I-SEM TRIALLING OF EUPHEMIA:

INITIAL PHASE REPORT

30/09/2015

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2 EXECUTIVE SUMMARY

The I-SEM trialling of EUPHEMIA is an on-going analysis project being conducted by SEMO at the request of the Regulatory Authorities (RAs). The project involves trialling the EUPHEMIA[1] algorithm using orders which are reflective of the expected I-SEM design. The overall goal of the trialling is to develop the understanding of the functioning of the algorithm of SEMO, industry, the RAs and any other relevant stakeholders. The trialling is broken into two phases:

- **The Initial Phase –** trials performed by SEMO
- **The Commercial Phase –** trials performed by SEMO in conjunction with industry

This document outlines the methodologies, assumptions and results of the Initial Phase of trialling. The goal of the Initial Phase was for SEMO to develop its understanding of EUPHEMIA to a level sufficient to co-ordinate industry during the Commercial Phase and share this developed understanding with industry.

The Initial Phase trials were broken into three batches, as follows:

- **Batch One –**used to assess the order types available given SEMO's initial assumptions without coupling
- **Batch Two –**used to assess the effects of coupling with another bidding zone
- **Batch Three –**used to further assess the assumptions and coupling given stressed conditions

Across all trial batches, three main order types were assessed in looking at thermal generator units:

- **Complex orders –** price quantity pairs with conditions attached
- **Linked block orders –** interdependent blocks of energy each representing part of a potential profile
- **Exclusive group orders –** a group of mutually exclusive profiles considered as a single order in EUPHEMIA

The main objective of this representation was to as closely as possible mirror the unit's SEM representation.

Complex orders led to price formations which reflected bid prices and underlying conditions in a manner similar in principle to the SEM. However, the assumptions used in the application of complex orders led to a reduced ability to manage scheduling and cost recovery risks.

Both linked block orders and exclusive group orders were entered based on profiling of units' SEM data, guaranteeing revenues and schedules consistent with their underlying characteristics. However, due to the functioning of these orders in EUPHEMIA, units using these orders were prevented from directly setting the price. This led to volatile prices which did not reflect cost or scarcity. Additionally, the level of complexity used was very high, which also contributed to the poor results and led to poor algorithm performance; these effects were more pronounced with exclusive group orders.

In all cases, access to the interconnectors led to improved price formation (i.e. less volatility) and a lower average price. This was of particular benefit in the linked block datasets where the issues with price formation were addressed by access to orders outside of the I-SEM; however, these benefits were only applicable up to the point of interconnector constraint (i.e. congestion or constraint due to ramping limits). Though interconnection was of benefit to linked block datasets, as the fundamental issue with price formation was not solved, it will not act as a comprehensive solution to the issues observed.

[1] EUPHEMIA is the day ahead market algorithm currently in use to calculate energy allocations and prices across Europe developed by the Price Coupling of Regions (PCR) initiative.

Moyle and EWIC were represented as close as possible to their SEM representation, i.e. separate losses, ATC and ramping values. As EUPHEMIA accounts for the losses of interconnectors in scheduling, and Moyle has lower losses in the SEM than EWIC, Moyle may be scheduled ahead of EWIC (i.e. at lower price spreads between the I-SEM and adjacent zones); the results show evidence of Moyle being scheduled at full capacity more often than EWIC and periods where Moyle is scheduled and EWIC has a schedule of zero.

For clarity, any comparisons between SEM and EUPHEMIA outputs within this document are included for reference only. The results of the Initial Phase are not reflective of expected outturn results for a variety of reasons including demand elasticity, use of interconnectors, order characteristics, EUPHEMIA (day-ahead) results only representing a portion of the overall I-SEM and as such conclusions should not be drawn of final I-SEM prices based on the results of the Initial Phase.

The robust nature of the trials has contributed to SEMO's increased understanding of EUPHEMIA. However, a number of items for further study have been identified and will be explored in the Commercial Phase. The items and their potential benefits are as follows:

- **Price making load/wind –** participation of suppliers or wind units on a price making basis will improve price formation and may be more reflective of how participants will act in the I-SEM
- **Combinations of order types –** a dataset using multiple order types (e.g. complex and linked block) for thermal units may provide benefits to different types of units
- **Refinement of block order assumptions –** revision of how block orders are represented, e.g. number of blocks in an exclusive group may improve algorithm performance and results of these order types
- **Refinement of complex order assumptions –** revision of the assumptions used may help to manage the risks associated with these orders and lead to more efficient scheduling

SEMO will continue to engage with the I-SEM EUPHEMIA Working Group[2] on these items during the Commercial Phase. The Commercial Phase will provide an opportunity to complete additional trialling and to refine assumptions in a heuristic manner.

[2] The I-SEM EUPHEMIA working group was set up in April 2015 and has representatives from 17 companies and the Regulatory Authorities. Terms of reference are available: http://www.sem-o.com/Publications/General/Terms%20of%20referrence%20-%20ISEM%20EUPHEMIA%20Working%20Group.pdf

3 INTRODUCTION

EUPHEMIA is the day ahead pricing algorithm currently in use throughout Europe. It was developed by the Price Coupling of Regions (PCR) initiative, an organisation of European power exchanges. The use of EUPHEMIA for the day-ahead market in the I-SEM is outlined in the SEM Committee's decision on the high level design (HLD) for the I-SEM (SEM-14-015A). While the use of EUPHEMIA is mandated by the HLD, the precise implementation will be decided as an implementation phase consideration.

EUPHEMIA allows for a number of different formats of bids and offers, collectively referred to as orders, each of which has related characteristics and limitations. The Regulatory Authorities (RAs) requested SEMO, in their role as market operator of the SEM, member of EUROPEX and associate member of the PCR, to investigate the feasibility of possible implementations of EUPHEMIA for the I-SEM.

In June 2014, SEMO engaged with the PCR Algorithm Working Group (ALWG) to organise a programme for a trial of EUPHEMIA. The PCR ALWG agreed to allow this trialling to take place and nominated APX Power B.V. as the designated member to complete this work.

Following agreement with the PCR ALWG, SEMO began preparing datasets for use in the trial based on historical SEM Trading Days and prepared a detailed programme for the trialling process. This programme was discussed with the I-SEM Euphemia Working Group and RAs in order to agree a final plan. Details of this final plan can be viewed here; at a high level this plan is composed of two main phases:

1. **Initial Phase –** trials performed by SEMO
2. **Commercial Phase –** trials performed by SEMO in conjunction with industry participation

This document outlines the process for and results of the Initial Phase. It provides a high level overview of the process, details of the assumptions used and details of the output results. It closes with the conclusions drawn by SEMO and areas for further studies. This report has been discussed with the I-SEM EUPHEMIA Working Group, terms of reference for which can be viewed here, in order to come to agreement on the areas of mutual interest for study in the Commercial Phase.

4 GOAL OF TRIALS

The primary goal of the I-SEM trialling of EUPHEMIA is for market participants and SEMO to gain first-hand experience in the formation of orders and related strategies for EUPHEMIA and to share the key learnings gained with all relevant stakeholders. This will involve investigating the feasibility, quality, and performance of the algorithm using different order types, noting that:

- By feasibility, we mean whether certain characteristics of the I-SEM can be represented in EUPHEMIA;
- By quality, we mean the degree that the algorithm produces an outcome that aligns with the policy objectives of the I-SEM in terms of efficiency of prices and volumes, stability of prices and volumes, etc.; and
- By performance, we mean the extent that the inclusion of I-SEM market orders, affects the solution time of the algorithm and optimality of the solution.

While this is subject to the order formats and other characteristics of EUPHEMIA and their limitations, the objective is to, as best as possible, represent SEM orders in EUPHEMIA and assess the results of doing so. It is the goal of the Initial Phase to develop a sufficient understanding of EUPHEMIA in SEMO to allow for co-ordination of further trials and to share this understanding with industry in order to prepare for the Commercial Phase.

5 ASSUMPTIONS

5.1 REPRESENTATION OF THE I-SEM

In order to represent the I-SEM in EUPHEMIA as closely as possible to the existing SEM a number of key assumptions were used throughout all trials, namely:

- SEM Trading Day timelines (06:00 – 06:00) are used
- Suppliers and price taker generators participate on a price taker basis
- Generator bids are based on COD and TOD submitted for the Trading Day
- Interconnectors (Moyle and EWIC) are modelled separately
- Generators should only be scheduled where their fixed and variable costs are recovered
- Generator orders should allow for as many SEM characteristics as possible, subject to the limits of the order format being used
- Orders for pumped hydro storage units and energy limited hydro units will be reflective of the limitations of those units in the SEM, e.g. energy limits, max reservoir levels etc., as best possible
- All data used in the trials will be based on EA1, or the closest alternative, for the relevant Trading Day
- All price/quantity curves will be stepwise curves
- All units wish to be scheduled in the day ahead market for their availability/forecast position
- Market participants will not seek to take advantage of price arbitrage opportunity
- The bidding code of practice is applied, as best possible, through use of commercial data from the SEM

These assumptions were used to best represent the SEM in EUPHEMIA and also to avoid, as much as possible, assumptions being made by SEMO as to possible market participant behaviour or market power mitigation measures in the I-SEM.

5.2 ROLE OF PCR ALWG AND INTERACTION WITH EUPHEMIA ALGORITHM

The trials are being performed by SEMO, as market operator and associate PCR member, in conjunction with the PCR ALWG. As an associate member of PCR, SEMO does not have direct access to the EUPHEMIA algorithm or any related trading platforms. As such, the primary role of the PCR ALWG is to facilitate use of the algorithm. To allow for this, SEMO and the PCR ALWG have agreed a process whereby SEMO produces datasets which model historical SEM Trading Days and submits these to the PCR ALWG in a pre-defined format. The PCR ALWG then uses these datasets in EUPHEMIA and shares relevant results with SEMO. It was decided that the trials would be performed in batches of multiple datasets rather than ad hoc trialling of individual datasets.

In addition to this role, given the level of expertise held by the PCR ALWG, they are providing advice on the results, inputs and possible avenues of further study. This includes advice on interpretation of results, on formation of input data and on how the available order formats may be used to represent the generator and suppliers of the SEM under I-SEM conditions.

5.3 STRUCTURE OF TRIALS

As outlined above, the EUPHEMIA trials are broken into an Initial Phase and a Commercial Phase. The Initial Phase, the phase outlined in this report, is comprised of all trials prepared by SEMO. It can be broken down into a number of distinct trial batches, outlined in table 1 below.

Name	Trading Days	Datasets	Order Formats	Order Books
Batch One (including revisions)	3	36	Complex; Linked Blocks; Exclusive Groups	SEM Only
Batch Two	3	12	Complex; Linked Blocks	SEM and PCR
Batch Three	19	33	Complex; Linked Block	SEM and PCR

Table 1: Overview of Initial Trial Batches

5.4 TRADING DAYS INCLUDED IN THE TRIALS

Batches one and two were modelled based on the same three Trading Days. It was decided to take this approach to allow for a heuristic process with revision of assumptions related to Trading Days with known and studied conditions. The Trading Days chosen were 03/03/2014, 19/03/2014 and 23/03/2014. These days were chosen to allow for a period with similar conditions (e.g. dates with similar underlying fuel costs due to them occurring in the same month) but allowing for differing wind and load profiles. In choosing these Trading Days the total load, total wind and total margin (being the difference between the two) were the main deciding factors.

In addition to this, the dates used in batch three were agreed with industry and the RAs following multilateral discussions by SEMO. The batch three Trading Days were chosen to meet a number of scenarios desired by industry representatives. A summary of the Trading Days and relevant conditions is included in the sections below.

5.4.1 03/03/2014

The first Trading Day chosen was 03/03/2014. This date was chosen due to it providing a relatively stable margin throughout the day and a steady wind profile. Due to its average wind values and stable profile, this day offered advantages as a proxy for average market conditions. Data on the wind, load and margin per trading period on an aggregate basis can be seen below in figure 1.

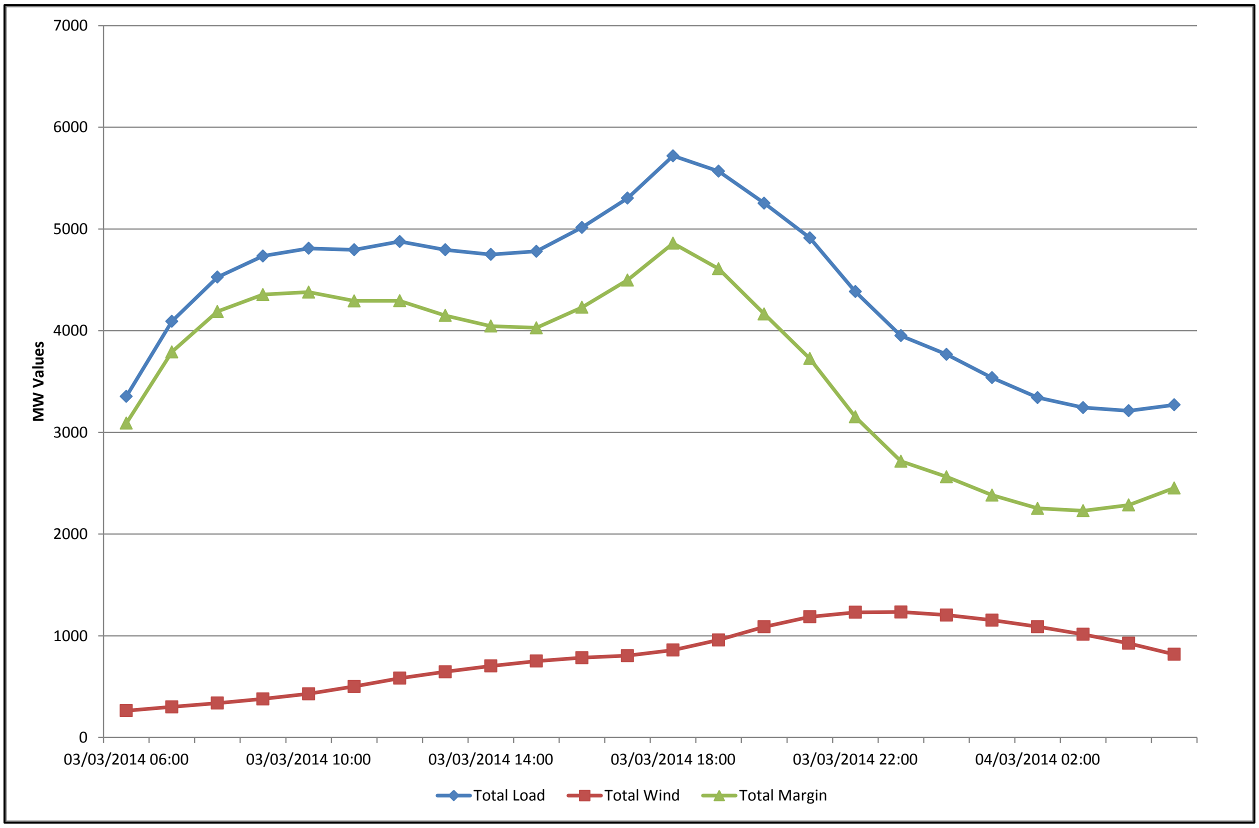

Figure 1: Aggregate Wind, Load and Margin Data for 03/03/2014

5.4.2 19/03/2014

The second Trading Day chosen was 19/03/2014. It was chosen due to its consistently high wind profile which offered the opportunity to study a high wind profile day. Details of the aggregate wind, load and margin values for 19/03/2014 are presented in figure 2 below.

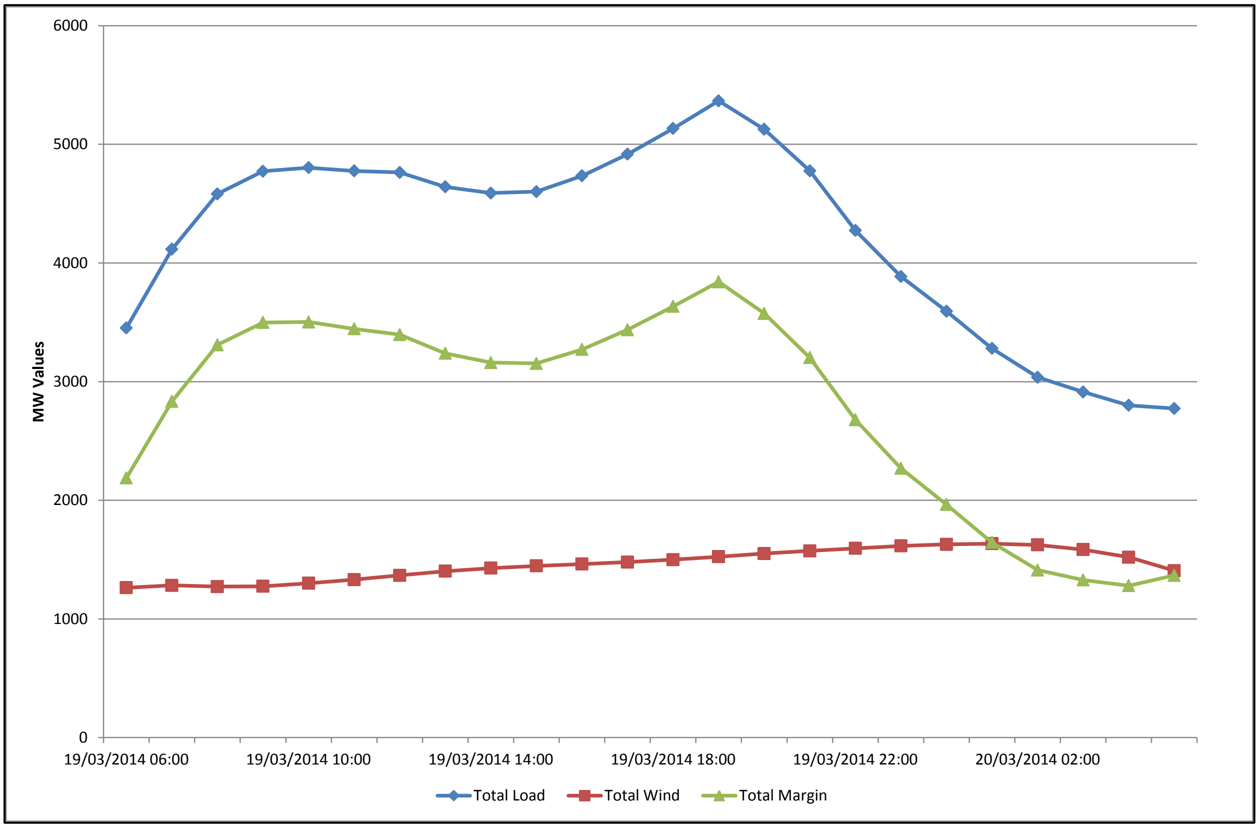

Figure 2: Aggregate Wind, Load and Margin Data for 19/03/2014

5.4.3 23/03/2014

The final Trading Day chosen was 23/03/2014. This day was chosen due to the large variations in the wind profile throughout the day. The wind in this day moves from an average value, to a very low value and then reaches a very high value. This variation allowed the opportunity to study the effects of the unpredictability of wind in EUPHEMIA. The wind, load and margin values for this day are presented in figure 3 below.

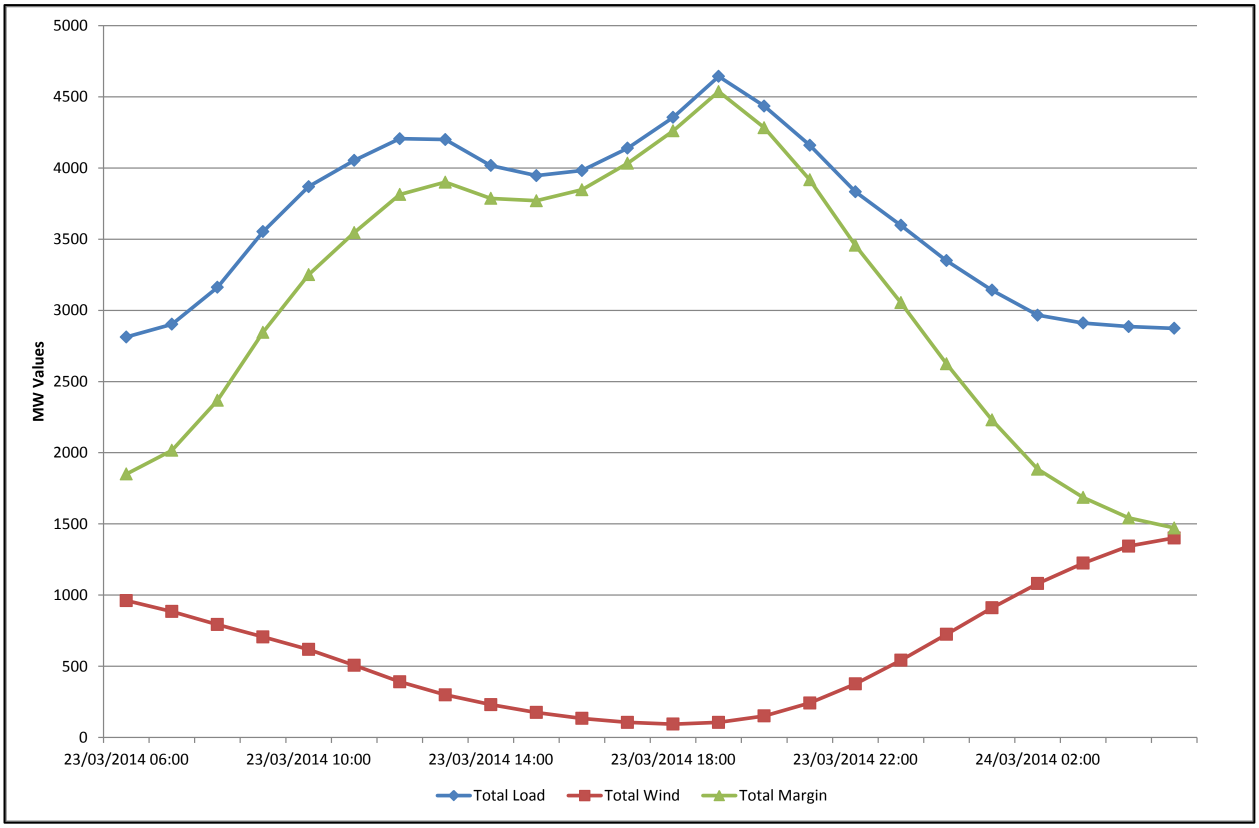

Figure 3: Aggregate Wind, Load and Margin Values for 23/03/2014

5.4.4 BATCH THREE TRADING DAYS

The Trading Days for the batch three trials were agreed between SEMO, industry representatives and the RAs. It was decided that, to allow for SEMO and PCR availability, the total number of datasets used would be approximately equivalent to one month of trialling (i.e. approximately 30 datasets), but the Trading Days to be used did not need to be sequential and a single Trading Day could be used multiple times.

It was decided that a number of different scenarios (e.g. high wind, high demand) would be covered and that a Trading Day from each season would be used. Details of the Trading Days and conditions used in batch three trials are presented in table 2 below.

Trading Day	Day	Season	Load	Wind
07/03/2014	Friday	Spring	High Demand	High Wind
19/04/2014	Saturday	Spring	Average Demand	Low Wind
08/05/2014	Thursday	Summer	Average Demand	Average Wind
20/07/2014	Sunday	Summer	Low Demand	Low Wind
10/08/2014	Sunday	Autumn	Low Demand	Average Wind
09/09/2014	Tuesday	Autumn	Average Demand	Low Wind
03/10/2014	Friday	Autumn	Average Demand	Average Wind
18/10/2014	Saturday	Autumn	Average Demand	High Wind
21/10/2014	Tuesday	Autumn	Average Demand	High Wind
03/12/2014	Wednesday	Winter	High Demand	Low Wind
07/01/2015	Wednesday	Winter	High Demand	High Wind
08/01/2015	Thursday	Winter	High Demand	High Wind
09/01/2015	Friday	Winter	High Demand	High Wind
09/01/2015	Friday	Winter	High Demand	High Wind
10/01/2015	Saturday	Winter	High Demand	High Wind
11/01/2015	Sunday	Winter	Average Demand	High Wind
12/01/2015	Monday	Winter	Average Demand	High Wind
13/01/2015	Tuesday	Winter	High Demand	High Wind
22/01/2015	Thursday	Winter	High Demand	Average Wind

Table 2: Details of Batch Three Trading Days

In addition, a number of these days were agreed to be run with revised wind levels and interconnector availability or with an alternate order format applied. Details of the datasets used are outlined in section 6.7.

5.5 ORDER TYPES USED

As part of the trials, a wide range of order formats were used. The assumptions used relating to each specific order format varied as SEMO's knowledge of EUPHEMIA increased. Details of how SEM data was converted to the EUPHEMIA order format are available here.

All of the following order formats have been used as part of the I-SEM EUPHEMIA trials:

- Hourly Simple Orders
- Flexible Orders
- Linked Block Orders
- Exclusive Group Block Orders
- Complex Orders

5.6 ORDER BOOKS USED

It was decided that trial batch one would involve the SEM order book (market data, bids and offers) only, i.e. no interconnection to any other bidding zone. This was to allow a comparison between outputs of the EUPHEMIA algorithm and relevant SEM outputs, i.e. SEM runs for the Trading Days rerun with interconnectors unavailable. Batch one was repeated until the implications of order format decisions were better understood.

Batches two and three, which occurred following sufficient analysis of batch one under multiple assumptions, included the SEM order book and interconnection to a representative PCR order book. The PCR order book used was representative of the bidding zones involved in multi-regional coupling (MRC) for the relevant Trading Days. Interconnection was represented between the I-SEM and GB but EUPHEMIA allowed for all other relevant zones through further interconnection, e.g. GB to France interconnection.

5.7 INTERCONNECTOR REPRESENTATION

One of the key assumptions about representing I-SEM is to, as closely as possible, match the SEM; accordingly, it was decided to represent interconnection between I-SEM and Great Britain as in the SEM, i.e. both the Moyle and EWIC interconnectors are represented separately.

This meant that in the trials both Moyle and EWIC were represented with distinct ramping capabilities, capacities and transmission losses. This is reflective of the SEM where each interconnector has its own characteristics and no aggregation is in place. To achieve this, each line was represented as being between the I-SEM and one of the two GB bidding zones, run by N2EX and APX respectively. As there is infinite interconnection between both GB zones in EUPHEMIA, this is equivalent to having two separate interconnections between the I-SEM and combined GB. In production, separation of interconnectors would most likely be achieved using virtual zone(s); however, the treatment used achieved the goal of closely matching the SEM characteristics of each interconnector.

As the interconnectors are represented with different losses, and EUPHEMIA accounts for losses in interconnector scheduling, the scheduling of each interconnector will be different. The interconnector losses have been represented in EUPHEMIA according to the TLAF values in the SEM (where the loss entered is 1 – TLAF). Scheduling of interconnectors in EUPHEMIA is a function of the price spread between bidding zones and the characteristics of the interconnectors. As Moyle has a higher TLAF, and accordingly lower losses represented in EUPHEMIA, than EWIC this will results in a range of values of price spread where Moyle may be scheduled while EWIC remains unscheduled. An illustration of this principle (ignoring other characteristics such as ramping) is presented in figure 4 below.

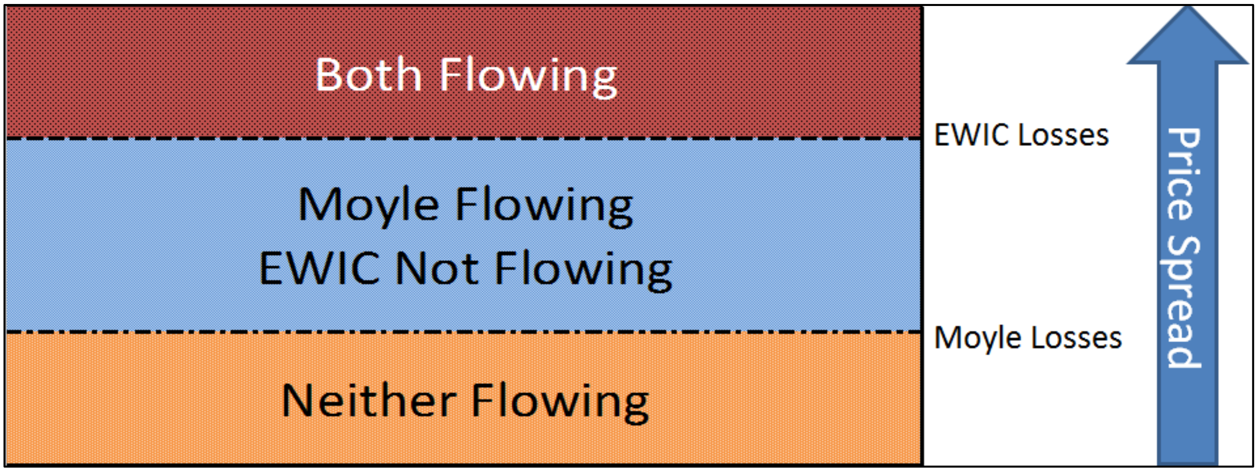

Figure 4: Illustrative explanation of the relation between losses, price spread and scheduling

5.8 COMPARISON WITH SEM PRICES

There are many differences between the SEM Market Scheduling and Pricing (MSP) software and EUPHEMIA. These cover a range of differences both in functionality and the objective function of the algorithms. Some of the key differences are as follows:

- The SEM MSP uses Lagrangian relaxation as a primary solver, with mixed integer programming (MIP) as a secondary solver, while EUPHEMIA uses MIP only;
- The SEM MSP seeks to lower production costs in the SEM while EUPHEMIA seeks to maximise social welfare over all bidding zones;
- The SEM MSP has a number of features to optimally represent units with specific characteristics (e.g. pumped storage) while EUPHEMIA has products which must be adapted, for the purpose of producing commitment starting point for dispatch, for a range of technologies;
- The SEM MSP allocates volumes to interconnectors based on the bids of interconnector units while EUPHEMIA bases interconnector allocations on the price spread between bidding zones;
- Participants in coupled markets are not subject to any Bidding Code of Practice while this is implicitly maintained in the SEM participant data used in the trials;
- The SEM MSP has access to significantly more information for units than EUPHEMIA and this may alter how the units are scheduled, ultimately affecting the price; and
- The SEM MSP has an uplift function which allows a lower merit unit to serve peak load and recover fixed cost while EUPHEMIA only has access to units order information.

Given the above points, it is not possible to directly compare prices or schedules produced by EUPHEMIA to the outturn SEM prices and schedules. Moreover, these trials are at an early stage and the results thus far are not necessarily reflective of the results of EUPHEMIA once the I-SEM goes live. Any comparisons between SEM and EUPHEMIA outputs are included for reference only; results are not reflective of expected outturn results and therefore conclusions should not be drawn of final I-SEM prices.

6 TRIALS

6.1 BATCH ONE – INPUTS (ORIGINAL ASSUMPTIONS)

As stated above, trial batch one contained three Trading Days of data and did not allow for interconnection. Each of these three Trading Days was completed with a distinct treatment of thermal generation:

- complex orders;
- exclusive group orders; and
- linked block orders

This distinction in thermal generator profiling allowed datasets to be categorised based on inputs. The treatment of thermal generators under these order formats is outlined in section 5.5. Initially 9 datasets were trialled; the details of these datasets are presented in table 3 below.

Dataset ID	Trading Day	Thermal Units	Pump Storage	Energy Limited Hydro
201403031	03/03/14	Linked Block	Linked Block	Flexi
201403032	03/03/14	Complex	Linked Block	Flexi
201403033	03/03/14	Exclusive Groups	Linked Block	Flexi
201403191	19/03/14	Linked Block	Linked Block	Flexi
201403192	19/03/14	Complex	Linked Block	Flexi
201403193	19/03/14	Exclusive Groups	Linked Block	Flexi
201403231	23/03/14	Linked Block	Linked Block	Flexi
201403232	23/03/14	Complex	Linked Block	Flexi
201403233	23/03/14	Exclusive Groups	Linked Block	Flexi

Table 3: Trial Batch One (Original) Dataset Details

6.2 BATCH ONE – RESULTS (ORIGINAL ASSUMPTIONS)

6.2.1 PRICE

This section outlines the prices produced by EUPHEMIA for all datasets. For comparison, a SEM study run was completed for each Trading Day involved in the trial. These SEM study runs were performed using conditions as similar to EUPHEMIA as possible. The conditions used were:

- Interconnector availability was set to zero for each trading period; and
- Study runs were completed using the MIP 600[3] solver

SEM study run data is included in all comparisons below; however, it should be noted that, as outlined in section 5.8, there are numerous differences between the SEM algorithm and EUPHEMIA including representation of units and the objective functions. As such, the trial is not attempting to replicate SEM prices or other SEM results, SEM study run prices are included for reference only.

[3] Mixed integer programming (MIP) is the alternate solver in the SEM. MIP solver runs are subject to a time limit expressed in seconds. MIP 600 denotes a run with a ten minute time limit as with EUPHEMIA runs.

6.2.1.1 LINKED BLOCK DATA

The prices produced by linked block datasets over all three Trading Days were unstable and not directly linked to the volume of load or wind. Details of the prices produced by linked block order types are presented below.

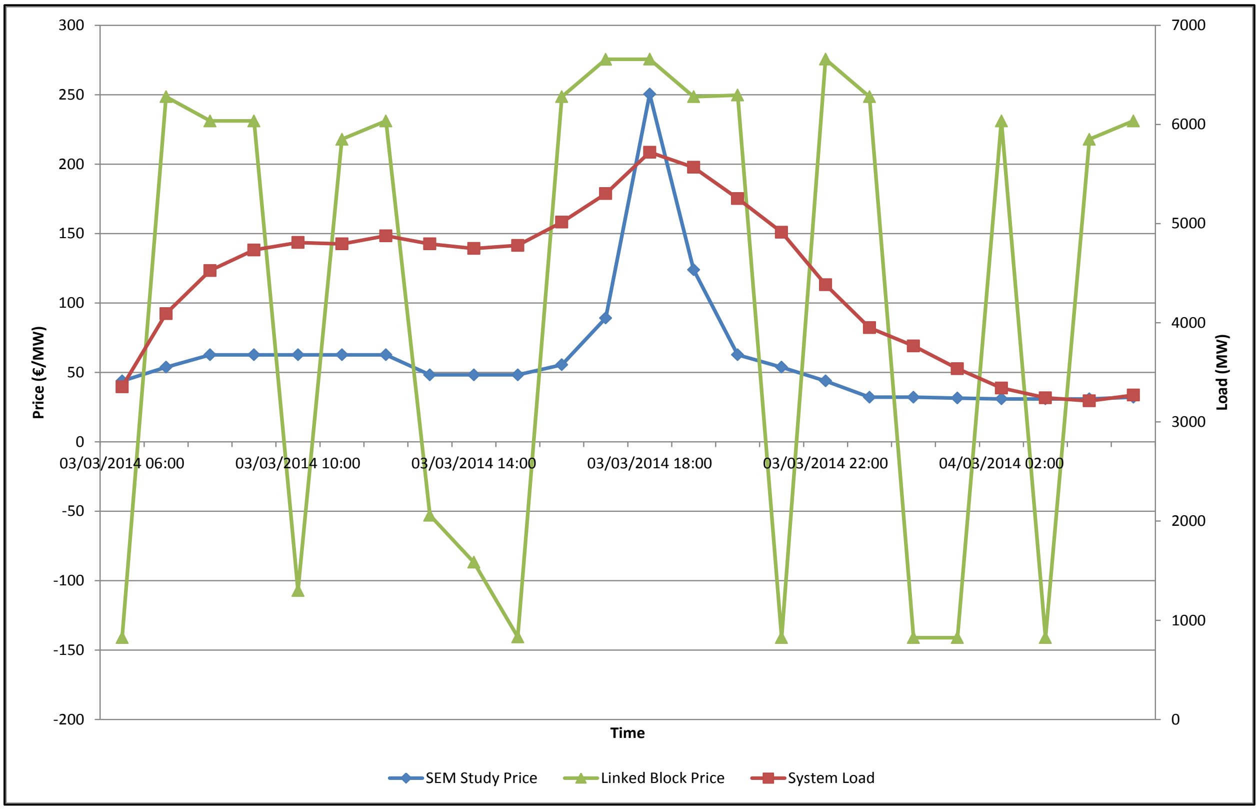

Figure 5: Hourly prices for linked block and SEM study run for 03/03/2014

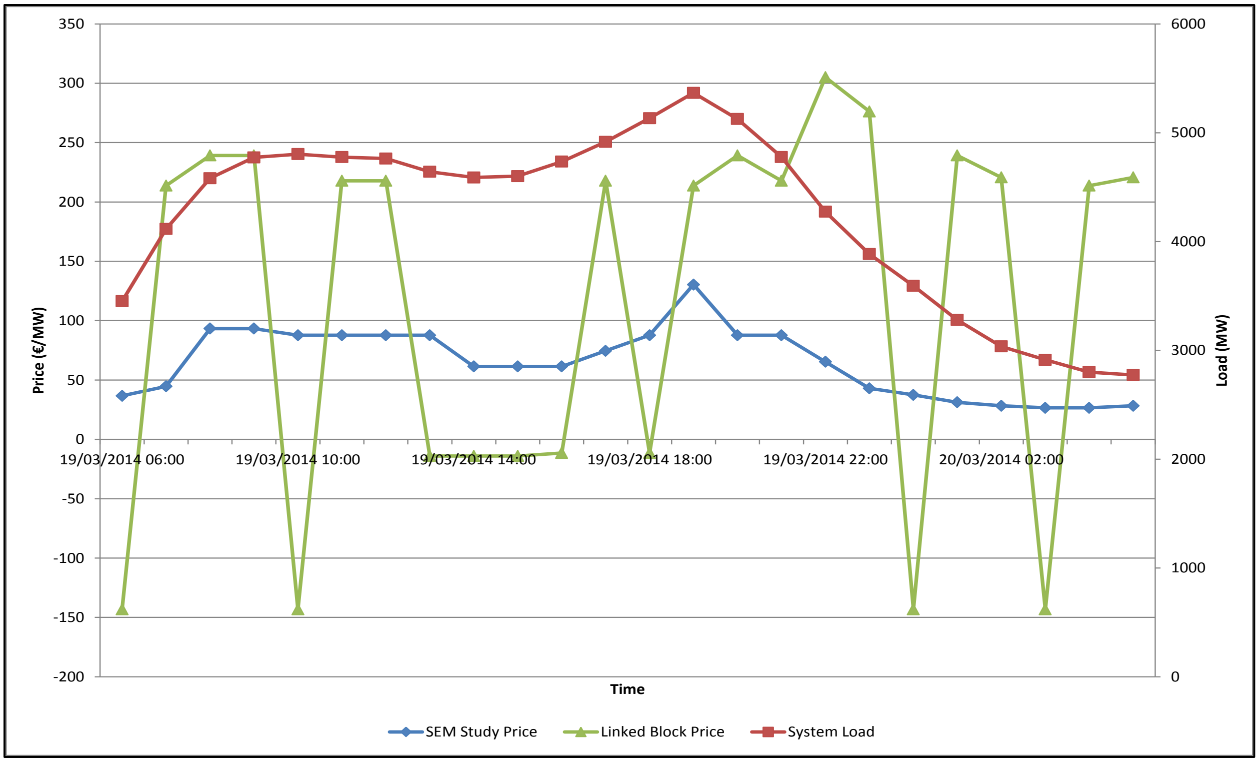

Figure 6: Hourly prices for linked block and SEM study run for 19/03/2014

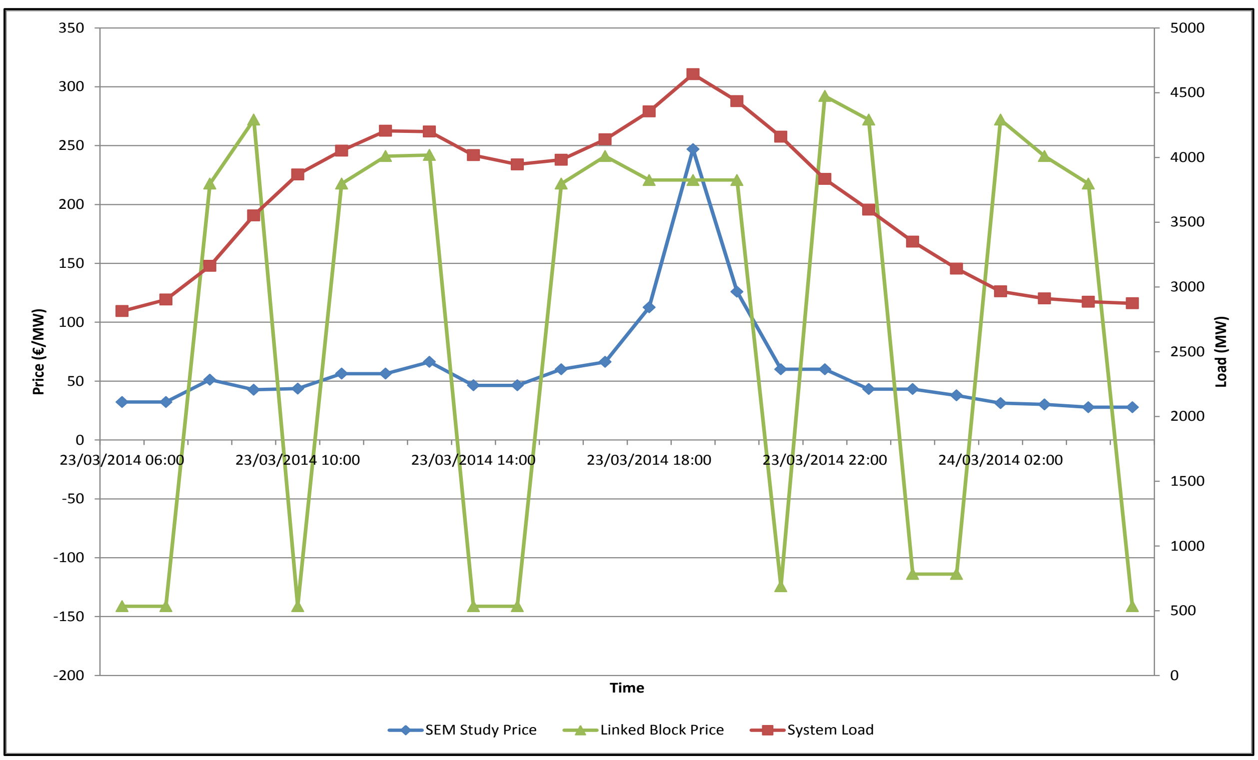

Figure 7: Hourly prices for linked block and SEM study run for 23/03/2014

Section 6.2.1.4, below, explains the reasons behind the prices from the Linked Block Orders.

6.2.1.2 COMPLEX ORDER DATA

Across the three trial days, the complex orders offered prices which were stable, linked to scarcity of margin and were transparently formed. Details of the prices from complex datasets are presented below.

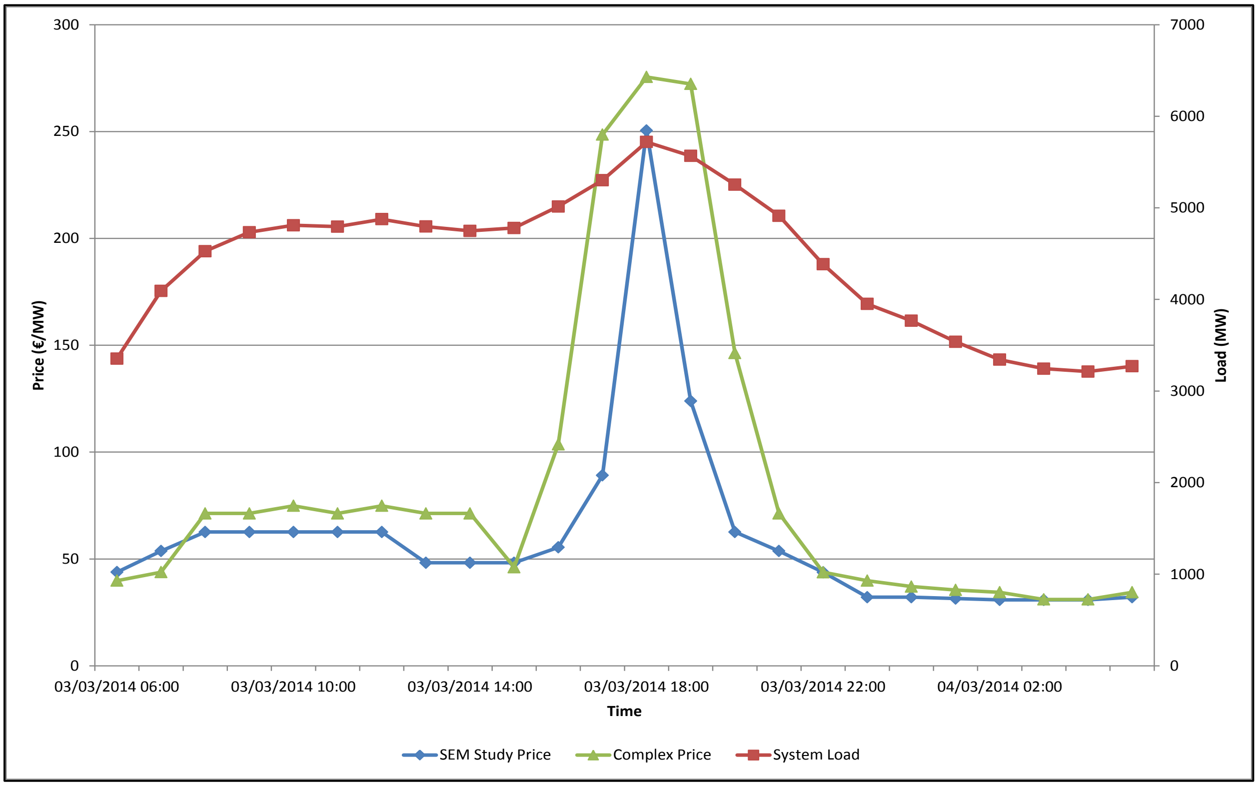

Figure 8: Complex and SEM study run hourly prices for 03/03/2014

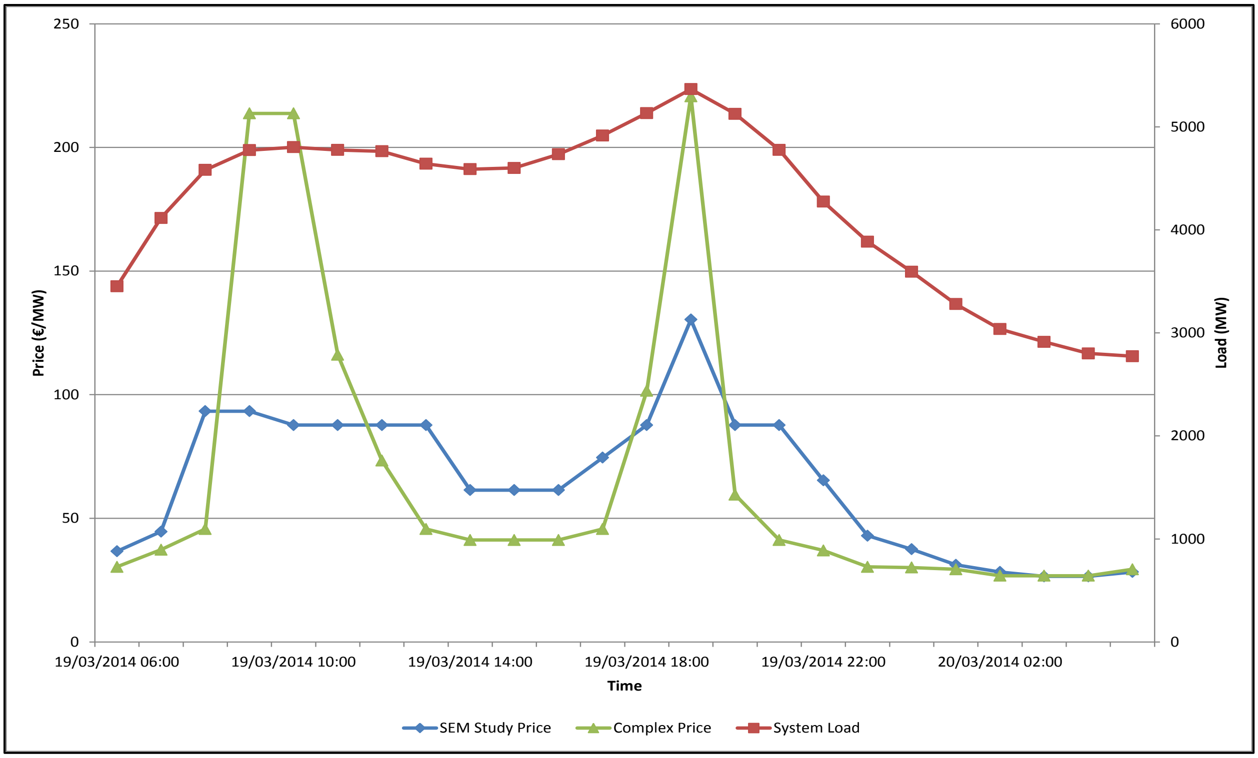

Figure 9: Complex and SEM study run prices for 19/03/2014

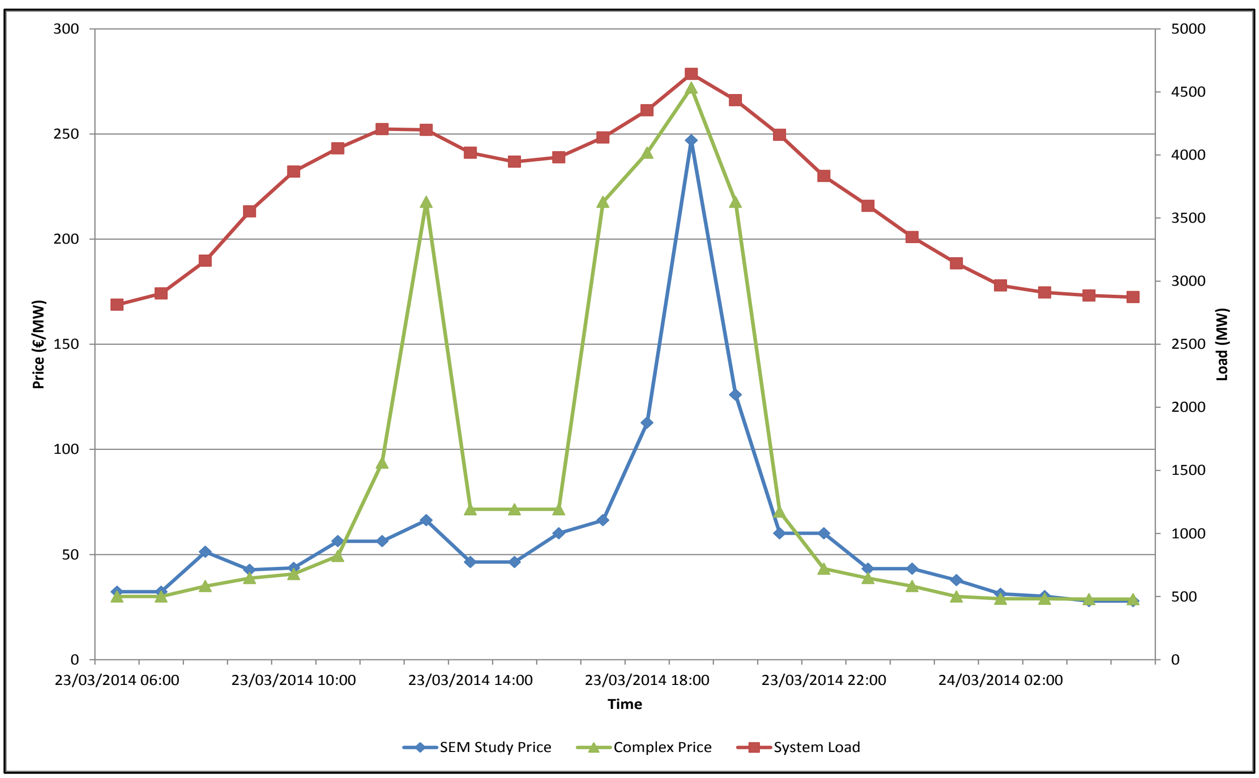

Figure 10: Complex and SEM study run hourly prices for 23/03/2014

In addition to the price stability seen in the complex orders, price formation remains transparent with prices set being directly linked to bids which were input to the system. The units setting the price in each hour are listed in table 4 below.

Trading Period	SEM - Unit Name	Complex - Unit Name
03/03/2014 06:00	Aghada 2 Generator Unit	Ballylumford Generator Unit (CCGT20)
03/03/2014 07:00	Coolkeeragh ESB CCGT Generator Unit	Aghada 2 Generator Unit
03/03/2014 08:00	Turlough Hill 1 Generator Unit	AES Ballylumford Limited
03/03/2014 09:00	Turlough Hill 1 Generator Unit	AES Ballylumford Limited
03/03/2014 10:00	Turlough Hill 1 Generator Unit	Ballylumford B6
03/03/2014 11:00	Turlough Hill 1 Generator Unit	AES Ballylumford Limited
03/03/2014 12:00	Turlough Hill 1 Generator Unit	Ballylumford B6
03/03/2014 13:00	Ballylumford Generator Unit (CCGT20)	AES Ballylumford Limited
03/03/2014 14:00	Ballylumford Generator Unit (CCGT20)	AES Ballylumford Limited
03/03/2014 15:00	Ballylumford Generator Unit (CCGT20)	Ballylumford Generator Unit (CCGT10)
03/03/2014 16:00	Ballylumford Generator Unit (CCGT20)	Ballylumford B6
03/03/2014 17:00	Turlough Hill 1 Generator Unit	Tawnaghmore Peaking 1 Generator Unit
03/03/2014 18:00	Cushaling Power PPMG1	AGHADA CT14 Generator Unit
03/03/2014 19:00	Tawnaghmore Peaking 1 Generator Unit	Ballylumford Power Station
03/03/2014 20:00	Turlough Hill 1 Generator Unit	Turlough Hill 1 Generator Unit
03/03/2014 21:00	Turlough Hill 1 Generator Unit	AES Ballylumford Limited
03/03/2014 22:00	Aghada 2 Generator Unit	Bord Gais ROI - Whitegate Generator Unit
03/03/2014 23:00	AES Kilroot - K1	Ballylumford Generator Unit (CCGT20)
04/03/2014 00:00	AES Kilroot - K1	Tynagh Generator Unit
04/03/2014 01:00	AES Kilroot - K1	Coolkeeragh ESB CCGT Generator Unit
04/03/2014 02:00	Moneypoint 1 Generator Unit	Aghada 2 Generator Unit
04/03/2014 03:00	Moneypoint 1 Generator Unit	Bord Gais ROI - Whitegate Generator Unit
04/03/2014 04:00	Moneypoint 1 Generator Unit	Bord Gais ROI - Whitegate Generator Unit
04/03/2014 05:00	AES Kilroot - K1	Aghada 2 Generator Unit

Table 4: Marginal Units trading day 03/03/2014 – Complex dataset v SEM study run

This table shows the transparency of using complex orders as well as the overlap of the units setting the price across the day between the SEM study run and complex dataset.

6.2.1.3 EXCLUSIVE GROUP DATA

The exclusive group datasets produced prices which, while not as volatile as linked block prices, were volatile (unexpectedly dropping to negative prices in two periods). Additionally, the prices did not reflect the underlying conditions with high prices throughout each day regardless of the underlying wind and load conditions. Details of the prices produced by exclusive group datasets are presented below.

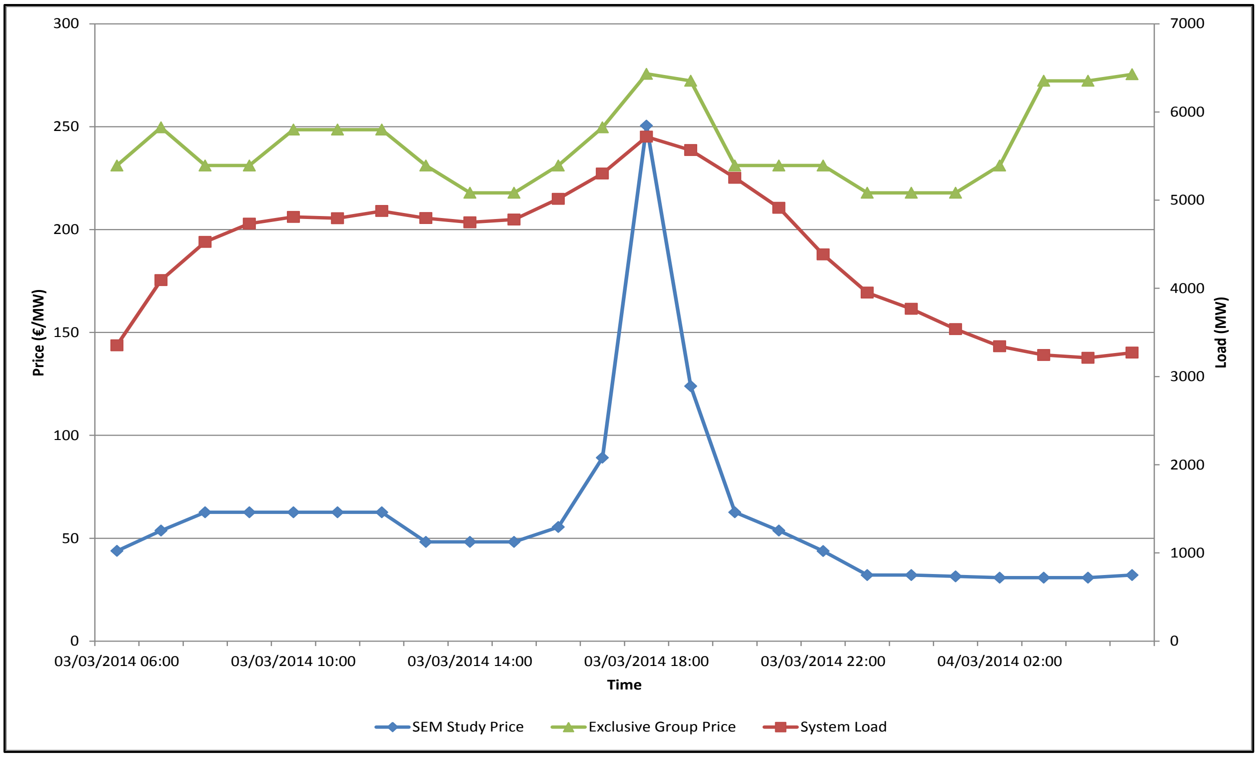

Figure 11: Hourly prices for exclusive groups and SEM study run for 03/03/2014

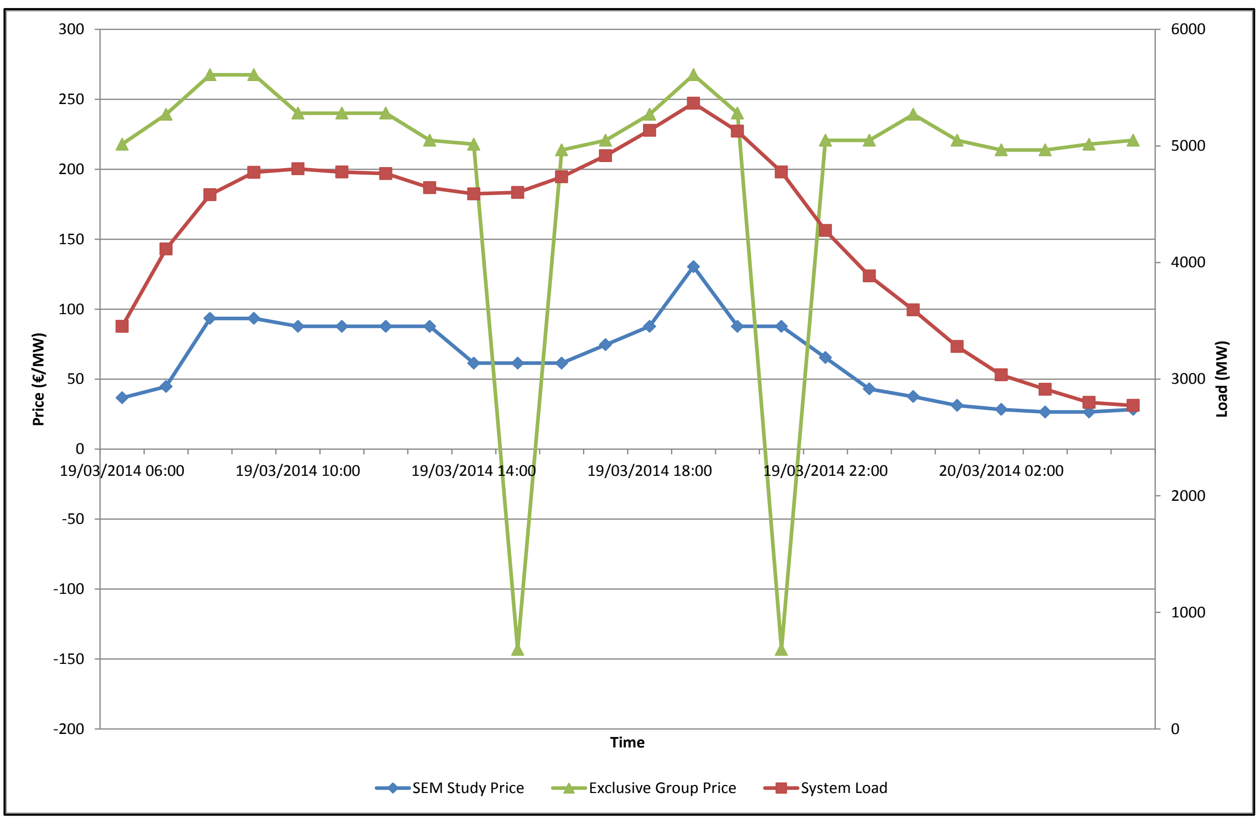

Figure 12: Hourly prices for exclusive groups and SEM study run for 19/03/2014

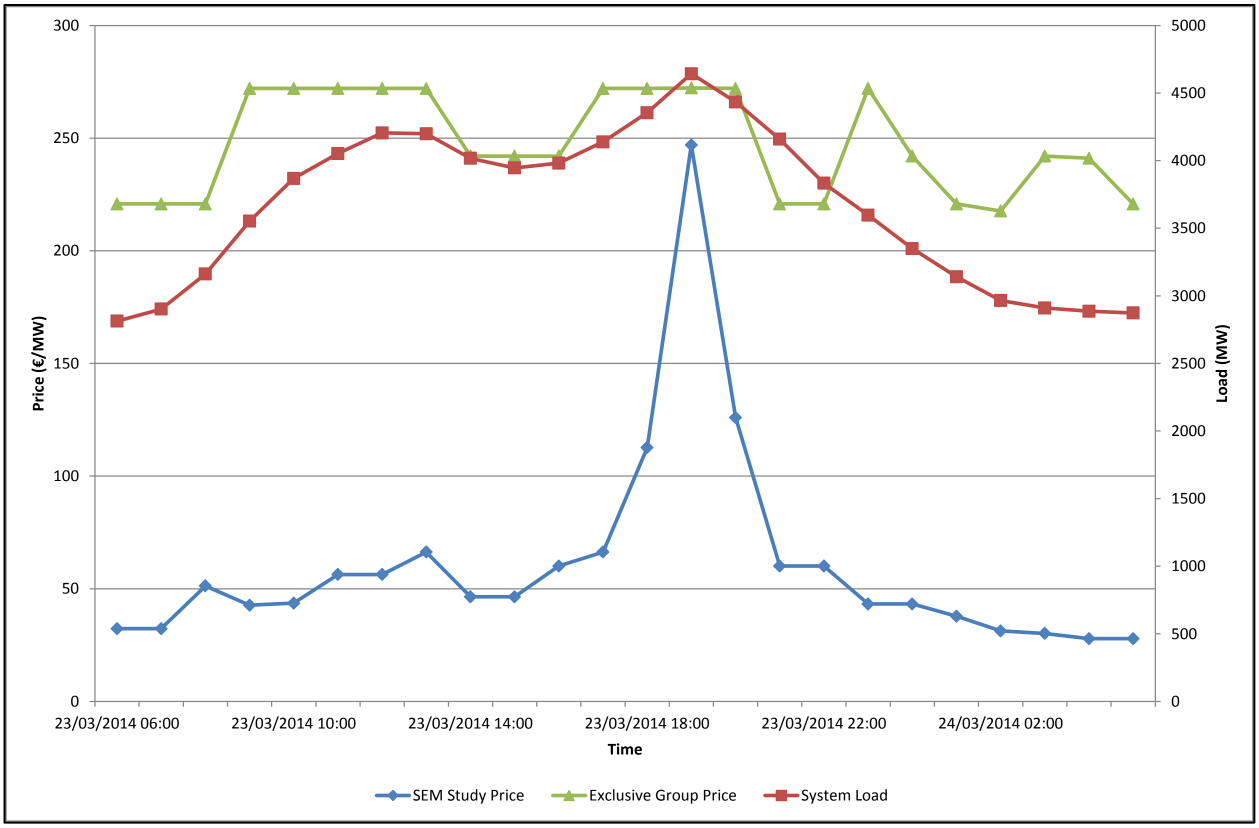

Figure 13: Hourly prices for exclusive groups and SEM study run for 23/03/2014

6.2.1.4 ISSUES WITH PRICE FORMATION – BLOCK ORDER FORMATS

The majority of block orders (linked block orders, flexible orders and exclusive group orders) were entered into EUPHEMIA with a minimum acceptance ratio of 100% (known as 'kill-or-fill'), meaning that the entire block must be accepted or rejected as a whole. The reason for this treatment was that fixed costs of units were factored into the prices of blocks such that the cost is spread over the entire volume of the block. Were a unit to be scheduled to only a portion of this block, that unit would only recover a portion of their fixed costs. As a principle of the SEM is that generator costs are recovered, it was felt that partial recovery would not meet the suitability criterion of these trials.

The effect of defining an order as a block is that the order cannot then be a full price maker. Rather, block orders may impose a bound on the range of prices possible while the price being set would still need to come from the simple order or complex order curves. This is because the decision to execute the order is an integer decision (i.e. the order is executed or not executed) and the decision on whether to accept a block occurs before the price determination sub-problem. The bound created by the last accepted block order would function to affect the price (by limiting possible values) but could not directly set this price.

For the linked block and exclusive group datasets, the majority of thermal units (the exception being peaking generator units) were represented using blocks. As these generator units usually set the price of electricity in the SEM, and are unable to do so using blocks, these datasets were unable to set the prices in the way that the same units do in complex datasets despite each dataset representing the same units.

This was discussed with the PCR ALWG representative, APX, who confirmed that without the blocks setting the price, the price could only be set by other price makers, i.e. simple orders or complex orders, or the price indeterminacy rules of EUPHEMIA[4]. Prices seen in the linked block and exclusive group datasets were set by a combination of peaking generator units (prices of approximately €200 - €300) and ostensibly price taking participants. In EUPHEMIA, price takers are represented by submitting a "price taking order" where the submission explicitly states the volume of energy offered with a price range of -€500 to €3000 (the values of price floor and price cap respectively). This is interpreted that the volume of energy can be sold at any price in this range; however, because the price is explicitly set in the order, this can be considered in the calculation of the clearing price. Therefore, while the volume is "price taking", the actual prices can be seen as "price making". The PCR ALWG noted that adding more price makers would lead to improved price formation and the following were discussed as possible avenues to explore:

- **Price making demand –** in the SEM all demand is treated as fully inelastic. If this demand were allowed to submit price maker bids (i.e. set levels at which they no longer wish to participate in the DAM) this would allow for a higher volume of price makers in the market
- **Review of price taking generators –** if more units (e.g. wind units) were able to take part in the DAM as price makers (e.g. simple orders) there would be more prices from which to derive the clearing price
- **Interconnection –** linking the order book of the I-SEM to other order books through interconnection would allow price formation based on those order books (e.g. a GB generator could set the price in the I-SEM). It was noted that this could only improve price formation up to the point of interconnector constraint, i.e. once all interconnectors are at full capacity or constrained by ramp limitations the price would again be determined by an I-SEM participant
- **Combinations of order types –** mixing block orders with more complex or simple orders would increase the number of price makers in the solution, thereby, improving results

6.2.2 SCHEDULE

Comparison of the complex schedule to the SEM study run schedule shows a lower utilisation of pumped storage and a higher utilisation of oil units in the complex schedule. Details of the schedules by fuel for complex and SEM study run for 03/03/2014 are presented below.

[4] https://www.apxgroup.com/wp-content/uploads/Euphemia-public-description-Nov-20131.pdf

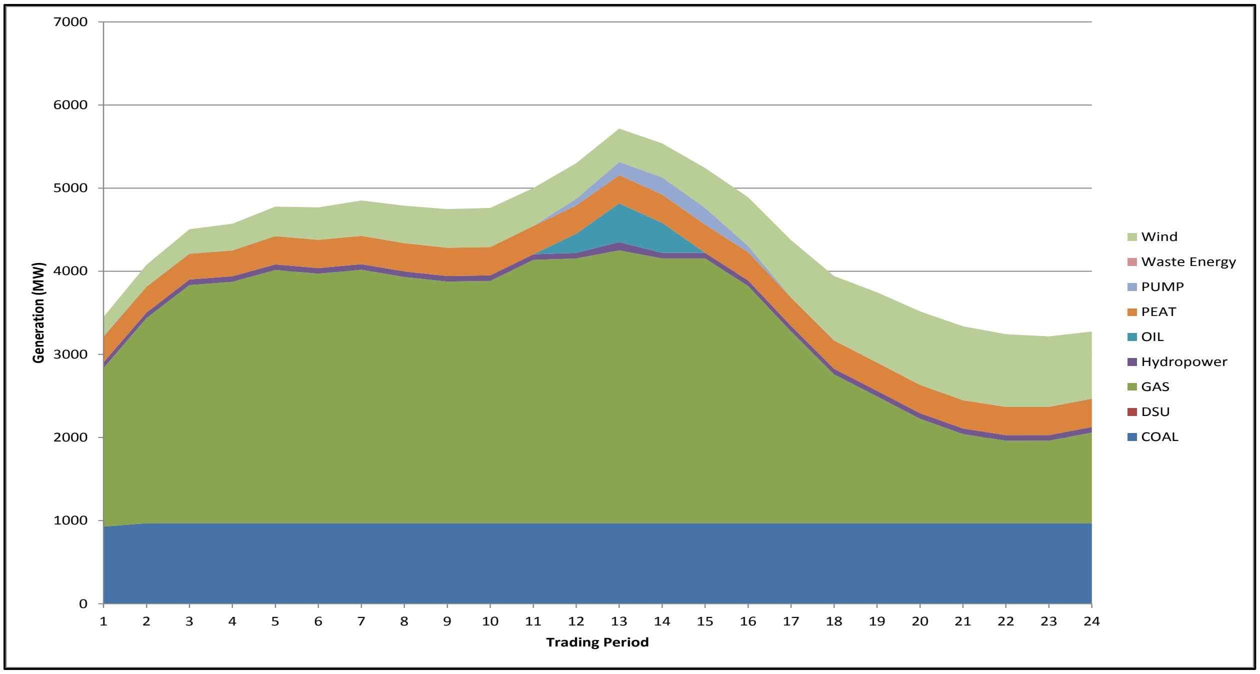

Figure 14: Output by fuel for complex dataset for 03/03/2014

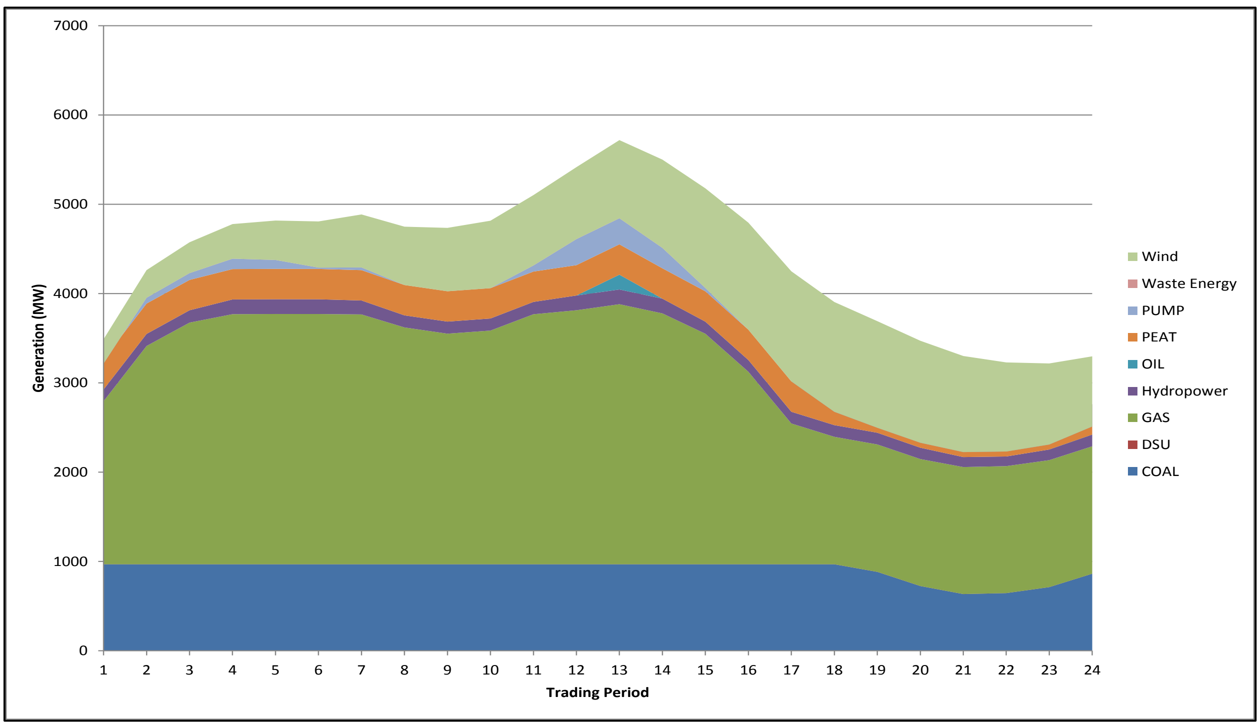

Figure 15: Output by fuel SEM study run for 03/03/2014

This lower utilisation of pumped storage is directly linked to the higher utilisation of oil units. The SEM study run is able to use pumped storage more flexibly than the EUPHEMIA run due to its representation in the SEM. As a result of this, the SEM study run is able to use pumped storage where the EUPHEMIA run uses oil based peaking generator units; this leads to the price spikes seen in the EUPHEMIA run not being seen in the SEM study run.

It should also be noted that the SEM study run is an EA1 run and was completed using the EA1 wind forecast. This data could not be extracted for creation of EUPHEMIA datasets. In the trial, the latest available wind forecasts were used in their place, i.e. different input data was used for the SEM and EUPHEMIA runs; this led, in some cases, to a discrepancy in the wind available to each algorithm for the same Trading Day. This is demonstrated in figure 16 below for 03/03/2014.

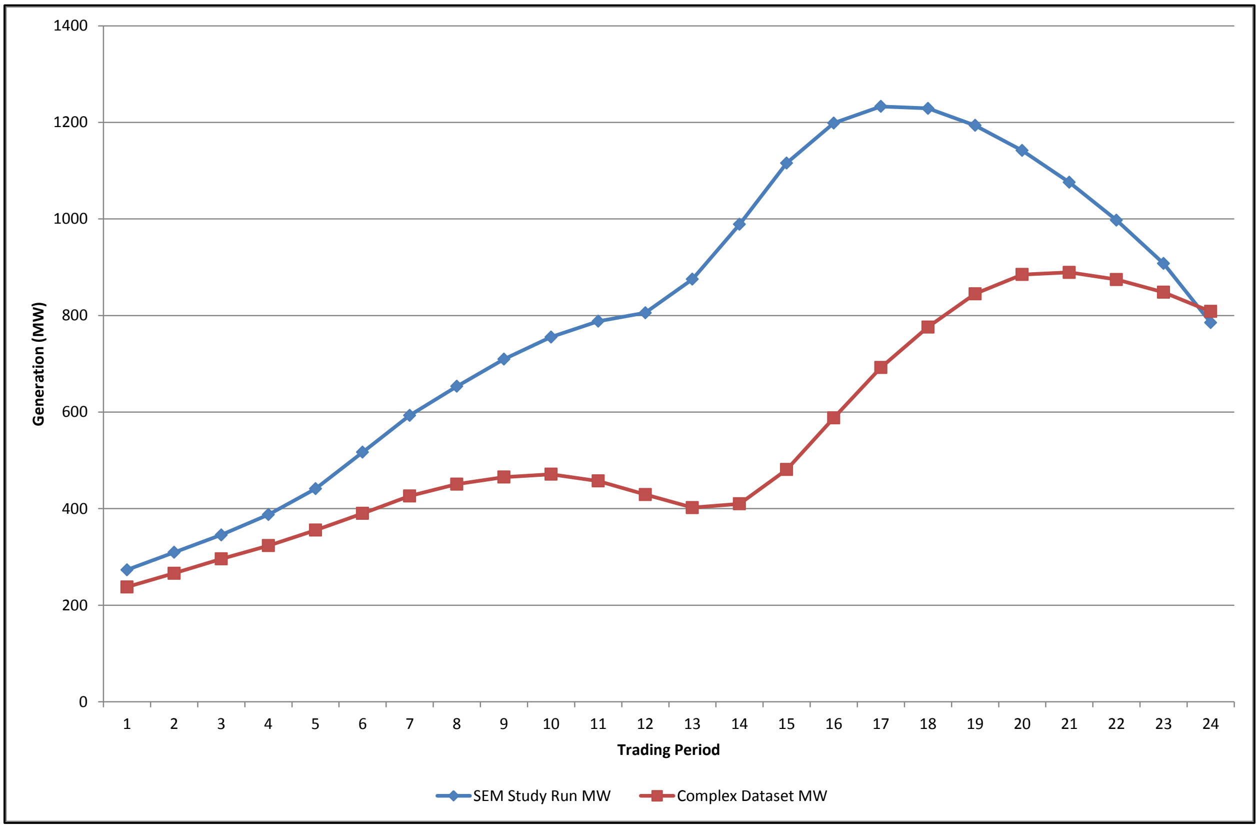

Figure 16: Wind availability SEM Study run v EUPHEMIA complex dataset

This difference in wind forecasts, as well as different treatment of certain unit types, makes direct comparison of schedules spurious; however, SEM study run data is included for reference.

As peaking generator units were required for price formation in the linked block and exclusive group datasets, a high level of oil based generation can be seen in these dataset outputs. Outputs of these datasets for 03/03/2014 are presented below for comparison.

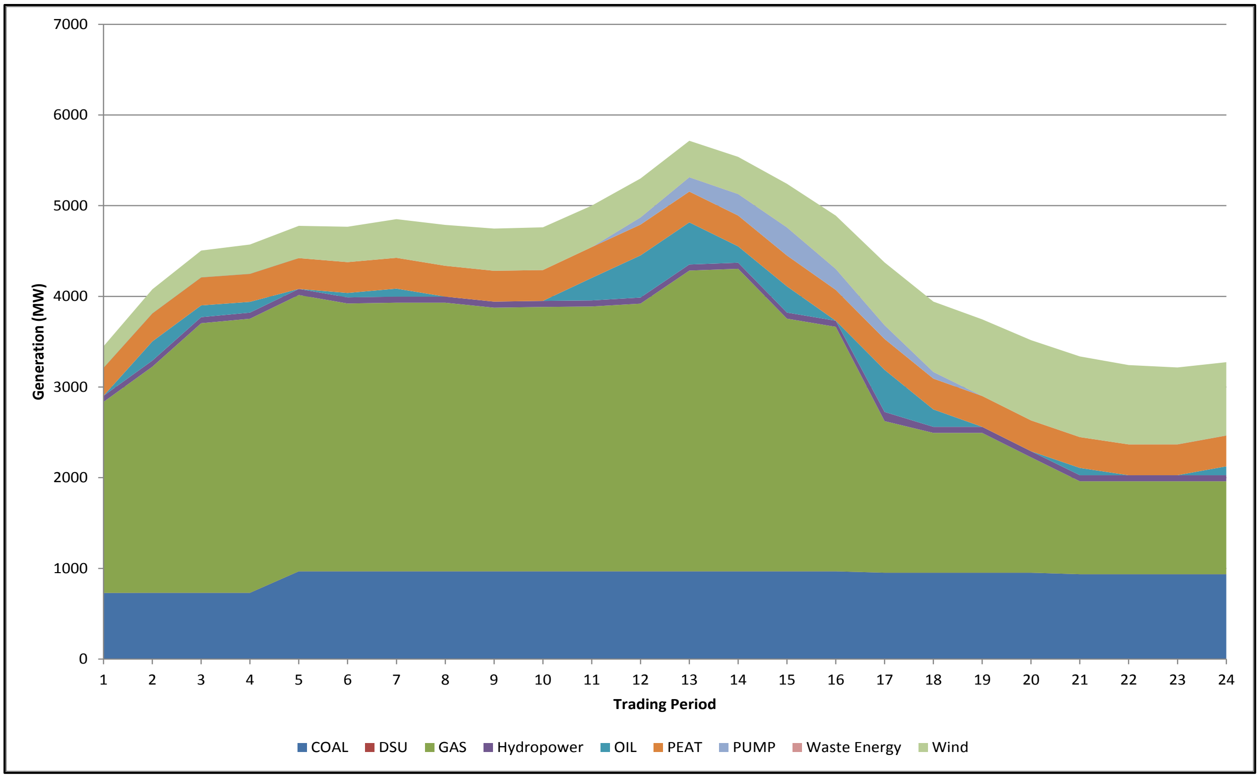

Figure 17: Output by fuel type linked block dataset 03/03/2014

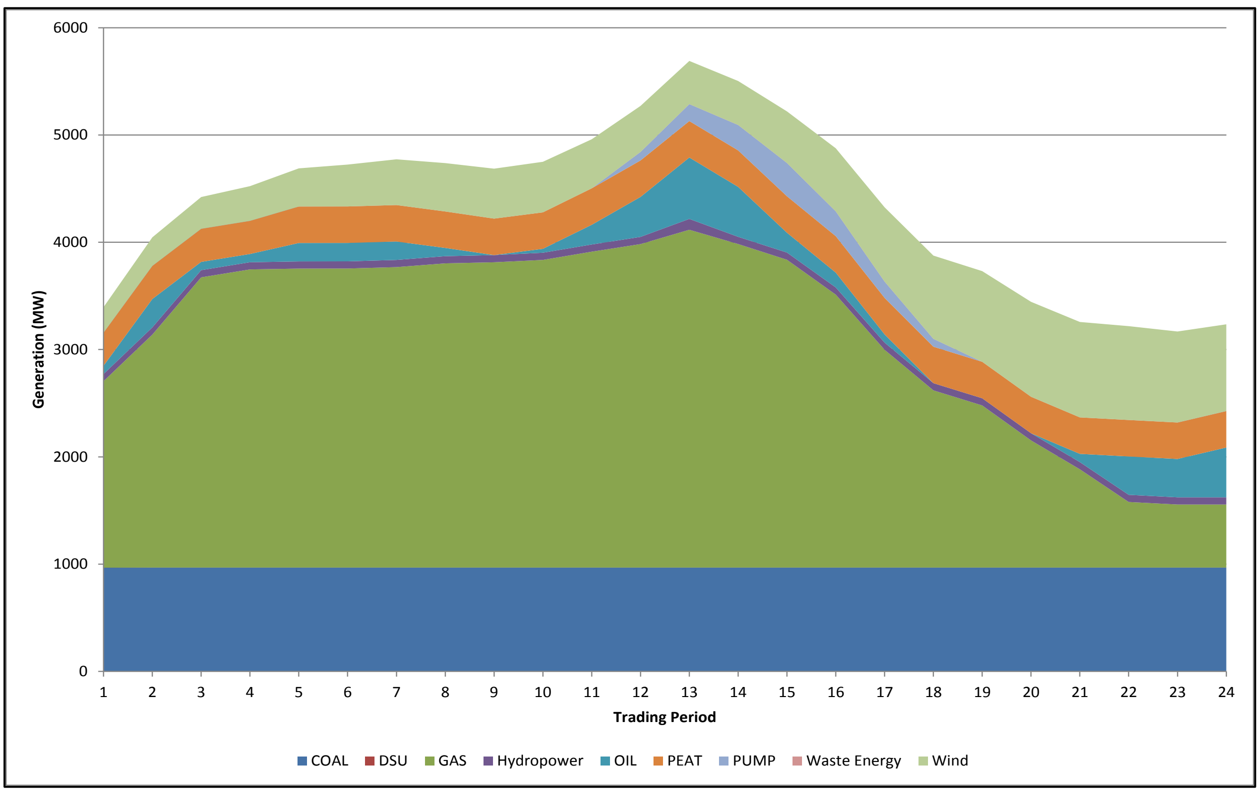

Figure 18: Output by fuel type exclusive group dataset 03/03/2014

6.2.2.1 SCHEDULING OF ENERGY LIMITED HYDRO AND PUMP STORAGE

The utilisation of pumped storage and energy limited hydro was below that of the SEM study run. This was linked to the representation of these units in the EUPHEMIA trials as the order types available are far less reflective of the unit conditions than the SEM representation of these units. In the SEM, each of these unit types has specific rules to allow for their unique characteristics. Attempts were made to model energy limited hydro and pumped storage in EUPHEMIA, using flexi orders and linked block orders respectively. As outlined in section 6.3, the assumptions used to model these unit types were reviewed following analysis of the first results in an attempt to better model these unit types.

6.2.3 ALGORITHM PERFORMANCE

As this trial was used as a proof of concept, algorithm performance metrics were not analysed. These metrics were analysed as part of batch one trials using revised assumptions and are outlined in section 6.4.3.

6.3 BATCH ONE – INPUTS (REVISED ASSUMPTIONS)

Following analysis of the results under the original assumptions, it was noted that both energy limited hydro and pumped storage units had significantly lower utilisation in EUPHEMIA than in the relevant SEM results. As there are no specific order types available for these unit types in EUPHEMIA, assumptions must be made about how to enter these units. These assumptions may lead to a less than optimal representation of these units; this is elaborated upon in the following sections.

6.3.1 ENERGY LIMITED HYDRO

The use of flexi orders for energy limited hydro units led to underutilisation of these units. This is due to the fact that a flexi order can only be executed in one trading period (hour); where the value of the energy limit exceeds the value the unit can output in one hour, a flexi order cannot provide full utilisation of the energy available to the unit in the DAM. As an example, if unit X is subject to an energy limit of 25 MWh and can produce 10 MWh in an hour the unit cannot bid 10 MW in all 24 hours and if only turned on at their full value for one hour would have 15 MWh of energy not used in the DAM. The unit cannot submit multiple flexi orders as there is a strong possibility that multiple orders would clear in the same hour leading to the unit having a DAM position in excess of its maximum output. As an assumption of the trial is that market participants will attempt to have all energy scheduled in the DAM, this needed to be addressed by revising assumptions.

To allow for hydro units which are subject to an energy limit[5], the unit was entered using a simple order format, i.e. price quantity pairs, over a number of hours which would fulfil the energy limit only. As an example, if unit X was subject to an energy limit of 50 MWh and could produce 5MWh in an hour, unit X would be entered as a simple order in 10 hours. The hours entered were chosen according to the load and wind forecasts for the day with the values entered into the hours with the largest difference between load and wind (margin) in an attempt to maximise revenues, i.e. these hours would have comparatively less cheap energy and so the marginal unit would be higher in the bid stack increasing the revenue of all scheduled units.

[5] For these purposes an energy limit is taken to mean where the unit has insufficient energy available to bid at their maximum output for 24 hours. Where no energy limit is applicable hydro units are entered into the market based on their SEM price quantity pairs over the full day.

A possible extension of this, discussed with APX, would be to enter multiple profiles, created in line with the principles outlined previously, in an exclusive group. In such an exclusive group, a profile representing the limited running of the unit could be entered in various different time periods (e.g. one profile in hours 12 – 15 and another in hours 14 – 17). This would offer potential flexibility of the unit by allowing multiple profiles to bid without risking over-allocation in a single hour. Given the issues encountered with the use of exclusive groups with SEMO's initial assumptions, this was not explored further in the Initial Phase. This principle will be discussed further with the I-SEM EUPHEMIA Working Group and, if a sufficient level of interest exists, will be further explored in the Commercial Phase.

6.3.2 PUMPED HYDRO STORAGE

The approach to pumped hydro storage was revised. On analysis of the outputs, it was clear that the utilisation of the Turlough Hill units was much higher under similar conditions in the SEM study run, see figure 19 below.

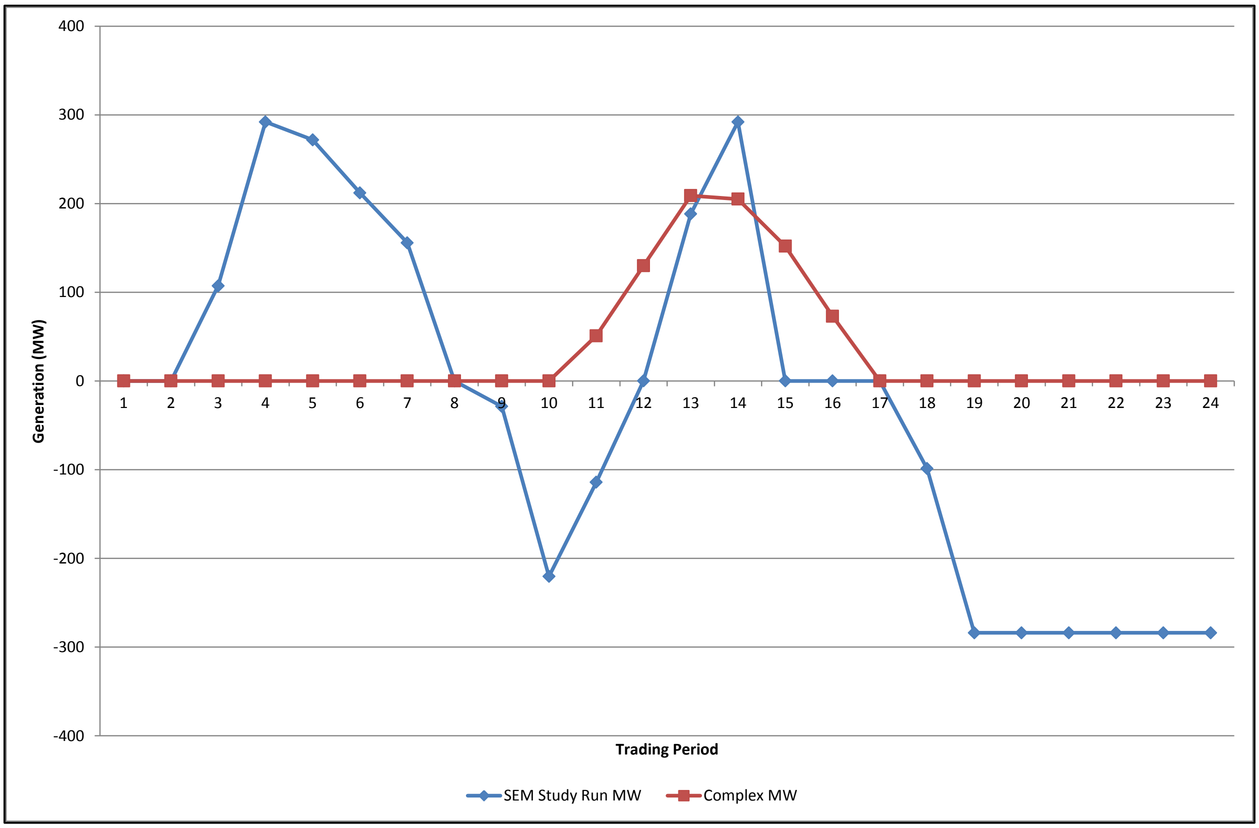

Figure 19: Hourly output of Turlough Hill (TH) 19/03/14 – Complex dataset with linked block (TH) v SEM study run

As can be seen in figure 19, given the same load and wind conditions, the SEM algorithm is capable of running Turlough Hill units with much greater flexibility throughout a day than EUPHEMIA due to the rigid profile of the linked block orders. Figure 19 is indicative of all datasets in this trial in terms of relative Turlough Hill utilisation. Though not represented in figure 19, it should be noted that EUPHEMIA did produce both demand and generation values for the pumped storage units in some datasets.

The reason for this difference in utilisation is that the SEM algorithm has access to the Turlough Hill units throughout the entire day, subject to reservoir and technical limits, while the linked blocks submitted to EUPHEMIA only cover a subset of hours. The original linked block profiles were made up of an initial buy block in the first hours (1 – 4) and related sell block in later hours (12 – 16) representing the purchase and sale of energy between the initial reservoir capacity and maximum capacity; this excluded hours which were not included in the blocks (5 – 11; 17 – 24). The linked block profile was entered with an accompanying regular block sell order which represented the sale of the initial reservoir capacity. To account for this issue two different treatments were investigated:

1. **Extended Linked Blocks –** here the linked block order format continued to be used but additional blocks were inserted to allow use throughout the day. These were a series of related buy and sell blocks such that if energy was sold in one hour the reservoir would be restored in a later hour to maintain availability.
2. **Simple pump storage –** here the pumped storage units were entered into EUPHEMIA using simple buy and sell orders. These were set to sell above a certain price and buy below a certain price based on an estimate of average price with a deadband between where the unit outputs at 0 MW to reflect cycle efficiency, i.e. the energy lost between pumping to fill the reservoir and releasing energy from the reservoir. Given the functioning of simple orders, there is no link between buy and sell orders; however, given the price levels entered, the unit cannot be scheduled to buy and sell in the same hour.

As revised assumptions were also used in relation to energy limited hydro units, datasets were also prepared using the original pumped storage assumption with a revised hydro assumption.

6.3.3 DATASET DETAILS

The datasets used in this trial batch are outlined in table 5 below.

Dataset ID	Trading Day	Thermal Units	Pump Storage	Energy Limited Hydro
201403031	03/03/14	Linked Block	Linked Block	Simple
201403032	03/03/14	Complex	Linked Block	Simple
201403033	03/03/14	Exclusive Groups	Linked Block	Simple
201403034	03/03/14	Linked Block	Linked Block Extended	Simple
201403035	03/03/14	Complex	Linked Block Extended	Simple
201403036	03/03/14	Exclusive Groups	Linked Block Extended	Simple
201403307	03/03/14	Linked Block	Simple	Simple
201403038	03/03/14	Complex	Simple	Simple
201403039	03/03/14	Exclusive Groups	Simple	Simple
201403191	19/03/14	Linked Block	Linked Block	Simple
201403192	19/03/14	Complex	Linked Block	Simple
201403193	19/03/14	Exclusive Groups	Linked Block	Simple
201403194	19/03/14	Linked Block	Linked Block Extended	Simple
201403195	19/03/14	Complex	Linked Block Extended	Simple
201403196	19/03/14	Exclusive Groups	Linked Block Extended	Simple
201403197	19/03/14	Linked Block	Simple	Simple
201403198	19/03/14	Complex	Simple	Simple
201403199	19/03/14	Exclusive Groups	Simple	Simple
201403231	23/03/14	Linked Block	Linked Block	Simple
201403232	23/03/14	Complex	Linked Block	Simple
201403233	23/03/14	Exclusive Groups	Linked Block	Simple
201403234	23/03/14	Linked Block	Linked Block Extended	Simple
201403235	23/03/14	Complex	Linked Block Extended	Simple
201403236	23/03/14	Exclusive Groups	Linked Block Extended	Simple
201403237	23/03/14	Linked Block	Simple	Simple
201403238	23/03/14	Complex	Simple	Simple
201403239	23/03/14	Exclusive Groups	Simple	Simple

Table 5: Trial Batch One (Revised) Datasets

6.4 BATCH ONE – RESULTS (REVISED ASSUMPTIONS)

6.4.1 PRICE

Price formation in general was as outlined in section 6.2.1; this section outlines the changes to price formation caused by the changes in assumptions.

6.4.1.1 LINKED BLOCK DATASETS

The issues with linked block price formation persisted where linked block pumped storage was used with linked block thermal generation. However, there was an improvement to price formation where simple orders were used for pumped storage. Figure 20 below shows the prices for Trading Day 03/03/2014 using linked block thermal orders and all methods of representing pumped storage.

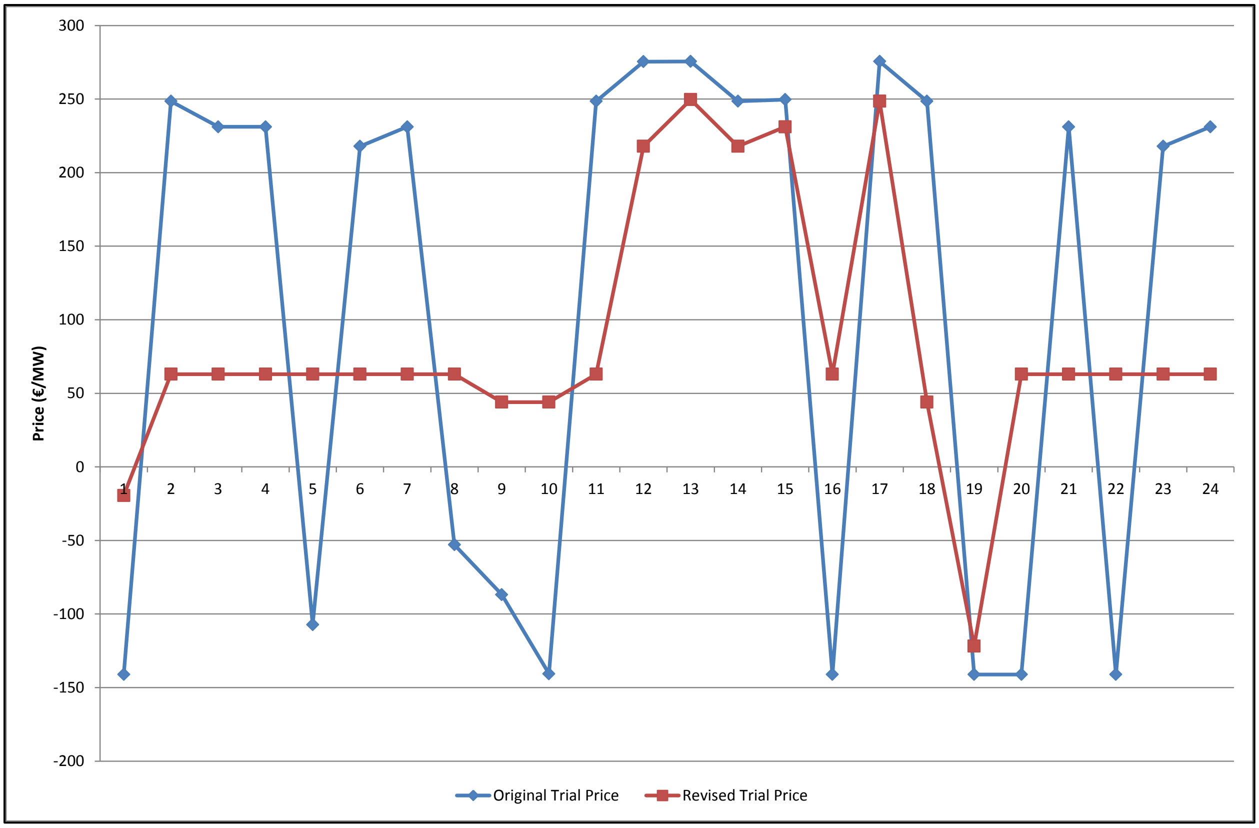

Figure 20: Hourly prices for linked block thermal generation with differing pump storage representation

As figure 20 shows, the price is set by pumped storage (values of €63/MWh or €44/MWh) in 17 of 24 (51 of 72 across all Trading Days) hours using simple pumped storage. This is due to the simple order nature of the pumped storage orders being able to act as price makers; this level of price setting occurred with the addition of a relatively small amount of volume (total hourly capacity of Turlough Hill is 292 MW – this is 288 MW of demand) compared to the total load (average load for the relevant Trading Day was 4436 MW). This provides evidence that, where additional price makers are available in the market, price formation in linked block orders can be improved. This effect was seen in a less pronounced way in exclusive group datasets (25 of 72 periods across all Trading Days).

An expansion of this investigation would be to permit demand to participate on a price maker basis, i.e. bid a price at which they no longer wish to serve their demand in the DAM, and or to have price making wind bids. This is discussed in section 8, but has been deemed out of scope for the Initial Phase of these trials and was not explored in further batches; however, this will be explored further in the Commercial Phase of the trials.

The average prices for all linked block datasets are presented in table 6 below.

Date	Original Pump Storage	Extended Linked Block Pump	Simple Pump
03/03/2014	101.04	109.22	88.83
19/03/2014	124.21	114.42	69.53
23/03/2014	131.13	274.33	81.31

Table 6: Average prices for linked block datasets

Given the results, the price formation issues persist regardless of the methodology studied; however, the simple pumped orders did, in all cases, lead to lower average prices. It should also be noted that the simple pump datasets had a lower price despite having less instances of negative prices.

6.4.1.2 COMPLEX ORDER DATASETS

The complex orders continued to demonstrate the most stable and transparent price formation. In comparing the effects of differing pumped storage values on price formation, the effects on 03/03/2014 are presented in figure 21 below.

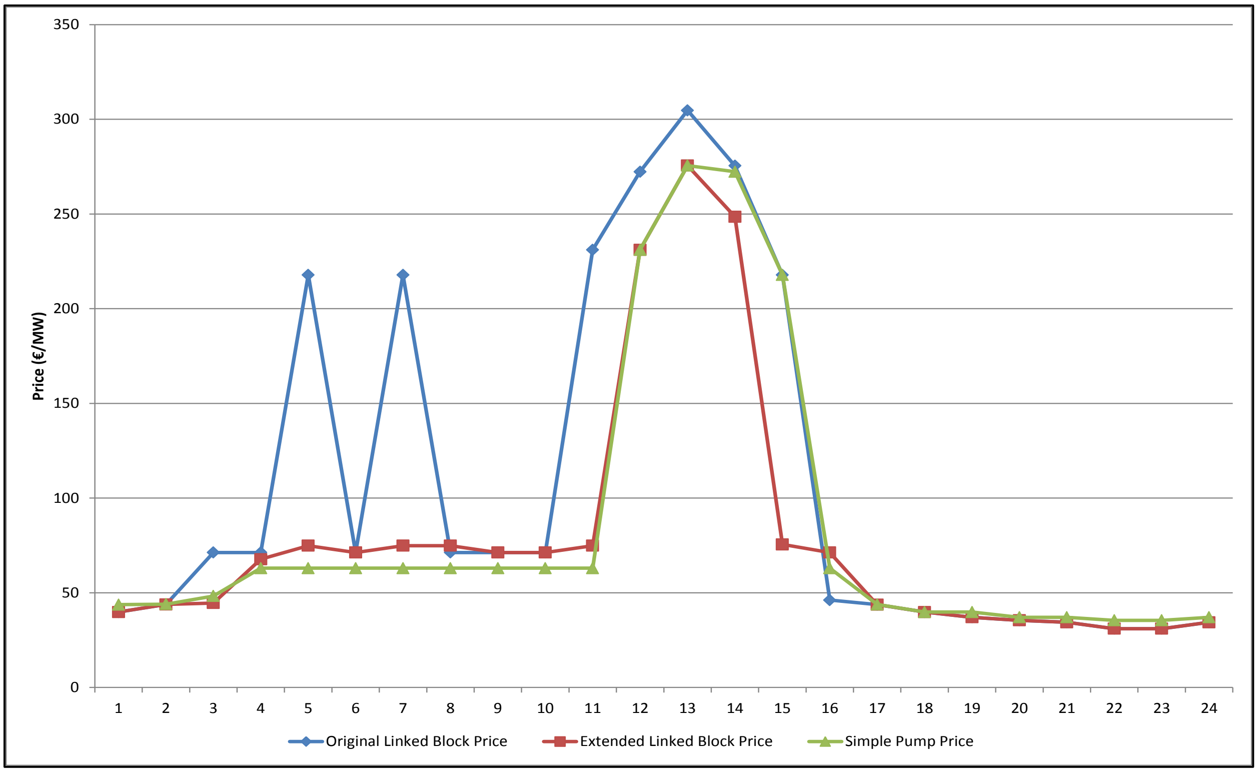

Figure 21: Hourly price data complex orders 03/03/2014

The simple order pump storage allows use of pump storage units throughout the day. As these were offered at prices close to the average, these units being scheduled in hours 5 and 7 avoided the price spikes seen under the original assumptions of linked block. Similar effects are seen throughout the datasets with the simple pump storage datasets having more stable prices than either of the linked block pump storage datasets.

Average prices of complex order datasets are presented in table 7 below.

Date	Original Pump Storage	Extended Linked Block Pump	Simple Pump
03/03/2014	107.58	79.11	83.56
19/03/2014	78.54	98.15	60.74
23/03/2014	84.61	71.36	65.90

Table 7: average daily prices complex order datasets

Given the results, it is not conclusive which methodology produced the lowest average prices; each methodology had stable transparent price formation linked to scarcity of margin (load minus price taking generation).

6.4.1.3 EXCLUSIVE GROUP DATASETS

In the same manner as linked block order datasets, exclusive group datasets benefitted in terms of price formation from simple order pump storage. The hourly prices for 03/03/2014 using exclusive group datasets are presented in figure 22 below.

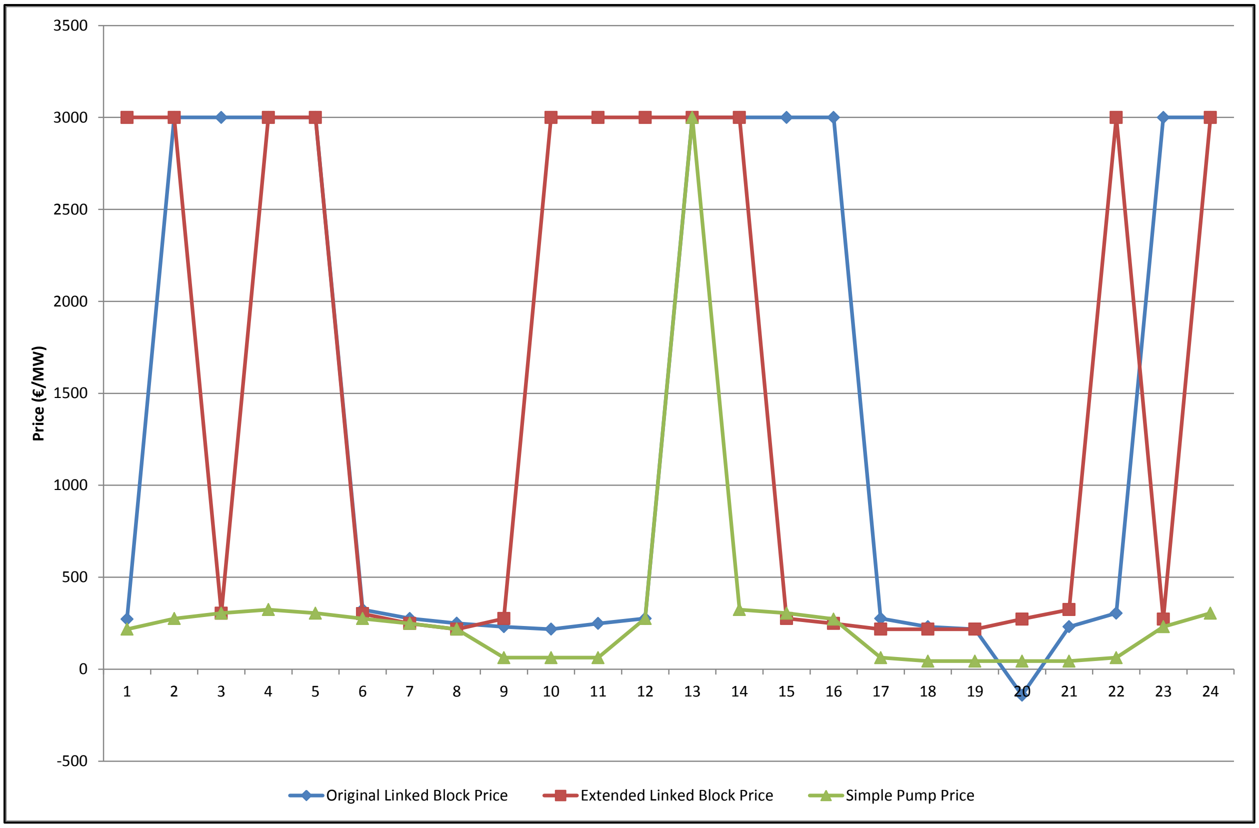

Figure 22: Exclusive group hourly prices for 03/03/2014

The effect of adding pumped storage is less pronounced than with the linked block datasets; here, pumped storage sets the price on only 9 of 24 (compared to 17 of 24) hours. As with linked block orders, adding price maker volume to the market allows for better price formation; however, the benefit of the pumped storage values are not as pronounced under the exclusive group orders as with the linked block orders.

It should be noted that the conditions used, specifically relating to energy limited hydro, were different than those outlined in section 6.3. As such, even where the same pumped storage treatment is used, results may differ from those outlined in section 6.3 for otherwise same conditions. The average prices of exclusive group orders are presented in table 8 below.

Date	Original Pump Storage	Extended Linked Block Pump	Simple Pump
03/03/2014	1,382.58	1,402.61	307.18
19/03/2014	1,177.73	1,403.22	311.46
23/03/2014	1,794.85	1,436.50	425.10

Table 8: Average daily prices for exclusive group order datasets

Given the results, the price formation issue persist with all methodologies studied. While the average prices using simple pump are significantly lower than the other methodologies, these are still much greater than the prices seen in the complex datasets.

6.4.2 SCHEDULE

In general, scheduling results were consistent with section 6.2.2; this section outlines the effects of changing assumptions.

6.4.2.1 ENERGY LIMITED HYDRO UNITS

The revision to energy limited hydro units overcame the issue experienced when flexi orders were used for these units. This methodology was applied using simple orders but could equally be applied using complex orders to allow explicit consideration of fixed or variable minimum income conditions or a load gradient, if desired, without violating the revised assumption; however, if such conditions were added, this would add complexity to the orders themselves which may affect performance. It should be noted that fixed and variable costs are accounted for implicitly in the price of simple orders (i.e. the price quantity pair includes start-up and no load costs) but would be explicitly accounted for with complex orders (i.e. the price quantity pairs do not include start-up or no load costs). The methodology used here was used in further trial batches.

6.4.2.2 PUMP STORAGE UTILISATION

A key element of the revised assumptions of batch one was to attempt to improve the utilisation of pumped hydro storage in EUPHEMIA. As outlined in section 6.3, a number of different methods were used to represent pumped hydro storage. The results have shown that each method used had benefits and disbenefits; these are outlined in table 9 below.

Method	Benefits	Disbenefits
Linked Block (original)	Accounts for reservoir levels; simplest linked block representation; units are price takers	Inflexible due to limited hours; does not restore to target level as used; requires prediction of load and price
Linked Block (extended)	Accounts for reservoir levels; allows use in multiple time periods; units are price takers	Inflexible as rejection of one hour causes rejection of all future hours; requires prediction of load and price
Simple	Allows full utilisation; allows units to be price makers; allows greatest flexibility to follow price signals; does not require prediction of load	Does not account for reservoir level limitations; would require significant actions post DAM; requires prediction of price

Table 9: Characteristics of Pumped Hydro Methodologies

As a further illustration of the above, figure 23 presents the results for 03/03/2014 using complex orders and the three methods for pumped hydro storage.

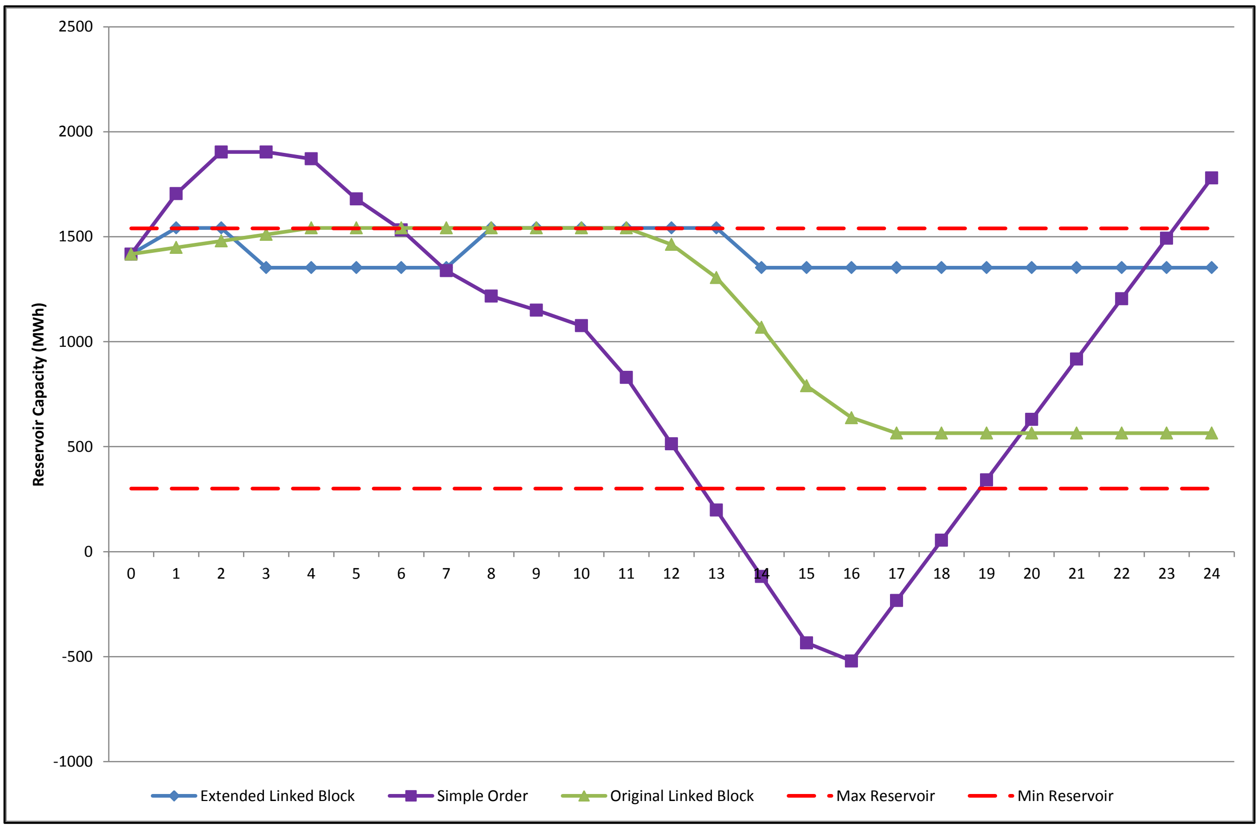

Figure 23: Hourly Reservoir Levels for Trading Day 03/03/2014 using complex thermal orders

The original linked block order representation account for the reservoir level in that the amount sold in later hours is linked to the starting level and amount bought at the start, i.e. if energy is bought in the first hours, then the max level may be sold later, otherwise only the starting level may be sold.

The main issue with this treatment is the lack of flexibility (the hours in which energy is bought or sold must be decided in advance of the run regardless of outturn price) which may lead to suboptimal revenues for the unit and inefficient scheduling, e.g. if peak prices occur in hours in which the unit has not bid. Another concern is that the unit is only available for a small number of hours in the day, this means that the unit cannot take advantage of scarcity at other times, e.g. the morning rise, despite, in reality, being fast acting and flexible.

The extended blocks allow the unit to be utilised in more hours; figure 23 shows the unit being used during the early hours of the day, but the number of links involved add complex dependencies. As represented, sell orders in later hours are linked to sell orders, via intermediate buy orders, in the earlier hours; therefore, if a sell order in the early hours of a day is not executed all subsequent hours will not be executed due to the link relations.

The simple order format circumvents the inflexible nature of the linked block orders; however, as shown in figure 23, these orders lead to an overutilization of the unit with respect to the maximum, minimum and target reservoir levels. As represented in simple order format, the scheduling of the units is related only to the price and, if price conditions dictate, the unit may sell more energy than is available in the reservoir or buy more energy than can be stored. Figure 24 below presents the outcomes for the Turlough Hill units for Trading Day 19/03/2014 using complex orders for thermal units.

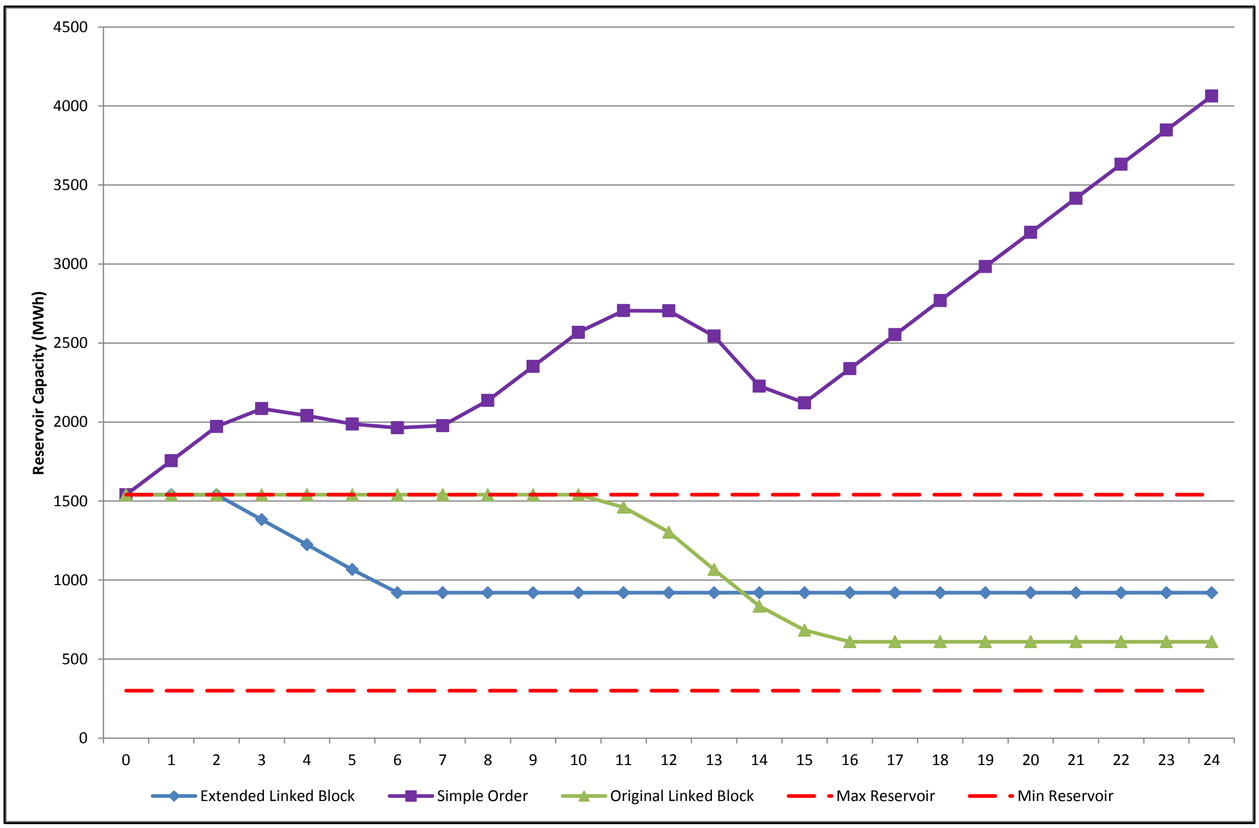

Figure 24: Reservoir Levels for complex thermal orders for 19/03/2014

This Trading Day had a high level of wind and began with a full reservoir. As the prices remained low throughout the day, it was favourable for the unit to buy over several hours. In this case, this resulted in the final reservoir level being more than twice the maximum capacity.

Due to the issue with reservoir levels, SEMO feels that linked block orders are more appropriate for pumped storage as they better match the SEM representation, and underlying physical characteristics, of these units. Further trial batches were all completed using linked block pumped storage representation.

6.4.3 ALGORITHM PERFORMANCE

Analysis of the algorithm calculation times for each dataset provides insight into the performance criterion of the trials. Solutions which lead to inappropriately long solution times do not meet the performance criterion sufficiently.

All datasets were run in EUPHEMIA using a time limit of 890 seconds[6] (approximately 15 minutes). Solutions which have found an optimal solution, based on EUPHEMIA's standard solution criteria, should stop before this time limit. Otherwise, runs will be forced to finish when the time limit is reached. The details of time taken for each dataset to solve in EUPHEMIA is presented in table 10 below.

[6] EUPHEMIA is typically run using a time limit of 600 seconds (10 minutes).

Dataset ID	TYPE	CALCULATION TIME (Seconds)
201403031	Linked/linked PS	13
201403032	Complex/linked PS	5
201403033	Exclusive/linked PS	890
201403034	Linked/Extended PS	888
201403035	Complex/Extended PS	5
201403036	Exclusive/Extended PS	889
201403037	Linked/Simple PS	889
201403038	Complex/Simple PS	5
201403039	Exclusive/Simple PS	889
201403191	Linked/Linked PS	13
201403192	Complex/linked PS	7
201403193	Exclusive/linked PS	890
201403194	Linked/Extended PS	888
201403195	Complex/Extended PS	12
201403196	Exclusive/Extended PS	889
201403197	Linked/Simple PS	8
201403198	Complex/Simple PS	4
201403199	Exclusive/Simple PS	889
201403231	Linked/linked PS	802
201403232	Complex/linked PS	5
201403233	Exclusive/linked PS	889
201403234	Linked/Extended PS	889
201403235	Complex/Extended PS	888
201403236	Exclusive/Extended PS	890
201403237	Linked/Simple PS	35
201403238	Complex/Simple PS	5
201403239	Exclusive/Simple PS	889

Table 10: EUPHEMIA Solution Times for Batch One Datasets

As can be seen in table 10, datasets using complex orders solved within a manner of seconds and had the shortest solve times of any dataset. The sole exception to this was dataset 201403235 which had a solve time of 888 seconds. Following discussion with the PCR ALWG on this dataset, it was clarified that the first solution found was accepted and was found in under 10 seconds; however, in order to assess the optimality of the solution, the algorithm needed to continue until it was cut off by the time limit.

Also of note is the high solution times associated with both linked block and exclusive group orders. In all cases the exclusive group order datasets reached the algorithm time limit and in many cases linked block order datasets did also. While there are examples of linked block order datasets solving in shorter timeframes, no set of assumptions led to a consistently short solution time.

From discussion with the PCR ALWG, the primary cause for these high solution times was the level of complexity used in the orders submitted by SEMO. Exclusive Group orders, where each exclusive group represented a distinct generator unit, were submitted with as many as 300 distinct blocks in each exclusive group; in production environments, the number of blocks in an exclusive group is limited (e.g. limit of 8 and 24 in EPEX Spot and APX respectively). Similarly, the level of complexity employed in the implementation of linked block orders was very high. The level of complexity used was chosen to provide a level of stressing to the trials. Additionally, as described in section 6.4.1, the fill-or-kill implementation leads to a shortage of price makers in linked block and exclusive group datasets. The combination of these factors resulted in the long solution times and tendency for reaching the algorithm solution time limit. Analysis of the solution times has shown the impact of added complexity and highlighted the need for limits on these orders in production environments.

Following this analysis, SEMO have deemed that linked block and exclusive group datasets do not sufficiently meet the performance criterion as trialled. A significant revision of the assumptions used for these order formats would be required to meet this criterion; this is discussed in section 8.2.

6.5 BATCH TWO – INPUTS

For trial batch two, it was decided to use datasets of which SEMO had the best understanding in order to determine the results of interconnection independent of other factors. To this end, as datasets including simple pumped storage were deemed to violate assumptions too greatly, datasets using complex orders with linked block pumped storage were chosen to be used. The datasets were those from batch one (revised) with relevant interconnector data included. The datasets used are presented in table 11 below.

Dataset ID	Trading Day	Thermal Units	Pump Storage
201403032	03/03/2014	Complex	Linked Block
201403035	03/03/2014	Complex	Linked Block Extended
201403192	19/03/2014	Complex	Linked Block
201403195	19/03/2014	Complex	Linked Block Extended
201403232	23/03/2014	Complex	Linked Block
201403235	23/03/2014	Complex	Linked Block Extended
201403031	03/03/2014	Linked Block	Linked Block
201403034	03/03/2014	Linked Block	Linked Block Extended
201403191	19/03/2014	Linked Block	Linked Block
201403194	19/03/2014	Linked Block	Linked Block Extended
201403231	23/03/2014	Linked Block	Linked Block
201403234	23/03/2014	Linked Block	Linked Block Extended

Table 11: Datasets used in trial batch two

6.6 BATCH TWO - RESULTS

6.6.1 PRICE

For the complex order datasets, in five out of six of the datasets, the average price over the day was lower in the batch two results than in the batch one results, ceteris paribus. The average prices are presented below in table 12.

Dataset ID	Average Price (Batch One)	Average Price (Batch Two)
201403032	107.58	59.60
201403035	79.11	63.60
201403192	78.54	85.97
201403195	98.15	55.18
201403232	84.61	80.92
201403235	71.36	56.09

Table 12: Average prices compared between Batch One and Batch Two

The result here is largely as expected, as when EUPHEMIA has access to prices in other bidding zones, the average price would be expected to be lower in the majority of cases. It should be noted that the objective function of EUPHEMIA is to maximise social welfare across all bidding zones. This means that it is possible that interconnection with other zones leads to higher prices in the I-SEM but higher overall social welfare in the EUPHEMIA solution. By contrast, the SEM objective function seeks to lower production costs in the SEM only. This, coupled with the issues highlighted in section 6.3 relating to utilisation of technically limited units, makes direct comparison of prices from the trading day in the SEM less useful.

In the linked block datasets, the average price was significantly lower in all cases in batch two compared to the same dataset in batch one. Average prices from batch one and two are presented in table 13 below.

Dataset ID	Average Price (Batch One)	Average Price (Batch Two)
201403031	€ 101.13	€ 66.95
201403034	€ 109.31	€ 70.78
201403191	€ 124.13	€ 75.77
201403194	€ 99.39	€ 76.18
201403231	€ 113.91	€ 59.31
201403234	€ 158.40	€ 59.61

Table 13: Average prices compared between Batch one and Batch Two

The primary reason for this lower pricing is the access to price making generators in other order books. As outlined in section 6.1, the linked block orders entered to EUPHEMIA could not set the price and, therefore, price formation was poor in linked block datasets. With the inclusion of the interconnectors, the prices can be set by orders in other bidding zones. A comparison of hourly prices from batch one and two are presented in figure 25 below. It should also be noted that the batch two average prices are lower even though there are a significant number of trading periods in each batch one dataset with negative prices.

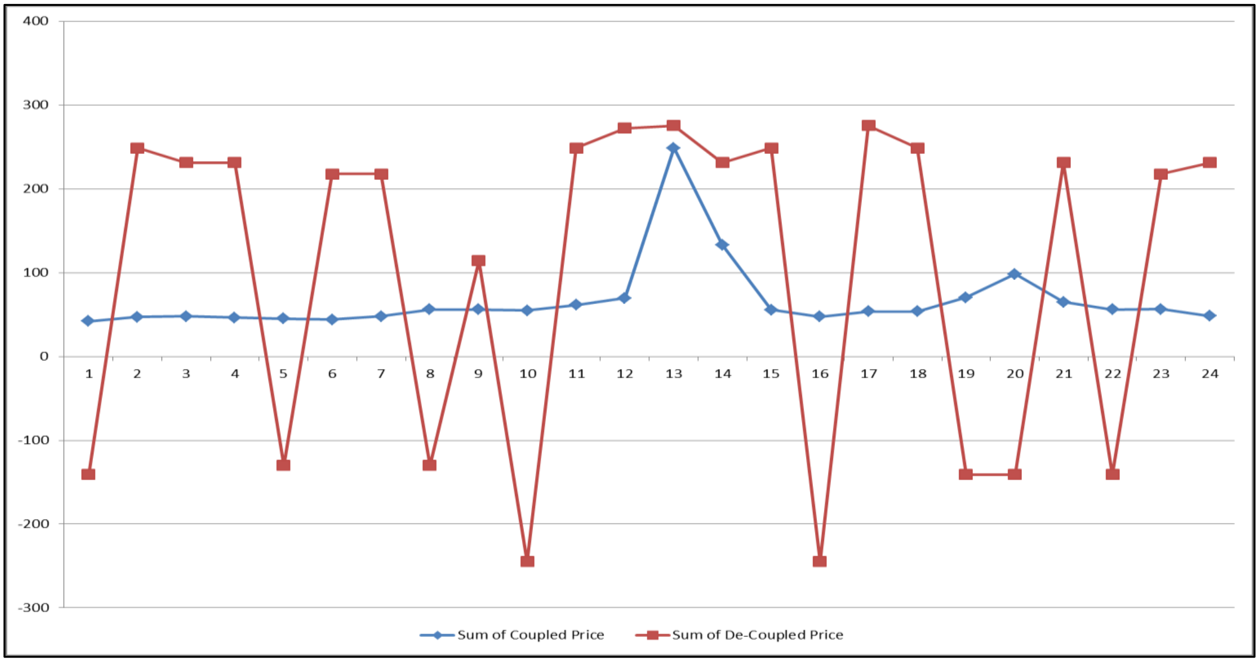

Figure 25: Hourly linked block prices from batch one (de-coupled) and batch two (coupled)

These batch two results show the positive effect that coupling can have with linked blocks in terms of price stability and average price. However, it should be noted that the effects of coupling can only be applied to the point of interconnector constraint (i.e. congestion or ramp constraint). Once Moyle and EWIC are constrained, the price will need to be set within the I-SEM and the issues outlined in section 6.1 would apply in these datasets. While this is not evident in the results seen in batch two, it is expanded upon in section 6.7.

6.6.2 SCHEDULE

In general, unit scheduling followed the same principles as with other batches. Results presented below demonstrate the allocation of volumes to the Moyle and EWIC interconnectors. Figure 25 below shows the allocations of Moyle and EWIC under SEM and EUPHEMIA.

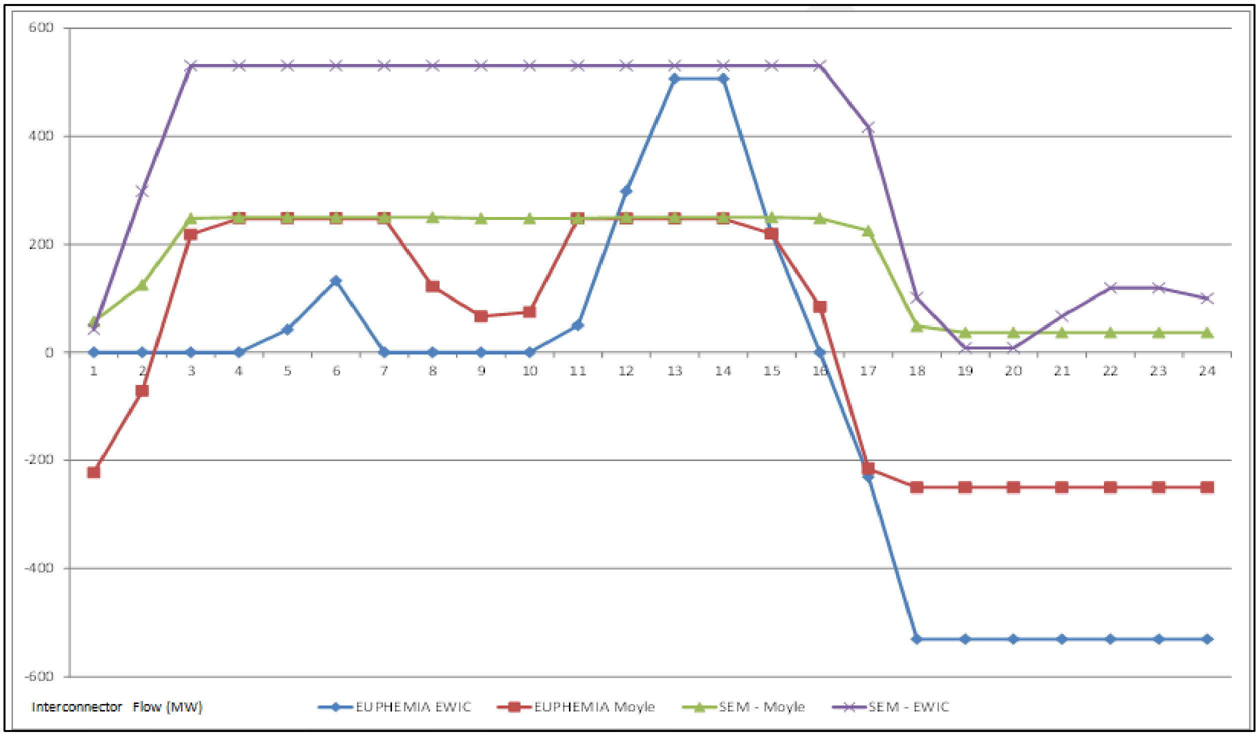

Figure 26: Interconnector Allocations for 03/03/2014 – EUPHEMIA v SEM

There are two main effects to be seen from analysis of interconnector allocations, namely:

- The effect of price on allocations in EUPHEMIA; and
- The effect of differing losses on allocation in EUPHEMIA

In EUPHEMIA all interconnectors are allocated volumes based on the interconnectors' characteristics (e.g. losses, ATC and ramping) and the price difference between the bidding zones involved. Where prices are lower in zone A than adjacent zone B, energy will flow on interconnectors from zone A to B (and vice versa), subject to the characteristics of the interconnectors, either to the point of price convergence or interconnector constraint[7] at full ATC or if subject to a ramp constraint. This will lead to better overall social welfare across all bidding zones as implemented in the EUPHEMIA solution.

The results analysed (as presented in figure 26) show the effect of this coupling with both Moyle and EWIC being allocated for exports in later hours of the day when the price in the I-SEM is low (see figure 21). As prices in the de-coupled datasets were high as compared to the coupled datasets (see table 12), a level of import throughout the day can also be seen. By contrast, SEM interconnectors are scheduled based on the bids of interconnector units. These represent the actions of market participants and are not dictated by overall DAM social welfare[8] across all bidding zones. As such, this may result in power flows in the SEM that appear to be counter to the price spread of the markets. Analysis of the results presented in figure 26, show this to be the case. While EUPHEMIA produces the expected allocations, SEM allocations are influenced by other factors not directly related to the price (e.g. later hours show imports where it would appear that energy should be exported if based purely on prices).

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[7] For these purposes, an interconnector is constrained if allocated at full ATC or if subject to a ramp constraint

[8] SEM interconnector units bid into the SEM to secure import or export on the interconnector. However, income on these trades relates to a number of factors other than the price spread and, therefore, trading activity may reflect other elements.

In addition to the price sensitivity of interconnector allocations in EUPHEMIA, allocation is subject to the constraints of the interconnectors in a way that the SEM allocation is not. Of note for the I-SEM, as outlined in section 5.7, EUPHEMIA takes explicit account of losses in allocation, i.e. where an interconnector has 2% loss, the price difference must exceed 2% for the interconnector to be allocated. While this is not explicitly accounted for in the SEM, bids of interconnector units would account for losses in their bid price as with conventional generators, i.e. a unit will raise their bid price as they are settled based on a loss adjusted volume. This is important for the I-SEM as both Moyle and EWIC have different losses (approximately 0.9% and 3.8% respectively[9] over the studied days as represented in the SEM by their TLAFs). Due to Moyle's lower losses, the Moyle interconnector will always be allocated by EUPHEMIA ahead of the EWIC interconnector as it leads to improved social welfare benefit in the DAM solution, subject to the constraints of the representation of the interconnectors. Additionally, due to the gap between losses, a range of values (i.e. values of price spread between 0.9% and 3.8%) is created where Moyle may be fully utilised and EWIC remains un-utilised. Analysis of the results shows that in a number of hours these effects can be seen with Moyle being fully allocated while EWIC remains un-utilised. By contrast, as this is not accounted for in the SEM, Moyle and EWIC may both be fully utilised in trading periods as scheduling depends on the activities of interconnector unit participants.

Due to these factors, it can be seen that EUPHEMIA is likely to lead to allocations of power flows between the markets that are more reflective of the DAM price spreads. Further information on the relation between interconnector schedules and price spreads is presented in section 6.8.2.

6.7 BATCH THREE - INPUTS

The inputs for trial batch 3 were agreed following multi-lateral discussions between SEMO, the RAs and industry representatives. A limit of approximately 30 datasets was imposed but there was no requirement for Trading Days used to be sequential and a single Trading Day could be trialled a number of times to examine the effect of incremental changes to assumptions.

Discussions around which Trading Days to be used were highlighted by a desire from industry[10] to trial a number of stressed conditions (e.g. high wind days) as well as average conditions in order to assess the differences. Additionally, there was an interest in trialling datasets using conditions which constrained interconnection, had pumped storage unavailable or were at a level of wind consistent with 2020 levels. The full list of trial datasets are presented in table 14 below.

[9] Losses of interconnectors in the SEM vary by time of day and seasonally. Values included herein are average of all values in the period 01/03/2014 to 31/01/2015 based on actual SEM TLAF values.
[10] As represented by members of the RAs rules liaison group (RLG) who responded to requests for input into the EUPHEMIA trialling process

DELIVERY DATE	Dataset ID	Season	Load	Wind	Conditions	Order Format
07/03/2014	201403071	Spring	High	High	Normal	Complex
07/03/2014	201403072	Spring	High	High	2020 Wind	Complex
07/03/2014	201403073	Spring	High	High	2020 Wind - Constrained I/C & No Pump	Complex
07/03/2014	201403074	Spring	High	High	2020 Wind - Constrained I/C & No Pump	Linked Block
19/04/2014	201404191	Spring	Average	Low	Normal	Complex
08/05/2014	201405081	Summer	Average	Average	Normal	Complex
20/07/2014	201407201	Summer	Low	Low	Normal	Complex
10/08/2014	201408101	Autumn	Low	Average	Normal	Complex
10/08/2014	201408102	Autumn	Low	Average	2020 Wind	Complex
10/08/2014	201408103	Autumn	Low	Average	2020 Wind - Constrained I/C & No Pump	Complex
10/08/2014	201408104	Autumn	Low	Average	2020 Wind	Linked Block
09/09/2014	201409091	Autumn	Average	Low	Normal	Complex
03/10/2014	201410031	Autumn	Average	Average	Normal	Complex
03/10/2014	201410032	Autumn	Average	Average	Normal	Linked Block
17/10/2014	201410171	Autumn	Average	High	Normal	Complex
17/10/2014	201410172	Autumn	Average	High	2020 Wind	Complex
18/10/2014	201410181	Autumn	Average	High	Normal	Complex
21/10/2014	201410211	Autumn	Average	High	Normal	Complex
21/10/2014	201410212	Autumn	Average	High	2020 Wind	Complex
21/10/2014	201410213	Autumn	Average	High	2020 Wind - Constrained I/C & No Pump	Complex
21/10/2014	201410214	Autumn	Average	High	2020 Wind	Linked Block
21/10/2014	201410215	Autumn	Average	High	2020 Wind - Constrained I/C & No Pump	Linked Block
03/12/2014	201412031	Winter	High	Low	Normal	Complex
07/01/2015	201501071	Winter	High	High	Normal	Complex
08/01/2015	201501081	Winter	High	High	Normal	Complex
09/01/2015	201501091	Winter	High	High	Normal	Complex
09/01/2015	201501092	Winter	High	High	2020 Wind	Complex
09/01/2015	201501093	Winter	High	High	2020 Wind - Constrained I/C & No Pump	Complex
10/01/2015	201501101	Winter	High	High	Normal	Complex
11/01/2015	201501111	Winter	Average	High	Normal	Complex
12/01/2015	201501121	Winter	Average	High	Normal	Complex
13/01/2015	201501131	Winter	High	High	Normal	Complex
22/01/2015	201501221	Winter	High	Average	Normal	Complex

Table 14: Datasets used in Initial Phase Trial Batch 3

In order to accommodate the conditions beyond the SEM, assumptions were required around how to alter data. These assumptions were as follows:

- Where the datasets calls for interconnectors to be constrained, the ATC values were divided by 2;
- Where the datasets calls for 2020 wind levels, the wind output values were multiplied by 1.55; and
- Where the datasets calls for no pumped storage, these units were omitted entirely

The multiplier for wind was an estimated multiplier based on best available data. The most recent EirGrid ten year transmission development plan[11] estimates that between 3200 and 3700 MW of wind would be required to meet 2020 targets. The datasets studied are all in the range of 01/02/2014 and 31/01/2015, installed wind capacity was 1964 MW and 2373 MW respectively at these dates. While there are a range of possible values to uplift wind by, it was decided that, for consistency, a single multiplier value would be used for all datasets based on an estimate of the increased capacity required to reach 2020 targets. The figures used to calculate this average multiplier are presented below.

2020 Projection	Installed Capacity	Multiplier Required
3200	1964	1.6
3700	1964	1.8
3200	2373	1.3
3700	2373	1.5

Table 15: Installed Wind Capacity – Current levels v 2020 levels

The average multiplier required based on these figures was 1.55. For any dataset requiring 2020 wind levels, all wind forecast data used to create the wind orders for that dataset were multiplied by this factor to increase the overall level wind to an estimate of the 2020 level, using the below formula.

$$Increased\ Wind\ MW_h = SEM\ Wind\ Forecast\ MW_h * 1.55$$

Where h represents trading period

As regards interconnector values, while the losses on interconnectors increase with lower outputs, as no data was available for the effects of lower ATC on seasonal or day/night loss factors no adjustment was made to loss factors. In reality, the average losses incurred by each interconnector would not significantly change unless output was at a very low level (approx. less than 50 MW); the average losses incurred at half capacity are approximately equal to the average losses incurred at full capacity. Consequently, where a dataset required constrained interconnectors, adjustment was made to each interconnector's ATC only. Where a dataset required constrained interconnector and the Trading Day had an interconnector on outage, the 0.5 multiplier was applied to all active interconnectors irrespective of outages.

6.8 BATCH THREE – RESULTS

Pricing and scheduling in general followed the same principles as outlined in sections 6.4 and 6.6. Consequently, this section will outline additional insights gained from analysis of conditions specific to trial batch three.

[11] http://www.eirgrid.com/media/2014All-IslandTenYearTransmissionForecastStatement.pdf

6.8.1 PRICES

The main result in terms of pricing was the effect of 2020 wind levels on the prices in the I-SEM. In the majority of cases, the increase to 2020 wind levels had the expected effect in that it lowered the average price. Figure 27, below, presents a comparison of the average price for complex datasets using normal wind conditions and 2020 wind conditions.

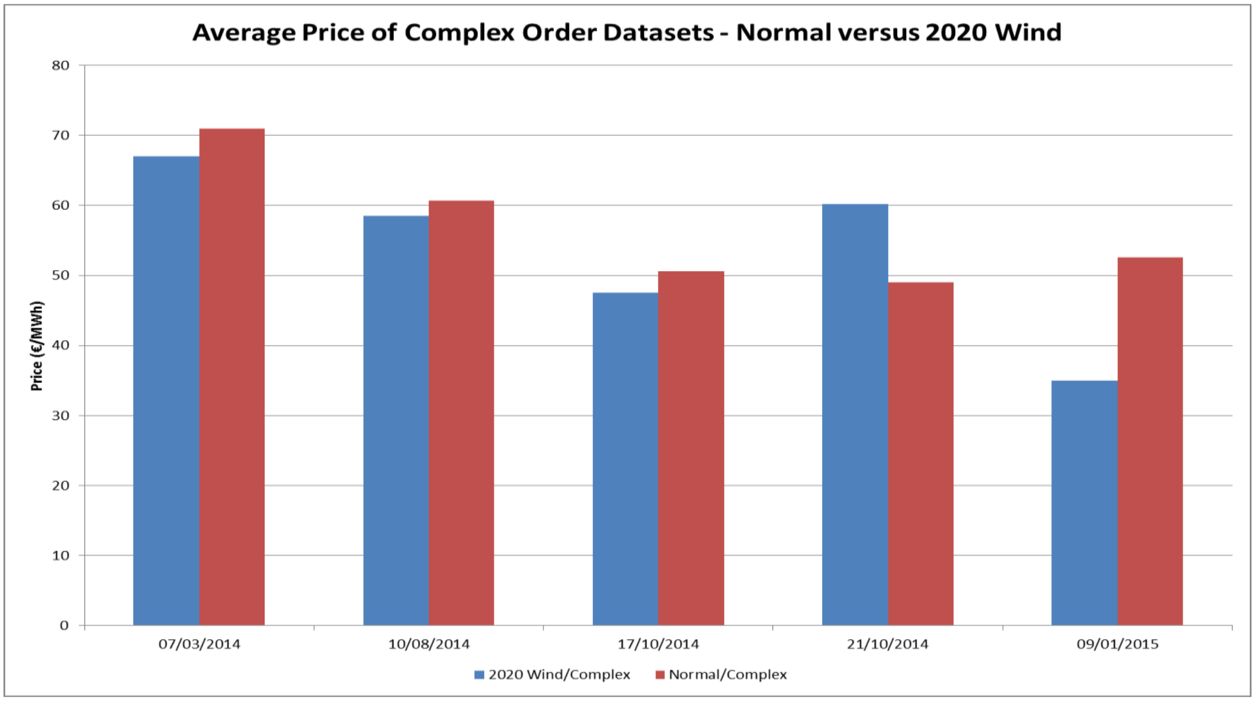

Figure 27: Average daily prices for complex datasets using normal and 2020 wind conditions

There is one day which has higher average prices with 2020 wind. While the expectation is that on average 2020 wind levels will lower prices, this will not necessarily lower the daily average of each day. Based on the wind and load profiles for the day, units may not be able to meet their minimum income conditions with 2020 wind where they could with normal wind. This could lead to a situation where a more expensive unit is required to meet this demand. Therefore, for a specific day the average price may be increased with the increased wind level. As such, the data from 21/10/2014 is not considered anomalous.

Further to the 2020 wind levels, some datasets included the 2020 wind level but with a constrained interconnector and an outage of pumped storage. A comparison of prices between datasets including fully available interconnectors and constrained interconnectors is available in table 16 below.

Date	Average of MCP	Max of MCP	Min of MCP
07/03/2014			
2020 Wind - Constrained I/C & No Pump/Complex	28.80	277.65	-500.00
2020 Wind/Complex	67.06	248.47	29.49
10/08/2014			
2020 Wind - Constrained I/C & No Pump/Complex	48.54	173.60	23.98
2020 Wind/Complex	58.52	173.60	30.64
21/10/2014			
2020 Wind - Constrained I/C & No Pump/Complex	50.53	223.30	25.25
2020 Wind/Complex	60.21	209.16	25.25
09/01/2015			
2020 Wind - Constrained I/C & No Pump/Complex	-9.27	168.96	-500.00
2020 Wind/Complex	34.94	66.95	-27.49

Table 16: Pricing information of 2020 wind datasets

With access to interconnection, the effect of pumped storage on the price is lessened and so the outage of pumped storage units did not seem to have a significant effect on price. The more significant effect is linked to the reduction of interconnection. As a higher wind level will lower prices, the level of export in datasets with 2020 wind was high and often resulted in interconnector congestion. At points of interconnector congestion, the marginal unit will be a unit within the I-SEM coming from the relevant point in the merit order stack. Where interconnection is constrained, the level of export is reduced and so the marginal unit will come from a point lower in the merit order stack with a lower price. This is illustrated in figure 28 below.

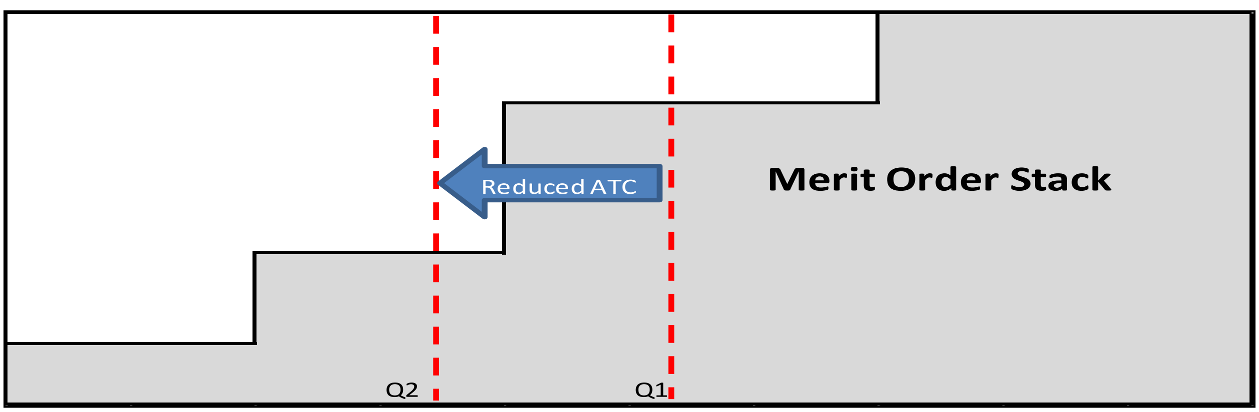

Figure 28: Illustrative example of the effect of reduced export on the merit order stack

Trial batch three allowed for a comparison of the pricing of linked block datasets using 2020 wind levels. A comparison of the results from linked block datasets and complex datasets is presented in table 17 below.

	Average of Price	Max of Price	Min of Price
10/08/2014			
2020 Wind/Complex	58.52	173.60	30.64
2020 Wind/Linked Block	43.91	173.50	-84.70
21/10/2014			
2020 Wind/Complex	60.81	209.16	25.25
2020 Wind/Linked Block	54.93	209.16	-129.95

Table 17: Pricing information for linked block and complex datasets using 2020 wind

As can be seen in table 17, the average price in linked block datasets is lower than in complex datasets. However, the linked block datasets contain instances of negative pricing which decrease this average price. This more volatile pricing is less efficient overall than the pricing in the complex datasets even though the average price levels are lower. The 10/08/14 and 21/10/2014 hourly prices are presented in figures 29 and 30, below, respectively.

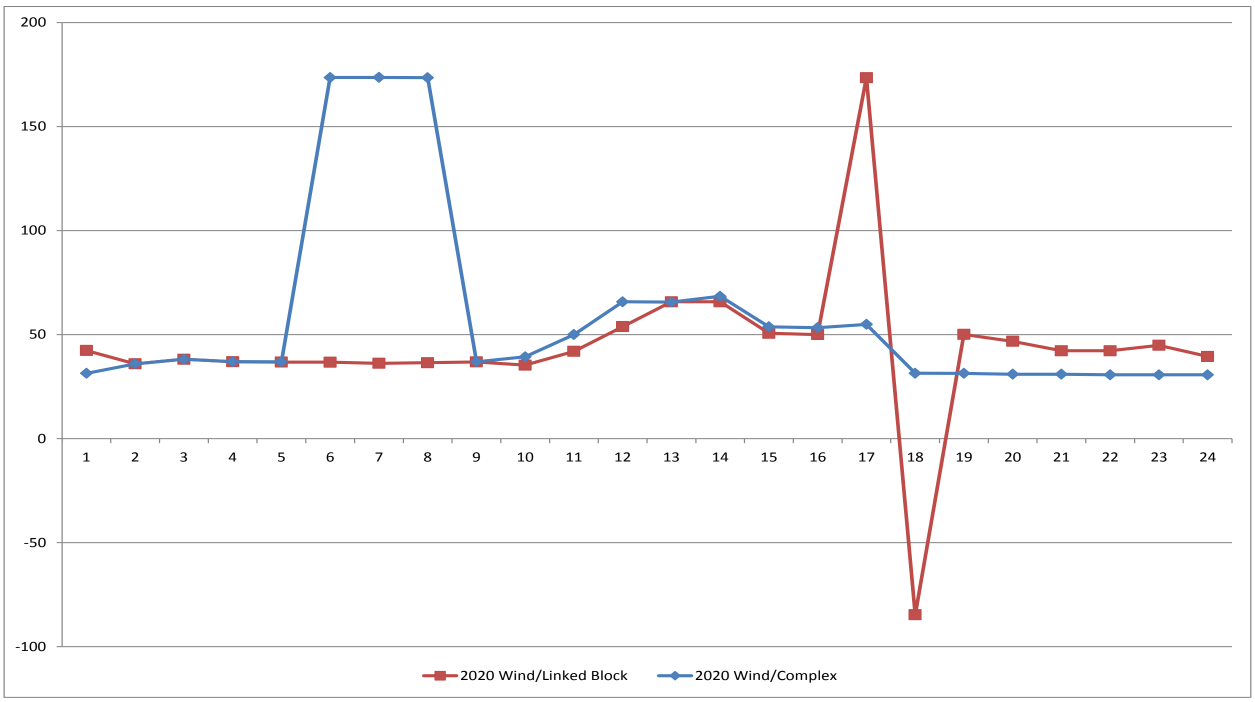

Figure 29: Hourly prices for 10/08/2014 with 2020 wind using complex and linked block orders

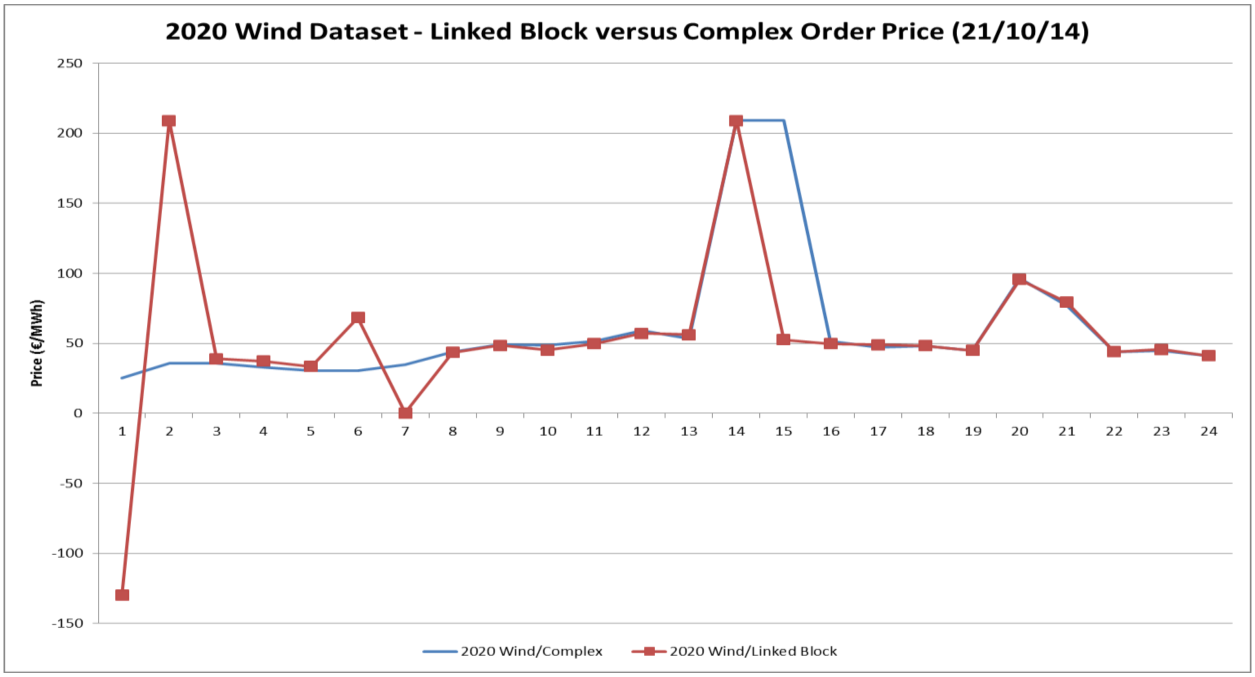

Figure 30: hourly prices for 21/10/2014 with 2020 wind using complex and linked block orders

The reason for this volatility is that at points of interconnector constraint, which may include periods where ramp rate restrictions apply, the marginal price will be set by a unit in the I-SEM. In the case of linked block datasets, the fundamental approach to linked block order was not altered from trial batch one or two; therefore, the issues outlined in section 6.4 and 6.6 remain prevalent. For illustration, figure 31 below shows the hourly prices with the load and generation values.

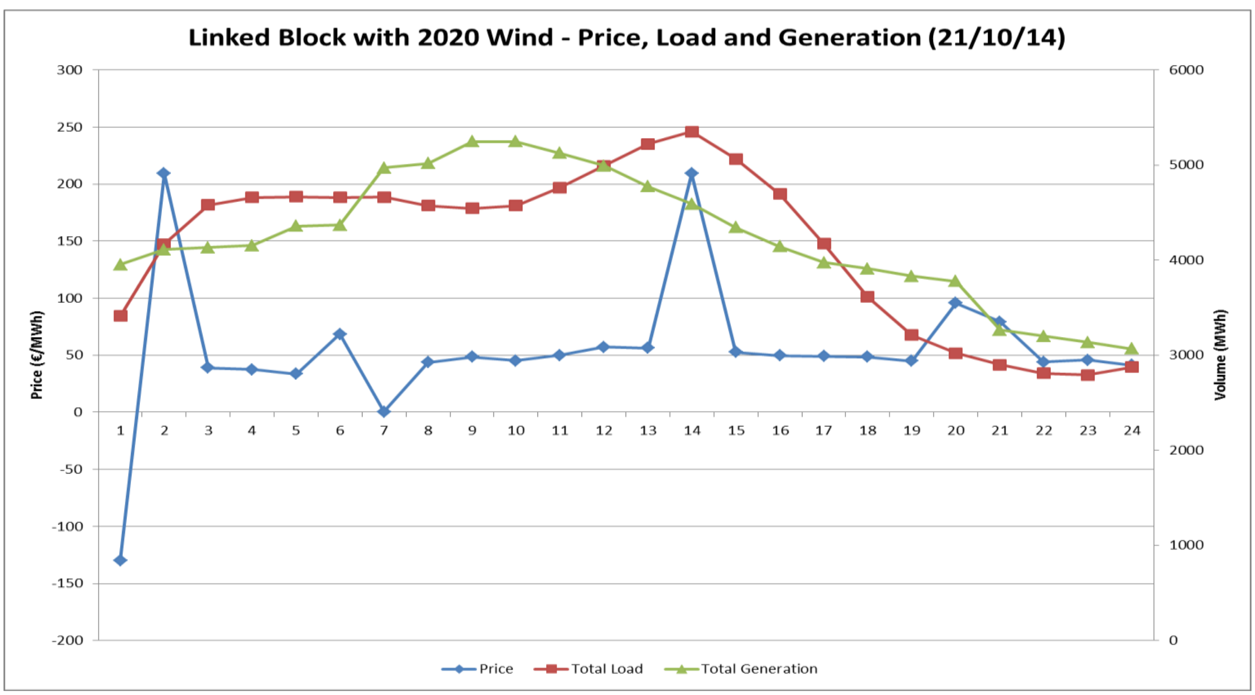

Figure 31: Price, load and generation for linked block data for 21/10/2014 with 2020 wind

Figure 31 shows volatile pricing in hours 1 and 2 and hours 5 and 7. This pricing is occurring at times when there is a large change in net position (the difference between load and generation) resulting in interconnector ramp constraints. Analysis of these runs, as well as the data presented in section 6.6, shows that while coupling is effective in producing a more efficient price in linked block datasets, it is not a comprehensive solution to the issues encountered with linked blocks. Further details on possible solutions to these issues are outlined in section 7.

6.8.2 SCHEDULE

Batch three offered the opportunity to analyse the results of interconnector positions across a number of trading days. As these trading days were chosen to reflect a wide range of market conditions, results will be reflective of a wide range of conditions. As stated in section 6.6.2, Moyle and EWIC are allocated volumes separately in EUPHEMIA due to having different characteristics represented. The effects of this allocation can be seen in figure 32 below.

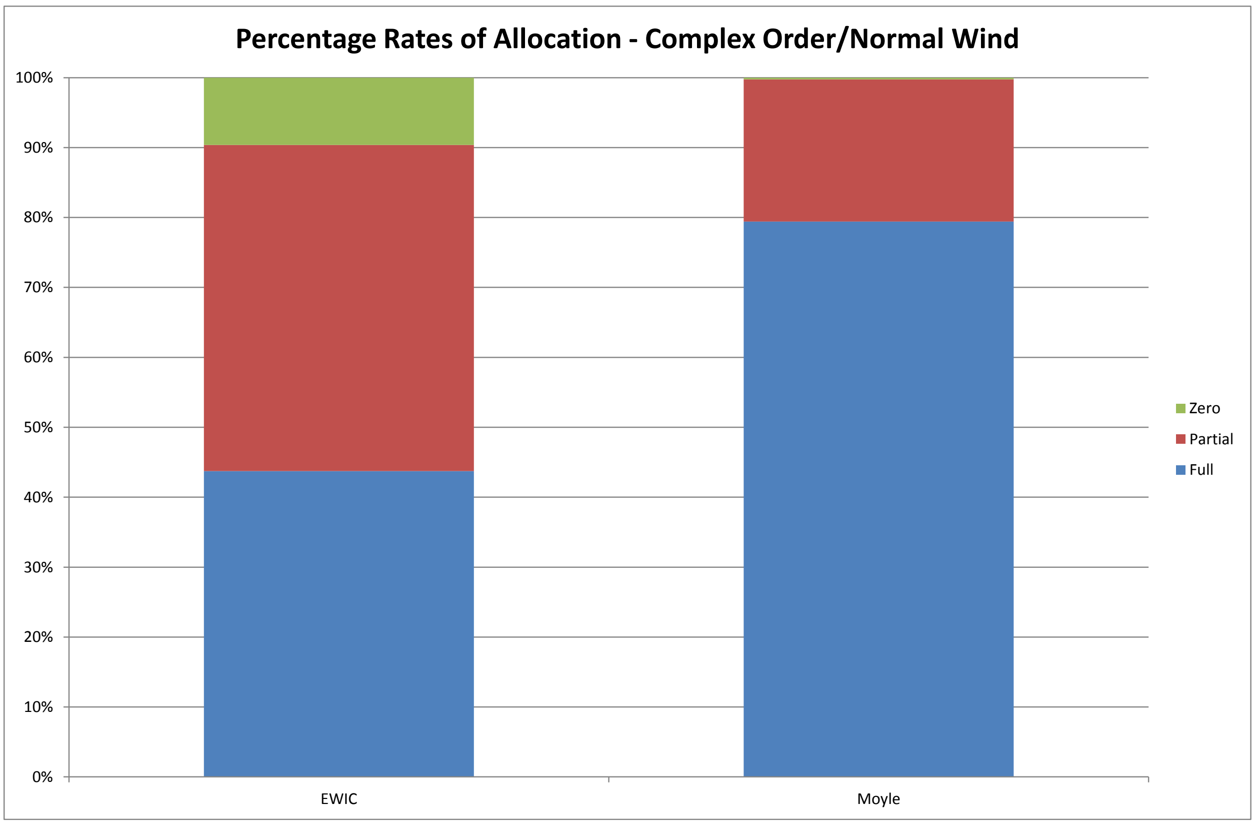

Figure 32: Rates of allocation for Moyle and EWIC for all complex order datasets with normal wind conditions

As can be seen in figure 32, Moyle has far more instances of full allocation than EWIC while EWIC has more instances of partial or zero allocation. This is reflective of the representation of the interconnectors where Moyle (0.9% average losses) has lower losses than EWIC (3.8% average losses) and so is scheduled at lower values of price spread than EWIC. This is also the case when 2020 wind conditions are included, as shown in figure 33 below.

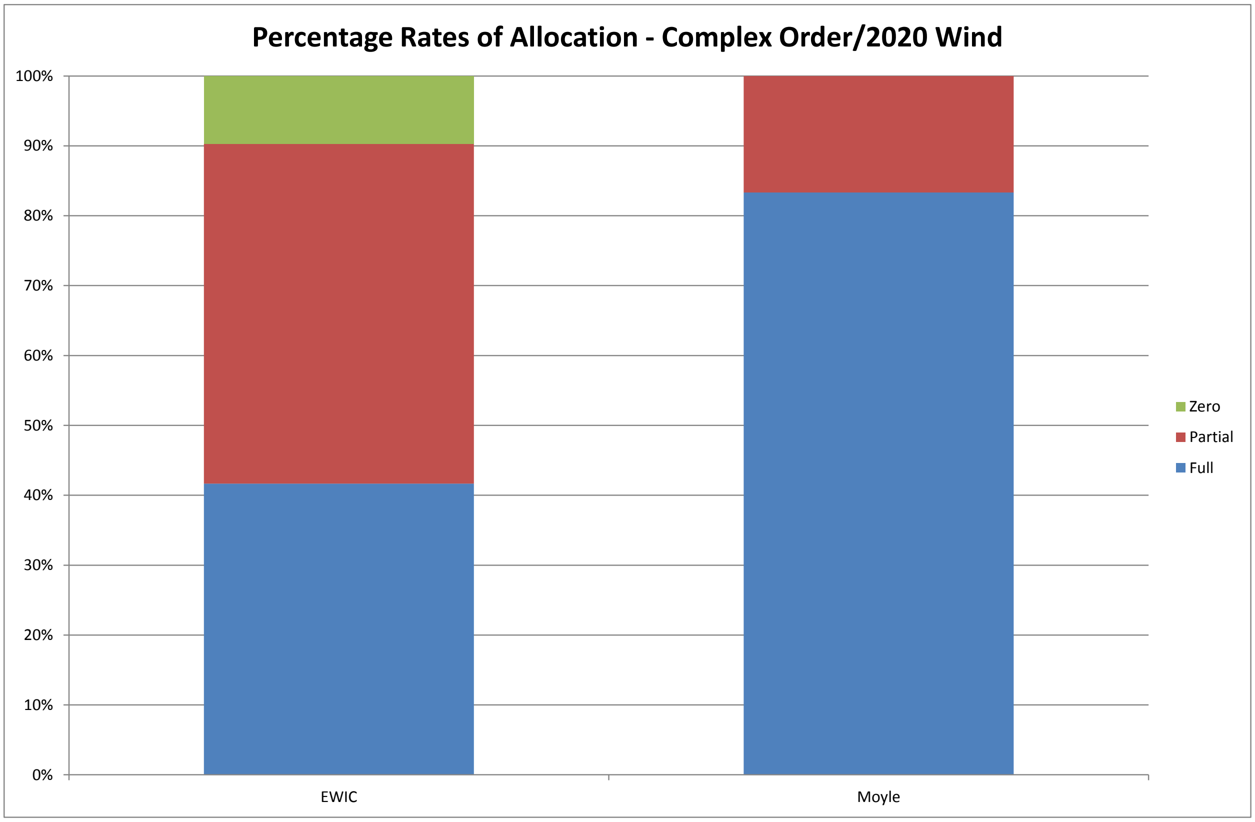

Figure 33: Rates of allocation for Moyle and EWIC for all complex order datasets with 2020 wind conditions

While there is less underlying data in the 2020 wind cases (4 datasets) than the normal wind condition cases (19 datasets) the same trend can be seen. However, with 2020 wind conditions and reduced interconnection the pattern of allocation is different. The allocation values for 2020 wind with interconnector constraints are presented in figure 34 below.

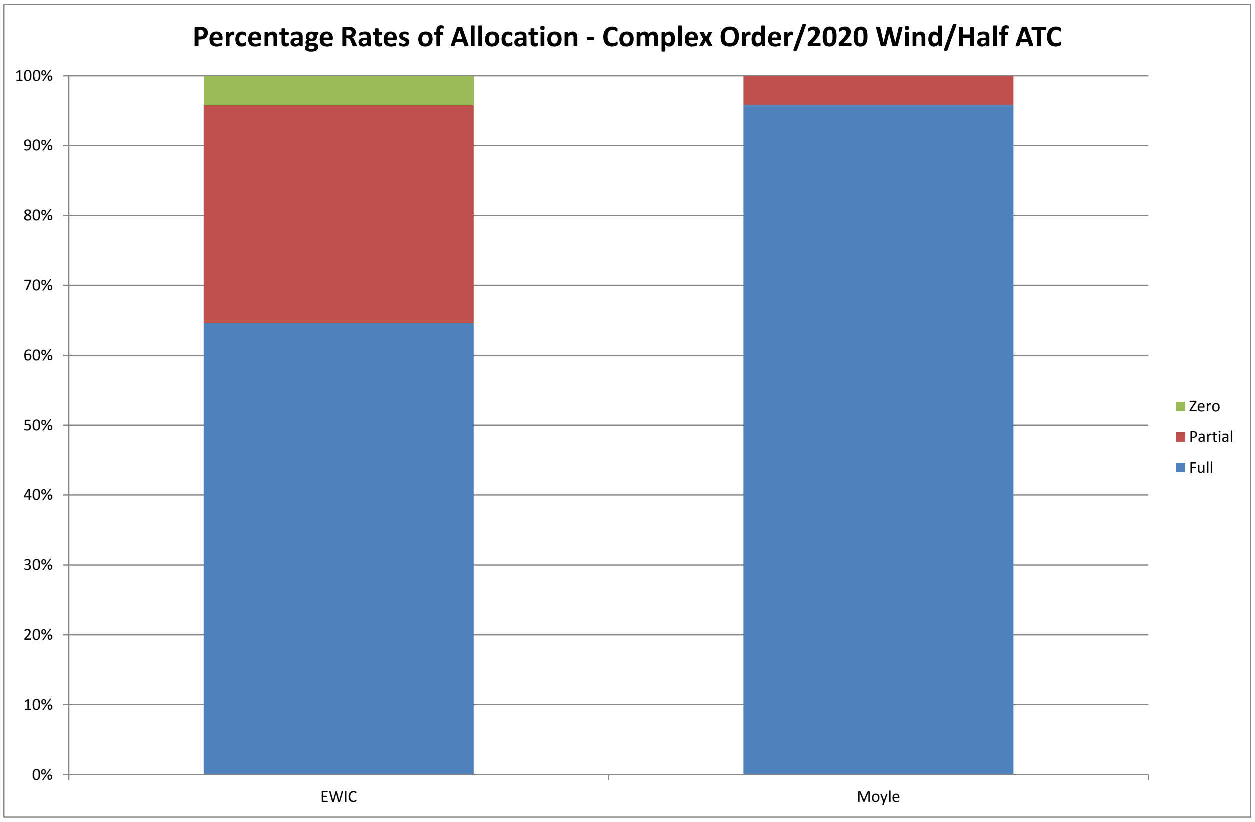

Figure 34: Percentage rates of allocation for interconnectors for 2020 wind data with 50% ATC constraints

Figure 34 demonstrates that where both interconnectors are only available at 50% of their trading day ATC, subject to any outages on the trading day, the number of times where EWIC is operating at full capacity is greatly increased. This is a function of Moyle's decreased ability to contribute to price convergence and a lower allocation of volume being required from EWIC to meet its full capacity.

Analysis of the flows on these interconnectors in relation to the price spread between the I-SEM and GB bidding zones indicates the efficiency of the flows produced. Figure 35, below, shows the results of this analysis in relation to trial batch three results.

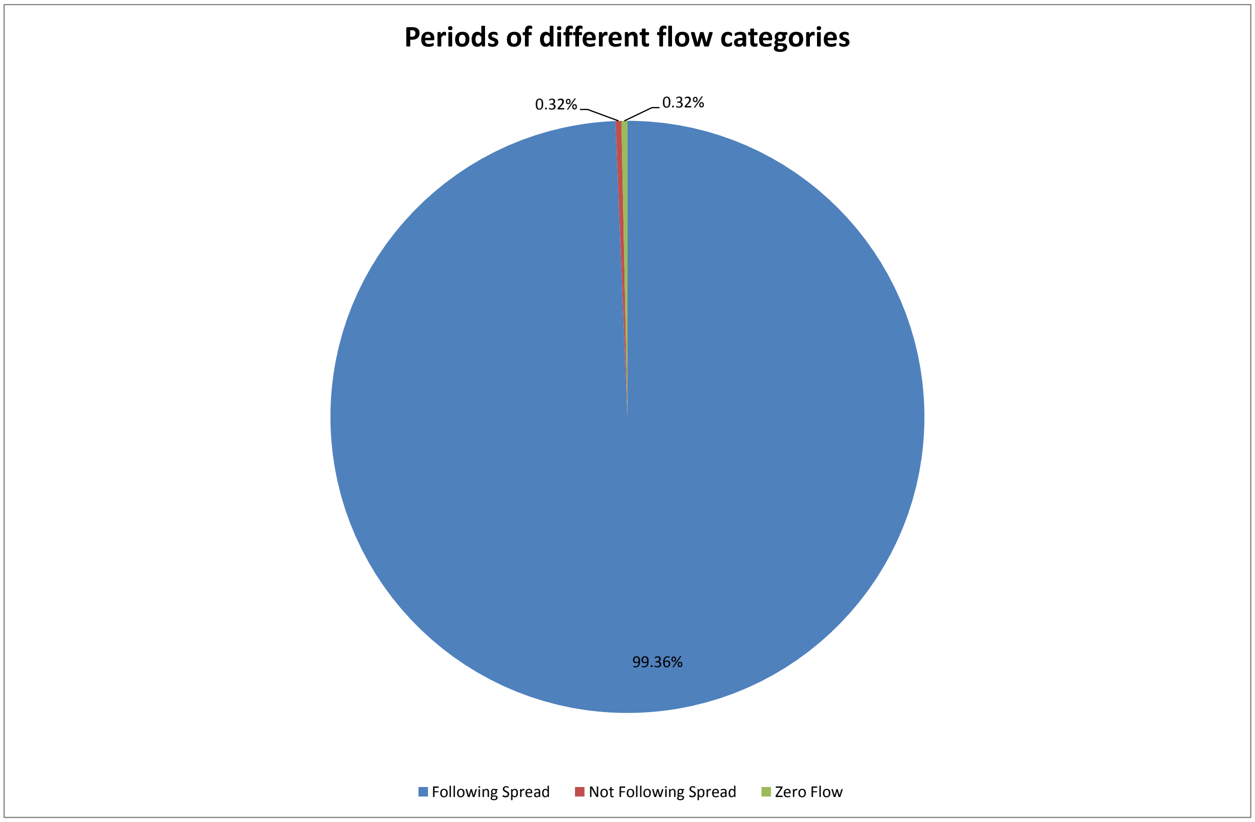

Figure 35: Periods of different interconnector flow categories in trial batch three results

Figure 35 demonstrates that in the majority of trading periods (99.36%) the flow of interconnectors follows the price spread. It should be noted in analysis of these results that a price spread exists in all studied trading periods between the I-SEM and GB bidding zones. This is due to the characteristics of the interconnectors, in the majority of the cases losses, i.e. the price spread is reduced to the level of losses as the marginal benefit of using the interconnectors is outweighed by the social welfare lost in transmission.

Of the three cases where a price spread exists but no flow occurs, these were due to the price spread being lower than the losses on Moyle. Of the three cases of adverse flows, these were linked to the ramping limitations as represented in EUPHEMIA, i.e. where the price quickly shifts from the I-SEM being higher than GB to GB being a higher price than the I-SEM, the power system is not able to meet this change in flow due to ramping limits applied at the points of interconnection.

While in the majority of cases the flow of interconnectors follows the price spread, the percentage utilisation should be linked to the value of price spread. The imposition of ramping and loss limits on the interconnectors affects how the price spread is followed. Data on the percentage of utilisation and price spread for trial batch three is presented in figure 36 below.

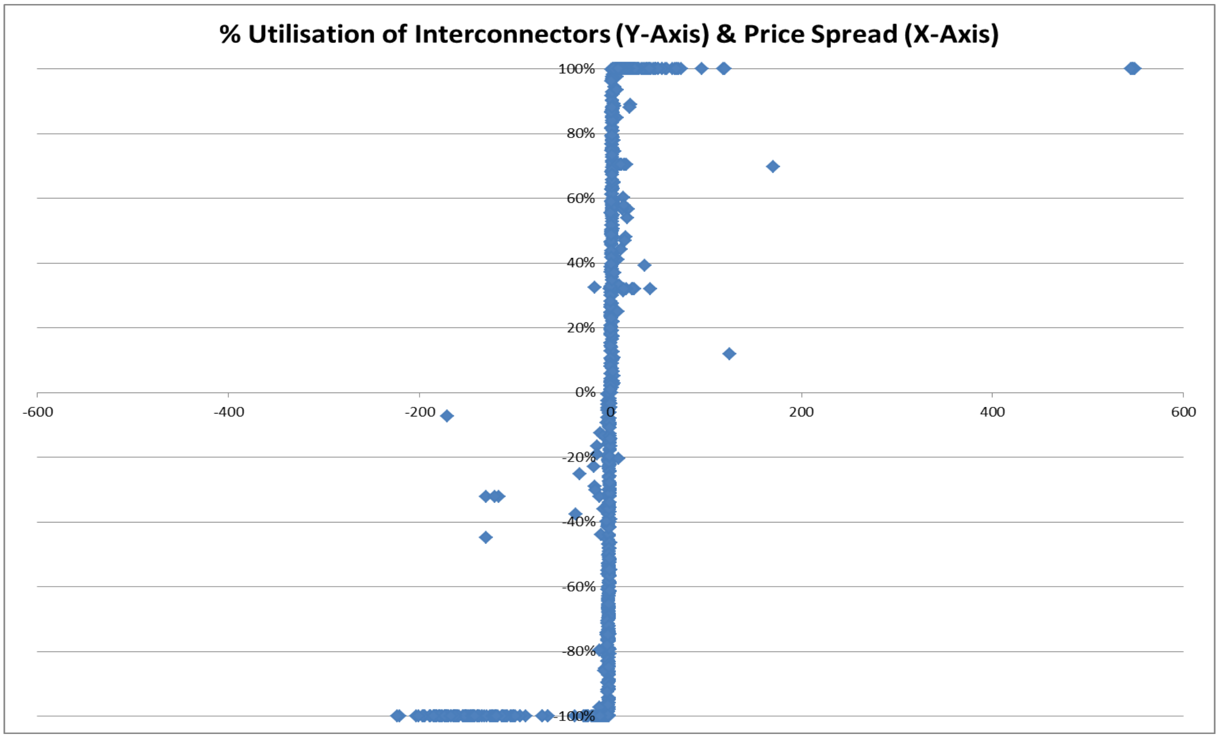

Figure 36: Price spread and interconnector utilisation values for all trading periods in trial batch three

Figure 36 presents utilisation data on an aggregate basis (i.e. percentages are in relation to total available capacity in a trading period and total flow on both interconnectors) and shows a trend of the price spreads being followed. The expectation here is that large values of price spread should only occur where interconnection is fully utilised; this is an extension of the analysis of direction of flow above and is observed in the majority of cases. However, deviations from the trend line (central backwards Z shape in figure 36) show the effects of ramping and loss constraints, i.e. values of large price spread where there is unused interconnector capacity. There are two common causes of these price spread values:

- Points where the Moyle interconnector is fully allocated but EWIC remains unallocated due to losses
- Points where the ramping limits prevent fully efficient utilisation of either interconnector

While the effects of losses and ramping impact the flows between zones, it should be noted that EUPHEMIA calculated the most efficient flows based on the input data. SEMO feels that the representation of interconnectors used in the Initial Phase is reflective of best available data on the representation required for the I-SEM.

6.9 ADDITIONAL ANALYSIS

To supplement the analysis of trial batches in terms of pricing and scheduling, SEMO performed additional analysis of outputs to better understand the implications of the results seen. This analysis focused on the feasibility of the DAM schedules produced, in terms of the overall I-SEM context. This analysis looked at the following areas:

1. System Non-Synchronous Penetration (SNSP);
2. Units scheduled below their minimum stable generation; and
3. Units scheduled for multiple starts in a single day beyond their technical capability.

6.9.1 SNSP

SNSP is a measure of the amount of non-synchronous generation on the system, e.g. Wind Generation and HVDC interconnector imports and exports. SNSP has been calculated for the study using the formula below.

$$SNSP_h = \frac{Total\ Wind\ Generation_h + Total\ Interconnector\ Imports_h}{Total\ Load_h + Total\ Interconnector\ Exports_h}$$

Where h represents trading period

Note that for trial batch one, including revised assumptions, the interconnectors were not included in the datasets. As such, SNSP is equal to wind penetration in these datasets based on the formula above.

The transmission system is currently run with a limit of 50% SNSP; values of SNSP beyond this limit will require actions by the TSO to reduce the SNSP value below the limit. As EUPHEMIA does not account for this constraint, it may schedule energy such that the SNSP limit is breached warranting actions in later timeframes. The purpose of the analysis outlined herein was to quantify the frequency and magnitude of breaches of this limit to help understand the need for actions in later timeframes.

The limit of SNSP relates to a number of factors which affect how the system operator can run the transmission system. These are being investigated as part of EirGrid's DS3 programme. The expectation is that following the DS3 programme, the SNSP limit will be increased to 75%. As such, datasets using a 2020 level of wind were further analysed using a 75% limit as this is the expected limit.

6.9.1.1 TRIAL BATCH ONE

As trial batch one featured the same wind and load data regardless of the assumptions used, only three days of data can be derived across all trial datasets. The hourly SNSP values from this trial in relation to the 50% limit are presented below.

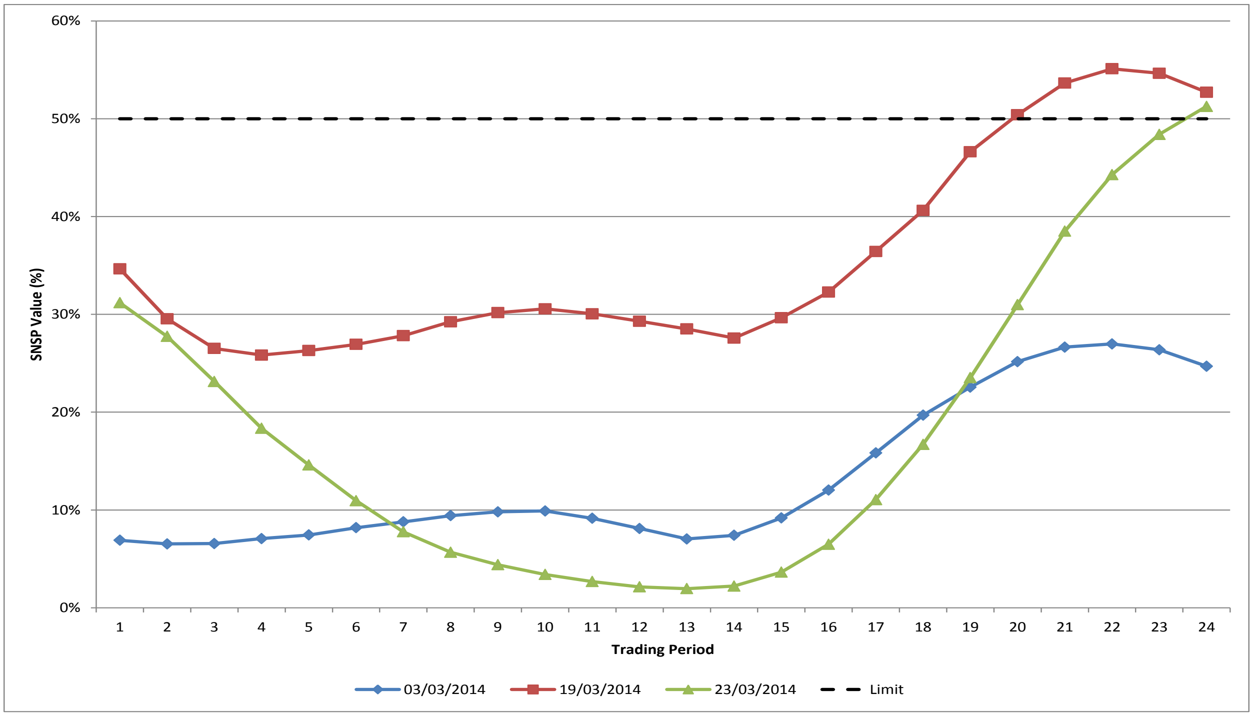

Figure 37: Hourly SNSP values for trial batch one

As can be seen in figure 37, there are six trading periods in which the value of SNSP is above the 50% limit. As stated above, as trial batch one did not include interconnectors, the SNSP values in this trial batch are equal to the hourly wind penetration. Of the six instances where the limit is breached, five occur on 19/03/2014 which was selected as the high wind day for the study.

6.9.1.2 TRIAL BATCH TWO

For trial batch two, the same wind and load data was used as in trial batch one and as this data was entered as price taking the same values will apply to batch two; however, the inclusion of the interconnectors leads to different SNSP values than those seen in trial batch one. As the price in the I-SEM, or more accurately the price spread between the I-SEM and interconnected bidding zones, determines interconnector allocations, each revised set of assumptions in trial batch two lead to a different SNSP value than those seen in trial batch one.

In batch two, there were no instances of SNSP being in excess of 50%. As the wind and load values remained unchanged, the only factor affecting SNSP in batch two compared to batch one was the allocation of volumes of import and export. While imports increase SNSP, exports reduce SNSP. As can be seen in figure 32 above, the instances where SNSP was in excess of 50% were all in the later hours of the day and with a high wind value. With the interconnectors included, the excess wind is exported in these hours and so the SNSP is reduced.

These values show that the inclusion of the interconnector can help to reduce SNSP. However, there are two points of note in relation to this:

- There is a limit to how much energy can be exported both in terms of ATC and ramping
- When the interconnector is importing, SNSP will be increased

6.9.1.3 TRIAL BATCH THREE

Trial batch three contained data across seasonal conditions and using varying load and wind conditions, allowing for analysis of SNSP across a range of conditions. Across the conditions studied, the 50% limit was exceeded approximately 4.8% (21/435) of the time. As this accounts for a wide range of wind and load conditions this offers a good insight of the typical conditions across seasons given current wind capacity.

As batch three involved rerunning specific days with revised assumptions, it was possible to assess the effects of these revised assumptions on SNSP. While the number of trading periods exceeding 50% SNSP was higher in 2020 wind datasets, the number of cases in excess of the expected 75% SNSP limit was low. The percentage of trading periods in breach of the 50% and 75% limits (as well as information on the number of datasets from which each column is derived) are presented in figures 38 and 39, below, respectively.

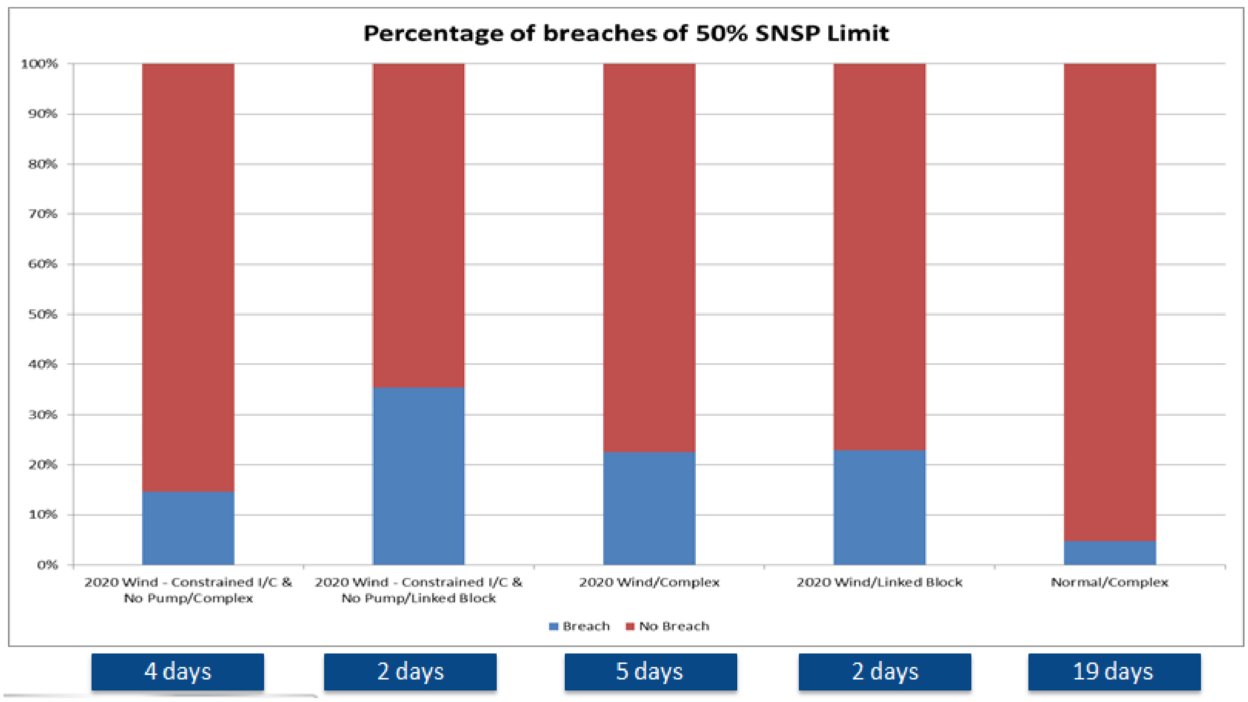

Figure 38: Percentage of trading periods exceeding the 50% SNSP limit

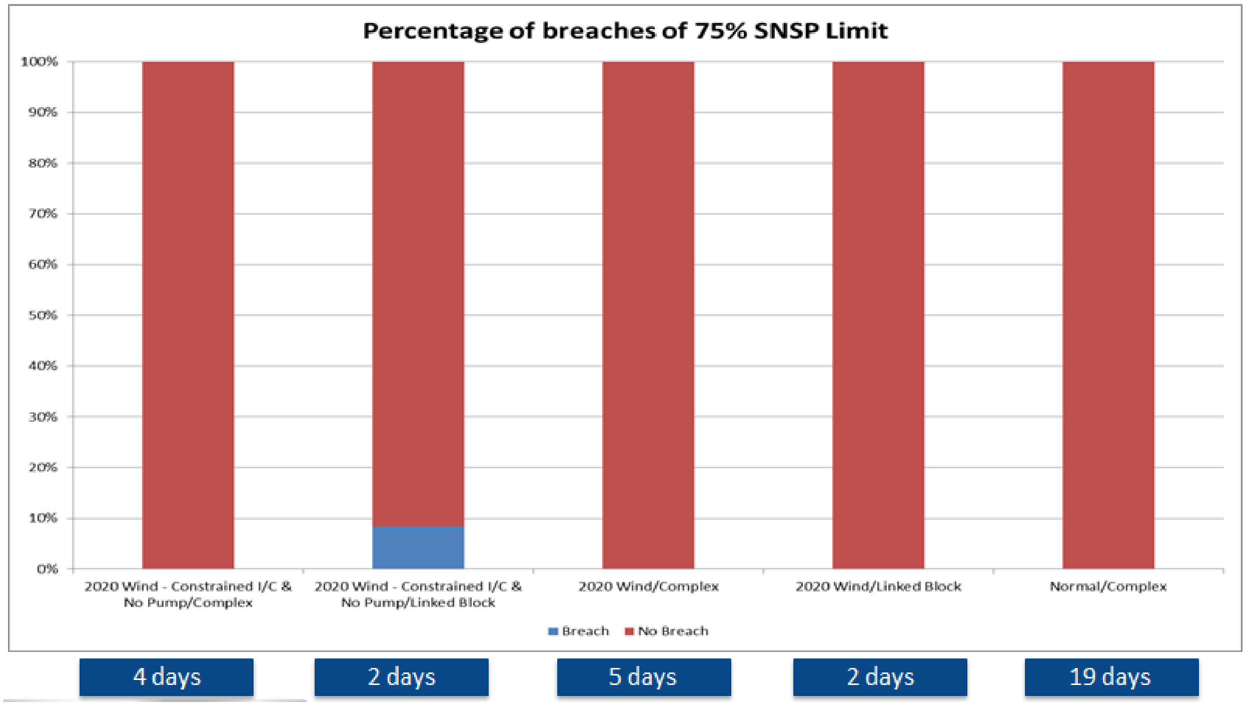

Figure 39: Percentage of trading periods exceeding the 75% SNSP limit

While the percentage of trading periods exceeding 50% SNSP is relatively high in 2020 wind scenarios, it is expected that a 75% limit will be in place at this time and, therefore, the number of actions required to alter the DAM schedules for this particular constraint will be reduced accordingly.

6.9.2 UNITS SCHEDULED BELOW THEIR MINIMUM STABLE GENERATION

Complex orders only explicitly take account of a limited number of characteristics of a unit in its order. One of the key characteristics not explicitly accounted for in complex orders is minimum stable generation. As such, SEMO investigated instances of units being scheduled below their minimum stable generation.

In trial batch one, instances of units being scheduled below their minimum stable generation were investigated over all complex datasets using all relevant assumptions (12 datasets in total) and it was found that there were 102 instances. These occurred in each trading day investigated and across a number of hours, fuels and units. The only correlation between instances and hours was that instances were unlikely in hours around peak net demand where the generator requirement is highest. As an illustration of this point, figure 40 below presents the percentage of minimum stable generation that units were scheduled for across 03/03/2014 including all instances of generation below the minimum level.

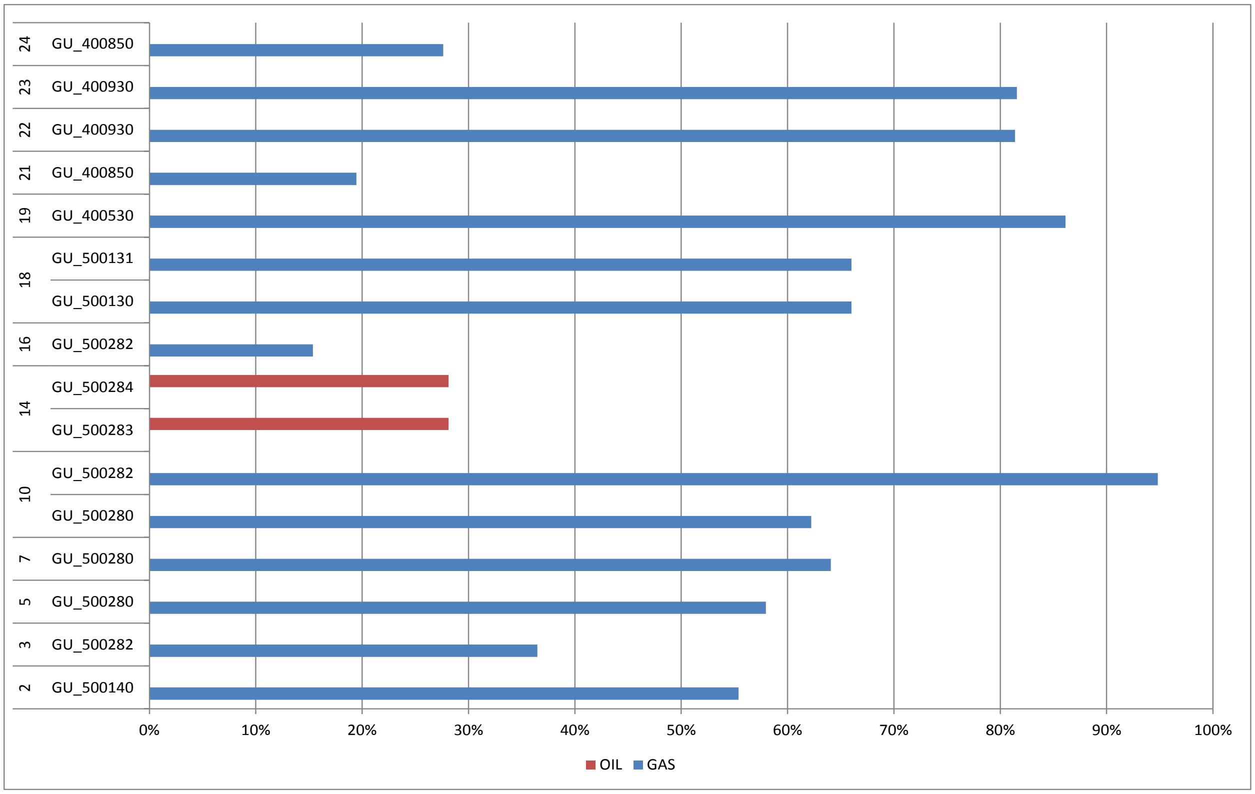

Figure 40: Percentage of minimum stable generation for generator schedules 03/03/2014

While there are many instances of this occurring, the context of these instances in relation to the rest of the unit's schedule, and in light of the other market timeframes available, is important. For example, a unit scheduled at a level close to its minimum stable generation could sell additional energy to meet its minimum stable generation. Conversely, a unit scheduled at a value close to zero could buy additional energy to return its net position for the trading period to zero. This point is illustrated in figure 39, below.

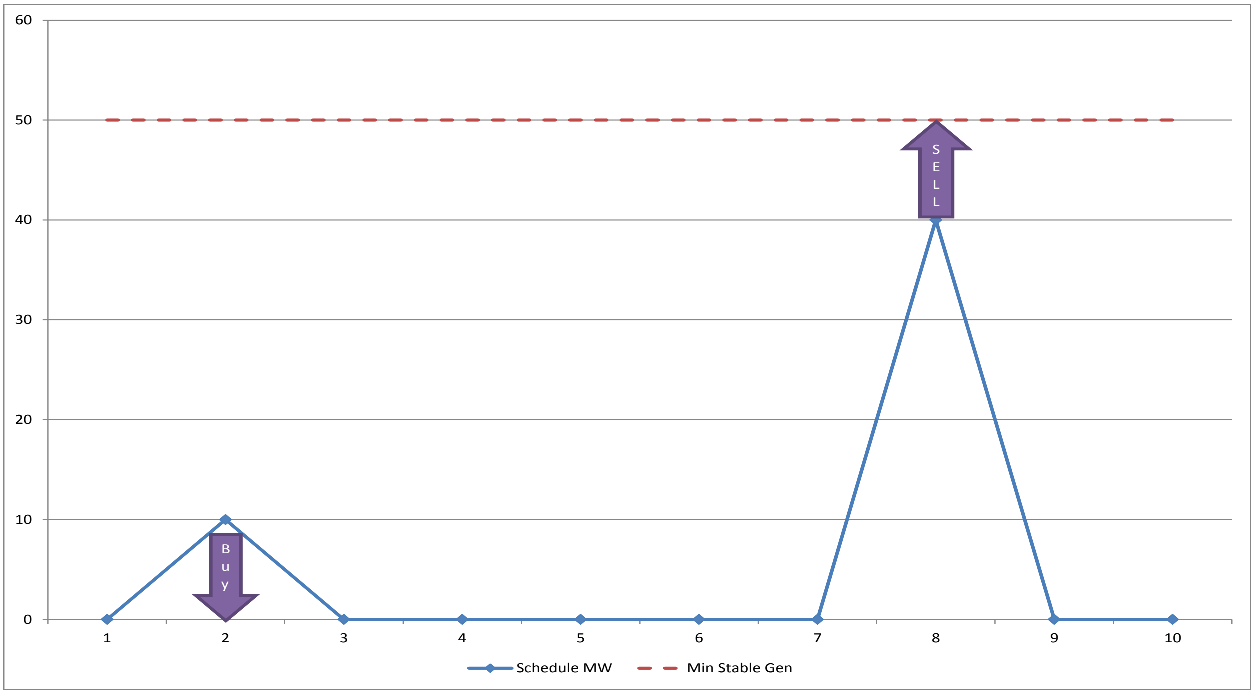

Figure 41: Illustrative example of possible actions to remedy infeasible schedules

The closer the unit's schedule is to zero, the less it will have to buy but the more it would need to sell in order to return to a feasible schedule. Conversely, the closer the unit is to its minimum stable generation, the less energy it will need to sell but the more it would need to buy in order to return to a feasible schedule.

In addition to the size of the action required, the context in which the action is required is important. The majority of instances of a unit being scheduled below their minimum stable generation value occur due to unit ramping, i.e. the unit takes multiple hours to ramp on or off and so is below their minimum stable generation in one of these hours. An example of such a profile is presented in figure 42 below.

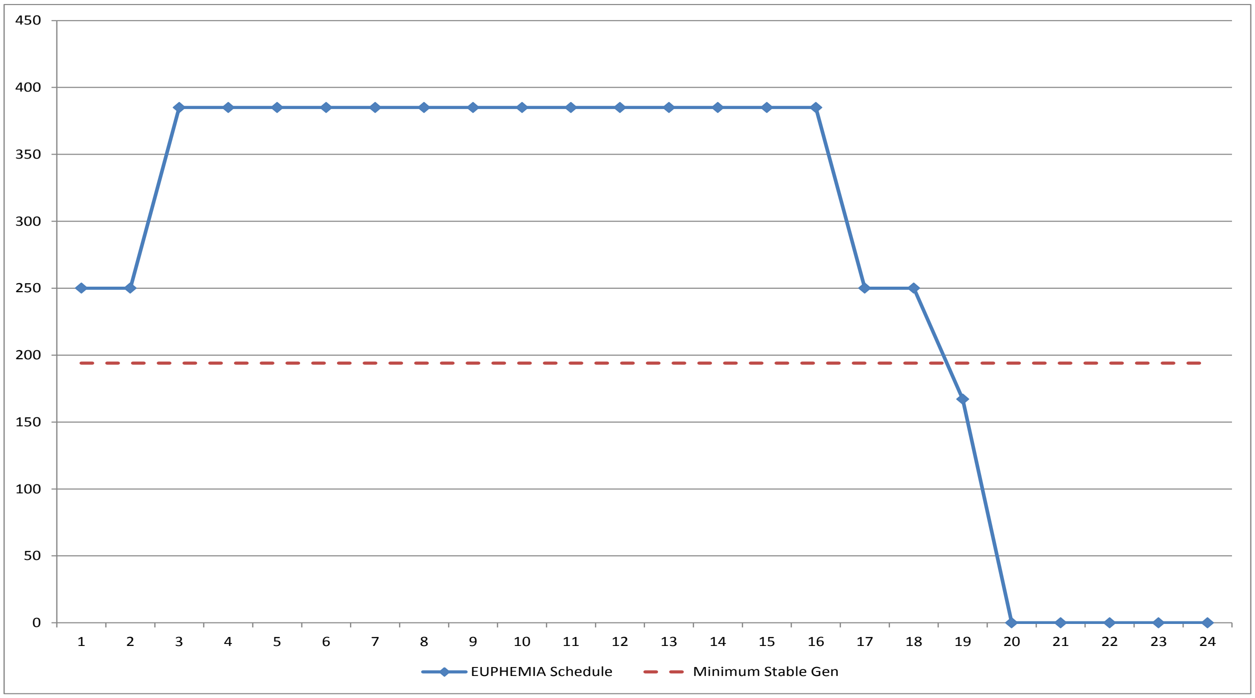

Figure 42: EUPHEMIA schedule for GU_400530 for 03/03/2014

As can be seen in figure 42, the unit requires multiple hours to move from its maximum level to zero and, in hour 19, the unit is scheduled below its minimum stable generation. This is based on the load gradient values submitted to EUPHEMIA which limit how the unit can be scheduled between hours. As the ramping rates submitted to EUPHEMIA are a single average ramp rate, the ramping profile produced is unlikely to be reflective of the actual technical characteristics of the unit[12]. Accordingly, actions will be required by the unit to address the ramping activities and there will be a synergy between the actions to address ramping and actions to address generation below the minimum level.

It is important to note also that minimum stable generation values could be implicitly represented in the complex orders. This could be achieved by having the first quantity as the unit's minimum stable generation with a low price to secure this volume of generation. Subsequent price quantity pairs could then reflect the cost of the minimum stable generation schedule, as well as additional output. This would allow participants to avoid undesired costs which may be incurred for running profiles below minimum stable generation. This approach has been discussed with APX and the Iberian power exchange OMIE.

Such an approach was not adopted in the Initial Phase as all orders were based on the SEM bids of units. In the SEM, the bidding code of practice (BCOP) dictates that a unit's bids reflect short run marginal costs. The BCOP would not allow for a unit to submit orders reflective of the approach suggested by APX and OMIE and so basing complex orders on BCOP bids created risks which may be mitigated through a more flexible use of the complex order type. It is currently unclear whether, or in what form, a BCOP will apply to the I-SEM DAM. This concept will be explored further in the Commercial Phase.

[12] This is also the case in the SEM, where the ramp rates submitted by the unit are averaged by the algorithm into a single value used to produce the unit's profile; however, this ramp rate will only apply between a unit's min stable generation and max availability.

While the majority of instances of generation below the minimum stable value are due to ramping constraints, there are a number of instances of this occurring due to a unit being scheduled below their minimum stable generation in one or many hours with no other related profile in adjacent hours. These instances are elaborated upon in the following section.

6.9.3 UNITS SCHEDULED FOR MULTIPLE STARTS IN A SINGLE DAY

One of the baseline assumptions used in all trials outlined in this document is that for complex orders, the fixed MIC element of their order would cover start-up and no load costs. This was done on the basis that the order would contain 24 no load costs and, if relevant to the unit and day, one start-up cost. In EUPHEMIA, this fixed MIC (along with the variable MIC if applicable) is implemented to give the unit a minimum level of revenue. Where the fixed MIC is reflective of the run profile, and therefore the fixed costs, of the unit, this will help to ensure the unit's costs are recovered.

However, if a unit incurs more than one start in a given trading day that unit will have a MIC value not reflective of their actual fixed costs causing a risk that the unit will under recover their costs. This situation would typically occur where a unit has multiple profiles, one of which is able to satisfy the fixed MIC on its own. As the fixed MIC is satisfied by this profile, other hours would only need to consider the variable MIC (weighted average of price quantity pairs) and additional starts may be incurred for small volumes where the unit provides the last unit of energy in the hour. As EUPHEMIA does not account for start-up costs, once the MIC is satisfied the unit may be scheduled according to the price quantity pairs in any other hours. An example of such a profile is presented in figure 43, below.

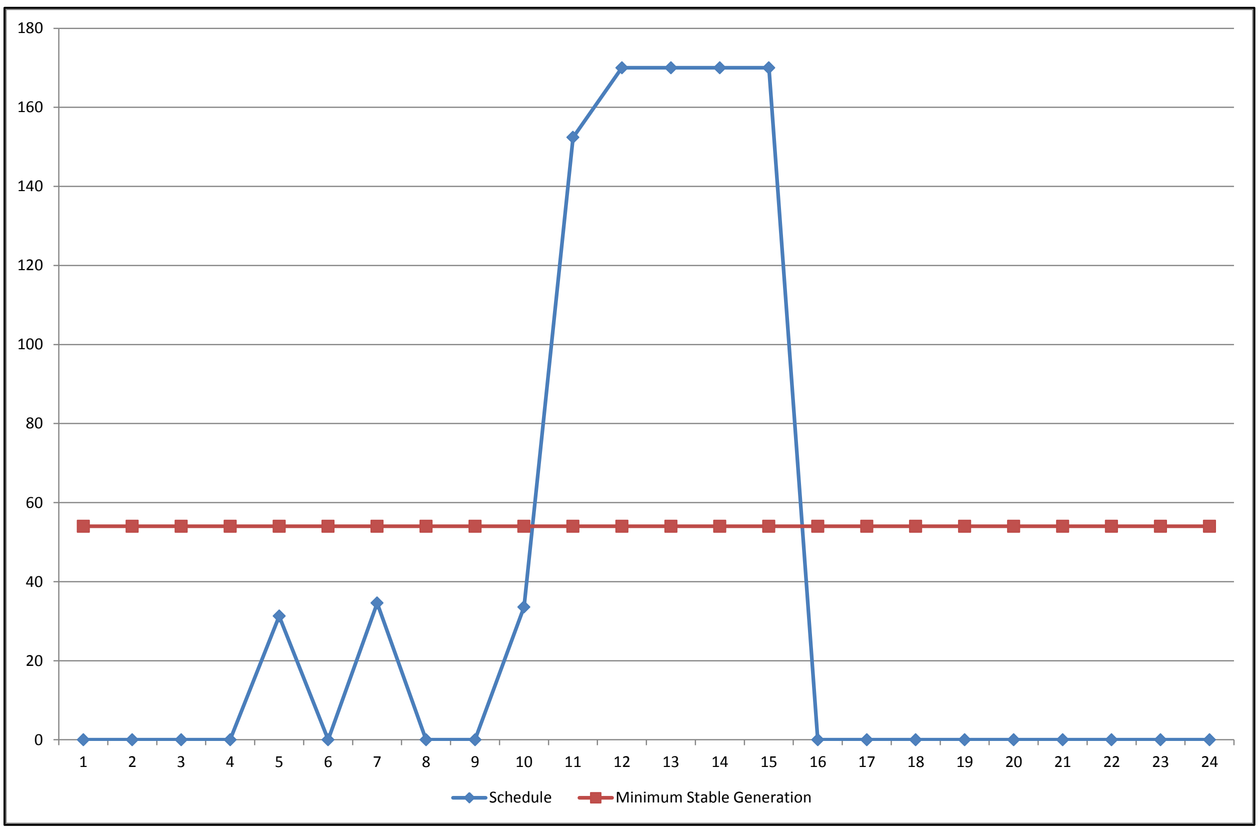

Figure 43: Schedule values of GU_500280 for 03/03/2014

For the unit included in figure 43 (GU_500280), the main profile (hours 9 to 16) is centred on the peak demand and so each hour is at a high price and the unit's fixed MIC is recovered in these hours. As the MIC will be met with the main profile, secondary profiles may be scheduled in hours 5 and 7. In these hours, the unit is marginal in the market and so only recovers variable costs and not the costs of the incurred starts. As EUPHEMIA does not account for starts, these additional costs are ignored and the unit is at a risk of under recovery of costs.

In total in batch one (12 complex order datasets), there were 20 instances of units incurring multiple starts in a single day. The majority of these instances were units using complex orders; however, there were instances of peaker units incurring multiple starts. A peaker unit's simple bid includes the cost of a start and so when a peaker incurs multiple starts it does not bear the same risk as a unit using complex orders. Of the 20 instances of units incurring multiple starts, only 3 instances lead to under recovery of costs in the DAM. The figures from this analysis are presented in table 18, below.

Unit ID	Pump Type	Trade Date	Revenue Received	Production Costs	Revenue Minus Production Costs	Cost Recovery
GU_400850	n/a	03/03/2014	771,928.69	499,218.55	272,710.15	Recovered
GU_500280	n/a	03/03/2014	182,546.60	184,631.23	-2,084.63	Under Recovered
GU_500901	n/a	03/03/2014	4,871.88	3,037.90	1,833.98	Recovered
GU_500902	n/a	03/03/2014	4,871.88	3,037.90	1,833.98	Recovered
GU_500903	n/a	03/03/2014	4,871.88	3,037.90	1,833.98	Recovered
GU_400850	Extended	03/03/2014	711,177.90	499,218.55	211,959.36	Recovered
GU_500280	Extended	03/03/2014	160,276.12	184,818.46	-24,542.34	Under Recovered
GU_400850	Linked	03/03/2014	1,003,451.01	499,380.72	504,070.30	Recovered
GU_400530	Simple	03/03/2014	681,141.30	458,918.88	222,222.42	Recovered
GU_500040	n/a	19/03/2014	580,793.41	479,212.81	101,580.60	Recovered
GU_500280	n/a	19/03/2014	13,907.01	16,330.94	-2,423.93	Under Recovered
GU_500904	n/a	19/03/2014	15,900.14	9,919.99	5,980.15	Recovered
GU_500040	Extended	19/03/2014	887,819.48	477,817.61	410,001.87	Recovered
GU_500904	Extended	19/03/2014	22,503.00	9,372.08	13,130.92	Recovered
GU_500040	Linked	19/03/2014	493,329.93	479,212.81	14,117.12	Recovered
GU_500280	Linked	19/03/2014	192,336.20	186,410.17	5,926.02	Recovered
GU_500904	Linked	19/03/2014	22,503.00	9,372.08	13,130.92	Recovered
GU_500820	n/a	23/03/2014	39,424.99	32,895.75	6,529.24	Recovered
GU_500821	n/a	23/03/2014	39,424.99	32,895.75	6,529.24	Recovered

Table 18: Cost recovery data of units incurring multiple starts in trial batch one

For each of the 20 instances outlined above, the unit risked under recovery due to the MIC being insufficient to cover incurred fixed costs. However, in 17 instances costs were still recovered. This is due to the infra-marginal rent (i.e. the difference between the units marginal cost and the clearing price in an hour) the unit receives in some hours compensating for the additional cost. While these units are profitable in the DAM, their operators could still pursue intraday market actions to increase their I-SEM revenues.

As can be seen in table 18, all of the instances of under recovery of costs were related to GU_500280. In these instances, the unit incurred multiple starts around a main profile as illustrated in figure 41. While the DAM results for this unit under recover the costs, the unit would have opportunities to address this profile in the intraday market by seeking additional revenue knowing that a start cost has been incurred or seeking to buy energy to avoid costs. It is important to consider these later market timeframes in analysis of revenues.

Additionally, as all of the instances of under recovery of cost were related to profiles below the minimum stable generation, the unit could mitigate the risk of this occurring through manipulation of their price quantity pairs as outlined in section 6.9.2. This would help to ensure a minimum level of scheduling and avoid unwanted start-up costs being incurred.

While other market timeframes are available, a unit may also manage this risk in the DAM by adjusting the MIC that they enter in their complex bid. A larger MIC guarantees larger revenue and mitigates the risk of under recovery; however, a larger MIC increases the risk that the unit will not be scheduled. In scheduling complex orders, EUPHEMIA must satisfy the MIC to activate the order. If the MIC cannot be met, the unit will not be scheduled even if its bid price is below the clearing price in one or multiple hours. This is referred to as paradoxical rejection and as the MIC is increased the risk of paradoxical rejection is increased. This principle is illustrated, in a simplified form, in figure 44 below.

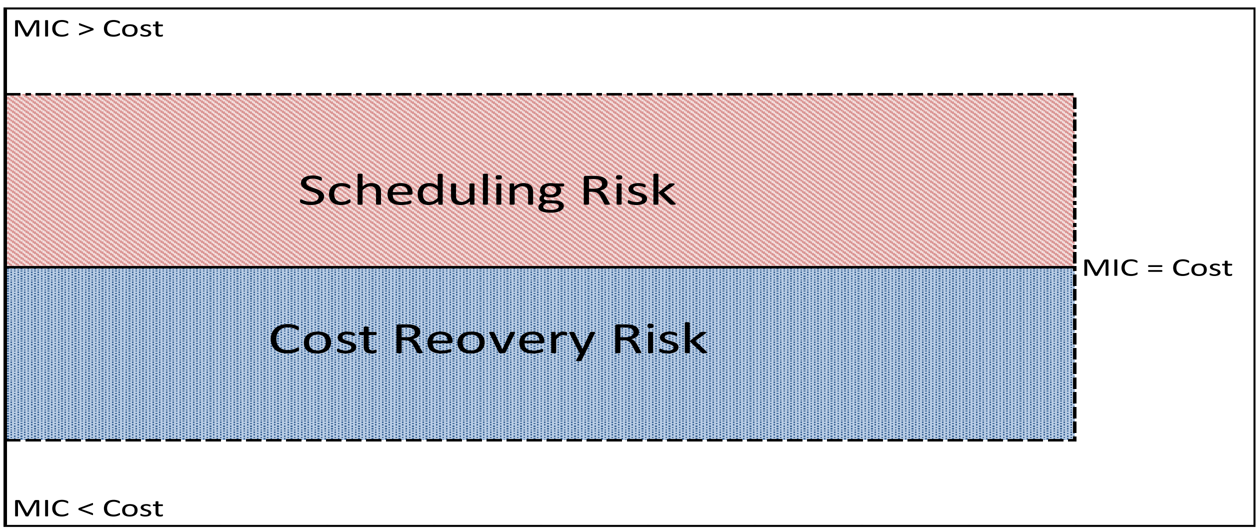

Figure 44: Indicative illustration of high level relationship of MIC value to risk

The additional risk from use of EUPHEMIA, as compared to the SEM, can be managed through informed use of complex orders. Different use of the MIC and price quantity pair values will lead to different levels of risk facing participants. It will be the decision of market participants on how best to manage these risks in the DAM and other market timeframes of the I-SEM and this will depend on how each participant values the different risks as well as any relevant SEMC decisions in respect of Market Power rules.

7 CONCLUSIONS

It should be noted that this report outlines the results and methods of the Initial Phase of the I-SEM EUPHEMIA trials only. As such, any conclusions outlined herein are conclusions based on the first phase of a two phase trial process. Further analysis will be performed in conjunction with industry during the Commercial Phase.

As the Initial Phase was completed by SEMO only, with industry input only on the trial dates used, the assumptions and methods used were developed by SEMO in isolation. The assumptions and methods used will be revised following consultation with the I-SEM EUPHEMIA Working Group and it is expected that these assumptions and methods will be refined as the process progresses. All conclusions outlined in this report are dependent on the assumptions and methods used in arriving at the Initial Phase results.

7.1 LINKED BLOCK AND EXCLUSIVE GROUP ORDERS

As noted in section 6, linked block orders consistently led to issues in terms of price formation and algorithm performance. The primary reasons for these issues were a lack of supplementary orders (i.e. use of orders in isolation leading to too few price makers) and too high a level of complexity being used, respectively.

While the use of linked block and exclusive group orders largely in isolation led to issues, price formation was consistently improved by the inclusion of additional price makers, i.e. the simple order implementation of pumped hydro storage outlined in section 6.4 or the coupled results presented in sections 6.6 and 6.8. In these datasets prices were lower and less erratic than those of trials performed with linked block or exclusive group orders in isolation. This provides evidence that inclusion of additional price makers in the datasets may allow for an implementation with the advantages of blocks in terms of scheduling but with superior price formation than the results seen in sections 6.1 and 6.2.

Additionally, following consultation with the PCR ALWG, it was noted that a reduction to the complexity of the order types would improve algorithm performance. The inclusion of additional price makers would also serve to reduce the complexity of the problem as it would be easier to arrive at a final price. As the level of complexity used was significantly high, as compared to production environments of EUPHEMIA, SEMO is open to exploring less complex implementations of linked block and exclusive group order types.

7.2 COMPLEX ORDERS

In all trials, complex order datasets provided the results most in line with the SEM and with the best algorithm performance. As such, the complex order datasets provided the results which best accounted for the criteria, assumptions and methods of the Initial Phase.

However, as outlined in section 6, the prices of the complex orders were still significantly higher than those of the relevant SEM study runs. This was consistent across all datasets trialled in the Initial Phase. While it is not a goal of the Initial Phase to replicate the results of the SEM in EUPHEMIA, further trialling is required in order to refine the assumptions and methods used for complex order datasets in order to better align the price and schedules produced by EUPHEMIA with expectations based on relevant SEM results. This will include a refinement of the assumptions used to form the MIC elements based on the risks outlined in section 6.9.3.

7.3 AREAS FOR FURTHER STUDY

SEMO has identified a number of areas for further study. These are areas of investigation which either violated the assumptions made at the beginning of the trial or were felt to be dependent on insights outside of SEMO's expertise as market operator. While in some cases assumptions were made to estimate market participant behaviour, SEMO is eager to engage on the work already completed and the below items for further study with industry representatives during future trials.

7.3.1 PRICE MAKING DEMAND

As outlined in section 6, the primary issue encountered in the use of linked block and exclusive group orders is that, as trialled, these units are unable to set the price in EUPHEMIA. Without these units, an insufficient proportion of units in the market are represented as price setters and, therefore, price formation is sub optimal. While exposure to price setters in other markets through interconnection mitigates this issue (as outlined in sections 6.6 and 6.8), this would only be applicable to the point of interconnector constraint. Beyond this point, price formation would still need to come from units in the I-SEM, as outlined in section 6.8.1, and there may be an exposure to volatility if price formation issues are not addressed.

A possible way to create more price makers would be to remove the assumption that, as in the current SEM, all suppliers have fully inelastic demand. In doing this, suppliers would each enter a level at which they do not wish to buy from the day ahead market. This value would, most simply, be input using price quantity pairs as a simple order. It would allow suppliers to enter a range of price quantity pairs which could differ hour to hour. Suppliers could still maintain a portion of their portfolio as a price taker (i.e. accept any price up to price cap) while having another portion below this level (i.e. accept only prices up to a designated price) by having different prices on a stepped curve as shown below.

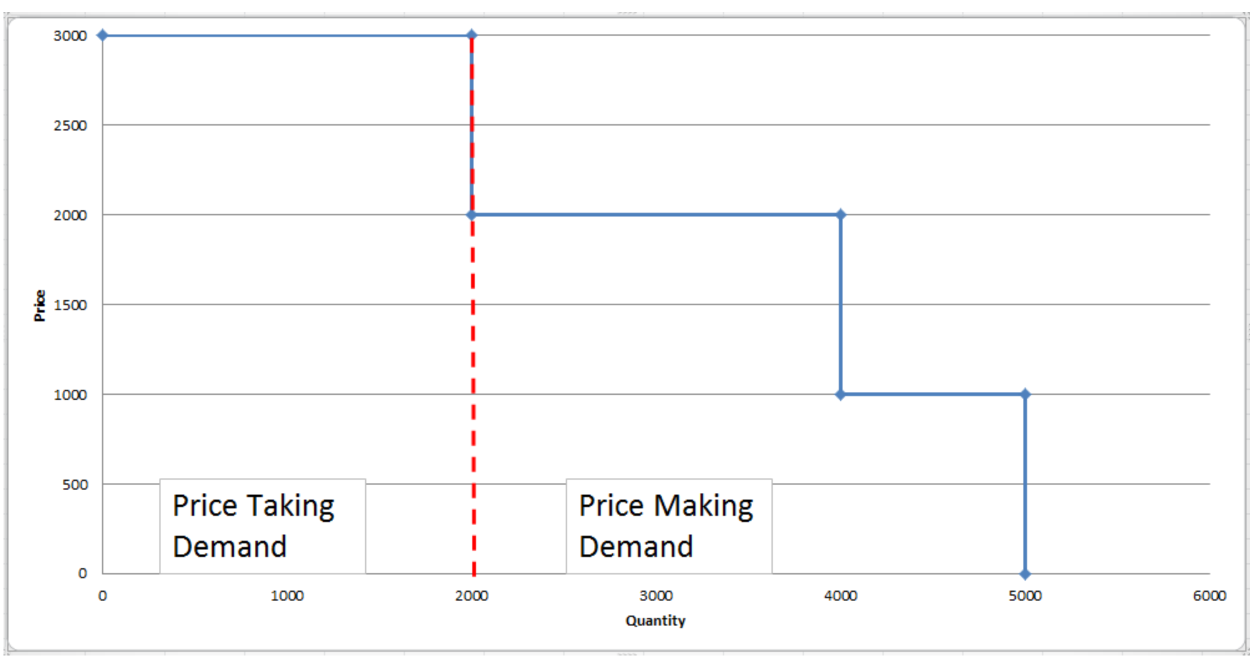

Figure 45: Illustrative example of price making versus price taking demand in single bid curve

SEMO has discussed using such a practice with the PCR ALWG which has confirmed that allowing price making demand would improve price formation, especially in the problematic linked block and exclusive group datasets. This would work in the same way that price formation in these datasets was improved when simple pumped storage was used, as outlined in section 6.4.

SEMO has discussed this item with the I-SEM EUPHEMIA working group and it will be explored in the commercial phase of trials. The main points to be explored in relation to this item are:

- What volume or proportion of demand should be price making?
- What price should be used for demand orders?
- How should suppliers be differentiated in the DAM?

7.3.2 LINKED BLOCK ORDERS AND EXCLUSIVE GROUP ORDERS

As highlighted by the algorithm performance issues, the implementation of linked block and exclusive group orders used in the trials appears too complex to be used in a production environment.

While SEMO would not support an implementation involving linked blocks or exclusive groups as trialled in the initial phase, there are potential benefits to the use of these order formats. As such, SEMO remains open to the possibility of investigating other potential ways of implementing these order formats. SEMO has engaged with the industry working group to explore other possible methods for implementing linked block and exclusive group orders and both will be investigated as part of the commercial phase of trials.

7.3.3 REPRESENTATION OF HYDRO AND PUMPED STORAGE UNITS

As noted in section 6.3, SEMO has investigated various options for the representation of pumped storage and energy limited hydro. These units, while explicitly represented in the SEM, pose a unique issue in representation in EUPHEMIA. Representing pumped storage as a simple order was not further explored due to the fact that it would require significant actions in later markets to manage the fact that reservoir levels are not accounted for by simple orders; however, were further analysis performed on possible implementations, or the assumption about closely representing the SEM relaxed, it may be possible to determine different ways of representing such units. This would be tied to the relaxation of the assumptions around the bidding code of practice, outlined in section 7.3.4 below.

While SEMO remains open to further exploring the use of these units, other refinements to the process represent greater potential benefits as well as new behaviours not seen in the SEM such as those outlined in sections 7.3.1 and 7.3.5 and should be prioritised.

7.3.4 PRINCIPLES OF THE BIDDING CODE OF PRACTICE

It is not currently decided if the I-SEM will maintain a bidding code of practice or other similar market power mitigation measures. Any altering of the bidding code of practice directly affects the way in which market participants are permitted to bid into the market. An assumption of the trialling has been that a bidding code of practice, similar to that of the SEM, is in place. If this assumption were relaxed or removed, it would expand the possibilities for units to submit bids based on desired commercial behaviour and not necessarily on short run marginal costs. SEMO has included the possibility of performing trials not subject to the bidding code of practice as part of the Commercial Phase of these trials.

As outlined in section 6.9.2, application of the BCOP limited the way in which complex orders could be utilised, thereby, affecting the ways in which participants may use these orders to mitigate risks. Relaxation of this assumption may lead to improved results from complex orders.

7.3.5 ADDITIONAL PRICE MAKING GENERATORS

As outlined in section 7.3.1, additional price makers in linked block or exclusive group datasets would lead to superior price formation. Section 7.3.1 discusses adding price makers on the demand side; however, additional price makers could also come from the supply (generation) side. This could be achieved in a number of ways, primarily:

- Wind or other price taker units participate as price makers using simple or complex bids; and/or
- Exploring mixes of simple, linked block and complex orders in a single dataset.

Such options have been discussed with the PCR ALWG who has confirmed that any additional price makers will lead to better price formation. As there is insufficient data on which to base price making bids for price takers, SEMO has deemed this to be out of scope of the Initial Phase but will explore this further in the Commercial Phase. Additionally, SEMO will further investigate datasets using multiple order types to assess the effects of this on price, schedule and algorithm performance.

Both of these methods above have been discussed with the I-SEM EUPHEMIA working group and a number of potential solutions have been identified. These will be explored in the Commercial Phase of these trials.

7.3.6 REFINEMENT OF COMPLEX ORDERS

As trialled, complex orders necessarily make assumptions about the running of the unit in order to calculate fixed cost variables, e.g. assumption that the unit will incur one start. The output of EUPHEMIA may result in a schedule for the unit which does not incur the same costs, e.g. the unit is scheduled for two starts. As outlined in section 6.9.3, this leads to a risk that costs will be under recovered as the minimum income level changes depending on the schedule of the unit but this is not reflected by the algorithm. As outlined in section 6.9.2, a different approach to use of price quantity pairs in complex orders would help participants to mitigate the risk encountered in the trial. This would be linked to the use of the BCOP and may also require relaxation of this assumption in future trials. SEMO will further engage with the I-SEM EUPHEMIA working group in order to explore ways that this risk may be managed by adjusting the inputs to EUPHEMIA.

8 NEXT STEPS

While this report concludes the Initial Phase of these trials, SEMO has been engaging with the I-SEM EUPHEMIA working group since April 2015 in order to co-ordinate the Commercial Phase. This Commercial Phase will involve further trialling of EUPHEMIA with trials being performed by SEMO in conjunction with the I-SEM EUPHEMIA Working Group.

The process for the Commercial Phase will be reflective of the feedback received from the working group and will investigate the items outlined in section 7.3. It is SEMO's intention that the Commercial Phase will continue to elaborate on the results presented herein and contribute to the further understanding of EUPHEMIA of industry, SEMO and any relevant stakeholders.