Quality Assurance of CMP213 Modelling 2014

This report has been prepared by Lane Clark and Peacock LLP ("LCP"). It is addressed to Ofgem and presents our Quality Assurance (QA) findings on the models used for analysis of the effect of different options under the Connection and Use of System Code (CUSC) Modification Proposal 213 ("CMP213").

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Executive Summary

We have reviewed certain elements of the updated CMP213 modelling and have found no issues with the implementation of the agreed methodology that we believe would materially affect the conclusions reached from the modelling results.

We have found some minor issues with the implementation, which we have outlined in this report, but we do not believe that these issues should fundamentally affect the main modelling results. Many of these relate to usability and flexibility and are only of concern if there is intention to use the model again for further analysis.

To reach these conclusions we have reviewed key calculations within the models through a combination of code/formula review, delta comparison and sensitivity analysis. We cannot guarantee that the model will produce correct results under all conditions, particularly if the data set was to change significantly. It should also be noted that some areas of the model were not available for review due to intellectual property rights.

In the appendix to this document we have provided an issues log of the minor issues that we have found. This log contains a description of each issue, the implications and a suggested action where appropriate.

Although, as requested, the focus of our review was on the implementation of the model methodology, we have also been asked to provide a high-level view on the nature of the updates and the model methodology itself.

The principal question that the modelling is attempting to answer remains a challenging one: how will changes in transmission charging affect investment, retirement and dispatch decisions? Any analysis that attempts to answer this question will inevitably be very sensitive to modelling assumptions and this should be taken into account when drawing any conclusions from the analysis produced.

However, it is clear that the updates made to the modelling since our previous QA of the model in 2013 represent a significant improvement to the previous methodology. We believe these updates both provide a better theoretical reflection of reality and should improve the consistency of the results produced.

1. Background

Project TransmiT was established by Ofgem to review the charging arrangements for transmission networks. In May 2012 Ofgem published the results of its Significant Code Review (SCR) which concluded that industry should develop an improved version of the current Investment Cost Related Pricing (ICRP) for calculating Transmission Network Use of System (TNUoS) tariffs. That report used analysis based on a model methodology developed by National Grid Electricity Transmission (NGET) and Baringa (formerly Redpoint Energy) that provides a quantitative assessment of the cost benefit characteristics of different charging options. In 2013 LCP provided quality assurance of the implementation of the models used to produce this analysis.

In August 2013 Ofgem published its Impact Assessment which announced a minded-to position to approve the "Workgroup Alternative Connection and Use of System Code Modification 2 (WACM2)" option. Alongside this report Ofgem published a review of NGET's analysis performed by Baringa.

The consultation responses to the minded-to position included some challenges to the underlying analysis. Baringa reviewed these consultation reports and as a result were commissioned to develop updates to the Impact Assessment modelling to address comments received and to more closely reflect the latest policy proposals on the implementation of the Electricity Market Reforms (EMR) by DECC.

1.1. Overview of the modelling approach

The modelling methodology combines together three main models:

- **The TransmiT Decision Model (TDM)** – This model was developed by Baringa and acts as the engine for the modelling and controls the other two models. It calculates investment decisions in new plant and constructs the merit-order stack.
- **The Transport and Tariff (T&T) model** – This model was developed by National Grid and calculates the tariffs that apply. A different version of the model exists for each of the CMP213 options being considered as well as the status quo.
- **The Electricity Scenarios Illustrator (ELSI) model** – This model was developed by National Grid and is capable of performing dispatch allowing for network constraints. This allows it to calculate the constraint cost which is then used to determine investment in network reinforcement. ELSI is also used to calculate generation and income for each unit.

Each of these models has been implemented within Excel using a combination of VBA code and standard Excel formulae. There is also an associated Transport Model Interface Spreadsheet which passes information from the TDM to the T&T and vice versa.

Since our review of the modelling in 2013 Baringa have updated the TDM model in three main areas:

- **The modelling of the Capacity Mechanism**, in particular the way in which it targets the required margin. Previously different scenarios would result in materially different capacity margins, which is contrary to the aim of the mechanism. The modelling has been updated to better reflect how the mechanism will work in practice and this makes the results of different scenarios more comparable.
- **The modelling of renewable support**. This update has brought forward the implementation of CfDs to 2015 and updated the methodology for setting the strike prices so that build decisions are consistent with a constrained competitive allocation framework for onshore and offshore wind technologies. This makes the modelling more consistent with DECC's analysis and also makes the results of different scenarios more comparable.
- **A number of small updates to assumptions and methodology.** Of particular note is a change to the way Carbon Capture and Storage (CCS) and Nuclear are modelled and changes to OCGT Capex.

In addition to these modelling updates Baringa have also produced a new "Alternative Case" and a number of sensitivities.

1.2. Scope of our review

The overall aim of this QA project is to provide Ofgem and other stakeholders confidence that the modelling methodology has been implemented as intended and that all data and assumptions are being used correctly. To provide that confidence this project performed a front-to-back review of the modelling updates applied by Baringa and an assessment of whether the results are consistent with the Updated Modelling Methodology that has been set out.

Specifically the following scope was agreed with Ofgem for this QA:

- Verification that the calculations have not changed since the previous QA exercise where no changes have been intended. This includes all areas of the TDM model and the code that makes decisions on network reinforcements within the ELSI model.
- Verification that the data mappings between the model components are still functioning correctly, in particular:
  - TDM and T&T model interface
  - TDM and ELSI model
- A full review of the new Capacity Mechanism module and its interaction with the wider model.

- A full review of the new CfD allocation methodology.
- Verification that changes in input data are as intended and indicated changes are correctly implemented,

As requested this review did not require a review of the core ELSI or T&T models as these are unchanged from last year's analysis.

2. Review of the TDM

2.1. Approach to the review

We have analysed the TDM using two approaches.

For new or updated functionality we have outlined the calculation that is being performed and our conclusion as to whether we believe the approach is in line with the agreed modelling methodology. In any area where the methodology has not been explicitly defined we provide our view on whether the approach is reasonable.

For existing functionality where the functionality of the model was intended to be unchanged since our 2013 QA review we have performed a 'delta check' where we identify any changes and ensure these are appropriate. It should be noted that some areas of the TDM were not available for review due to intellectual property rights.

Below we provide a high-level overview of our findings and additional information can be found in the appendices.

2.2. Verification of changes to the TDM model

A complete 'delta check' was performed on changes to the TDM model since the previous QA. This task involved a comprehensive automated process to identify all differences between the spreadsheets and the nature of those differences. This was also performed on the VBA code within the TDM model and linked spreadsheets.

All significant differences were then investigated and are reported in Appendix A6. We found all the differences to be appropriate and generally represent updates to assumptions as expected. We do however note that a number of small issues that were found in the previous QA remained in the current version of the model as detailed in Appendix A1. We understand that this was intentional to ensure comparability with previous results.

2.3. Interaction of the TDM with the other models

The previous QA undertook a complete review of how the TDM manages the relationship between the three models and the data flows between these models.

For the purposes of this review we conducted a 'delta check' on this functionality. We checked the same data transfer processes were being performed by the TDM and that the VBA for performing this transfer, and the data ranges being transferred, remained unchanged.

We found this functionality to be unchanged and that it continues to operate as intended. An overview of the simulation loop performed by the TDM can be found in Appendix A2.

2.4. Review of the Capacity Mechanism approach and implementation

The modelling of the Capacity Mechanism has been overhauled to better reflect the latest information on how the mechanism will operate. This has been achieved by developing a separate 'module' to the TDM model that simulates the capacity auctions and the resultant investment decisions.

We have conducted a full review of the new calculation and how the separate Capacity Mechanism (CM) module interacts with the TDM. We have also provided a high level comment on our view of the new approach.

2.4.1. Purpose of the calculation

The CM module spreadsheet represents a simplified auction process where existing and potential new build plant are selected to meet a required capacity margin. The process involves ranking plant by their expected gross margins and determining the lowest cost selection required to achieve the target capacity level. The 'bid' of the unit marginal in this auction defines the capacity mechanism clearing price and therefore expected capacity payments. A detailed overview of the calculation can be found in Appendix A4.

The outputs from this process are the decisions on new build CCGT and OCGT plant, the dates at which existing units retire, and the resultant payments to eligible units.

2.4.2. Result of our review

We have reviewed each of the metrics and have found no issues with any of the values calculated above. We have included a number of comments on how this module could be made more flexible and user friendly in the future in Appendix A1.

We have also reviewed how the TDM manages the data flow with the CM module and found the process to be functioning appropriately. An overview of the data flow process can be found in Appendix A3.

2.5. Review of the changes to CfD treatment and implementation

In order to bring the model closer to DECC's latest projection the implementation of CfDs has been brought forward to 2015. Further, the methodology for setting the strike prices for onshore and offshore wind has been updated so that build decisions are consistent with a constrained competitive allocation framework.

In practice this means running the model with a sufficiently high strike price for onshore and offshore wind to achieve the target level of build. The model then determines the strike price that would be consistent with a competitive allocation through post processing. The updated modelling process is detailed in Appendix 2.

2.5.1. Purpose of the calculation

A separate spreadsheet is now used to perform the post processing of CfD strike prices for onshore and offshore wind plant. For each technology the spreadsheet determines the highest Long Run Marginal Cost (LRMC) of a plant built endogenously each year. This LRMC of the marginal plant defines an estimate of the strike price that would result from a competitive allocation. Full details of the calculation are included in Appendix A5.

2.5.2. Result of our review

We have reviewed the calculation and found no issues with the values reported for CfD prices given the input copied from the TDM. We have included a number of comments on how this module could be made more flexible and user friendly in the future in Appendix A1.

We have also reviewed how this calculation interacts with the TDM. The current process requires results to be manually copied and pasted between the CfD calculation spreadsheet and the TDM model. This process is detailed in Appendix A3. From a practical point of view the manual nature of this process introduces a potential risk of user error which ideally would be removed in any future analysis.

2.6. Review of changes to data and assumptions

2.6.1. Changes to input assumptions

The undertaking of a delta test clearly identifies where assumptions have changed since the previous modelling. A full list of changes is included as part of Appendix A6. These changes were reviewed and considered to be intentional updates to assumptions.

2.6.2. Changes to CCS and Nuclear modelling

The build plan of Nuclear and CCS units has been locked for the current modelling and analysis, reflecting the insensitivity of these large decisions to small changes in transmission charging.

The code that determines these build decision was not available to review in full but we have verified that the final build of these units is consistent between cases.

3. High-level comments on updated modelling methodology

In addition to our review of the implementation of the updated TransmiT modelling we have also been asked to provide a view on the changes to the model methodology.

With any model of this type there is a need to balance model complexity with practicality and all our comments should be viewed in this light. The principal question that the modelling is attempting to answer is a challenging one: how will changes in transmission charging affect investment, retirement and dispatch decisions? These decisions are strongly driven by macroeconomic conditions and the evolving policy environment, and any results should be viewed in this context.

In particular, the modelling of EMR will play a fundamental role as the Capacity Market and Contracts for Difference (CfDs) will, between them, drive the majority of investment decisions in new generation capacity – it should be noted that the transmission pricing drivers studied here could therefore easily be "swamped" by the EMR drivers. As such the improvements made to the modelling of these areas represent welcome enhancements to the general approach and can be expected to improve the robustness of the results.

We discuss the Capacity Mechanism and Contracts for Difference in more detail below.

3.1. The capacity mechanism

The design of the capacity mechanism has evolved significantly since the start of the original CMP213 modelling work. The current policy is both detailed and complex in a number of dimensions and as such an understandably simplified version of the mechanism has been implemented within the modelling. However, the approach used has been significantly enhanced from last year's analysis.

Previously in the modelling there was not a direct link between the capacity auction process and the emerging investment and retirement decisions. Any discrepancies could lead to the capacity margins moving away from the targeted system security level which would in turn materially affect any cost-benefit analysis.

The updates to the model have largely removed this issue by creating a direct link between the capacity auctions and the investment and retirement decisions. This means the model produces more consistent results between scenarios aiding comparability. It is however worth noting that this additional functionality does increase the impact of the Capacity Mechanism modelling on the analysis as a whole. In particular we note that building new plant in turn for closing existing plant is a feature of certain model runs. This behaviour should be taken into account when interpreting the results of the analysis as the high volume of new plant investment could magnify the effect of changes to locational charging.

3.2. Contracts for Difference (CfDs)

Under CfDs a strike price for each technology will be determined that provides a subsidy for investment in low carbon generation. Initially the subsidy levels will be set administratively at a level chosen in order to target a given level of overall investment in low carbon generation. It is expected that at some point in the future these strike prices may be set by a competitive allocation with the strike price set by the marginal plant required to achieve a given target.

When assessing the effect of transmission charging changes, it should be considered that the main effect of any changes to the cost of generation investment will be to require higher or lower strike prices to be set in order to achieve the same renewable targets. For this reason any changes to charges applied to renewable generators are likely to mean that higher or lower support levels are required in order to achieve the same level of renewable investment.

The changes to the modelling of onshore and offshore wind are intended to reflect these facts. The updated modelling technique ensures the target capacity is acquired and that a strike price is determined based upon the cost of the marginal plant required. We consider this methodology to be consistent with the theory of a constrained allocation of CfD contracts and a better reflection of the likely reality.

Also, the build plan for CCS and Nuclear plant has now been locked as previously small changes in transmission charging could lead to changes in the build of these technologies. Given the large uncertainty in the development of the new technologies and the wider uncertainties around these projects this approach appears sensible. This will also help improve the comparability of different model runs.

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Appendices

A1. Issues log

#	Issue	Rating	Location	Comment	Resolved?
1.	**Outstanding issue from 2013 QA:** The calculation of the SRMC of each generating unit within the TDM had not picked up fuel transport costs.	Amber, intentional	TDM: E_StackSpec	This leads to the SRMC of coal plant being £2 - £3 lower than was intended in all years.	We understand that retaining this issue was intentional to ensure comparability with previous results.
2.	**Outstanding issue from 2013 QA:** For three plant (c3.3GW of capacity) the limited load factor factors have not been applied to the low availability stack.	Amber, intentional	TDM: E_SupplyCurves	If this was updated it would result in slightly higher prices in summer months which could have a minor knock on effect on other variables	We understand that retaining this issue was intentional to ensure comparability with previous results.
3.	**Outstanding issue from 2013 QA**: For plant that fit SCR the maximum winter load factor is applied meaning that availability is higher in summer than in winter	Amber, intentional	TDM: E_SupplyCurves	Only affects one plant but would lead to slightly lower winter prices and slightly higher summer prices.	We understand that retaining this issue was intentional to ensure comparability with previous results.
4.	The capacity for one unit differs between the Status Quo and WACM2 models for the alternative scenario.	Intentional	TDM: Capacities	The treatment of this unit has been intentionally changed to address the simplified 'plant' size granularity of the model.	Intentional modelling adjustment.
5.	Cell formula for 'Cumulative capacity – ranked' changed after 2026 to prevent any further CCGT new build in the alternative scenario.	Intentional	TDM: Capacities	Intentional adjustment to reflect the probable behaviour of new build as capacity prices fall to 0 in this scenario.	Intentional modelling adjustment.

#	Issue	Rating	Location	Comment	Resolved?
6.	Additional CM Module retirement decisions can be made between auction year and delivery year.	Minor, documentation	CM Module	Need to ensure as intended and documented but can be considered broadly sensible.	
7.	The NET CONE is not being passed into the calculations correctly by year.	Minor	CM Module: Demand Curve, CM Auction	**No effect on results** as NET CONE does not change by year.	
8.	Heading columns included in sumproduct calculation.	Very minor	CM Module: CM Auction	**No effect on results**. Calculation of capacity payments due for new build before 2022.	
9.	In a number of places the reported capacity margin is not including retired legacy contracts.	Minor, usability	CA Module: Demand Curve and CM Auction sheets	The final outturn capacity margin is correct and internal auction calculations are correct. However, reported margins in a number of places are incorrect and it would be important not to accidentally use these values.	
10.	The table FORWARD VIEW GROSS MARGIN (£/kW) in the TDM is not cleared when re-executing the model and is passed to the CM Module with results from any previous run.	Minor, usability	TDM: ExpectedMargins	**No effect on results.** This does not change results with the current CM module setup of a five year look ahead, however, it could cause a problem if this setting was changed.	
11.	The second table in the analysis sheet of the CfD calculation incorrectly calculates marginal unit and marginal CfD price.	Minor, usability	CfD Calculation: SQAnalysis, WACM Analysis	**No effect on results.** These values are not intended to be used in the calculation but given the manual copy and paste required there is potential for mistakes. We recommended this table is removed.	
12.	The CM update macro within a given year will produce different results if run an even or odd number of times.	Minor, usability	CM Module: CM Auction	**No effect on results.** Not an issue as macro is called once per year by the TDM. Could be resolved by changing reference to 'Capacity of new CCGT / OCGT build for given year (not	

#	Issue	Rating	Location	Comment	Resolved?
				cumulative) (MW)' to 'Volume of prevailing new build'.	
13.	Proportion of new build for margin can produce DIV/0 errors.	Minor, usability	CM Module: CM Auction	**No effect on results.** Only present in cases where the error will not propagate.	
14.	Input assumptions are not all clearly labelled and located on control sheet	Minor, usability	CM Module: Demand Curve, CM Auction	Demand curve minimum price and minimum build sizes for CCGT, OCGT are input assumptions not located on control sheet.	
15.	Extensive use of specific cell references within formula.	Minor, usability	CM Module	In several places formulae refer to specific cell/ranges instead of using INDEX and MATCH to find the correct reference. This will create difficulties if the spreadsheet is to be used again, particularly changing the list of plant in any way would create numerous difficulties for the module.	
16.	VBA code in CM module not commented.	Minor, usability	CM Module	While the code is reasonably simple to step through it is still best practice to provide comments at least as descriptions of subroutines.	

A2. The TDM Simulation loop

The TDM goes through the following steps in each run:

- Initial data transfer from the TDM to ELSI – Plant and demand data.
- Initial data transfer from ELSI to the TDM – Reinforcement data.

Then for each modelling year (Y) from the current year to specified end year:

- Data transfer to ELSI – Plant capacities, Short Run Marginal Costs (SRMCs) and Interconnector flows.
- ELSI dispatch algorithm is run for year Y, Y + 1, Y + 3, Y + 5.
- Results transferred from ELSI to the TDM – Prices, gross margins, Interconnector flows and constraint costs.
- ELSI's Transmission Investment model is run.
- Reinforcement decisions reported from ELSI to the TDM.
- Transfer data to T&T model, via the T&T interface, based on year Y + 1 and Y + 5: Generation, MAR, Project costs, Demand information.
- For both Y + 1 and Y + 5
    - Calculate tariffs in the T&T for the year
    - Transfer results to transport model – Tariff for plant, wider tariffs, HH demand, NHH demand and Final MAR
- Run ELSI from transport model
- Transfer results to CM Module – Plant capacity and build potential, gross margins Y + 5, and demand data.
- Calculate new build CCGT, OCGT in Y + 5 and expected economic retirements from Y to Y + 5.
- Transfer new build and retirement decisions as well as expected capacity payments to TDM. Transfer new capacity to ELSI interface.

Run next year.

A final step is now required at the completion of the model run:

- Copy final plant capacity, minimum build and fixed costs to CfD calculation spreadsheet from the TDM.

- Copy LRMC for the marginal onshore and offshore wind units by year to the TDM to set CfD strike prices.

More details on the individual components and how they are calculated can be found in section 2.

A3. Summary of the new data flows between the models

Yearly transfer from TDM to CM Module

Data item	Description	Source in TDM	Use in CM Module	Mapping correct
Auction Capacities for CM Module	Capacities for CM module. For potential new build CCGT, OCGT this is the maximum possible build capacity.	Calculated in capacities sheet.	Pool of available capacity for capacity mechanism auction. In the first year a copy is taken to record pre-auction capacities.	Yes
Gross Margins Y+5	Expected gross margins by year for year y + 5 from 2016 onwards. Hard coded in TDM not to update with future information.	Annual Gross Margin (after fixed costs) calculated in E_PlantwiseGenResults sheet for year Y + 5 with a uniqueness adjustment.	Pricing capacity bids into CM auction.	Yes
Peak Demand	Peak Demand.	Graphing Sheet, input assumption.	With required margin determines required capacity for auction.	Yes
Current Year	Current year of TDM simulation loop.	Control Sheet.	Determines year Y + 5 year to make build and economic retirement decisions.	Yes

Yearly transfer from CM Module to TDM

Data item	Description	Source in CM Module	Use in TDM	Mapping correct
New Build decisions	New build decisions of CCGT and OCGT plant from CM Module.	Cumulative new build (MW) from CM Auction sheet.	Used to determine capacities of existing / planned units.	Yes
Economic Retirement Flag	Retirement of existing units which are not needed by CM module.	Economic retirement decision from CM Auction sheet.	Used to determine capacities of existing units.	Yes
Expected Capacity Payments	Capacity payments due (£/kW) - nominal capacity basis.	Capacity payments due (£/kW) - nominal capacity basis from CM Auction sheet.	Used to determine generator gross margins and profits.	Yes

Final transfer from TDM to CfD Calculation spreadsheet

Data item	Description	Source in TDM	Use in CfD Calculation	Mapping correct
Capacity	The capacity of all plant by year.	Determined by build and retirement decisions both in the TDM and the CM module.	Used to determine which wind plant added capacity in a given year endogenously and could therefore potentially be considered the marginal unit.	Manually performed, not checked
LRMC	The long run marginal cost by plant by year.	LRMC by unit by year. It should be noted base availability is the assumed load factor in this calculation as opposed to realised load factor.	Used to determine the price at which the marginal unit would be setting the CfD strike price.	Manually performed, not checked
Minimum Build	The minimum build by plant by year.	Capacities Sheet, input assumption.	Used to determine which wind plant added capacity in a given year endogenously and could therefore potentially be considered the marginal unit.	Manually performed, not checked

Final Transfer from CfD Calculation spreadsheet to TDM

Data item	Description	Source in CfD Calculation	Use in TDM	Mapping correct
LRMC of marginal unit	By technology by year the LRMC of the marginal endogenous plant.	The highest LRMC for a unit that endogenously added capacity for offshore and onshore wind.	Used as input CfD strike price for offshore and onshore wind.	Manually performed, not checked

A4. Overview of CM Module Calculation

Capacity from TDM

Calculation element	Description / calculation
Natural Retirements - Initial	Sum of capacity retired in 'initial results from TDM'. Full and derated values reported.
Natural Retirements - Outturn	Sum of capacity retired in 'Capacity from TDM. Full and derated values reported.
TDM New Build	Sum of capacity increased in 'Capacity from TDM' where previous capacity was zero.

Demand Curve

Calculation element	Description / calculation
Required Auction Capacity	Peak demand increased by required margin then less derated interconnector capacity, legacy contract volume and retired legacy contract volume then adjusted by the fraction of capacity to auction.
Representation of demand curve volumes	Creates 15 volumes above and 15 volumes below required auction capacity for a 31 point curve. Calculated based upon the addition / subtraction of demand curve maximum / minimum values.
Representation of demand curve prices	Creates 15 prices above and 15 prices below CONE for a 31 point curve. Calculated based upon the demand curve maximum / minimum price values.
Lookup bid prices from auction for that demand	Attempts to match the demand at each of the 31 points with the first level of cumulative supply capacity that exceeds this value (from CM auction) and returns the matching missing money bid. Where this returns an error it returns the demand curve maximum price
Difference between auction bid and demand curve price	Difference between Representation of demand curve prices and Lookup bid prices from auction for that demand
Reset auction demand to the point where demand curve and auction supply cross	Attempts to find the point where supply matches demand (the first positive value from Difference between auction bid and demand curve price above). Reports demand, margin and supply price at this level (if supply price not found reports maximum price). Note the

Calculation element	Description / calculation
	required margin does not correctly control for retired legacy contract volume.
Fixed margin curve	Takes the Required Auction Capacity and finds the supply price at this level (if supply price not found reports maximum price). Note the required margin does not correctly control for retired legacy contract volume.

CM Auction

Calculation element	Description / calculation
Bids (derated) into capacity mechanism	Takes gross margin for participating plants - zero for non-participating plants - and derates to account for real basis of payments. Includes a uniqueness adjustment.
Inclusion in capacity mechanism flag	Flags if “yes” passed from capacity from TDM sheet and after first year of auction.
Ranks	Ranks each plant according to above bids.
Derated capacities	Derated capacity by plant, set to 0 for retired plant and units existing under legacy contracts.
Economic retirement flag (0 for retirement)	Hard coded by macro from calculated values.
Ordered missing money bids	Finds corresponding bid for ordered list of ranks capped at multiplier * CONE.
Capacities for rank	Capacity for ordered rank from derated capacities.
Cumulative capacities	Cumulative capacity from ‘capacities for rank’

Calculation element	Description / calculation
Control	A number of controls for the CM model, importantly the current year, earliest year for retirement and new build as well as the look ahead.
Capacity mechanism	Reports Peak Demand, Required Margin, Derated contract volume, and required derated capacity. Note the required margin does not correctly control for retired legacy contract volume.
Pool of available capacity	Reports Total available derated capacity (GW), Total available for CM (GW), Derated interconnector capacity (GW), Derated legacy contract volume (GW), and Available margin (inc. interconnectors). Note the required margin does not correctly control for retired legacy contract volume.
Capacity mechanism demand curve	Required derated capacity (excl. interconnectors and legacy contracts) (GW) - If demand curve enabled then the point where supply and demand meet, otherwise demand increased by fixed margin. Capacity payment (£/kW) – Capacity Payment from Demand Curve Sheet Total CM payments (£bn) – Required Derated Capacity * Capacity Payment. Marginal plant rank – Plant rank where supply and demand meet. Marginal plant – Name of plant at marginal rank.
Capacity Margin	Reports Total pool of available derated capacity (GW), Derated interconnector capacity (GW), Derated legacy contract volume (GW), Retired derated legacy contract volume (GW), Available derated new build capacity (GW), and Derated new build capacity (GW). Calculates: Capacity margin for total pool (following economic retirements) - From above excluding available new build as included in total pool.

Calculation element	Description / calculation
	Derated unbuilt capacity (GW) – Difference between Available derated new build capacity (GW) and Derated new build capacity (GW).
	Derated outturn capacity (GW) – Total pool of available derated capacity (GW) plus Derated interconnector capacity (GW) plus Derated legacy contract volume (GW) plus Retired derated legacy contract volume (GW) less Derated unbuilt capacity (GW).
	Outturn capacity margin (GW) – Difference between Derated outturn capacity (GW) and Peak Demand.
	Outturn capacity margin – Outturn capacity margin (GW) divided by Peak Demand as a percentage.
Plant change schedule	Reports Economic retired capacity (GW), Derated economic retired capacity (GW), Naturally retired capacity (GW), Derated naturally retired capacity (GW), CM new build (GW), Derated CM new build (GW), TDM new build (GW), and Derated TDM new build (GW).
Total payments	Reports Capacity payment (£/kW), Qualifying capacity - not new build (GW), Qualifying capacity - new build (GW), Total cleared in indicated year (£bn), Prevailaing legacy contracts (GW), Total settled under legacy contracts in indicated year (£bn), and Total payments in indicated year (£bn).
Capacity payments due (£m)	Capacity payment (£/kW) * Derated Capacity * Inclusion in capacity mechanism flag / 1000
	For New Build: Current capacity price paid to new build in year and retired legacy contract units. Historical capacity price paid to legacy built units. Derated and divided by 1000.
Effective new build capacity payments (£/kW)	Capacity payments due (£m) * 1000 divided by Derated cumulative new build

Calculation element	Description / calculation
Capacity payments due (£m) - hardcoded	Hard coded values of the table 'Capacity payments due (£m)' created by the CM update macro for year y + 5.
Capacity payments due (£/kW) - de-rated capacity basis	Capacity payments due (£m) * 1000 divided by (Derated Capacity rounded to nearest MW) For New Build: Effective new build capacity payments (£/kW)
Capacity payments due (£/kW) - nominal capacity basis	Capacity payments due (£/kW) - de-rated capacity basis * Derating
Hardcorded outcomes	Hardcoded values from Output above
Economic retirement decision	Makes decisions for years before current year + look ahead and after the first economic retirement year. Retires units if unit is ranked above the marginal rank and included in the capacity mechanism.
Flag of new CCGT / OCGT build	For years after the first allowed new build year then flag indicates rank is less than or equal to the marginal rank. i.e. a unit that would receive a capacity market contract.
Proportion of new build for margin	If the marginal unit is a new build calculates the proportion of potential build capacity for that unit required to meet capacity requirement.
Capacity of new CCGT / OCGT build for given year (not cumulative) (MW)	If a new build plant has a 'flag of new CCGT / OCGT' this table uses the 'Proportion of new build for Margin' to determine how much of potential capacity should be build. This value is rounded up according to minimum new build size.
Capacity of new CCGT / OCGT build for given year (not	The table records hard coded values from the 'Capacity of new CCGT / OCGT build for given year (not cumulative) (MW)'. When the

Calculation element	Description / calculation
cumulative) - hardcoded record (MW)	calculation is performed for a given year y, the build for the year y +5 is hard coded here by the macro CM update.
Cumulative new build (MW)	Cumulative new build of 'Capacity of new CCGT / OCGT build for given year (not cumulative) - hardcoded record (MW)'
Volume of prevailing new build	For each year the sum of cumulative 'Capacity of new CCGT / OCGT build for given year (not cumulative) - hardcoded record (MW)' for all previous years.
Volume of prevailing legacy contracts	Sum of the previous nine years of 'Capacity of new CCGT / OCGT build for given year (not cumulative) - hardcoded record (MW)'
Volume of retired legacy contracts	For each year and plant type the cumulative new build (MW) built in the years ten years previous.

A5. Overview of the CfD Calculation spreadsheet

A separate Analysis tab is included for both the Status Quo and WACM cases containing the following tables.

Calculation element	Description / calculation
Table 1	For each onshore and offshore endogenous location, for each year: Capacity – The difference between the current capacity and the minimum build capacity. Representing where the plant has been built endogenously in the TDM LRMC – LRMC sourced from TDM for the plant considered. Rank by LRMC – For each technology a ranking of the plant by LRMC
Table 2	This table incorrectly calculates a marginal LRMC based upon the Capacity in table 1 above without controlling for the fact that this

Calculation element	Description / calculation
Table 3	Capacity is cumulative i.e. the marginal increase over minimum build may have been in a previous year. It is recommended that this table is removed to avoid confusion. Capacity – Change in the capacity from table 1 in each year. Indicating that a unit has increased its capacity in a given year and can be considered a potential marginal unit in that year. LRMC – LRMC for the units which have a change in capacity as calculated above. Max of LRMC by technology – For each technology the maximum LRMC of a unit which endogenously increased its capacity in that year. This is the estimate for the clearing price in an allocative auction process that is copied back to the TDM.

A6. Data inputs

Updated data inputs in the TDM model

#	Data / Formula Changes Since CMP213	Location	Comment
1.	Small Gen Discount hard coded to 'No' for An Suidhe,and Eishken New OCGTs	TMI IIRCP: Input Generation	A correction made to be more consistent with other new build OCGTs.
2.	CFD Start Date and years, % LRMC and CFD Reset	TDM: ScenarioAssumptions	CfD treatment intentionally updated in the modelling.
3.	CAPEX for Island Wind - Zone S Western Isles	TDM: Offshore Wind	This change made to make the CAPEX consistent between different diversity scenarios.
4.	Various changes to OCGT modelling assumptions.	TDM: CommonAssumptions	The treatment of OCGT units has been updated to be consistent with the value for CONE used in the new CM module. Without this update the cost of OCGT units was too high to be built by the CM module.

#	Data / Formula Changes Since CMP213	Location	Comment
5.	Various changes to CCGT modelling assumptions.	TDM: CommonAssumptions	The values for new build CCGT plant have been updated to be more consistent with the values for existing plant. This is important for the new CM module new build and retirement decision making process.
6.	Various changes to input assumptions around new build of plant.	TDM: CommonAssumptions	The inputs for '% Planning in forward view' and maximum build for different technologies have been updated to be consistent with build decisions being made in the new CM module.
7.	Change to the capital costs for onshore wind in 2030.	TDM: CommonAssumptions	Change made to be more consistent with other years.
8.	Creation of offshore Scotland wind for zone O	TDM: CommonAssumptions	Change made for the purpose of creating a chart, not used in calculation.
9.	Change to DUMMY plant types	TDM: CommonAssumptions	Dummy gas units are not used in calculation. Change made to be more consistent with plant ranking methodology in internal calculations.

New CM Module Data inputs

Data item	Location	Description	Comment
Fraction of required capacity to auction	Control	Fraction of required capacity to run in auction process	Modelling assumption.
Margin	Control	Required capacity margin.	Reasonable assumptions although it is recommended sensitivities are conducted around this value.
Net CONE	Control	Net CONE and multiplier used to determine maximum auction price.	While the Net CONE value is consistent with DECC analysis the multiplier of 3 creates a maximum price slightly higher than current expectations
Demand Curve	Control	Flag on whether to use a demand curve or simply a fixed capacity requirement.	A vertical demand curve is assumed in the modelling, this is a simplification of the sloped demand curve to be used.
Demand curve volumes	Control	Volumes used in demand curve, defined as maximum difference from target.	A vertical demand curve is assumed in the modelling, this is a simplification of the sloped demand curve to be used.
Interconnection	Control	Interconnector capacity and derating used in auction.	Interconnector values differ by scenario. The rating of 0% in the Status Quo case seems unnecessarily pessimistic but is intended to keep the results consistent with previous analysis.
Demand Curve Minimum Price	Demand Curve	Minimum price used in demand curve.	Modelling assumption.
Year of first CM auction	CM Auction	First year in which the CM auction is run.	Consistent with current policy.
Start year of analysis	CM Auction	First year of analysis.	Modelling assumption.
Construction time for new build	CM Auction	Not used in calculation.	Not used in calculation.

Data item	Location	Description	Comment
Earliest new build	CM Auction	First year in which the module can make new build decisions.	Modelling assumption.
Earliest economic retirement year	CM Auction	First year in which the module can make economic retirement decisions.	Modelling assumption.
Look ahead	CM Auction	The number of years in advance in which an auction is run, i.e. the difference between auction year and delivery year.	Modelling assumption.
Proportional new build flag	CM Auction	Whether to build only the required amount of the marginal plant or the maximum potential capacity.	Modelling assumption.
Minimum build size	CM Auction	Minimum build sizes for new CCGT and OCGT.	Modelling assumption.

Legacy data inputs

Data item	Location	Description	Comment
Plant data			
Base availability	Common assumptions	The standard operating availability by plant	Assumption appears reasonable
Derating	Common	The derating factor applied for the capacity mechanism	Consistent with assumptions used for DECC EMR consultation

Data item	Location	Description	Comment
	assumptions	and for some capacity margin calculations	
Shape of availability (for 4 seasons)	Common assumptions	The seasonal variation in availability	Calibrated via testing in ELSI combined with review against PLEXOS
Base VOM (£/MWh)	Common assumptions	Variable operation and maintenance costs in £/MWh	Sourced from DECC-commissioned reports. Source differs by technology: E&Y (marine), ARUP (others renewable), and PB Power (non-renewable) reports. Assumptions agreed against PB power report, other assumptions appear reasonable
Balancing cost (£/MWh)	Common assumptions	Balancing costs, only non-zero for intermittent technologies	Assumption appears reasonable
Base FOM (£/kw)	Common assumptions	Fixed operation and maintenance costs in £/kW pa	Sourced from DECC-commissioned reports. Source differs by technology: E&Y (marine), ARUP (others renewable), and PB Power (non-renewable) reports. Assumptions agreed against PB power report, other assumptions appear reasonable
Efficiency	Common assumptions	The base efficiency assumption for the plant type	Sourced from DECC-commissioned reports. Source differs by technology: E&Y (marine), ARUP (others renewable), and PB Power (non-renewable) reports. Assumptions agreed against PB power report, other assumptions appear reasonable
Emissions intensity (t/MWh)	Common assumptions	Tonnes of CO_2 per MWh of generation	Standard Redpoint modelling assumptions, appears reasonable
Abatement (%) for CCS	Common assumptions	90% Abatement for CCS technology	Assumptions of 90% for CCS is reasonable and not material to the modelling results
Individual unit assumptions	Common assumptions	Generation fleet information: online, offline dates, capacities, efficiencies etc.	Based on ELSI plant data with plant specific updates to known announcements
Build decision assumptions			

Data item	Location	Description	Comment
Build planning/decision	Common assumptions	The build time for new projects	Sourced from DECC-commissioned reports. Source differs by technology: E&Y (marine), ARUP (others renewable), and PB Power (non-renewable) reports. Assumptions agreed against PB power report, other assumptions appear reasonable
Economic life	Common assumptions	The economic life time for the build decision	Sourced from DECC-commissioned reports. Source differs by technology: E&Y (marine), ARUP (others renewable), and PB Power (non-renewable) reports. Assumptions agreed against PB power report, other assumptions appear reasonable
Operational life	Common assumptions	The expected operational life time of the plant	Sourced from DECC-commissioned reports. Source differs by technology: E&Y (marine), ARUP (others renewable), and PB Power (non-renewable) reports. Assumptions agreed against PB power report, other assumptions appear reasonable
Generic generation type load factor	Common assumptions	Used for the generic plant for the transport model interface	From National Grid, assumptions appear reasonable
Max retirement (MW)	Common assumptions	Annual retirement limit in MW	Based partially on NG accelerated growth scenarios. Assumptions appear reasonable
Max annual commitment (MW)	Common assumptions	Annual build limit in MW	Modelling assumption informed by NG accelerated growth modelling scenario, assumptions appear reasonable
Capital costs	Common assumptions	Capital costs by plant type and by year (£/kw)	Based on latest DECC views, assumptions appear reasonable.
Hurdle rates	Common assumptions	Hurdle rate required by technology	Derived from the fundamentals: Cost of Debt, Equity premium, Risk free rate, Inflation, Tax rate and then Equity Beta and debt gearing by plant type. Assumptions appear reasonable
Foundation costs	Common assumptions	Capital cost and assumed depth. It is assumed that the default capital costs for offshore wind include an allowance for foundation costs at an assumed depth. This input is used to adjust the capital costs of other wind	Appears reasonable

Data item	Location	Description	Comment
		projects based on their capital costs.	
Zonal assumptions			
Zones	Common assumptions	Master zones and their mapping to TNuOS, System and Gas exit zones.	Assumptions Informed by Redpoint and National grid.
Gas exit charges	Common assumptions	Gas exit charges by zone and amount in £ / kw/ yr	Sourced from the Charging Statement
LCPD/IED assumptions			
Constraint type / unit choice	Scenario assumptions	LCPD, IED-LLO, IED TNP or Fit SCR for each relevant plant	
Limited load factor	Scenario assumptions	Limited load factor for the relevant periods based on the constraint type	Model calibration parameter. Derived from calibration against PLEXOS
Maximum winter operating factor	E_SupplyCurves	A maximum of 42.857%	Model calibration parameter. Derived from calibration against PLEXOS
Fuel and carbon			
Gas and coal prices	Scenario assumptions		Central scenario from DECC's 2012 Energy and Emissions Projections. Checked raw data and conversion to MWh calculation
Carbon price	Scenario assumptions	EUETS price underpinned by the CPS	DECC's carbon price: "For modelling purposes". Checked against raw data

Data item	Location	Description	Comment
Gas oil and Fuel oil	Scenario assumptions		Assumptions appear reasonable
Biomass and nuclear	Scenario assumptions		Assumptions appear reasonable
Carbon intensity (t/MWH)	Common assumptions	By fuel type	Assumptions appear reasonable
Shadow carbon intensity (abatement specific)	Common assumptions	By fuel type	Assumptions appear reasonable
Transportation cost (£/GJ)	Common assumptions	By fuel type	Assumptions appear reasonable
Gas price seasonality	Common assumptions	By fuel type	Assumptions appear reasonable
Demand			
Demand load curve shape	E_PowerPriceCalcs	The 100 percentiles of the demand distributions in each season	Based on historical data. Assumptions appear reasonable
Peak demand growth	E_PowerPriceCalcs	Each percentile of the demand distributions growth rate over time	Checked against National Grid Gone green scenario
Embedded generation			
Load factors	Common	Load factors and derating for each type of embedded	From NG Gone Green scenario (supporting spreadsheet which may not have been

Data item	Location	Description	Comment
	assumptions	generation source	published)
Capacity	Capacities	Capacity of each type of embedded generation type by year	From NG Gone Green scenario (supporting spreadsheet which may not have been published)
Other			
Price mark-up	Common assumptions		Assume this is a derived based on historical data/calibrated against PLEXOS
VoLL	Common assumptions		£1000 seems low, assume this is adjusted to avoid high price spikes
Wind			
Wind load factors	WindLoadFactor	The annual average load factor achieved in different location	Assumptions appear reasonable
High level investment modelling parameters			
Build look forward	Common assumptions	Look forward period used for new build decisions	Agreed with the TransmiT working Group as part of methodology discussions
Retirement look forward	Common assumptions	Look forward period used for retirement decisions	Agreed with the TransmiT working Group as part of methodology discussions
% planning in forward view	Common assumptions		Modelling assumption

Data item	Location	Description	Comment
% retirements in forward view	Common assumptions		Modelling assumption
Require derated capacity margin	Common assumptions	Assumption to approximate the security standard for the Capacity Mechanism	Consistent with assumptions used for DECC EMR consultation
Capacity mechanism start date	Common assumptions	The first delivery year the for the capacity auction	Consistent with 2018/2019 date stated by Government in latest documents
Stack split	Common assumptions	The percentile of the demand distribution where the switch occurs between the high and low availability stack in the modelling	Calibrated via testing in ELSI combined with review against PLEXOS
Ratio High/Low stack	Common assumptions	The ratio of high availability to low availability by plant type	Calibrated via testing in ELSI combined with review against PLEXOS