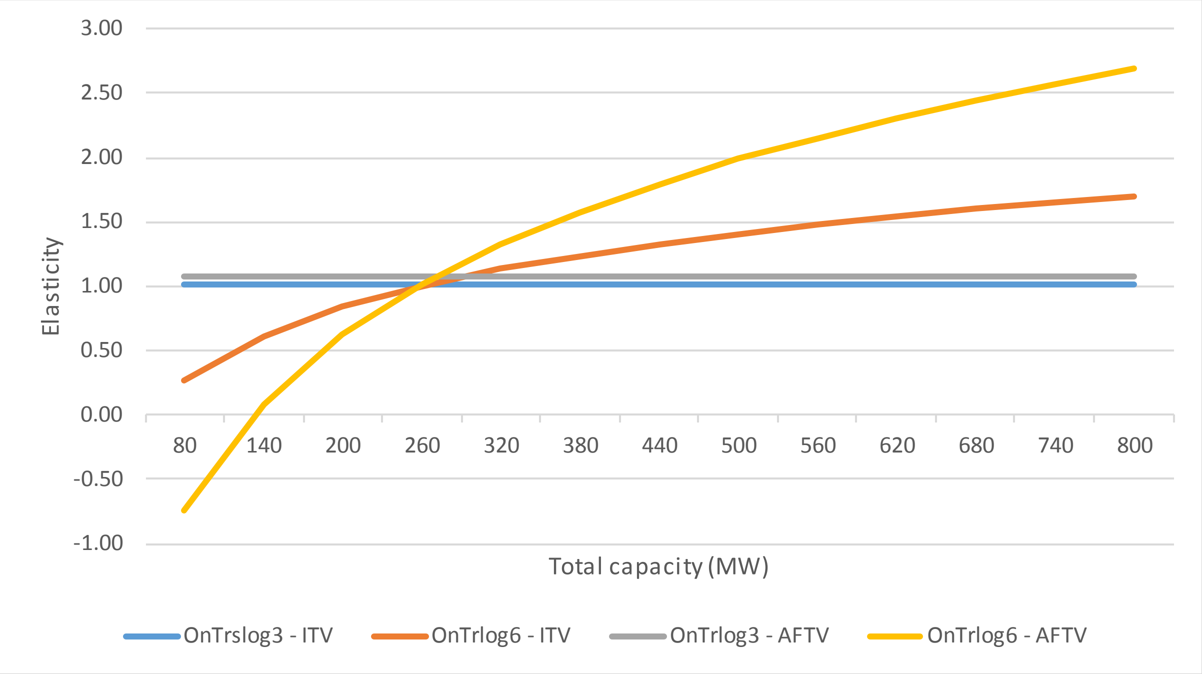
We tested the feasibility of unit level models, i.e., costs divided by the number of transformers, however the models did not produce any feasible results and we have excluded them from this report.

5.2.3. Assessment

The models that we estimated indicated that:

- The very small number of observations led to very few models providing plausible or robust estimates.
- Log models performed better, however all models with transformer capacity indicated diseconomies of scale and where varying economies of scale was allowed for, these models indicated decreasing economies of scale. This is illustrated in Figure 5.1.

Figure 5.1 – Elasticity of costs to onshore transformer capacity



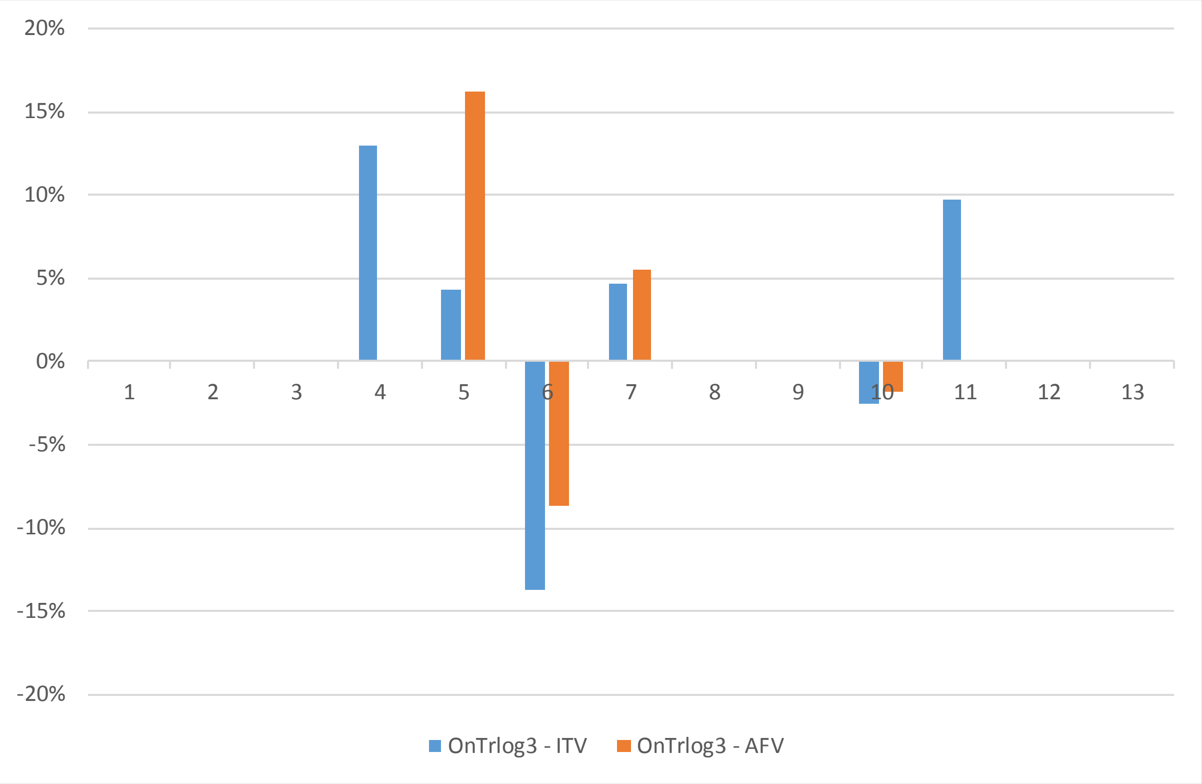
We set our assessment of the more plausible models below. We were only able to identify one model which had plausible coefficients and test statistics. However, the small sample size prevented us from satisfying all our assessment criteria.

Table 5.4: Onshore transformer model assessment

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTrlog3	Onshore transformer capacity	G	A	A
		Capacity significant at 1% for ITV then 5% levels. Constant significant at 1% for ITV, DFTV then at 5% for AFTV.	R-squared = 0.986 (ITV), 0.972 (DFTV), 0.987 (AFTV) Passes White, RESET Normality na Alpha factor around 1	Relatively stable coefficients. Very small sample size.

The differences between the models' predictions and the actual values are shown in Figure 5.2 below. A positive percentage means the predicted value is above the actual.

Figure 5.2 – Onshore transformer model predictions compared to actuals



The predictions were relatively close for both ITV and AFTV with the maximum and minimum distances away from actuals being around 15%. While the magnitude of these differences is reassuring, the very small sample size means that a cautious approach should be exercised when using these values to assess/ set other projects' costs.

5.3. Onshore substation total costs (excluding onshore other) costs

Definition:- This relates to cost for supply and installation of transmission assets such as onshore transformers, reactive equipment, harmonic equipment and the cost of onshore connections, but excludes the category of costs denoted as 'onshore other costs'. Onshore other costs include a variety of non-equipment costs which may include a proportion of onshore civils costs, project management costs and insurance.

5.3.1. Data and cost drivers

We had a complete set of data (13 observations) for the ITV stage and there were only two observations not available for the AFTV stage.

Table 5.5 below details our understanding of the cost category and our rationale for include potential cost drivers for onshore total costs excluding onshore other.

Table 5.5: Cost drivers for onshore total costs excluding onshore other (identifier in italics)

Cost driver	Rationale
Onshore transformer capacity - *OnTransCap*	Greater capacity will lead to increased costs as the construction of the transformer requires are greater amount of materials and size of the transformer, which itself may lead to higher costs in installing the transformer
Onshore reactive capacity – *OnReCap*	Greater reactive capacity will lead to increased costs as the construction of the reactive equipment requires a greater amount of materials, which itself may lead to higher costs in installing the equipment.
Onshore transformer dummy (variable equals 1 if there is an onshore transformer, 0 if not) - *OnTransDummy*	The construction of onshore transformers will increase costs relative to not constructing them. Compared to modelling transformers alone, we would expect this to have less of an effect as it relates directly to one area of cost and the presence of a transformer may offset costs in other areas of onshore.
Number of onshore substations - *OnSPno*	Onshore substations involve costs in purchase and installation (including labour). Our expectation is that existing substations can be connected to at a lower cost than creating new onshore substations.
Generation Capacity - *GenCap*	There will be additional costs expected with additional generation capacity. This will be through the greater number of assets and the greater complexity of asset to deal with the higher capacity.
Constant	*We would expect some element of fixed costs.*

As expected there were strong correlations between onshore transformer capacity, onshore reactive capacity and overall generation capacity.

Table 5.6: Correlation between cost drivers for onshore total costs excluding other

	OnTransCap	OnReCap	OnTransDummy	GenCap
OnTransCap	1.0000			
OnReCap	0.5467	1.0000		
OnTransDummy	0.6859	0.5732	1.0000	
GenCap	0.7798	0.8684	0.3342	1.0000

A plot of onshore total costs excluding onshore other costs against onshore transformer capacity did not show a clear relationship between generation capacity and onshore total costs excluding other costs, however this may be due to the small sample size.

5.3.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate form. These models are set out in Table 5.7 below. As we identified in the last sections, there were few projects which installed transformers onshore. This means running any models which include transformer capacity would reduce the sample size significantly. We still tested a number of models using these variables, but we focused on models using a main cost driver of generation capacity with a transformer dummy variable. We ran each model specification in both a linear and log-linear form.

Table 5.7: Onshore total costs excluding onshore other models

Explanatory variables	**Model identifier**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
OnTransCap	✓	✓	✓				
OnReCap		✓					
OnTransDummy					✓	✓	
GenCap			✓	✓	✓	✓	✓
OnTransCap_sqrd							
GenCap_sqrd						✓	✓
Constant	✓	✓	✓	✓	✓	✓	✓

We have provided our assessment of the models in the section below. ANNEX F contains the full output from these models and a summary each model's performance against our assessment criteria.

5.3.3. Assessment

The models that we ran indicated that:

- The cost drivers available did not adequately explain the variation in costs.
- While log models performed slightly better than linear models, we were unable to identify any robust models.

With the data currently available we were unable to identify any plausible models at this level of disaggregation.

5.4. Onshore substation total costs

Definition: This includes the onshore substation costs in totality i.e., the supply and installation costs for onshore transformers, reactive equipment, harmonic equipment, onshore connections and onshore substation other costs.

5.4.1. Models

We estimated the same models for total onshore costs as we did for total onshore costs excluding other. The list of the models we ran is provided in

Table 5.8 below.

Table 5.8: Onshore total costs model

Explanatory variables	Model identifier						
	1	2	3	4	5	6	7
OnTransCap	✓	✓	✓				
OnReCap		✓					
OnTransDummy					✓	✓	
GenCap			✓	✓	✓	✓	✓
OnTransCap_sqrd							
GenCap_sqrd						✓	✓
Constant	✓	✓	✓	✓	✓	✓	✓

In the section below we have provided our assessment of the models. ANNEX F contains the full output from these models and a summary each model's performance against our assessment criteria.

5.4.2. Assessment

The models that we ran indicated that:

- The cost drivers appeared to work slightly better for total onshore costs (rather than costs excluding other).
- Log models performed better than linear models and we were able to identify one model which produced plausible coefficients and test statistic. This is shown in Table 5.9 below.
- In the only plausible model, the coefficient on generator capacity indicated that there were diseconomies of scale in relation to onshore costs for generation capacity, i.e., a 1% increase in capacity led to a greater than 1% increase in costs.

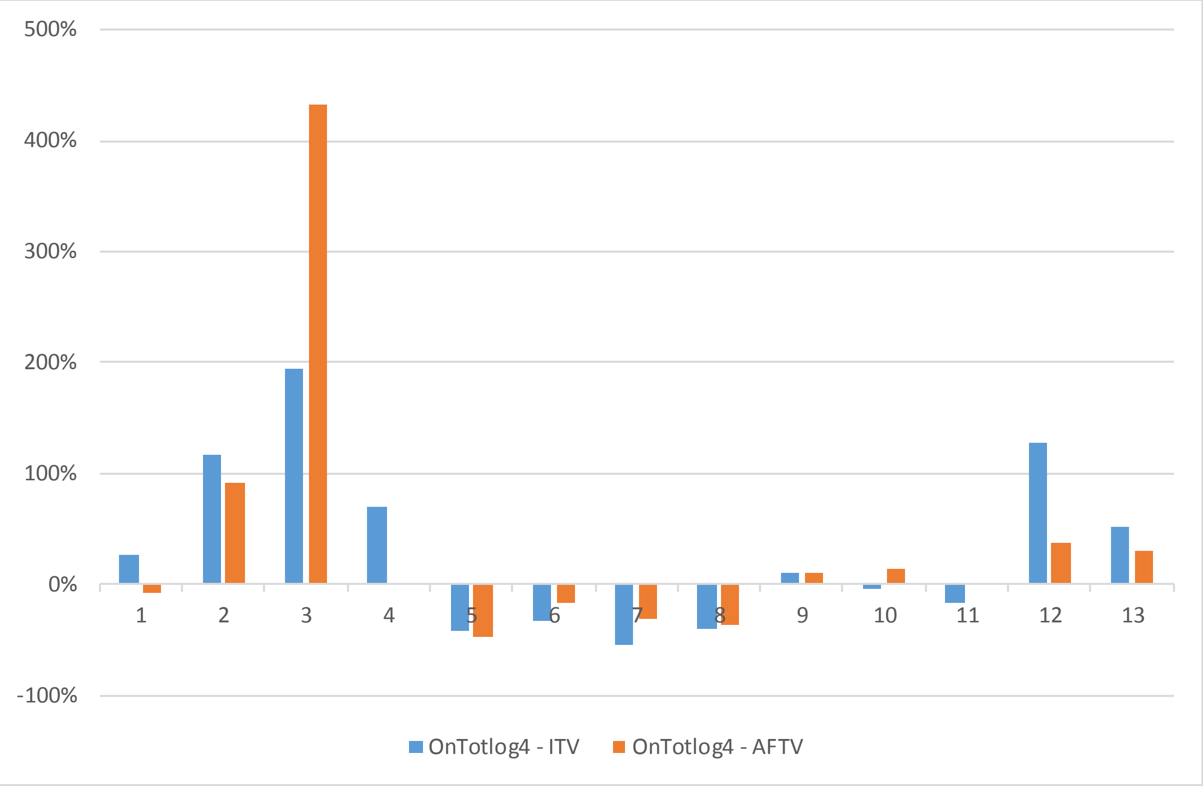
Table 5.9: Onshore total costs model assessment

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTotlog4	Generation capacity	G	A	A
		Generation	R-squared = 0.689	Coefficients

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		capacity coefficient significant at the 1% level.	(ITV), 0.821 (DFTV), 0.635 (AFTV) Passes White and RESET. Fails Normality at AFTV. Alpha factor is not close to 1	relatively stable to across stages. Relatively stable to the removal of smallest/ largest observations.

The differences between the models' predictions and the actual values are shown in Figure 5.3 below. A positive percentage means the predicted value is above the actual. As we can see from this figure, while the model's coefficients seemed ok, its predictions vary widely across projects. The prediction for one model is over five times as great as the actuals.

Figure 5.3 – Onshore total cost comparison of predictions to actuals.



Given the significant differences in the predictions to actuals, we were not confident in recommending an econometric model for total onshore substation costs.

6. CABLING COSTS

6.1. Introduction

In this section we set out our modelling approaches for cables. As set out in Table 2.3, disaggregated cost data was only available for:

- sea cable supply;
- sea cable installation; and
- land cable total costs.

As mentioned in the preceding section we adopted an approach based on a 'traffic-light' system to indicate how well the model performs against a given criterion, i.e., a 'green light' corresponds to 'good', 'amber light' corresponds to 'acceptable but with a few issues', and a 'red light' means that the model is flawed.

For these cost categories, we set out our rationale behind each of the cost drivers below. We developed this rationale in conjunction with our engineering support and in ANNEX D we set out a list of other ideal drivers. For reasons we discussed in Section 2.2 we focused on ITV and AFTV costs. However, we provide results for ITV, AFTV and DFTV in ANNEX G.

6.2. Sea cable supply costs

Definition:- Sea cable supply costs refer to only the purchase of sub-sea cables, spares and accessories used for transmission of power.

6.2.1. Data and cost drivers

There were 13 ITV observations and 11 AFTV observations available for this cost category.

Table 6.1 details our understanding of the cost category and our rationale for including each of the cost drivers for sea cable supply costs.

Table 6.1: Cost drivers for sea cable supply (identifier in italics)

Cost driver	Rationale
Total sea cable length (sum of all sea cable lengths) - *SClen*	Greater cost is expected for greater quantity i.e., we would expect a 100km cable to cost more than a 50km cable. We note that there may be economies of scale, i.e. the marginal cost of adding 1km of cable to a 1km cable will likely cost more than increasing a cable from 100.0km to 101.0km.
Sea cable size - *SCsize*	As the cable increases in size, due to greater material use we expect that the cost will increase. The cable size should reflect the output requirements (i.e., transmission capacity).
Sea cable rating - *SCrate*	A higher capacity/ rating of the sea cable will require a larger conductor size and as such should drive costs, including materials and construction, higher.

Cost driver	Rationale
Constant	There is likely to be an underlying fixed cost associated with the cable construction, e.g. sales costs. So our modelling included a constant.

We used a squared term for length to test whether the data indicated an existence of economies of scale in the construction of the cables. A negative coefficient on the squared term would indicate that as length increased, cost per kilometre would fall.

Table 6.2 below provides the pairwise correlations between the explanatory variables. We can see that there are no strong correlations (either negative or positive) between sea cable length, size or rating. This means that there is a low risk of multicollinearity.

Table 6.2: Correlation between cost drivers for sea cable supply

	SClen	SCsize	SCrate
SClen	1.0000		
SCsize	0.0236	1.0000	
SCrate	0.1090	0.1005	1.0000

From a plot of sea cable supply costs against sea total cable length we observed a strong positive linear relationship between cost and cable length.

6.2.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. The specifications for these models are set out in Table 6.3 below. We ran each model specification in both a linear and log-linear form.

Table 6.3: Sea cable supply models

Explanatory variables	Model identifier							
	1	2	3	4	5	6	7	8
SClen	✓	✓	✓	✓	✓	✓	✓	✓
SClen_sqrd		✓		✓		✓		✓
SCsize	✓	✓			✓	✓		
SCrate					✓	✓	✓	✓
Constant	✓	✓	✓	✓	✓	✓	✓	✓

We considered and tested using a per kilometre dependent variable. However, we found that the explanatory power of the remaining cost drivers was insufficient to produce results robust enough for consideration.

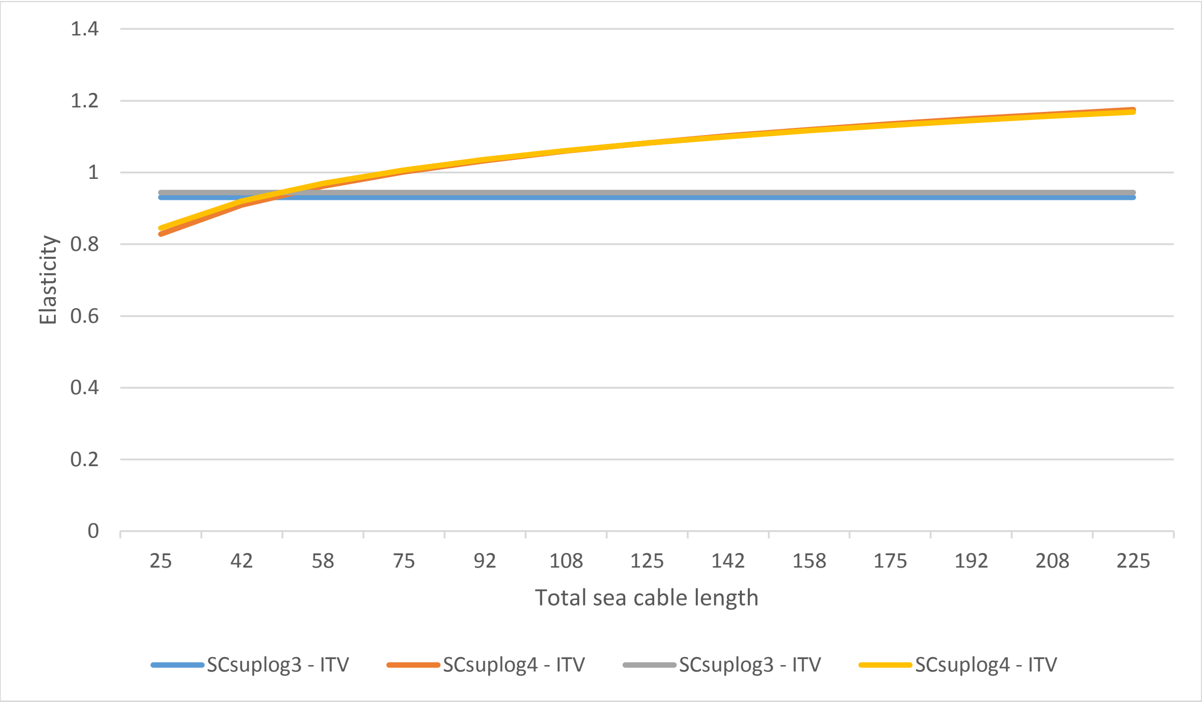
We have provided our assessment of the more plausible models in the section below. Full results and a summary of each model's performance against our assessment criteria are included in ANNEX G.

6.2.3. Assessment

The models that we ran indicated that:

- As expected length is the main driver of sea cable supply costs. All models with sea length included had a high adjusted R-squared value.
- Our models indicated that there appeared to be economies of scale in relation to sea cable length, the squared length term being jointly significant with length (see Figure 6.1 below). However, the models with varying economies of scale were much more sensitive to the removal of projects from the dataset.

Figure 6.1 – Elasticity of costs to sea cable length



- The more parsimonious models,[34] which included sea cable length, were relatively robust to the removal of outliers and the coefficients did not change much across the different stages.

We set our assessment of the more plausible models below.

Table 6.4: Sea cable supply model assessment

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCsuplin3	Sea cable length	G	A	A
		Sea cable length significant at 1% for all stages,	Adjusted R2 = 0.947 (ITV), 0.929 (DFTV), 0.944	Relatively stable to removal of smallest cost

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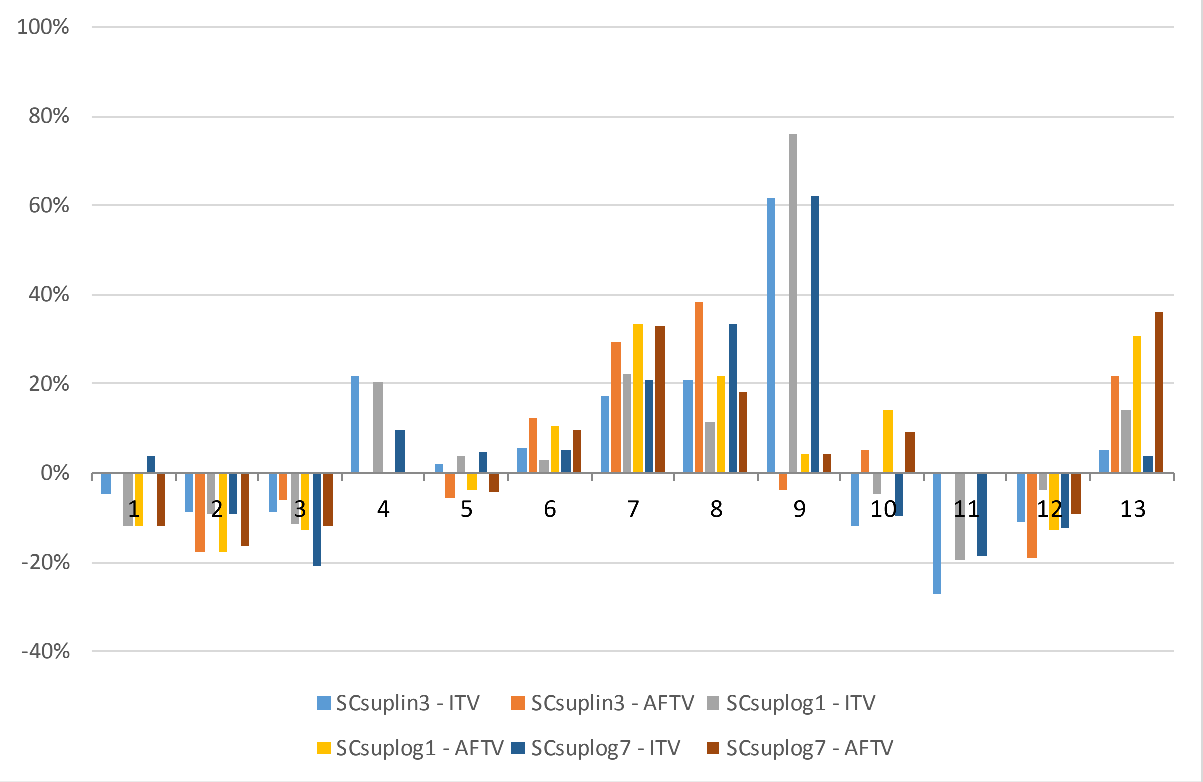
[34] I.e., models including the fewest possible variables, while still producing a 'good' model against the assessment criteria.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		stable across stages.	(AFTV). Fails White and RESET at AFTV (passes at ITV). Passes Normality.	observation. Larger change when largest cost observation removed. Not much change been ITV and AFTV stages.
SCsuplog1	Sea cable length, sea cable conductor size	G	A	A
		Sea cable length significant at 1% for all models. Coefficient just below 1 is as expected. Sea cable size not significant, though correct expected sign. Constant significant at 1% for all.	Adjusted R2 = 0.922 (ITV), 0.941 (DFTV), 0.948 (AFTV). Passes White, RESET. Fails Normality at ITV (passes at AFTV). Alpha factor around 1.	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplog3	Sea cable length	G	G	A
		Sea cable length significant at 1% for all models. Coefficient stable and just below 1 is as expected. Constant significant at 1% for all.	Adjusted R2 = 0.923 (ITV), 0.932 (DFTV), 0.945 (AFTV). Passes White, Normality, RESET. Alpha factor around 1.	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplog7	Sea cable length, sea cable rating	A	G	A
		Sea cable length significant at 1% for all models. Coefficient stable and just below 1 is as expected. Rating not significant, but changes sign from ITV to AFTV.	Adjusted R2 = 0.923 (ITV), 0.945 (DFTV), 0.951 (AFTV). Passes White, Normality, RESET Alpha factor around 1	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages. Aside from SCrate which changes sign, but is not significantly

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		Constant significant at 1% for all.		different zero.

Overall, our modelling, based on the available dataset, indicated that a linear or log transformed model using a sea cable length driver, with either a single secondary driver of size or rating in the case of a log model, performed best. The differences between the models' predictions and the actual values are shown in Figure 6.2 below. A positive percentage means the predicted value is above the actual.

Figure 6.2 – Sea cable supply predictions compared to actuals



While we expect some difference between the predictions and the actuals (due to efficiencies/ inefficiencies and heterogeneity not captured by the drivers), the large difference in the ITV stage is unexpected. However, as the coefficients are relatively robust across the stages, we believe that 'outliers' in the ITV stage are likely to have driven these differences.

6.3. Sea cable installation costs

Definition:- Sea cable installation costs refer to only the installation of sub-sea cables and accessories used for transmission.

6.3.1. Data and cost drivers

There is complete data availability at the ITV stage (13 observations), but a couple of the projects have not reached the AFTV stage, so there is a smaller data set available there (11 observations).

Table 6.5 below details our understanding of the cost category and our rationale for including potential cost drivers for sea cable installation costs. We do not consider that cable (current) rating provides an indication of the costs for installation of sea cables and have not included it in our modelling.

Table 6.5: Cost drivers for sea cable installation (identifier in italics)

Cost driver	Rationale
No of sea cables - *SCno*	Additional sea cables may require multiple campaigns to install them, or at least have additional joints that may take up time and increase costs of ship hire and labour.
Sea cable length - *SClen*	Longer cable length should require longer to install the cable and may require more joints that take time and impose cost, in terms of skilled labour and in terms of equipment hire over a longer period.
Sea cable size - *SCsize*	The greater weight from additional material, as the size increases, may lead to cost increases in delivery and installation.
Constant	We expect that there should be a large fixed cost element here and thus expect a constant.

We have used a squared term for cable length to test whether the data indicates an existence of economies of scale in the installation of sea cables. A negative coefficient on the squared term would indicate that as length of cable increased cost per kilometre would fall.

Table 6.6: Correlation between cost drivers for sea cable installation

	SCno	OSPdist	SClen
SCno	1.0000		
OSPdist	0.8835	1.0000	
SClen	0.8991	0.9567	1.0000

There are highly correlated explanatory variables included above. We have decided to exclude OSP distance from shore from the sea cable models given this high correlation.

From a plot of sea cable installation costs against sea cable length we observed a strong positive relationship between sea cable installation costs against sea cable length.

6.3.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. The specification for these models are set out in Table 6.7 below. We ran each model specification in both a linear and log-linear form.

Table 6.7: Sea cable installation models

Explanatory variables	Model identifier					
	1	2	3	4	5	6
SCNo	✓	✓				
SClen	✓	✓	✓	✓	✓	✓
SClen_sqrd		✓		✓		✓
SCSize					✓	✓
Constant	✓	✓	✓	✓	✓	✓

In the section below we have provided our assessment of the more plausible models. Full results are included in ANNEX G.

6.3.3. Assessment

The models that we ran indicated that:

- As expected, length is the main driver of sea cable installation costs. All models with sea length included had a relatively high adjusted R-squared value (~0.70).
- Our models did not indicate that economies of scale were present in relation to installed sea cable length. However, the models with varying economies of scale were much more sensitive to the removal of projects from the dataset.
- The linear models were not robust, with the log transformed models performing much better.
- The more parsimonious models, which included sea cable length, were relatively robust to the removal of outliers and the coefficients did not change much across the different stages.

We set our assessment of the more plausible models below.

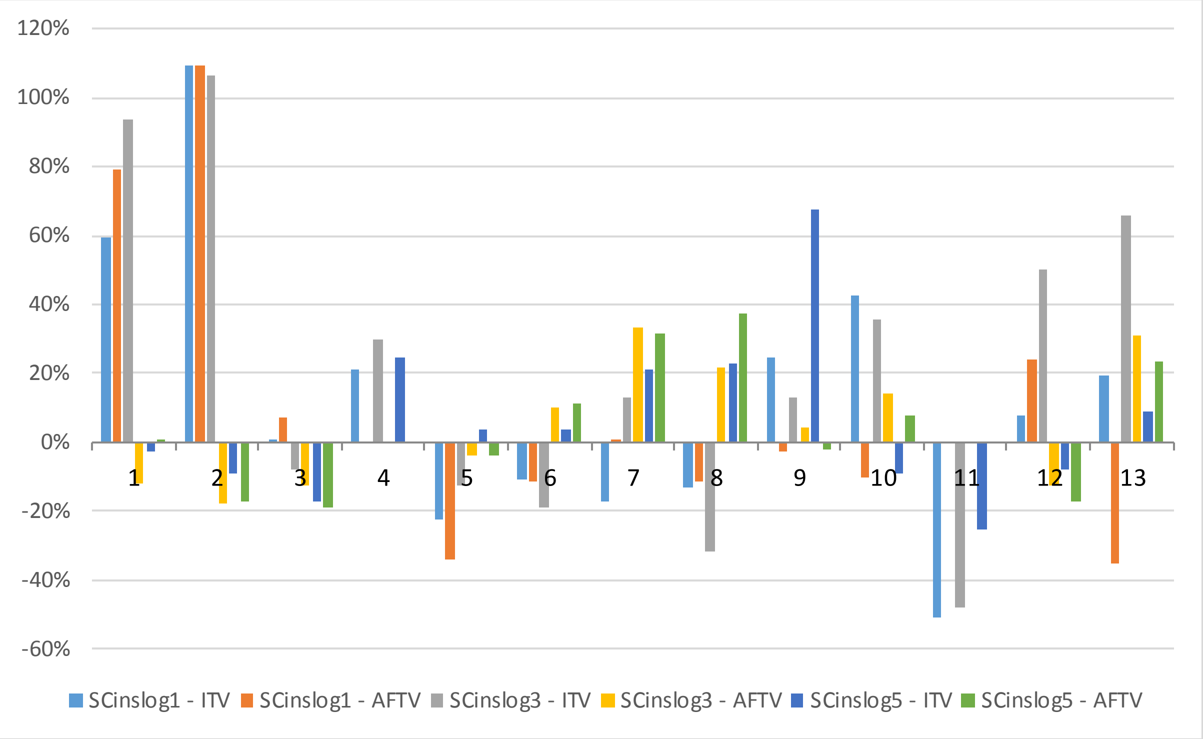
Table 6.8: Sea cable installation model assessment

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCinslog1	Sea cable numbers (above 1), Sea cable length	G	A	A
		Sea cable length significant at 10% level and relatively stable. Signs are as expected.	Adjusted R2 = 0.707 (ITV), 0.704 (DFTV), 0.699 (AFTV) Passes White, Normality and RESET.	Relatively stable to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
			Alpha factor relatively high for ITV.	
SCinslog3	Sea cable length	G	A	A
		Sea cable length significant at 1% level for all stages. Signs are as expected.	Adjusted R2 = 0.666 (ITV), 0.729 (DFTV), 0.692 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high.	Relatively stable to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCinslog5	Sea cable length, sea cable size	G	A	A
		Sea cable length significant (5% for ITV, DFTV, 10% for AFTV) and relatively stable. Signs are as expected.	Adjusted R2 = 0.640 (ITV), 0.712 (DFTV), 0.668 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high.	Relatively stable to the removal of smallest/ largest cost observation. Marginal large differences been ITV, DFTV and AFTV stages.

Overall, our modelling, based on the available dataset, indicated log transformed model using a sea cable length driver, with either a single secondary driver of number of sea cables or size, performed best. The differences between the models' predictions and the actual values are shown in Figure 6.3 below. A positive percentage means the predicted value is above the actual.

Figure 6.3 – Sea cable installation costs comparison of prediction to actuals



While we expect some difference between the predictions and the actuals (due to efficiencies/ inefficiencies and heterogeneity not captured by the drivers), the large differences (greater than 60%) for a number of projects is concerning. The coefficients are relatively robust across the stages, we believe that outliers in the ITV stage are likely to have driven some of these differences. However, we would advise caution when using a sea cable installation econometric model.

6.4. Sea cable total costs

In addition to our analysis above, we have also considered sea cable total costs. This is a combination of sea cable supply and sea cable installation costs. The models utilise a combination of the same cost drivers noted above.

6.4.1. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. As sea cable length was the main driver of costs for both supply and installation we only ran models including this variable. We also excluded rating from our models as we did not consider this to be a driver of installation costs and we considered that size was a better driver for combined supply and installation costs.

Table 6.9: Sea cable total costs models

Explanatory variables	Model identifier			
	1	2	3	4
SClen	✓	✓	✓	✓
SClen_sqrd		✓		✓
SCsize			✓	✓
Constant	✓	✓	✓	✓

We ran each model specification in both a linear and log-linear form.

In the section below we have provided our assessment of the more plausible models.

6.4.2. Assessment

The models that we ran indicated that:

- All models with sea length included had a high adjusted R-squared value (0.89-0.96).
- Our models did not indicate that economies of scale were present in relation to sea cable length. In addition, the models with varying economies of scale were much more sensitive to the removal of projects from the dataset.
- The linear models were not robust, with the log transformed models performing much better.

We set our assessment of the more plausible models in Table 6.10 below.

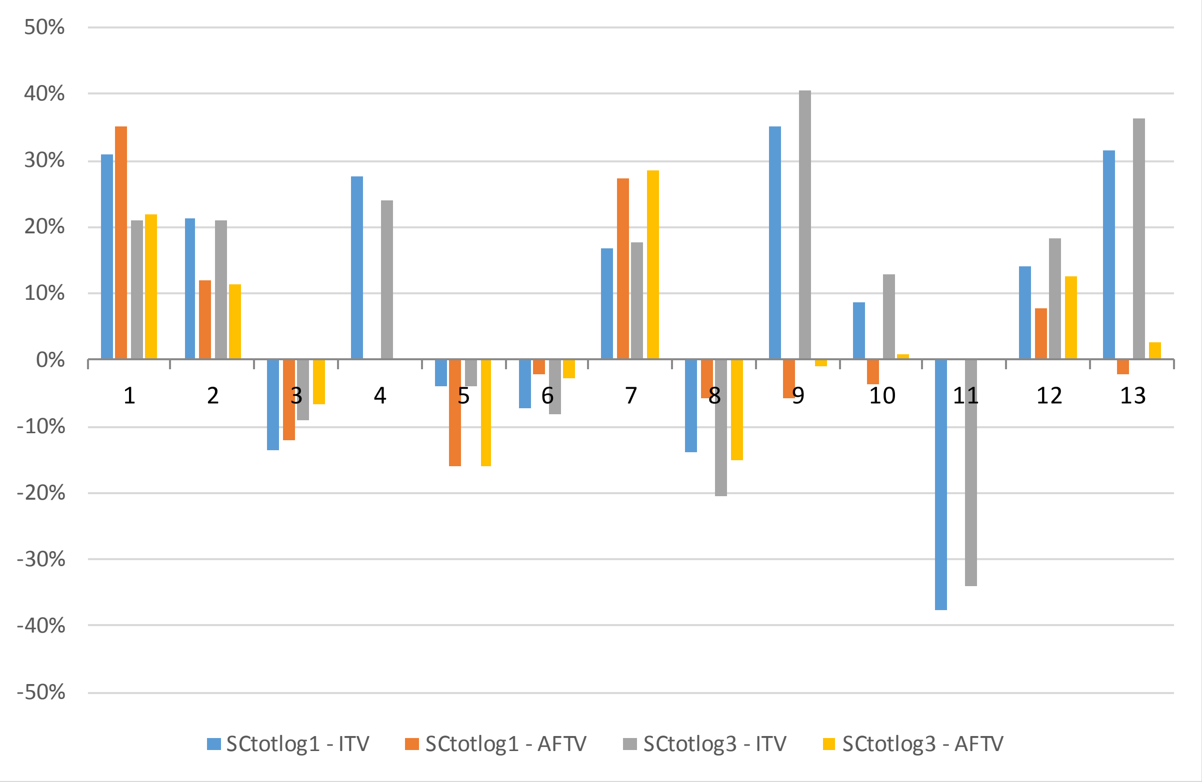
Table 6.10: Sea cable total costs model assessment

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCtotlog1	Sea cable length	G	G	A
		Sea cable length significant at 1%. Signs are as expected.	Adjusted R2 = 0.895 (ITV), 0.952 (DFTV), 0.957 (AFTV) All stages pass the tests. Alpha factor relatively close to 1.	Relatively stable to the removal of smallest/ largest cost observation. Although rather large movement in the constant when small cost observation removed. Not much change been ITV, DFTV and AFTV stages.
SCtotlog3	Sea cable rating, sea cable conductor size	G	A	A
		Sea cable length	Adjusted R2 =	Relatively stable to

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		significant at 1%. Signs are as expected.	0.890 (ITV), 0.959 (DFTV), 0.960 (AFTV) All stages pass the tests. Alpha factor relatively close to 1, although ITV stage a little high.	the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.

Overall, our modelling, based on the available dataset, indicated log transformed models using a sea cable length driver, or with a single secondary driver of sea cable size, performed best. The differences between the models' predictions and the actual values are shown in Figure 6.4 below. A positive percentage means the predicted value is above the actual.

Figure 6.4 – Sea cable total costs comparison between predictions and actuals



Aside from a few projects the predictions across the two models are relatively similar. However, the differences between the predictions and the actuals are relatively large on average. This could be down to inefficiencies/ efficiencies across the projects, however a number of projects' predictions to actuals exceed 20%. This reflects the heterogeneity in the projects for which we do not have the cost drivers (or observations) to control for.

6.5. Land cable total costs

Definition:- Land cable total costs refer to both the supply and installation of land cable.

Note, the installation costs may vary significantly from project to project due to the differing amount of 'civil' work required in each project.

6.5.1. Data and cost drivers

We have 13 ITV observations and 11 AFTV observations in the cost data.

Table 6.11 below details our understanding of the cost category and our rationale for including potential cost drivers for land cable total costs (a breakdown of supply and installation is not available).

Table 6.11: Cost drivers for land cable

Cost driver	Rationale
Land cable length - *LClen*	Greater cost is expected for greater quantity. There will be a fixed cost associated with the purchase of material i.e. a 0.1km cable will cost more than the marginal cost of increasing a cable from 100.0km to 100.1km.
Land cable size - *LCsize*	Greater cost is expected for greater quantity. There will be a fixed cost associated with the purchase of material i.e. a 10mm2 cable will cost more than the marginal cost of increasing a cable from 100mm to 110mm2.
Land cable material (interaction variable) - *CopInter*[35]	Unlike sea cables, there are more likely to be variations in conductor material type. We expect copper cable to be higher cost than aluminium cable, although a smaller quantity of material is likely to be required.
Constant	*As with sea cables, we expect there to be fixed costs and thus a constant.*

We have used a squared term for cable length to test whether the data indicates an existence of economies of scale in the supply and installation of land cables. A negative coefficient on the squared term would indicate that as length of cable increased cost per kilometre would fall. We have also used a squared term for land cable conductor size.

Table 6.12: Correlation between cost drivers for land cables

	LCsize	LClen
LCsize	1.0000	
LClen	0.1992	1.0000

There is a weak correlation between the cost drivers, therefore it is possible to include both terms in a multivariate regression.

From a plot of land cables cost against land cable length, we observed that overall there appears to be a relationship between cost and length, although at lower levels of length this did not appear to hold.

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[35] We multiple cable length by a copper 'dummy' variable (i.e.1), therefore the coefficient on the variable will pick up any incremental per km costs from using copper over aluminium.

6.5.2. Models

We estimated a number of different models to assess the performance of the explanatory variables either in univariate or multivariate plausible arrangements. The specification for these models are set out in Table 6.13. We ran each model specification in both a linear and log-linear form.

Table 6.13: Land cable models

Explanatory variables	Model identifier						
	1	2	3	4	5	6	7
LClen	✓	✓	✓	✓	✓	✓	✓
LClen_sqrd			✓		✓		✓
LCsize		✓	✓			✓	✓
CopInter	✓	✓	✓				
Constant	✓	✓	✓	✓	✓	✓	✓

ANNEX G contains the full output from these models and a summary each model's performance against our assessment criteria.

In the section below we have provided our assessment of the models.

6.5.3. Assessment

The models that we ran indicated that:

- All were all highly sensitive to the sample of projects used in the modelling, either across the different stages or via the removal of outliers.
- We could not identify a single model which produced robust results.

The data available did not allow us to identify any robust models for total land cable costs (supply and installation). We believe that one of the key factors for this is the inability to separate out the installation costs and identify the extent of civil work required by each project. However, given that total land cable costs make up a relatively small proportion of total costs (around 5.1%), we consider that it may be ok to use one of the better performing models (i.e., LCtotlin6) in order to predict total project capex costs (this is discussed further in Section 7 overleaf).

7. AGGREGATING THE DIFFERENT COMPONENTS

In this report we tested different approaches to benchmarking disaggregated OFTO construction costs. In general we found that econometric (parametric) approaches tended to perform well and, as expected, scale or size variables were the best cost drivers. Ideally cost drivers would be outside of companies' control, i.e., MVA required. However, this type of data is not always available and it is likely to be less explanatory in terms of the specific characteristics of the construction requirements. In light of these issues it is common practise to use size or scale variables.[36] Size and scale variables, e.g. weight of platform and size/number of transformers, are reflective of the solution type (in order to meet the output requirements) but are not necessarily reflective of whether the developer has chosen the most cost effective solution (to provide the output).[37] Therefore, in conjunction with cost models, it is best practise to undertake sense checks of projects to ensure that a company is not over engineering ('gold-plating') a project. A further option could be to undertake an *ex-post* evaluation of the volume/ size of the work undertaken, i.e. is the final weight of the offshore platform in line with the original engineering plans.

For most of the disaggregated cost categories we identified a number of models which, based on the available data set, appeared to provide reasonable cost predictions. Although there were some cost categories for which we were unable to identify as robust models, these tended to be for smaller cost areas (e.g. land cable costs). In most cases we identified more than one suitable model for each of the disaggregated and aggregated cost categories.

Each model may provide a slightly different view of the efficiency of a project and we do not consider that there is a robust and objective way to choose between these viable models. Therefore we propose that at each cost level the predictions could be averaged across the models. This takes into account the difference between the models, allowing multiple cost drivers or functional forms to be considered (which may provide alternative results), without assigning specific weights to any one model (i.e., all the models are given the same weight). We consider that an averaging approach mitigates the risk of choosing a single model which, for any project, may have a large variance between the estimate and the 'correct' answer.

Figure 7.1 indicates each of the cost categories which we benchmarked. The percentages indicate the average share of costs for each of the disaggregated categories to next (aggregate) level based on the AFTV stage, e.g. on average offshore cable supply makes up 88.9% of total offshore cable costs and total cable costs (onshore and offshore) represent 46.4% of capex costs.

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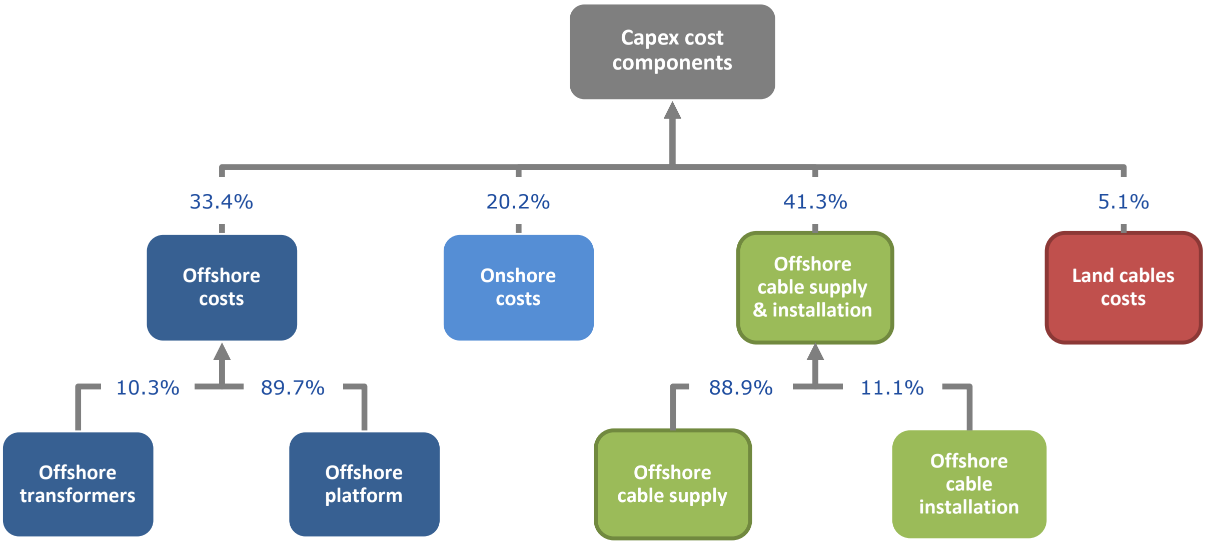
[36] Ofgem's RIIO price controls tend to rely on scale and size variables (customer numbers, length of network, and volume of assets) for its benchmarking. Likewise, Ofwat's PR14 econometric models rely on length of mains and density explanatory variables.

[37] We would expect there to be a strong correlation between the size/scale of a project and the outputs of the project, e.g. a large cable(s) should reflect a higher capacity requirement of the OFTO.

We have included one of the most robust land cable models (LCtotlin6) to allow aggregation up to the total capex level. It should be noted that, on average, land cables only make up 5.1% of capex at the AFTV stage so the overall impact from this model on predictions of total project costs is likely to be small.

Figure 7.1 – Modelled cost categories and their aggregation[38]



In addition to the disaggregated cost categories benchmarked as set out in Figure 7.1 above, we also benchmarked *Onshore transformers* and *Onshore total cost excluding other*. We did identify a robust model for onshore transformers, but not for onshore total costs excluding other. We did not include these in the above diagram as we could not aggregate them without a corresponding model which covered the excluded costs.

7.1. Approach

As we found multiple models across the different levels of aggregation, we propose that at each cost level the predictions could be averaged across the models. This would proceed on the basis of:

1. estimating the average across all the models for a single cost category;
2. combining the (average) estimates from the disaggregated models; then
3. estimating the average across the estimates from the disaggregated models (calculated in the preceding step) and the aggregate model.

For example, offshore transformer predictions *plus* offshore platform (excluding transformers) averaged with offshore total costs. Figure 7.2 and Figure 7.3 below illustrate our proposed aggregation process for total offshore costs and total sea cable costs respectively (onshore and land cable costs did not require separate aggregation).

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[38] Note, due to cost allocation issues in the data it was not always clear if developers had allocated costs in the correct areas. This led to some cost categories not summing to the totals correctly. In most cases this was a relatively small difference.

Figure 7.2 – Illustration of averaging and aggregation process – Total offshore costs

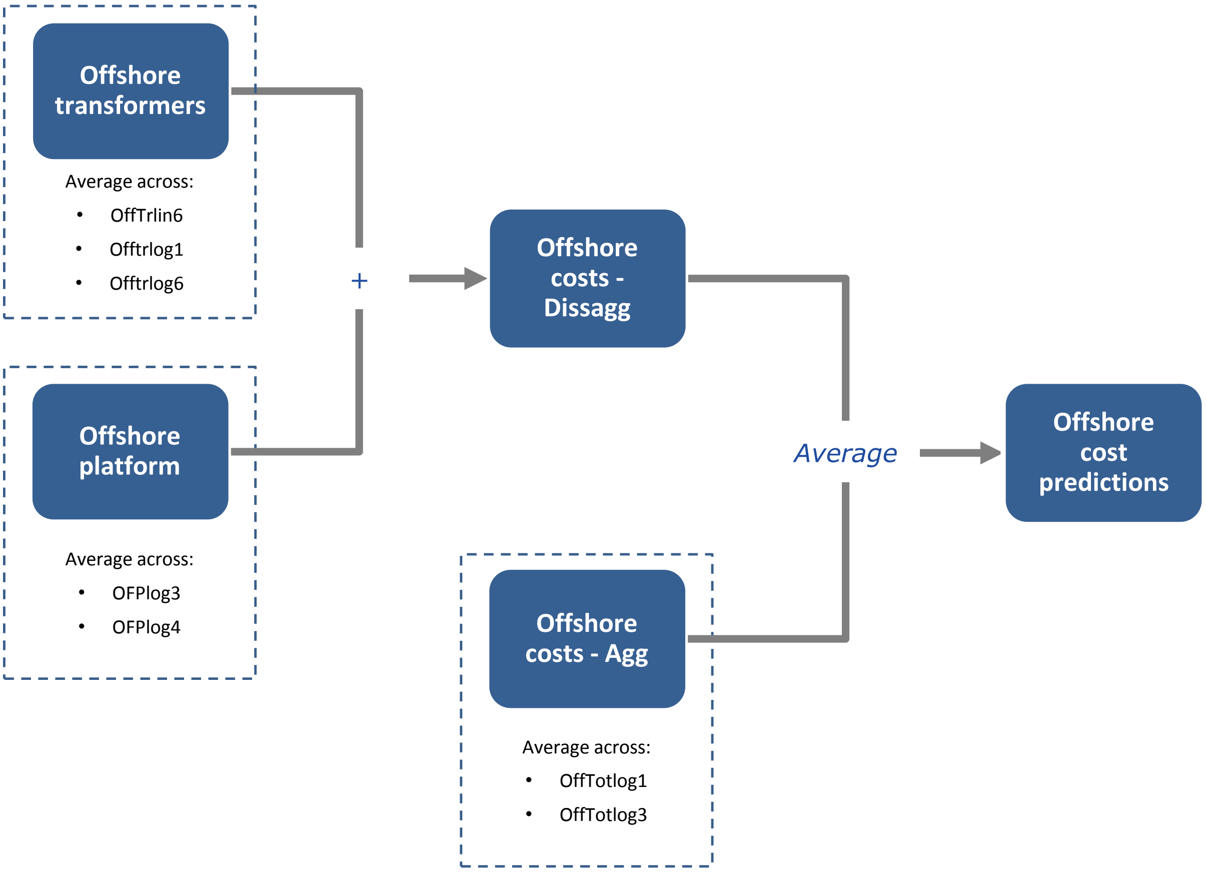
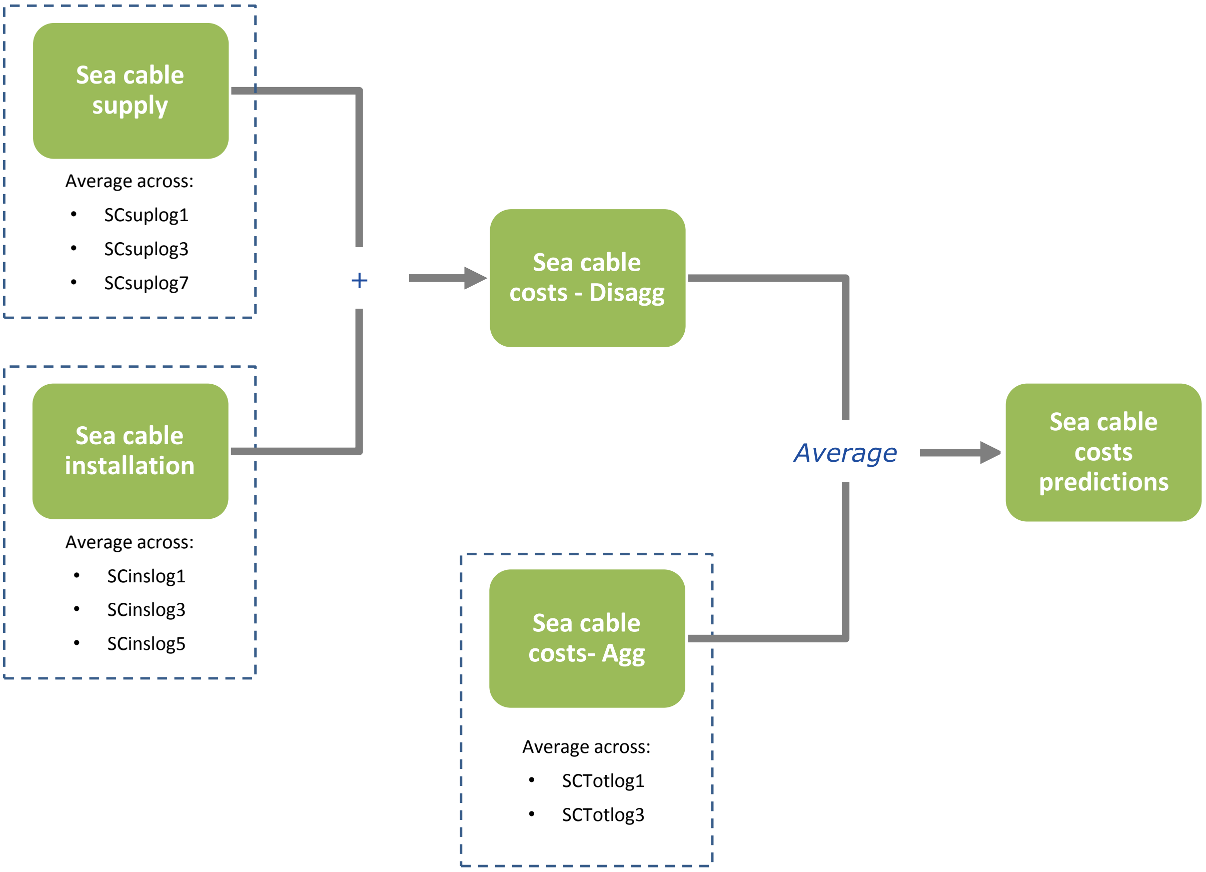


Figure 7.3 – Illustration of averaging and aggregation process – Total sea cable costs



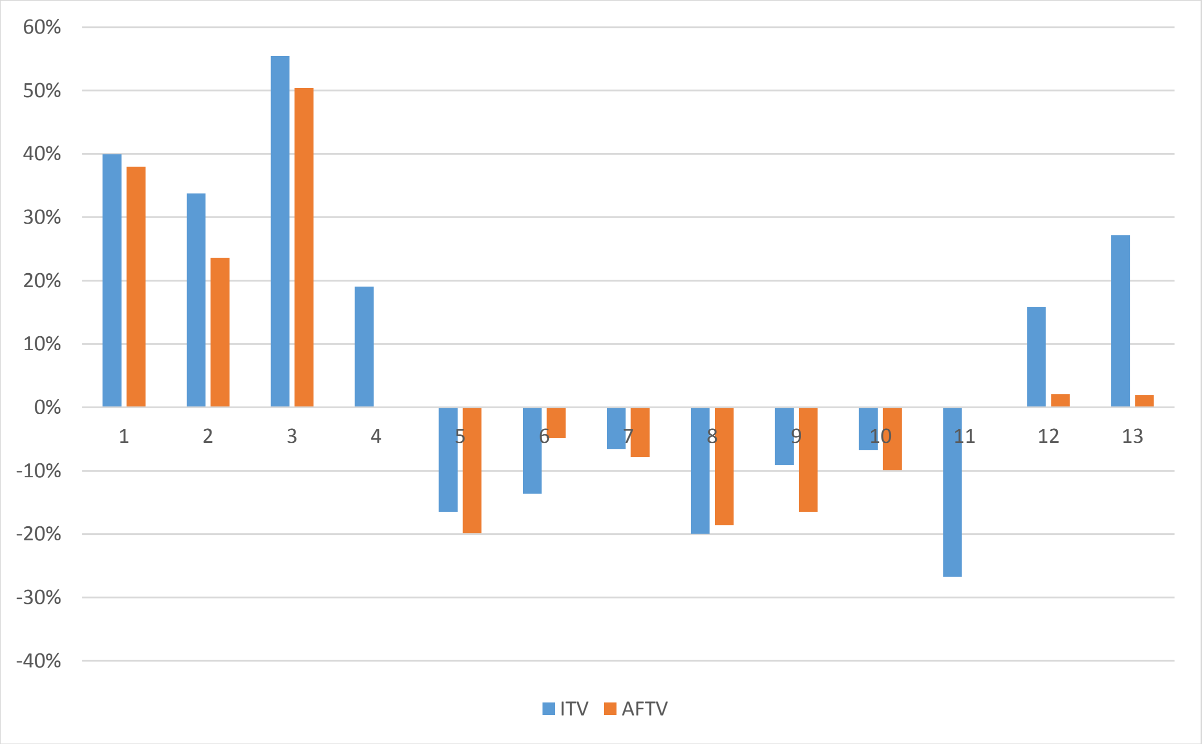
In the approach set out above we have simply averaged over the different models' predictions for a category. This takes into account the difference between the models, allowing multiple cost drivers or function forms to be considered, without assigning specific weights to any one model. However, this approach can be adjusted to assign specific weights to particular models if it were decided that some models were preferred to others. We consider that an averaging approach mitigates the risk of choosing a single model which, for any project, may have a large variance between the estimate and the 'correct' answer.

Ofgem, in its RIIO price controls, has weighted together different modelling approaches using equal/average weights, for example in its RIIO-ED1 final determinations it applied a 50/50 weight across two totex models before averaging with the result with its disaggregated models.[39] Ofwat, during PR14, has averaged across models at the same aggregation levels.

7.2. Predictions

Based on the above approach, Figure 7.4 provides the overall difference between actual capex and the predicted costs at the project level. A positive percentage means the predicted value is above the actual.

Figure 7.4 – Predicted versus actual total capex



There is significant variation between the predictions and the actual capex for some projects. We note that the largest variations relate to TR1 projects where the cost reporting

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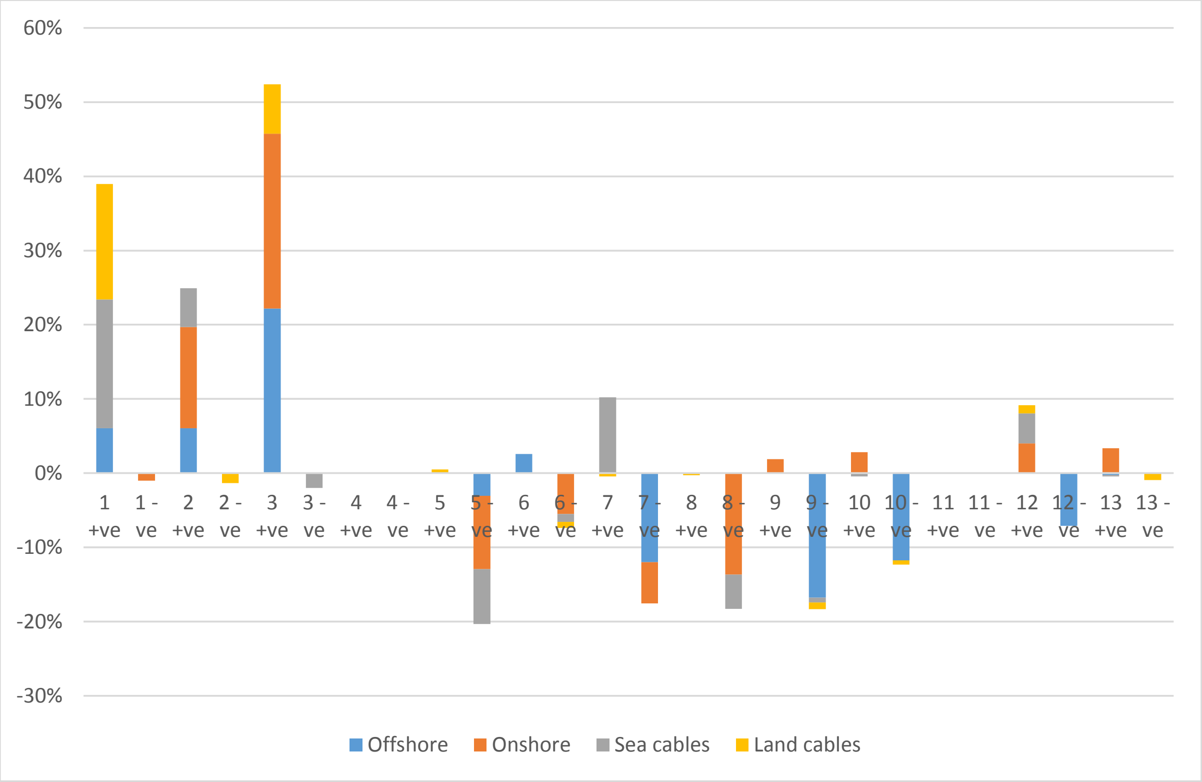
[39] Ofgem, *RIIO-ED1, Final determinations for the slow-track electricity distribution companies: Business plan expenditure assessment,* 28 November 2014.

was done retrospectively. Figure 7.5 shows the split in the total difference across the four difference cost categories for AFTV only.

Figure 7.5 – Predicted versus actual total capex breakdown by cost category, AFTV



For the projects where the percentage difference is much smaller, it is worth noting that the magnitude of the difference can still be quite large. This would raise questions around the use of these models to arrive at an exact estimate of costs. However, the overall degree of accuracy observed above may be acceptable for certain uses of benchmarking, for example, assessing the cost efficiency of future projects in broad terms (i.e., whether a proposed project appears efficient or inefficient).

7.3. Conclusion

As noted, we were able to identify some plausible models at varying levels of aggregation of capex. For some models we identified large differences between the modelled and actual costs. We do not believe that these are solely down to efficiency differences between the projects[40]. Instead we believe there are a number of additional factors driving the observed differences between modelled and actual costs. These are as follows:

- Predominately for earlier projects, we had a lack of certainty over cost allocation and missing data in certain cost categories.

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[40] In theory, the difference between actual and modelled costs in benchmarking models are down to efficiency differences alone if there are no measurement errors and operating environment differences are accounted for.

- We also found the level of data granularity available for individual project components were not as detailed at the ITV stage compared to the AFTV stage. This is because costs are more likely to be estimates at ITV stage whereas more detailed cost information is available for assets at the AFTV stage.
- There is reasonable heterogeneity between projects for which there are insufficient cost drivers and/or observations to model adequately.
- For some projects there were additional costs due to delays, etc in high cost areas, e.g. sea cable installation.

However, even with these issues/limitations we believe that the benchmarking is a useful tool to look at the level of costs for OFTO projects and identify potential cost outliers. The models may be useful for assessing the costs of future projects, although at this stage with the current data set and given the variation in modelled estimates to actual costs, we consider that the data does not support the introduction of a strong ex-ante target cost incentive mechanism.

ANNEX A DATA DESCRIPTION

Table A.1: Summary of starting cost categories

Code used in model	#	Costs relating to….	Unit
OSPnonelec	1	Offshore platform non-electrical equipment	£
OffTr	2	Offshore transformer	£
OSPelec	3	Offshore platform electrical equipment	£
OSPtot	4	Offshore platform totals (1+3)	£
Offtot	5	Offshore totals (1+2+3)	£
OnTr	6	Onshore transformers	£
OnReCo	7	Onshore reactive equipment	£
OnHaCo	8	Onshore harmonic equipment	£
OnSPother	9	Onshore platform other costs	£
OnConn	10	Onshore connections	£
Ontot	11	Onshore total (6+7+8+9+10)	£
SCsup	12	Sea cable supply	£
SCins	13	Sea cable installation	£
LCtot	14	Land cable supply + installation	£
Cabtot	15	Cable totals (12+13+14)	£
Cont	16	Contingency	£
Dev	17	Development	£
Trans	18	Transaction	£
IDCCo	19	Interest During Construction	£
Othertot	20	Non-onshore non-offshore total (16+17+18+19)	£
TTV	21	Total Transfer Value (5+11+15+20)	£
Additional variables			
OffTrUnit	22	Offshore transformer costs per transformer	£/tr
OSPtotUnit	23	Offshore platform costs per platform	£/osp
OnshoreTot_NoOther	24	Onshore costs excluding onshore other costs	£
SCsupadj	25	Sea cable costs adjusted for copper prices	£ adj
SCsupUnit	26	Sea cable supply costs per kilometre of sea cable	£/km
SCtotUnit	27	Sea cable total costs per kilometre of sea cable	£/km
LCtotUnit	28	Land cable total costs per kilometre of land cable	£/km

Table A.2: Summary of cost drivers

Code used in model	Description	Unit
ACvolt	AC cable voltage	kV
GenCap	Generation capacity of wind farm	MW
SyCap	Transmission system capacity	MVA
OSPtotwt	Offshore platform total weight (topside + jacket)	Tonnes
OSPno	Number of offshore platforms	Number
OSPdist	Distance of offshore platform from onshore substation	km
OSPshore	Distance of offshore platform from shore	km
OffTransCap	Offshore transformers total capacity	MVA
OnSPno	Number of onshore substations	Number
OnTransCap	Onshore transformer total capacity	MVA
OffReComp	Offshore reactive compensation	MVA
OnReCap	Onshore reactive capacity	MVAr
OnHaCap	Onshore harmonic capacity	MVA
MWkm	Parameter megawatt kilometres	MWkm
OffTransNo	Number of offshore transformers	Number
OffTransVolt	Offshore transformer total voltage	kV
OnTransNo	Number of onshore transformers	Number
OnTransVolt	Onshore transformer total voltage	kV
SClen	Sea cable total length	km
SCno	Number of sea cables	Number
SCrate	Sea cable rating individually	MVA
SCsize	Sea cable conductor size	mm2
SCwt	Sea cable (dry) weight	kg/m
SCmat	Sea cable conductor material	Name
LCno	Number of land cables	Number
LClen	Land cable length	km
LCsize	Land cable conductor size	mm2
LCwt	Land cable weight	kg/m
LCmat	Land cable conductor material	Name

ANNEX B CONSTRUCTION START AND END DATES

Table B.1: Construction start and end dates

Project	Construction start	Construction end
Barrow	Jan-04	Feb-06
Gabbard	May-08	May-12
Gunfleet	Mar-08	Jul-09
Ormonde	Aug-09	Jul-11
Robin Rigg	Aug-05	Sep-09
Sheringham Shoal	Oct-08	Jul-11
Thanet	Apr-08	Jun-10
Walney 1	Dec-08	Dec-10
Walney 2	Jul-09	Aug-11
London Array	Jun-09	Sep-10
Lincs	Apr-09	Dec-12
Gwynt y Mor	Jun-10	Ongoing
WODS	Dec-13	Ongoing

ANNEX C BENCHMARKING APPROACHES

C.1. Econometric (parametric)

Out of the wide range of econometric approaches available, we can use a limited number for this project due to the small sample size (sometimes as few as six observations). These tend to be relatively simple approaches, focusing on univariate regressions (taking only one cost driver into account).

While there are a number of different estimation methods available, because of the relatively small sample size and the nature of the data available, e.g. single project estimates, we focus on ordinary least squares (OLS) estimation techniques. The nature of the data does not lend itself to a panel based estimation approach.[41] We also test three different functional forms depending on the cost category – linear, log-linear and quadratic – as well as normalised costs. There are several statistical tests that we conduct to assess the robustness of the models once we are comfortable with coefficient estimates.

We discuss all these elements of the econometric approach to benchmarking below.

C.2. Estimation approach

OLS is a method by which linear regression analysis seeks to derive a relationship between company performance and characteristics of the production process. This method is used when companies/ projects have relatively similar inputs and outputs. Using available information to estimate a line of best fit (by minimising the sum of squared errors) the average cost or production function is calculated. In terms of unit cost approaches, this is the most widely used regression approach as it is relatively simple and well understood.

C.2.1. Functional form

The functional forms we test for this project are linear, log-linear, and quadratic.

Linear versus log-linear

The main difference between linear and log-linear is that linear regressions assume that marginal costs are constant, while log-linear regressions allow them to vary (Cobb-Douglas functional form). The log-linear form also allows the simple interpretation of the coefficient as the elasticity of the dependent variable to the cost driver. The log-linear functional form basically transforms both the dependent variable and the driver in natural logarithms and the coefficients from this regression can be interpreted as the elasticity of cost with respect to that driver.[42] The disadvantage of log-linear regressions is that the raw model estimates

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[41] A panel based approach uses both cross section and longitudinal data in estimating models. Our data does not exhibit changes in the cost drivers, but includes changes in the costs.

[42] Log-linear models with both the dependent and explanatory variables transformed can also be referred to as log-log functional form models.

require an adjustment to avoid log-transformation bias.[43] We recommend the use of an 'alpha factor' which Ofgem has used previous in its benchmarking (e.g. RIIO-ED1, RIIO-GD1, DPCR5). An alternative to the alpha factor is the smearing factor which Ofgem has used for the recently published RIIO-ED1 draft determinations. In practise the alpha factor and smearing factor should give similar results.

Table C.1: Log transformation adjustments formulae

Estimator	Adjustment formula
Smearing estimator	$\frac{\sum_{i=1}^{N} e^{\varepsilon_i}}{N}$
Alpha factor (Ofgem)	Coefficient of the regression when running the actual cost (£m) on the predicted costs (£m transformed from logs) without a constant

Besides statistical testing, one normally uses theoretical judgement to choose between linear and log-linear functional forms. That is, are there any expectations about the shape of the cost curve.

In Text box C.1 below, we set out the calculation for converting the model parameter estimates (as set out in Appendices E to G) in to estimates for each project.

Text box C.1: Converting parameters and cost drivers to estimates

Linear

Converting the estimates in linear form into an estimate for each project follows the following formula:

$$\hat{Y}_{lin} = Constant + \beta_1 \times Cost\ driver_1 + \beta_2 \times Cost\ driver_2 + \cdots$$

For example for sea cable supply SCsuplin3(ITV):

$$\hat{Y}_{lin} = 1487804 + 443915 \times SClen$$

Log

Converting the estimates in log form into an estimate for each project follows the following formula:

$$\hat{Y}_{log} = \alpha \times e^{(constant+\beta_1 \times Cost\ driver_1+\beta_2 \times Cost\ driver_2)}$$

For example for offshore platform total cost OSPlog3(ITV):

$$\hat{Y}_{log} = 1.003845 \times e^{(-9.36551+5.872517\times\log(OSPtotwt)+0.447569\times\log(\mathrm{OSPshore})+-0.32977\times\log(\mathrm{OSPtotwt}^2))}$$

Quadratic

Another functional form could be a quadratic equation in which the driver is also squared. This can take into account different returns to scale – e.g. economies of scale if the coefficient on the squared term is negative. Such terms provide further flexibility to the cost curve but they reduce the degrees of freedom of the regression, which can in turn affect statistical testing and robustness.

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[43] This is due to Jensen's inequality.

Fixed costs

We also test the presence of fixed costs. In linear models, fixed costs are the constant. Running a regression without a constant term effectively forces the regression line to go through the origin. This can artificially change the slope of the regression line and reduce the model's fit to the data. Furthermore the normal R-squared calculation can only be interpreted as a measure of the variation in the dependent variable explained by independent variables only in a regression with a constant term. In a regression ran without a constant term the R-squared can be very large even when the correlation between the dependent and explanatory variables is weak.

Running the regression without a constant term should only be undertaken when there are strong reasons to do so (i.e. when we know that the dependent variable should be 0 when the independent variable is 0). Sometimes a negative constant could indicate that a preferred functional form would be one with no fixed costs.

Normalised costs

For some categories, where appropriate, we model normalised costs, e.g. cost/km as a dependent variable and conductor size as a driver. This is applicable in cases where we do not think there are substantial economies of scale and should really be on a per unit basis.

C.2.2. Testing

Considering that the models that can be run with sometimes as few as six observations, the range of statistical testing is relatively limited compared to more elaborate multi-variable regressions. There are several main statistics that we will look at to test the model robustness:

- **T-statistic and coefficient significance**: It is used to determine the probability that the true value of the coefficient is different from zero (i.e. the coefficient is statistically significant).
- **Normality (skewness)**: A linear regression assumes a normal distribution of the error term. The error distribution may however be skewed by the presence of a few large outliers, usually more than three standard deviations away from the mean.
- **Heteroskedasticity of residuals (White test)**: If the error terms are biased (i.e. if heteroskedastic) then the calculation will be skewed by placing greater emphasis on extreme cases.
- **General misspecification (RESET test):** Tests whether non-linear combinations of the variables help improve the explanatory power of the model.
- **Goodness of fit (R^2):** Tests how much of the variation in costs is explained by variation in the driver.

- **Alpha factor:** An adjustment factor to convert log values into linear when regressions are used to predict costs.

These are discussed in turn. For low numbers of observations the power/ significance of some of the tests we have conducted is going to be low.

Coefficient significance

The t-statistic for a regression coefficient is the ratio of the coefficient to its standard error. It is used to determine the probability that the true value of the coefficient is different from zero (i.e. the coefficient is statistically significant).

The t-statistic is compared by regression software packages with values in the t-distribution to determine the P-value. A low P value means there is greater confidence that the variable is having a statistically significant effect. A P-value = 0.05 (5%) means there is only a 5% chance that the coefficient could be 0.

Skewness and Kurtosis test for normality (sktest)

A linear regression assumes a normal distribution of the error term. The error distribution may however be skewed by the presence of a few large outliers. In this case the calculation of confidence intervals may be compromised. Skewness is a measure of the asymmetry of the probability distribution of a variable about its mean. A positive skew means the longer tail of the distribution is on the right hand side of the distribution. Kurtosis is an indicator that measures the heaviness of the tails of a distribution. A normal distribution with a skewness =0 will have kurtosis equal to 3.

The STATA sktest conducts a test for normality based on skewness and another based on kurtosis. It then produces a combined statistic that tests the hypothesis that the variables are normally distributed. A low p-value means we can reject the normally distributed variables hypothesis at the chosen confidence level (i.e. for a 5% confidence level, we can reject the hypothesis based on a p-value equal to or lower than 0.05).

White test

White's test checks for heteroskedasticity in a regression. OLS regressions work on the assumption that the variance of the error term is constant (homoskedastic). Heteroskedasticity refers to the situation when the variance of the error term in a regression is not constant. This may occur for example when the error terms increase as the value of the variables increase. If heteroskedasticity occurs, then the estimated OLS regression line will not provide the best fit among the unbiased estimators. This happens because the OLS regression gives more weight to observations with the largest error terms in order to minimise the sum of the residuals. If the error terms are biased (i.e. their variance is not constant) then the calculation will be skewed by placing greater emphasis on extreme cases.

Log-linear models are less prone to heteroskedasticity but on the other hand it has implications on the factor used to transform values from log to linear.

The STATA test produces a chi-squared and p-value to test the null hypothesis of homoskedasticity. A p-value above 0.05 (for a 5% confidence level) means we cannot reject the hypothesis that the error term is homoskedastic. If the value were equal to or below 0.05 then we could reject the null hypothesis (of homoskedasticity) and conclude that, at the 95% level, the errors are heteroskedastic.

RESET test

The Ramsey Regression Specification Error Test (RESET) is a general misspecification test for the linear regression model which tests whether non-linear combinations of the variables help improve the explanatory power of the model.

The Ramsey test checks whether there is some form of misspecification of the model but does not indicate what the correct specification may be. It tests the null hypothesis that there are no non-linear specifications of the explanatory variables omitted in the model (i.e. the linear specification is correct).

STATA produces a probability value for the Ramsey RESET test. A low probability value (i.e. <0.05 or 5%) means we cannot reject the null hypothesis, therefore there could be non-linear specifications of the explanatory variables that could improve our model. Conversely a higher probability value means we can reject the null hypothesis therefore the linear specification is the correct functional form for the model.

R^2

The R^2 is a standard goodness of fit measure that is widely used in the industry. However, it should be used carefully and should not be the only reason for preferring a model. The R^2 is only comparable in cross-sectional samples (not in panels). It is also not directly comparable between log-linear and linear models as log-linear models consistently yield higher values. The measure is also less relevant if the regressions specify that no constant is to be included.

In addition, a high R-squared may not always be indicative of a good model. As discussed in the heteroskedasticity section above, the OLS regression places more emphasis on observations with larger error terms. As such, a high R-squared may be driven by a few observations which are significantly larger than the rest. Therefore, we do not recommend solely relying on the R-squared during this model selection.

The “alpha factor”

Another factor that we need to take into consideration when choosing between log-linear and linear functional forms is how sensitive the predictions would be when we transform log values into levels values. In large samples the possible adjustments are usually negligible (less than 1%) but in the case of unit cost models where we sometimes have as little as six observations, they may be significant, thus leading to higher uncertainty around the log-linear estimates.

There are several ways to transform values predicted by log-linear equations into absolute values. Some of the transformation methods require an adjustment to the exponent of the predicted log value, while others do not. The rationale behind making an adjustment to the exponent of the log value is that the expected value of the error is zero in logarithmic terms. There are different approaches to log transformation and there is no consensus regarding the adjustment method that needs to be used.

The “alpha factor” is an adjustment factor that Ofgem used for electricity in 2009. This is the coefficient of the regression when running the actual cost (£m) on the predicted costs (£m transformed from logs) without a constant. More specifically, the alpha factor is obtained by running a regression of the form:

$$\mathrm{Y} = \alpha * \text{exponent} \ (\hat{\log} \ \mathrm{y}),$$

where Y is actual expenditure, lôg y are the fitted values from the regression of log(y) on log(x) and α, the alpha factor, is the coefficient of the dependent variable (the regression is run without an intercept).

The alpha factor can also be calculated as the ratio of the sum of the product of each company’s actual expenditure and the exponent of the predicted log values, to the sum of the square of the exponent of the predicted log values:

$$\alpha = \frac{\text{sum(actual expenditure} * \text{exponent of predicted log)}}{\text{sum(exponent of predicted log}^2)}$$

Ofgem argued in DPCR5 that the exponential transformation into costs of the predicted log values tends to underestimate the modelled costs for a given cost driver and an upward adjustment had to be made (i.e. they only made an adjustment when it was >1).[44] However, in RIIO-GD1 the adjustment was made regardless of whether the alpha factor was above or below 1.[45]

C.3. Non-parametric

Non-parametric statistical techniques differ from econometric techniques because they do not require the statistician to specify the functional form of a regression.

There are a range of non-parametric techniques which are feasible. However, as our analysis needs to focus on project benchmarking, we do not consider on several approaches which

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[44] Ofgem, *Electricity Distribution Price Control Review Final Proposals - Allowed revenue - Cost assessment appendix*, 2009.

[45] Ofgem (2012) RIIO GD1: Final Proposals – Supporting document – Cost efficiency, Supplementary appendices.

are used to consider industry efficiency e.g. Data Envelopment Analysis, Total Factor Productivity, Malmquist indices, etc. Therefore, in this section we focus on unit cost modelling.

C.3.1. Introduction to unit cost modelling

Unit cost modelling is a relatively simple means of developing benchmark metrics for different projects. It involves calculating the costs per unit of output or volume, and then comparing these for the different proposed projects.

A typical comparator metric used in energy generation is the levelised cost,[46] which is a single unit cost figure that takes into account project costs, the level of generation (including the loading factor), and the expected lifetime of the project. Additional metrics could also be provided to assess the cost per unit of capacity (rather than generation), the expected subsidy level per unit of output, etc.

C.3.2. Key issues

Although unit cost modelling calculations are relatively simple, there are some key issues.

Data availability

As with any quantitative measures there is a dependency on data. This includes, at the most basic level, the availability of data and then extends to the quality and consistency/ comparability of it. In particular, unit costs are only truly comparable across different projects if they are based on similar categories of data inputs.

For example, in relation to opex costs, have all projects included the same categories of expenditure (e.g. maintenance, administrative staff, licence fees, etc.)? A company whose bid is less well-prepared could miss some future areas of expenditure, which would make their costs appear lower, and thus achieving a better unit cost score.

Therefore it is important to ensure that cost and output data is available on as comparable a basis as possible across the projects. Analysis of unit cost modelling results should clearly highlight whether there are any differences or discrepancies data inputs, and it may be necessary to caveat the quantitative results if differences are large.

Assumptions

Related to the section above, there are further risks around data comparability when modelling involves forecasts of project costs (as is the case with OFTO tendering), rather than historical actual costs. If different projects are underpinned by very different assumptions, this will reduce the potential for robust cross-project comparison. Therefore, it

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[46] The levelised cost of generation is the discounted (present value) lifetime cost of building and using a generation asset, expressed as a unit cost of generation (e.g. £/MWh).

is important for project cost / output data to be supported with clear assumptions about how the data has been calculated.

While differing assumptions have the potential to reduce the effectiveness of unit cost modelling, there are some potential solutions to this problem. As discussed in the following subsections, choosing the most appropriate denominator and/or making simple (well-justified) adjustments to the data can be a way of mitigating any problems from differing project assumptions.

Appropriate choice of denominator

While there will not necessarily be a 'correct' denominator to choose when calculating unit costs, some choices are more appropriate than others. Furthermore, given that the choice of denominator affects the results, a robust approach is to decide ex-ante which metrics to use when comparing projects, as there can be 'mid-project' pressures to choose a particular metric over another.

As an example of where choice is important, variations in the assumed project load factor could mean that a project's efficiency (relative to other projects) might differ if 'capacity' is used as the denominator rather than 'generation'. Load factor projections may become an increasingly important issue given the seemingly more extreme weather patterns which are being experienced in the UK, such as the storms in December 2013.

Adjustments

Even with the most relevant denominator, it may be that simple unit cost metrics are not sufficiently robust to provide a relevant efficiency comparison. However, it may be possible to make adjustments that can correct the metric to make it more applicable.

One example is that very large wind turbines could have a cost advantage over smaller turbines if the former are able to benefit from economies of scale in operating costs. In this instance, it may be necessary to make an assumption around the likely benefits to be gained from economies of scale, and then to adjust the unit cost metrics accordingly.

Although it is possible to undertake research to ensure that the rationale for adjustments is well-founded, most adjustments involve a degree of subjectivity, and therefore should be kept to a minimum. Ideally, the metrics themselves and any potential adjustments should be determined prior to receiving the data, in order to minimise the risk of any bias arising during the project.

ANNEX D DATA AVAILABILITY SUMMARY

Table D.1: Missing cost drivers for offshore costs

Cost driver	Rationale
Weight of topside Weight of jacket Weight of foundations	This cost category may have been better able to identify what element of platform weight has the greatest implication for costs and which are linked to other factors e.g. water depth which effects jacket weight but not topside weight.
Water depth	The increasing water depth should mean that the jacket needs to be larger in size. This may be by a factor greater than the water depth itself, as it may be that the wave potential is greater in deeper water and thus the platform needs to be stronger as well as taller.

There were no missing cost drivers for onshore costs.

Table D.2: Missing cost drivers for cable installation

Cost driver	Rationale
Weight of sea cable Weight of land cable	For cable installation, we are missing a cost driver relating to the weight of the cable (available for small number of projects). Greater weight of cable may imply higher transportation costs (larger vessels or more cable drums), more vessel campaigns and joints and so we expect that this will involve higher cost.

For the cable itself, different cable protection types involve different costs e.g., single armour protection, or double armour. In future there could be more variables, so greater granularity of cable type might be necessary.

ANNEX E OFFSHORE RESULTS AND ASSESSMENT TABLES

Note, all linear models are in £'s (e.g. a 34979.9 coefficient on capacity means an increase in costs of £34,980 per MVA of capacity), while all log models are elasticities (e.g. a 0.9 coefficient on capacity means a 1% increase in capacity will increase costs by 0.9%).

E.1. Offshore transformers

E.1.1. Linear models

Table E.1: Offshore transformers results, linear models (Part 1)[47]

Variables/ statistics/ tests	Data units for variable	OffTrlin1			OffTrlin2			OffTrlin3			OffTrlin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OffTransNo	#	161116	1936894 *	2071890 *	358118	1728293 *	1715744 *	1984998 *	2435234 **	2848993 *			
OffTransCap	MVA	10688.7 **	3063.98	3838.52	10530.6 **	3137.33	3753.46				12370.8 ***	12542.4 *	16399.8
OffTransVolt	kV							34979.9	-17196.3	-68474.1	-42652.6	-74327.4	-178018
OffTransCap_sqrd	MVA												
Constant	£	473541	-594070	-1026545				-4312485	1560163	7596797	6021576	1.08E+07	2.36E+07
Adjusted R2	n/a	0.93678	0.75837	0.76361	n/a	n/a	n/a	0.70951	0.73644	0.74050	0.96303	0.51354	0.49868
No of observations	n/a	8	9	8	8	9	8	8	9	8	8	9	8
Normality test	n/a	0.51520	0.18333	0.08496	0.3847072	0.4567467	0.5189324	0.53783	0.31010	0.62625	0.24003	0.00109	0.00977
Ramsey RESET	n/a	0.55307	0.02728	0.10118	0.6531091	0.8760322	0.3284027	0.79214	0.86100	0.68795	0.45978	0.54915	0.59314
White	n/a	0.22796	0.12754	0.21461	0.158775	0.1212167	0.1894178	0.35872	0.1604	0.13353	0.60032	0.65805	0.61982

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[47] * = significant at the 99% confidence level, ** = significant at the 95% confidence level, *** = significant at the 90% confidence level. This is the case for all subsequent data tables in these annexes.

Table E.2: Offshore transformers results, linear models (Part 2)

Variables/ statistics/ tests	Data units for variable	OffTrlin5			OffTrlin6			OffTrlin7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OffTransNo	#									
OffTransCap	MVA	13744.12*	30182.15	30490.61	11396.25***	11228.58*	11896.92*	13300.17*	27511.78	27566.17
OffTransVolt	kV	-42053.6	55180.31	61713.22						
OffTransCap_sqrd	MVA	-1.68417	-24.1435	-24.7364				-2.31193	-19.7267	-19.2313
Constant	£	5727160	-8770557	-9665230	568778.4	1362084	1214778	269750.1	-1167642	-1206233
Adjusted R2	n/a	0.955076	0.502104	0.398896	0.946157	0.567845	0.52234	0.937325	0.579511	0.517946
No of observations	n/a	8	9	8	8	9	8	8	9	8
Normality test	n/a	0.615797	0.012442	0.022141	0.683452	0.000727	0.002036	0.628787	0.009514	0.019876
Ramsey RESET	n/a	0.615652	0.614229	0.470084	0.940314	0.581364	0.520164	0.557186	0.757644	0.612999
White	n/a	0.310958	0.614536	0.67564	0.219283	0.502978	0.561841	0.370102	0.593608	0.557149

Table E.3: Offshore transformers assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrlin1	Number of offshore transformers, offshore transformer voltage	A # of transformers significant at 5%. Negative constant coefficients for the DFTV and AFTV stages.	A Marginal pass & marginal fail for Reset & Normality respectively at AFTV. White's test passes.	R OffTransNo becomes insignificant and highly negative. Normality not calculable.
OffTrlin2	Number of offshore transformers, offshore transformer capacity, no constant	A # of transformers significant at 10% from DFTV. Capacity significant at 5% level at ITV.	A R2 not applicable. Passes all tests.	R OffTransNo becomes insignificant and highly negative. Normality not calculable.
OffTrlin3	Number of offshore transformers, offshore transformer voltage	R # of transformers significant at 5%. Coefficient on capacity negative for AFTV and DFTV.	A Passes Reset, Normality, and White's tests. R2 is OK (ranging from 0.70-0.74).	R Removal of max/min: OffTransNo now perfectly collinear with OffTansVolt.
OffTrlin4	Offshore transformer capacity, Offshore transformer voltage.	R Insignificant coefficients at AFTV, transformer voltage negative at all stages.	A Passes Reset and White's tests, fails normality at AFTV and DFTV.	A Normality test incalculable, large changes in transformer voltage coefficient (though still insignificant)
OffTrlin5	Offshore transformer capacity, Offshore transformer voltage, offshore transformer capacity squared.	R No significant coefficients at 5%.	A Passes Reset and White's tests, fails normality at AFTV and DFTV.	A Normality test incalculable, large changes coefficients (though still insignificant)

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrlin6	Offshore transformer capacity.	G	A	A
		Transformer capacity significant at 5%.	Passes Reset and White's tests, fails normality at AFTV and DFTV.	Stable and significant coefficient, R-squared greatly increased. Normality test incalculable.
OffTrlin7	Offshore transformer capacity, offshore transformer capacity squared.	R	A	A
		No significant coefficients at 5%.	Passes Reset and White's tests, fails normality at AFTV and DFTV.	Normality test incalculable, large changes coefficients (though still insignificant)

E.1.2. Log models

Table E.4: Offshore transformers, log models (Part 1)

Variables/ statistics/ tests	Data units for variable	OffTrlog1			OffTrlog2			OffTrlog3			OffTrlog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OffTransNo	#	0.04825	0.53696	0.57577	-2.65375*	-2.20317*	-2.00844	1.15566*	1.12760**	1.18732*			
OffTransCap	MVA	.851460**	0.49372	0.50783	2.97175***	2.99585***	2.97842***				.925056***	.834285**	.883069*
OffTransVolt	kV							0.99398	0.07797	-0.33835	-0.99028	-0.79634	-1.31348
OffTransCap_sqrd	MVA												
Constant	-	10.3172***	12.0798***	11.9857***				9.538562	14.0274	16.0307	14.7959**	14.4825	16.7527
Adjusted R2	n/a	0.95340	0.78441	0.75867	0.99774	0.99575	0.99517	0.70114	0.67001	0.61833	0.96636	0.72146	0.68084
No of observations	n/a	8	9	8	8	9	8	8	9	8	8	9	8
Normality test	n/a	0.98677	0.65076	0.33998	0.47271	0.79246	0.56485	0.53060	0.73419	0.57929	0.78940	0.02268	0.07969
Ramsey RESET	n/a	0.66430	0.11175	0.17001	0.01693	0.07042	0.05927	0.64470	0.73763	0.65706	0.87636	0.71772	0.43447
White	n/a	0.32272	0.17151	0.28795	0.19862	0.11281	0.15819	0.45445	0.09387	0.12786	0.40907	0.75410	0.79343
Alpha factor	n/a	1.00057	1.02211	1.03499	0.57322	0.44267	0.38758	0.96504	1.03543	1.05130	1.00423	1.02854	1.04987

Table E.5: Offshore transformers, log models (Part 2)

Variables/ statistics/ tests	Data units for variable	OffTrlog5			OffTrlog6			OffTrlog7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OffTransNo	#									
OffTransCap	MVA	0.62942	-0.14054	-2.93842	.8795642***	.8095767**	.8285773**	1.016812	0.5211329	0.2597924
OffTransVolt	kV	-1.04836	-1.38476	-4.84461						
OffTransCap_sqrd	MVA	0.026818	0.088898	0.358459				-0.0123386	0.0258205	0.0513827
Constant	-	15.88272*	19.99646	44.07208	10.19065***	10.72445***	10.62565***	9.814907*	11.51944	12.18055
Adjusted R2	n/a	0.958599	0.670689	0.648214	0.960858	0.758465	0.726805	0.9531493	0.718706	0.6742295
No of observations	n/a	8	9	8	8	9	8	8	9	8
Normality test	n/a	0.952911	0.010009	0.02776	0.981074	0.015006	0.036405	0.929845	0.010714	0.0219791
Ramsey RESET	n/a	0.790097	0.430446	0.426494	0.749982	0.677434	0.75759	0.6411434	0.6672679	0.7540137
White	n/a	0.41812	0.793631	0.689108	0.155385	0.55542	0.647802	0.2919095	0.657801	0.7471394
Alpha factor	n/a	1.000314	1.015809	1.018274	1.002052	1.022192	1.03096	1.016812	0.5211329	0.2597924

Table E.6: Offshore transformers assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrlog1	Number of offshore transformers, offshore transformer capacity	R AFTV and DFTV no significant coefficients at 5%. ITV, weight significant at 5% level, signs as expected.	G R-squared = 0.987 (ITV), 0.651 (DFTV), 0.34 (AFTV). Passes Ramsey Reset, Normality and White's tests. Alpha factor close to 1.	R Large changes in coefficients across stages. Normality not calculable. ITV sensitivities show relatively small changes in the coefficients.
OffTrlog2	Number of offshore transformers, offshore transformer capacity, no constant	A Coefficient for total capacity significant at 1% level. Number is insignificant and wrong sign, but multicollinearity between number and capacity.	A R-squared not applicable. Passes Normality and White's tests. Fails RESET test at ITV and only very marginal passes at AFTV.	A Relatively large change in voltage (still insignificant). Normality not calculable.
OffTrlog3	Number of offshore transformers, offshore transformer voltage	A # of transformers significant at (5% at DFTV), and reasonable value. Voltage negative at AFTV (but insignificant)	A R-squared = 0.701 (ITV), 0.670 (DFTV), 0.618 (AFTV). Passes Ramsey Reset, Normality and White's tests.	R Removal of max/min: OffTransNo now perfectly collinear with OffTransVolt.
OffTrlog4	Offshore transformer capacity, Offshore transformer voltage.	R Voltage negative and insignificant.	A R-squared = 0.966 (ITV), 0.721 (DFTV), 0.681 (AFTV) Passes Ramsey Reset, White's tests. Fails Normality test at DFTV/ AFTV.	A Relatively large change in voltage (still insignificant). Normality not calculable.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrlog5	Offshore transformer capacity, Offshore transformer voltage, offshore transformer capacity squared.	R Voltage and capacity highly negative and insignificant.	A Passes Ramsey Reset, White’s tests. Fails Normality test at DFTV/ AFTV.	A Relatively large change in voltage (still insignificant). Normality not calculable.
OffTrlog6	Offshore transformer capacity.	G Transformer capacity significant at 5% and reasonable value.	A Passes Ramsey Reset, White’s tests. Fails Normality test at DFTV/ AFTV.	A Relatively small change in capacity coefficient (still significant at 5%). Normality not calculable.
OffTrlog7	Offshore transformer capacity, offshore transformer capacity squared.	R No significant coefficients at 5%. First order value also quite low.	A Passes Ramsey Reset, White’s tests. Fails Normality test at DFTV/ AFTV.	A Relatively large change in coefficients (still insignificant). Normality not calculable. R-squared much higher.

E.1.3. Unit cost models, linear

Table E.7: Offshore transformers results, linear unit cost models

Variables/ statistics/ tests	Data units for variable	OffTrunitlin1			OffTrunitlin2			OffTrunitlin3			OffTrunitlin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OffTransCapUnit	MVA per transformer	12328.9 **	8657.83	9097.82	18865.1	-12960.3	-9166.95	10391.2 **	8137.49 *	8408.77	17567.7	-14733.8	-12927.1
OffTransVolt	kV	-21320.9	-16432.7	-20108.7	-21163.9	-6638.14	-9905.28						
OffTransCapUnit_sqrd	MVA				-19.2512	68.5531	57.1453				-21.091	73.5826	68.0568
Constant	£	3039275	3086902	3559108	2514660	3287875	3464746	437787	958062	954691	-115983	2535745	2416159
Adjusted R2	n/a	0.85001	0.31763	0.33216	0.82254	0.28646	0.22562	0.78744	0.38941	0.40516	0.75457	0.40102	0.37154
No of observations	n/a	8	9	8	8	9	8	8	9	8	8	9	8
Normality test	n/a	0.77255	0.56538	0.75736	0.99434	0.53749	0.66567	0.44805	0.51125	0.68930	0.63782	0.49462	0.56937
Ramsey RESET	n/a	0.93220	0.40264	0.18247	0.61026	0.19385	0.13549	0.85040	0.49862	0.18770	0.74814	0.22282	0.14490
White	n/a	0.34339	0.46461	0.46512	0.38386	0.54647	0.71028	0.47819	0.37892	0.40239	0.51972	0.57704	0.72194

Table E.8: Offshore transformers assessment, linear unit cost models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrunitlin1	Offshore transformer capacity, offshore transformer voltage	R Only capacity significant at ITV stage (at 5%). Wrong expected sign for voltage.	A R2 high at ITV, falls for AFTV (0.85,0.33). Passes all tests.	A Small sample size. Some variation in coefficient.
OffTrunitlin2	Offshore transformer capacity, offshore transformer voltage, offshore transformer capacity squared	R No significant coefficients. Wrong expected sign for voltage.	A R2 high at ITV, falls for AFTV (0.82,0.23). Passes all tests.	R Significant change in coefficients. Small sample size.
OffTrunitlin3	Offshore transformer capacity	A Capacity significant at 5% stage for ITV, not at AFTV. Constant more than doubles between stages.	A R2 high at ITV, falls for AFTV (0.79,0.41). Passes all tests.	A Jump in constant, but other coefficient not varying by excessive margin.
OffTrunitlin4	Offshore transformer capacity, offshore transformer capacity squared	R No significant coefficients.	A R2 relatively high at ITV, falls for AFTV (0.75,0.37). Passes all tests.	R Significant change in coefficients. Small sample size.

E.1.4. Unit cost models, log

Table E.9: Offshore transformers results, log unit cost models

Variables/ statistics/ tests	Data units for variable	OffTrunitlog1			OffTrunitlog2			OffTrunitlog3			OffTrunitlog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OffTransCapUnit	MVA per transformer	.899586 **	0.53085	0.56691	-0.36039	-9.9322	-9.70607	.793828 **	0.50345	0.52617	0.44226	-10.1182	-10.0432
OffTransVolt	kV	-1.07312	-0.75844	-1.00776	-1.10703	-0.26536	-0.3051						
OffTransCapUnit_sqrd	MVA				0.12577	1.06168	1.03917				0.03500	1.07962	1.07211
Constant	-	15.2739 **	15.6386	16.7006	18.5824	38.8718	38.5038	10.5308 ***	12.0583 ***	11.9618 ***	11.4098	38.0508	37.8651
Adjusted R2	n/a	0.84611	0.17374	0.16901	0.81093	0.21890	0.14591	0.82198	0.28026	0.28757	0.78658	0.34749	0.31470
No of observations	n/a	8	9	8	8	9	8	8	9	8	8	9	8
Normality test	n/a	0.83038	0.84632	0.94350	0.94520	0.87012	0.88133	0.89472	0.76913	0.83759	0.88555	0.86065	0.87237
Ramsey RESET	n/a	0.89837	0.10700	0.13966	0.75298	0.16882	0.14232	0.85499	0.15120	0.10766	0.85452	0.78169	0.09311
White	n/a	0.41217	0.38533	0.38679	0.47298	0.46082	0.54411	0.62070	0.28079	0.30982	0.63696	0.36387	0.46516

Table E.10: Offshore transformers assessment, log unit cost models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTrunitlog1	Offshore transformer capacity, offshore transformer voltage	A	A	R
		Only capacity significant at ITV stage (at 5%). Wrong expected sign on voltage.	R2 high at ITV, but falls significantly for AFTV (0.85,0.17) Passes all tests.	Capacity coefficient changes significantly between phases. Small sample size.
OffTrunitlog2	Offshore transformer capacity, offshore transformer voltage, offshore transformer capacity squared	R	A	R
		No significant coefficients. Wrong expected sign on voltage.	R2 high at ITV, but falls significantly for AFTV (0.81,0.15) Passes all tests.	Capacity coefficient changes significantly between phases. Small sample size.
OffTrunitlog3	Offshore transformer capacity	A	A	R
		Only capacity significant at ITV stage (at 5%). Constant significant at 1%.	R2 high at ITV, but falls significantly for AFTV (0.82,0.29) Passes all tests. Marginal pass on RESET at AFTV.	Capacity coefficient changes significantly between phases. Small sample size.
OffTrunitlog4	Offshore transformer capacity, offshore transformer capacity squared	R	A	R
		No significant coefficients. Wrong expected sign on voltage.	R2 high at ITV, but falls significantly for AFTV (0.79,0.31) Passes all tests. Marginal pass on RESET at AFTV.	Capacity coefficient changes significantly between phases. Small sample size.

E.2. Offshore platforms

E.2.1. Linear models

Table E.11: Offshore platforms results, linear models (Part 1)

Variables/ statistics/ tests	Data units for variable	OSPlin1			OSPlin2			OSPlin3		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OSPno	#	1.42E+07	1.38E+07	9821695						
OSPtotwt	Tonnes	20415.69*	23481.14**	22097.86*	24727***	27630***	24191**	43539.61*	43170.8	39178.33
OSPshore	km				274592	247905	258620	280513.4	258432.5	267621.3
OSPtotwt_sqrd	Tonnes							-4.44137	-3.69277	-3.54058
Constant	£	-8256584	-9786583	-4174573	-7252005	-7732690	-4423763	-2.34E+07	-2.10E+07	-1.72E+07
Adjusted R2	n/a	0.8062872	0.8508138	0.7962628	0.793781	0.839378	0.799238	0.795831	0.833253	0.789198
No of observations	n/a	12	11	10	12	11	10	12	11	10
Normality test	n/a	0.7743809	0.4083236	0.5667459	0.52484	0.82558	0.489468	0.638163	0.962972	0.885033
Ramsey RESET	n/a	0.6880729	0.8387892	0.7412684	0.654066	0.866259	0.672355	0.576404	0.532803	0.7581
White	n/a	0.2586322	0.85348	0.6742252	0.168876	0.138427	0.236731	0.19506	0.219266	0.281108

Table E.12: Offshore platforms results, linear models (Part 2)

Variables/ statistics/ tests	Data units for variable	OSPlin4			OSPlin5		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV
OSPno	#						
OSPtotwt	Tonnes	26367.96***	29149.15***	25882.93***	44916.65*	44153.18*	40372.38
OSPshore	km						
OSPtotwt_sqrd	Tonnes				-4.37085	-3.5507	-3.40966
Constant	£	-39019.4	-1382188	2083014	-1.58E+07	-1.39E+07	-1.00E+07
Adjusted R2	n/a	0.798353	0.845836	0.806277	0.799911	0.840195	0.797242
No of observations	n/a	12	11	10	12	11	10
Normality test	n/a	0.361108	0.592389	0.703924	0.022154	0.070009	0.090253
Ramsey RESET	n/a	0.767418	0.810904	0.85674	0.935314	0.939874	0.803055
White	n/a	0.495485	0.609685	0.473831	0.620894	0.767272	0.593307

Table E.13: Offshore platforms assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OSPlin1	Number of offshore platforms, weight of offshore platform	A	A	A
		Number of platforms insignificant. Weight significant at the 10% level (5% for DFTV).	R-squared = 0.806 (ITV), 0.851 (DFTV), 0.796 (AFTV) Passes normality, RESET and White test.	Relatively large movements in the non-significant coefficients.
OSPlin2	Weight of offshore platform, distance from shore	A	G	A
		Weight significant at 1% level at ITV, DFTV, 5% level for AFTV. Signs are as expected for variables, but negative constant.	R-squared = 0.793 (ITV), 0.839 (DFTV), 0.799 (AFTV) Passes normality, RESET and White test.	Relatively small changes in coefficients, apart from constant.
OSPlin3	Weight of offshore platform, distance from shore, total weight of offshore platform squared	R	G	A
		No significant variables except weight at 10% for ITV. Signs are as expected, however negative constant.	R-squared = 0.796 (ITV), 0.833 (DFTV), 0.789 (AFTV) Passes normality test and White.	Coefficients not exhibiting too much variation across project stages.
OSPlin4	Weight of offshore platform	A	G	A
		Weight coefficient significant at the 1% level. Negative constant at ITV/ DFTV.	R-squared = 0.798 (ITV), 0.846 (DFTV), 0.806 (AFTV) Passes normality, RESET and White test.	Coefficient not exhibiting too much variation across project stages.
OSPlin5	Weight of offshore platform, total	R	A	A

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
	weight of offshore platform squared	Signs as expeccted apart from constant. Weight only significant at the 10% level. Constant coefficient very large and negative.	R-squared = 0.800 (ITV), 0.840 (DFTV), 0.797 (AFTV) Passes RESET test and White. Marginal pass on the normality test at DFTV/ AFTV.	Significant change in constant term, but not much variation by weight.

E.2.2. Log models

Table E.14: Offshore platforms results, log models (Part 1)

Variables/ statistics/ tests	Data units for variable	OSPlog1			OSPlog2			OSPlog3		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OSPno	#	0.180472	-0.17169	-0.21729						
OSPtotwt	Tonnes	1.123078**	1.493448**	1.483842**	1.104184***	1.343528***	1.328989**	5.872517	11.52806**	12.09499*
OSPshore	km				0.393233	0.298643	0.288062	.4437569*	.4228541*	0.41486
OSPtotwt_sqrd	Tonnes							-0.32977	-.704926*	-.7480987*
Constant		9.155236**	6.541471*	6.605311*	7.950125***	6.555381**	6.687199*	-9.36551	-30.4343*	-32.25957*
Adjusted R2	n/a	0.760138	0.775491	0.733058	0.833136	0.805923	0.764472	0.854288	0.915241	0.901289
No of observations	n/a	12	11	10	12	11	10	12	11	10
Normality test	n/a	0.048138	0.540522	0.435534	0.271116	0.841169	0.625639	0.266029	0.289098	0.307145
Ramsey RESET	n/a	0.654605	0.129834	0.203739	0.440363	0.099488	0.130514	0.640915	0.616317	0.719126
White	n/a	0.808626	0.443413	0.530052	0.175098	0.095175	0.10975	0.282894	0.296476	0.397654
Alpha factor	n/a	0.963223	0.909015	0.888107	0.939479	0.869199	0.837755	1.003845	0.996162	0.991223

Table E.15: Offshore platforms results, log models (Part 2)

Variables/ statistics/ tests	Data units for variable	OSPlog4			OSPlog5		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV
OSPno	#						
OSPtotwt	Tonnes	1.202176***	1.418857***	1.398036***	4.598333	10.05234*	10.63287*
OSPshore	km						
OSPtotwt_sqrd	Tonnes				-0.23426	-0.59574	-0.6399
Constant		8.613925***	7.048376**	7.187617**	-3.62576	-24.0385	-25.9376
Adjusted R2	n/a	0.780396	0.798115	0.76239	0.775481	0.862604	0.843972
No of observations	n/a	12	11	10	12	11	10
Normality test	n/a	0.02204	0.438613	0.289466	0.001032	0.006936	0.014776
Ramsey RESET	n/a	0.780026	0.13976	0.190475	0.938121	0.576959	0.686392
White	n/a	0.693312	0.068828	0.086101	0.708371	0.851446	0.890302
Alpha factor	n/a	0.976232	0.899096	0.872424	1.028598	1.024481	1.023743

Table E.16: Offshore platforms assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OSPlog1	Number of offshore platforms, weight of offshore platform	A	R	A
		Incorrect (negative) coefficient on number of offshore platforms. However, variable insignificant. Weight significant at the 5% level.	R-squared = 0.760 (ITV), 0.775 (DFTV), 0.733 (AFTV) Fails normality for ITV. Passes RESET and marginal pass for White test. Alpha factor quite different from 1.	Relatively large movements in the coefficients. However, coefficients are still reasonable.
OSPlog2	Weight of offshore platform, distance from shore	A	A	A
		Signs as expected. Weight significant at either the 1% or 5% level. Constant significant at the 1% level for ITV, 5% DFTV, 10% AFTV. Distance not significant.	R-squared = 0.833 (ITV), 0.806 (DFTV), 0.764 (AFTV) Passes all tests. Marginal passes on RESET and White. Alpha factor around 1.	Some movement in coefficients, but not excessively so.
OSPlog3	Weight of offshore platform, distance from shore, total weight of offshore platform squared	G	G	A
		Coefficients significant between the 5% and 10% level for DFTV and AFTV. Weight elasticities become negative at greater weigths (likely due to correlation with distance).	R-squared = 0.854 (ITV), 0.915 (DFTV), 0.901 (AFTV) Passes all tests. Alpha factor around 1.	Jumps in coefficient between ITV and AFTV.
OSPlog4	Weight of offshore platform	G	G	A

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		Weight coefficient significant at the 1% level. Constant significant at at least the 5% level.	R-squared = 0.780 (ITV), 0.798 (DFTV), 0.762 (AFTV) Passes RESET and White test. Only ITV fails normality test.	Some movement in coefficients, but not excessively so.
OSPlog5	Weight of offshore platform, total weight of offshore platform squared	A	A	R
		Signs as expeccted apart from constant. Weight only significant at the 10% level.	R-squared = 0.775 (ITV), 0.862 (DFTV), 0.844 (AFTV) Passes RESET test and White. Fails normality test.	Relatively large movements in the coefficients. Small sample size.

E.3. Offshore platforms total cost

E.3.1. Linear models

Table E.17: Offshore platforms total cost results, linear models

Variables/ statistics/ tests	Data units for variable	OSPtotlin1			OSPtotlin2		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV
OSPtotwt	Tonnes	8769.172	10642.93	8000.09	9419.789	11017.11	8597.709
OSPshore	km				118799.8	41979.17	70413.27
OSPtotwt_sqrd	Tonnes						
OffTransCap	MVA	87894.86	88245.47	83422.78	81521.79	85361.01	78594.61
Constant	£	533821.4	2911254	6780284	-2529897	1793654	4936384
Adjusted R2	n/a	0.842201	0.824934	0.7826357	0.825471	0.800257	0.747838
No of observations	n/a	12	11	10	12	11	10
Normality test	n/a	0.658611	0.766372	0.3153933	0.487693	0.657536	0.144415
Ramsey RESET	n/a	0.346793	0.616457	0.5438584	0.326812	0.640453	0.446948
White	n/a	0.340733	0.800447	0.9112386	0.35365	0.368892	0.350485

Table E.18: Offshore platforms total cost assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTotlin1	Weight of offshore platform, offshore transformer capacity	A	A	A
		Signs are as expected. Magnitudes appear reasonable. No coefficients are significant, however likely multicolinearity issue between weight and capacity.	Adj R-squared = 0.842 (ITV), 0.825 (DFTV), 0.783 (AFTV). Passes normality, RESET, and White.	Large movements in the constant coefficient from ITV to the AFTV. However, coefficients on the other variables relatively stable.
OffTotlin2	Weight of offshore platform, distance from shore, offshore transformer capacity	A	A	A
		Signs are as expected, expect for negative coefficent on constant (ITV only). Magnitudes appear reasonable. No coefficients are significant, however likely multicolinearity issue between weight and capacity.	Adj R-squared = 0.825 (ITV), 0.800 (DFTV), 0.748 (AFTV). Passes normality, RESET, and White.	Large movements in the constant coefficient from ITV to the AFTV.

E.3.2. Log models

Table E.19: Offshore platforms total cost results, log models

Variables/ statistics/ tests	Data units for variable	OSPtotlog1			OSPtotlog2		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV
OSPtotwt	Tonnes	0.1422919	0.300172	0.2822234	0.268575	0.44169	0.41613
OSPshore	km				0.206892	0.158969	0.14783
OSPtotwt_sqrd	Tonnes						
OffTransCap	MVA	.9537692*	0.916563	0.9044586	0.788095	0.748588	0.748039
Constant		10.9612***	10.11104***	10.29465**	10.26505***	9.480892**	9.693902**
Adjusted R2	n/a	0.8846773	0.832017	0.7942588	0.893211	0.819283	0.771803
No of observations	n/a	12	11	10	12	11	10
Normality test	n/a	0.8834234	0.722167	0.6125727	0.251536	0.964569	0.888675
Ramsey RESET	n/a	0.6682206	0.155642	0.2151733	0.367383	0.186413	0.254747
White	n/a	0.3314557	0.204687	0.2432162	0.414757	0.308385	0.350485
Alpha factor	n/a	0.9817052	0.926864	0.9053963	0.962477	0.910279	0.887147

Table E.20: Offshore platforms total cost assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OffTotlog1	Total weight of offshore platform, offshore transformer capacity	A Signs are as expected. Elasticities appear reasonable. Only constant and one capacity coefficient are significant, however likely multicolinearity issue between weight and capacity.	A Adj R-squared = 0.885 (ITV), 0.832 (DFTV), 0.794 (AFTV). Passes normality, RESET, and White. Alpha factor not close to 1 (mainly for AFTV).	A Coefficient relatively stable from ITV to the AFTV.
OffTotlog2	Total weight of offshore platform, distance from shore, offshore transformer capacity	A Signs are as expected. Elasticities appear reasonable. Only constant and one capacity coefficient are significant, however likely multicolinearity issue between weight and capacity.	A Adj R-squared = 0.893 (ITV), 0.819 (DFTV), 0.771 (AFTV). Passes normality, RESET, and White. Alpha factor not close to 1.	A Coefficient relatively stable from ITV to the AFTV. Althought coefficient on weight almost doubles.

ANNEX F ONSHORE RESULTS AND ASSESSMENT TABLES

Note, all linear models are in £'s (e.g. a 1905794 coefficient on onshore transformer number means an increase in costs of £1,905,794 per transformer), while all log models are elasticities (e.g. a 0.9 coefficient on voltage means a 1% increase in voltage will increase costs by 0.9%).

F.1. Onshore transformers

F.1.1. Linear models

Table F.1: Onshore transformers, linear models (Part 1)

Variables	Data units for variable	OnTrlin1			OnTrlin2			OnTrlin3			OnTrlin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransNo	#	1905794	2264113	1815697	1116444*	1746374	1141164						
OnTransCap	MVA				12067.17**	11773.26*	13211.62	14791.7***	16089.47*	16693.7*	22053.54*	47308.3	37371.39*
OnTransCap_sqrd	MVA												
OnTransVolt	kV	19265.95*	21428.96*	23086.93							-14767.5	-64625.9	-43445.6*
Constant	£	-3878855	-4701851	-4248079	-1533087	-2421566	-1675729	-322001	-461410	-448710	1046367	4849651	3146908*
Adjusted R2	n/a	0.91352	0.94650	0.93898	0.98287	0.96484	0.97562	0.93745	0.87464	0.94706	0.95094	0.95575	0.9998
No of observations	n/a	6	5	4	6	5	4	6	5	4	6	5	4
Normality test	n/a	.	.	.	.	.	.	.	.	.	.	.	.
Ramsey RESET	n/a	0.34154	0.03407	.	.	.	.	0.04810	0.02481	0.02771	0.04927	0.03257	.
White	n/a	0.85124	0.17246	0.26146	0.21254	0.28730	0.26146	0.07909	0.08613	0.13538	0.39375	0.17180	0.13534

Table F.2: Onshore transformers, linear models (Part 2)

Variables	Data units for variable	OnTrlin5			OnTrlin6			OnTrlin7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransNo	#	963869.3	1096986	109350.7				885592.5	958099.4	109350.7
OnTransCap	MVA	14985.16	27719.27	35548.88	-494.58	-29647.9	-14048.2	6854.255	-10595.7	-12168.4
OnTransCap_sqrd	MVA				19.78208	58.68066	38.95424*	7.475118	31.19872	36.14944
OnTransVolt	kV	-5176.8	-29687.3	-40317.4						
Constant	£	-887893	747065.2	2770437	1368946	4079929	2596897*	-643702	877696.7	2260028
Adjusted R2	n/a	0.978772	0.948094	.	0.962832	0.964008	0.9998	0.979951	0.953349	.
No of observations	n/a	6	5	4	6	5	4	6	5	4
Normality test	n/a	.	.	.	.	.	.	.	.	.
Ramsey RESET	n/a	.	.	.	0.056601	0.036113	.	.	.	.
White	n/a	0.306219	0.287298	0.261464	0.199158	0.171797	0.135335	0.306219	0.287298	0.261464

Table F.3: Onshore transformers assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTrlin1	Number of onshore transformers, onshore transformer voltage	R	R	A
		No significant coefficients. Negative constant.	R-squared = 0.914 (ITV), 0.947 (DFTV), 0.939 (AFTV) Passes RESET at ITV, White at both ITV and AFTV Normality na. RESET na at AFTV.	Some variation in coefficients but not excessively so. Small sample size.
OnTrlin2	Number of onshore transformers, onshore transformer capacity	A	R	A
		Capacity significant at 5% level at ITV, 10% for DFTV, AFTV. Negative constant.	R-squared = 0.983 (ITV), 0.965 (DFTV), 0.976 (AFTV) Passes White Normality na. RESET na.	Some variation in coefficients but not excessively so. Small sample size.
OnTrlin3	Onshore transformer capacity	A	R	A
		Capacity significant at 1% for ITV and 10% for DFTV and AFTV. Constant negative.	R-squared = 0.937 (ITV), 0.875 (DFTV), 0.947 (AFTV) Passes White test (marginal for ITV and DFTV) Fails RESET Normality na	Some variation in coefficients but not excessively so. Small sample size.
OnTrlin4	Onshore transformer capacity, onshore transformer voltage	A	R	R
		Capacity significant at 10% level through for ITV and AFTV. Voltage coefficient negative.	R-squared = 0.951 (ITV), 0.956 (DFTV), 0.999 (AFTV) Passes White test Fails RESET at ITV and	Large variation in coefficients. Small sample size.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
			DFTV, na for AFTV Normality na	
OnTrlin5	Number of onshore transformers, onshore transformer capacity, onshore transformer voltage	R	R	R
		No significant coefficients. Negative voltage.	R-squared = 0.979 (ITV), 0.948 (DFTV), n/a (AFTV) Passes White test Normality, RESET na	Large shift in values between coefficients. Small sample size.
OnTrlin6	Onshore transformer capacity, onshore transformer capacity squared	R	R	R
		No significant coefficients.	R-squared = 0.963 (ITV), 0.964 (DFTV), 0.999 (AFTV) Passes White test Marginal pass of RESET at ITV, fails at DFTV. AFTV na. Normality na	Large shift in values between coefficients. Small sample size.
OnTrlin7	Number of onshore transformers, onshore transformer capacity, onshore transformer capacity squared	R	R	R
		No significant coefficients.	R-squared = 0.979 (ITV), 0.953 (DFTV), na (AFTV) Passes White Normality, RESET na	Large shift in values between coefficients. Small sample size.

F.1.2. Log models

Table F.4: Onshore transformers, log models (Part 1)

Variables	Data units for variable	OnTrlog1			OnTrlog2			OnTrlog3			OnTrlog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransNo	#	0.44902	0.46051	0.36677	0.25152	0.33946	0.23106						
OnTransCap	MVA				.9281384***	.9290176**	0.976872	1.011037***	1.044931**	1.070547**	1.474454*	2.924617	2.394772
OnTransCap_sqrd	MVA												
OnTransVolt	kV	1.325889**	1.422979*	1.485738							-0.72762	-3.02934	-2.14629
Constant	-	7.605835**	7.127784*	6.853833	9.780706***	9.74806**	9.561156*	9.471302***	9.314801***	9.19727**	10.8577**	15.28008*	13.45884
Adjusted R2	n/a	0.960786	0.974755	0.973123	0.994519	0.98706	0.99292	0.985599	0.972716	0.987123	0.988597	0.987614	0.997916
No of observations	n/a	6	5	4	6	5	4	6	5	4	6	5	4
Normality test	n/a	.	.	.	.	.	.	.	.	.	.	.	.
Ramsey RESET	n/a	0.222694	0.026341	.	.	.	.	0.295334	0.031363	0.026359	0.295334	0.172214	0.18365
White	n/a	0.994789	0.176086	.	0.428996	0.287298	0.261464	0.137761	0.084305	0.135921	0.423575	0.171797	0.135335
Alpha factor	n/a	1.028286	1.032186	1.025898	1.012249	1.022568	1.014319	1.021806	1.033188	1.023929	1.008405	1.008033	1.000013

Table F.5: Onshore transformers, log models (Part 2)

Variables	Data units for variable	OnTrlog5			OnTrlog6			OnTrlog7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransNo	#	0.208443	0.198165	0.103633				0.200549	0.190172	0.103633
OnTransCap	MVA	1.181715*	2.120753	2.000781	-2.46666	-10.8695	-7.29291	-0.86841	-6.48151	-5.11193
OnTransCap_sqrd	MVA				0.311852	1.06465	0.746575	0.162607	0.666743	0.548136
OnTransVolt	kV	-0.37585	-1.84287	-1.57581						
Constant	-	10.44386**	13.19664	12.48933	18.94052*	41.80477	32.0205	14.65547	29.90454	26.11733
Adjusted R2	n/a	0.994296	0.985547	.	0.989683	0.988532	0.997916	0.994556	0.986401	.
No of observations	n/a	6	5	4	6	5	4	6	5	4
Normality test	n/a	.	.	.	.	.	.	.	.	.
Ramsey RESET	n/a	.	.	.	0.335624	0.183663	0.208838	.	.	.
White	n/a	0.306219	0.287298	0.261464	0.518908	0.171798	0.135335	0.306219	0.287298	0.261464
Alpha Factor	n/a	1.005525	1.007637	1	1.007121	1.007193	1.000013	1.004901	1.006895	1

Table F.6: Onshore transformer assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTrlog1	Number of onshore transformers, onshore transformer voltage	R	R	A
		Voltage and constant significant at 5% level at ITV, DFTV at 10%. No significant coefficients at AFTV. Signs as expected.	R-squared = 0.961 (ITV), 0.975 (DFTV), 0.973 (AFTV) Passes White and RESET at ITV, normality na AFTV all tests are na Alpha factor around 1	Relatively stable coefficients. Very small sample size.
OnTrlog2	Number of onshore transformers, onshore transformer capacity	A	R	A
		Capacity significant at 1% at ITV, but not significant at AFTV. Constant significant at 1%, then 5% for DFTV.	R-squared = 0.995 (ITV), 0.987 (DFTV), 0.993 (AFTV) Passes White Normality, RESET na Alpha factor around 1	Relatively stable coefficients. Very small sample size.
OnTrlog3	Onshore transformer capacity	G	A	A
		Capacity significant at 1% for ITV, and 5% for DFTV and AFTV. Constant significant at 1% for ITV and DFTV, and at 5% for AFTV.	R-squared = 0.989 (ITV), 0.988 (DFTV), 0.998 (AFTV) Passes White DFTV and AFTV fail RESET Normality na Alpha factor around 1	Relatively stable coefficients. Very small sample size.
OnTrlog4	Onshore transformer capacity, onshore transformer voltage	A	A	R
		Capacity significant at 10% for ITV. Constant significant at 5% for	R-squared = 0.986 (ITV), 0.972 (DFTV), 0.987 (AFTV) Passes White, RESET	More substantial variation in coefficients. Very small sample size.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		ITV, and at 10% for DFTV.	Normality na Alpha factor around 1	
OnTrlog5	Number of onshore transformers, onshore transformer capacity, onshore transformer voltage	R	R	R
		No significant coefficients at AFTV or DFTV.	R-squared = 0.994 (ITV), 0.986 (DFTV) na (AFTV) Passes White Normality, RESET na Alpha factor around 1	More substantial variation in coefficients. Very small sample size.
OnTrlog6	Onshore transformer capacity, onshore transformer capacity squared	R	R	R
		No significant coefficients at AFTV or DFTV.	R-squared = 0.990 (ITV), 0.989 (DFTV), 0.998 (AFTV) Passes White, RESET Normality na Alpha factor around 1	More substantial variation in coefficients. Very small sample size.
OnTrlog7	Number of onshore transformers, onshore transformer capacity, onshore transformer capacity squared	R	R	R
		No significant coefficients.	R-squared = 0.995 (ITV), 0.986 (DFTV), na (AFTV) Passes White Normality, RESET na	Large shift in values between coefficients. Small sample size.

F.2. Onshore total costs excluding onshore other

F.2.1. Linear models

Table F.7: Onshore total costs excluding other, linear models (Part 1)

Variables	Data units for variable	OnTotExclin1			OnTotExclin2			OnTotExclin3			OnTotExclin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA	11487.2	16249.98	13456.26	1394.634	8310.549	2823.107	-12726.4	-946.94	-998.503			
OnReCap	MVAr				39517.1	31469.14	37169.67*						
OnTransDummy	#												
GenCap	MW							44091.4*	31206.43	28642.03	46863.78***	39471.17**	39050.99**
GenCap_sqrd	MW												
Constant	£	1.57e+07*	9646998	1.00E+07	1.12E+07	6233836	6167737	9042309	4804334	5437794	267631	911638.5	1007296
Adjusted R2	n/a	0.049886	0.398892	0.24579	0.37612	0.675138	0.900731	0.706783	0.812677	0.647394	0.709147	0.642279	0.554176
No of observations	n/a	7	6	5	7	6	5	7	6	5	11	11	10
Normality test	n/a	.	.	.	.	.	.	.	.	.	0.664714	0.6463	0.831644
Ramsey RESET	n/a	0.683997	0.434883	0.377113	0.197165	.	.	0.255477	.	.	0.435157	0.356818	0.401639
White	n/a	0.977049	0.174853	0.084621	0.233229	0.306219	0.287298	0.325677	0.306219	0.287298	0.275452	0.627053	0.748582

Table F.8: Onshore total costs excluding other, linear models (Part 2)

Variables	Data units	OnTotExclin5	OnTotExclin6	OnTotExclin7

	for variable	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA									
OnReCap	MVAr									
OnTransDummy	#	1.11e+07**	2677550	2708869	1.04e+07**	2063965	2061315			
GenCap	MW	31021.83**	35818.17*	35347.09*	51273.16	114753.2*	117710.3	115024.2*	120371.5*	123336*
GenCap_sqrd	MW				-26.4435	-106.183	-112.415	-93.5983	-109.993	-116.288
Constant	£	-2862207	331203.6	421660	-5285666	-1.03E+07	-1.06E+07	-9005846	-1.02E+07	-1.05E+07
Adjusted R2	n/a	0.901348	0.61993	0.518543	0.892277	0.690126	0.60924	0.739135	0.715712	0.648993
No of observations	n/a	11	11	10	11	11	10	11	11	10
Normality test	n/a	0.742087	0.028965	0.057343	0.704956	0.742179	0.842732	0.635159	0.93843	0.8419
Ramsey RESET	n/a	0.693984	0.377749	0.434755	0.208311	0.746606	0.810825	0.33681	0.40018	0.458249
White	n/a	0.131049	0.03755	0.053426	0.238169	0.158412	0.213157	0.289568	0.365564	0.498508

Table F.9: Onshore total costs excluding others assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTotExclin1	Onshore transformer capacity	R	R	R
		No significant coefficients.	R-squared = 0.050 (ITV), 0.399 (DFTV), 0.246 (AFTV) Passes White and RESET Normality na	Significant variation in coefficient, especially for constant. Very small sample size.
OnTotExclin2	Onshore transformer capacity, onshore reactive capacity	R	R	R
		Reactive capacity significant at 10% level for AFTV only.	R-squared = 0.376 (ITV), 0.675 (DFTV), 0.901 (AFTV) Passes White test Normality, RESET na for AFTV and DFTV	Significant variation in coefficient, especially for constant. Very small sample size.
OnTotExclin3	Onshore transformer capacity, generation capacity	R	R	R
		Generation capacity significant at 10% for ITV.	R-squared = 0.707 (ITV), 0.813 (DFTV), 0.647 (AFTV) Passes White test Normality, RESET na for AFTV and DFTV	Significant variation in coefficient, especially for constant. Very small sample size.
OnTotExclin4	Generation capacity	A	A	A
		Generation coefficient significant at the 1% level for ITV and 5% level for DFTV and AFTV.	R-squared = 0.709 (ITV), 0.642 (DFTV), 0.554 (AFTV) Passes all test.	Reasonable large variation in coefficient, especially for constant. Coefficients relatively stable to removal of smallest cost observation, however large variation with removal of

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
				largest.
OnTotExclin5	Generation capacity, onshore transformer dummy	A	A	R
		Transformer dummy significant for ITV, however constant negative. Generation coefficient significant at the 5% level for ITV, 10% level for DFTV and AFTV.	R-squared = 0.901 (ITV), 0.620 (DFTV), 0.519(AFTV) ITV passes all tests. DFTV and AFTV fail normaility and White.	Significant variation in coefficient. Coefficients relatively stable to removal of smallest cost observation, however large variation with removal of largest.
OnTotExclin6	Generation capacity, generation capacity squared, onshore transformer dummy	R	A	R
		Transformer dummy significant for ITV, however constant negative. Generation capacity coefficient significant at the 10% level for DFTV.	R-squared = 0.892 (ITV), 0.690 (DFTV), 0.609 (AFTV) Passes all test.	Significant variation in coefficient. Coefficients relatively stable to removal of smallest cost observation, however large variation with removal of largest.
OnTotExclin7	Generation capacity, generation capacity squared	A	A	A
		Generation capacity significant at 10% level for all stages. Coefficient on generation capacity square is as expected. Jointly significant.	R-squared = 0.739 (ITV), 0.715 (DFTV), 0.649 (AFTV) Passes all test.	Coefficients relatively stable. Coefficients relatively stable to removal of smallest cost observation. Reasonably large variation with removal of largest for DFTV and AFTV.

F.2.2. Log models

Table F.10: Onshore total costs excluding onshore other, log models (Part 1)

Variables	Data units for variable	OnTotExclog1			OnTotExclog2			OnTotExclog3			OnTotExclog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA	0.172623	0.327141	0.284152	-0.05339	0.150997	0.090366	-0.23301	0.000219	-0.00177			
OnReCap	MVAr				0.596402	0.485302	0.505655						
OnTransDummy	#												
GenCap	MW							.8712394**	.6946196*	0.658747	1.57158*	1.37791**	1.40316*
GenCap_sqrd	MW												
Constant	-	15.79511***	14.6729***	14.8781***	13.951***	13.14325***	13.33297**	13.04825***	12.49605***	12.69926**	7.262985*	8.326504**	8.197075*
Adjusted R2	n/a	0.01329	0.443166	0.318561	0.576581	0.761632	0.831575	0.817721	0.911282	0.838892	0.477642	0.525406	0.471964
No of observations	n/a	7	6	5	7	6	5	7	6	5	11	11	10
Normality test	n/a	.	.	.	.	.	.	.	.	.	0.024599	0.149154	0.192108
Ramsey RESET	n/a	0.769342	0.621238	0.484543	0.659511	.	.	0.269324	.	.	0.916728	0.812411	0.837246
White	n/a	0.965992	0.454099	0.167902	0.318718	0.306219	0.287298	0.262969	0.306219	0.287298	0.37639	0.280904	0.401244
Alpha factor	n/a	1.037467	1.027839	1.030501	0.999791	0.998056	0.998845	1.001585	1.002826	1.00314	0.935378	0.958239	0.947929

Table F.11: Onshore total costs excluding onshore other, log models (Part 2)

Variables	Data units for variable	OnTotExclog5			OnTotExclog6			OnTotExclog7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA									
OnReCap	MVAr									
OnTransDummy	#	2.175149**	0.925221	0.928564	2.210483**	0.919361	0.921567			
GenCap	MW	0.537959	.985196*	1.016435	-1.17764	3.671082	3.572266	5.637007	4.404259	4.421596
GenCap_sqrd	MW				0.152849	-0.24135	-0.23139	-0.36579	-0.2722	-0.27359
Constant	-	11.45269***	9.923086**	9.761341**	16.18759	2.535788	2.778373	-3.90529	0.006477	-0.0453
Adjusted R2	n/a	0.847822	0.629136	0.58167	0.828372	0.585325	0.520794	0.424481	0.476296	0.407145
No of observations	n/a	11	11	10	11	11	10	11	11	10
Normality test	n/a	0.077093	0.084897	0.139617	0.105228	0.121983	0.174223	0.007577	0.062612	0.091939
Ramsey RESET	n/a	0.97989	0.041568	0.084519	0.981912	0.039679	0.091898	0.449978	0.415118	0.497972
White	n/a	0.031635	0.067394	0.096747	0.090138	0.295443	0.370671	0.529825	0.364137	0.449504
Alpha Factor	n/a	1.022962	0.909905	0.885702	1.007687	0.959558	0.947622	1.026872	1.028766	1.04146

Table F.12: Onshore totals excluding onshore other assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTotExclog1	Onshore transformer capacity	R	R	R
		No significant coefficients, aside from constants.	R-squared = 0.013 (ITV), 0.443 (DFTV), 0.319 (AFTV) Passes White and RESET Normality Alpha factor close to 1.	Reasonably large variation in coefficient. Very small sample size.
OnTotExclog2	Onshore transformer capacity, onshore reactive capacity	R	R	R
		No significant coefficients, aside from constants. Negative transformer capacity in the ITV stage.	R-squared = 0.577 (ITV), 0.761 (DFTV), 0.832 (AFTV) Passes White test Normality, RESET na for AFTV and DFTV (and ITV for normality). Alpha factor close to 1.	Reasonably large variation in coefficient for transformer capacity between ITV and AFTV stages. Relatively stable to the removal of the smallest/largest cost observation. Very small sample size.
OnTotExclog3	Onshore transformer capacity, generation capacity	R	A	R
		Generation capacity significant at 10% for ITV and DFTV. Negative coefficient for transformer capacity at the ITV and AFTV stages.	R-squared = 0.818 (ITV), 0.911 (DFTV), 0.839 (AFTV) Passes White test Normality, RESET na for AFTV and DFTV Alpha factor close to 1.	Significant variation in coefficient, especially for constant. Sensitive to the removal of the smallest/largest cost observation. Very small sample size
OnTotExclog4	Generation capacity	A	R	A

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		Generation capacity coefficient significant at the 5% level for DFTV and 10% for ITV and AFTV.	R-squared = 0.478 (ITV), 0.525 (DFTV), 0.472 (AFTV) Passes White Passes RESET Normality fails for ITV only. Alpha factor not close to 1.	Relatively small variation for capacity. Sensitive to the removal of the smallest/largest cost observation.
OnTotExclog5	Generation capacity, onshore transformer dummy	A	A	R
		Transformer dummy significant at the 5% level for ITV. Generation capacity coefficient significant at the 10% level for DFTV. Signs as expected.	R-squared = 0.848 (ITV), 0.629 (DFTV), 0.582 (AFTV) Fails White, RESET for AFTV and DFTV. Fails normality for ITV and DFTV. Alpha factor not close to 1 for DFTV and AFTV.	Large differences in coefficients from ITV to AFTV. Sensitive to the removal of the smallest/largest cost observation.
OnTotExclog6	Generation capacity, generation capacity squared, onshore transformer dummy	R	A	R
		Transformer dummy significant at the 5% level for ITV.	R-squared = 0.828 (ITV), 0.585 (DFTV), 0.521 (AFTV) ITV fails White. DFTV and AFTV fails RESET Alpha factor not close to 1 for AFTV.	Large differences in coefficients from ITV to AFTV. Sensitive to the removal of the smallest/largest cost observation.
OnTotExclog7	Generation capacity, generation capacity squared	R	R	R
		No significant coefficients. Constant negative at ITV.	R-squared = 0.424 (ITV), 0.477 (DFTV), 0.407 (AFTV) Passes White and RESET	Little variation in coefficients. Very small sample size.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
			All stages fails normality. Alpha factor around 1	

F.3. Onshore total costs

F.3.1. Linear models

Table F.13: Onshore total costs, linear models (Part 1)

Variables	Data units for variable	OnTotlin1			OnTotlin2			OnTotlin3			OnTotlin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA	105095.5	114046.4	120750	94423.27	109849.2	118728.4	41114.65	67835.53	61234.12			
OnReCap	MVAr				41786.63	16636.23	7066.925						
OnTransDummy	#												
GenCap	MW							116504.9	83856.71	117930.4	171089.9 **	163453.2 ***	187979.2 ***
GenCap_sqrd	MW												
Constant	£	5339969	2718417	1674034	565975.2	914040.7	936850.7	-1.23E+07	-1.03E+07	-1.73E+07	-1.75E+07	-1.33E+07	-2.00E+07
Adjusted R2	n/a	0.265449	0.511386	0.485331	0.095839	0.351687	0.228652	0.220779	0.454157	0.459751	0.599857	0.69203	0.73143
No of observations	n/a	7	6	5	7	6	5	7	6	5	13	11	11
Normality test	n/a	.	.	.	.	.	.	.	.	.	0.093808	0.335116	0.433083
Ramsey RESET	n/a	0.025158	0.208065	0.164677	0.120195	.	.	0.012076	.	.	0.003196	0.016106	0.024666
White	n/a	0.066908	0.138106	0.106659	0.260843	0.306219	0.287298	0.297961	0.306219	0.287298	0.003766	0.02218	0.021959

Table F.14: Onshore total costs, linear models (Part 2)

Variables	Data units for variable	OnTotlin5			OnTotlin6			OnTotlin7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA									

Variables	**Data units for variable**	**OnTotlin5**			**OnTotlin6**			**OnTotlin7**		
		ITV	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**
OnReCap	MVAr									
OnTransDummy	#	1.06E+07	7828198	8864175	1.43E+07	9572689	1.10E+07			
GenCap	MW	154302.9**	152773.1**	174383.9**	-132575	-71648	-89704.3	-78827.1	-45590.2	-55955.1
GenCap_sqrd	MW				386.8664	301.8887	360.4837	344.1781	284.2169	337.1733
Constant	£	-1.90E+07	-1.50E+07	-2.11E+07	1.95E+07	1.51E+07	1.41E+07	1.71E+07	1.54E+07	1.32E+07
Adjusted R2	n/a	0.577331	0.665418	0.714481	0.612695	0.680177	0.760859	0.620234	0.702573	0.765436
No of observations	n/a	13	11	11	13	11	11	13	11	11
Normality test	n/a	0.043977	0.243892	0.158521	0.477412	0.782969	0.110772	0.827637	0.602017	0.278695
Ramsey RESET	n/a	0.002774	0.01287	0.010092	0.000154	0.061176	0.082111	0.001964	0.05105	0.035264
White	n/a	0.024367	0.085041	0.058998	0.08068	0.37197	0.232158	0.015294	0.276998	0.173847

Table F.15: Onshore total costs assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTotlin1	Onshore transformer capacity	R	R	R
		No significant coefficients.	R-squared = 0.265 (ITV), 0.511 (DFTV), 0.485 (AFTV) Passes White ITV fails RESET Normality na	Significant variation in coefficient, especially for constant. Very small sample size.
OnTotlin2	Onshore transformer capacity, onshore reactive capacity	R	R	R
		No significant coefficients.	R-squared = 0.096 (ITV), 0.352 (DFTV), 0.229 (AFTV) Passes White test. Normality, RESET na for AFTV and DFTV (normality na for ITV)	Significant variation in coefficient, especially for constant. Very small sample size.
OnTotlin3	Onshore transformer capacity, generation capacity	R	R	R
		No significant coefficients.	R-squared = 0.221 (ITV), 0.454 (DFTV), 0.456 (AFTV) Passes White test Normality na RESET na for AFTV and DFTV, fails for ITV.	Significant variation in coefficient, especially for constant. Very small sample size.
OnTotlin4	Generation capacity	A	A	R
		Coefficients on generation capacity significant at the 5% level for ITV, and 1% level for AFTV and DFTV.	R-squared = 0.600 (ITV), 0.692 (DFTV), 0.731 (AFTV) Fails White and RESET.	Significant movements in coefficient, mainly for the constant.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		Constant is negative.	DFTV and AFTV pass normality.	Very sample size.
OnTotlin5	Generation capacity, onshore transformer dummy	A	R	R
		Coefficients on generation capacity significant at the 5%.	R-squared = 0.577 (ITV), 0.665 (DFTV), 0.714 (AFTV) Fails White and RESET. DFTV and AFTV pass normality.	Significant movements in coefficient. Very sample size.
OnTotlin6	Generation capacity, generation capacity squared, onshore transformer dummy	R	R	R
		No significant coefficients.	R-squared = 0.613 (ITV), 0.783 (DFTV), 0.111 (AFTV) DFTV and AFTV pass White. Fails RESET Passes normality.	Significant movements in coefficient. Very sample size.
OnTotlin7	Generation capacity, generation capacity squared	R	A	R
		No significant coefficients.	R-squared = 0.620 (ITV), 0.703 (DFTV), 0.765 (AFTV) DFTV and AFTV pass White. Fails RESET Passes normality.	Not excessive variation in significant variable coefficient, although large jump in constant term.

F.3.2. Log models

Table F.16: Onshore total costs, log models (Part 1)

Variables	Data units for variable	OnTotlog1			OnTotlog2			OnTotlog3			OnTotlog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA	0.503946	.6948659 *	0.69468	0.432812	0.651824	0.640447	0.238304	0.423009	0.397297			
OnReCap	MVAr				0.187705	0.118586	0.141512						
OnTransDummy	#												
GenCap	MW							0.570554	0.577622	0.68515	1.60476***	1.400153 ***	1.627398 **
GenCap_sqrd	MW												
Constant	-	14.63228 ***	13.5283***	13.52493 **	14.05189 **	13.15452 **	13.09251 *	12.83343 **	11.7181*	11.25876 *	7.931806 ***	9.258292 ***	7.860898 **
Adjusted R2	n/a	0.36095	0.66401	0.598099	0.225946	0.56081	0.413133	0.340295	0.684134	0.619823	0.688714	0.82103	0.634734
No of observations	n/a	7	6	5	7	6	5	7	6	5	13	11	11
Normality test	n/a	.	.	.	.	.	.	.	.	.	0.486235	0.570598	0.032496
Ramsey RESET	n/a	0.102157	0.628007	0.346665	0.691286	.	.	0.074941	.	.	0.943595	0.553956	0.859873
White	n/a	0.159254	0.492655	0.262004	0.247921	0.306219	0.287298	0.471998	0.306219	0.287298	0.556101	0.63184	0.72327
Alpha factor	n/a	1.162323	1.10767	1.14895	1.164909	1.108376	1.148046	1.15966	1.08835	1.122791	1.122291	1.067839	1.13632

Table F.17: Onshore total costs, log models (Part 2)

Variables	Data units for variable	OnTotlog5			OnTotlog6			OnTotlog7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnTransCap	MVA									

Variables	Data units for variable	OnTotlog5			OnTotlog6			OnTotlog7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
OnReCap	MVAr									
OnTransDummy	#	.9884677*	0.489334	0.801915	.9881348*	0.486221	0.801059			
GenCap	MW	1.119869**	1.192453***	1.257654*	2.254077	2.619297	-0.23725	2.792364	3.007052	0.040774
GenCap_sqrd	MW				-0.102	-0.12821	0.135329	-0.10681	-0.14453	0.143594
Constant	-	10.02133***	10.1027***	9.440601**	6.900099	6.178286	13.53032	4.663898	4.840613	12.20218
Adjusted R2	n/a	0.826921	0.863346	0.723484	0.809032	0.847494	0.686663	0.65891	0.802743	0.591718
No of observations	n/a	13	11	11	13	11	11	13	11	11
Normality test	n/a	0.96203	0.922431	0.04517	0.95783	0.930748	0.05342	0.550605	0.564327	0.040286
Ramsey RESET	n/a	0.093843	0.123027	0.282886	0.137727	0.130731	0.351656	0.958005	0.362267	0.741839
White	n/a	0.101862	0.324958	0.728987	0.277453	0.504021	0.587436	0.09851	0.762951	0.817894
Alpha Factor	n/a	1.084332	1.053257	1.087509	1.10028	1.076973	1.048476	1.145971	1.095252	1.087738

Table F.18: Onshore total costs assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTotlog1	Onshore transformer capacity	R	R	R
		Transformer capacity significant at the 1% level for DFTV only.	R-squared = 0.361 (ITV), 0.6664 (DFTV), 0.598 (AFTV) Passes White, Normality, and RESET Alpha factor is not close to 1	Relatively large movements in coefficients. Very small sample size.
OnTotlog2	Onshore transformer capacity, onshore reactive capacity	R	A	R
		No significant coefficients, aside from constants.	R-squared = 0.226 (ITV), 0.561 (DFTV), 0.413 (AFTV) Passes White and RESET for ITV. Normality na. Alpha factor is not close to 1	Relatively large movements in coefficients. Very small sample size.
OnTotlog3	Onshore transformer capacity, generation capacity	R	R	R
		No significant coefficients, aside from constants.	R-squared = 0.340 (ITV), 0.684 (DFTV), 0.620 (AFTV) Passes White. Fails RESET at ITV, na for DFTV and AFTV. Normality na. Alpha factor is not close to 1	Relatively large movements in coefficients. Very small sample size.
OnTotlog4	Generation capacity	G	A	A
		Generation capacity coefficient significant at the 1% level for DFTV, 5% otherwise.	R-squared = 0.689 (ITV), 0.821 (DFTV), 0.635 (AFTV) Passes White and RESET. Fails Normality at AFTV. Alpha factor is not close to 1	Coefficients relatively stable to across stages. Relatively stable to the removal of smallest/ largest observations.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
OnTotlog5	Generation capacity, onshore transformer dummy	A	A	A
		Generation capacity coefficient significant at the 1% level, for DFTV and 5% for ITV and 10% for AFTV. Transformer dummy coefficient significant at the 10% level for ITV.	R-squared = 0.827 (ITV), 0.863 (DFTV), 0.723 (AFTV) Passes White and RESET. Fails Normality at AFTV. Alpha factor is not close to 1.	Coefficients relatively stable to across stages. Sensitive to the removal of the largest observation.
OnTotlog6	Generation capacity, generation capacity squared, onshore transformer dummy	R	A	R
		Transformer dummy coefficient significant at the 10% level for ITV.	R-squared = 0.809 (ITV), 0.847 (DFTV), 0.687 (AFTV) Passes White and RESET. Fails Normality at AFTV. Alpha factor is not close to 1	Relatively large movements in coefficients.
OnTotlog7	Generation capacity, generation capacity squared	R	A	R
		No significant coefficients.	R-squared = 0.659 (ITV), 0.803 (DFTV), 0.592 (AFTV) Passes RESET. Fails White at ITV. Fails Normality at AFTV Alpha factor is not close to 1	Relatively large movements in coefficients.

ANNEX G CABLING RESULTS AND ASSESSMENT TABLES

Note, all linear models are in £'s (e.g. a 442942 coefficient on length means an increase in costs of £442,942 per km), while all log models are elasticities (e.g. a 0.9 coefficient on length means a 1% increase in length will increase costs by 0.9%).

G.1. Sea cable supply

G.1.1. Linear models

Table G.1: Sea cable supply results, linear models (Part 1)

Variables/ statistics/ tests	Data units for variable	SCsuplin1			SCsuplin2			SCsuplin3			SCsuplin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SClen	km	442942 ***	466282 ***	470289 ***	530008 **	620317 **	750777 **	443915 ***	466379 ***	470527 ***	560338 ***	628721 **	750197 ***
SClen_sqrd	km				-395.086	-697.389	-1260.44				-529.065	-735.054	-1257.9
SCsize	mm^2	11563.0	9165.88	4027.078	10065.7	8072.19	-228.131						
SCrate	MVA												
Constant	£	-6137257	-4635774	-872523	-8104817	-8982428	-6885338	1487804	1200662	1728737	-2469246	-4114780	-7015004
Adjusted R2	n/a	0.95173	0.92637	0.93751	0.94983	0.92652	0.95484	0.94714	0.92986	0.94374	0.94774	0.93137	0.96048
No of observations	n/a	13	12	11	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.93844	0.08584	0.071781	0.95210	0.24753	0.2477	0.12944	0.13853	0.08618	0.64748	0.28555	0.24928
Ramsey RESET	n/a	0.32117	0.02228	0.01639	0.03759	0.00750	0.09305	0.63269	0.03089	0.01056	0.69802	0.07228	0.05431
White	n/a	0.30322	0.24998	0.20762	0.55864	0.16089	0.21558	0.29176	0.04199	0.03721	0.30330	0.15116	0.05351

Table G.2: Sea cable supply results, linear models (Part 2)

Variables/	Data	SCsuplin5			SCsuplin6			SCsuplin7			SCsuplin8		

statistics/ tests	units for variable	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SClen	km	448344.7***	472360.7***	457928.9***	596117.5***	759237.9**	723264.1**	448934.3***	470525.1***	467245.3***	626717.6***	741998.2**	740480.8**
SClen_sqrd	km				-665.533	-1278.36	-1176.32				-801.245	-1210.64	-1219.42
SCsize	mm^2	12956	14112	-28080	10719.3	15785.7	-22784.4						
SCrate	MVA	-57897.2	-56453.4	222301.7	-69772.4*	-98433	158141	-52641.9	-38173.6	51178	-68030.9	-75876.5	18120.61
Constant	£	2057648	1331630	-1.42E+07	424083	-2198640	-1.59E+07	9774038	7365596	-6103604	6203608	4699946	-9520747
Adjusted R2	n/a	0.96253	0.92819	0.936547	0.96814	0.94689	0.95187	0.95400	0.92712	0.93979	0.96273	0.94087	0.95525
No of observations	n/a	13	12	11	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.57243	0.03819	0.194865	0.14581	0.12742	0.50609	0.72010	0.10620	0.07832	0.57228	0.19827	0.27963
Ramsey RESET	n/a	0.30341	0.01540	0.044615	0.36209	0.08089	0.19229	0.31083	0.03707	0.01603	0.47661	0.03072	0.08476
White	n/a	0.79757	0.22321	0.313635	0.36904	0.36364	0.35751	0.12852	0.05440	0.06558	0.64262	0.21508	0.20208

Table G.3: Sea cables assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCsuplin1	Sea cable length, sea cable conductor size	A	A	A
		Sea cable length significant at 1% for all stages, conductor size not significant, relatively stable across stages.	Adjusted R2 = 0.952 (ITV), 0.926 (DFTV), 0.938 (AFTV). Passes White, Normality Passes RESET at ITV, fails at AFTV	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplin2	Sea cable length, sea cable conductor size, sea cable length squared	A	A	R
		Sea cable length significant at 5%, wrong expected sign for size at AFTV. Length squared suggests economies of scale.	Adjusted R2 = 0.95 (ITV), 0.926 (DFTV), 0.954 (AFTV). Passes White, Normality Passes RESET at AFTV, fails at ITV	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCsuplin3	Sea cable length	G	A	A
		Sea cable length significant at 1% for all stage, stable across stages.	Adjusted R2 = 0.947 (ITV), 0.929 (DFTV), 0.944 (AFTV). Fails White and RESET at AFTV (passes at ITV) Passes Normality	Relatively stable to removal of smallest cost observation. Larger change when largest cost observation removed. Not much change been ITV, DFTV and AFTV stages.
SCsuplin4	Sea cable length, sea cable length squared	A	A	R
		Sea cable length significant at 1% for ITV, AFTV, 5% for DFTV. Length squared suggests	Adjusted R2 = 0.948 (ITV), 0.929 (DFTV), 0.944 (AFTV). Passes White, Normality and RESET	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		economies of scale. Large negative constant not expected.	Normality and RESET only marginal passes at AFTV.	in coefficients between ITV and AFTV stages.
SCsuplin5	Sea cable length, sea cable conductor size, sea cable rating	R	A	R
		Sea cable length significant at 1%. Coefficients for size and rating change sign between models. Negative constant at AFTV.	Adjusted R2 = 0.948 (ITV), 0.929 (DFTV), 0.944 (AFTV). Fails RESET at AFTV (passes at ITV) Passes White, Normality	Relatively stable to removal of smallest cost observation. Larger change when largest cost observation removed. Reasonably large differences in coefficients between ITV and AFTV stages.
SCsuplin6	Sea cable length, sea cable conductor size, sea cable length squared, sea cable rating	R	G	R
		Sea cable length significant at 1% for all stages. Length squared suggests economies of scale. Sign changes for rating after DFTV. Negative constant at AFTV stage.	Adjusted R2 = 0.968 (ITV), 0.947 (DFTV), 0.952 (AFTV). Passes White, Normality, RESET	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCsuplin7	Sea cable length, sea cable rating	A	A	R
		Sea cable length significant at 1% for all, and stable coefficient. Rating changes sign for AFTV stage.	Adjusted R2 = 0.954 (ITV), 0.927 (DFTV), 0.940 (AFTV). Passes all test at ITV Fails RESET and marginally passes White at AFTV	Relatively stable to removal of smallest cost observation. Larger change when largest cost observation removed. Reasonably large differences in coefficients between ITV

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
				and AFTV stages.
SCsuplin8	Sea cable length, sea cable length squared, sea cable rating	A	G	R
		Sea cable length significant at 1% for ITV, 5% for AFTV, DFTV. Length squared suggests economies of scale. Changing sign for sea cable rating. Negative coefficient for constant at AFTV.	Adjusted R2 = 0.963 (ITV), 0.941 (DFTV), 0.955 (AFTV). Passes White, Normality, RESET	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.

G.1.2. Log models

Table G.4: Sea cable supply results, log models (Part 1)

Variables/ statistics/ tests	Data units for variable	SCsuplog1			SCsuplog2			SCsuplog3			SCsuplog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SClen	km	.9193189***	.9139377***	.9315212***	0.327454	0.357127	0.395014	.930844***	.9270079***	.9438465***	0.321051	0.303563	0.37105
SClen_sqrd	km				0.076576	0.071892	0.069041				0.078828	0.080376	0.073603
SCsize	mm^2	0.156819	0.262521	0.191056	0.149945	0.245793	0.178939						
SCrate	MVA												
Constant	£	12.36637***	11.75512***	12.16231***	13.50589***	12.89273***	13.23436***	13.33119***	13.38524***	13.34146***	14.46069***	14.54096***	14.40463***
Adjusted R2	n/a	0.922428	0.941971	0.947935	0.923897	0.944033	0.949393	0.923679	0.932913	0.945987	0.925682	0.935893	0.948122
No of observations	n/a	13	12	11	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.029441	0.381808	0.235032	0.0725	0.168385	0.164619	0.253212	0.325304	0.530658	0.493712	0.386975	0.627668
Ramsey RESET	n/a	0.398539	0.171451	0.388287	0.372202	0.291404	0.603887	0.561882	0.588251	0.295838	0.817429	0.405324	0.440992
White	n/a	0.810734	0.601805	0.646192	0.756053	0.467222	0.625887	0.720257	0.847066	0.387672	0.68652	0.867843	0.75567
Alpha factor	n/a	1.048398	1.053867	1.036587	0.987562	0.995204	0.977224	1.041206	1.050748	1.030905	0.976765	0.983306	0.96607

Table G.5: Sea cable supply results, log models (Part 2)

Variables/ statistics/ tests	Data units for variable	SCsuplog5			SCsuplog6			SCsuplog7			SCsuplog8		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SClen	km	.9342148***	.9350666***	.9147703***	0.331825	0.430015	0.377589	.9448651***	.9268572***	.9225861***	0.321948	0.30136	0.390928
SClen_sqrd	km				0.077962	0.064933	0.069123				0.080581	0.080512	0.068457
SCsize	mm^2	0.228665	0.389902	-0.29084	0.222607	0.361878	-0.30391						
SCrate	MVA	-0.29741	-0.29972	0.893143	-0.30131	-0.26933	0.89488	-0.20668	0.001644	0.39693	-0.21319	0.012467	0.376567
Constant	£	13.34934***	12.38299***	10.82109***	14.52236***	13.34681***	11.89181**	14.32148***	13.37746***	11.42363***	15.50727***	14.48391***	12.51085***
Adjusted R2	n/a	0.927845	0.943657	0.945956	0.930587	0.944189	0.947353	0.922795	0.925459	0.95111	0.925396	0.927903	0.952876
No of observations	n/a	13	12	11	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.006825	0.518328	0.431539	0.01403	0.39908	0.217834	0.227151	0.325467	0.498905	0.458495	0.379024	0.208049
Ramsey RESET	n/a	0.519649	0.305441	0.538881	0.556696	0.30441	0.73132	0.284992	0.425519	0.379749	0.483021	0.284289	0.62957
White	n/a	0.932965	0.303837	0.702981	0.369041	0.363643	0.357518	0.820388	0.336959	0.780175	0.912321	0.61753	0.217201
Alpha factor	n/a	1.038898	1.033881	1.038583	0.976066	0.980645	0.980169	1.036073	1.050833	1.038528	0.967695	0.984075	0.980259

Table G.6: Sea cables assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCsuplog1	Sea cable length, sea cable conductor size	G	A	A
		Sea cable length significant at 1% for all models. Coefficient just below 1 is as expected. Sea cable size not significant, though correct expected sign. Constant significant at 1% for all.	Adjusted R2 = 0.922 (ITV), 0.941 (DFTV), 0.948 (AFTV). Passes White, RESET Fails Normality at ITV (passes at AFTV) Alpha factor around 1	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplog2	Sea cable length, sea cable conductor size, sea cable length squared	R	G	R
		Only constant is significant. Coefficient of length lower than expected (c.0.3-0.4).	A Adjusted R2 = 0.924 (ITV), 0.944 (DFTV), 0.950 (AFTV). Passes White, RESET Marginally passes Normality at ITV (passes at AFTV) Alpha factor around 1	Sensitive to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplog3	Sea cable length	G	G	A
		Sea cable length significant at 1% for all models. Coefficient stable and just below 1 is as expected. Constant significant at 1% for all.	Adjusted R2 = 0.923 (ITV), 0.932 (DFTV), 0.945 (AFTV). Passes White, Normality, RESET Alpha factor around 1	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplog4	Sea cable length, sea cable length squared	R	G	R
		Only constant is significant. Coefficient of length lower	Adjusted R2 = 0.926 (ITV), 0.936 (DFTV), 0.948 (AFTV).	Sensitive to the removal of smallest/ largest cost

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		than expected (c.0.3-0.4).	Passes White, Normality, RESET Alpha factor around 1	observation. Not much change been ITV, DFTV and AFTV stages.
SCsuplog5	Sea cable length, sea cable conductor size, sea cable rating	A	A	A
		Sea cable length significant at 1% for all models. Coefficient stable and just below 1 is as expected. Sign changes on model for size and rating between stages. Constant significant at 1% for all.	Adjusted R2 = 0.928 (ITV), 0.943 (DFTV), 0.945 (AFTV). Passes White, RESET Fails Normality at ITV (passes at AFTV) Alpha factor around 1	Relatively stable to removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCsuplog6	Sea cable length, sea cable conductor size, sea cable length squared, sea cable rating	R	A	R
		Only constant is significant. Coefficient of length lower than expected (c.0.3-0.4). Sign changes on model for size and rating between stages.	Adjusted R2 = 0.930 (ITV), 0.944 (DFTV), 0.947 (AFTV). Passes White, RESET Fails Normality at ITV (passes at AFTV) Alpha factor around 1	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCsuplog7	Sea cable length, sea cable rating	A	G	A
		Sea cable length significant at 1% for all models. Coefficient stable and just below 1 is as expected. Rating not significant, but changes sign from ITV to	Adjusted R2 = 0.923 (ITV), 0.945 (DFTV), 0.951 (AFTV). Passes White, Normality, RESET Alpha factor around 1	Relatively stable to removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages. Aside from SCrate which changes

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		AFTV. Constant significant at 1% for all.		sign, but is not significantly different zero.
SCsuplog8	Sea cable length, sea cable length squared, sea cable rating	R	G	R
		Only constant is significant. Coefficient of length lower than expected (c.0.3-0.4). Sign changes for rating between stages.	Adj R2 high (0.92,0.95) Passes White, Normality, RESET Alpha factor around 1	Sensitive to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages. Aside from SCrate which changes sign, but is not significantly different zero.

G.2. Sea cable installation

G.2.1. Linear models

Table G.7: Sea cable installation, linear models

Variables	Data units for variable	SCinslin1			SCinslin2			SCinslin3		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SCNo_inc	#	6337209	-560143	4158546	6152407	-214347	3708129			
SClen	km	245354.2	319295.4	254444.4	223256.5	358480.8	201991.1	334034.2***	311461.9**	312618.4***
SClen_sqrd	km				112.1722	-199.32	264.2637			
SCsize	mm^2									
Constant	£	-529437	1.03E+07	3862297	467937.1	8576233	6084423	4902404	9834448	7418807
Adjusted R2		0.601613	0.600697	0.66158	0.557695	0.551973	0.615204	0.6258607	0.6405165	0.6925491
No of observations		13	12	11	13	12	11	13	12	11
Normality test		0.081506	0.088438	0.061717	0.071646	0.067866	0.101788	0.0961684	0.0876029	0.073468
Ramsey RESET		0.107373	0.042043	0.009334	0.142159	0.008405	0.009854	0.0774066	0.0239858	0.0089901
White		0.386466	0.144082	0.156457	0.423554	0.153269	0.204924	0.1508012	0.0601878	0.0414541

Table G.8: Sea cable installation, linear models

Variables	**Data units for variable**	**SCinslin4**			**SCinslin5**			**SCinslin6**		
		ITV	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**
SCNo_inc	#									
SClen	km	280844.5	356647.8	230484.7	332476.7**	311385.5**	312265.7**	219228.5	349427.9	211402.8
SClen_sqrd	km	241.7133	-204.5933	369.4191				513.896	-172.2362	453.2535
SCsize	mm^2				18501.03	7204.647	5983.552	20448.69	6934.535	7513.719
Constant	£	6710257	8354960	9986668	-7297822	5246839	3553778	-4738577	4173333	5715978
Adjusted R2		0.5899456	0.6017364	0.6576569	0.619285	0.6048633	0.6571864	0.584131	0.5563913	0.6140725
No of observations		13	12	11	13	12	11	13	12	11
Normality test		0.0713962	0.0672327	0.1423286	0.4300561	0.0834792	0.0763482	0.4028697	0.067345	0.1657399
Ramsey RESET		0.1067274	0.0132888	0.0142024	0.0074307	0.0290671	0.0123403	0.0132668	0.0132098	0.0281081
White		0.3092259	0.0265868	0.0279066	0.19158	0.3311523	0.100671	0.1305754	0.1580902	0.2033856

Table G.9: Sea cable installation assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCinslin1	Sea cable numbers (above 1), Sea cable length	R	A	R
		No significant variables. Sign on Sea cable numbers is not as expected at DFTV.	Adjusted R2 = 0.602 (ITV), 0.601 (DFTV), 0.662 (AFTV) Passes White and Normality. DFTV and AFTV fails RESET.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCinslin2	Sea cable numbers (above 1), Sea cable length, sea cable length squared	R	R	R
		No significant coefficients. Squared term wrong sign from ITV and AFTV.	Adjusted R2 = 0.558 (ITV), 0.552 (DFTV), 0.615 (AFTV) Passes White and marginal pass for Normality. DFTV and AFTV fails RESET.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCinslin3	Sea cable length	G	A	R
		Sea cable length significant (1% for ITV, AFTV, 5% for DFTV) and relatively stable. Sign as expected.	Adjusted R2 = 0.626 (ITV), 0.641 (DFTV), 0.693 (AFTV) Marginal passes White and Normality. DFTV and AFTV fails RESET, ITV marginal.	Relatively stable to removal of smallest cost observation. Larger change when largest cost observation removed. Reasonably large differences in coefficients between ITV and AFTV stages.
SCinslin4	Sea cable length, sea cable length squared	A	R	A
		No significant coefficients. Squared term jointly significant with length. Squared term	Adjusted R2 = 0.590 (ITV), 0.602 (DFTV), 0.658 (AFTV) Very marginal passes on White,	Relatively stable to removal of smallest cost observation. Larger change when largest

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		wrong sign from ITV and AFTV.	Normality and RESET.	cost observation removed. Reasonably large differences in coefficients between ITV and AFTV stages.
SCinslin5	Sea cable length, sea cable size	A	A	A
		Sea cable length significant at the 5% level and relatively stable. Signs as expected, apart from the constant in the ITV stage.	Adjusted R2 = 0.619 (ITV), 0.605 (DFTV), 0.657 (AFTV) Passes White and marginal pass Normality for DFTV and AFTV (pass ITV). ITV fails RESET, and AFTV and DFTV marginal.	Relatively stable to removal of smallest cost observation. Larger change when largest cost observation removed. Not much change been ITV, DFTV and AFTV stages.
SCinslin6	Sea cable length, sea cable length squared, sea cable size	R	R	R
		No significant coefficients. Squared term jointly significant with length. Squared term wrong sign from ITV and AFTV. Negative constant in ITV stage.	Adjusted R2 = 0.584 (ITV), 0.556 (DFTV), 0.614 (AFTV) Very marginal passes on Normality and RESET. Pass on White.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.

G.2.2. Log models

Table G.10: Sea cable installation, log models

Variables	Data units for variable	SCinslog1			SCinslog2			SCinslog3		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SCNo_inc	#	0.6104365	0.1394535	0.427793	0.623055	0.255195	0.52819			
SClen	km	.4846445*	.6511119*	.5340355*	0.550974	1.259527	1.065299	.749197***	.7114771***	.7195378***
SClen_sqrd	km				-0.00928	-0.0849	-0.07386			
SCsize	mm^2									
Constant		14.66567	14.42168***	14.64712***	14.54794***	13.34071***	13.70166***	13.92778***	14.25328***	14.1297***
Adjusted R2	n/a	0.7075519	0.7039159	0.699075	0.675193	0.680945	0.666572	0.665875	0.729103	0.691819
No of observations	n/a	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.5888457	0.1469296	0.359796	0.628335	0.229893	0.447306	0.8261	0.179145	0.29575
Ramsey RESET	n/a	0.4363185	0.4571128	0.233521	0.224695	0.172056	0.175331	0.928271	0.758429	0.863514
White	n/a	0.6032355	0.7345431	0.666692	0.43672	0.186641	0.28383	0.795669	0.419289	0.680134
Alpha Factor	n/a	1.065405	1.037957	1.035873	1.070289	1.070428	1.068752	1.135337	1.052554	1.087851

Table G.11: Sea cable installation, log models

Variables	**Data units for variable**	**SCinslog4**			**SCinslog5**			**SCinslog6**		
		ITV	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**
SCNo_inc	#									
SClen	km	0.08136	1.060257	0.642463	.7377081***	.7016898***	.7054484**	0.087713	1.105743	0.671609
SClen_sqrd	km	0.086331	-0.04497	0.009904				0.084096	-0.05217	0.004355
SCsize	mm^2				0.156327	0.196583	0.218404	0.148778	0.208721	0.217639
Constant		15.16479***	13.60673***	14.27276***	12.96599***	13.0326***	12.78177***	14.21743**	12.20709**	12.84939**
Adjusted R2	n/a	0.645768	0.703453	0.653507	0.639763	0.71162	0.668154	0.613746	0.682258	0.620794
No of observations	n/a	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.738047	0.242699	0.303836	0.646157	0.322634	0.509858	0.727888	0.506592	0.517326
Ramsey RESET	n/a	0.20735	0.229241	0.784865	0.918474	0.836093	0.770521	0.164771	0.708605	0.582037
White	n/a	0.351771	0.088595	0.115779	0.109436	0.588667	0.287891	0.195152	0.160418	0.284225
Alpha Factor	n/a	1.080338	1.075122	1.082166	1.142527	1.05308	1.090501	1.091348	1.07742	1.088222

Table G.12: Sea cable installation assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCinslog1	Sea cable numbers (above 1), Sea cable length	G	A	A
		Sea cable length significant at 10% level and relatively stable. Signs are as expected.	Adjusted R2 = 0.707 (ITV), 0.704 (DFTV), 0.699 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high for ITV.	Relatively stable to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCinslog2	Sea cable numbers (above 1), Sea cable length, sea cable length squared	A	A	R
		No significant coefficients. Length and squared term jointly significant at the 10% level.	Adjusted R2 = 0.675 (ITV), 0.681 (DFTV), 0.666 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large (and signs) changes in coefficients between ITV and AFTV stages.
SCinslog3	Sea cable length	G	A	A
		Sea cable length significant at 1% level for all stages. Signs are as expected.	Adjusted R2 = 0.666 (ITV), 0.729 (DFTV), 0.692 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high.	Relatively stable to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCinslog4	Sea cable length, sea cable length squared	A	A	R
		No significant coefficients. Squared term wrong sign from ITV and AFTV stages. Length and squared term jointly	Adjusted R2 = 0.646 (ITV), 0.703 (DFTV), 0.653 (AFTV) Passes White (marginal for DFTV), Normality and RESET.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large (and signs)

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		significant at the 5% level.	Alpha factor relatively high.	changes in coefficients between ITV and AFTV stages.
SCinslog5	Sea cable length, sea cable size	G	A	A
		Sea cable length significant (1% for ITV, DFTV, 5% for AFTV) and relatively stable. Signs are as expected.	Adjusted R2 = 0.640 (ITV), 0.712 (DFTV), 0.668 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high.	Relatively stable to the removal of smallest/ largest cost observation. Marginal large differences been ITV, DFTV and AFTV stages.
SCinslog6	Sea cable length, sea cable length squared, sea cable size	R	A	R
		No significant coefficients. Squared term wrong sign from ITV and AFTV stages.	Adjusted R2 = 0.614 (ITV), 0.682 (DFTV), 0.621 (AFTV) Passes White, Normality and RESET. Alpha factor relatively high.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large (and signs) changes in coefficients between ITV and AFTV stages.

G.3. Sea cable total

G.3.1. Linear models

Table G.13: Sea cable total costs, linear models

Variables/ statistics/ tests	Data units for variable	SCtotlin1			SCtotlin2			SCtotlin3			SCtotlin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SClen	km	777949.5***	777841***	783144.9***	841182*	985368.9**	980681.9**	775418.6***	777667.3***	782554.8***	749236.2	969744.7**	962179.4**
SClen_sqrd	km				-287.3516	-939.6477	-888.4781				118.8102	-869.6251	-807.1891
SCsize	mm^2							30064.06	16370.52	10010.63	30514.35	15006.72	7285.588
Constant	£	6390208	11000000	9147544	4241010	4240181	2971664	-1.34E+07	611064.2	2681255	-1.28E+07	-4809096	-1169360
Adjusted R2	n/a	0.8758385	0.9413772	0.9661459	0.8639449	0.9403929	0.9662868	0.8836714	0.939857	0.9637488	0.870841	0.9376281	0.9625394
No of observations	n/a	13	12	11	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.0017396	0.0119792	0.0702382	0.0032551	0.158288	0.5114608	0.0615681	0.0037748	0.0343665	0.0531987	0.060229	0.3936714
Ramsey RESET	n/a	0.3288832	0.3593788	0.0099854	0.1992344	0.3564331	0.0252413	0.0440592	0.3319321	0.0164616	0.0014328	0.0330611	0.0367921
White	n/a	0.3115045	0.1251823	0.0634414	0.5767076	0.0533564	0.0409508	0.0497141	0.4764053	0.1191654	0.1347665	0.1727933	0.2023641

Table G.14: Sea cable total cost assessment, linear models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCtotlin1	Sea cable length	A	R	A
		Sea cable length significant at 1%. Signs are as expected. Rather large variation in the constant from ITV to AFTV.	Adjusted R2 = 0.876 (ITV), 0.941 (DFTV), 0.966 (AFTV) Passes White. AFTV fails RESET. All stages fail normality (although marginal pass for AFTV).	Relatively stable to the removal of smallest/ largest cost observation. Although rather large movement in the constant. Although rather large variation in the constant from ITV to AFTV.
SCtotlin2	Sea cable length, sea cable length squared	A	R	R
		Sea cable length significant at 5% for DFTV and AFTV, and at the 10% level for ITV. Coefficients jointly significant. Signs are as expected.	Adjusted R2 = 0.864 (ITV), 0.940 (DFTV), 0.966 (AFTV) Only ITV pass White. AFTV fails RESET. All stages fail normality (although marginal pass for AFTV).	Sensitive to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCtotlin3	Sea cable length, sea cable conductor size	A	R	A
		Sea cable length significant at 1%. Signs are as expected. Rather large variation in the constant from ITV to AFTV.	Adjusted R2 = 0.884 (ITV), 0.940 (DFTV), 0.964 (AFTV) AFTV and DFTV pass White. ITV and AFTV fails RESET. All stages fail normality (although marginal for ITV).	Relatively stable to the removal of smallest/ largest cost observation. Although rather large movement in the constant. Rather large variation in the constant from ITV to AFTV.
SCtotlin4	Sea cable length, sea cable	R	R	R

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
	length squared, sea cable conductor size	Only length coefficient significant for DFTV and AFTV. Constant with negative sign.	Adjusted R2 = 0.871 (ITV), 0.938 (DFTV), 0.963 (AFTV) Passes White (marginal for DFTV). All stages fails RESET. Marginal pass for ITV and DFTV for normality.	Sensitive to the removal of smallest/ largest cost observation. Reasonably large (and signs) changes in coefficients between ITV and AFTV stages.

G.3.2. Log models

Table G.15: Sea cable total costs, log models (Part 1)

Variables/ statistics/ tests	Data units for variable	SCtotlog1			SCtotlog2			SCtotlog3			SCtotlog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
SClen	km	.8463209***	.8360428***	.8470458***	0.198012	0.647288	0.504064	.8371571***	.8261223***	.8367611***	0.203022	0.689819	0.52447
SClen_sqrd	km				0.083807	0.024335	0.044073				0.082044	0.017599	0.040187
SCsize	mm^2							0.124689	0.199258	0.159425	0.117324	0.195163	0.152371
Constant	-	14.32416***	14.47281***	14.40213***	15.525***	14.82272***	15.03874***	13.55702***	13.23552***	13.41821***	14.77792***	13.514***	14.04223***
Adjusted R2	n/a	0.895432	0.951942	0.957405	0.897782	0.9478	0.95608	0.889719	0.958513	0.959683	0.891085	0.954026	0.957707
No of observations	n/a	13	12	11	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.113088	0.839502	0.386751	0.011799	0.899078	0.52093	0.260597	0.728816	0.896647	0.030849	0.663665	0.935843
Ramsey RESET	n/a	0.698635	0.748325	0.535449	0.359268	0.417499	0.278084	0.48392	0.883761	0.797967	0.021905	0.240048	0.403674
White	n/a	0.916732	0.772579	0.635789	0.770598	0.480242	0.466922	0.107812	0.110952	0.067179	0.231406	0.22312	0.207193
Alpha factor	n/a	1.061031	1.013893	1.020971	1.000286	0.9973	0.988514	1.066847	1.015691	1.024718	1.008868	1.004096	0.996068

Table G.16: Sea cable total cost assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
SCtotlog1	Sea cable length	G	G	A
		Sea cable length significant at 1%. Signs are as expected.	Adjusted R2 = 0.895 (ITV), 0.952 (DFTV), 0.957 (AFTV) All stages pass the tests. Alpha factor relatively close to 1.	Relatively stable to the removal of smallest/ largest cost observation. Although rather large movement in the constant when small cost observation removed. Not much change been ITV, DFTV and AFTV stages.
SCtotlog2	Sea cable length, sea cable length squared	A	A	R
		Coefficients jointly significant. Signs are as expected.	Adjusted R2 = 0.864 (ITV), 0.940 (DFTV), 0.966 (AFTV) All stages pass the tests expect for ITV failing normality test. Alpha factor relatively close to 1.	Sensitive to the removal of smallest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.
SCtotlog3	Sea cable length, sea cable conductor size	G	A	A
		Sea cable length significant at 1%. Signs are as expected.	Adjusted R2 = 0.890 (ITV), 0.959 (DFTV), 0.960 (AFTV) All stages pass the tests. Alpha factor relatively close to 1, although ITV stage a little high.	Relatively stable to the removal of smallest/ largest cost observation. Not much change been ITV, DFTV and AFTV stages.
SCtotlog4	Sea cable length, sea cable	R	A	R

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
	length squared, sea cable conductor size	Only constant significant. Signs are as expected.	Adjusted R2 = 0.891 (ITV), 0.954 (DFTV), 0.958 (AFTV) ITV fails RESET and normality. All others passed.	Sensitive to the removal of smallest cost observation. Reasonably large differences in coefficients between ITV and AFTV stages.

G.4. Land cable total costs

G.4.1. Linear models

Table G.17: Land cable total costs, linear model (Part 1)

Variables/ statistics/ tests	Data units for variable	LCtotlin1			LCtotlin2			LCtotlin3			LCtotlin4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
LClen	km	394598.2***	347651.7***	128242.5	401315.1**	364128.8**	-8661.241	-576629.4	-417205.7	600372	470680.3***	442771.9**	998976.9***
CopInter	km	204546.3	224069.4	319723.3	190401.9	207003.2	368090.8	489366.6	441305	-2465248*			
LCsize	mm2				-828.2009	-1771.484	-2028.634	929.5594	-2068.379	4412.931			
LClen_sqrd	km							21313.83	17403.9	432922.1**			
Constant	-	2789760*	3354232*	3747727	3382422	4401346	5226209	4279598	6042961	1708922	4206542*	5001925*	2662267
Adjusted R2	n/a	0.7819327	0.7913702	0.4838115	0.754647	0.7647549	0.4064802	0.7490131	0.7354425	0.9014691	0.621827	0.5468983	0.8137823
No of observations	n/a	11	10	9	11	10	9	11	10	9	13	12	11
Normality test	n/a	0.9213532	0.5236553	0.4820635	0.9711111	0.2473868	0.3535327	0.6837997	0.4204679	0.400637	0.1511343	0.0451337	0.9987664
Ramsey RESET	n/a	0.0106167	0.0871474	0.0339873	0.046745	0.1646345	0.2434613	0.0152252	0.0829777	0.6647412	0.0001508	0.0015776	0.0929013
White	n/a	0.56316	0.7368246	0.8037166	0.2757143	0.3504852	0.342296	0.357518	0.3504852	0.342296	0.0202409	0.0234271	0.4418689

Table G.18: Land cable total costs, linear model (Part 2)

Variables	Data units for variable	LCtotlin5			LCtotlin6			LCtotlin7		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
LClen	km	1186888**	1422111**	-91314.89	502290***	523790.1**	967544.3***	1153686**	1310976**	-19967.19
CopInter	km									
LCsize	mm2				-4970.991	-10128.12	-4736.703	-4280.443	-6181.806	-3558.523
LClen_sqrd	km	-17219.12	-23600.45*	50692.71				-15766.47	-19730.61*	46277.49
Constant	-	1827581	1873055	5120588**	7178103*	10100000**	5338717	4587041	5498535	6917200*
Adjusted R2	n/a	0.716585	0.7515056	0.8693924	0.6696222	0.6435145	0.8240718	0.754578	0.7743243	0.8717018
No of observations	n/a	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.4399743	0.8037096	0.7891897	0.5822617	0.2975792	0.3876475	0.9630828	0.8030806	0.1666494
Ramsey RESET	n/a	0.0017653	0.0319762	0.0307881	0.0098665	0.0231682	0.3351776	0.0303781	0.1539379	0.325893
White	n/a	0.3170256	0.5788126	0.9041923	0.1283762	0.1475175	0.6292878	0.8973945	0.8228547	0.2888222

Table G.19: Land cable total cost assessment, linear model

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
LCtotlin1	Land cable length, copper interaction	A	R	R
		Length coefficient significant at the 1% level for ITV and DFTV. Signs are as expected.	Adjusted R2 = 0.782 (ITV), 0.791 (DFTV), 0.484 (AFTV) Fails RESET test.	Sensitive to the removal of largest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlin2	Land cable length, land cable conductor size, copper interaction	A	A	R
		Length coefficient significant at the 5% level for ITV and DFTV. Signs are not as expected for AFTV or LCsize.	Adjusted R2 = 0.755 (ITV), 0.765 (DFTV), 0.401 (AFTV) Only ITV fails RESET test.	Sensitive to the removal of largest/smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlin3	land cable length, land cable conductor size, copper interaction, land cable length squared	R	A	R
		Not many significant coefficients. Signs are not as expected for a number of coefficients. Length and length squared jointly significant.	Adjusted R2 = 0.749 (ITV), 0.735 (DFTV), 0.901 (AFTV) Only ITV fails RESET test.	Sensitive to the removal of largest/smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlin4	Land cable length	A	R	R
		Length coefficient significant at the 1% level for ITV and AFTV, at the 5% level for	Adjusted R2 = 0.622 (ITV), 0.547 (DFTV), 0.814 (AFTV) Fails RESET test (marginally at	Sensitive to the removal of largest cost observation. Reasonably large differences

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
		DFTV. Signs are as expected.	AFTV). ITV and DFTV fail White. DFTV fails normality.	in coefficients between ITV and DFTV, and AFTV stages.
LCtotlin5	Land cable length, land cable length squared	A	R	R
		Coefficient significant at the 5% level for ITV and DFTV. Signs are as expected for ITV and DFTV. Length and length squared jointly significant.	Adjusted R2 = 0.717 (ITV), 0.752 (DFTV), 0.869 (AFTV) Fails RESET test.	Sensitive to the removal of largest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlin6	Land cable length, land cable conductor size	A	A	R
		Length coefficient significant at the 1% level for ITV and AFTV, at the 5% level for DFTV. Signs are not as expected for LCsize across all three stages.	Adjusted R2 = 0.670 (ITV), 0.644 (DFTV), 0.824 (AFTV) ITV and DFTV fail the RESET test.	Sensitive to the removal of largest/smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlin7	Land cable length, land cable length squared, land cable conductor size	A	A	R
		Length coefficient significant at the 5% level for ITV and DFTV, not significant for AFTV. Signs are not as expected for AFTV or LCsize across all three stages.	Adjusted R2 = 0.755 (ITV), 0.774 (DFTV), 0.872 (AFTV) ITV fails the RESET test.	Sensitive to the removal of largest/smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.

G.4.2. Log models

Table G.20: Land cable total costs, log models (Part 1)

Variables/ statistics/ tests	Data units for variable	LCtotlog1			LCtotlog2			LCtotlog3			LCtotlog4		
		ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV	ITV	DFTV	AFTV
LClen	km	0.346778	0.362965	0.001883	0.35314	0.364128	-0.1493	-0.37911	-0.25815	0.469035	0.293424	0.321996	0.272132
CopInter	km	-0.17043	-0.11883	0.177907	-0.17703	-0.11944	0.311086	0.00894	0.085382	-1.65841			
LCsize	mm2				-0.04522	-0.01268	-0.32995	-0.16016	-0.31856	0.412181			
LClen_sqrd	km							0.235884	0.197037	.9019562*			
Constant	-	15.07784***	15.16353***	15.20311***	15.36582**	15.24296**	17.28927**	16.21388**	17.20134**	12.43642*	15.17047***	15.27021***	15.30148***
Adjusted R2	n/a	0.020201	0.134067	-0.22272	-0.11857	-0.01015	-0.38804	0.189714	0.193159	0.433832	0.106736	0.220698	0.073667
No of observations	n/a	11	10	9	11	10	9	11	10	9	13	12	11
Normality test	n/a	0.152705	0.260092	0.295582	0.130796	0.247055	0.072453	0.006216	0.035399	0.906422	0.135239	0.277302	0.482444
Ramsey RESET	n/a	0.39753	0.108443	0.073363	0.479438	0.097808	0.302416	0.592243	0.359194	0.457626	0.018967	0.031371	0.055202
White	n/a	0.844177	0.850772	0.958844	0.275747	0.350485	0.342296	0.357518	0.350485	0.342296	0.966143	0.862963	0.831003
Alpha factor	n/a	1.307576	1.183856	1.204524	1.311302	1.185764	1.199282	0.925847	1.014634	1.014139	1.422122	1.306535	1.37106

Table G.21: Land cable total costs, log models (Part 2)

Variables	**Data units for variable**	**LCtotlog5**			**LCtotlog6**			**LCtotlog7**		
		ITV	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**	**ITV**	**DFTV**	**AFTV**
LClen	km	-0.44558	-0.22655	-0.36945	0.335522	0.363537	0.286615	-0.40228	-0.21199	-0.33
CopInter	km									
LCsize	mm2				-0.31593	-0.36648	-0.46289	-0.30586	-0.46931	-0.34417
LClen_sqrd	km	.263149*	.1933543*	.3123017*				.2622426*	.2069748*	.298343*
Constant	-	15.28291***	15.33643***	15.25519***	17.10937***	17.49772***	18.13882***	17.15959***	18.19363***	17.36692***
Adjusted R2	n/a	0.479736	0.461074	0.503965	0.068807	0.202723	0.080153	0.475447	0.518469	0.509114
No of observations	n/a	13	12	11	13	12	11	13	12	11
Normality test	n/a	0.029444	0.378522	0.190114	0.034995	0.077901	0.107517	0.001615	0.020568	0.017625
Ramsey RESET	n/a	0.59893	0.505648	0.904026	0.07868	0.169635	0.294826	0.57451	0.670818	0.966401
White	n/a	0.973485	0.942154	0.825055	0.931801	0.773873	0.704329	0.464762	0.365763	0.386035
Alpha factor	n/a	0.82737	0.900856	1.038741	1.42301	1.31719	1.350229	0.895054	0.985973	1.012058

Table G.22: Land cable total cost assessment, log models

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
LCtotlog1	Land cable length, copper interaction	R	R	R
		No significant variables. Sign on CopInter not as expected.	Adjusted R2 = 0.020 (ITV), 0.134 (DFTV), -0.223 (AFTV).[48] Passes tests, although marginal pass for AFTV on the RESET. Alpha factor not close to 1.	Sensitive to the removal of largest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlog2	Land cable length, land cable conductor size, copper interaction	R	R	R
		No significant coefficients. Signs not as expected.	Adjusted R2 = -0.119 (ITV), -0.010 (DFTV), -0.388 (AFTV) Only DFTV fails RESET test. Alpha factor not close to 1.	Sensitive to the removal of largest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlog3	land cable length, land cable conductor size, copper interaction, land cable length squared	R	R	R
		No significant coefficients, expect length squared. Signs not as expected for many variables.	Adjusted R2 = 0.190 (ITV), 0.193 (DFTV), 0.434 (AFTV) Only DFTV fails normality test. Alpha factor not close to 1.	Sensitive to the removal of largest/smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlog4	Land cable length	A	R	R
		Length coefficient not significant. Signs are as expected.	Adjusted R2 = 0.107 (ITV), 0.221 (DFTV), 0.074 (AFTV) Fails RESET test.	Sensitive to the removal of largest cost observation. Reasonably large differences in

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[48] Note, the adjusted R-squared can be negative when there are few observations and/ or the R-squared is low. In this case the latter applies.

Model reference	Explanatory variables	Coefficients	Statistical test	Robustness
			Alpha factor not close to 1.	coefficients between ITV and DFTV, and AFTV stages.
LCtotlog5	Land cable length, land cable length squared	R	R	R
		Length squared coefficient significant at the 10% level. Signs are not as expected.	Adjusted R2 = 0.480 (ITV), 0.461 (DFTV), 0.504 (AFTV) ITV fails normality test. Alpha factor not close to 1.	Sensitive to the removal of smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.
LCtotlog6	Land cable length, land cable conductor size	R	R	R
		No significant coefficients. Signs are not as expected for LCsize across all three stages.	Adjusted R2 = 0.069 (ITV), 0.203 (DFTV), 0.080 (AFTV) ITV fails normality and the RESET test.	Sensitive to the removal of largest cost observation.
LCtotlog7	Land cable length, land cable length squared, land cable conductor size	A	A	R
		Length squared coefficient significant at the 10% level. Length and length squared jointly significant. Signs are not as expected for size.	Adjusted R2 = 0.475 (ITV), 0.518 (DFTV), 0.509 (AFTV) All stages fail normality.	Sensitive to the removal of smallest cost observation. Reasonably large differences in coefficients between ITV and DFTV, and AFTV stages.