Information paper on approach for modelling I-SEM with PLEXOS for Directed Contracts

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Version History

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1 Introduction

In September 2017 the Regulatory Authorities ("RAs") commissioned Baringa Partners LLP ("Baringa") to provide support in a work package for "Assistance to Support I-SEM PLEXOS model validation and Directed Contracts". As part of this work, a PLEXOS model of I-SEM will be developed and validated, to be made public (with confidential data redacted) for use by market participants and to be used by the RAs for the purpose of setting Directed Contracts ("DCs") as well as for other policy work in I-SEM.

This information paper details the key issues in modelling I-SEM in PLEXOS, outlines different options for resolving these issues, and gives our suggested approach at this stage. The issues described in this paper are technical in nature, and are intended for an audience with prior experience of electricity market modelling using PLEXOS.

The remainder of this document is structured as follows:

- Section 2: Provides an overview of the PLEXOS validation process and Directed Contracts
- Section 3: Details proposed updates required for I-SEM PLEXOS model, and the suggested approach for updates. Specific questions related to the proposed updates are set out.

Baringa wish to engage market participants as far as possible in the development of the I-SEM PLEXOS model, but must balance this with the need to deliver a model in the short timescales necessary to allow it to be used for the first round of I-SEM Directed Contacts in early December 2017. We request feedback on this information paper from interested parties, by taking part in a short online questionnaire:

https://www.research.net/r/ISEM_PLEXOS_Modelling

The questionnaire includes all questions outlined in this information paper, and allows for free text comments. All feedback received through this questionnaire will be taken into account in the development of the I-SEM model. A short note which states the modelling decisions made in developing an I-SEM model will be published on the SEM Committee website prior to the first I-SEM DC round in December 2017. A public meeting will be held after the first I-SEM DC round to discuss the I-SEM model in more detail. The PLEXOS model and validation report will be made public via the SEM Committee website after this meeting.

I-SEM is a new market structure with no out-turn data available, which results in considerable uncertainty for specific elements of the model validation exercise (replicating generator bidding behaviour, treatment of uplift etc). Getting the views of market participants is therefore an important source of information in the development of the I-SEM validated model. As I-SEM goes live and develops it will be possible to use out-turn data to test some of the assumptions taken in the first I-SEM validated model. It is likely that some of the initial assumptions will have to be recalibrated in future models to match out-turn I-SEM behaviour.

The questionnaire relating to this information paper will remain open until 20th October 2017.

2 PLEXOS Validation and Directed Contracts Overview

Introduction

The all-island Single Electricity Market (SEM) in Ireland and Northern Ireland was introduced in 2007 and will continue under current arrangements until the implementation of the new Integrated Single Electricity Market (I-SEM) arrangements, originally planned for Quarter 4 2017 and now planned for 23rd May 2018[1].

NOTE: Following the implementation of the "Integrated Single Electricity Market" (I-SEM) market arrangements in May 2018, the all-island electricity market will still be referred to as the "Single Electricity Market" (SEM), but, for the purposes of this document, we refer to the existing arrangements as the "SEM" and the new arrangements as the "I-SEM".

Under the SEM arrangements, a mechanism is in place to mitigate market power. Certain generators are obliged to sell power to suppliers at rates determined by the RAs, via agreements known as Directed Contracts (DCs), which are financial Contracts for Difference (CfDs) for quarterly baseload, mid-merit and peak power. The RAs have decided that this process continues in the initial stages of I-SEM[2].

There will be Quarterly rounds for I-SEM DCs, with DCs being allocated on a rolling basis between 2 and 5 Quarters ahead. The RAs are responsible for setting the parameters of DCs, including:

- Obligation to offer DCs: The RAs decide which generators are obliged to offer DCs. Currently, the only generators required to offer DCs are ESB Generation and Power NI PPB.
- Quantity: the quantity of DCs offered is determined by the RAs using outputs from a validated PLEXOS model.
- Pricing: The price of power sold under DCs is set through a formula which includes commodity and constant terms. The coefficients on commodity prices are set through analysis of the relationship between the parameters and the Day-Ahead power price.

The Reference price for Directed Contracts in I-SEM will be the Day-Ahead-Market (DAM) price, and the validated model and resulting pricing formula will project this DAM price.

The pricing formula is derived in two stages. In the first stage, a model of the SEM in PLEXOS for Power Systems is validated. In the second stage, the model is populated with a range of commodity price scenarios and DAM price results are generated and averaged for each quarterly contract period. These results are used to populate a statistical regression analysis, the outcome of which is a regression formula for the impact of variables on power price. This sets the DC pricing formula.

[1] SEMC, I-SEM Project Plan Quarterly Update, December 2016, SEM-17-002

[2] SEMC, Measures to promote liquidity in the I-SEM forward market, 16th March 2017, SEM-17-015

The current terms in the DC formula for each quarter and product are:

- Gas price in NBP terms for the relevant quarter, converted to Euros;
- Coal price on an ARA basis for the relevant quarter, converted to Euros;
- European Emissions Allowance (EUA) price for December for the relevant calendar year;
- Scaling coefficients for each price term above; and
- A constant term.

The RAs have engaged Baringa to provide support in developing a PLEXOS model of I-SEM to be used when setting the DC formulae and volumes for the first four DC rounds of I-SEM. Table 1 shows the DC round requirements and periods the model will cover moving into I-SEM. The new I-SEM model will cover the period Q1 2018 – Q4 2019 inclusive, and will be used for I-SEM Round 1, with only minor updates included for Rounds 2-4.

Table 1

Round	Date	DC Quarters	Update PLEXOS model
I-SEM R1	December 2017	Quarter 2 2018 to Quarter 1 2019	No (use newly validated I-SEM model)
I-SEM R2	March 2017	Quarter 3 2018 to Quarter 2 2019	Yes – minor updates
I-SEM R3	June 2018	Quarter 4 2018 to Quarter 3 2019	Yes – minor updates
I-SEM R4	September 2018	Quarter 1 2019 to Quarter 4 2019	Yes – minor updates

3 I-SEM model updates

3.1 Introduction

The process of setting Directed Contracts will likely remain largely unchanged in I-SEM, using a PLEXOS model to project Day-Ahead power prices through the derivation of regression formulae on commodity prices, as outlined in a recent consultation paper[3].

The starting point in the development of the RAs' I-SEM PLEXOS model is the current SEM Validated model, published in August 2017[4]. A number of changes are needed to develop a model that can be used for projecting generation and prices under I-SEM for the period 2018-19.

In this section, we set out the key proposed changes to the current model to allow it to be used for modelling I-SEM, in terms of approach, settings, and required inputs. Modelling options for each area of development are discussed, where we have a suggested approach this is clearly stated. Specific questions for interested market stakeholders are included at the end of each subsection.

In some areas of investigation we have tested the effect of changing the appropriate settings in PLEXOS. We have used the 2017 SEM Validated model as the starting point for these tests, with dummy commodity prices (consistent across all tests).

3.2 Assumptions

The process of developing a model for new market arrangements is one that requires a number of assumptions to be made about participant behaviour, in the absence of outturn market data that can be used as evidence. In general, our approach in updating the current SEM validated model to an I-SEM model is to assume that current behaviour seen in SEM will remain, unless there is clear evidence or reason for why this may change under I-SEM.

Additionally, there are a number of specific assumptions that we have made to allow us to produce a model of I-SEM that is robust, internally consistent and can be developed within the timescales outlined previously:

Specific Assumptions

1. All forecast generation and demand will clear in DayAhead-Market
    a. While this is unlikely to be true, we assume that the DAM will be liquid enough that prices from the DAM will be very close to a scenario where all generation and demand clears in the DAM
    b. Actual demand and generation may vary from forecasts that will lead to real time imbalances, but this is balanced after the Day-Ahead stage

[3] Directed Contracts Implementation Paper, SEN-17-064, https://www.semcommittee.com/publication/sem-17-064-directed-contracts-implementation-consultation-paper
[4] https://www.semcommittee.com/publication/sem-17-056-baringa-sem-plexos-forecast-model-2017-18

2. Generator bidding behaviour will settle down after an initial "learning period"
   a. Experience of new arrangements in other markets suggests that there may be an initial period where generator behaviour and resulting prices are somewhat erratic as generators "learn" how to operate in the market
   b. We assume that this learning period will be short, and that generators will quickly bid in an economically rational way
   c. The I-SEM model will represent this "steady state" behaviour rather than any early testing behaviours
3. Generators have a good view of their likely scheduling and have the capabilities to bid correctly to reflect costs and technical constraints
4. Generators will seek recovery of start and no-load costs in the DAM by internalising these in their offers

Question 1: Do you agree with the high level assumptions outlined, for the purposes of developing an I-SEM PLEXOS model?

3.3 PLEXOS model settings

3.3.1 Replicating EUPHEMIA scheduling algorithm

PLEXOS is the RAs' chosen software for the I-SEM model validation against EUPHEMIA Day-Ahead-Market prices.

PLEXOS is an advanced market modelling tool, incorporating a number of approaches to the modelling of interconnected markets, and alternative pricing algorithms ranging from marginal cost pricing through to game-theory approaches. It is used worldwide by energy companies, investors and system operators.

PLEXOS simulations are based on a mathematical programming formulation of power market dynamics. PLEXOS can apply linear and mixed integer programming solution techniques to determine the dispatch and pricing outcomes, taking full account of short-term dynamic constraints including ramp rates and min on/off times. This approach provides results that fully capture the complexity of power markets. It is also conceptually similar to the way in which the current SEM market dispatch software works.

Under I-SEM arrangements the market schedule and resulting prices will no longer be set using the current SEM market dispatch software. The EUPHEMIA algorithm will be used exclusively for establishing the Day-Ahead market schedule[5]. The EUPHEMIA algorithm is already used widely across European electricity markets. Unlike the SEM market algorithm, EUPHEMIA does not explicitly account for generator technical and commercial parameters such as start costs, no-load costs, and minimum run times. However, EUPHEMIA provides participants with a selection of order types,

[5] http://www.sem-o.com/MarketDevelopment/Pages/EUPHEMIA.aspx

allowing many generation parameters to be represented. It should be noted that in I-SEM there will be a requirement for unit based bidding, whereas in most other markets EUPHEMIA allows portfolio bidding. Unit based bidding increases the onus on accurate representation of technical and commercial parameters at the unit level, as these are not "averaged" through a generation portfolio.

The key order types available in EUPHEMIA are as follows:

- **Simple Hourly Orders** consisting of a price and quantity pair for a given hour;
- Block Orders applying to multiple hours:
  - **Simple Block Orders** consisting of a price with a fixed quantity over a set time
  - **Profiled Block Orders** consisting of a price with a varying quantity over a set time
  - **Linked Block Orders** introducing conditionality whereby the acceptance of a 'child' or 'grandchild' block is dependent on the acceptance of a 'parent' block
  - **Exclusive Groups** consisting of Simple or Profiled Block Orders where the combined acceptance ratio cannot exceed 1
  - **Flexible Block Orders** consisting of a price and quantity pair for a set duration but with the block start time not specified;
- **Complex Orders** consisting of simple orders with constraints such as Minimum Income Conditions, Scheduled Stop or Load Gradients.

Each order type allows different technical and commercial data to be represented, but no order type allows for full representation as per current SEM market software. A summary of how the different order formats can be used is given in Table 2.

Table 2 Summary of EUPHEMIA order types

Order Type	Features	Limitations	Potential Application
Simple Hourly Orders	Orders in each hour clear independently	Risk of technically infeasible schedules for baseload and mid-merit generators, as minimum on and off times are not represented	• Flexible peaking generators • Hydro generators • Pumped storage • Load
Simple Block Orders	Block duration can represent minimum on time constraints. 'All or nothing' acceptance criteria proxies Minimum Stable Generation (MSG)	Participant needs to pre-determine the hours in which the block applies	• Baseload generators • Mid-merit generators • Less flexible peaking generators • Load
Profiled Block Orders	Profile shape can reflect technical ramp constraints and/or expectations of market value (e.g. lower volumes offpeak)	Participant needs to pre-determine the profile shape based on market fundamentals as well as internal constraints	• Baseload generators • Mid-merit generators • Hydro generators
Linked Block Orders	No-load and start costs may be allocated to parent block, allowing competitive pricing of incremental energy in child blocks. Allows reflection of higher costs for part-loading. Sale and purchase blocks may be linked.	Risk of price formation volatility if not enough price makers[6] use other order types. Other power exchanges have limited the number of child blocks per parent, reducing potential flexibility.	• Mid-merit generators • Pumped storage
Exclusive Groups	Allows participant to submit alternative profiles for the market algorithm to optimise, without risk of over-commitment	Risk of price formation volatility if not enough price makers use other order types. Algorithm delivers market optimal outcomes, which may not be the profit maximising outcome for participant. Cannot be combined with Linked Block Orders.	• Mid-merit generators • Hydro generators • Energy limited plant • Load response
Flexible Block Orders	Fixed duration and volume block with flexible start time to be optimised by market algorithm	Other power exchanges have limited the number of Flexible Block Orders per portfolio.	• Energy limited plant • Flexible peaking generators • Load response
Complex Orders	Allows participant to specify a Minimum Income Condition (e.g. for start cost recovery) and Load Gradient (to proxy ramp rates)	May require active strategies to manage risk of being scheduled for multiple starts or below Min Stable Level	• Baseload generators • Mid-merit generators • Less flexible peaking generators

[6] Price-makers refer to dispatchable or controllable generators

Exactly which of these order types will be available to I-SEM market participants is currently still undecided, the desire to make all available being constrained by run-time requirements for the algorithm on a pan-European basis. Block orders in particular make the algorithm slow to solve.

While PLEXOS provides a great deal of flexibility for modelling energy markets, there are no explicit settings for replicating all of the EUPHEMIA order types above. Baringa has shown previously that it is technically possible to replicate results from EUPHEMIA using Linked Block Orders and Complex Orders using PLEXOS[7], using "Decision Variables", validating this against the outputs of the SEMO EUPHEMIA trials. However, there are difficulties in replicating these orders in full for use in a PLEXOS model to be used for projections for I-SEM Directed Contracts:

1. The process of replication requires the development of a highly complex PLEXOS model with slow run times and additional post processing requirements:
    a. This introduces significant risk of error in implementation
    b. This introduces significant extra effort in using the model in each DC round
2. A view must be taken of the bidding behaviour of each generator, in terms of the order type selected for each unit for each time period in the model; and this raises the following issues:
    a. Participants would be expected to refine their bidding strategies dynamically in light of experience and changing market conditions, so a static view is unrealistic
    b. Across the market as a whole, there is a very large number of combinations of daily generator choices for order types and other parameter choices such as the configuration of block periods, parent-child relationships, and Minimum Income Conditions
    c. This is extremely difficult to predict *a priori* for specific generators, and is outside the scope of the work being considered in this project

Because PLEXOS has additional functionality for representing specific technical and commercial constraints directly, ie. not constrained to hourly block representation, there is an alternative approach to forcing PLEXOS to replicate exactly each EUPHEMIA order type, which is to allow PLEXOS to run in its normal mode: taking into account all technical and commercial constraints and balancing supply and demand at least cost. While this approach results in different algorithms in PLEXOS and EUPHEMIA, it can give similar outputs in terms of prices and generation.

Baringa uses PLEXOS to model a number of European electricity markets which use EUPHEMIA to settle their DAMs, and undertakes regular backcasts to validate this approach. When performing a backcast model the following historical inputs are used in PLEXOS:

- Actual plant availability in each market
- Actual spot commodity prices (fuel and carbon prices)
- Actual hourly electricity demand in each market
- Wind, solar and hydro inflow profiles

[7] Replicating EUPHEMIA Day-Ahead order formats in PLEXOS, Adrian Palmer, PLEXOS Users Group Meeting Barcelona 2017, https://energyexemplar.com/clientarea/?view=presentations

The PLEXOS model uses technical and commercial data to calculate generator bids, schedule the market in each hour, and set hourly prices. While some historical information can be obtained and included in the model, it should be noted that some is unknown, and when this is the case we need to use typical or 'generic' values in lieu of actual data. For instance, historical plant availability data (hourly data for each individual generating unit) is incomplete in most markets, especially with respect to distributed generation; electricity demand data does not always take account of autogeneration or demand that is embedded in low voltage networks; meteorological data (wind and solar irradiation) is unavailable at the granularity of individual plant and individual hours; and net transfer capacities on interconnectors may not exist in the public domain for each interconnector in each hour.

Focusing first on the most proximate market to SEM, i.e. GB, we observe good agreement between the prices from PLEXOS and those from the price exchanges. Figure 1 shows backcast GB monthly baseload results, while Figure 2 and Figure 3 show the diurnal shape for Summer and Winter respectively. Given only a subset of historical inputs are used in the backcast, the results are quite close to the outturn EUPHEMIA results. Our analysis suggests that in 2016 EUPHEMIA was used to schedule generation in DAMs (N2EX and APX) equal to approximately 60% of demand, and so the DA price can be considered a good reference price to validate PLEXOS against.

Figure 1 Monthly GB DA baseload power prices, historical vs PLEXOS backcast

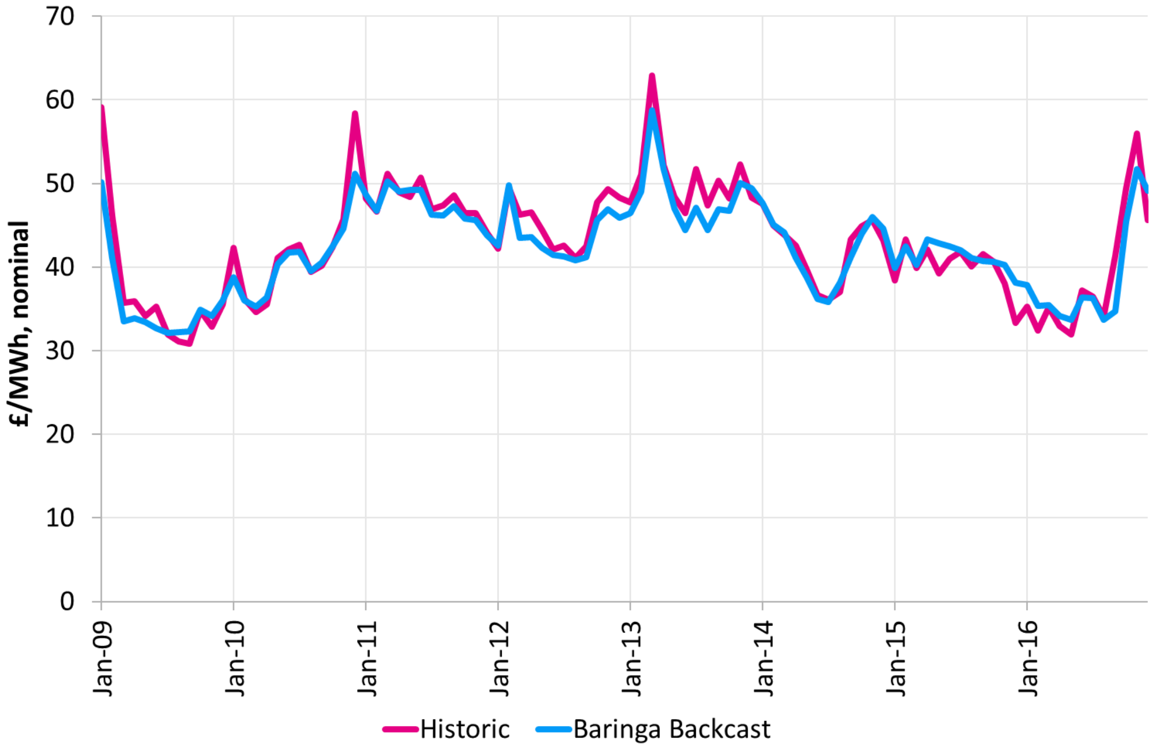


Figure 2 Average Summer diurnal GB DA price profile, historical versus PLEXOS backcast

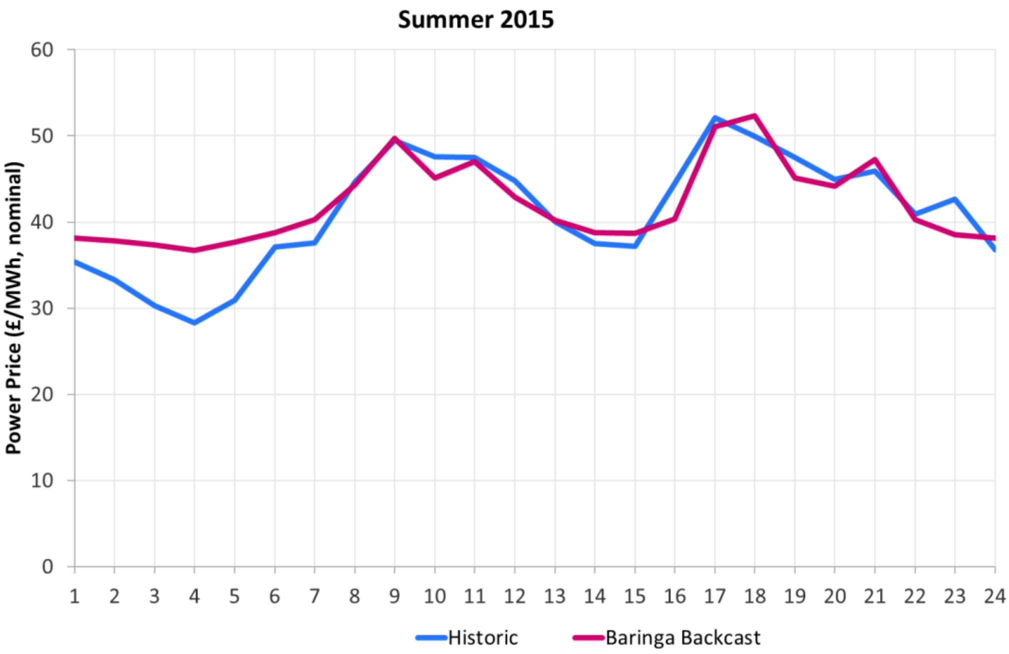
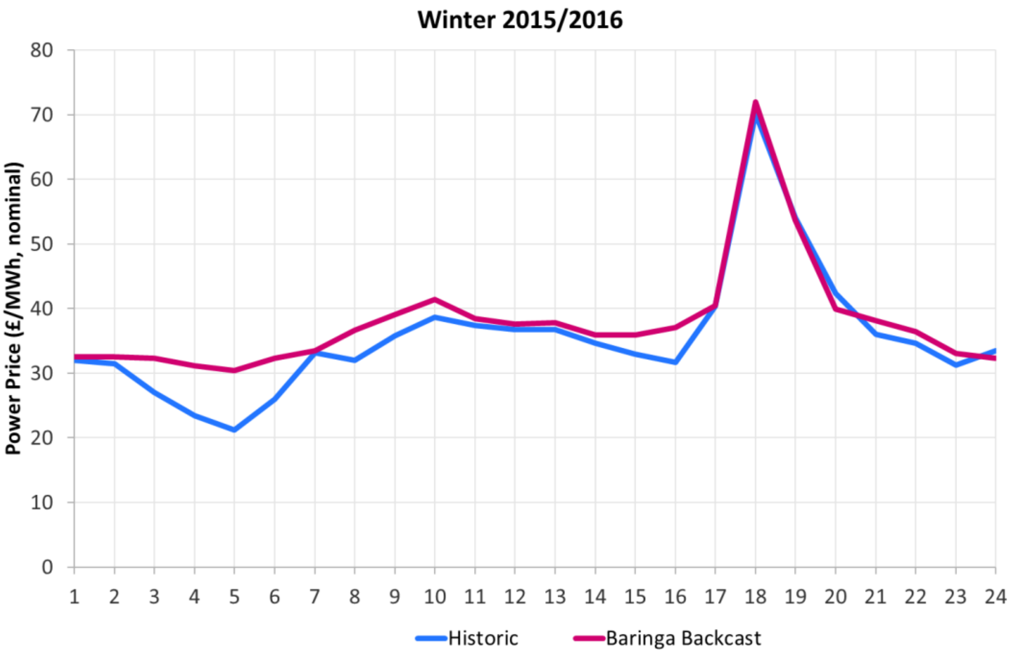
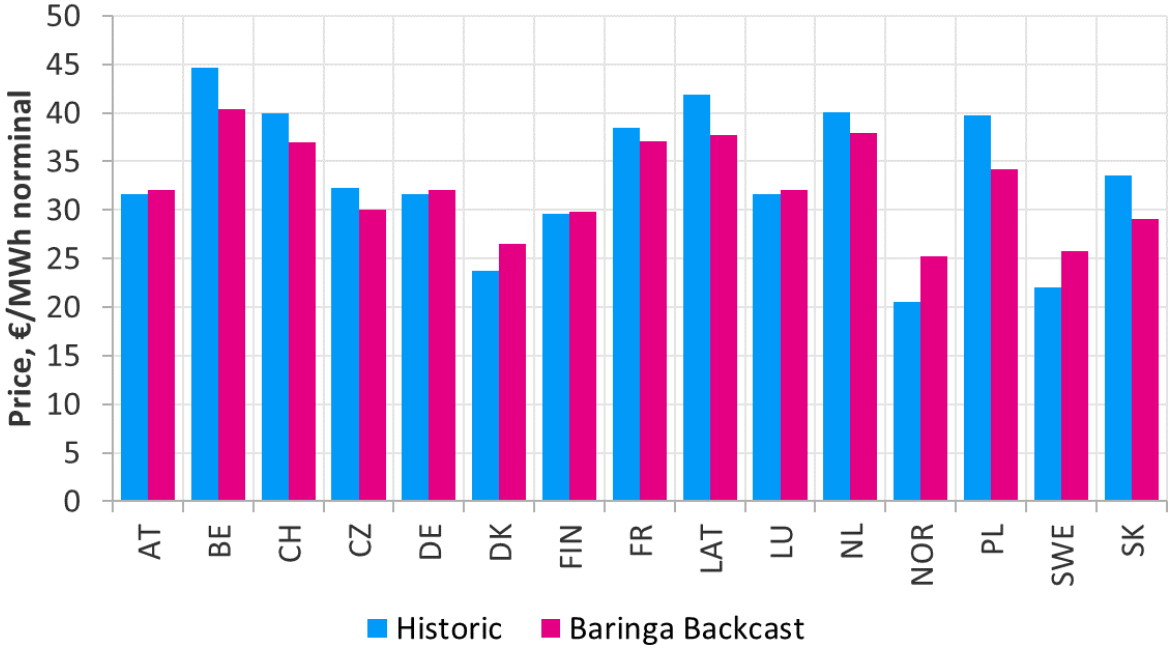


Figure 3 Average Winter diurnal GB DA price profile, historical versus PLEXOS backcast



We have performed similar analysis for other European markets using the Baringa North West Europe PLEXOS model. Figure 4 shows Day-Ahead baseload power prices for 2015 from both EUPHEMIA and from the Baringa NWE PLEXOS model, run in backcast mode. It can be seen that while there are some differences, given the range of input uncertainties the baseload power price is well captured by PLEXOS, despite the differences in the scheduling algorithm. Though there are some differences in individual countries, there is no systematic bias between EUPHEMIA and PLEXOS.

Figure 4 2015 Annual average DA baseload power prices, historical EUPHEMIA versus PLEXOS backcast



Suggested approach: Given the complexity of replicating EUPHEMIA algorithms explicitly in PLEXOS, and the good agreement seen between PLEXOS (in normal mode) and EUPHEMIA produced prices, PLEXOS should be used in normal mode with all technical and commercial data used to schedule dispatch.

Question 2: Do you agree with the suggested approach of using PLEXOS in normal mode, with all technical and commercial data used to produce market schedule and prices?

3.3.2 PLEXOS Version

The current Validated SEM PLEXOS model uses PLEXOS version 6.207. This is the last version for which a full backcast exercise has been performed. This version is somewhat outdated (2012) and is now unsupported by the software providers, Energy Examplar. This provides a risk to both the RAs and market participants when developing future (I-SEM) models as there is no support for model issues that may arise. Additionally, there have been significant improvements in the performance and functionality of PLEXOS in the multiple incremental versions that have been released since 6.207. Many market participants are using more recent PLEXOS versions for their own modelling, which introduces further risk of error as some properties must be input in a different format between 6.207 and the more recent version.

Given the move to I-SEM and the fact that a backcast is not possible for a new market, we recommend this to be the right time to upgrade to a more recent version.

There is a choice of which version to use, as there are a number of recent releases that may be suitable. Baringa use 7.300 widely across our suite of PLEXOS models, and have found it to be a stable and reliable version. The most recent version is the newly released 7.500.

Table 3 gives the high level pros and cons for each of these releases.

Table 3

PLEXOS Version	Pros	Cons	Applicability to I-SEM model
7.500	Newest model release by Energy Examplar, promises significant performance improvements	Minimal experience to date means exposure to potential unknown issues due to upgrade. Initial testing shows very poor performance with RAs' SEM model (see run times below)	
7.300	Established model with no known bugs or model issues Widely used by the industry	Not the latest version of PLEXOS released, lacks latest features	

We have upgraded the RAs' Validated SEM model to these versions of PLEXOS and compared results when run in 6.207, 7.300, and 7.500, as shown in Table 4.

Table 4

Version	Results	Infeasibilities when performing 53 regression runs	Run time
6.207	-	140	35 mins
7.300	Similar to 6.207	49	30 mins
7.500	na	na	>3 hours (stopped early)

While 7.500 promises improved performance, initial testing has shown extremely poor performance with the RAs' SEM model. The reasons for this poor performance are being investigated by Energy Exemplar, but this performance issue highlights the risk in using a newly released version of PLEXOS that may have some upgrade issues that are still to be resolved. Given the timescales available to develop a new I-SEM model we do not recommend using 7.500 at this stage.

Version 7.300 gives similar results to 6.207, with a modest speed improvement. When the SEM model is run in self tune Rounded Relaxation , occasionally there are infeasibilities for specific days and Rounded Relaxation thresholds. Using PLEXOS version 7.300across the 53 runs used as part of the regression analysis in the Directed Contracts process reduces the number of these infeasibilities from 140 to 49 – meaning better results from these runs.

Baringa has been using version 7.300 since 2016 and uses it as the base version of PLEXOS across all of our modelling. This is a well-established version of PLEXOS and we are not aware of any significant issues that would cause problems when modelling I-SEM.

We propose upgrading to PLEXOS 7.300 from the current version PLEXOS 6.207, with the resulting benefits:

- Improved performance
- Reduction in infeasibilities
- Additional functionality
- Support by Energy Exemplar

Suggested approach: Upgrade SEM model to PLEXOS version 7.300 for development of validated I-SEM model

Question 3: Do you agree with the upgrade to PLEXOS version 7.300?

3.3.3 Rounded Relaxation

Rounded relaxation (RR) refers to a specific unit commitment method which has been used for previous SEM PLEXOS model validations. Our experience suggests that the market is comfortable with Rounded Relaxation as it offers a good compromise between capturing individual unit commitment, which is important for a market like SEM with a few large units, and tractable model run times. Alternate approaches are to use a linear optimiser (worse unit commitment but very fast performance and more straightforward treatment of interconnectors) and Mixed Integer Programming (better unit commitment but worse performance). We propose continuing to use Rounded Relaxation as the best compromise between the two.

PLEXOS offers the ability for the model to 'self tune' the threshold used for Rounded Relaxation unit commitment. In this mode the model tests a number of threshold values and chooses the one that gives the most optimal results. The current Validated SEM model uses a 'self-tuning increment' of 0.05, meaning that each simulation is run 17 times while all threshold values are tested.

We have tested increasing the self-tune increment from 0.05 to lower granularity, and the effect on price and generation volumes. We have found excellent replication of results at much lower self-tune granularities. Table 5 shows baseload SMP and run time for decreasing granularities. At a self-tune increment of 0.2 there is negligible difference with the current 0.05 setting.

Table 5 Testing Rounded Relaxation threshold

Setting	Baseload SMP 2018, €/MWh	Run time, mins
Self-Tune 0.05	50.0	35
Self-Tune 0.1	50.0	21
Self-Tune 0.2	50.0	14
Self-Tune 0.3	50.1	12
Fixed threshold 0.5	51.4	7

Figure 5 and Figure 6 show the diurnal shape of SMP for Winter and Summer using the same Rounded Relaxation self-tune settings. All profiles look very similar other than when using a single fixed threshold value.

Figure 5 Hourly Winter SMP profile with varying self tuning increments

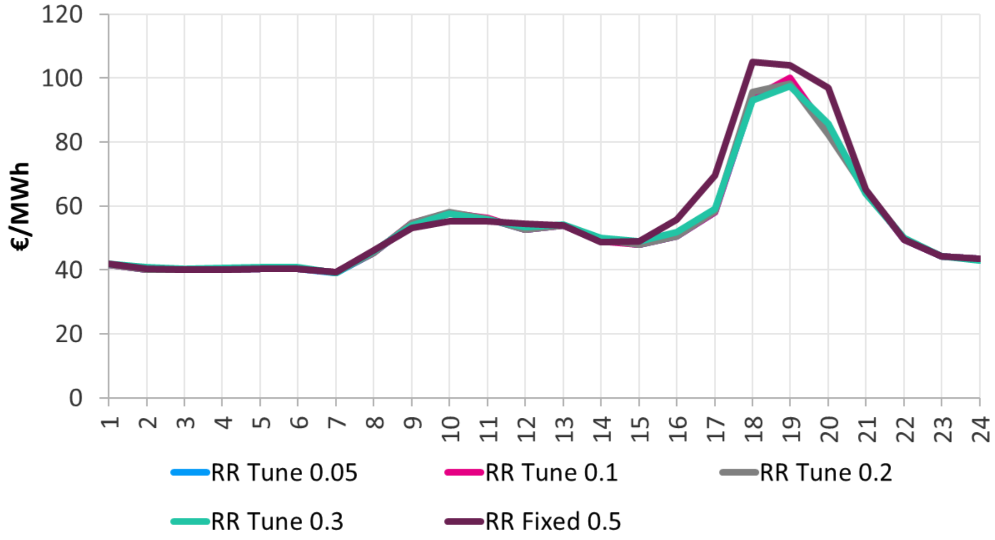
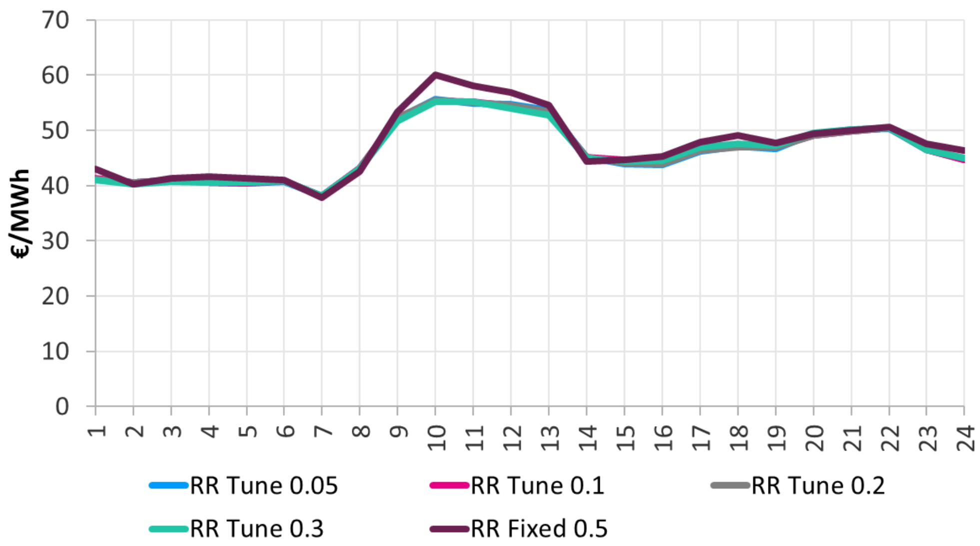


Figure 6 Hourly Summer SMP profiles with varying self-tuning increments



Suggested approach: Increase the Rounded Relaxation self-tuning increment from 0.05 to 0.2, with significant reduction in run times (-60%) and negligible impact on SMP.

Question 4: Do you agree with increasing the Rounded Relaxation self-tuning increment to 0.2?

3.3.4 Price caps and floors

In the current SEM validated model there is a price cap and floor of €1000/MWh and - €100/MWh respectively.

Under EUPHEMIA the cap and floor levels are €3000/MWh and -€500/MWh respectively.

Suggested approach: Set price cap and floor levels to €3000/MWh and -€500/MWh respectively in Validated I-SEM model, aligned with EUPHEMIA

Question 5: Do you agree with these changes to price cap and floor?

3.3.5 Horizon settings

There are a number of changes to be made to the horizon used to model I-SEM versus the current SEM model.

1. Long-term horizon
    a. The model must be validated for use in projecting to the end of 2019 (versus 2018 currently)
2. Short-term horizon granularity
    a. EUPHEMIA has hourly settlement, rather than half-hourly in SEM
    b. Changing to hourly granularity in the Validated I-SEM model is more reflective of I-SEM trading arrangements and reduces model run times
3. Start of trading day
    a. EUPHEMIA has a trading day from 11pm-10pm, rather than 6am-5:30am in SEM
4. Look-ahead
    a. The current SEM model uses a look-ahead of 12 half-hour periods from 6am-12noon to allow the model to see morning pick up in the subsequent trading day, and keep plant online to meet this
    b. A 12 hour look-ahead from 11pm-11am would allow the Validated I-SEM model to see the same morning pick up

Suggested approach: Change long-term horizon to cover all of 2019, for use in Directed Contracts Rounds 1-4. Change short-term horizon to hourly granularity, from 11pm-10pm, with a look-ahead of 12 hours to capture the morning pick up of the following day.

Question 6: Do you agree with these changes to modelling horizon?

3.3.6 Solver settings

The current SEM validated model uses Xpress MP with default settings. For larger problems, performance improvements can be made through both "concurrent" solve algorithms and by using a multicore Xpress MP licence to run in parallel. However, the SEM model results in a relatively "small" problem (ie fewer than 250,000 non-zeros) that does not benefit from these methods. Baringa has tried altering these settings with no effect on performance. Given that the I-SEM model is likely to be of a similar problem size as the current SEM Validated model we do not think there is scope for significant improvement in performance through changing this solver settings.

Suggested approach: Do not change solver settings from current defaults.

Question 7: Do you agree with keeping the current solver settings?

3.4 Uplift

Uplift in SEM represents the recovery of start-up and no-load costs of generators. The current SEM uplift algorithm takes account of price volatility as well as the cost of uplift to consumers; and in so doing, it tends to dampen price spikes compared with outturn prices observed in EU markets.

In I-SEM, as in EU markets, there will not be an explicit Uplift algorithm and these costs will be internalised within the prices that generators offer into the market. It is not clear how uplift costs (essentially the start-up and no-load costs of generators) will be incorporated within offer prices by generators once I-SEM goes live, or how uplift pricing will interact with the EUPHEMIA algorithm for market coupling. It is possible that the price impact will be similar in I-SEM, as generators seek to replicate current revenue levels in their offers. Alternatively, generators may change pricing behaviour to be in a manner more typical of Continental markets, that is to say both the levels of start-up and no-load costs and the way in which they are recovered are more similar to Continental markets. Currently, there is evidence that start-up and no-load costs tend to be relatively high in SEM and they are spread in a manner that tends to dampen price volatility, other things being equal, relative to Continental prices.

One important assumption is around the costs that generators are seeking to recover. The current "start costs" in the SEM Validated model have been validated against SEM market submissions, and so can be considered cost reflective under the SEM Bidding Code of Practice. However, we note that these start costs for SEM generators are generally higher than those observed for similar plant in other markets, ie GB. It may be that greater competitive pressures under I-SEM could lead to a reduction in start costs recovered through the market. Conversely, due to the greater risk of imbalance under I-SEM "risk premia" may increase. It is difficult to speculate the net effect of these factors at this stage.

Therefore in the absence of any historical evidence we propose keeping the start costs from the current SEM Validated model for use in the I-SEM model. As I-SEM market data becomes available it will be possible to update these values.

Suggested approach: Use current SEM Validated model start costs for use in I-SEM model

Question 8: Do you agree with using current SEM start costs for use in I-SEM model?

Once the level of costs to be recovered is known, there are a number of possible approaches to the modelling of uplift in I-SEM:

1. Make uplift costs linear (ie use a Linear solve, rather than Rounded Relaxation), so that they form part of the shadow price reported by PLEXOS
    a. This ensures recovery of all start-up and no-load costs but does not respect generator technical constraints (ie min stable level, min up/down times etc)
2. Keep using Rounded Relaxation and retain the current SEM uplift algorithm
    a. Assumes all generators bid in a way that results in full cost recovery for every plant on the system, while limiting price volatility
3. Keep using Rounded Relaxation and use the alternative default PLEXOS algorithm ("Korean" algorithm)
    a. Assumes generators have perfect foresight of how long they will be scheduled on for and spread start-up and no-load costs across each interval of contiguous operation as uplift over SRMC
4. Define custom uplift algorithm in PLEXOS using OpenPLEXOS functionality
    a. This provides flexibility in the cost recover algorithm used, but requires evidence of what generators' behaviour is likely to be in order to formulate a bespoke algorithm

Below we go through each option in more detail.

Linear uplift:

We have updated the current SEM Validated model to use a linear solver rather than Rounded Relaxation. When running in linear mode all start and no-load costs are included in the shadow price of PLEXOS, however unit commitment is linearised and so min stable level, min up time and min down time constraints are not necessarily observed in the solution (in effect, they become soft constraints rather than hard constraints). For large liquid markets this simplification is reasonable, and the comparisons shown in Figure 1-Figure 3 use a Linear PLEXOS model of these markets. In SEM the "lumpiness" of the generation supply stack means that using a linear solve is a less appropriate simplification.

Figure 7 and Figure 8 show the impact on hourly winter and summer SMP profiles of running the validated model with uplift included through a linear solve versus the current SEM uplift algorithm. In both seasons, SMP decreases significantly as a result of reduced uplift using the linear approach, and this effect is not confined to peak periods. It seems unlikely that such large reductions in price will be observed in the initial months of I-SEM, as bidders are likely to seek to recover all current generation costs and remain technically feasible at the Day-Ahead stage, as would be the case currently using the SEM software.

Based on the result below we think that using a linear solve results in too large a change in prices, due to dynamic technical constraints not being observed.

Figure 7 Hourly Winter SMP profile with linear uplift costs

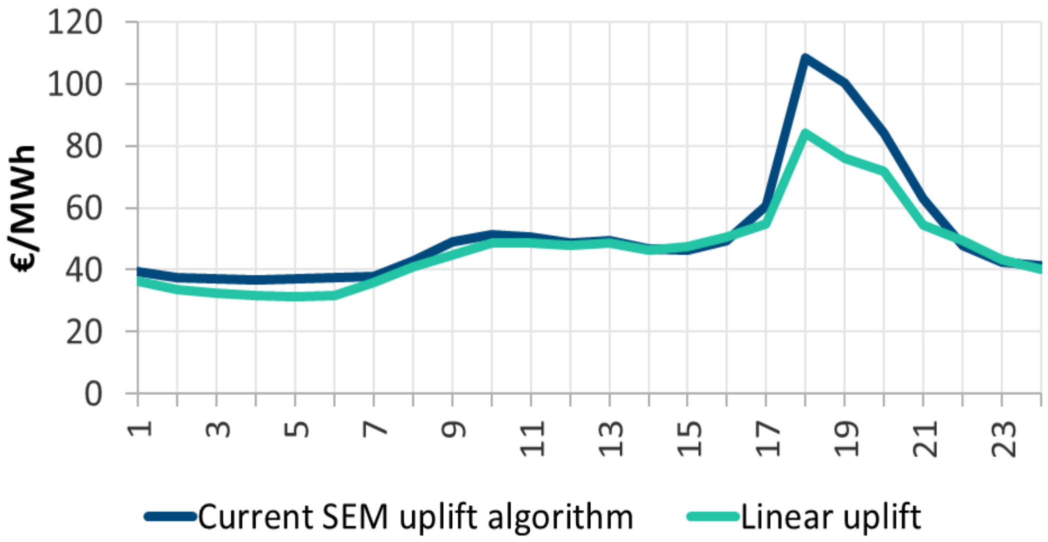
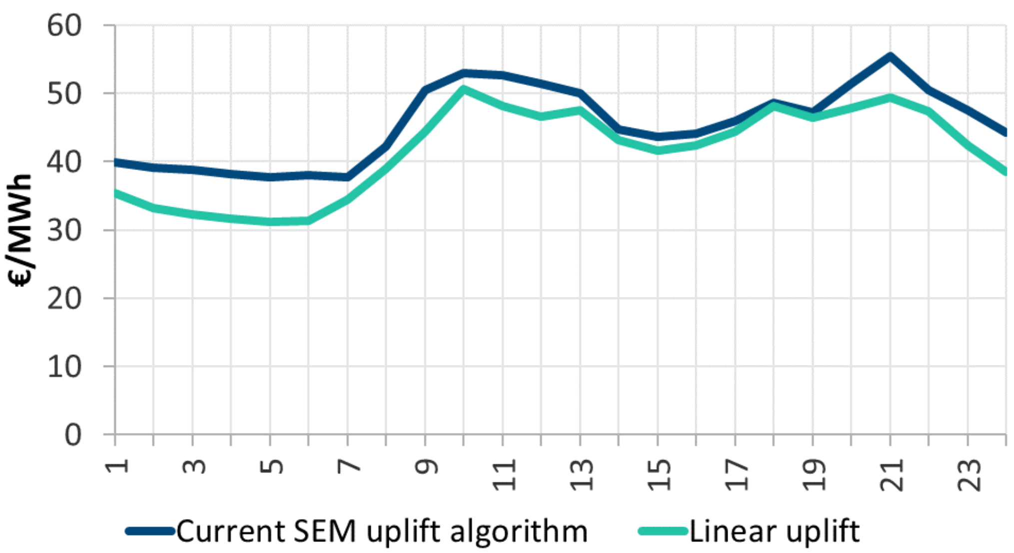


Figure 8 Hourly Summer SMP profile with linear uplift costs



Rounded Relaxation and current SEM Uplift:

If SEM Uplift algorithm is used for I-SEM this means the following assumptions are being taken:

1. Generators seek to recover all current costs, as per current market software algorithm
   a. This seems like a reasonable assumption, especially in the early days of I-SEM while generators are learning how to operate in the new market
2. Generators bid as one in such a way that uplift is smeared across all periods as in the current algorithm, which is optimised to reduce volatility

a. This seems less likely, as current SEM Uplift is set market wide rather than through individual generator decisions that will occur as part of I-SEM

Korean uplift:

The Korean uplift algorithm is easy to implement in PLEXOS, and has the benefit over the SEM uplift algorithm of representing one simple strategy generators may take at an individual level to ensure full cost recovery. Generators increase their bids based on perfect foresight of the duration of each period of operation, smearing their costs over these periods.

Figure 9 and Figure 10 show the impact on hourly winter and summer price profiles of running the SEM Validated model using the Korean uplift versus the SMP using the current SEM uplift algorithm. (We note that in changing the uplift method to Korean a number of other SEM specific settings in PLEXOS are changed, such as step-wise treatment of warmth states for start costs, so the results here come from more than just changing uplift itself – further testing is required to test the incremental effect of all of these changes). Using the Korean algorithm, uplift is increased in peak periods and reduced in off-peak periods. The effect on annual average prices is negligible, but there is more "shape" to prices. This change in price would suggest a change in generator behaviour that pushes down prices in more competitive periods and up in less competitive periods, which seems a reasonable way for generators to behave in a market with no explicit bidding code of practice in the Day-Ahead-Market, like I-SEM.

Figure 9 Hourly Winter SMP profile with Korean uplift costs

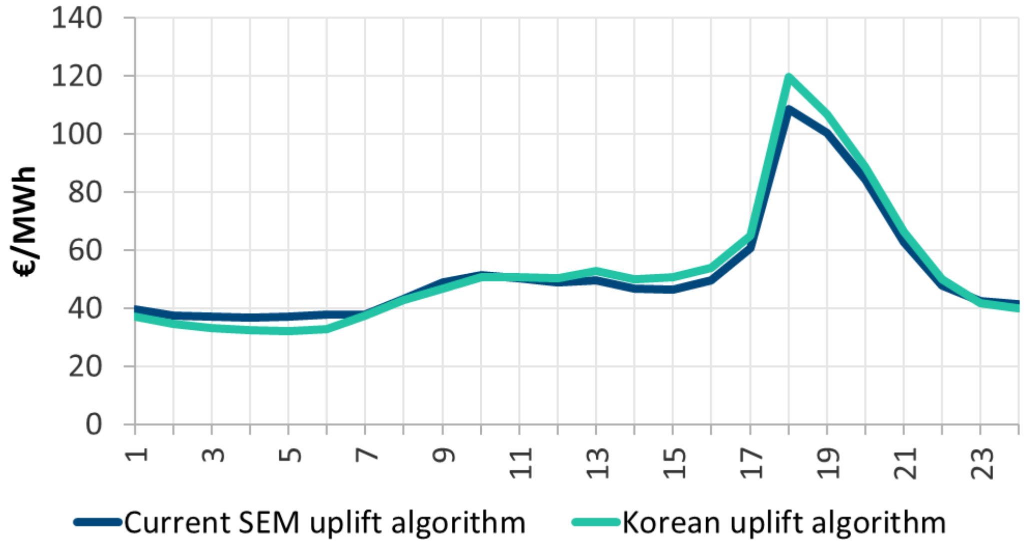
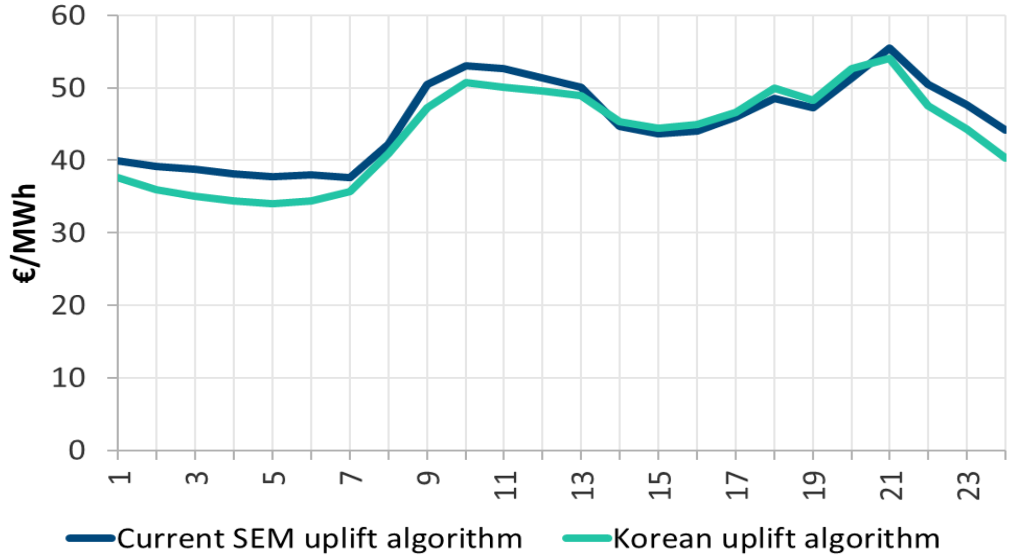


Figure 10 Hourly Summer SMP profile with Korean uplift costs



Custom uplift:

Using OpenPLEXOS to design a bespoke approach can work well, and gives flexibility to the model developer. Baringa has used this before on a number of occasions, including for custom uplift algorithms. The difficulty in developing one for I-SEM is in forming a view of what the behaviour is that is trying to be replicated, before the market goes live and behaviour can be observed.

Suggested approach: We suggest using the Korean algorithm to model uplift in the I-SEM validated model, as this gives baseload prices close to the current SEM model but with a higher proportion of uplift recovered in peak periods.

Question 9: Do you agree with using the Korean algorithm for modelling uplift in I-SEM?

3.5 Scarcity

Scarcity bidding refers to the practice whereby generators may bid above their short-run marginal cost levels (including start-up and no-load costs) to seek extra profits to recover fixed costs and earn a return on capital (to the extent this is not possible through the Capacity Remuneration Mechanism). In a market with unrestricted bidding, in principle this behaviour could happen anytime, but is likely to be significant only when capacity is 'scarce', i.e. when the capacity margin is low due to a combination of high demand and/or low plant availability. Bidding above short-run marginal costs is not currently allowed in SEM under the Bidding Code of Practice, but in I-SEM generators will be free to bid at whatever level they wish in the Day-Ahead-Market, cost reflective or otherwise (in the BM restrictions will remain on cost reflective bids).

In other European markets using EUPHEMIA some level of historical scarcity pricing has been observed, though in recent years this has all but disappeared and is not visible in the forward curves of any major market. This is primarily a result of falling demand and relatively high capacity margins.

There are a number of approaches to including scarcity pricing in PLEXOS:

1. Bertrand pricing
    a. Generators increase their offers up to the cost based offer of the next generator. This results in a modest increase in prices, accentuated in periods of tight supply. It is not clear whether this mimics real generator behaviour or not.
2. Market wide scarcity mark-ups using the Residual Supply Index (RSI) functionality
    a. This applies a market wide mark-up to all generators based on the capacity margin of the system. It relies on historical market data to calibrate. There is currently very low scarcity in major European markets making it difficult to calibrate a scarcity function reliably.
3. Ex-post mark-ups
    a. Outside of PLEXOS prices in peak periods can be increased using a number of ex-post calculations. Again, this requires historical data to calibrate.

If market data were available, we believe option 2 to be the best, as it results in a single PLEXOS model which has an endogenous calculation of scarcity pricing based on real world data. Without I-SEM market data to calibrate with, and noting low levels of scarcity pricing in other markets, we propose that scarcity is not included in the I-SEM model at this stage. This assumes that generators will not engage in bidding above short-run marginal costs, and will seek to recover all other generation costs through infra-marginal rent and the Capacity Remuneration Mechanism.

It is possible that scarcity pricing might be a feature of I-SEM in the future, particularly where the new Capacity Remuneration Mechanism sends an exit signal, and capacity margins become tighter. However, at this stage in the absence of historic data we do not believe it possible to speculate on the extent of future scarcity pricing. As a result it is possible that forward prices, particularly peak prices, could be underestimated in the I-SEM PLEXOS model towards the end of the modelled horizon. A further consideration is the effect of the new CRM, which in our view will reduce the incentive on generators holding Reliability Options to push DAM prices above the RO strike price (~€500/MWh). The proposal to link DCs to a call option at the RO strike price – effectively 'truncating' the pay-out on DC CfDs at this level – would also reduce the incentive for generators holding a DC and call option to push DA prices above the RO strike price.

Though we do not propose including scarcity in the I-SEM model, we do propose undertaking some off-model analysis to assess how VoLL pricing and Administrative Scarcity Pricing in the Balancing Mechanism could influence scarcity pricing in the DAM.

Suggested approach: Do not include scarcity bidding in the I-SEM Validated model, ie assume all bidding is cost reflective (including start and no-load costs).

Question 10: Do you agree with the approach of leaving scarcity bidding out of the I-SEM model?

3.6 Treatment of GB and Interconnectors

The treatment of interconnectors is related to the treatment of GB. The current SEM Validated Model does not represent GB prices, but rather GB bids on the interconnectors.

3.6.1 Treatment of GB

In treating the interconnected electricity market of GB there are a number of approaches that could be followed. Representing interconnected markets in PLEXOS is always a trade-off between:

- Quality of representation
- Ease of updating
- Modelling an overall region that is not too disproportionate relative to the size of the home market (avoiding PLEXOS optimising interconnected market at expense of market of interest)

The change to I-SEM arrangements does not materially change how GB should be represented. Outlined below are some possible approaches to modelling GB in an I-SEM PLEXOS model:

1. Fixed hourly price series
2. Fully detailed plant level representation
3. Representative stack (for instance, 1 Nuclear, 1 Wind, 2 CCGT, 1 Coal, 1 OCGT plant)
4. Single GB gas generator with calibrated heat rate to reflect Interconnector bids

Table 6 Approaches for modelling GB

GB representation	Pros	Cons	Applicability to I-SEM model
1. Fixed hourly price series	• Simple to implement in PLEXOS • Quick to run	• Need a way of calculating GB price (another model) • Assume SEM is price taker • Does not reflect commodity charges	
2. Full GB representation in PLEXOS	• Excellent GB price calculation	• Slow to run • Requires a lot of maintenance • Optimiser “favours” larger market	

3. Simplified GB stack	• Good GB price calculation • Reasonable run times	• Requires regular maintenance of stack properties, which is quite difficult	●
4. Single GB generator	• Quick to run • Quick to recalibrate	• GB price calculation not as accurate as other methods • Embeds recent historical behaviour into GB bids	●

Table 6 summarises the pros and cons of each approach. In the current SEM Validated Model Option 4 is used, a single GB generator calibrated using recent historical data, as this is quick to recalibrate for a model that is used regularly. The move to I-SEM market arrangements will have little effect on the GB market, and so we propose keeping the current approach in the Validated I-SEM Model.

The GB generator in the PLEXOS model represents bids on the SEM-GB interconnectors (ICs) rather the wholesale price of electricity in the GB market. The current methodology uses a single GB Gas generator object in PLEXOS with a heat rate that represents GB bids on the ICs based on the prevailing cost of gas in GB (NBP gas and EUA carbon). Under SEM arrangements IC imports receive SEM capacity payments, and therefore will offer below the GB DA power price in an effort to capture these.

When calibrating the implied heat rate for the dummy GB generator in the current SEM Validated Model we remove SEM capacity payments from the GB DA power price before comparing these resulting IC bids with the DA NBP gas price and EUA carbon price. A regression is performed to find the relationship between IC bids (£/MWh) with gas costs (£/GJ) to find the implied heat rate (GJ/MWh). This is performed in 4 hour blocks, for Summer and Winter, then is smoothed to avoid sharp block edges in the heat rate profile.

Under I-SEM arrangements, IC imports will no longer receive SEM Capacity Payments. To calibrate the implied heat rate of GB IC bids the methodology above would need to be adapted to use the full GB DA power price, without the removal of SEM Capacity payments from IC bids. This will likely reduce imports to I-SEM. By using the DA power price, any "uplift" in GB (ie recovery of start and no-load costs) is included in the implied heat rate based on recent historical market behaviour, and no additional uplift mechanism is required for GB bids.

Suggested approach: We propose Option 4 remains as the method for representing GB in the I-SEM model, due to the time availability and desire to reduce the number of 'moving parts'. We would update the calibration process with distortion of capacity payments removed.

Question 11: Do you agree that GB should be represented as a single gas generator in the I-SEM model, calibrated using recent historical market data?

3.6.2 Treatment of Interconnectors

As a result of representing GB by bids on the interconnectors, the interconnectors themselves can be represented as physical assets, without the need for wheeling charges or other modelling "fixes" that mimic the effect of trading arrangements over the interconnectors (ie imports receiving SEM Capacity payments, as discussed in Section 3.6).

Under current SEM arrangements, ICs are scheduled on the basis of shadow prices, but receive SMP when importing to SEM (ie shadow plus uplift). This means that GB bidders are willing to remove an estimate of SEM uplift from their bids, as they will receive this back if scheduled to import to SEM. The current SEM Validated Model uses Rounded Relaxation, which correctly mimics the market arrangements by scheduling interconnectors based on shadow price in SEM. As part of the calibration process of the GB Interconnector bid heat rate we remove historical SEM uplift from GB bids, such that the final GB IC bid used for the heat rate regression is calculated as:

GB IC bid = GB DA power price - (SEM Capacity Payments + SEM Uplift)

Under I-SEM arrangements ICs will be scheduled on the I-SEM full price (ie equivalent to current SMP) and will receive the full price, so GB prices used to schedule flows on the ICs will no longer have SEM uplift subtracted. However, if Rounded Relaxation is used for the I-SEM model, IC flows will be scheduled on "shadow price" within the PLEXOS model. If there is no calibration of GB prices or interconnector charges, interconnector flows in the PLEXOS model will tend to over-schedule exports from SEM to GB versus those from the EUPHEMIA software. The issue is that in a Rounded Relaxation model I-SEM shadow price will not contain I-SEM start and no-load costs but the GB price will contain GB start and no-load costs, from historical GB DA prices.

A number of options exist for tackling this issue. Below we highlight two potential solutions:

1. Use historical SEM uplift to calibrate the GB interconnector bid heat rate:
   - This is the current approach, whereby historical SEM uplift and SEM capacity payments are removed from historical GB DA prices to calculate the implied GB interconnector bids, before calculating the implied heat rate of the gas generator representing GB IC bids. [In I-SEM capacity payments would not be removed, as discussed in Section 3.6]
   - The benefit of this approach is that it is a continuation of the current methodology and reduces the number of changes in the modelling. It would be easy to recalibrate the GB interconnector bid heat rate omitting capacity payments and uplift and using the most recently available data.
   - However, there is an issue with this approach in that it assumes the nature of SEM uplift seen historically will continue in I-SEM. This assumption is likely to be wrong for two reasons
     a. 1. Interconnector behaviour in I-SEM will likely change (higher exports to GB) due to the removal of capacity payments on imports, which is likely to change uplift in I-SEM (uplift has been found previously to be fairly sensitive to interconnector flows due to the flexibility the ICs provide the system)

b. 2. If the PLEXOS model is changed to use Korean uplift rather than SEM uplift this assumes that final price shape will change, which will not be reflected in historical SEM uplift data used to calibrate the GB IC bid

2. Use an I-SEM model to predict I-SEM uplift, then use this to alter Interconnector bids in a two stage model:
   - This could be implemented through a wheeling charge on the interconnector, bringing the I-SEM price that the interconnector sees up from shadow price to "SMP"
   - The first pass model would have a coarse view of uplift and the level of this wheeling charge (i.e. X €/MWh in all periods), and would output detailed hourly uplift levels.
   - The second pass model would use these uplift levels to give a more refined view of uplift to the interconnector, and re-dispatch to give final price and quantity levels.
   - The half-hourly uplift from the first pass could be passed to the interconnector wheeling charges in the second pass model by either:
     - Using an automatically generated data file to pass half-hourly wheeling charges directly to the second pass model (allowing the two stages to be run back-to-back without user input); or
     - Using additional semi-manual tool (likely Excel based) to process half-hourly uplift from first pass to give a characteristic day/period wheeling charge for use in the second pass of the model.
   - In this methodology we would propose performing the initial calibration run as part of the I-SEM PLEXOS model validation, then would fix the wheeling charges until a future validation exercise. This is similar to the current approach, where historic uplift is used to calibrate the GB IC bid heat rate, and is done once a year as part of the validation exercise. In both cases a credible set of uplift values are used to calibrate the interconnectors, and this is done approximately once per year.
   - The benefit of this approach is that it gives a more accurate view of the nature of uplift in I-SEM and uses this to ensure correct interconnector flows
   - The downside of this approach is that it requires at least a two stage model, which may be impractical for some purposes.

Suggested approach: We propose using Method 2, using a first stage model to project uplift then use a semi-manual tool to give characteristic day/period uplift values that are included in the Validated I-SEM model as a wheeling charge on the interconnectors.

Question 12: Do you agree with using an I-SEM model to predict I-SEM uplift, then using this to set interconnector flows in the Validated I-SEM Model through a wheeling charge?

3.7 Validation of input data

There are several input data sources which need to be validated as part of the SEM model and going forwards into the I-SEM model.

3.7.1 Wind and demand profiles

The current SEM Validated Model approach for including wind and demand load profiles at a half-hourly level is to use a base year of outturn half-hourly data. The base year in the Validated Model, 2015, is aligned to the Generation Capacity Statement 2017-2026 for both wind and demand profiles. Using a single base year for wind and demand presents the issue that it builds into the forward looking model any atypical behaviour seen in the historical year used.

There is no reason to expect wind or demand profiles to change as a result of the move to I-SEM. However, as part of producing as robust Validated I-SEM Model we have identified the following approaches to including wind and demand profiles:

1. Use the current base year, 2015, as per the 2017 Model Validation and aligned to the most recent CGS as published by Eirgrid.
    a) Using a single year for both wind and demand ensures correct correlations;
    b) We note that there is some atypical demand and wind in Q4 of 2015 which gives unusual results in these months in all future years of the model.
2. Use a different base year. Baringa uses 2012 data for much of our modelling.
    a) Baringa has identified 2012 as a “typical” year, though we note that no year is truly “typical” and there may be some peculiar features of 2012 in SEM which may not yet be noted
3. Use correlated wind and demand profiles from multiple base years using a Monte Carlo simulation, similar to the current approach used for outage patterns in the SEM Validated Model.
    a) This approach reduces the risks associated with using a single base year.
    b) Run times would increase, but can be offset by implementing the changes to Rounded Relaxation self-tune increment and short-term horizon settings suggested previously
4. Use a fundamentals based approach for wind and demand.
    a) This is a complicated modelling exercise and is out of scope due to the timings in producing a Validated I-SEM Model

We have gathered historical wind and demand profiles from the TSOs for 2007-2016. The wind profiles are for two regions only, NI and ROI, rather than the 13 regions used in the current SEM Validated Model. Given the purpose of the model is for unconstrained price projections we believe this granularity is sufficient, and would require the I-SEM model to be adjusted to use only two wind generator objects.

Suggested approach: Implement Option 3, using multiple base years under a Monte Carlo simulation, and taking the mean price from all runs as the output from the model. Would change model to have only two wind regions, NI and ROI to allow historical data to be used. Would use ~five wind and demand base years, such that run time of the I-SEM model is similar to current SEM model

Question 13: Do you agree with the above approach to modelling wind and demand profiles?

3.7.2 Wind capacities and demand levels

The current SEM Validated Model uses the GCS 2017 projections for both wind capacities and demand peak and annual energy levels. The I-SEM Validated model will need to extend these projections to the end of 2019.

Suggested approach: Continue to use GCS 2017 as source of wind and demand projections, but extend to 2019.

Question 14: Do you agree with using the GCS 2017 as the source for 2019 wind and demand projections?

3.7.3 Generator data

The most recent 2017 model validation involved a comprehensive collection and validation of SEM generator data. This data must be fully cost reflective under the SEM TSC.

Our assumption is that this data is:

1. A true reflection of generator technical and commercial properties
2. Is the most complete and best source of this data at this time
3. Unlikely to materially change from now to Q4 2019

Once I-SEM begins it will be possible to see generator in the DAM and the Balancing Market and test the assumptions above, but as the I-SEM Validated Model is to be produced before I-SEM goes live this source of data is not available at this time.

Suggested approach: Use the generator properties from the recently validated SEM model for the I-SEM model.

Question 15: Do you agree with using the same generator data from the SEM model in the I-SEM model?