Solver Choice in the SEM:
A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming

Contents

1 Executive Summary

The SEM is the wholesale electricity market covering the island of Ireland and has been operational since November 1st 2007. The market was designed as a centrally dispatched Gross Mandatory Pool model with a single System Marginal. Because the design is centrally dispatched, this requires the use of Unit Commitment software which must optimise the available generation portfolio to achieve the best economic dispatch of generators, working with the objective of minimising generator production costs in the market.

To solve unit commitment problems in power systems and markets, sophisticated mathematical optimisation software is used to determine the least cost production schedule. This software is largely seen as "black box" technology where commercial and technical data of participating generators is input and market schedules and prices are output. There are many optimisation techniques available; however, because of the non-convex nature of the unit commitment problem, more sophisticated methods are required.

Optimisation science was developed during the 1940s and 1950s using Linear Programming to solve convex problems but this could not be easily applied to unit commitment problems. The Lagrangian Relaxation (LR) method, which is now commonly applied to unit commitment problems, was first successfully developed in 1970. This has become the most commonly used technique for unit commitment in electricity markets around the world. Mixed Integer Programming (MIP) was also developed around this time but, due to computational requirements of this approach, its application was largely limited to academic circles. It has only been in the last ten years that improvements in computer processing power and memory have meant that MIP has become viable for use in commercial markets.

During the development of the Central Market Systems for use in the SEM, the MSP software was designed with the option of using either an LR or MIP solver. At that time, because LR was still considered the most reliable commercial standard solver this was selected for use in the SEM; however, the MIP solver was also included and retained for use as a back up.

On a number of occasions during the first months of the SEM, due to issues with the outputs of the LR solver, SEMO made use of the back up solver for determining the Market Schedules and System Marginal Prices. Participants were made aware of SEMO's limited use of the MIP solver when it was discussed during presentations in relation to the Dual Rated modification (Mod 34_08). After this, SEMO hosted a MOST (Market Operator Single Topic meeting) in August 2008. The purpose of this was to explain to Participants the high-level workings of the solvers and the process adopted by SEMO around the use of MIP in the SEM.

SEMO undertook to complete a comparative study of the two solvers. This report represents the results of that study. The intent of this study is to provide comparative analysis to Participants in the SEM and the Regulatory Authorities. It is hoped that this would provide assurance to Participants with regard to the issue of solver choice in the SEM and may inform future decisions and developments in this area.

A total of 154 Ex-Post Initial study cases and 16 Ex-Ante study cases were completed for this study. In each case, the original base case from SEM operations was used as a starting point but to ensure consistency of comparison, the latest version of the software was used. This means that the study cases completed with the LR program used later versions than that used in SEM operations and reviewers may note that the LR solutions used in this study differ from historical data published in the SEM.

Timeout settings were used on the MIP program where its execution would be terminated after five minutes, ten minutes and thirty minutes as appropriate.

We published a scope document[1] detailing the proposed areas for review which consisted of

[1] http://www.sem-o.com/Publications/General/MIP%20v%20LR%20-%20Scope%20-%20DRAFT%207.pdf

- MSP Production Costs,
- System Marginal Price,
- Revenue (Generator revenue and Consumer Costs),
- Scheduling of Energy Limited Generators (Hydro stations),
- Unit commitment relative to fuel and station technology type, and
- Constraint Payments.

During the course of the study, we extended the scope to cover

- Timeout settings of the MIP solver, and
- Internal software parameters.

A key observation, which is apparent, not just from the studies we completed but also from academic literature that we reviewed, is that using MIP does not provide a global optimal solution to the SEM. This is because the use of timeout settings and a convergence tolerance will always steer the MIP solver to terminate after a given parameter has been achieved (either the time or the MIP gap) thus leading to premature convergence. As a result, we must be clear that we are always comparing sub-optimal solutions.

We noted that the MIP solver produced good solutions and, in over 83% of study cases, the MSP Production Costs were observed to be lower than in the results from the LR. A key observation when reviewing the changes in the unit commitment outputs was the increased use of Energy Limited or Hydro stations. Using the MIP solver, we observed that full Energy Limits were more frequently used with significantly higher quantities of their Energy Limit being scheduled whereas this was not the case with respect to the LR results. Other fuel and station technology types did not appear to be impacted by the solver choice.

When we reviewed System Marginal Prices and Consumer Costs, we noted that the MIP solver produced higher results in over 57% of cases. This was despite an observed reduction in peak prices. Constraint Costs were also observed to increase in our study cases; however, as the Dispatch Production Cost is a static value across all studies, when one solver reduces the MSP Production Cost this will lead to increases of this nature.

Detailed observations can roughly be summed up as follows -

- Using MIP over LR will more frequently lead to reduced MSP Production Costs;
- Using MIP over LR has been observed to make better use of Energy Limited Generators;
- Using MIP with the five minute timeout setting provides best return;
- MIP schedules more frequently produced higher System Marginal Prices;
- MIP schedules more frequently produced higher Consumer Costs;
- MIP schedules more frequently produced higher Constraint Costs;

Taking account that the objective of the MSP software is to minimise the aggregate MSP Production Costs across the Optimisation Time Horizon, this would mean that the MIP solver appears to better implement the requirements of the Trading & Settlement Code; however, consideration should be given to our observations with regard to increasing Consumer Costs. The mathematical function does not refer to the calculation of System Marginal Price, which is completed by separate phases of the MSP software. Therefore, minimising the MSP Production Costs by producing a more efficient unit commitment will not directly affect the calculation of the System Marginal Price and the ensuing Consumer Costs. As such, we cannot state that the MIP solver will increase the System Marginal Price but we observe that, in our study cases that it did.

However, it needs to be recognised that because of the nature of optimisation science, it cannot be guaranteed that one solver will always perform better than the other will.

We should also highlight the key finding that the LR solutions are very good relative to the sub-optimal solutions found using MIP with the current timeout and convergence tolerance settings.

2 Study Overview

2.1 Introduction

The SEM was developed as an all-island market for electricity for the island of Ireland. The design is of a centrally dispatched Gross Mandatory Pool model with a single System Marginal Price paid and charged to all Participants in the SEM. Central Unit Commitment is a key component of the design. This means that the market must optimise the available generation portfolio to achieve the best economic dispatch of generators, working with the objective of minimising generator production costs in the market. The implementation of this in the Central Market Systems is with a three-stage process in the Market Scheduling and Pricing (MSP) software –

- Unit Commitment,
- Economic Dispatch, and
- Price Calculation.

To solve unit commitment problems in power systems and markets, sophisticated mathematical optimisation software is used to determine the least cost production schedule. This software is largely seen as “black box” technology where commercial and technical data of participanting generators is input and market schedules and prices are output. There are many optimisation techniques available; however, because of the non-convex nature of the unit commitment problem (that is, the inclusion of not just the linear programming problem of solving the market based on generator output and commercial/technical data, but also the integer decision of turning a generator on or off), more sophisticated methods are required.

Lagrangian Relaxation (or LR) has been most commonly used in electricity markets for a number of years. In Lagrangian Relaxation, the primal problem (schedule generation to minimise production costs subject to some constraints) is split into a number of smaller sub-problems. Each sub-problem is solved separately with Lagrangian multipliers applied to relax the constraints. Because of the nature of how LR works, it is well understood that it will generally produce sub-optimal solutions and not produce a global optimal solution. As a result, it is widely understood that there are likely better solutions available than the outcomes achieved using an LR solver. However, this technology is still used as a practical solver for market operations.

For a long time, an alternative method called Mixed Integer Programming (or MIP) was considered in academia to be a better optimisation model but the processing and time requirements to solve a problem using MIP were prohibitive and made this impractical for use in real-world scenarios. Recent innovations in CPU technology and improvements in the MIP algorithm (Bixby, Fenelon, Gu, Rothberg, Wunderling, 1999) have meant that it is now possible to use MIP based software for market and real time operations. PJM[2] in the USA, in partnership with AREVA, have developed a MIP solution for market operations and unit commitment, which has been in commercial use since 2005. CAISO is using a MIP solution in their new market since April 2009. EirGrid and SONI TSOs operate a MIP unit commitment engine to determine operating schedules on the island of Ireland.

During the implementation of the SEM, it was decided that LR based optimisation would be employed as the primary solver for unit commitment in the market. This was largely because LR techniques were considered proven and, outside of the work that was being done by PJM, no electricity market in the world was using MIP for central unit commitment problems. However, as part of the delivery of market systems prior to the start of the SEM, the Central Market Systems vendor provided a software solution that could utilise two commercial standard market solvers. One of these is proprietary software developed

[2] Pennsylvania-New Jersey-Maryland Interconnection.

by ABB which solves the market using Lagrangian Relaxation. The other solver is the CPLEX implementation which uses Mixed Integer Programming. Having selected the LR option as the primary solver for the SEM, the MIP solver was retained for back-up purposes for use in the event of infeasible LR solutions and other unforseen events.

Lagrangian-Relaxation (LR) is used in the SEM as the default solver to solve unit commitment. MIP has been run if certain predefined events occur, and only published if certain predefined criteria are met, namely around extreme price events driven by established bidding patterns. Details of these requirements are set out in the document "MIP_policy_V4 0 - Use of MIP for Determination of Market Schedules", available here[3] from the SEMO website. At present, it is not practical to run both solvers and compare results for each run given the current market deadlines and system and resource constraints.

The limited use of the MIP solver in study cases was openly discussed with Participants during presentations in relation to the Dual Rated modification (Mod 34_08). In response to suggestions from the Regulatory Authorities, and to provide greater assurance to Participants, SEMO hosted a Market Operator Single Topic (MOST) meeting in August 2008. During this session, presentations were given to explain the high-level workings of the solvers and the process adopted by SEMO for the use of MIP. This covered how SEMO would assess whether a schedule should be reviewed with the MIP solver and if the publication of a solution from the MIP solver was warranted. To provide further transparency to Participants, SEMO agreed to include in its Monthly Market Operator Report a listing of all Ex-Pos Initial MSP runs where the MIP solution had been published. Market Messages are also published to the SMEO website when the published schedule has been determined using the MIP solver.

At that time, SEMO also undertook to complete a comparative study of the two solvers.[4] The intent of this study is to provide comparative analysis to industry Participants and the Regulatory Authorities. It is hoped that this would provide assurance to Participants with regard to the issue of solver choice in the SEM.

The intention of this study is to provide observations on the merits of each solver and recommendations to the SEM as appropriate. It is hoped that this will provide an informed background to any consultation process with regard to changing the default solver in the SEM.

2.2 Background

In total, we examined 154 Trading Days based on Ex-Post Initial data and a further 16 Trading Days based on Ex-Ante data.

All study cases days were completed using the 1.4.11 version[5] of the MSP software. The MIP software used was CPLEX 10.0

The MIP implementation includes two operator configurable settings which are a time limit and a convergence tolerance, called the MIP Gap. We choose to set the time limit to five minutes. Where this did not achieve a solution within the MIP Gap, the study case would be re-run with the time limit set to ten minutes. Where this did not achieve a solution within the MIP Gap, the study case would be re-run with the time limit set to thirty minutes. We elected not to run the MIP solver for longer periods than this as there would be no practical application of a solution determined in this way.

As we will observe, only a subset of the Trading Days had to be run with the longer time limits. In total, we completed 576 individual study cases. Considering that each study case produces a set of MSP Production Costs, Market Schedule Quantities, System Marginal Prices, Shadow Prices, as well as the further values calculated from these such as Energy Payments, Constraint Payments, Consumer Costs, this resulted in the analysis of over 8.5 million individual pieces of data.

In general, study cases were completed with the market conditions that existed on the original Trading Day. The intention of this is to come up with a measure of the consequences of the solver choice on the market outcomes. A limited number of further runs were completed for the following issues:

- Altering LR ALTCOM parameters ,

[3] http://www.sem-o.com/market_publications/image.aspx?id=063edd35-221d-45b5-8632-dca2d8c0ff2b

[4] It was originally planned that this study might take place in Q4 2008 and Q1 2009. However, issues discovered with the MSP Demand meant a change in priority for the SEMO, which was to analyse the MSP Demand issue and provide details of this analysis to Participants.

[5] This means that previous published market schedules were not included in this study. As each run of the LR program was completed with a new version of the software, this will likely give rise to different results than those originally observed in actual market operations.

- Running consecutive Trading Days in blocks,
- Altering MIP Optimality Gap, and
- Amending commercial offer data for Hydro generators.

The inputs and outputs of each run of the MSP software were exported as CSV files for analysis. Most of the initial work was completed using Microsoft Access. After considerable number crunching had been completed using these tools, data was exported to Microsoft Excel. At this point, averages, trends and other points of interest were reviewed and data was further refined for inclusion in this report.

Our analysis takes the form of observing general trends in the solutions by reviewing averages, totals and standard deviations. When trying to measure the results from one solver to the next, we have done frequency analysis of these results to make observations and draw conclusions where appropriate.

In the final report, we have broken our analysis into the following areas –

- A comparison of the MIP timeout settings;
- Productions costs;
- Consumer Costs and Generator Revenues;
- System Marginal Prices;
- Commitment of generators;
- Scheduling of Energy Limited Generators;
- Constraint Payments; and
- MSP Software internal parameters.

Each of these is presented as a separate section that can be reviewed in isolation. Each section is made up of an introduction to summarise why this specific area was focused on, an Executive Summary, a background section to provide further detail on the issue and the analysis approach, a review of the findings of the analysis and final conclusions. Appendices for the report are maintained separately.

While each section can be reviewed in isolation, there is overlap between them. This Summary Overview section intends to provide an encompassing review of the findings.

2.3 Results and Review

The Unit Commitment problem is solved using complex optimisation software. In principle, the software takes the technical and commercial offer data for each generator in the SEM and uses this to determine a set of MSP Production Costs for feasible solutions. Considering the number of generators in the market and the number of pieces of input data, this produces a vast number of candidate solutions. The job of the optimisation software is to find the lowest cost feasible solution. This is done by stepping through a search space and testing the quality of each solution. Because of the non-convex nature of commercial offer data used in the SEM, this can lead to a search space where there may be several local minimum solutions. This is known as a multi-modal search space.

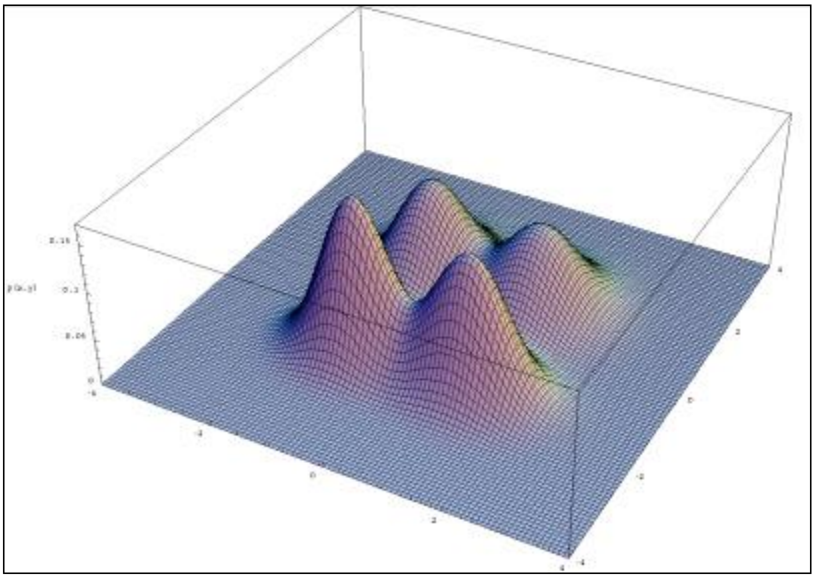

Figure 1 - Example of a multimodal search space

Some bidding patterns also add further complexity to the search space where they cause the area to become rugged; that is, the gradients in the search space become steeper and it becomes more difficult for the optimisation engine to find the best optimum solution. This was previously discussed at the SEMO MOST on the Lagrangian Relaxation and Mixed Integer Programming Solvers, held in August 2008.

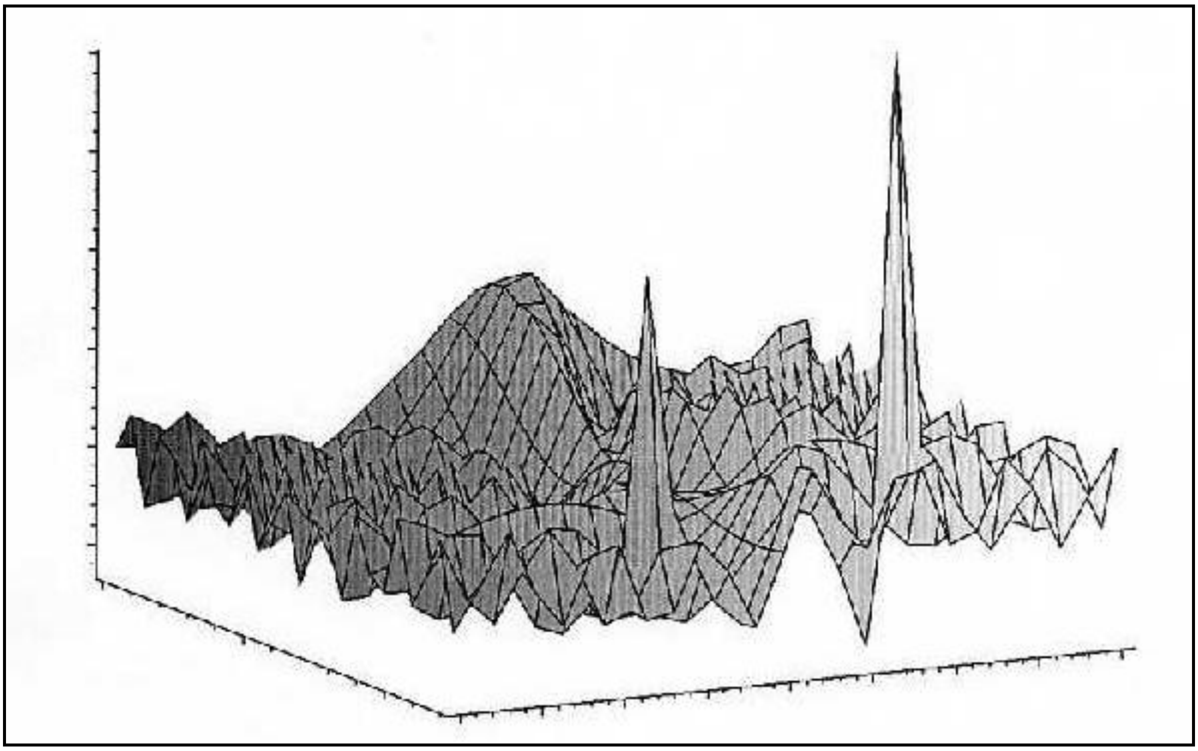

Figure 2 - Multimodal search space displaying ruggedness

These elements have led to premature convergence when using the LR program when the solvers produce solutions that are sub-optimal, based on selection of a local optimal and not the global optimal solution.

As we noted above, because of the nature of how LR works, it is widely understood that the solutions produced will most probably be sub-optimal solutions and this approach is not likely to produce a global optimal solution. The MIP method is considered a way to achieve a global optimal solution. However, this is only the case when MIP is run to complete convergence, which is not the case in the SEM or energy markets in general.

The MIP solver has a number of distinct phases. First of these is to solve a relaxed version of the problem. This is completed to get the lower bound on the overall solution. The Optimality Gap is calculated as the percentage variance between the best current solution and the best lower bound from this phase. The program then enters the Branch and Bound phases where it eliminates regions of the search space where the optimal solution cannot be found. This method will solve any problem to a global optimal solution but not in time limits that are practical for market operations.

The practice of applying timeout settings and convergence tolerances (or Optimality Gap limits) to MIP algorithms is quite common and is used in the SEM[6] as well as PJM (Streiffret, Philbrick, Ott, 2005). This is because, despite the improvments in MIP performance over recent years, allowing the solver to seach for a true global optimal solution is still not practical for real time operations of either markets or systems (Sioshansi, 2008). As a result, while we have a measure of how close the MIP solution is to the lower bound, and can therefore estimate how close the solution is to the true global optimal, at no point does the MIP solver produce a global optimal solution.

Therefore, we have to be keenly aware that in comparing the outputs of LR to the outputs of MIP, we are comparing two sub-optimal solutions. Both are imperfect and here we attempt to measure the quality of the solutions based on this fact.

One of our first reviews was with regard to the different timeout settings that could be used with the MIP solver. Of the 154 study cases completed based on the Ex-Post Initial days, over 100 solved to within the convergence tolerance within the five minute setting. As a result, only a third of cases needed to be completed with extended timeout limits. Of these, we noted that only 50% ever solved to within the

[6] This is done through a configurable parameter, the MIP Gap.

convergence tolerance and to achieve that, most had to be run for thirty minutes. We observed that the best improvements in terms of convergence was from a five minute run which stopped with a MIP gap of 1.56% which improved to 0.21% when run with the thirty minute setting; however, the solver took over 16 minutes to reach this solution. The quickest resolution when set at the thirty minute level was in just over eleven minutes. The average solution time of runs that achieved the convergence tolerance was 20.33 minutes.

We observed little extra value in the ten minute setting as only six out of the study cases that did not solve with the five minute setting achieved the convergence tolerance within ten minutes.

This thirty minute timeout setting was largely used for demonstration purposes only to see if the MIP solver could produce better results with the addition of more time. It was never a consideration that running the solver for thirty minutes would be practical in terms of daily market operations. Taking account of the tight timescales under which the SEM currently operates and that the LR solution currently in use produces solutions within one minute, this would represent a significant change to operational processes if these timings were to be considered.

In general, we noted that the longer running time improved the solutions, with MSP Production Costs specifically being reduced in almost all cases[7]. We also noted System Marginal Prices and Consumer Costs appeared to reduce with the longer runs but by less significant amounts than the MSP Production Cost improvement. Constraint Costs were largely unaffected in this question.

We took the findings and tried to see if there was a quality measure we could apply to the solutions. We approached this as taking the MSP Production Costs, Optimality Gap and solution time as the primary measures being as they are tied to the obligations SEMO must meet. Using the values returned from the study runs, we derived a "Solution Value"[8]. We then completed a frequency analysis of this "Solution Value" shown below.

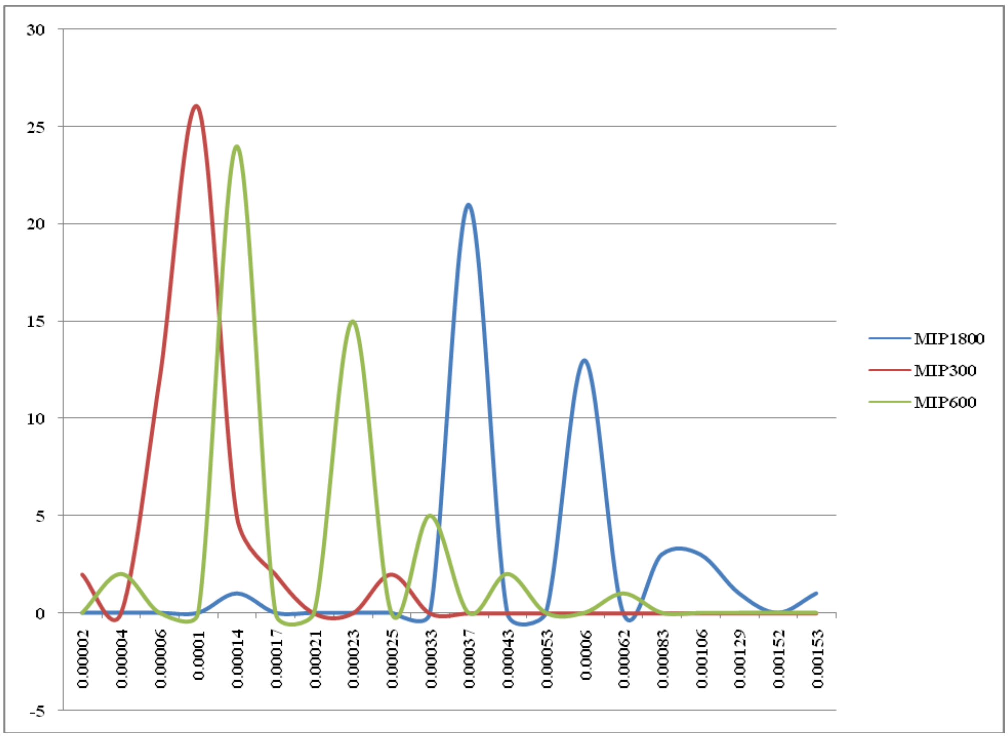

Figure 3 - Solution value.

The graph above shows that taking these three key inputs the MIP300 appears to have the best value for operations in the SEM. We draw the conclusion and make the recommendation that for future SEM operations where the MIP solver is run that it is run using the 300 second timeout only.

We also adopted this for the broader study on the comparison between the MIP and LR solvers and, for

[7] In general, the longer run time will result in a better solution. However, this is not always true especially when the MIP engine is stopped by the time limit. In this situation, the solution may vary at different runs depending on the CPU loading at each specific run. Also, the final polishing step of the algorithm may give a slightly different solution depending on the position of the best available solution in the entire search tree.

[8] This was calculated by taking the solution time in minutes, dividing by the Production Costs, and then again by the Optimality Gap.

the other areas of interest covered in this report, we exclusively use the results of the MIP300 runs for these comparisons.

With respect to MSP Production Costs, the results observed were very interesting. While the MIP solver performed better than the LR solver in most study cases, the quality of the solutions from the LR solver appeared to be quite high. MIP produced schedules with cheaper MSP Production Costs in over 83% of the study cases, while the LR solutions were better in the remaining. Of note, in just over 42% of the study cases where the LR solver performed better, the MIP solver had achieved its convergence tolerance. While recognising the improvement with the MIP solver, it is worth noting how close the LR solutions were. In 46.1% of study cases, there was a variance of +/-0.5% between the two solutions. In 82.46% of cases, the variance between the two was +/-1%. In two study cases, the variance between the LR and MIP solvers was 0.008%. In the cases where the MIP solver performed better than the LR, the average improvement on MSP Production Costs was only 0.59%. In only 16 of the study cases did MIP improve on the LR solution by more than 1%. Equally, when LR performed better, the average improvement was 0.88% with only 11 out of 26 study cases showing variances of more than 1%.

This shows that when dealing with sub-optimal solutions from both solvers, although the MIP solution is more frequently providing lower production cost results, the solutions from the LR solver are very good in terms of the overall objective function of minimising MSP Production Costs in the SEM

From the findings, we conclude that although MIP produces solutions with lower MSP Production Costs, the improvement over those observed using the LR solver is not as significant as many people may have previously been considered. On the evidence of this study, the MIP solver generally finds better sub-optimal solutions.

This would therefore deliver the obligation of the SEM rules, to minimise the aggregate MSP Production Costs, more consistently and efficiently than the LR solver. However, the analysis also indicates that should the SEM continue with the LR solver, the quality of the solutions is very high and comparable to those from the MIP solver.

We did also note that small improvements in the Production Cost can lead to large changes in the overall SEM outcomes with significant changes to Consumer Costs being observed. Some attention is given to a study case where although the MSP Production Costs in the two solutions are within 0.008%, the variance in Consumer Costs is quite significant with costs being 11.34% higher in the outcomes of the MIP solution.

As the optimisation programs seek only to minimise MSP Production Costs, their behaviour when it comes to other issues is provided here as observations. It is not possible for us to state categorically that the use of one solver over the other will have these impacts; however, we can observe in our studies that they did. One of the principal impacts is the overall increase in System Marginal Price that we noted with the results of the MIP solver over the LR. While we should have no expectations one way or another, it could be thought that by producing a lower Production Cost the MIP solver should produce commitment decisions that result in generators from lower in the merit order being used. However, in terms of commitment decisions, we have noted that the two solvers do not vary greatly in terms of how they commit generators except that the MIP solver will commit more generators than the LR solver. As noted above, LR decomposes the problem into sub-problems to solve. In effect, the LR solver breaks the market problem down to a unit problem and solves each unit separately. Because of this, we have noted a tendency with LR solutions to be blockier with how units are scheduled; that is, the final schedules from an LR study case are more likely to be at Min Stable Generation or Max Availability. As such, the LR solver commits just enough generators to meet the System Load in this manner. The MIP solver appears to commit more generators and, in doing so, allows the Economic Dispatch phase of the problem more freedom to schedule megawatt output in a more economical way. This extra generation, while still minimising MSP Production Costs better, does affect Consumer Costs.

The most notable exception in terms of commitment decisions is with respect to Energy Limited Generator Units. This generator type, which represents the Hydro generators in the SEM, does not appear to be committed as efficiently in the LR solver. We noted in all study cases improved scheduling of Hydro generators when using MIP. Daily Hydro limits were more frequently better used in the outcomes of the MIP solver. The improvements in Hydro scheduling appear to have knock on affects in all other areas, such as in terms of the number of generators committed. By making better use of the Hydro generators, MIP does not de-commit other generator units in the same schedule and will largely keep a similar portfolio of other generation committed as the LR solver. We also note that increased used of Hydro generators has led to these generators being marginal more frequently in the MIP results. This is in turn contributing to the increase in System Marginal Price, noted to be a result of how the Shadow Price is calculated in these circumstances.

We have also observed that LR solver has a tendency to commit a single generator unit for one Trading Period to meet a portion of the Schedule Demand when MIP will commit a combination of units. One affect of this is a larger volume of Uplift in the LR runs. However, because MIP schedules more generators especially Energy Limited generators, the overall Shadow Price in the MIP runs tends to be higher than with the LR.

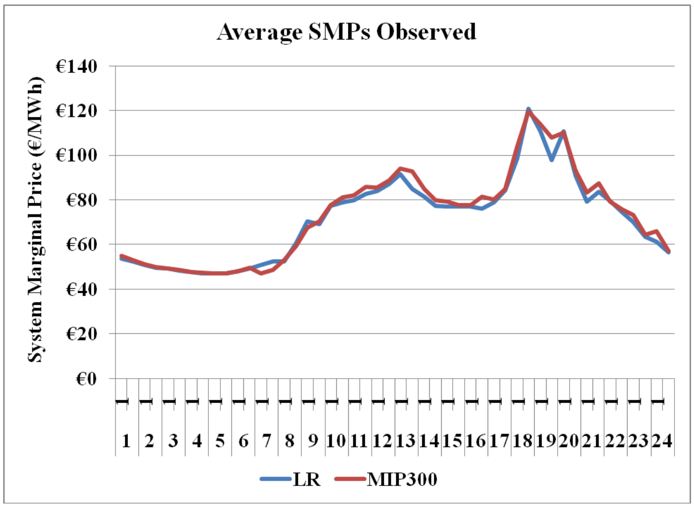

Figure 4 - Average SMP, Trading Period

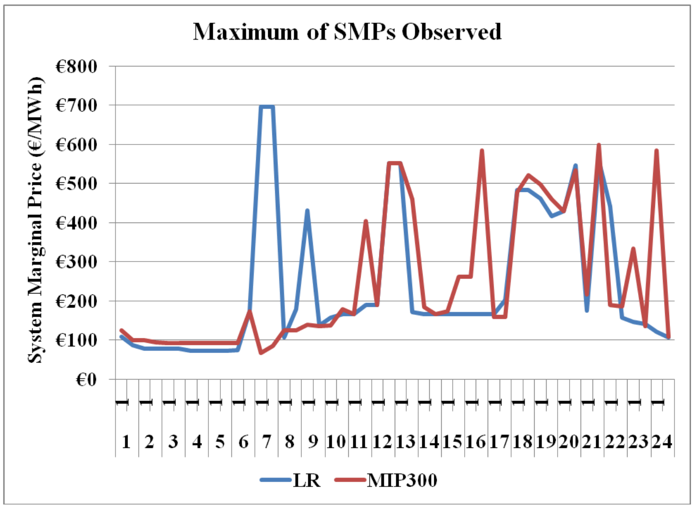

Figure 5 - Maximum SMP, Trading Period

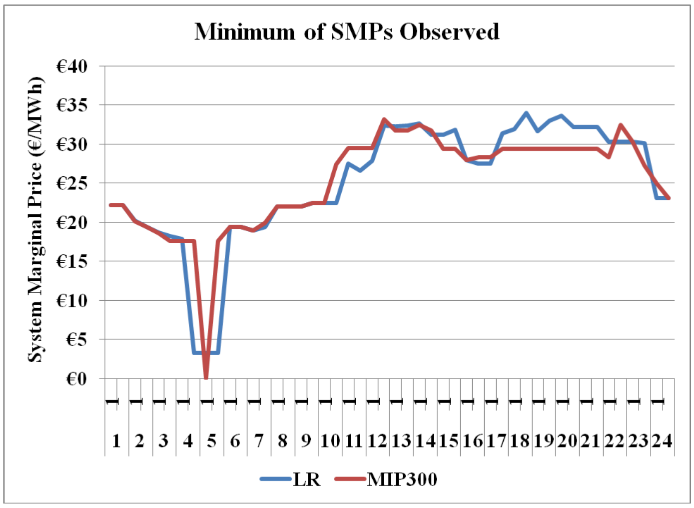

Figure 6 - Minimum SMP, Trading Period

This in turn has led to more incidents of higher System Marginal Prices, and therefore Consumer Costs, in the outcomes of the MIP solver. We found that the average daily System Marginal Price increased in 57% of our study cases when reviewing the results of the MIP cases. Peak prices did reduce with a decrease of 53% in the daily maximum System Marginal Price. Uplift also appeared reduced when using the MIP solver. This aligns with the patterns observed in terms of commitment where we noted that the LR solver is more likely to incur start ups and their respective costs than the MIP solver. This appears to relate to an observed behaviour of the MIP solver where generators once started are kept on for longer periods of operation. This longer period of operation makes it more likely for the generator to recover its costs at Shadow Price rather than needing Uplift when they are shut down after shorter periods, a behaviour noted in the solutions from the LR solver.

Interesting, we observed a study case where the MIP solution, which was within the convergence tolerance, included three Shadow Prices where the price was set by the Dual Rated generator in the SEM using its oil bid step while the LR solution, though with higher Production Costs, did not have the same impact. This study case had one of the most significant variances in Consumer Costs between the two solvers where the MIP solution was 31.79% more expensive than the LR.

While it may be considered that the reduction in Uplift, incidents of Peak Prices and lower daily Maximum System Marginal Prices in the outputs of the MIP solver should mean that this would produce cheaper prices, this is not the case as the daily Average shows. It can also be noted that the daily Minimum System Marginal Prices in the results of the LR solver were more frequently lower than those observed when using MIP. This means that while reducing Peak Prices and Uplift, the Shadow Prices in the MIP solutions are generally higher than those in LR.

These changes are leading to follow on changes in the Consumer Costs of the SEM. We have observed that Consumer Costs are increasing in 57% of the study cases with an average increase of €500,000 per Trading Day. The increase in Consumer Costs also means that revenue for suppliers and generators in the SEM is also impacted. The studies completed show generator revenues increasing by around 2.5% in the solutions from the MIP solver. Though not explicitly reviewed, because the SEM is a balanced market by design, this means that supplier charges will increase by approximately the same amount. This will in turn impact on the Credit Cover requirements on Participants in the SEM.

There is no observed relationship between the Consumer Costs and other key components of this study, particularly the MSP Production Costs and the Optimality Gap in MIP. The largest single percentage increase in Consumer Costs did align with an instance where the MIP solver failed to solve to within its convergence tolerance. However, other similar instances did not show similar increases in the Consumer Costs. With one of the largest observed increases of over 30% occurring when the MIP solver stopped with an Optimality Gap of 0.8%. This is the solution noted above that contained two Peak prices from the Dual Rated generator.

While reviewing the financial impact of the two solvers, we also took into account the economic downturn that has occurred within the timeframe of the study. To try highlight where variances were being driven by the solvers from the impact of the economic climate, for much of the financial reporting, we have separated the studies into those that related to dates before the economic downturn to those that come after. To try pinpoint when this should be we reviewed the System Marginal Price in the SEM across this timeframe. This is demonstrated in the graph below.

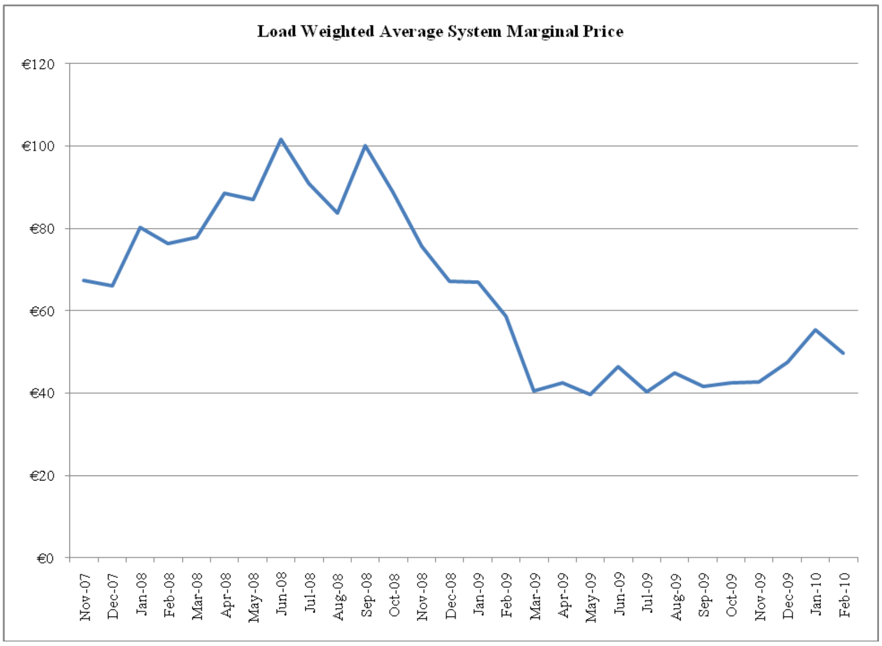

Figure 7 - Load Weighted Average SMP

Based on this above, we selected February 2009 as boundary of the economic downturn and have reflected this in our reporting.

As noted previously, one of the most significant changes we observed related to Hydro generators and how they were scheduled by the MIP solver over the LR. While the Trading & Settlement Code sets out rules for scheduling Energy Limited Generators as being that they cannot exceed their daily limits, as these units also bid in very low costs (generally, only a small Start Up cost and zero bid cost and zero No Load Cost), it could be fairly expected that they would be low in the merit order and should be used as much as possible. The inter-temporal nature of their operation which requires that the daily limit is not exceeded across all Trading Periods does add a complexity that could led to an amount of unused energy, regardless of the solver chosen. However, the unused quantities are significantly greater in the schedules from the LR solver than from the MIP. Because these units get used to their full limit in actual dispatch, this means that compensation should come from the Constraint Payments. However, with the given commercial offer data, these payments are usually zero. We do observe the quantities by which these units are being constrained in the market. This is because while the Hydro generators are being paid a zero Constraint Payment, other thermal generators are paying back Constraints. Though this figure cannot be effectively quantified, we do consider that this will mean Constraint Payments would also increase when using the MIP solver.

In our review of Constraint Payments, we have observed that these payments more frequently increase when calculated using the outputs of the MIP solver. This is partially due to the issue of the Hydros; however, other more general commitment decisions also impact strongly on the calculation. In general, the trend appears the same using the two solvers; that is, the net daily total is either positive or negative. Trading Days which moved from negative to positive were rare and in each case, largely the result of a single commitment decision on one generator.

2.4 MSP Parameters

A modification in both LR and MIP default parameters has been carried out on a limited number of Trading Days.

This analysis has confirmed that there is limited value in modifying both the ALTCOM parameters in LR and the Optimality Gap in MIP. We have observed incidents with both where the MSP Production Costs have been improved; however, full consideration should be given to all the other aspects impacted by such changes, like SMP, Consumer Costs and Generator revenue. This has not been done in sufficient detail for this report to reach any solid conclusions, as only a limited number of study cases have been considered.

We therefore recommend that the current settings continue to be used in SEM operations and further analysis be carried out in separate studies should this be required.

2.5 Recommendations

Based on the analysis completed, we believe that the MIP program better achieves the aims of the Trading & Settlement Code with respect to MSP Production Costs. However, when we consider the other impacts in terms of System Marginal Price, Consumer Cost and Constraint Cost, we would recommend that a consultation is undertaken to allow Participants in the SEM the opportunity to digest this report and comment and suggest proposals for next steps.

3 A Comparison of the MIP Timeout Settings

3.1 Introduction

The Mixed Integer Programming solution used by SEMO has configurable timeout settings. While the program has an Optimality Gap target, defined as the MIP Gap, timeout settings are used to ensure that the program does not continue to work for periods which are operationally impractical. In the SEM, when MIP is used two timeout settings can be employed as follows:

- After five minutes or MIP300 (300 seconds), and
- After ten minutes or MIP600 (600 seconds).

In each of these cases, if the solution found does not achieve the convergence tolerance within the set timeframe, the solver will finish and deliver the best solution found to that point, i.e. – the market solution resulting may be outside the convergence tolerance settings. For the purposes of this study, we also wanted to include an "unlimited" option. However, this was not available. In place of this, we set the timeout to 1800 seconds or 30 minutes.

In running the studies, the longer timeout settings were only used where the previous setting had timed out. As such, not all cases include runs at all settings. Before getting to the analysis of MIP against the Lagrangian Relaxation program, we will review the outputs of the various MIP runs against each other to assess if any pattern can be observed and any conclusions made. This is to determine if these can be excluded in the direct MIP to LR comparisons.

3.2 Executive Summary

A comparison of the MIP solver being run with the different timeout settings shows that while the longer runs do provide slight improvements in a number of areas, (such as better Optimality Gaps, reduced MSP Production Costs), the changes in other areas are negligible. For example, while Consumer Costs and System Marginal Prices are decreased with the longer runs, this does in turn lead to a reduction in Generator revenue, which may have separate unintended consequences in terms of encouraging investment. In addition, the changes in Consumer Costs and System Marginal Prices are not significant with the bulk of the changes occurring with the MIP1800 runs, a timeout setting that is not practical for SEM operations.

The analysis concludes that the improvements achieved by using the software with longer timeout settings do not outweigh the costs that come with the longer run time. Shorter run times are providing good quality solutions within practical timeframes for daily market operations.

It is recommended that when running the MIP solver, that the timeout setting of 300 seconds or five minutes is used – both in real operation of the SEM and through the rest of this study of MIP versus LR.

3.3 Background

To assess the results of the different MIP runs, comparative analysis has been done on the available runs under the following headings which are a subset of the criteria for analysis in the overall MIP-LR studies.

- MSP Production costs,
- Optimality Gap,
- System Marginal Prices,
- Consumer Costs,

- Constraint Payments, and
- Solution times.

The Optimality Gap is a measure of how close the found solution is from the best lower bound solution determined in the first phase of the MIP program. In the SEM implementation, there is a configurable parameter called the MIP Gap, currently set at 1%. This is used as a convergence tolerance which allows the program to stop when it has achieved a solution with an Optimality Gap better than the tolerance, once time limits have not been reached.

In the study, a total of 154 “standard” Trading Days were run using the different solver options. Of these, we found the MIP300 found a solution within the MIP Gap on 105 occasions. The remaining 49 all timed out with an Optimality Gap of more than 1%. In each of these cases, the MIP600 option was run. The solver found a solution within the MIP Gap in only six of these cases. The remaining 43 were completed using the MIP1800 option.

The analysis presented in this section is based on a review of these 49 study cases.

3.4 Analysis

1. Productions Costs

The objective function of the market solvers is to schedule Price Maker Generation, subject to some constraints while minimising MSP Production Costs across the full Optimisation Horizon. With this in mind, we have taken the measure of MSP Production Costs as being the primary measure for any analysis.

The analysis below covers the entire Optimisation Horizon and not just the Trading Day. In the SEM, this is a thirty hour period which runs from 6AM on the Trading Day to 12 noon on the following day. The Trading Day is a twenty four hour period from 6AM.

The graph below demonstrates the total MSP Production Costs, summed over the Optimization Horizon, for each of the 49 studies that were run with more than just the MIP300 option. What is noted here is that almost all studies that included extra time in the running of the solver showed reductions in the MSP Production Costs, the actual reduction in Production Cost is negligible. In some instances, the saving is so small as to be not apparent when looking at this representation.

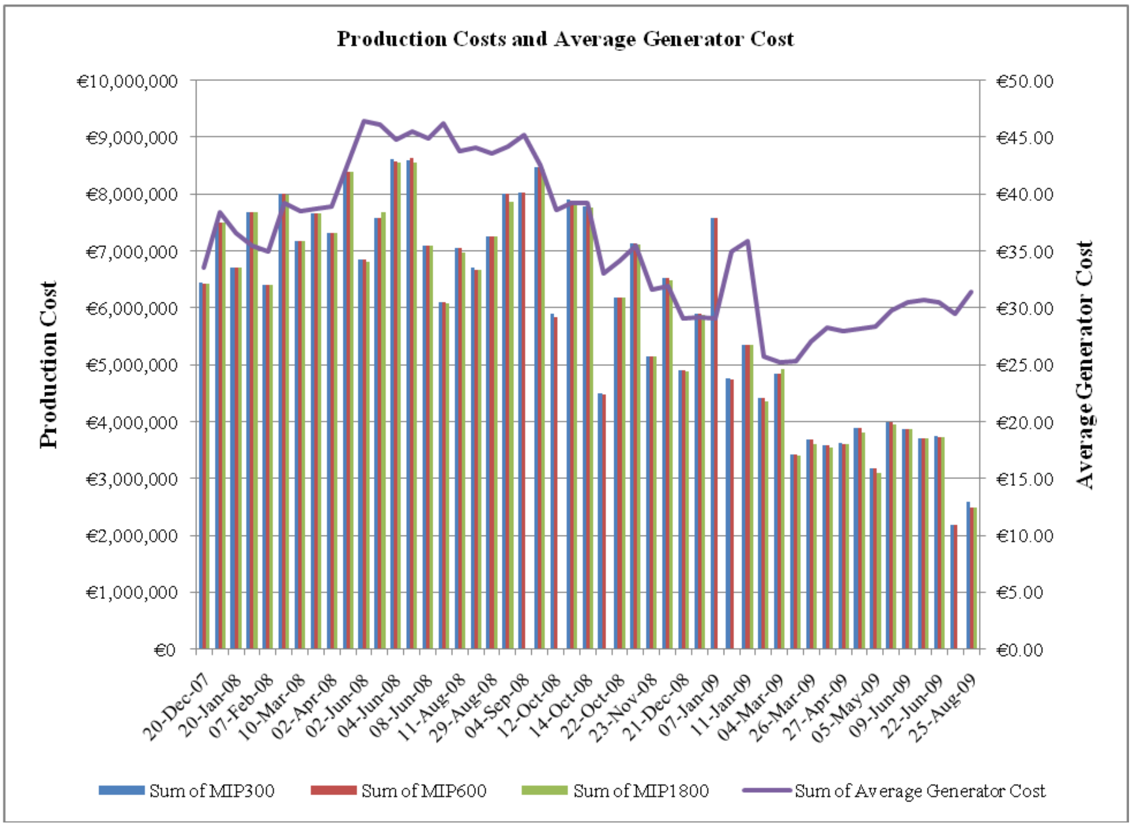

Figure 8 - MSP Production Costs across MIP runs

As can be observed, the studies covered dates from 2007 through to 2009 and the notable reduction in MSP Production Costs across the studies is driven by external market drivers and not the choice of solvers, a fact that can be further observed when the MSP Production Costs are compared to the outputs of the LR solver later on. This is also shown by comparison against the average Generator Cost. This is calculated by taking the Price Quantity pairs submitted by Generators and calculating an average bid price per MW. The trend observed in the Average Generator Cost line above closely corresponds to the trend observed in the summed MSP Production Costs for the studies.

To further analyse the results, we reviewed the change between the different runs taking the MIP300 as the “base” case as this is the default setting used in production in the SEM. This was done by calculating the percentage change between the MIP300 and the MIP600 runs and between the MIP300 and the MIP1800 runs calculated as -

$$\left(\frac{MSP\_Production\_Cost(BASECASE) - MSP\_Production\_Cost(STUDYCASE)}{MSP\_Production\_Cost(BASECASE)}\right) x100$$

The observed percentage changes are set out in Figure 8 below.

Notwithstanding one incident when the variance in Productions Costs was above +/-3% (the value of the Settlement Recalculation Threshold or SRT), across all studies the average improvement in MSP Production Costs between MIP300 and MIP600 was 0.00165%.

The average improvement between the MIP300 and the MIP1800 was 0.473%. However, between MIP300 and MIP1800 there was a higher instance of larger variances. 35 study runs were noted to have variances of more than +/-1%.

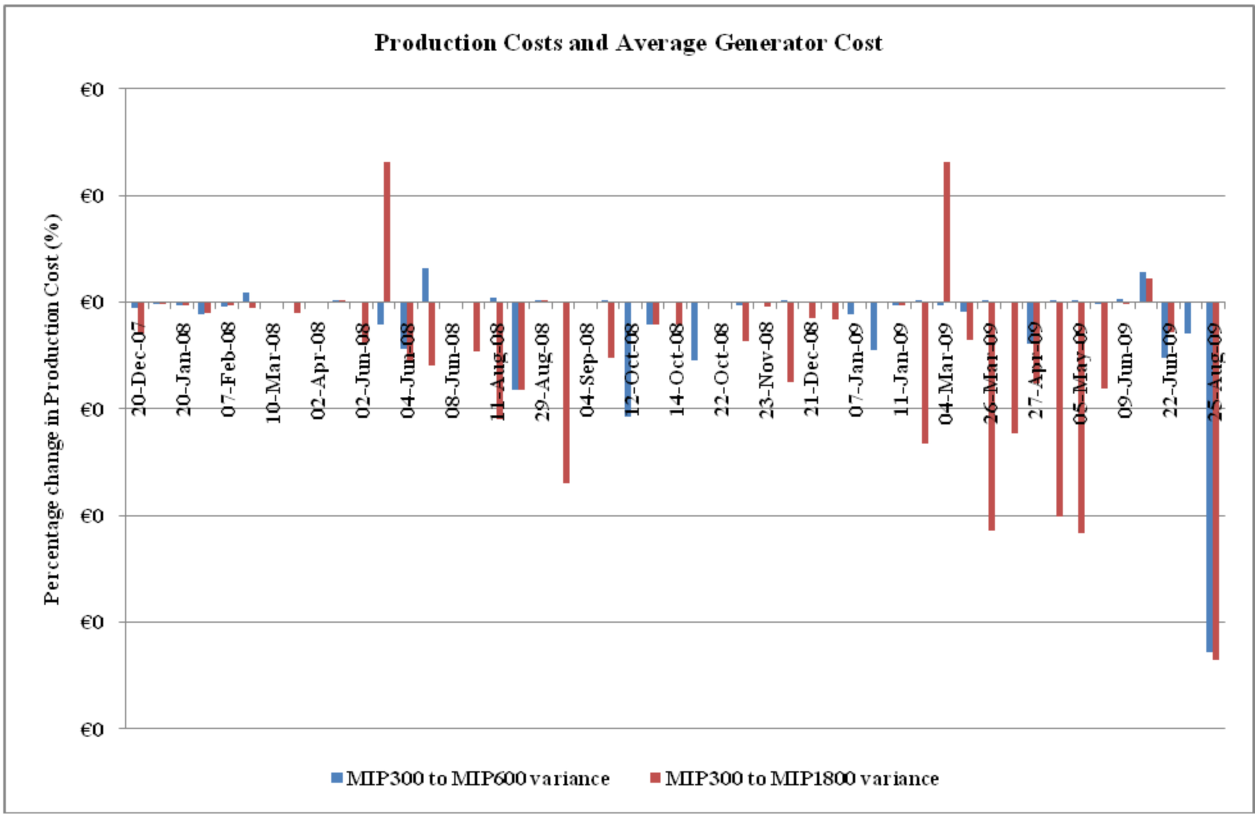

Figure 9 - Percentage Improvement in MSP Production Costs

The average monetary reduction observed between MIP300 and MIP600 was just over €7,000; while for MIP1800, the average monetary reduction we noted was €22,500.

The following graph demonstrates the results of a frequency analysis on changes in the MSP Production Costs between MIP300 and MIP600. This shows that the bulk of the changes are between +/-0.5% of the MIP300. Note the frequency value remains at zero largely between -3% and -1%.

This indicates that there is little improvement gained in the MSP Production Costs by extending the running time of the MIP solver by an extra five minutes.

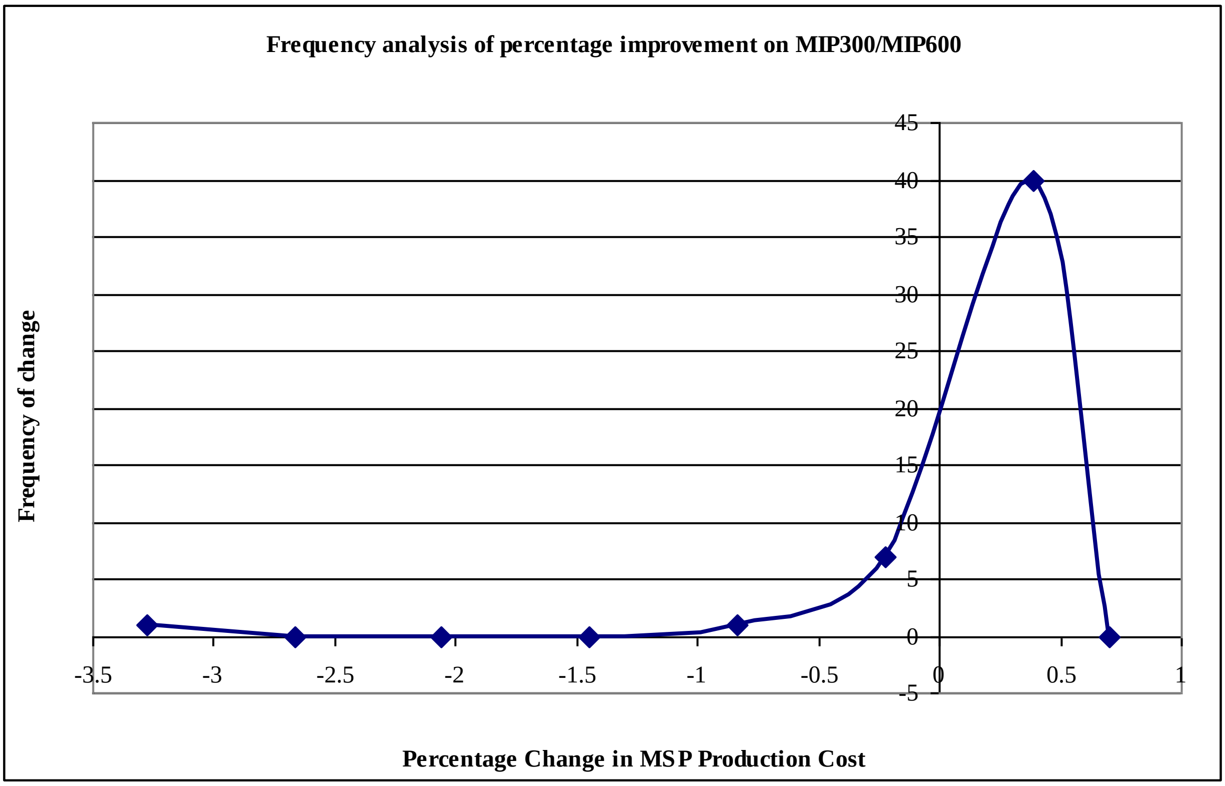

Figure 10 - Frequency Analysis of changes between MIP300 and MIP600 MSP Production Costs

A similar review of the changes in the MSP Production Costs between MIP300 and MIP1800 is below. This shows a larger number of changes between -3.5% and -1% though it still should noted that most changes are again between +/-0.5% of the MIP300.

The improvements observed in MSP Production Costs would be expected based on allowing more time to achieve a better optimal solution; however, it should be noted that these improvements were delivered by extending the running time of the solver from five minutes to 30 minutes, a time-scale that is currently not practical in normal market operations.

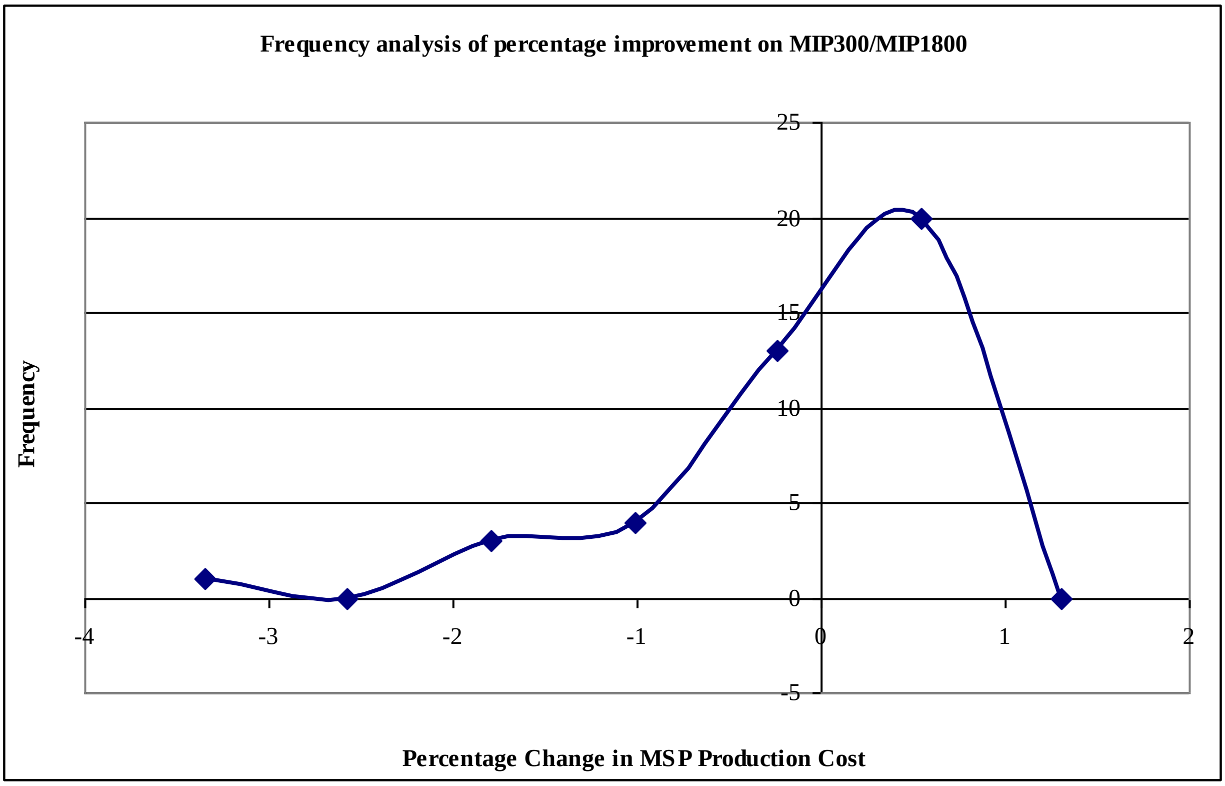

Figure 11 - Frequency Analysis of changes between MIP300 and MIP1800 MSP Production Costs

It should be noted that in the instances of +1% on MSP Production Costs between MIP300 and MIP1800 the MIP never solved to optimality and the Optimality Gap was better on the MIP300 and MIP600 runs than in the MIP1800 run[9].

2. Optimality Gap

The Optimality Gap is a value reported by the MSP solver. Recognising that commercial solvers rarely produce global optimal solutions and more frequently deliver the local optimal, this is a measure of how close the given solution is to the lower bound solution determined in the first relaxed phase of the problem solution. The lower the Optimality Gap, then the closer the solution is to the global optimal.

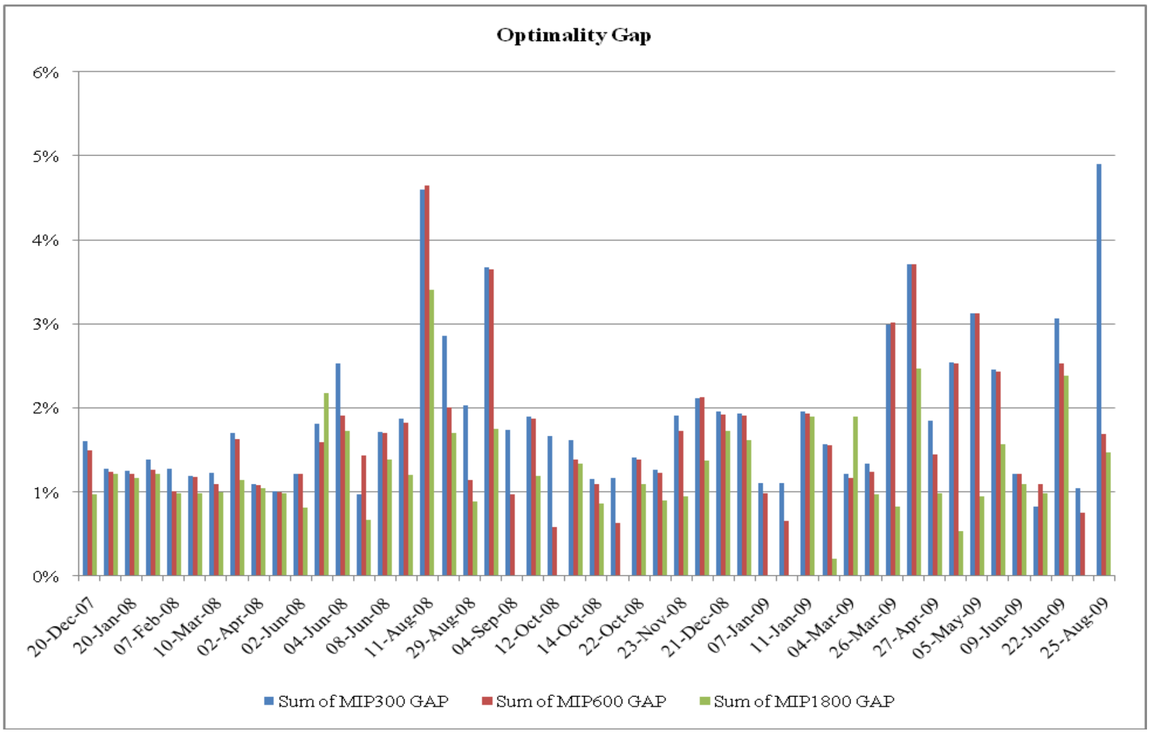

Figure 12 - Optimality Gap

Reviewing the findings summarised in the graph above, it can be observed that for the study cases which were completed using the three solver time settings, we only observed a few extreme variances in the Optimality Gap with most changes not being very significant. There are some notable exceptions such as August 25th 2009 where the Optimality Gap after the first five minute run was at 4.9%. The addition of extra time considerably improved the solution though even with a thirty minute run, this Trading Day never resolved to within the 1% MIP Gap. A similar occurrence can be noted on August 11th 2008. Again, an initial high Gap on the five minute run is improved in the thirty minute run, but still not to within the 1% MIP Gap.

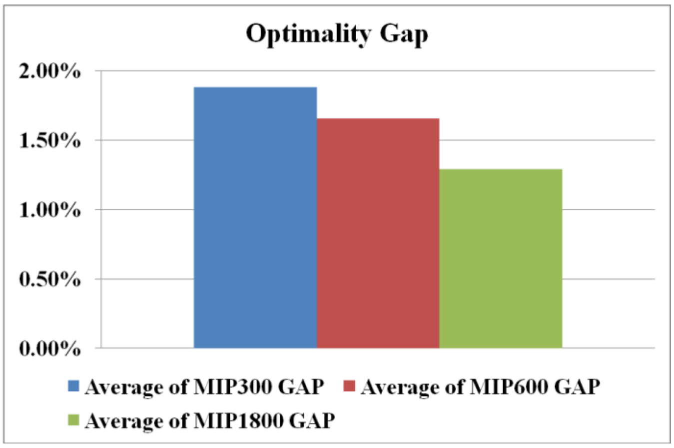

Figure 13 - Average Optimality Gap

The summary table here shows average values of Optimality Gap across the runs completed with the three time settings.

As expected, the additional time does provide for improvements in the Optimality Gap, mirroring the improvements noted in Production Costs above.

However when comparing the average Optimality Gap across all MIP runs completed, this shows a different story.

[9] In general, the longer run time will result in a better solution. However, this is not always true especially when the MIP engine is stopped by the time limit. In this situation, the solution may vary at different runs depending on the CPU loading at each specific run. Also, the final refining step of the algorithm may give a slightly different solution depending on the position of the best available solution in the entire search tree.

The summary table here shows average values of Optimality Gap across all the runs. Because MIP 300 was used in all cases, its average value is the lowest here.

Here the high number of five minutes runs that achieved the Optimality Gap demonstrate the quality of MIP300 solutions when compared to the other options. This further underlines the lack of benefit that can be observed with the additional time, already noted when discussing Production Costs above.

This is especially true considering the small improvements noted by the addition of an extra five minutes running time.

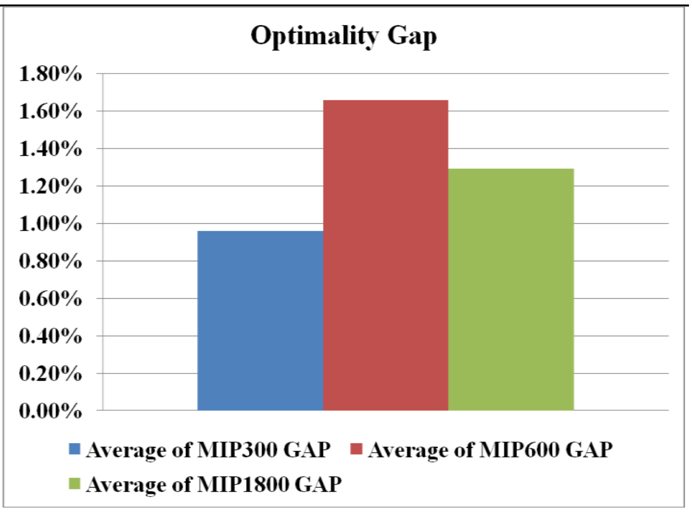

Figure 14 - Average Optimality Gap, all runs

As noted above, of the 154 “standard” Trading Days that were studied, in 105 cases the MIP Gap was reached. This is 68% of the dates sampled that the MIP solver achieved optimality within five minutes or less. Running for a further five minutes only solved a further 4% of the total cases to within the MIP Gap, or 12% of those originally unresolved. Extending the solution time to thirty minutes provided solutions in a further 12% of cases, or 46% of the cases run for this duration. In total, 84% of the Trading Days studied resolved to some level of optimality. That leaves 16% that timed out without achieving an optimal solution within the 1% MIP Gap target.

However, the improvements in the Optimality Gap are minimal with the extra time runs. With the MIP600 option, the Gap improved by an average of 0.24% over the MIP300. Running the solver for the thirty minute option only yielded a 0.7% improvement over the original MIP300. It has been observed that it is unlikely to gain any benefit from longer runs when the Gap in the MIP300 run is under 1.5%.

The graph below measures the Optimality Gap against the Solution times of the runs. Without highlighting each of the separate run types, this graph shows the times of the runs that achieved an optimality gap of less than 1% – that is, where a study run for a given Trading Day did not achieve optimality within a set timeframe and had to be run again with the longer setting, these results are not included here. This graph only includes the data for study runs that completed to below the Optimality Gap or those that failed to resolve even with a 30 minute run time.

The graph lines highlight the time limits of the three run types. As can be see here, a large number of the MIP runs completed to optimality within the 300 seconds demonstrating the observations above. Allowing and additional ten minutes for a study run yields no major benefit with only a small number or additional cases resolved. Again, with the further study runs that were done over the thirty minutes timeframe only a small benefit can be observed with a large proportion of cases still not solving to within the 1% MIP Gap target.

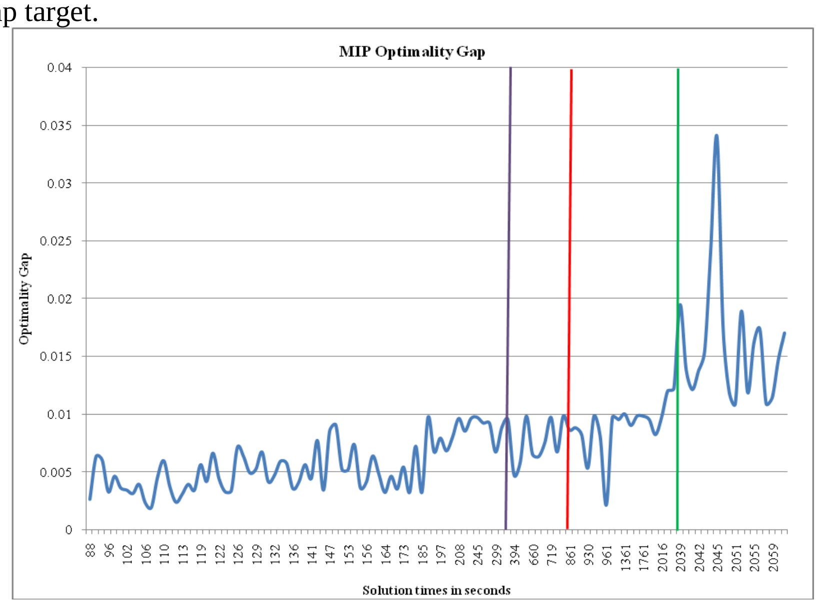

Figure 15 - Solution time with Optimality Gap

As noted above, the 1800 second running time is not practical for normal market operations given the requirements of the Trading & Settlement Code. It should also be noted that of the 32% of cases that did not solve to within the 1% MIP Gap target within five minutes, 69% of these solved with MSP Production Costs that were below those of the LR runs.

3. System Marginal Prices

A review of the System Marginal Price or SMP across the three run types demonstrated no clear pattern. As the SMP is largely the result of calculations done in the MSP software beyond the Unit Commitment phase (where the LR and MIP solvers apply) such as the Economic Dispatch and post processing phases, this was as expected. Also, the calculation of SMP is not part of the objective function that is to be solved under the Trading & Settlement Code.

However, to be fully confident we would expect to see a level of consistency between the three timeout settings. Taking a time-weighted average daily SMP, we have compared this across the 49 study runs completed with the extra timeout settings.

The results show a generally consistent pattern with similar values of average SMP across the three study run types. The graph below demonstrates the results of this comparison. It can be observed that barring two Trading Days (12th October 2008 and 22nd June 2009), the resulting SMP values are quite similar. For the two Trading Days noted with larger variances, 22nd June 2009 is one of the study cases where no solution was ever found within the Optimality Gap. However, the MSP Production Costs of the MIP300 solution were better than those of the LR study and no major improvement was found in MSP Production Costs with the longer MIP runs. The Trading Day of 12th October 2008 is one of the six cases where MIP600 improved on the original MIP300 and produced a solution within the Optimality Gap.

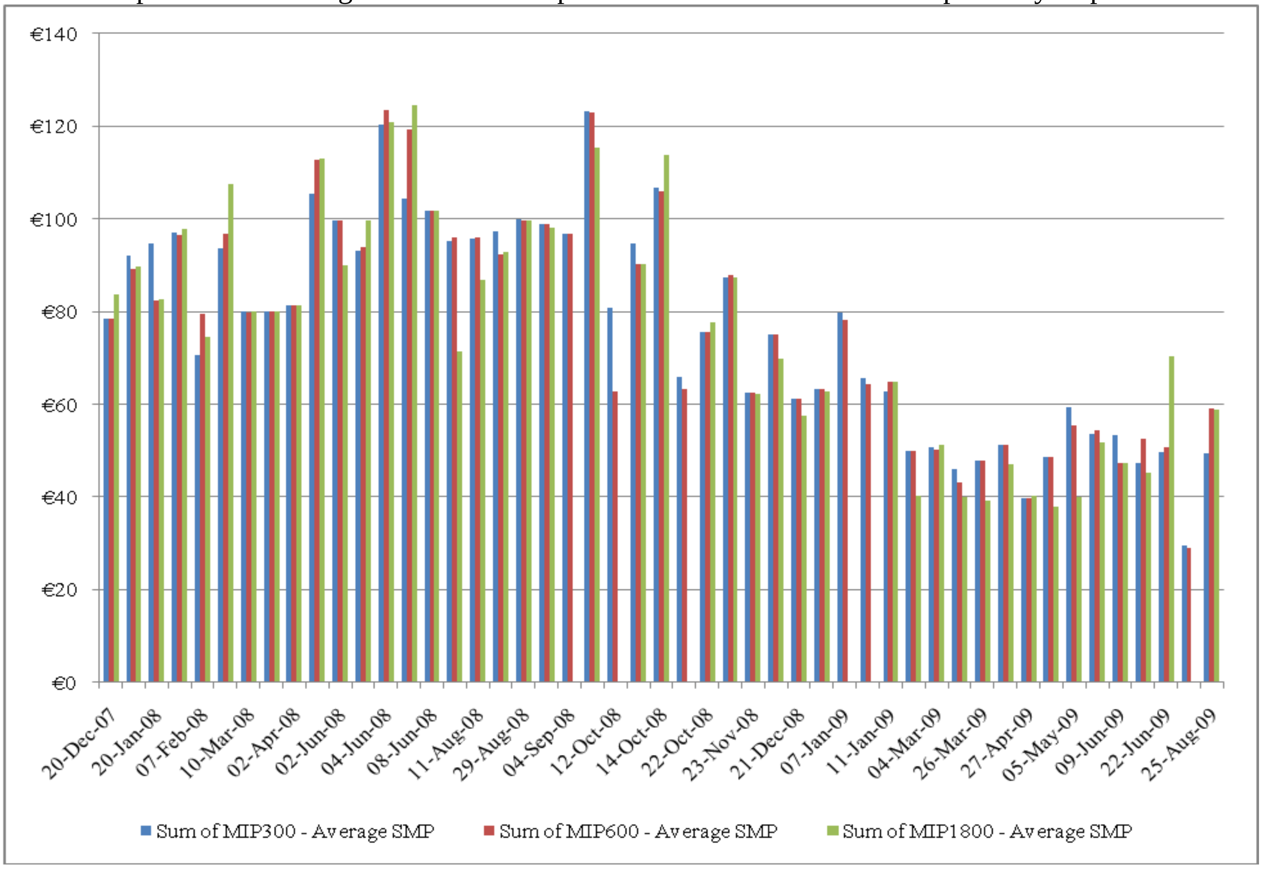

Figure 16 - System Marginal Price

While keeping in mind that the calculation of SMP is not part of the objective function, it is worth observing the changes that were noted. Of the 49 study cases, 25 solutions (or 51%) yielded higher daily average SMP values when run for an extra five minutes. Of the 43 study runs that were run for thirty minutes, 19 of these (or 44%) had higher daily average SMPs. The two charts below represent a frequency analysis of the changes noted in the daily average SMP.

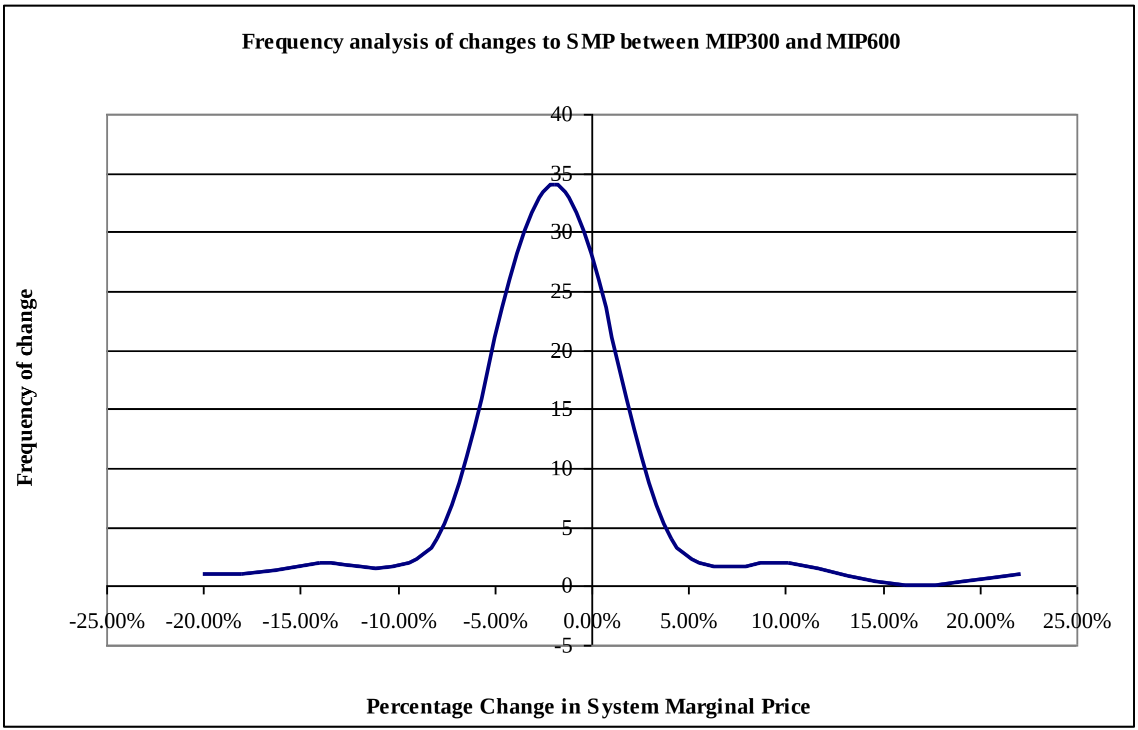

Figure 17 - Changes in SMP between MIP 300 and MIP 600

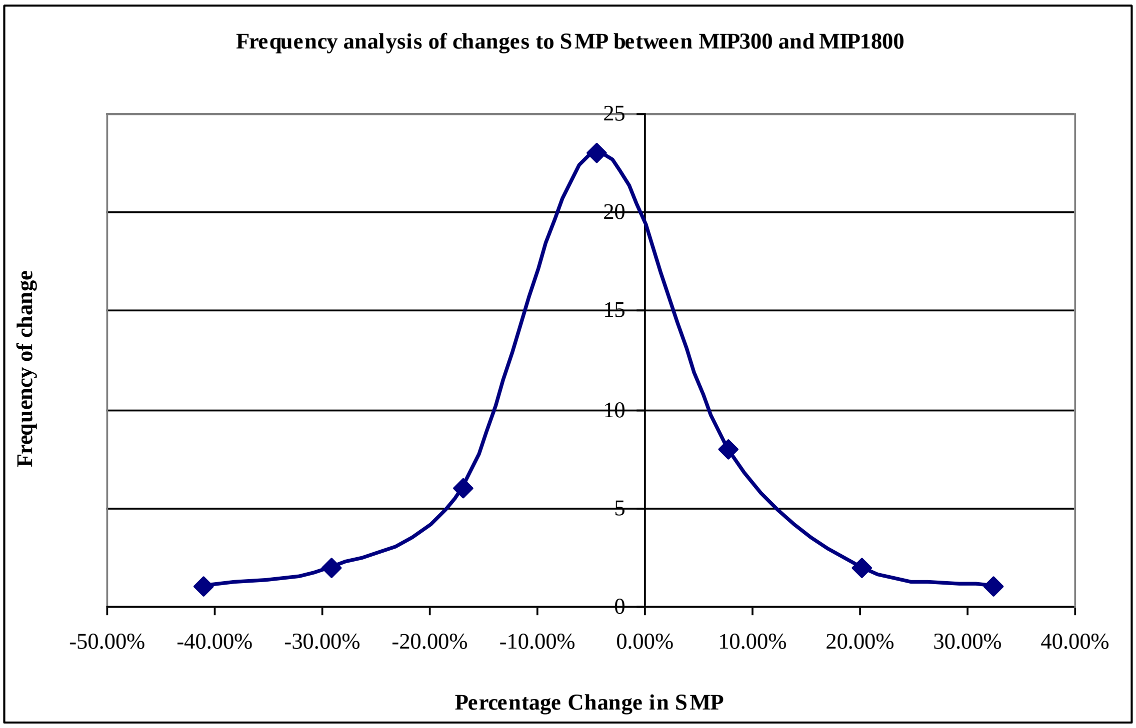

Figure 18 -Changes in SMP between MIP 300 and MIP 1800

Both these charts demonstrate that while large variances can be observed in the daily average SMP in each instance and that longer runs do appear to produce on average lower Daily SMPs, the prevailing trend is for a consistent value across all three timeout settings.

Looking at the Uplift portion of the SMP shown in figure 18 below, there is a general trend of reduction in the average daily Uplift calculation across the three run types with 63.25% of MIP600 cases and 71.4% if MIP1800 cases having smaller values of Uplift than the original MIP300 run. While taking note of this trend however, the actual monetary values of the changes noted are not always significant.

A frequency analysis of the variances, shown in figure 19 below, yields no valuable data as what can be observed as a significant percentage shift in value can be observed where little actual change in monetary terms has occurred. We have demonstrated this in the graph below where a percentage change of over 1800% can be noted. This however represents an increase of under €25 in the calculated value. Elsewhere changes of over 100% can be noted where the monetary change can be as low as €3.89.

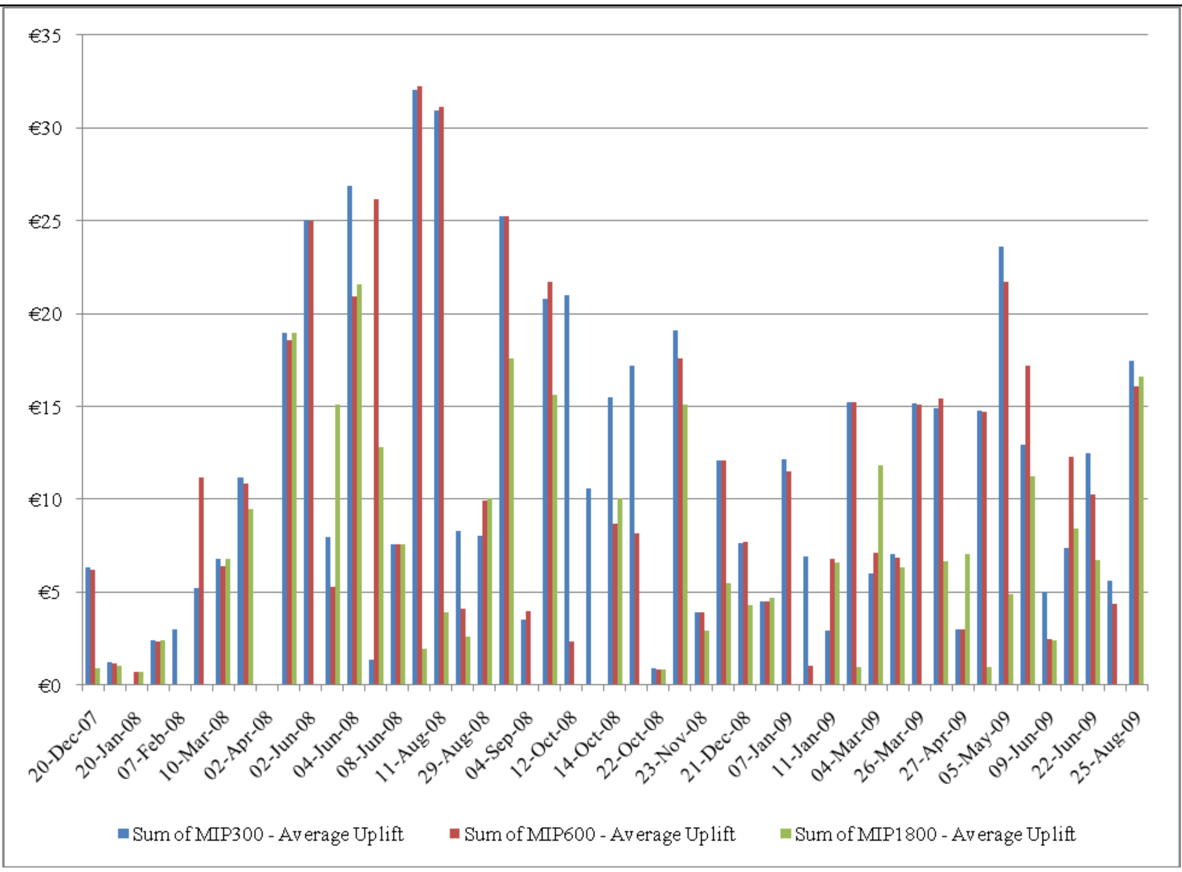

Figure 19 - Average Uplift in SMP

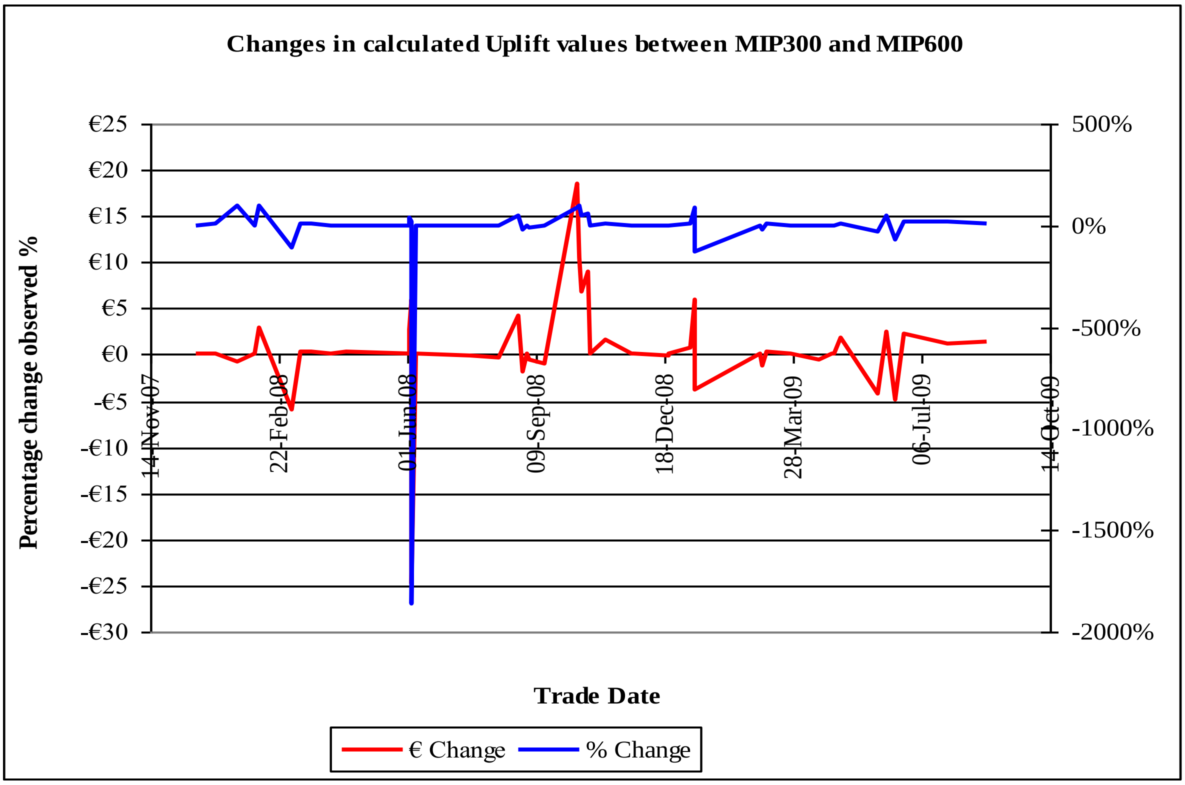

Figure 20 - Changes in Uplift, comparing % to € changes

As noted above, while the SMP and Uplift calculations are not part of the objective function and therefore not strictly impacted by the solver choices, the consistency of results observed here provides an assurance that there are no significant changes to results when it comes to the timeout settings of the MIP runs.

4. Consumer Costs

Consumer Costs is considered to be the final value that the end consumer of electricity will pay. In terms of how this is calculated the general approach has been to take an approximation of payments to Generators calculated as -

$$TPD \times \sum_{u,hint} MSQuh \times SMPh$$

Where

- TPD is Trading Period Duration;
- MSQuh is the Market Schedule Quantity for Generator Unit u in Trading Period h;
- SMPh is the System Marginal Price in Trading Period h.
- the summation $\sum_{u,hint}$ is a summation over all Generator Units u, and across all Trading Periods h within Trading Day t

Considering that the SEM is designed as a balanced market and that the sum of all payments to Generators should be funded directly through the sum of all charges on Suppliers, this approximation is suitable though it does not consider Constraint Payments which are charged on Suppliers through the Imperfections Charge. We have separately reviewed the Constraint Payments across the different runs types to take account of this.

As the system load remained static across all the study runs completed, this means that the changes to Consumer Costs observed are driven primarily by the changes to the System Marginal Price noted above. This can be seen when comparing the summed daily Consumer Costs against the average daily SMP in figure 15 above. As these are a financial calculation that is paid and charged out according to settlement rules, this analysis was only completed across the 24 hours of the Trading Day

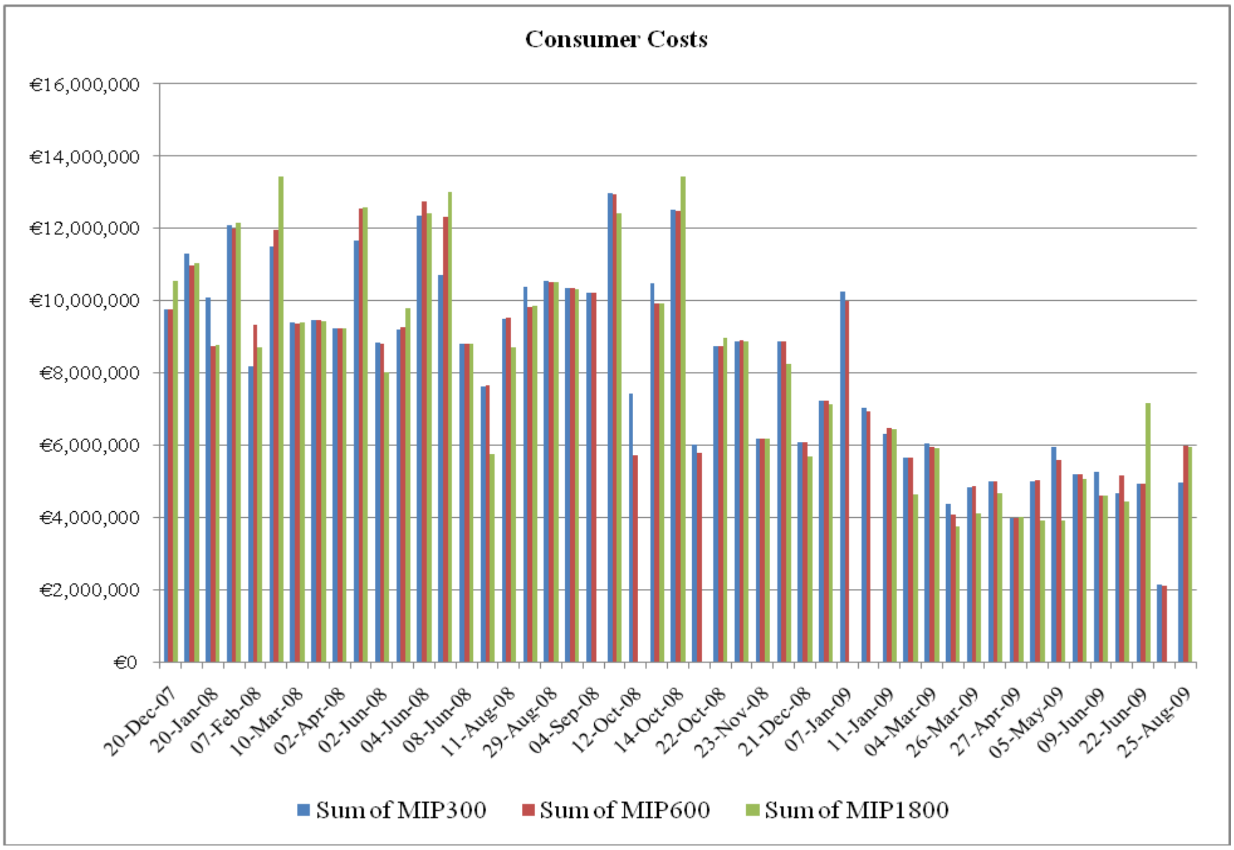

Figure 21 - Consumer Costs across the different MIP run types.

Equally a frequency analysis of percentage changes in the Consumer Costs shows similar trends to the same analysis on the SMP. Figure 21 below follows a similar curve to figure 16 above, reflecting that the percentage reduction in SMP does produce the expected reduction in Consumer Costs.

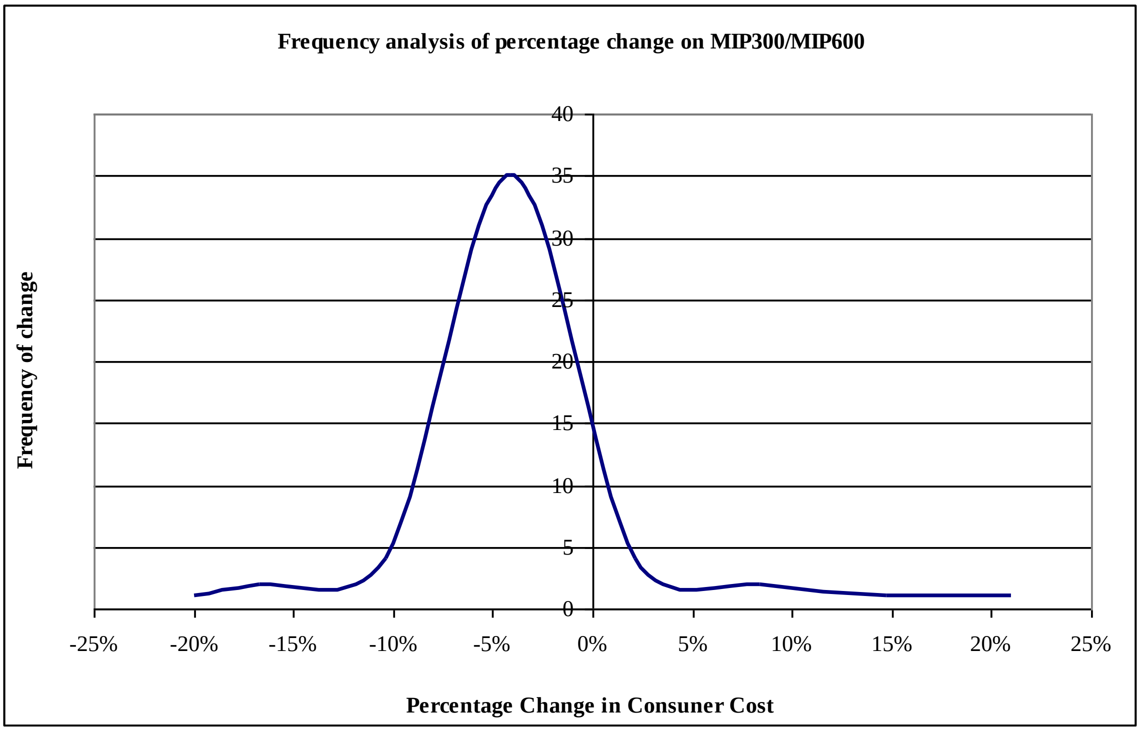

Figure 22 - Percentage Changes in Consumer Costs, MIP300 to MIP600

With the comparison of Consumer Costs between MIP30 and MIP1800 as graphed below, the shape is somewhat different.

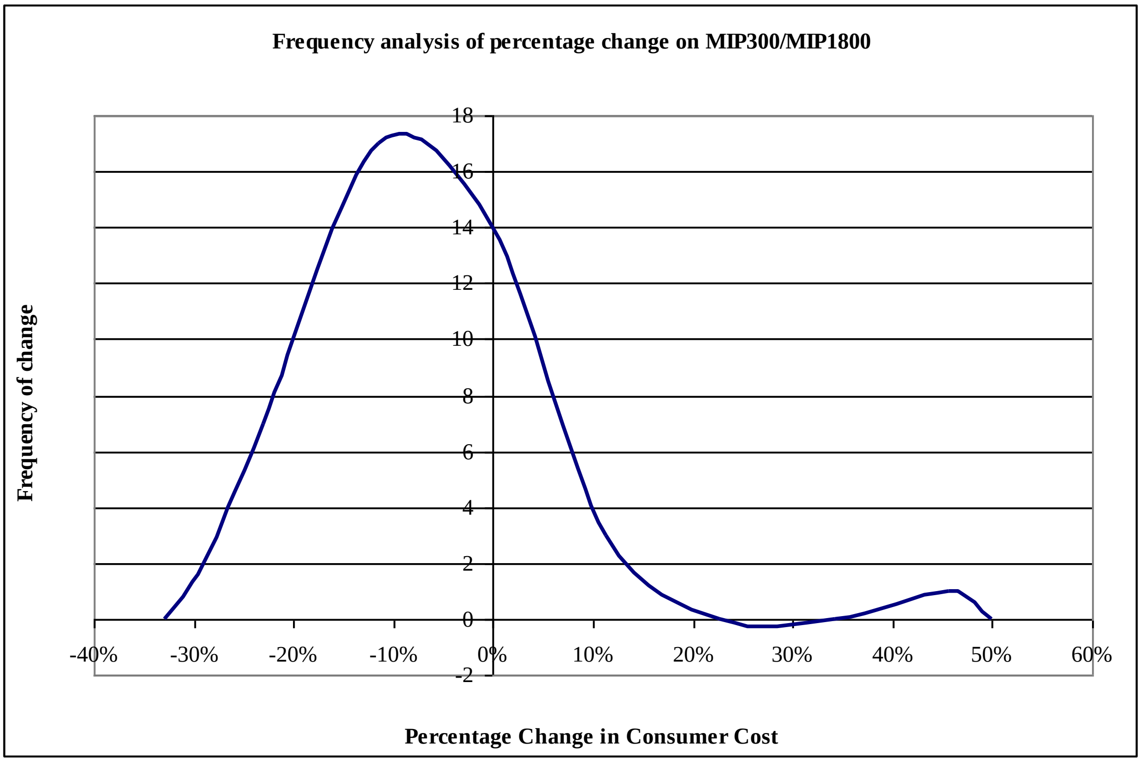

Figure 23 - Percentage Changes in Consumer Costs, MIP 300 to MIP1800

While showing similar reductions in Consumer Costs matching the percentage decreases in SMP, there is an anomaly where the Consumer Costs increased by over 45% in the MIP1800 study run over the MIP300. This was for Trading Day June 22nd 2009 where a considerably higher SMP in the MIP1800 run produced significant variances in the Consumer Costs.

With regard to this Trading Day, no study run achieved a solution that fell within the Optimality Gap of 1%. The reported gaps were 3.06%, 2.53% and 2.38% for each of the respective runs. The MSP Production Costs for this date in the MIP1800 run were in fact higher than those in the MIP600 run even though the solution was closer to Optimality which would support some of the caution urged with regard to the quality of solutions that result when MIP algorithms are timed out (Sioshansi, 2008). It is also noted that for this Trading Day, even the MIP300 run resolved with a lower Production Cost than the LR study.

5. Constraint Payments

Constraint Payments are outside the main objective function of the MSP software as they represent the variance between the MSP Production Costs that Generators would incur based on the Market Schedule and the MSP Production Costs they actually incur based on how they are run in dispatch by the Transmission System Operator. The management of the Constraints costs is done by the TSO in each jurisdiction and is outside the scope of the SEM. However, the costs are collected through the Constraint Payment calculation which is defined in the SEM rules and configured in the SEMO systems. These are funded through the Imperfections Charges levied on all Suppliers in the SEM and again, collected as part of the settlement of Trading Payments and Charges in the Central Market Systems.

As this is funded by Suppliers, it can be seen as part of a grander Consumer Cost as the charges to Suppliers will inevitably be factored into retail tariffs. With this in mind, we have completed some analyses on the variances in Constraint costs between the different timeout settings of the MIP algorithm.

In each case, the Constraint Payment was calculated as the Dispatch Production Cost less the Market Production Cost. The Dispatch Production Cost was calculated according to the Trading & Settlement Code based on the actual dispatch schedule of Generators on each of the relevant study days by the System Operator. As these are a financial calculation that is paid and charged out according to settlement rules, this analysis was only completed across the 24 hours of the Trading Day.

The graph below shows a comparison of total daily Constraint Payments for each of the study cases completed. While changes are noticeable, an initial review indicates that the Constraint Payments do not vary greatly across the different MIP runs.

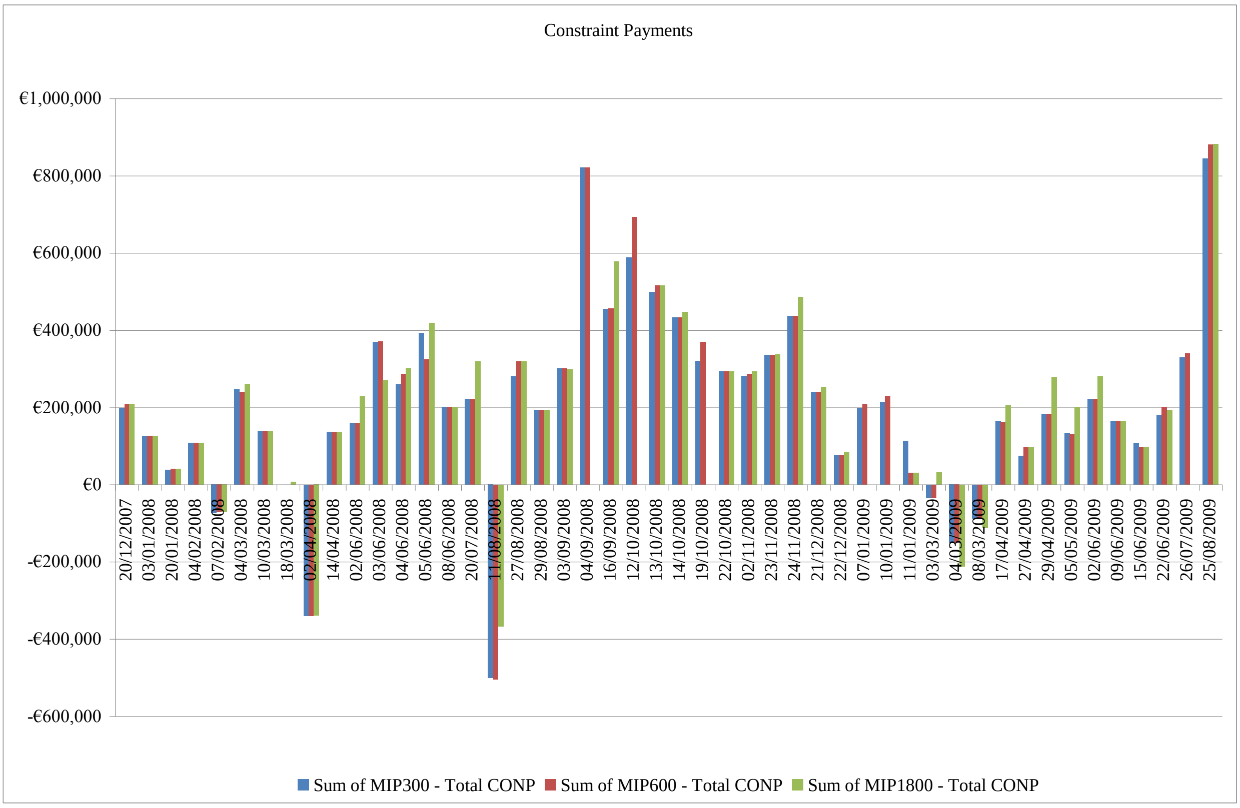

Figure 24 - Constraint Payments across MIP runs

This is further borne out by the frequency analysis below completed between the MIP300 and MIP600 data. This shows a high portion of cases with little or no change in the Constraint Payment values with only exceptions where the change in value is greater than +/-10%. Note that negative changes represent a reduction in the total Constraint Payments made under a study run.

Looking at the comparison between MIP300 and MIP600 in figure 23 above, 30 study cases out of 48 reviewed showed reductions in the total Constraint Payments, while 18 study cases showing increases. However, of these 26 study cases out of the total had changes that were less than +/-1%.

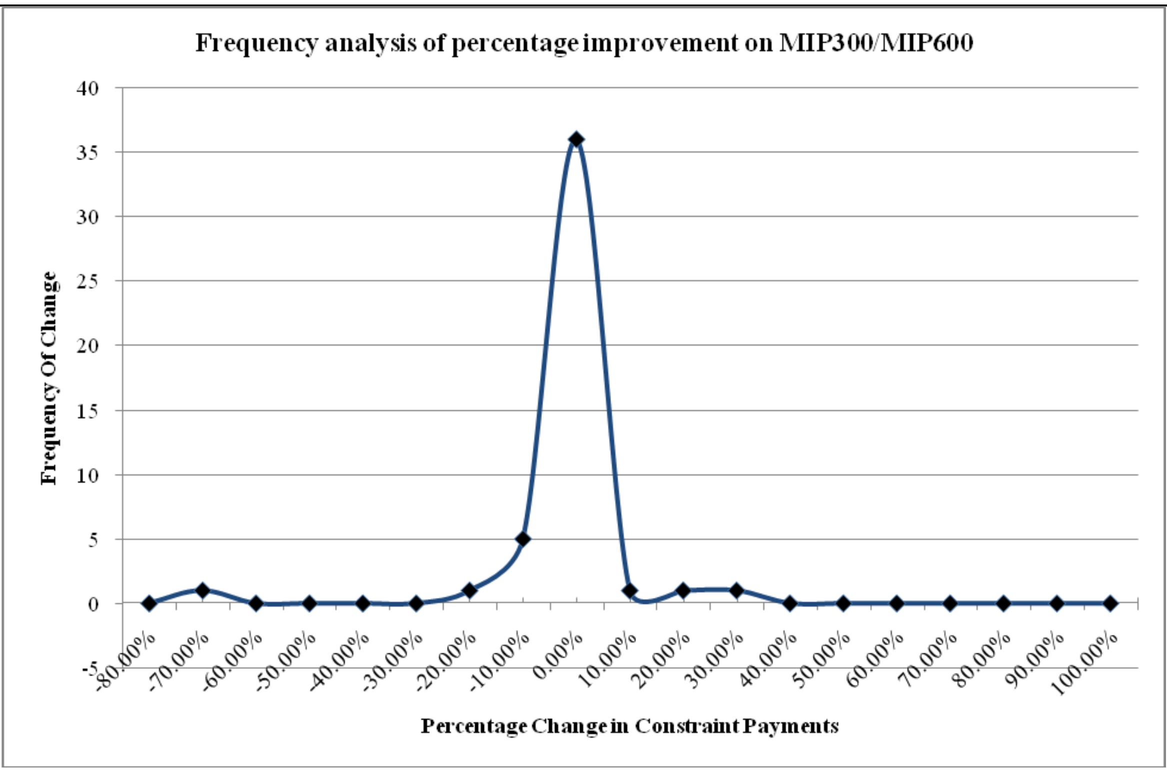

Figure 25 - Frequency analysis of MIP300 to MIP600 changes

With a comparison of the MIP600 with the MIP1800 study runs, again the bulk of the cases have only small changes though only 11 of the 42 study cases were in the +/-1% range.

In the graph below, we have excluded the Trading Day of March 18th 2008 from the frequency analysis below. This is because this Trading Day showed a change between the MIP300 and MIP1800 study runs of almost 1,500%; however, the actual monetary change between the runs was only €7,500

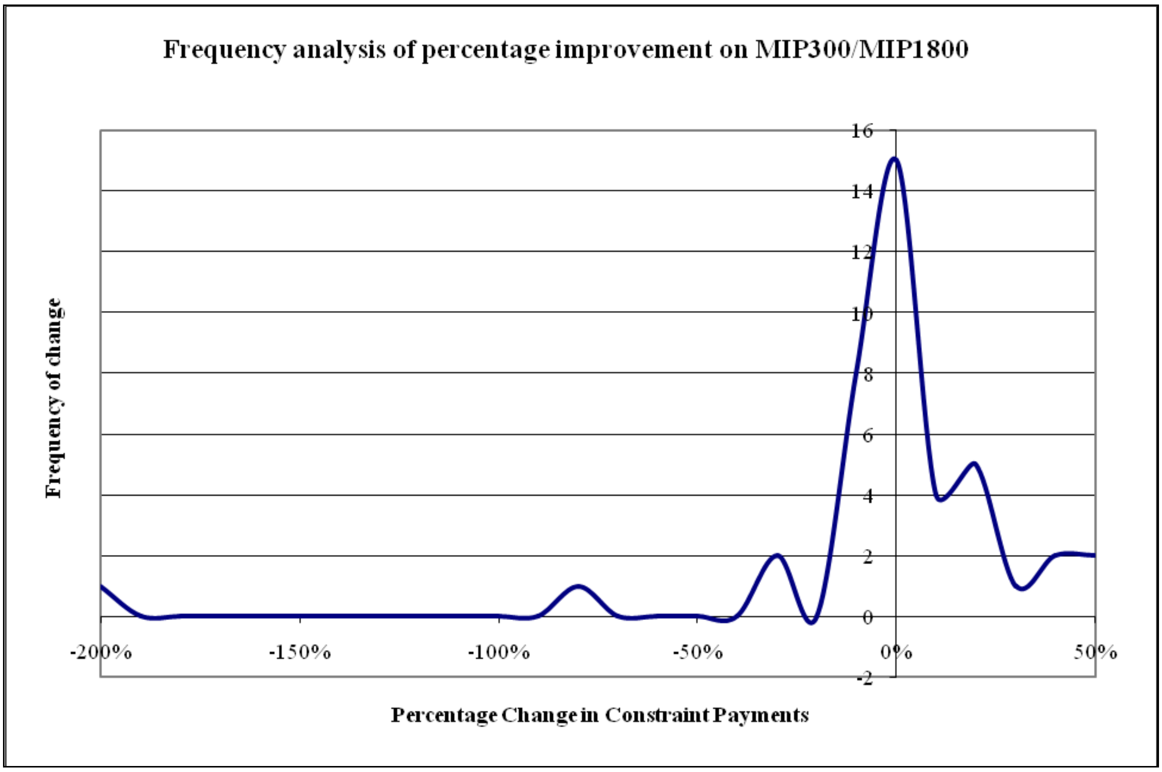

Figure 26 - Frequency analysis of MIP300 to MIP1800 changes

Because changes at a percentage level can be misleading, the Figures 20 and 21 below represent the frequency of the monetary changes between the MIP300 and MIP600 study cases, and between the MIP300 and the MIP1800 study cases.

Similarly to the percentage change, the indication is that large variances in the allocation of Constraint Payments are infrequent occurrences. In the comparison between MIP300 and MIP600 in Figure 20 below, 14 Trading Days of the 48 showed changes of less than €100, 32 Trading Days (including the 14 just mentioned) showed changes of less than €5,000.

There was a greater instance of monetary change in the MIP300 to MIP1800 runs demonstrated in Figure 21 below. This also showed that Constraint Payments were more frequently increasing in the longer MIP runs. We noted 11 Trading Days where the change was greater than €50,000. Of these, seven Trading Days are among those Trading Days that never solved to within the 1% Optimality Gap.

This again would be in line with academic findings that when MIP does not complete to optimality, unusual solutions can be observed.

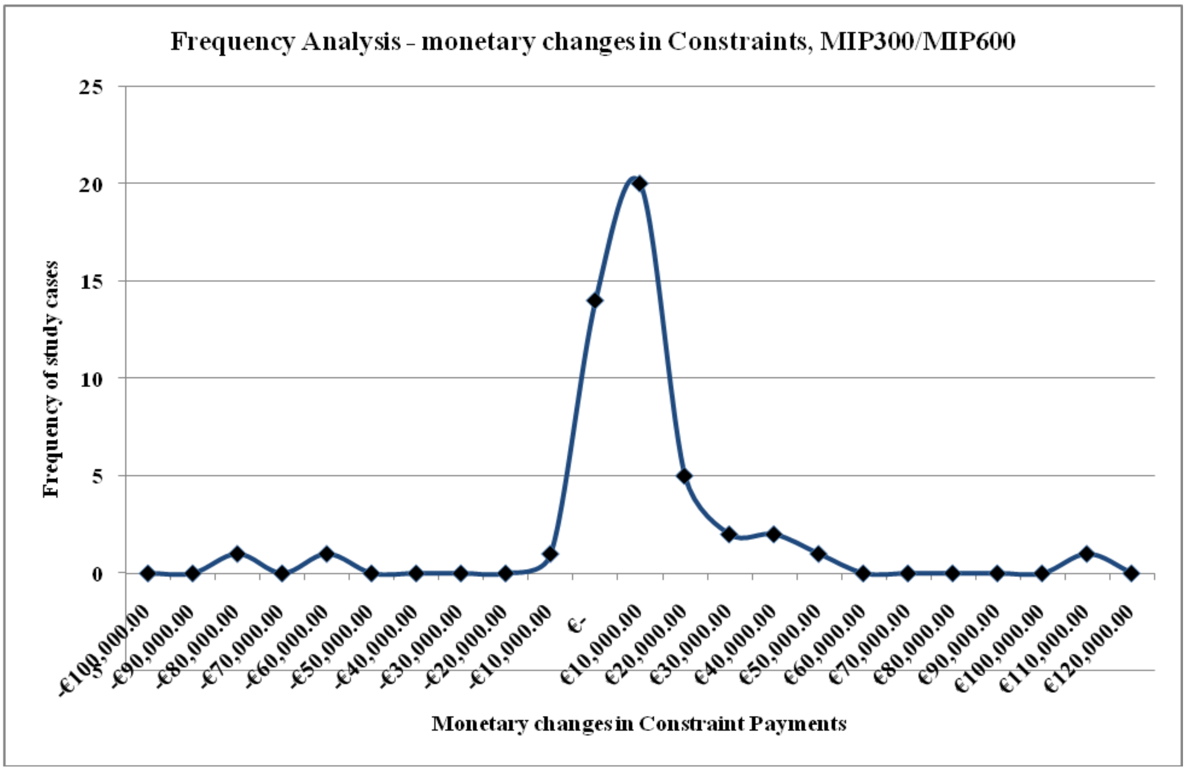

Figure 27 - Monetary Changes in Constraint Payments, MIP300 to MIP600

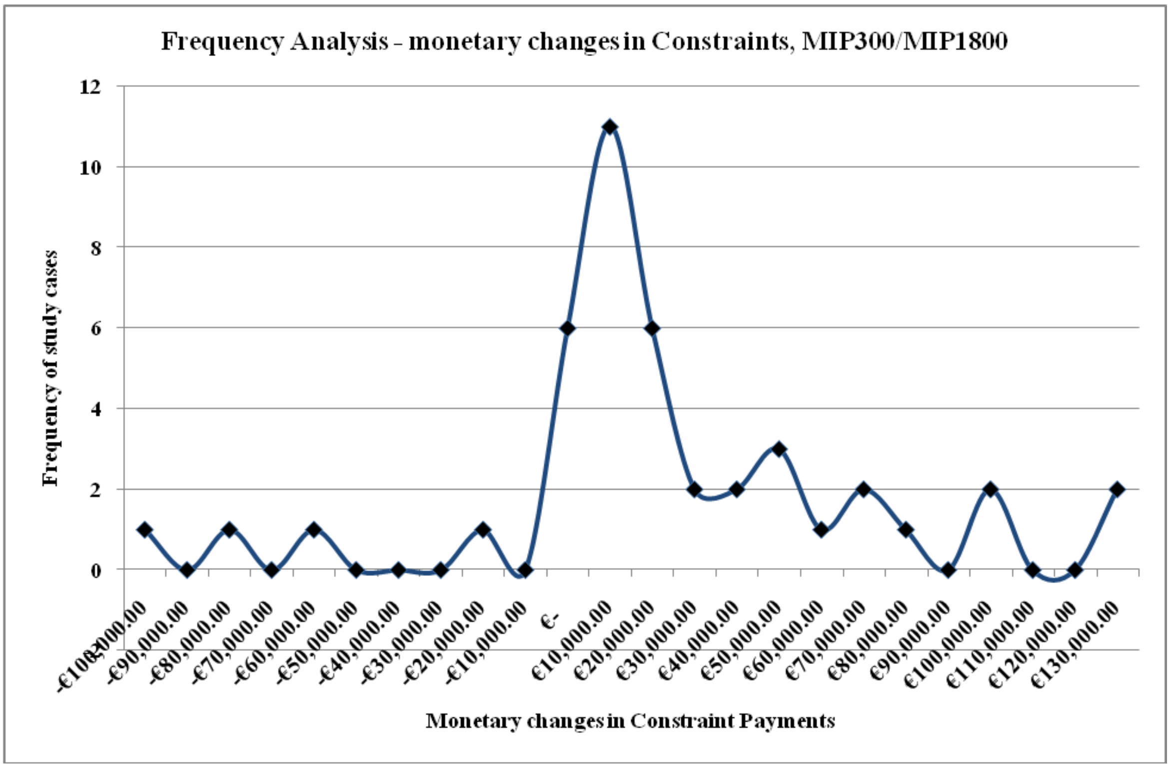

Figure 28 - Monetary Changes in Constraint Payments, MIP300 to MIP1800

Figure 22 below shows the average Constraint Payments made across the runs in total. While the MIP1800 runs did show more frequent increases and by larger amounts than the MIP600 runs, when taken as an average across all Trading Days, Constraint Payments are lowest with the longer run. Interestingly, on average Constraint Payments made under the MIP600 run would be higher than under the MIP300.

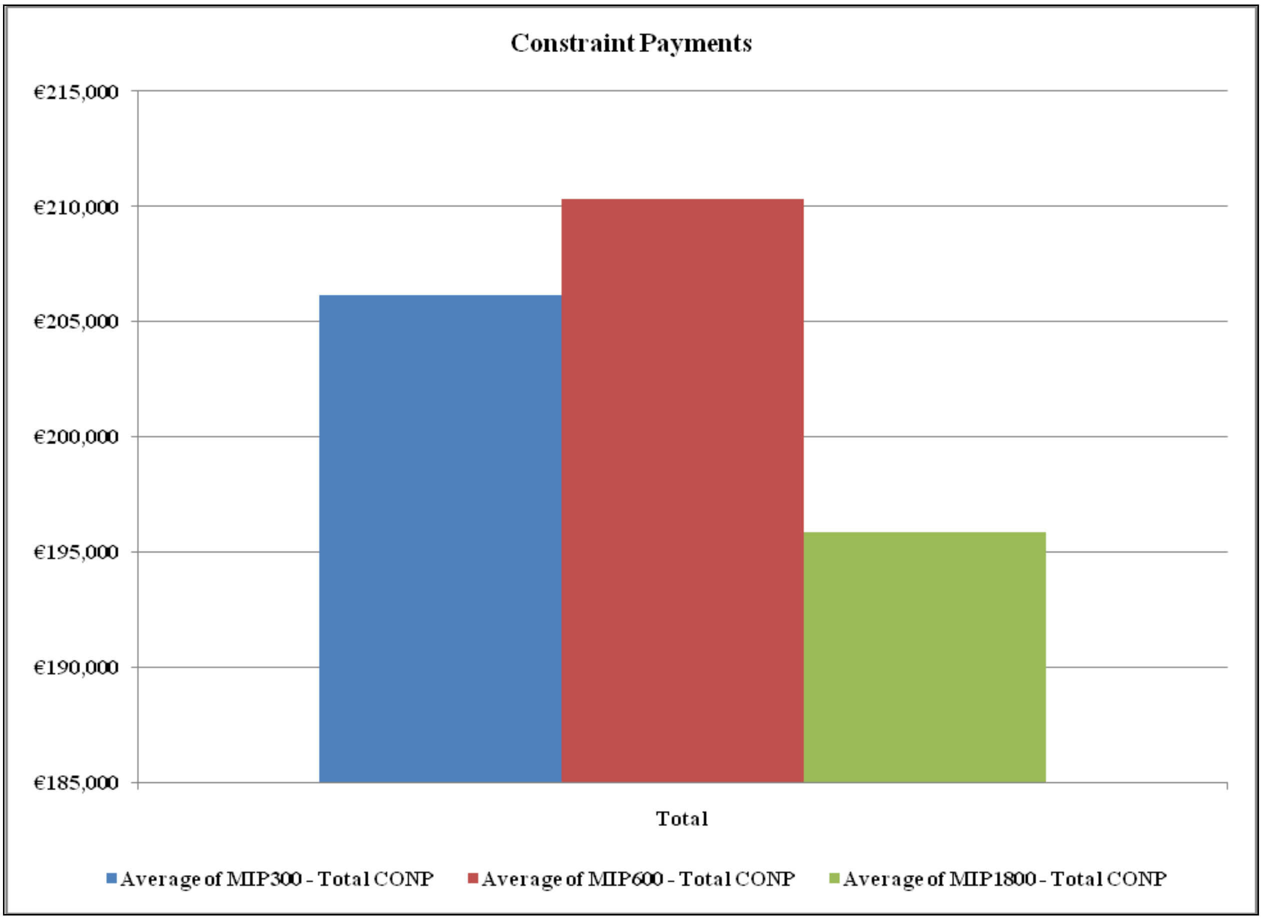

Figure 29 - Average Constraint Payments

However, in final review, the changes to Constraint Payments under MIP between the different timeout settings are not significant. The frequency analysis above indicates that between each of the settings large changes are exceptional and in general Constraint Payments to Generators do not vary to a major extent.

This indicates that the variance between how Generators are scheduled in the MIP runs with different timeout settings is not substantial.

6. Solution times

A key consideration when reviewing the MIP options is the solution time. Taking account of the tight timelines under which the SEM operates, it is essential that the solver selected for use as the MSP software should be able to produce quality solutions in a sufficient time so that operators can ensure accuracy of outputs and meet the publication timelines obligated in the Trading & Settlement Code.

While the LR program does not have specific timeout settings, the MIP program has configurable timeout settings. These are essential as with any optimisation problem, there is the potential for the program to take a considerable amount of time to reach a global optimal solution. As noted elsewhere, of the 154 study cases completed, 27 failed to solve to within 1% of optimality. Obviously, global optimal solutions exist for these study cases; however, it was not possible to find them within the time constraints we set upon ourselves when completing the study runs.

The settings of MIP300 and MIP600 are based on running the program for five and ten minutes respectively. This has been how the MIP program has been run by SEMO during other market studies and in the formulation of the SEM document, “MIP_policy_V4 0 - Use of MIP for Determination of Market Schedules”. We chose to run the program for 30 minutes as a version of an “open-ended” MIP run. This was done to assess how much longer it would take the program to produce an optimal solution and to review the quality of that solution compared to the one completed with the shorter timeout settings.

In essence, we wanted to see if study cases that had timed out at ten minutes would solve in an additional minute or two.

A 30 minute run of the program is only for study purposes and is not practical for daily operations of the SEM.

Figure 14 in the section on the Optimality Gap above has previously demonstrated the optimality measure of each study run across the 154 completed taking account of the solution times. This shows clearly that in the bulk of cases, good candidate solutions within the Optimality Gap were achieved within the time allocated when running the program for five minutes.

In terms of measure the success of the program at the different timeout settings, we have observed the following -

Timeout Settings	*Study Runs completed*	*Solved to Optimality Gap*	*Success Rate*
MIP300	154	105	68.18%
MIP600	49	6	12.24%
MIP1800	42	18	42.86%

Table 1 - Solution Times review

The success rate of MIP when run with the five minute timeout setting is clearly notable. As commented earlier, for 69% of the MIP300 study cases that did not achieve a solution within the convergence tolerance within the five minute setting, the performance in terms of MSP Production Costs was still superior to that of the LR program.

Figure 29 below provides a graphical representation of the solution times noted for runs that were completed using the extended timeout settings. As such, the MIP300 time is noted here as a flat-line around the 300 second mark[10].

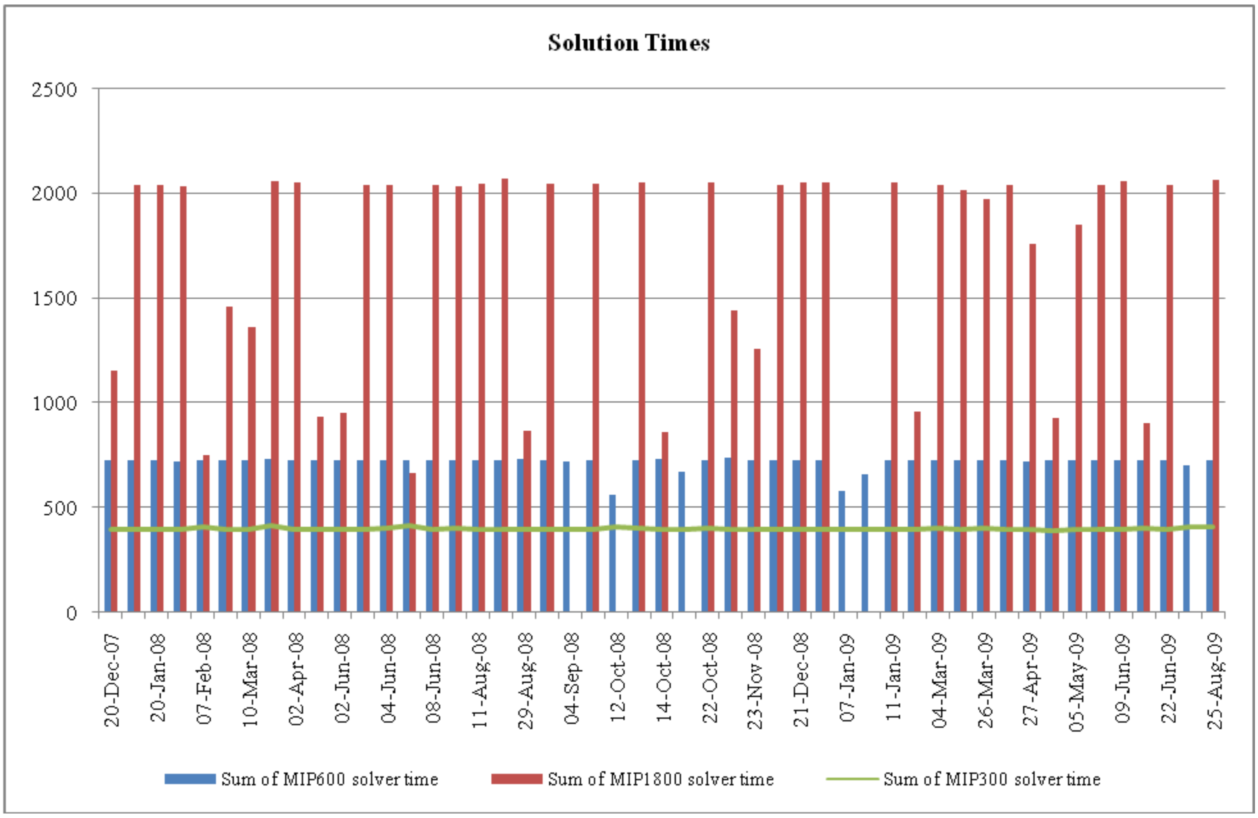

Figure 30 - Solution Times

In reviewing this, it can be noted that most study runs completed to the MIP600 timeout setting have a similar flat-line pattern with most timing out around the 730 second mark without achieving an optimal solution. While showing a greater level of success, the bulk of the MIP1800 runs can be noted to timeout around the 2000 second mark. Only nine cases produced solutions within 1000 seconds. Of these only four were within 900 seconds or fifteen minutes, a timescale that is impractical for market operations.

[10] The solution times observed are generally longer than the explicit limit of 300 seconds, 600 seconds or 1800 seconds. This is because the explicit limit is on the time allocated to unit commitment. Once this has elapsed, the program will continue some post processing for a short period beyond the stated limit. In this manner, solutions which timeout at 1800 seconds are observed to conclude after 2000 seconds.

3.5 Conclusion

To recap the findings of the comparison of the MIP study runs that were completed with additional running time –

- **MSP Production costs** - Although the longer run times provided for better MSP Production Costs, most solutions were within +/-1% of the original MIP300 study case.
- **Optimality Gap and Solution Times** - While running for longer times did improve on the Optimality Gap in all cases, taking an average across all study runs completed the MIP300 appears to out-perform the longer time settings by producing better levels of Optimality when it achieves solutions within the convergence tolerance. An observation is that in cases where the MIP300 did not achieve such a solution, in total only 50% of these ever solved to within the convergence tolerance when using the longer time settings. Only 20% of those that did not achieve this level of optimality using MIP300 solved within the Optimality Gap within a timeframe that could be considered practical for market operations.
- **System Marginal Prices and Consumer Costs** – The System Marginal Prices appear to reduce with the longer timeout settings. In most cases, the reduction is within 5% of the SMP value in the MIP300 study case. As the system load is fixed in all study runs, the reduction of the SMP generally led to a similar reduction in the Consumer Costs. In both instances, the MIP1800 runs showed better reductions in Consumer Costs and System Marginal Prices than the MIP600 but this change must be weighed against the practicality of running a version of the MSP software for 30 minutes or more. It also needs to be noted that decreasing Consumer Costs is not an objective function of the SEM rules.
- **Constraint Payments** - Barring some exceptions, the Constraint Payments that would be made under the longer runs were of the same order as those that would be made if the MIP300 were to be used. This indicates that the longer run times have no major impact, either positively or negatively, on these payments.

Taking the findings above, we gave some thought to how to measure the value of a solution. We approached this as taking the MSP Production Costs, Optimality Gap and solution time as the primary measures being as they are tied to the obligations the SEM must meet. Using the values returned from the study runs reviewed for this section, we derived a "Solution Value"[11]. We then completed a frequency analysis of this "Solution Value" shown below.

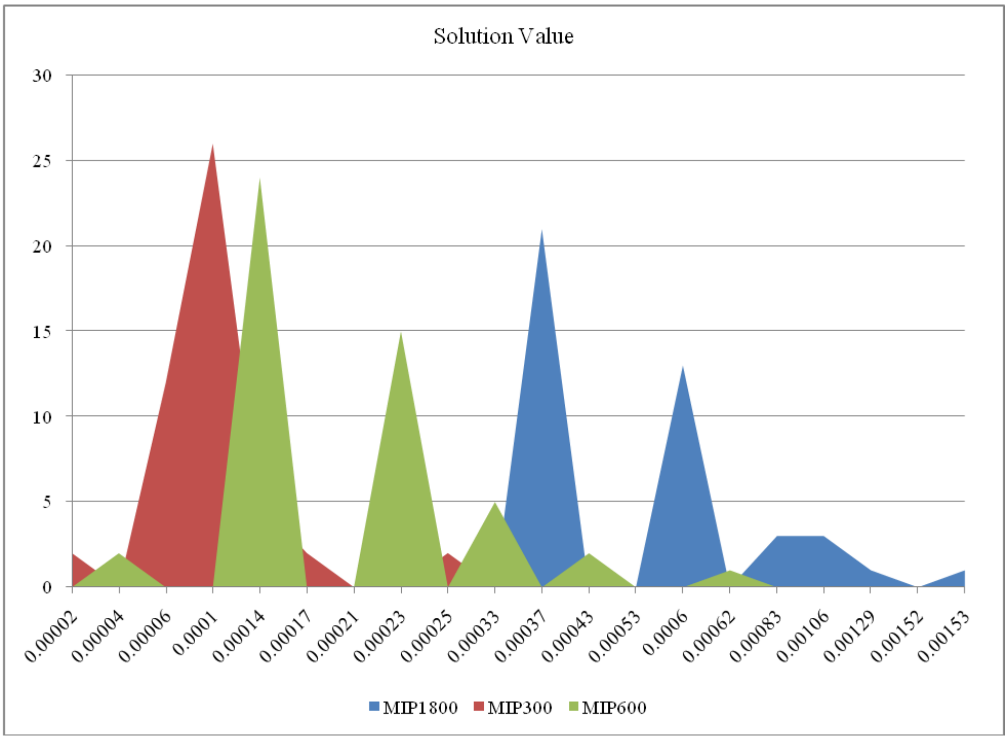

Figure 31 - Solution value

Figure 30 above shows that taking these three key inputs the MIP300 appears to have the best value for

[11] This was calculated by taking the solution time in minutes, dividing by the Production Costs, and then again by the Optimality Gap.

operations in the SEM.

Taking consideration of this and also the minimal impact noted on System Marginal Prices, Consumer Costs and Constraint Payments, a key conclusion is that the MIP solver run with the 300 second timeout setting provides good quality solutions within practical timeframes for daily market operations.

Based on this finding, we would recommend that for future SEM operations where the MIP solver is run that it is run using the 300 second timeout only.

Taking this conclusion, for the rest of this report on the comparison between the MIP and LR solvers, we will exclusively use the results of the MIP300 runs for these comparisons as it would be inappropriate to draw any conclusions on comparisons between MIP and LR if we included data derived using a software setting that we would not intend using in real market operations.

4 MSP Production Costs

4.1 Introduction

The objective of each run of the MSP software is set out in paragraph 4.67 of the Trading & Settlement Code. This objective is to "minimise the aggregate sum of MSP Production Costs for all Price Maker Generator Units over a given Optimisation Time Horizon". This is the core aim of the market solvers implemented in the SEM.

With this starting point, any study of the different solvers available to SEMO must concern itself principally with the impact on the MSP Production Costs. In this light, the value of MSP Production Costs has been recorded for all runs completed as part of this study. This chapter presents the findings of this review.

4.2 Executive Summary

A direct comparison of the solutions from the MIP and LR solvers, using MSP Production Costs as the sole metric indicates that the MIP solver performs better than the LR option; however, some other key points need to be considered.

- Although MIP does perform better than LR in most cases, LR has been observed to produce better solutions in almost 17% of study cases.
- In over 83% of study cases, the improvement in MSP Production Costs was within 1% from one solver to the other. Because MIP uses timeout settings and a tolerance setting for Optimality Gap, this means that the program will always terminate before reaching a global optimal solution. As a result, the comparison between MIP and LR is a comparison between two sub-optimal solutions.
- Small improvements in the MSP Production Cost can lead to large changes in the overall SEM outcomes with significant changes to Consumer Costs being observed.

The study has also examined the performance of the solvers relative to the margin in each study case and found that there is no correlation between these.

4.3 Background

The MSP software implemented in the SEM is made up of a number of phases. These follow the steps set out in paragraph N.16 of the Trading & Settlement Code, which reads –

> For each Trading Period h of the Trading Day, the MSP Software shall be used to calculate System Marginal Price (…), and the Market Schedule Quantity (…) for each Price Maker Generator Unit u that is not Under Test, as follows:
>
> <u>Step 1</u>
>
> Determine the Unit Commitment Schedule for each Price Maker Generator Unit that is not Under Test, including for each Pumped Storage Unit whether or not it is scheduled to pump or generate, in each Trading Period in the Optimisation Time Horizon;
>
> <u>Step 2</u>
>
> Taking the Unit Commitment Schedule as an input and therefore treating Start Up Costs, Shut Down Costs and No Load Costs as invariant, determine the Shadow Price (…) values and the Market Schedule Quantity (…) values for each Price Maker Generator Unit u that is not Under Test, for each Trading Period h in the Optimisation Time Horizon;
>
> <u>Step 3</u>

Calculate the Uplift (…) element of System Marginal Price for each Trading Period h in the Trading Day of the Optimisation Time Horizon, as set out in paragraphs N.64 to N.77 …; and

Step 4

Calculate System Marginal Price (…) for each Trading Period h in the Trading Day of the Optimisation Time Horizon

This has been implemented as three phases in the MSP software as follows -

- Unit Commitment, which produces a commitment schedule with basic MW quantities,
- Economic Dispatch, which produces Shadow Prices and final MSQs based on the input from the Unit Commitment phase, and
- Post Scheduling and Price Processing, which calculates Uplift and determines the final SMP.

The diagram below has been used previously to demonstrate the three phases within the software and the data inputs and outputs of each phase.

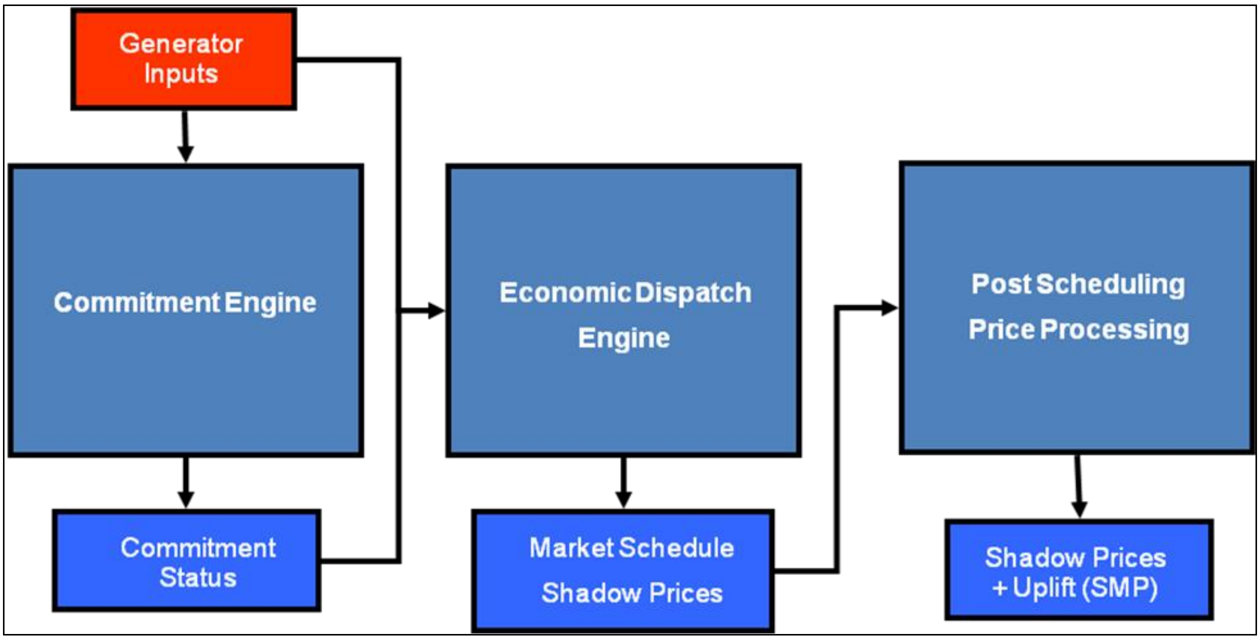

Figure 32 - Phases on the MSP software

The LR or MIP part of the program only applies with reference to the Commitment Engine. The Unit Commitment phase attempts to find an optimal commitment solution for the SEM based on input data, such as Generator technical offer data, commercial offer data (including Price Quantity pairs, Start Up Costs and No Load Costs) as well as the system demand, calculated as the MSP Schedule Demand in accordance of paragraph N 32 of the Trading & Settlement Code.

Because of the nature of optimisation software, it is common that the commitment solutions produced will not be the global optimal but more likely a local optimal solution (Salam, 2007). This is true of both LR and MIP solver options. It has been previously discussed that when using MIP solvers, which utilise Branch and Bound algorithms, that finding the true global optimal solution is dependent on solving the problem to completion and not using timeout or convergence tolerances (Sioshansi, 2008).

The practice of applying timeout settings and Optimality Gap limits to MIP algorithms is quite common and is used in the SEM as well as PJM[12] (Streiffret, Philbrick, Ott, 2005). This is because, despite the improvments in MIP performance over recent years (Bixby, Fenelon, Gu, Rothberg, Wunderling, 1999), allowing the solver to seach for a true global optimal solution is still not practical for real time operations of either markets or systems (Sioshansi, 2008).

Based on the commitment decisions of the Unit Commitment phase of the program, the Economic Dispatch will schedule megawatt quantities of output for Generators with the purpose of delivering the least cost Production Schedule. This is based on the inputs as given. Taking that the output of the Unit Commitment phase is likely to be a sub-optimal solution, the Economic Dispatch will produce the best solution based on these sub-optimal inputs. This does not make the final solution optimal, just that this phase of the problem produces optimal solutions based on a given set of inputs.

[12] Pennsylvania-New Jersey-Maryland Interconnection.

With the start-up decisions from the Unit Commitent phase and the MW of output scheduled in the Economic Dispatch phase, the MSP Production Costs can be determined.

While the MSP software produces the Unit Commitment Schedule from the first phase of the program based on the objective of minimising the aggregate MSP Production Costs, only the Unit Commitment Schedule is produced as output .The value used in this study as MSP Production Costs is the total cost based on the outputs of the complete MSP software run, that is, these Costs are calculated using the outputs of both the Unit Commitment and Economic Dispatch phases of the software.

4.4 Analysis

This section of the report is based on a review of 154 study cases based on Ex-Post Initial runs of the MSP software, run using both LR and MIP solvers. In the course of the study runs undertaken for this report, we have used the general timeout setting of 300 seconds on all cases and set the MIP Gap limit to 1% based on the value used in current SEM operations. We have undertaken a small number of further studies with the MIP Gap set to lower values to assess if this would impact on the solutions delivered. The results of these studies are discussed here. We also took the study cases that were stopped by the timeout setting before reaching the MIP Gap and ran these with the longer timeout settings of 600 seconds and 1800 seconds. The results of these studies are discussed here.

To demonstrate the trade off between finding the true global optimal solution and the practical solution, we took one of the study cases which had solved to the lowest Optimality Gap observed in the study, in a very short period of time. This observation was made in relation to the Trading Day of February 20th, 2008. The Optimality Gap noted for this study run was reported as 0.04% and this solved in 96 seconds. We altered the parameters for this run by setting the MIP Gap to 0%. This directs the MIP solver to go past the solution found at 0.04% to find the global optimal solution. As the original study had achieved its solution in 96 seconds, the timeout setting of 1800 seconds was used. The results are demonstrated below.

Study Type	*MSP Production Costs*	*MIP PC as a % of LR*	*Optimality Gap in MIP*	*Solution Time*
MIP300	€7,262,859.46	99.34%	0.04%	96 secs
MIP1800	€7,262,357.53	99.33%	0.03%	Stopped at 2081 secs

Table 2 - February 20th, 2008

This shows that although the MIP300 has delivered a very good solution, with improved MSP Production Costs over the LR solver, there is still a better solution available but within allowing for thirty minutes, the MIP solver was unable to achieve it. However, neither solution provided by the MIP solver is the global optimal solution with both being a small fraction of a percentage away. It must be acknowledged that regardless of the solver utilised in the SEM, the commitment solution is in practical terms likely to be always sub-otpimal.

In reviewing the 154 study cases completed, the MIP solver produced a solution with cheaper Prodcution Costs on 128 occasions or 83.117% of the total studies.

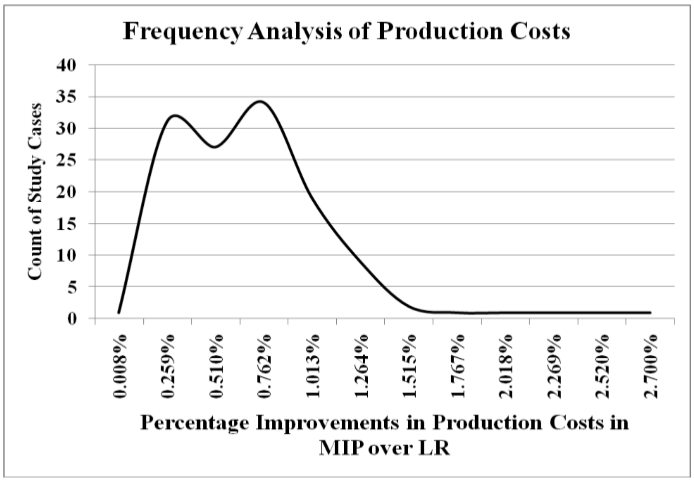

Figure 33 - Improvement in MSP Production Costs

Figure 33 demonstrates a frequency analysis of the improvements in the MSP Production Costs that have been observed in the 83.117% of cases where MIP has produced a better solution.

As can be noted here, although all study cases represented an improvement, the scale of the improvement can be quite small with most cases falling between 0 and 1% with a substantial number of cases (58) between 0 and 0.5%. The average improvement across all cases where MIP performed better was 0.591%.

In monetary terms, the daily average improvement noted was €35,356.

Taking account of the economic downturn noted over recent years, we have separated this into two values. The average improvement on MSP Production Costs in solutions from the MIP solver over the LR runs for Trading Days before February 2009 was € 38,097. The average improvement for Trading Days from February 2009 onwards was € 24,603.18[13].

The maximum observed improvement in MSP Production Costs is € 194,478.75 with the minimum being €456.52. Both the max and min values of improvement noted occurred in the period before the economic downturn became apparent in the SEM.

With respect to the remaining 26 study cases, the MSP Production Costs from the LR study cases were cheaper than those observed in the MIP runs. The average reduction in MSP Production Costs where LR performed better was 0.88%. 15 of the 26 study cases showed a reduction of less than 1%.

In terms of monetary changes, the average improvement across all cases was €41,509. As per our note above, splitting this between Trading Days from before the economic downturn and those after, the average for the cases before February 2009 was €34,586 and for cases after this point was €49,585.70. The higher average in the period from February 2009 is partially attributable to a large number of study cases in March 2009, which were completed as a block of consecutive Trading Days (see the section on Consecutive Days here). In this block, on seven out of eleven Trading Days the LR solver produced better results than the MIP including one study case, which had the single largest percentage improvement in MSP Production Costs for LR over MIP.

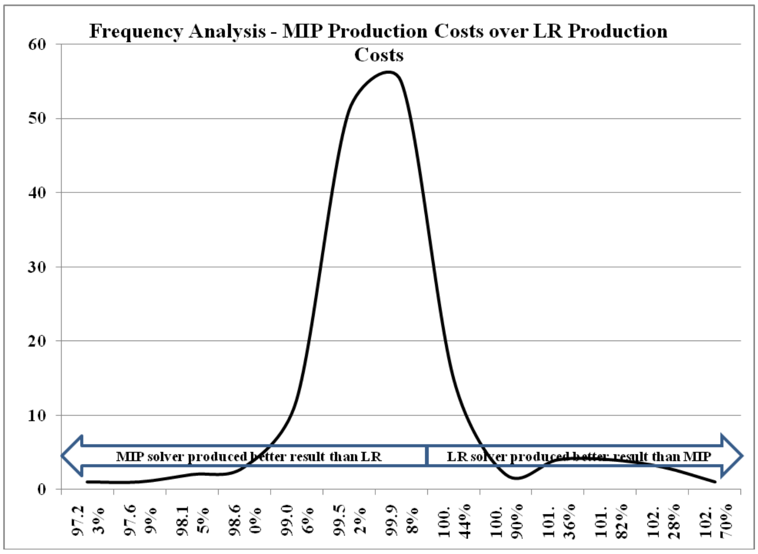

Figure 34 - Frequency analysis of solver performance, based on MSP Production Costs

Figure 34 shows the results of a frequency analysis of the solver performance. Using the metric of expressing the MSP Production Costs from the MIP study case as a percentage of those from the LR solver, this shows a larger block of study cases where the MIP performance was better than the LR.

However, there are still a number of cases where the LR performance was better. Also worthy of note is that most for most study cases, the variance between the two solvers was less than +/-1%.

While the number of cases where LR performed better than MIP is small (only 16.88%), it is noteworthy that out of these 26 cases 11 produced a cheaper Production Cost solution with LR where the MIP solution had achieved a solution within the Optimality Gap setting.

Trading Day	*MSP Production Costs in LR*	*MSP Production Costs in MIP*	*MIP MSP Production Costs as a % of LR*	*Optimality Gap*
01-Feb-08	€7,706,785.82	€7,716,434.56	100.125%	0.64%
13-Mar-08	€7,767,033.51	€7,770,717.92	100.047%	0.62%
05-Jun-08	€8,560,471.07	€8,597,920.05	100.437%	0.97%
17-Jul-08	€7,265,929.26	€7,287,333.48	100.295%	0.61%
06-Sep-08	€6,036,861.12	€6,056,271.31	100.322%	0.27%
07-Sep-08	€6,924,594.62	€7,016,998.61	101.334%	0.99%
19-Dec-08	€5,376,465.29	€5,378,191.91	100.032%	0.48%
09-Mar-09	€4,119,977.67	€4,177,497.10	101.396%	0.92%
10-Mar-09	€4,205,118.02	€4,291,796.97	102.061%	0.68%

Table 3 - Study cases where LR exceeded "optimal" MIP solutions

This further demonstrates the observation noted above that the MIP solver as utilised in real market operations does not achieve the global optimal solution. In the cases noted above, despite finding good

[13] February 2009 has been selected as a boundary of the economic downturn and is used elsewhere in this report when comparing monetary values across all study cases. This is based on the observed large drop in the load weighted average daily System Marginal Price from this point onwards.

optimal solutions using the MIP solver, the LR solver was able to find a better solution in the 26 study cases, closer to the global optimal. Of the 154 study cases reviewed here, 82.46% (127) of these had solutions where the MSP Production Costs from the LR solution were within +/-1% of those from the MIP solution. 46.1% of the cases had differences of +/-0.5%. Only six cases (or 3.89%), had differences of greater than +/-2%. The smallest variance between the two solvers was 0.008%, observed in two study cases, in January 2008 and January 2009. However, despite the MSP Production Costs being within a few hundred Euros in these cases, the overall solutions were vastly different with significantly higher Consumer Costs with the MIP run in both cases. Table 4 below demonstrates some of the key changes, noting that the variance between the two solutions is over 4% using the measure of SRT[14] to compare schedule outcomes.

January 19th, 2008	*LR*	*MIP*	*% Variance*
Consumer Costs per Trading Day	€8,184,122.98	€8,532,460.51	-4.26%
Average SMP	€73.33	€76.46	
Maximum SMP	€333.64	€328.90	
MSP Production Costs	€6,486,905.28	€6,486,355.37	.0.008%

Table 4 - Outcome comparison for January 14th, 2009

Table 5 below shows the same comparison for January 14th 2009. Here the SRT variance is over 10%.

January 14th, 2009	*LR*	*MIP*	*% Variance*
Consumer Costs per Trading Day	€6,853,581.82	€7,634,819.63	-11.399%
Average SMP	€57.64	€63.32	
Maximum SMP	€151.38	€156.94	
MSP Production Costs	€5,676,522.43	€5,676,065.91	0.008%

Table 5 - Outcome comparison for January 14th, 2009

Table 6 shows the impact on individual Generator Units. A combination of different commitment and scheduling options between the two solutions, along with variances in the final System Marginal Prices, results in significant changes for Generators as a whole with individual units showing considerable change in payments.

Generator Revenues	*19 January 2008*	*14 January 2009*
Max Increase	€20,497.71	€55,896.85
Max Reduction	-€51,679.03	-€64,597.02
Average Change	€4,572.11	€8,309.28
Total Changes[15]	€489,216.03	€889,092.90

Table 6 - Impacts on Generator revenue

This demonstrates that although both solvers achieved a similar level of optimality, the impact on the market revenue is substantial. The System Load and total Actual Availability for these Trading Days is shown in figures 35 and 36 below.

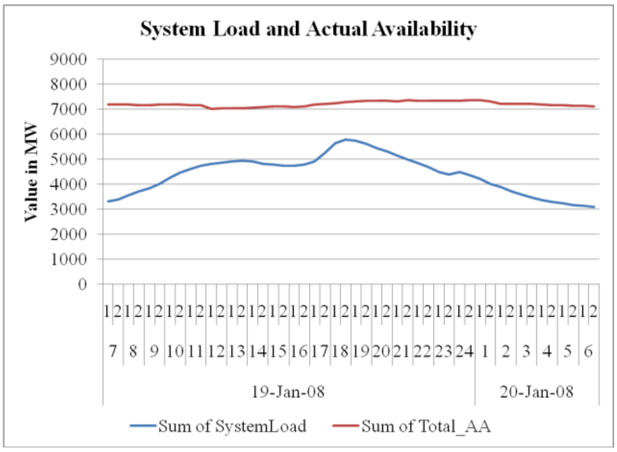

Figure 35 - 19th Jan 2008

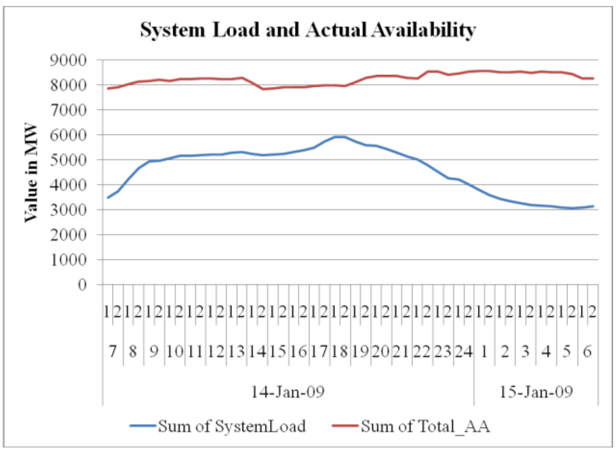

Figure 36 - 14th Jan 2009

[14] The SRT or Settlement Recalculation Threshold, currently set at 3% in the SEM, is the measure of whether a schedule from the MSP software should be re-run if inputs are found to have been incorrect. Schedules where the changes are greater than 3% require a re-run of the market.
[15] Total changes are measured in absolute terms whereas changes in Consumer Costs are not absolute. Readers will note therefore that the value listed for changes to Generator revenue is not the same as the total changes to Consumer Costs.

A review of the input data for the two Trading Days revealed no specific reason for why the two solvers produced solutions with such similar MSP Production Costs.

Particular attention was given to the values of average daily margin[16] in these particular Trading Days. Figure 5 below demonstrates the value of average daily margin with the MSP Production Costs from the MIP study case expressed as a percentage of those from the LR study case, as used elsewhere in this report. This second value represents a measure of the performance of the LR solver against the MIP. A value of 100% would mean that MSP Production Costs in both solvers are the same. Values of less than 100% mean that the MIP solver was able to achieve a Production Cost that was that percentage of the LR outcomes. Equally, a value of greater than 100% means the MIP solver solution was more expensive than the LR outcome by that ratio. As such, the higher this value, the better the LR solver has performed relative to the MIP.

On an initial review, peaks in the average daily margin would appear to correspond to dips in the second value. This led us to consider whether the LR solver performs better with lower margins.

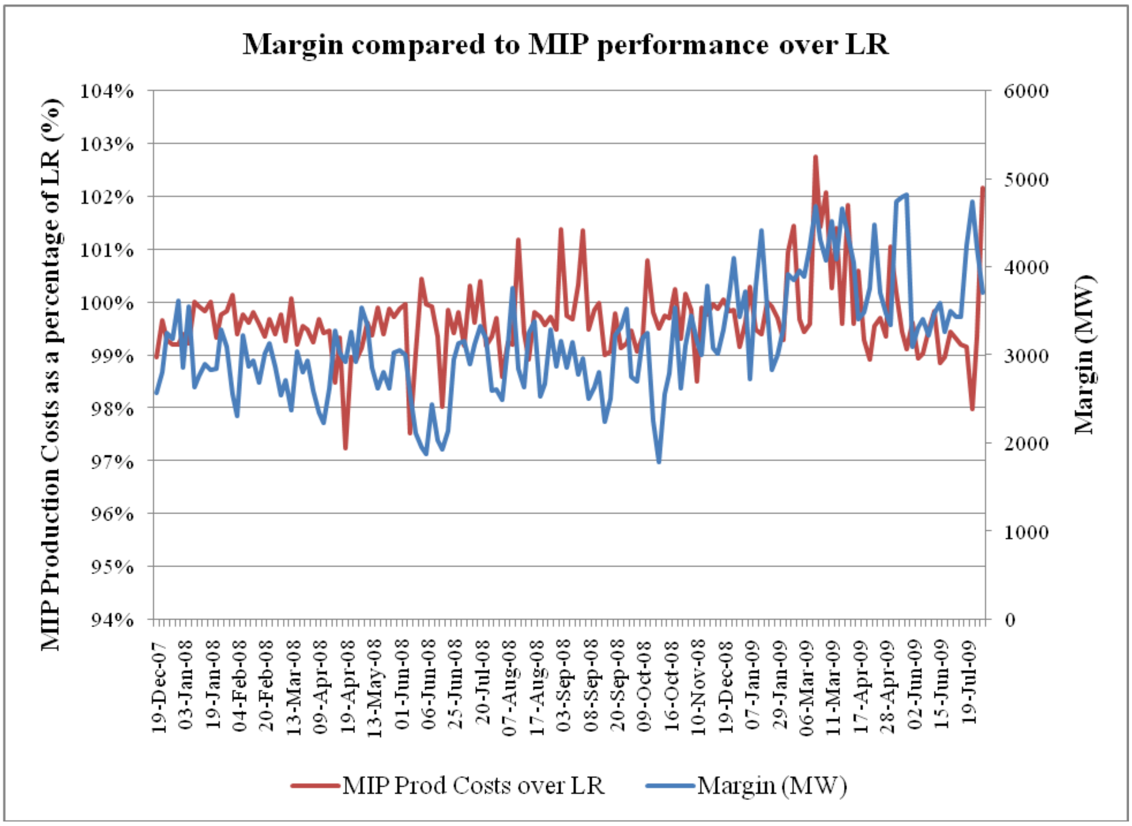

Figure 37 - Average Daily Margin compared with solver performance

We further investigated this by expressing the megawatt value of the average margin as a percentage of the average availability. This is demonstrated in figure 38 below.

[16] This was calculated as the difference between the average Actual Availability across the Trading Day and the average System Load.

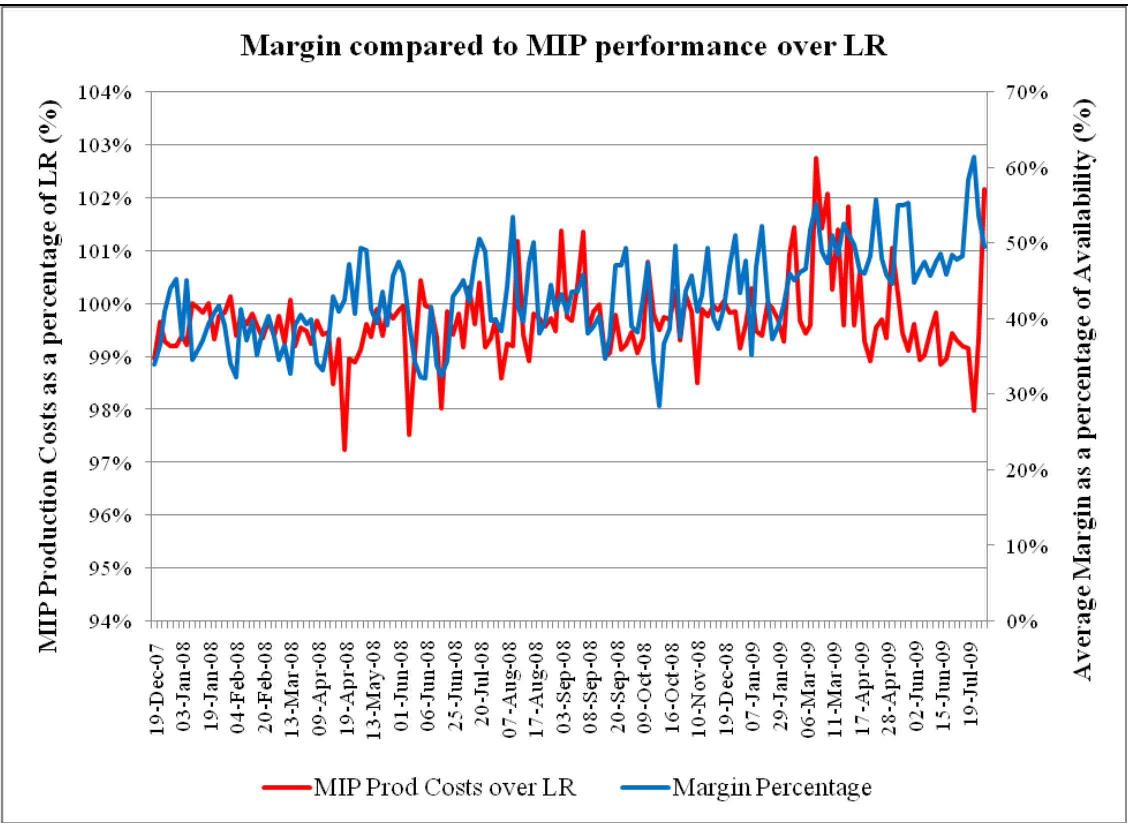

Figure 38 - Average Daily Margin as a percent compared with solver performance

While a pattern of peaks and dips in the two data sets can still be observed, expressing the margin as a percentage rather than using the absolute megawatt value demonstrates that there is no discernible relationship between the system margin and the performance of the LR solver.

In total across the study cases completed, the two solvers produced similar results in terms of MSP Production Costs with few large variances being observed further demonstrated in figure 38 below.

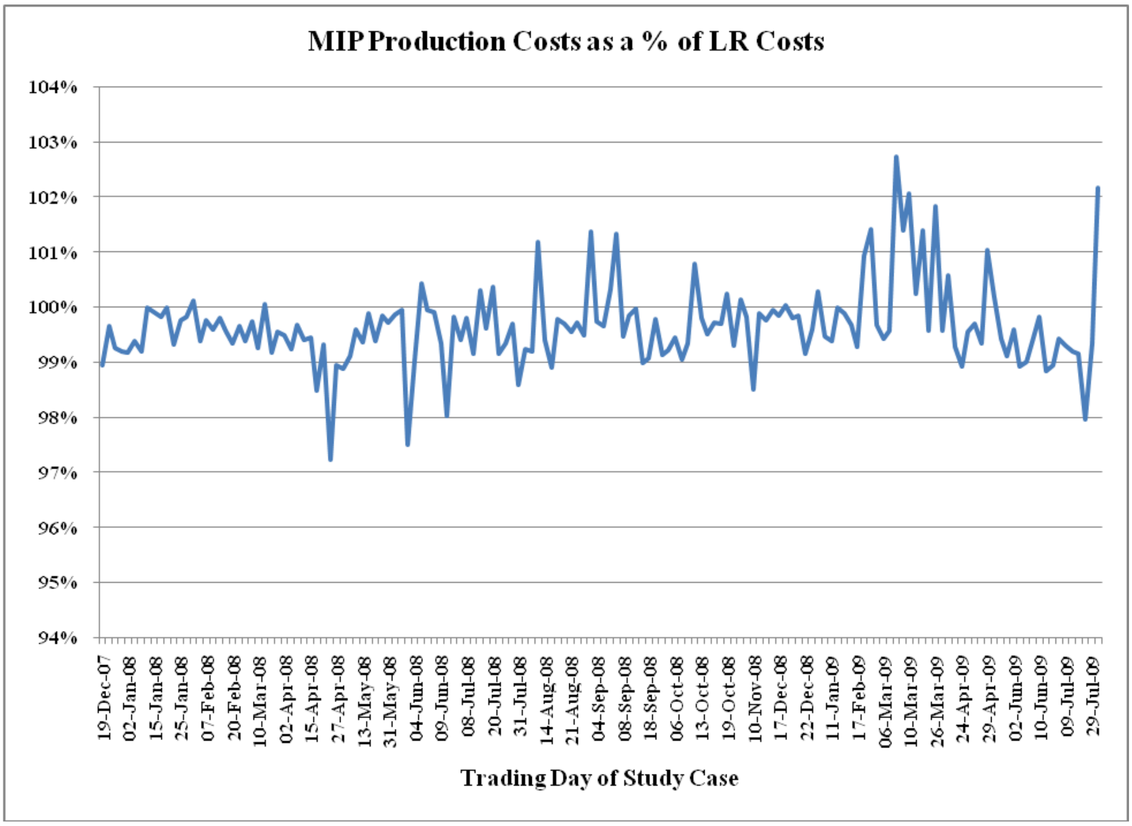

Figure 39 - MSP Production Costs from MIP as a % if LR Costs

In the figures below as with elsewhere in this report, the whole series has been divided in 3 graphs for ease of illustration - Graph1 2007 to May 2008; graph2 June 2008 to Dec 2008; graph3 Jan 2009 to Aug 2009. The following graphs show a comparison between the MSP Production Costs for the different solvers.

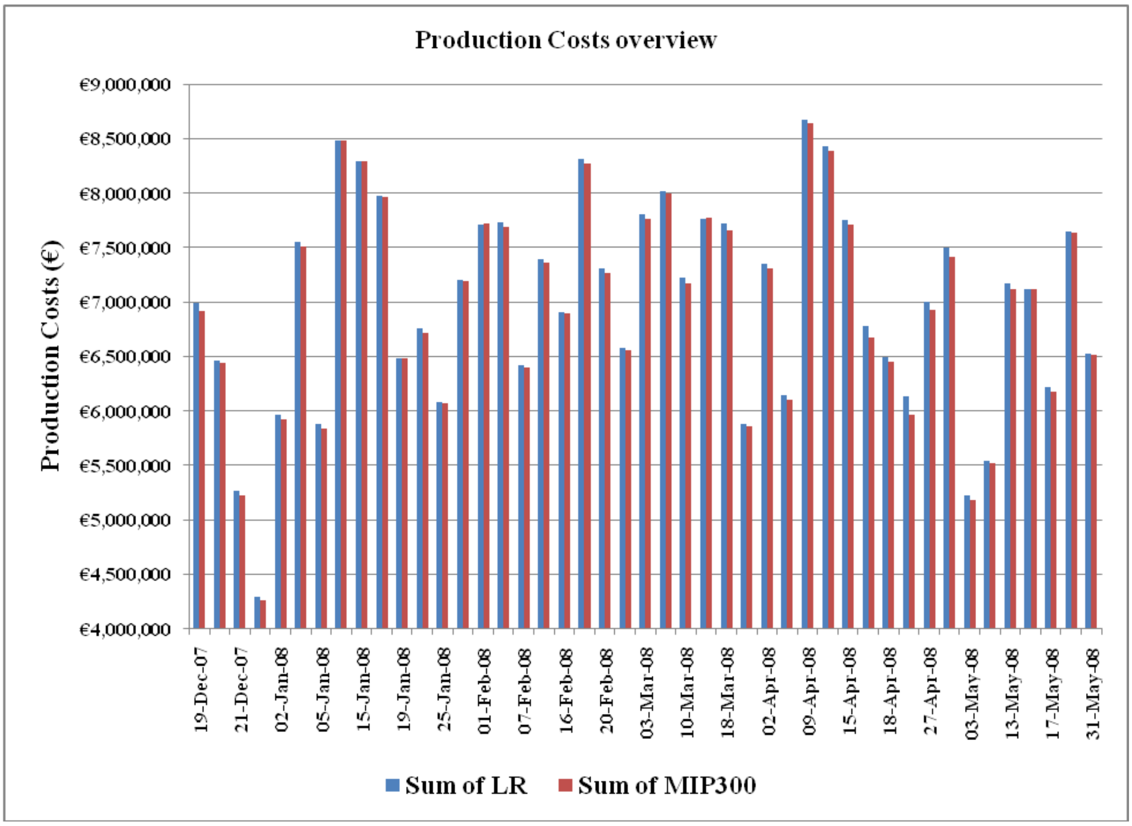

Figure 40 - MSP Production Costs comparison, 2007 to May 2008

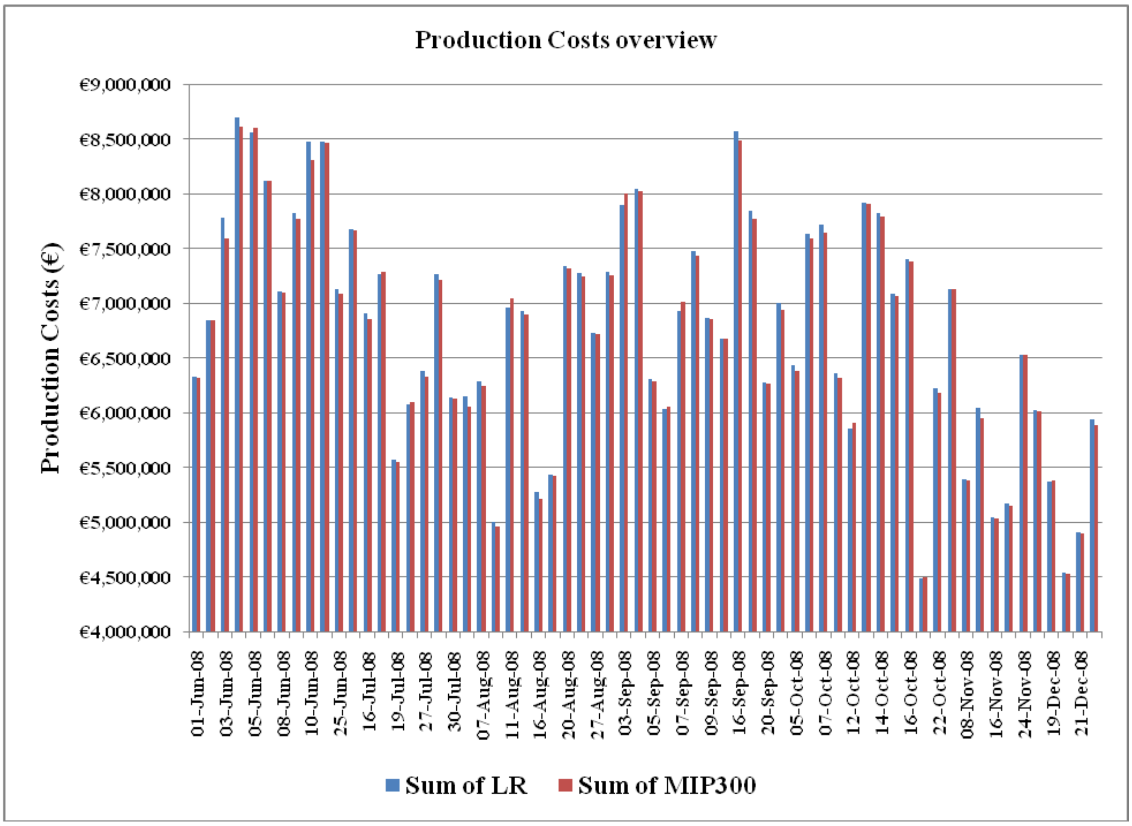

Figure 41 - MSP Production Costs comparison, June 2008 to Dec 2008

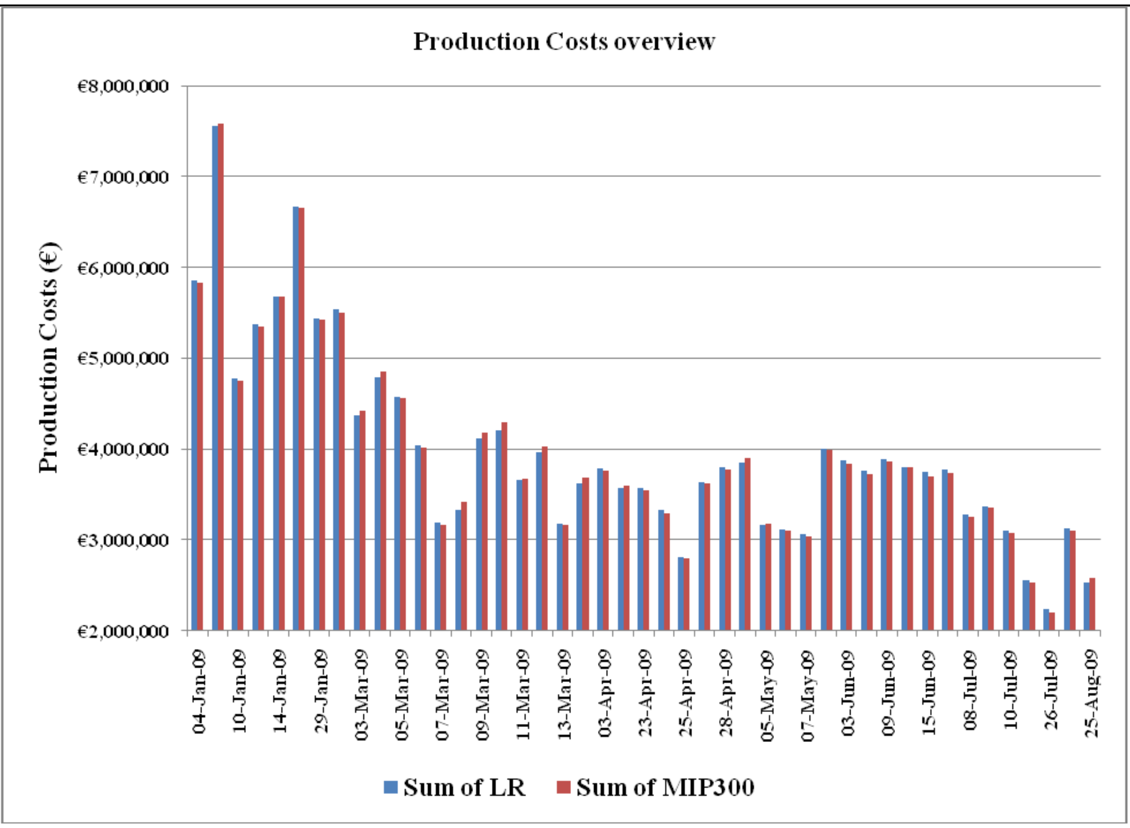

Figure 42 - MSP Production Costs comparison, Jan 2009 onwards

4.5 Consecutive Days

Within the study, we set aside blocks of Trading Days that were to be run in sequence. The purpose of this was to ascertain the impact of the choice of solver would have on the MSP Production Costs as the market solutions evolved over a number of days. The consecutive blocks ranged from as short as four days up to eleven days in length.

The key part of running the MSP software over consecutive days is that the ending conditions of a study case must be carried forward into the initial conditions of the next Trading Day in the block. We reset the initial conditions in three of the six blocks that we will review.

In reviewing the findings, we observed no evolving trends with respect to running days in blocks as opposed to running stand-alone study cases. Most of the blocks followed the same pattern as the rest of the study with MIP performing better than LR in most cases but with the overall variance in MSP Production Costs following the norms observed elsewhere though some of the larger variances noted in the overall study occurred within these consecutive day blocks (notably the block in March 2009 which contained five out of the eight largest observed variances between the two solvers).

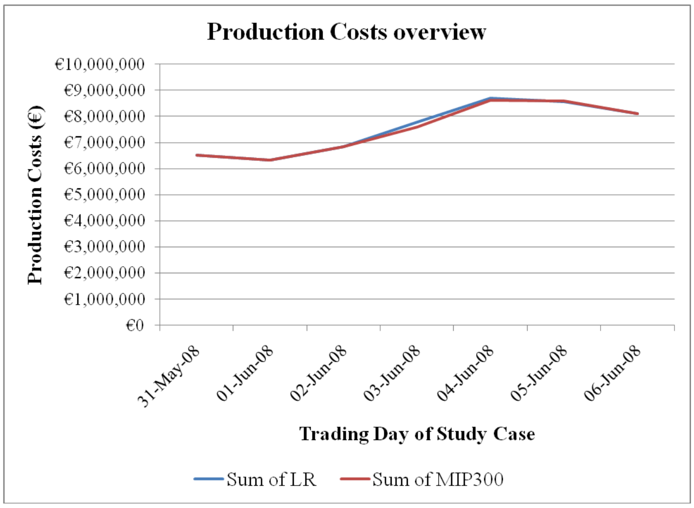

Figure 43 - Consecutive day review, Block 1

Trading Day	*LR Production Cost*	*MIP Production Costs*
31-May-08	€ 6,528.97K	€ 6,510.06K
01-Jun-08	€ 6,327.12K	€ 6,318.34K
02-Jun-08	€ 6,846.43K	€ 6,842.8K
03-Jun-08	€ 7,783.52K	€ 7,589.04K
04-Jun-08	€ 8,694.97K	€ 8,610.1K
05-Jun-08	€ 8,560.47K	€ 8,597.92K
06-Jun-08	€ 8,115.51K	€ 8,111.95K

Table 7 - Block 1, values in thousands

The average variance across the first block was 0.5%. On one of the Trading Days, the LR solution was better than the MIP by 0.43%. Within this block, June 3rd 2008 had a high variance of 2.5%.

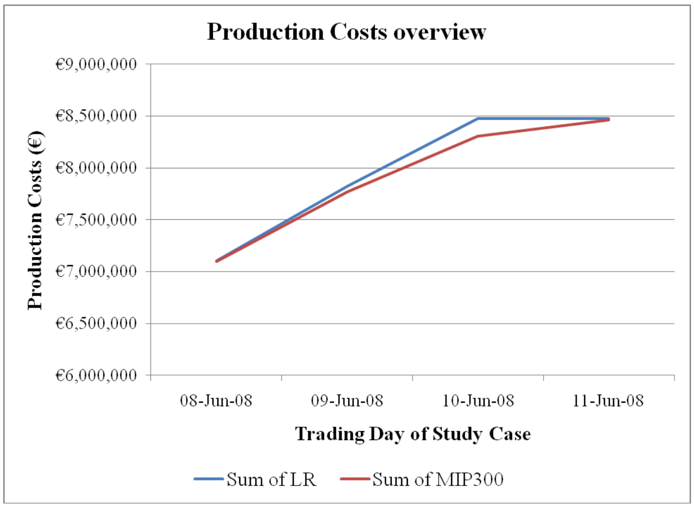

Figure 44 - Consecutive day review, Block 2

Trading Day	*LR Production Cost*	*MIP Production Costs*
08-Jun-08	€ 7,106.37K	€ 7,099.82K
09-Jun-08	€ 7,823.22K	€ 7,771.42K
10-Jun-08	€ 8,473.65K	€ 8,305.36K
11-Jun-08	€ 8,473.65K	€ 8,459.38K

Table 8 - Block 2, values

The average variance across the second block was 0.727%. In this block, all MIP solutions were better than the LR. The average optimality gap was 1.03; however, there was no evidence of the solution getting better or evolving over time as the Optimality Gap on June 10th was higher than that on June 9th.

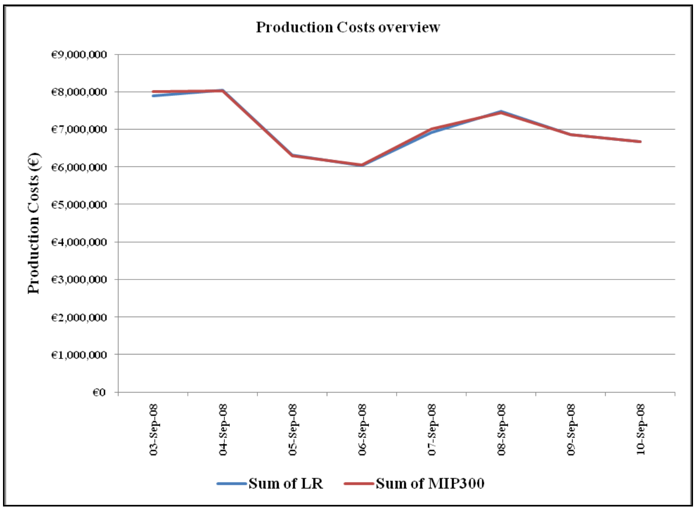

Figure 45 - Consecutive day review, Block 3

Trading Day	*LR Production Cost*	*MIP Production Costs*
03-Sep-08	€ 7895K	€ 8002.44K
04-Sep-08	€ 8043.32K	€ 8022.03K
05-Sep-08	€ 6307.74K	€ 6286.21K
06-Sep-08	€ 6036.86K	€ 6056.27K
07-Sep-08	€ 6924.59K	€ 7017K
08-Sep-08	€ 7476.78K	€ 7436.68K
09-Sep-08	€ 6867.85K	€ 6856.5K
10-Sep-08	€ 6676.96K	€ 6675.41K

Table 9 - Block 3, values

The average variance across this block was 0.211% with the average optimality gap being 1.01%. Of the eight study cases, in five the MIP solutions were better with the LR being better in the remaining three, including one case where the MIP solution had an Optimality Gap of 0.27%. Again, there is no observable pattern of improvement across this group. The first study case had a better LR solution and, although the last case of the block had a better MIP solution, the variance between the two for this case was only 0.023% (just over €1,500). The trend of the MSP Production Costs across this block seems to demonstrate further the closeness in quality between the two solvers.

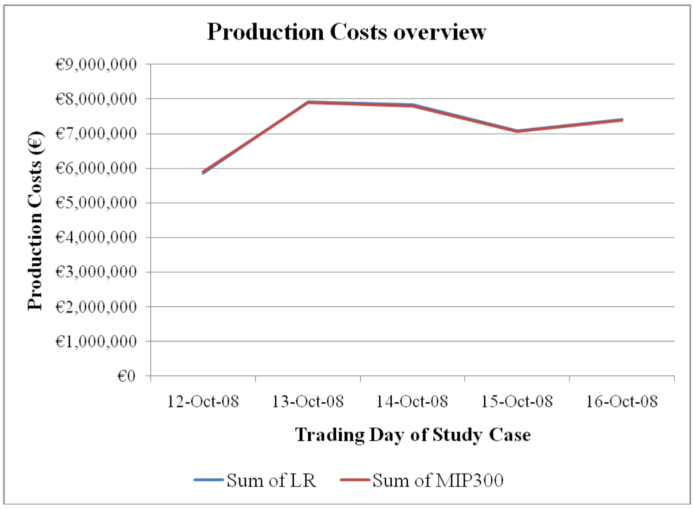

Figure 46 - Consecutive day review, Block 4

Trading Day	*LR Production Cost*	*MIP Production Costs*
12-Oct-08	€ 5,859.55K	€ 5,904.94K
13-Oct-08	€ 7,918.25K	€ 7,901.78K
14-Oct-08	€ 7,825.72K	€ 7,786.44K
15-Oct-08	€ 7,081.09K	€ 7,061.37K
16-Oct-08	€ 7,406.72K	€ 7,383.65K

Table 10 - Block 4, values

The average variance across the fourth block was 0.105%. In this block, the LR solution on the first Trading Day was better than the MIP; however, for all other Trading Days the MIP solution was the better. While the Optimality Gap showed a trending improvement across this block, the trend did not persist with the gap on the last day of the block being higher than the previous Trading Day and therefore a disimprovement.

This block is also interesting in the context of the next block, March 3rd to March 13th 2009. In this fifth block, in seven of the eleven study cases the solution from the LR solver had lower MSP Production

Costs than those from the MIP solver. As with block 4, on the first Trading Day of the block, the LR solver performed better than the MIP solver. The first two days have better LR solutions while the next three have better MIP outcomes. The following five Trading Days have better LR solutions again. This set includes four Trading Days where LR performed better than MIP even when MIP surpassed its tolerance setting for Optimality.

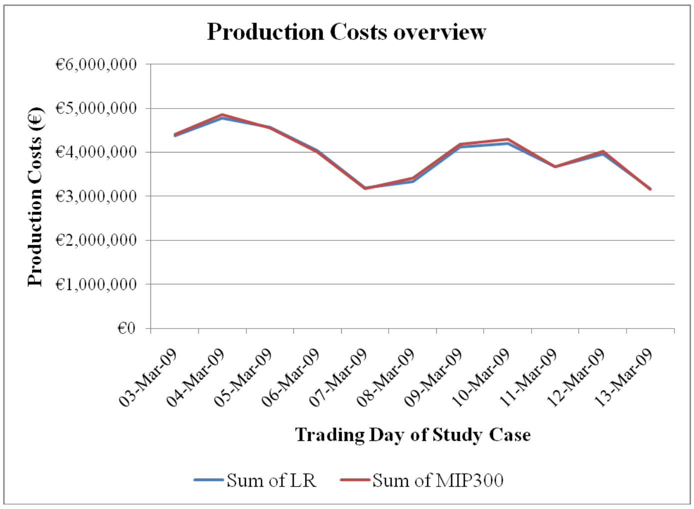

Figure 47 - Consecutive day review, Block 5

Trading Day	*LR Production Cost*	*MIP Production Costs*
03-Mar-09	€ 4,375.28K	€ 4,416.06K
04-Mar-09	€ 4,784.02K	€ 4,852.09K
05-Mar-09	€ 4,576.23K	€ 4,561.32K
06-Mar-09	€ 4,034.23K	€ 4,011K
07-Mar-09	€ 3,183.56K	€ 3,170.11K
08-Mar-09	€ 3,328.48K	€ 3,419.48K
09-Mar-09	€ 4,119.98K	€ 4,177.5K
10-Mar-09	€ 4,205.12K	€ 4,291.8K
11-Mar-09	€ 3,663.83K	€ 3,672.74K
12-Mar-09	€ 3,967.79K	€ 4,023.09K
13-Mar-09	€ 3,175.99K	€ 3,162.56K

Table 11- Block 5, values

Even reviewing the Optimality Gap from the MIP runs alone, this demonstrates that the solutions do not evolve across time. Each Trading Day/Optimisation Horizon is clearly a discrete problem for the MSP software, regardless of the solver chosen.

Figure 16 demonstrates this by illustrating the Optimality Gap trend across Block 5. Any improvement perceived cross the first four days is lost with reverse in the trend on the fifth and sixth days, a trend repeated on the tenth day of the block.

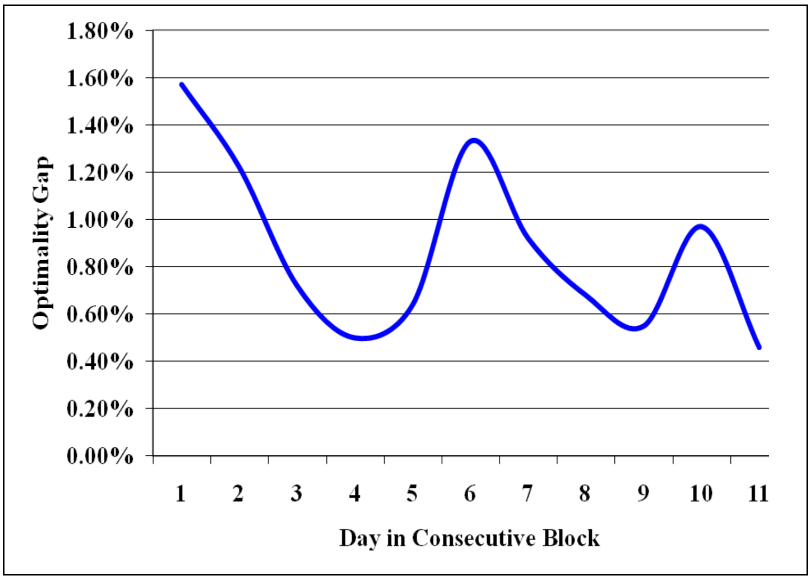

Figure 48 - Optimality Gap in Block 5

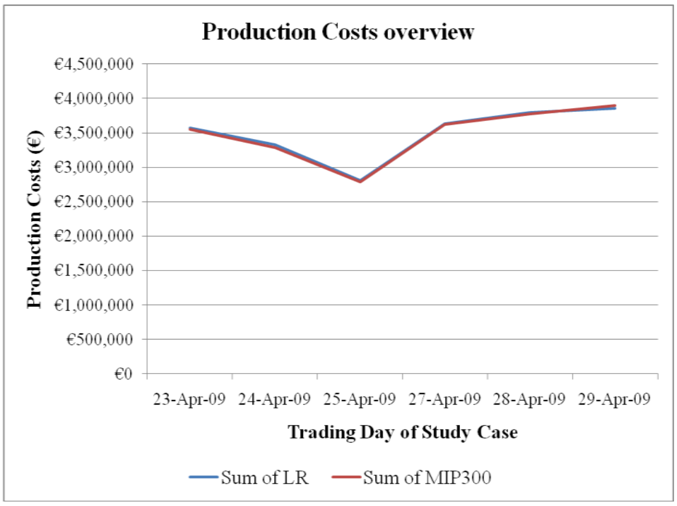

Figure 49 - Consecutive day review, Block 6

Trading Day	*LR Production Cost*	*MIP Production Costs*
23-Apr-09	€ 3,572.71K	€ 3,546.56K
24-Apr-09	€ 3,325.54K	€ 3,289.35K
25-Apr-09	€ 2,805.15K	€ 2,792.31K
27-Apr-09	€ 3,636.9K	€ 3,625.92K
28-Apr-09	€ 3,798.29K	€ 3,773.4K
29-Apr-09	€ 3,855.59K	€ ,3895.49K

Table 12 - Block 6, values

In the sixth block, MIP performed better than LR except for the last Trading Day. For this study case, the Optimality Gap was 2.54 which was the tenth highest gap noted in the entire study. The average variance between the solvers was 0.36% (though this is 0.65% when excluding the last study case).

Table 12 below summarises the results of the review of consecutive blocks. In this table, average changes are expressed subject to the direction of the change as opposed to the commentary above. In other words, rather than calculating an overall percentage variance between the solvers regardless of which performed better, here we calculate the percentage variance by which LR performed better than MIP when it performed in such a manner and the same of the MIP relative to LR.

Consecutive Block	*LR (average improvement over MIP)*	*MIP (average improvement over LR)*	*Initial Conditions Reset*
Block 1	0.44%	0.67%	Y
Block 2	-	0.73%	N
Block 3	1.09%	0.27%	Y
Block 4	0.77%	0.33%	N
Block 5	1.45%	0.44%	Y
Block 6	1.03%	0.65%	N

Table 13 - Performance of solvers on consecutive blocks

This data is presented graphically in Figure below.

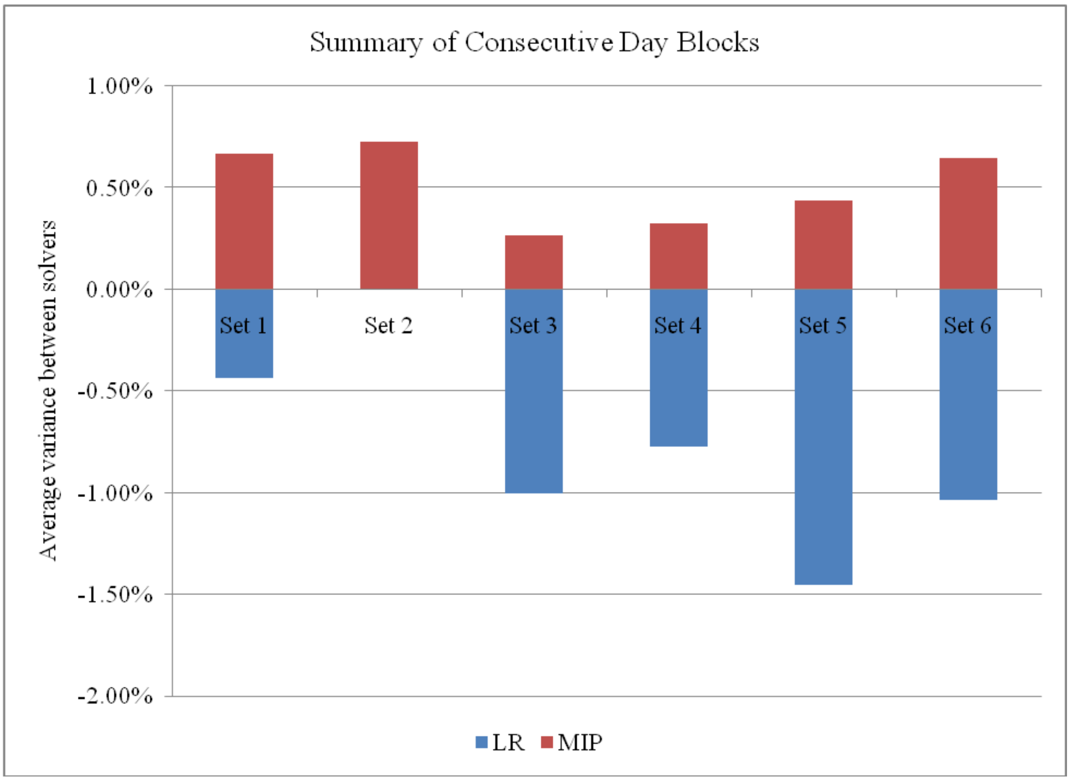

Figure 50 - Performance of solvers on consecutive blocks

In this section, we set out to see if using the same solver over a number of consecutive study cases with initial conditions carried forward would result in better solutions evolving over a number of Trading Days. Considering that each study case run using the MIP solver had as its starting point the end state from a previous LR study (as all our study cases were based on original market solutions from the SEM), we were interested to see if the performance of the MIP solver would evolve after a period of days to produce even better solutions.

In summary, the study has found no evidence that the choice of solver could result in better market solutions evolving over time. Instead, each study case is distinct unto itself. Despite initial conditions always carried being forward from case to case, even in normal operations, the MSP software does solves each study exclusively.

4.6 Conclusion

Based on the analysis completed, we can draw the following conclusions -

- The MIP solver performs better than the LR on most occasions (83.117%) when using Production Cost as the metric;
- Because the MIP solver uses timeouts and a tolerance setting for the Optimality Gap, it is not a global optimal solution and therefore cannot guarantee the optimal schedules and prices;

- Despite the better performance of the MIP solver, the LR solver performance is generally within 1% of MIP when comparing the MSP Production Costs.

From these findings, we would conclude that although MIP produces solutions with lower MSP Production Costs, the improvement over those observed using the LR solver is not as significant as may have previously been expected. In the cases where the MIP solver performed better than the LR, the average improvement on MSP Production Costs was only 0.59%. The MIP solver improved on the LR solution by more than 1% in only 16 of the study cases. Equally, when LR performed better, the average improvement was 0.88% with only 11 out of 23 study cases showing variances of more than 1%.

Considering the MSP Production Costs observed in the SEM are generally of the order of €5 or €6 million, in monetary terms the variances are not significant.

This indicates that the two solvers are performing to a high standard, both capable of finding good sub-optimal solutions for the SEM.

On the evidence of this study, the MIP solver generally finds better sub-optimal solutions. This would more regularly deliver the obligation of the SEM rules, to minimise the aggregate MSP Production Costs, more consistently and efficiently than the LR solver.

The graphs below demonstrate the average MSP Production Costs observed in the studies completed.

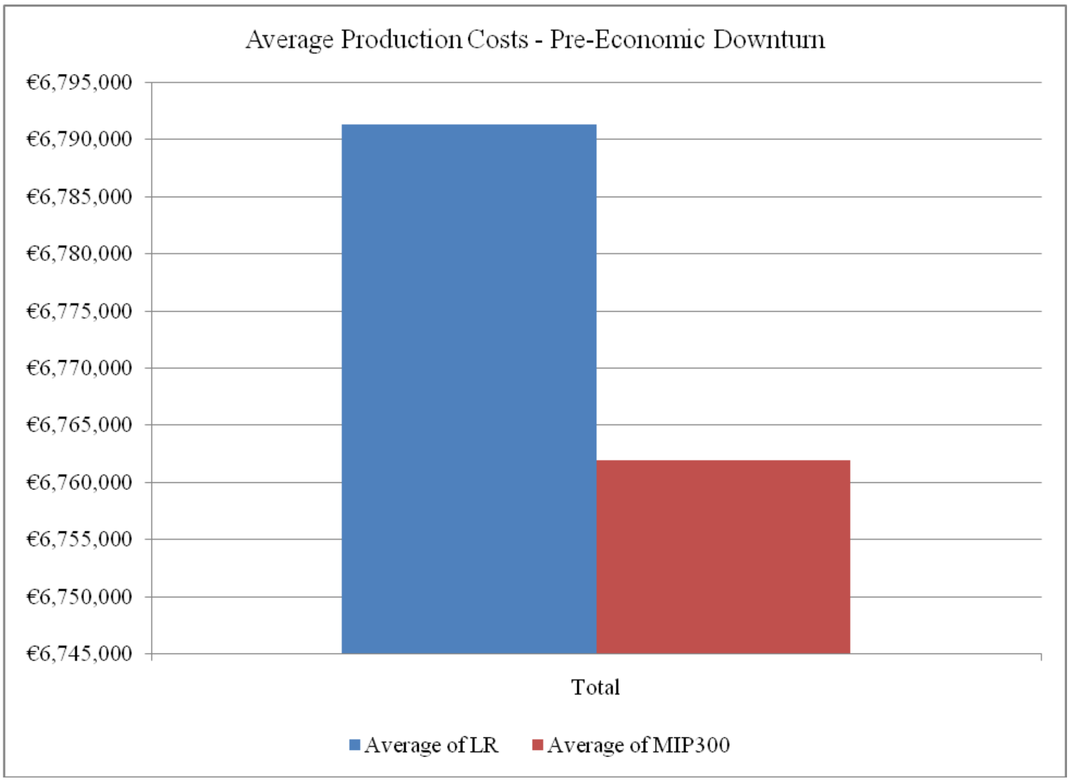

Figure 51 - Average MSP Production Costs, LR v MIP (based on dates before the economic downturn)

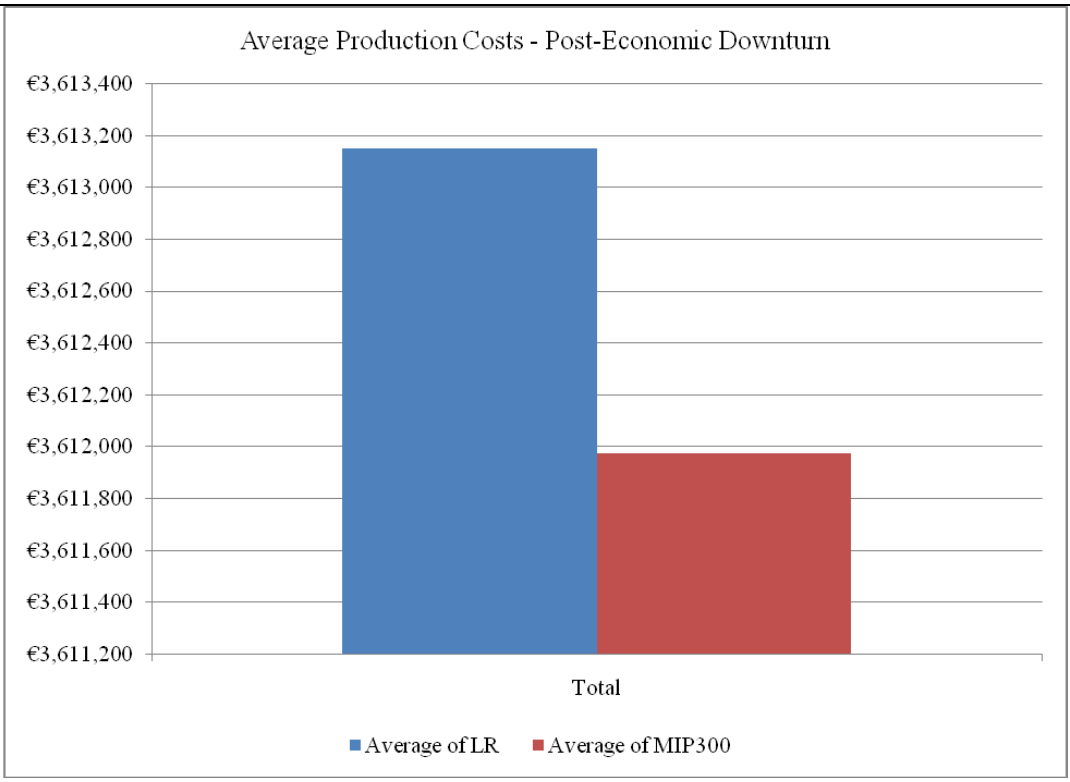

Figure 52 - Average MSP Production Costs, LR v MIP (based on dates after the economic downturn)

However, the analysis also indicates that should the SEM continue with the LR solver, the quality of the solutions is very high and comparable to those from the MIP solver.

5 Consumer Costs

5.1 Introduction

Consumer Costs are not defined in terms of the Trading & Settlement Code and are not a consideration in how the market solves. However, this has been used in the SEM with regard to decisions on application of the Settlement Recalculation Threshold.

Consumer Costs are calculated as the sum of all the Market Schedule Quantities, adjusted to MWh, multiplied by the System Marginal Price. It is broadly equivalent to the Energy Payments that are made to Generators and as such aligns closely with the total charges levied on Suppliers. Indirectly, it is considered that this represents the amount that the consumer on the island of Ireland pays for electricity from the SEM. With this in mind, it is prudent to consider during this study if there are any notable impacts on Consumer Costs dependent on the solver used. We also note that consumer prices and interests are a key a key objective of the Regulatory Authorities in both jurisdictions that make up the SEM.

It should also be noted that Consumer Costs are calculated across a Trading Day whereas MSP Production Costs are calculated across the entire 30 hour optimisation horizon.

5.2 Executive Summary

Changes to the System Marginal Price, reviewed in the SMP section, are leading to follow on changes in the Consumer Costs of the SEM. We have observed that increases in SMP, which give rise to increases in the Consumer Costs, are more common in the solutions from the MIP solver.

The review completed shows that, with the same System Load, Consumer Costs are increasing in 57% of the study cases with an average increase of €500,000 per Trading Day.

While increases in Consumer Costs are directly related to revenue for suppliers, it means that generator revenues in the SEM are also impacted. The studies completed show generator revenues increasing by around 2.7% in the solutions from the MIP solver. Though not explicitly reviewed, because the SEM is a balanced market by design, this means that supplier charges will increase by approximately the same amount. This will in turn influence the Credit Cover requirements on Participants in the SEM.

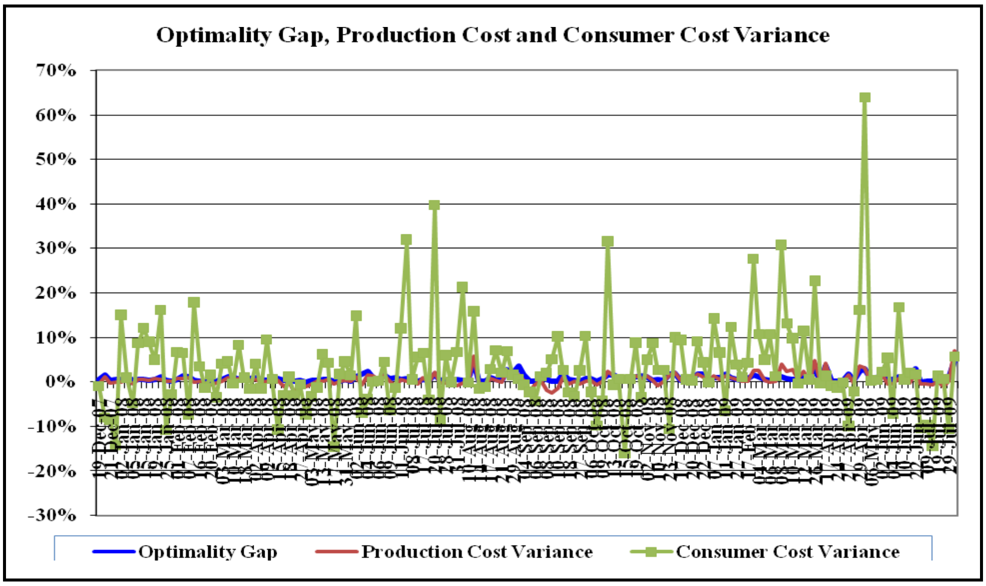

Figure 53 - Comparison of Optimality Gap, MSP Production Costs and Consumer Costs

There is no observed relationship between the Consumer Costs and other key components of this study, particularly the MSP Production Costs and the Optimality Gap in MIP. The largest single increase in Consumer Costs did align with an instance where the MIP solver failed to solve to within its convergence tolerance. However, other similar instances did not show similar increases in the Consumer Costs. With one of the largest observed increases of over 30% occurring when the MIP solver stopped with an Optimality Gap of 0.8%.

While this behaviour should not be unexpected, careful consideration needs to be given to the impact on revenue and Credit Cover in the SEM, as well as the impact on the final consumer when looking at the choice of market solver.

5.3 Background

Consumer Costs is taken to be the final value that the end consumer of electricity will pay based on the revenue their retailers are charged in the wholesale market. In terms of how this is calculated, the general approach has been to take an approximation of payments to Generators calculated as -

$$TPD \times \sum_{u,h\,in\,t} MSQuh \times SMPh$$

Where

- TPD is Trading Period Duration;
- MSQuh is the Market Schedule Quantity for Generator Unit u in Trading Period h;
- SMPh is the System Marginal Price in Trading Period h.
- the summation $\sum_{u,h\,in\,t}$ is a summation over all Generator Units u, and across all Trading Periods h within Trading Day t

As the SEM is a balanced market, the sum of all payments to Generators will correspond closely to the sum of all charges on Suppliers. As a result, it is reasonable to take this calculation as a replacement for the sum of all Energy Charges. To calculate this value to an accurate level would require the implementation of a full SEM settlement system for this project. As Consumer Costs are not part of the objective function of the MSP software and are a by-product of its outputs, albeit a crucial one, it was felt that this step was not necessary.

For convenience sake, this calculation does not consider the impact of Transmission or Distribution Loss Adjustment Factors. It is considered that the value calculated above will be sufficient to provide a robust proxy for assessment in this study, especially considering the approach of reviewing general trends and averages of the results of the two solvers.

As noted elsewhere, because this sections deals with issues of monetary impact, consideration has been given to the economic downturn that occurred in February 2009. Average data is presented separately for study cases that relate to Trading Days from before this period to those that come after.

With each study run completed in this study, a number of outputs from the MSP software are considered. Key among these is the System Summary and the Generator Schedule files. The System Summary reports at a per Trading Period level of detail and shows the System Load, total Wind Generation, total Non-Wind Generation, Interconnector flows, Demand Side Unit quantities, Shadow Price and the System Marginal Price. A sample System Summary file is shown in Appendix 2.

As the value of System Load is the total megawatt value which Generators must be scheduled to meet in the SEM, this means that the total Market Schedule Quantity is equal to the System Load as in this output. Therefore, we simply multiply the System Load, converted to megawatt hours, by the System Marginal Price. The result of this calculation will mirror the equation above.

The Generator Schedule output file includes the megawatt of output values for each Generator. To validate the above approach, we confirmed the results by calculating the non-loss adjusted generator revenue and summing these values across each Trading Period. This approach means that we have also produced approximate generator revenue values that can be reviewed taking account of the different Fuel Types and technology types that are registered in the SEM.

5.4 Analysis

This section of the report is based on a review of 154 study cases based on Ex-Post Initial runs of the

MSP software, run using both LR and MIP solvers. The calculation of Consumer Costs is based only on the Trading Day and not on the complete Optimisation Horizon as no settlement takes place with regard to the final six hours of the study period.

Reviewing the results of this, we have observed that in 88 study cases out of the total, the Consumer Costs were increased in the outputs of the runs completed with the MIP solver with decreases being noted in the remaining 66. The total increases observed summed to in excess of €47 million across all study cases with increases ranging from as low as €478 up to almost €3 million.

	MIP Decrease	*MIP Increase*	*MIP Decrease as %*	*MIP Increase as %*
MAX	-€1,929,885.96	€2,916,026.72	-0.019%	60.643%
MIN	-€617.45	€478.88	-16.431%	0.013%
AVERAGE	-€330,940.64	€541,790.45	-4.28%	7.936%
COUNT	66	88		
Total	-€21,842,082.33	€47,677,559.74		

Table 14 - Summary of Consumer Cost changes from LR to MIP

It is also noted that the largest single monetary increase of €2.9 million occurred in the Trading Days prior to the economic downturn on 25th June 2008. This monetary increase did not represent the largest percentage increase being in fact the third largest increase observed of just under 32%. However, the second largest monetary increase of €2.24 million, which represented the single biggest percentage increase, occurred in the period after the economic downturn. This is even with the marked reduction in the average Consumer Costs paid per Trading Day as demonstrated in Figure 2 below which shows pre downturn Trading Day averages of just under €9 million and post downturn Trading Day averages of around €4 million. The particular Trading Day with the single biggest increase had LR Consumer Costs of €3.7 million and MIP Consumer Costs of €5.9 million.

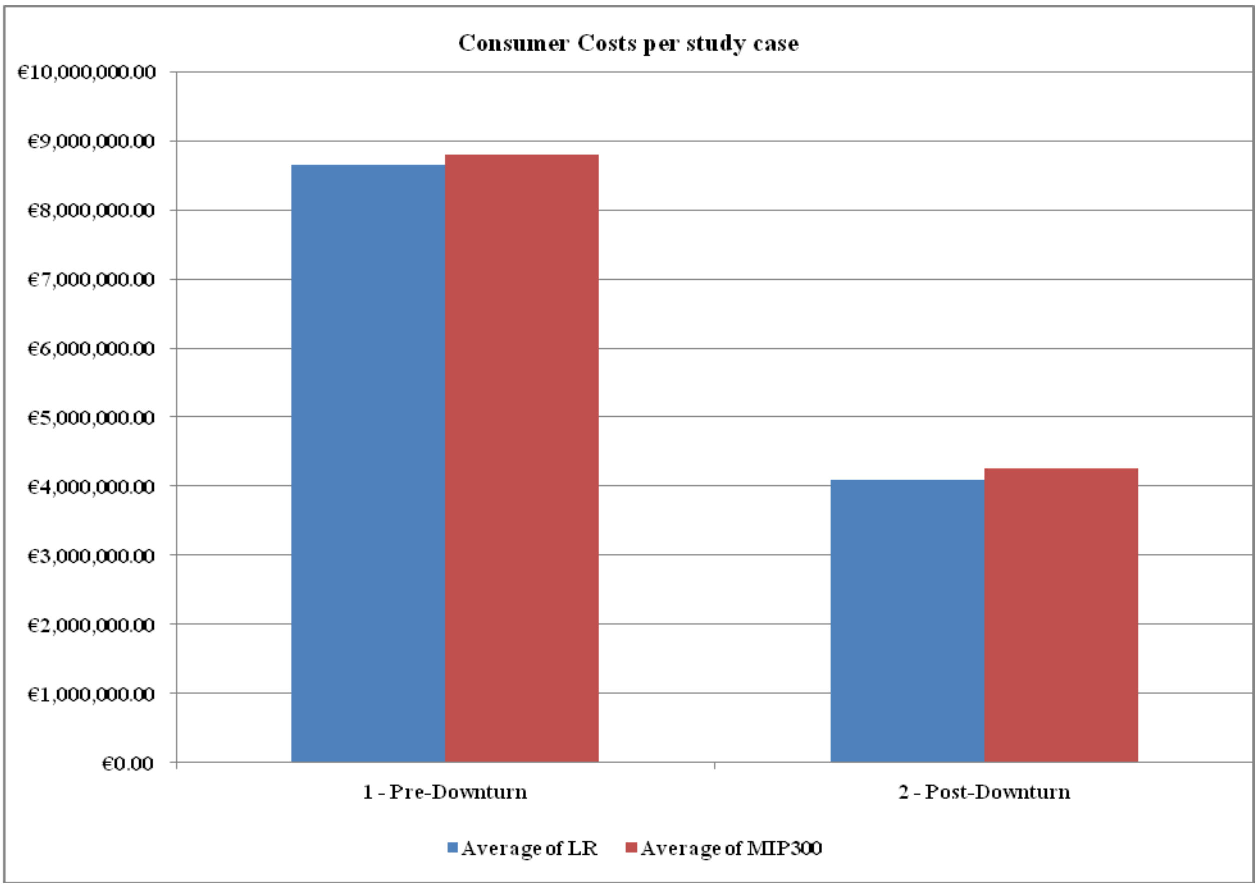

Figure 54 - Average Consumer Costs per Trading Day

The principle driver in such large changes to Consumer Costs is the System Marginal Price, as the overall System Load remains unchanged from one solver to the next.

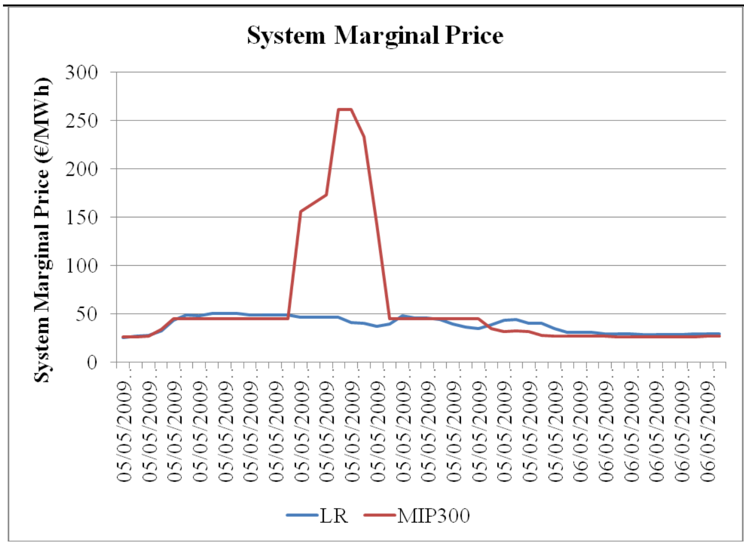

Figure 55 - SMP variance, 05/05/2009

Figure 54 here shows the variance between the SMP in the two solvers on 05/05/2009, the Trading Day with the largest single percentage variation in Consumer Costs. The large change in the SMP over a number of hours with the MIP price being at times over €200 dearer is the cause of this large change. The MIP solver failed to reach the Optimality Gap on this day and was stopped by the timeout settings with the gap at 3.12%. While the Production Costs between the two solvers were similar (a difference of only 0.17%), the generator schedules contained some significant difference. A mid-merit steam turbine generator is committed in the MIP schedule across the lunchtime/afternoon but was not run in the LR schedule. The inclusion of this unit incurred significant Uplift to the Shadow Price causing the large rise in System Marginal Price that is noted.

Of note with regard to the top two largest increases (of 37.49% and 60.64%, or €2.07 and €2.25 million) were both Trading Days where the MIP solver was stopped by the timeout settings. In both cases, the LR solver produced solutions with better MSP Production Costs.

Figure 55 below shows the System Marginal Price variations for the other Trading Days with the highest increase in Consumer Costs found using the MIP solver. In each case, the increase in the SMP under the MIP solver is quite apparent, as shown in figure 55 below.

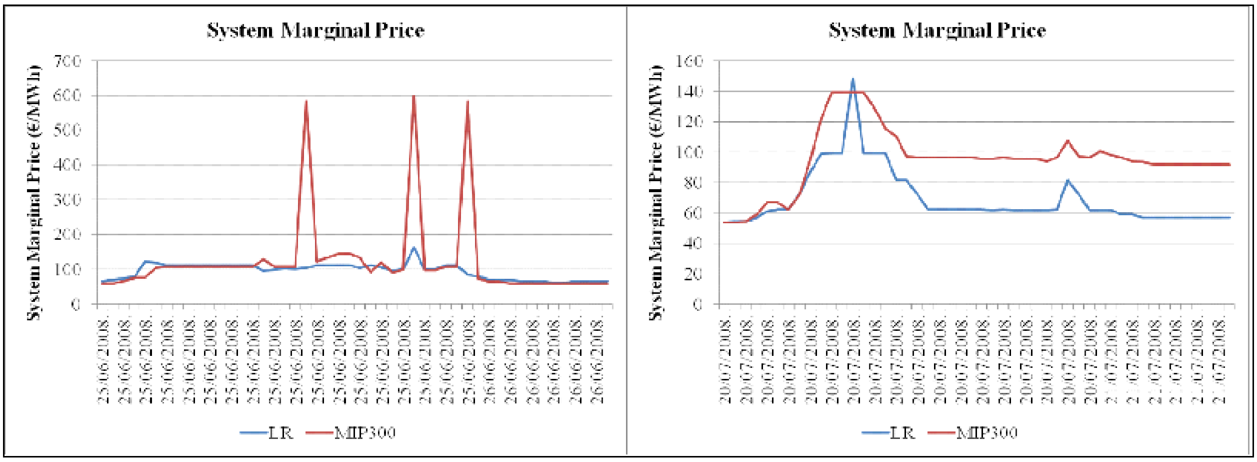

Figure 56 – Other significant SMP variations

As with other reviews of financial data in this study, in Tables 15 and 16 below separate summary data is provided for the periods before and after the economic downturn.

	MIP Decrease	*MIP Increase*	*MIP Decrease as %*	*MIP Increase as %*
MAX	-€1,929,885.96	€2,916,026.72	-16.431%	37.497%
MIN	-€1,450.92	€1,344.13	-0.023%	0.013%
AVERAGE	-€376,862.67	€580,485.18	-4.228%	7.141%
COUNT	50	66		
Total	-€18,843,133.46	€38,312,681.86		

Table 15 - Summary of Consumer Cost changes, pre economic downturn

	MIP Decrease	*MIP Increase*	*MIP Decrease as %*	*MIP Increase as %*
MAX	-€571,359.38	€2,247,484.36	-13.787%	60.643%

	MIP Decrease	*MIP Increase*	*MIP Decrease as %*	*MIP Increase as %*
MIN	-€617.45	€478.88	-0.019%	0.013%
AVERAGE	-€187,434.30	€425,676.27	-4.442%	10.319%
COUNT	16	22		
Total	-€2,998,948.87	€9,364,877.87		

Table 16 - Summary of Consumer Cost changes from LR to MIP, post economic downturn

In all sets of data, there are more instances of increases to Consumer Costs with the MIP solver when compared with the LR solver than vice versa. The average overall increase is 8.1% with pre-downturn averages of 6.24% and post downturn of over 10%. Average decrease in Consumer Costs with the MIP solver is around 4.28% in all events.

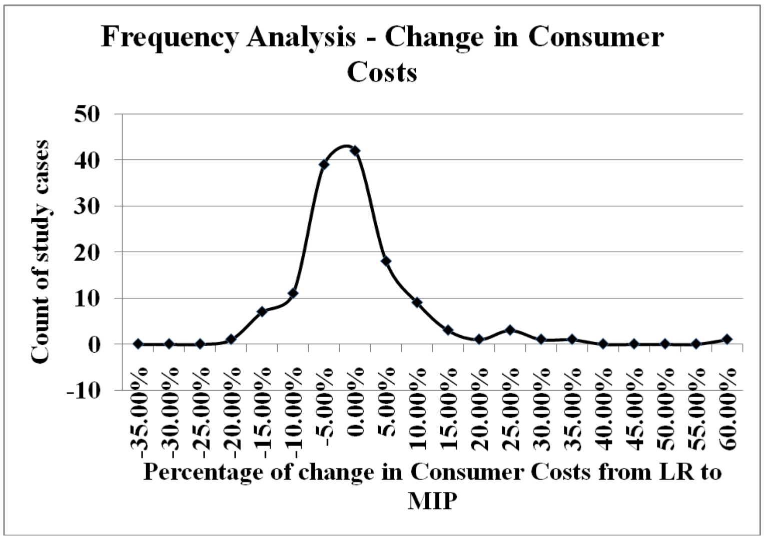

Figure 57 - Frequency of Consumer Cost changes

A frequency analysis of the changes shows that most of the changes observed are between +/-10% (that is, 126 study cases out of 154) with only exceptional cases with extreme variances such as the three cases noted above.

That said, 10% still represents a very substantial change. In monetary terms, changes of 10% average at almost €700K.

While a large number of the study cases are around the mean, most show increases to Consumer Costs under MIP. Table 17 below provides a count of study cases within the +/-10% range which demonstrates that the largest set of study cases are between +/-1%, where the average monetary increase is around €20K. However, this is only 31 study cases of the 154 completed, which is only 20%.

Variance	*Study Cases in this range, incremental*	*Study Cases in this range, absolute*	*Absolute count as %*
+/-1%	34	34	22.08%
+/-2%	17	51	33.12%
+/-3%	12	63	40.91%
+/-4%	14	77	50%
+/-5%	10	87	56.49%
+/-6%	5	92	59.74%
+/-7%	8	100	64.94%
+/-8%	8	108	70.13%
+/-9%	7	115	74.68%
+/-10%	7	122	79.22%

Table 17 - Study cases in the +/-10% range

In the figures below as with elsewhere in this report, the whole series has been divided in 3 graphs for ease of illustration - Graph1 2007 to May 2008; graph2 June 2008 to Dec 2008; graph3 Jan 2009 to Aug 2009. The following graphs show a comparison between the Consumer Costs for the different solvers.

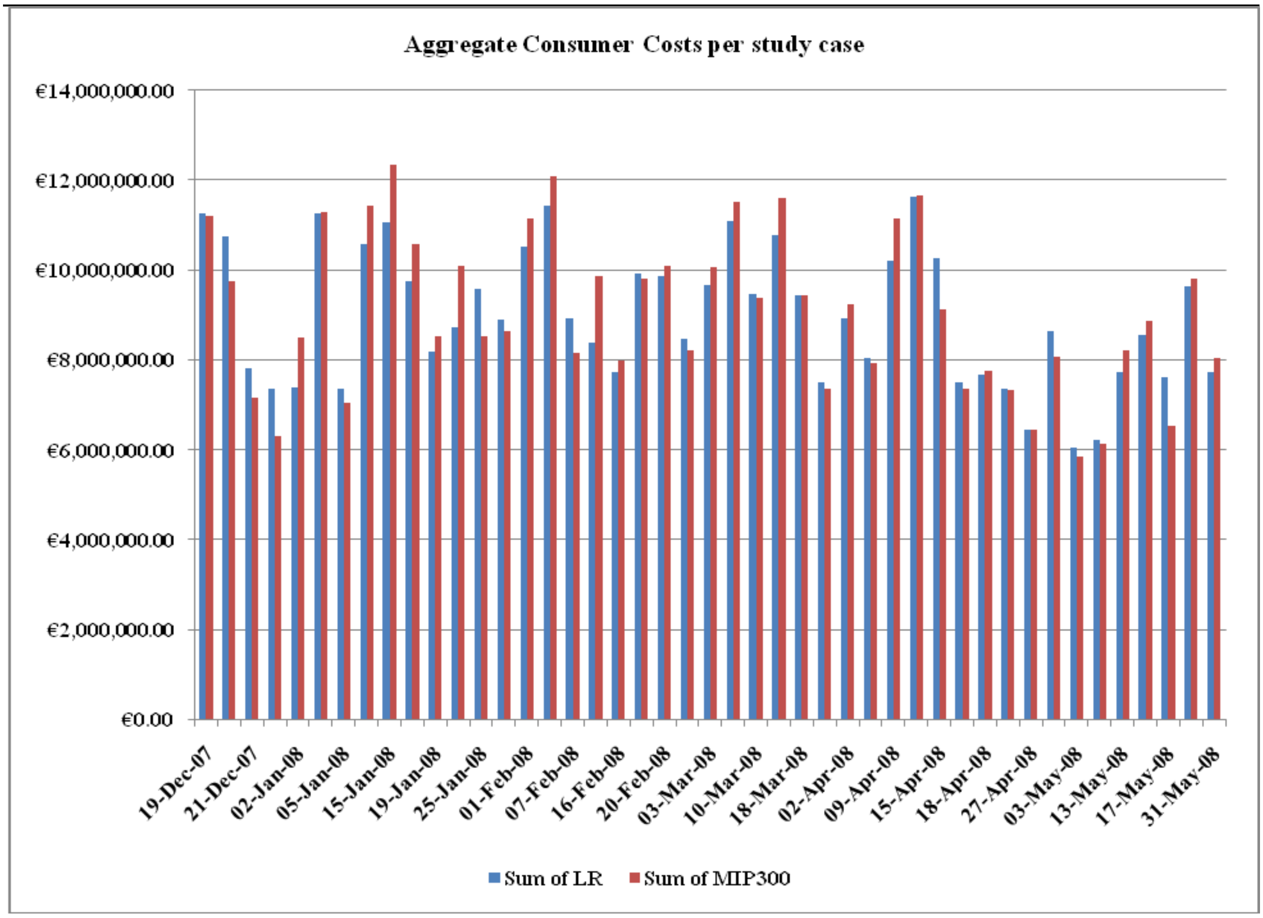

Figure 58 - Consumer Costs comparison, 2007 to May 2008

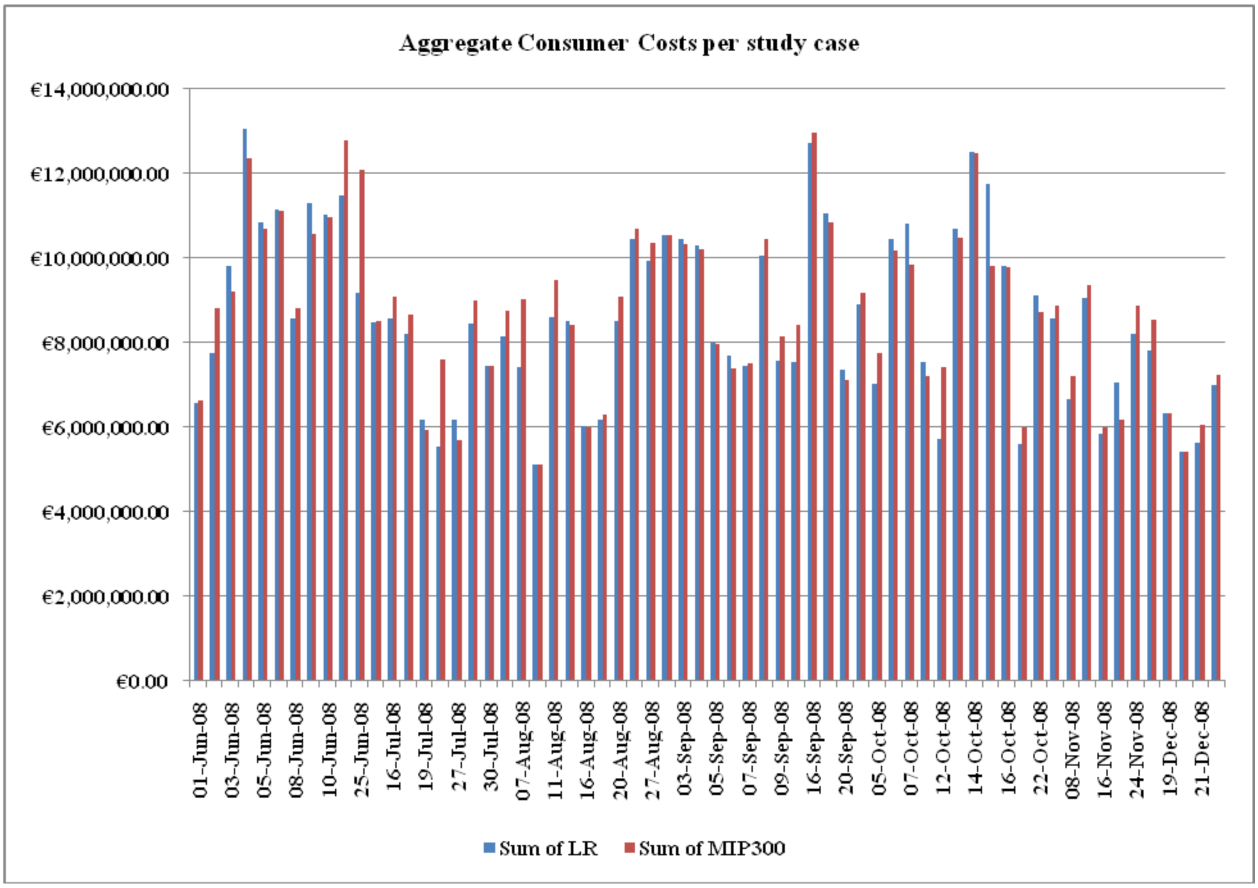

Figure 59 - Consumer Costs comparison, June 2008 to Dec 2008

The large increase in the daily Consumer Costs for May 5th 2009 discussed above can be clearly seen in Figure 7 below.

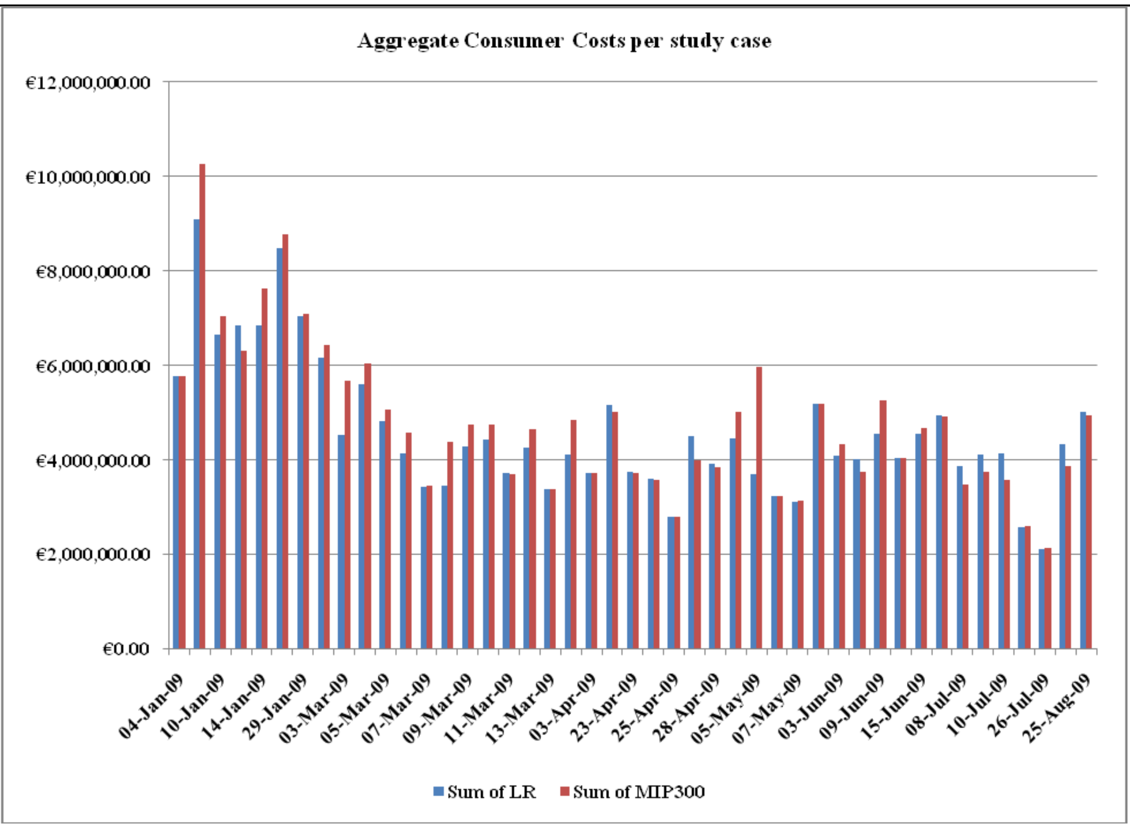

Figure 60 - Consumer Costs comparison, Jan 2009 onwards

As noted above, Consumer Costs relates closely to Generator Revenue with the application of the loss factors being the princpal difference. With this in mind, the values noted above can be taken as a proxy for the changes generators would likely see in their revenue streams between the two solvers. We have done a further review of these revenues both by technology type and by the registered fuel type in the SEM.

The graph below shows in absolute terms the change in revenue between the two solvers for the different technology types that exist in the SEM. Both solvers see the largest revenue to Combined Cycle Gas Turbine plant which is largely attributable to the large installed capacity of this type of generator in the SEM. Details of how generators are classed and intalled capacity are in Appendix 5.

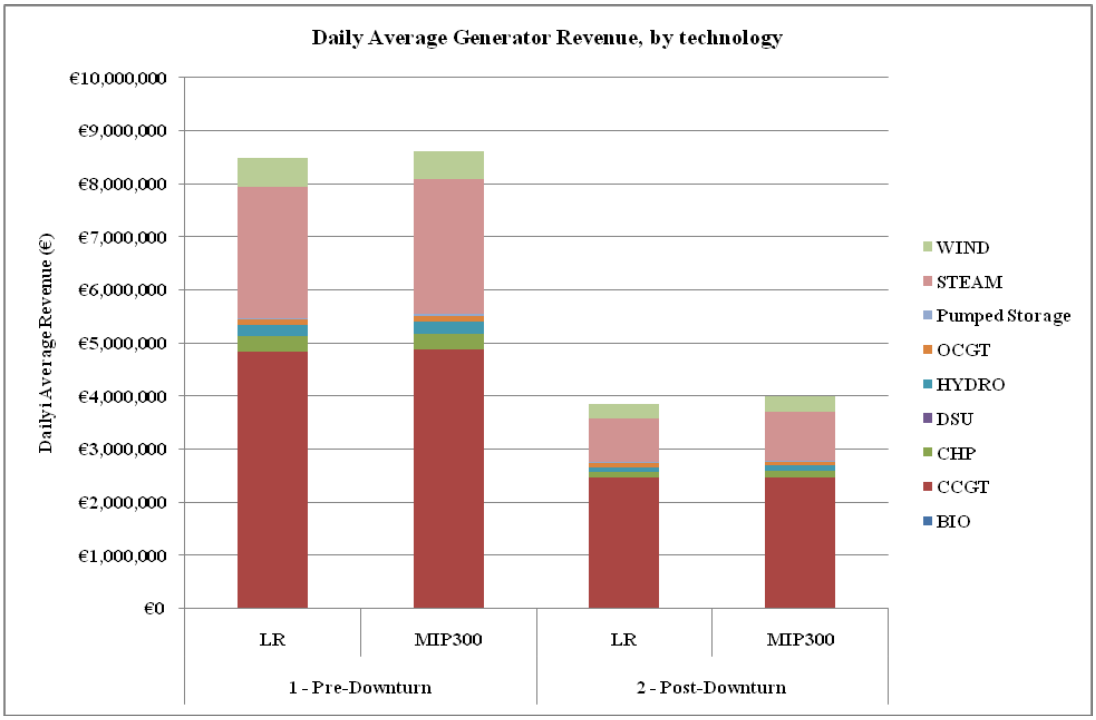

Figure 61 - Average daily Generator Revenue, shown by technology type

When we express the same data in percentage terms, there is no major change in how the revenue is allocated across the different groupings.

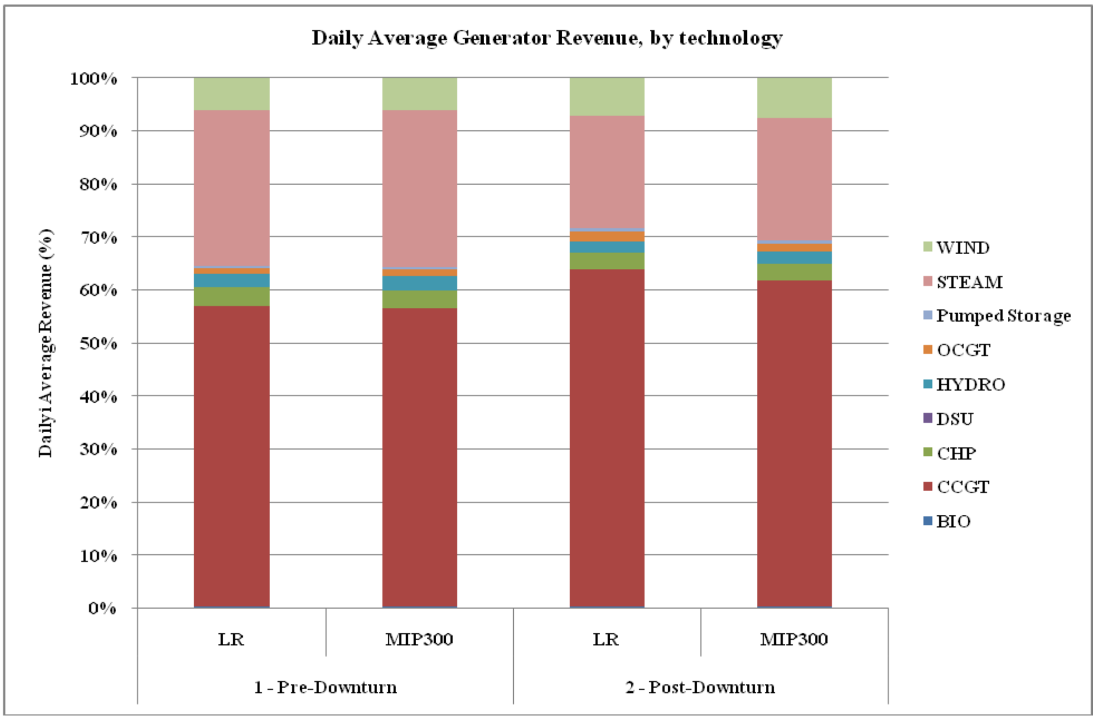

Figure 62 - Daily average Generator Revenue, by technology type, as percentage

This indicates that revenue changes are being driven principally by the changes to the System Marginal Price that have been observed in the outputs of the MIP solver rather than the scheduling of different types of generation. This further extends into how different fuel types are schceduled in the market runs. Using either solver, the commitment by fuel type appears largely unaffected resulting in similar trends of revenue for generators both pre and post the ecnonic downturn. This fits with the design of the market which is fuel neutral. The unit commitment is based not on fuel but on technical and commercial characteristics of the Price Maker generators. Wind generators are included here to demonstrate the impact the changing System Marginal Price will have on their payments. These are Price Takers and not considered in the unit commitment process.

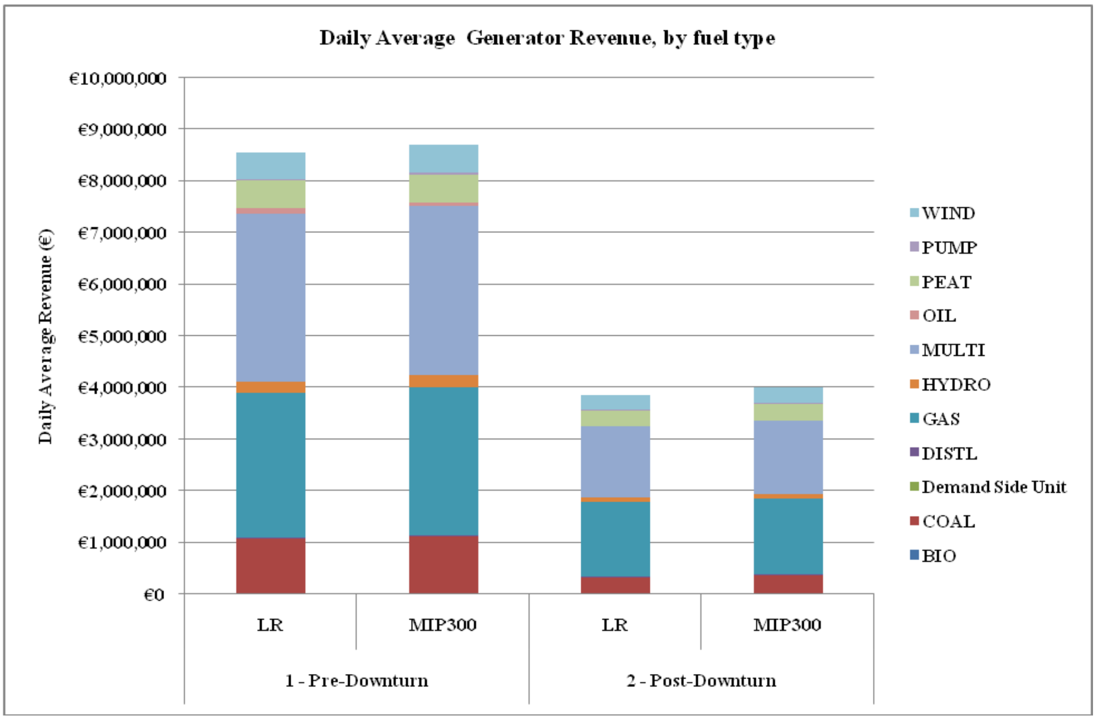

Figure 63 - Daily average Generator Revenue, by fuel type

Note that in both solvers, generators using Oil as their primary fuel do not appear in the schedules after the economic downturn reflecting their bid price. The reduction in system load from February 2009 onwards altered the merit order of the SEM with the result that high cost fuels were less likely to be scheduled after this time.

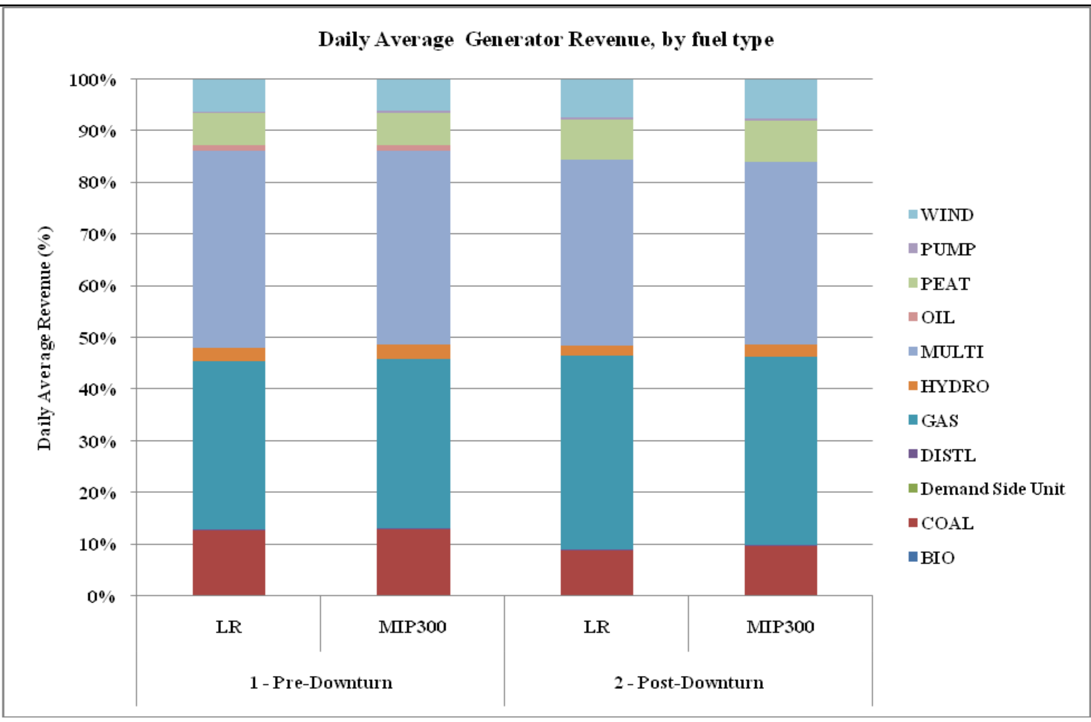

Figure 64 - Daily average Generator Revenue, by fuel type, as percentage

A large percentage of the generation portfolio is listed as MULTI to reflect some large generator unit's ability to use different fuels such as Gas or Oil. Taking account of the Fuel Mix Disclosure[17] figures, where Gas made up 60.6% of used fuel on the island, and EPA declarations that have been seen for 2008, it can be assumed that generators with multi-fuel capability have generally been using Gas as the main fuel. As such, the block of MULTI shown above can be considered to be synonymous with Gas and the different technology types associated with this.

5.5 Conclusion

In the study cases completed, it is more common for the outcomes of the MIP solver to result in increases to Consumer Costs over those observed under the LR solver. This is being driven by the increases observed in the System Marginal Price when using the MIP solver over the LR.

This is further reviewed in the System Marginal Price section of this report. The increases observed seem to stem from the MIP solver committing more Generator Units to meet the system load than the LR. While this leads to increases in Shadow Price and overall higher daily average System Marginal Prices, this does avoid peak prices observed in solutions using the LR solver.

Increases to Consumer Costs will of course mean increased revenue for generators in the SEM and increases to charges on suppliers. This must be considered as there will be a further affect on Credit Cover requirements for Participants in the SEM. We believe that a further detailed investigation of the impacts on Credit Cover requirements should be carried out before a final decision to change the main solver in the SEM.

[17] http://www.allislandproject.org/GetAttachment.aspx?id=ed79bf53-5e92-4ea7-83a0-31926f498160

6 System Marginal Price

6.1 Introduction

An obvious key output of the MSP software is the System Marginal Price. This is made up of Shadow Price formulated from the bid price for the marginal Generator Unit with an amount of Uplift added where required to ensure Generators recover their full costs (Start Up and No Load Costs).

The price outcomes are of interest in terms of frequency of peaks, volatility of the System Marginal Price within a Trading Day and requirement for Uplift additions. Such outcomes would be observed in the payment of Uplift where a higher frequency of starts could increase the Uplift portion. Equally, market solutions have been observed where the LR implementation has minimised MSP Production Costs with no regard for System Marginal Price and resulted in high Uplift values. The study aims to review these issues.

6.2 Executive Summary

This report concludes the following in relation to System Marginal Prices and Uplift:

- The Average Daily System Marginal Price increased in 57% of the total number of cases with the MIP solver over LR; however, the Maximum System Marginal Price decreased in 52% of the total number of cases with MIP than LR. In essence, what this shows is that while we have observed a tendency towards an increased overall System Marginal Price in the outcomes of the MIP study cases, the LR solver achieves a lower average System Marginal Price but conversely causes more instances of higher Peak Prices.
- The increases noted in the System Marginal Price and Shadow Price calculations appear to be consistent with the commitment of more Hydro generation in the results of the MIP schedules.
- There were nine Peak Prices[18] observed in the LR and MIP runs prior to the economic downturn. There were no Peak Prices observed in the dates following the economic downturn.
- The Average Daily Uplift calculated is greater in 66.94% of LR cases. This percentage is based on the 121 cases when Uplift was calculated in both the LR and MIP runs.

6.3 Background

It is not a primary objective of either the LR or the MIP solver to reduce System Marginal Prices and Uplift; however, they are of considerable interest to participants and can be a measure of the solver performance. A decrease in System Marginal Prices in turn will lead to a reduction in Generator revenue, which may have separate unintended consequences in terms of encouraging investment.

In accordance with the Trading and Settlement Code and Appendix N –

> "**PRICING ALGORITHM**
>
> **The MSP Software**
>
> **4.68** The overall objective for that part of the MSP Software which calculates Uplift is to set the System Marginal Price to reflect the marginal cost of producing or consuming electricity during the Optimisation Time Horizon, subject to balancing the following supplementary objectives and as set out in further detail within Appendix N "Operation of the MSP Software":

[18] Peak Prices are classed as System Marginal Price greater than €500.

1. energy prices should be reflective of underlying market dynamics; consequently the recovery of Start Up Costs and No Load Costs through System Marginal Price should not deviate significantly from the Shadow Prices (the Uplift Profile Objective); and
2. the revenue paid through Uplift revenues should be minimised (the Uplift Cost Objective).

Appendix N: Principles underlying the operation of the MSP Software

N.9 The System Marginal Price shall be calculated in each Trading Period so as to be the marginal cost of meeting the last unit of Schedule Demand (as defined within this Appendix N), plus Uplift, taking account of all constraints and limitations used within the relevant run of the MSP Software and bounded by the Market Price Cap (PCAP) and the Market Price Floor (PFLOOR), as further set out in paragraph N.16."

A total of 154 study cases based Ex-Post Initial schedules since the start of the Market were run using both the LR and MIP solvers.

To assess the results of the LR and MIP runs, comparative analysis has been done on all study runs under the heading System Marginal Prices and Uplift, which is a subset of the criteria for analysis in the overall MIP-LR study.

6.4 Analysis

6.4.1 System Marginal Prices

The following set of graphs demonstrates the comparison between the outcomes of all the study runs with regard to System Marginal Prices and Uplift. As has been noted elsewhere, the study cases selected for the MIP-LR studies span the economic downturn, which became apparent in early 2009. These cases also illustrate the impact that this Economic Downturn has had on these outputs.

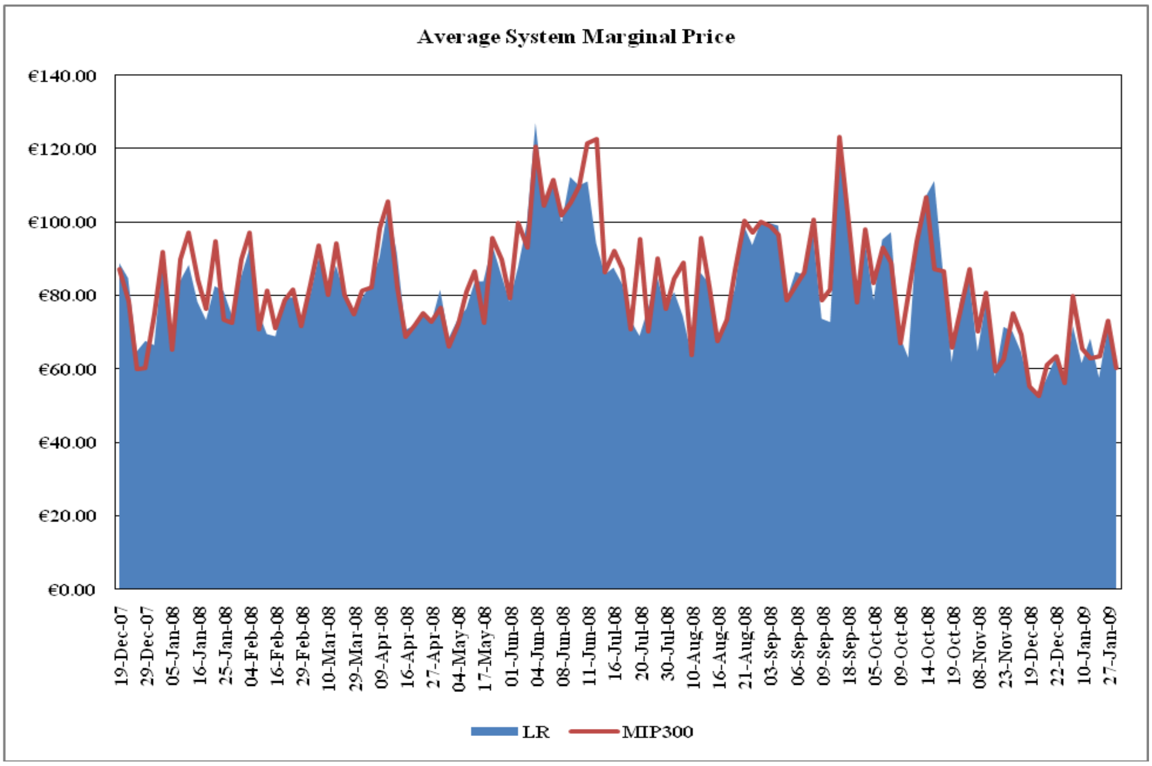

Figure 65 - Average System Marginal Prices Pre Economic Downturn (December 2007 – January 2009)

Taking the time-weighted average daily System Marginal Price, the following observations have been made:

- Of the 154 study cases, the daily Average System Marginal Price values changed between the LR and MIP runs in all cases.
- In 88 cases (equivalent to 57.14%), the average daily System Marginal Price is higher with MIP than LR.
- Of this total, 65 of these cases occur in the pre economic downturn phase and 23 in the post economic downturn phase.
- The largest increases were noted on the 25th June 2008, 20th July 2008 and 5th May 2009.

- The largest decrease was noted on the 15th October 2008.

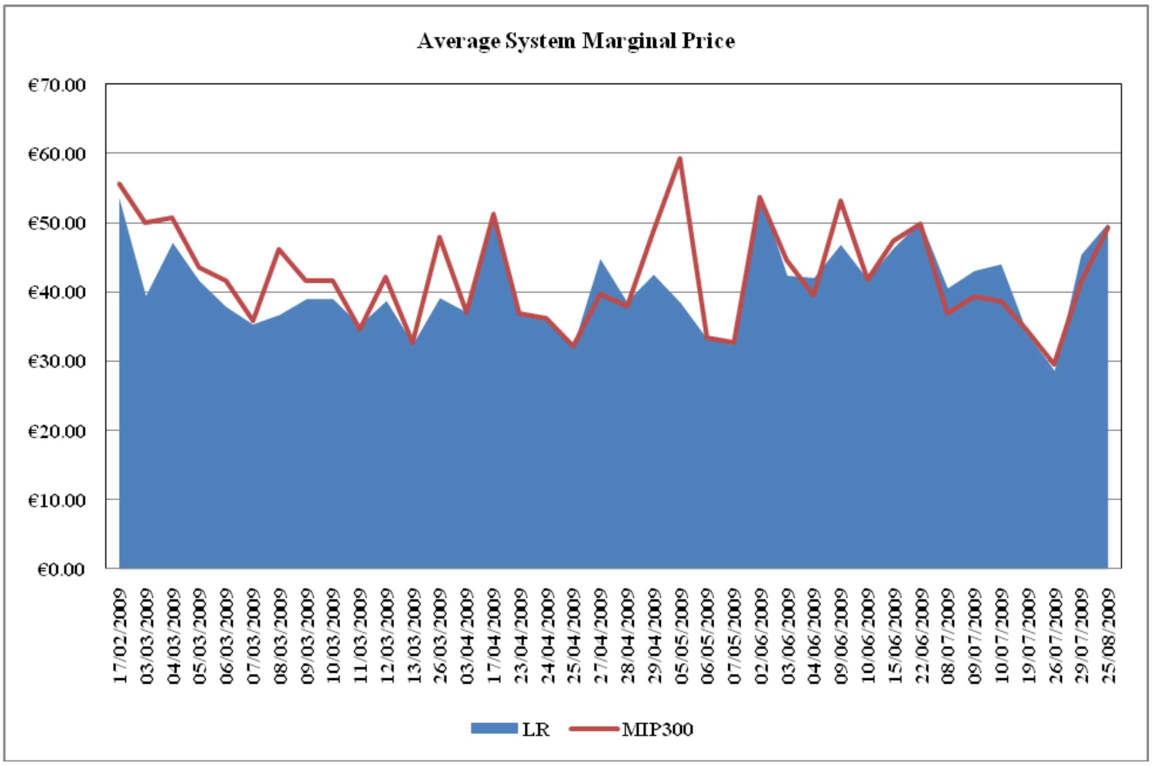

Figure 66 - Average System Marginal Prices Post Economic Downturn (February 2009 – August 2009)

It is clear from the above graphs that the economic downturn has had a significant impact on the Average System Marginal Price, which has reduced by half. Also, we can see the impact of trends in oil and gas prices which peaked in September 2008 before reducing toward December that year.

The highest Average System Marginal Price using the LR solver has dropped from €126.92 to €54.07 while the highest Average System Marginal Price from the MIP solver has dropped from €123.16 to €59.29. This directly correlates with the decrease in Commercial Offer Data being submitted. This is demonstrated in figure 66 below.

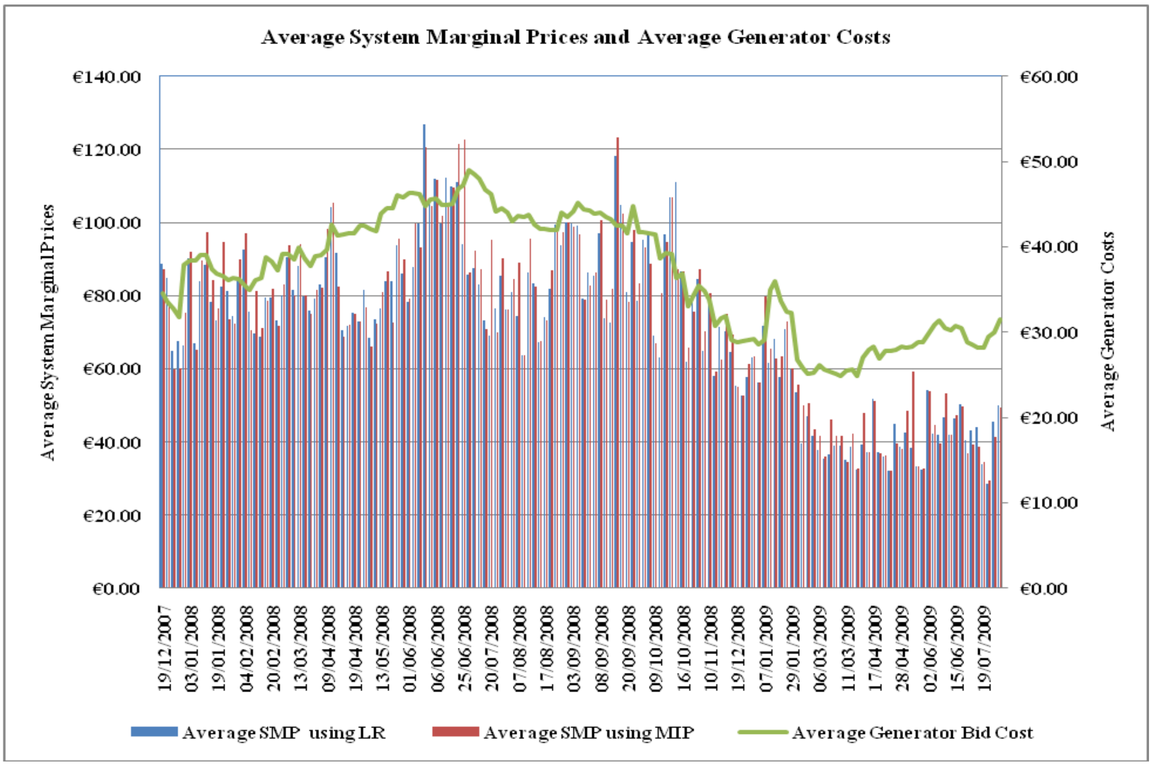

Figure 67 - Average System Marginal Prices and Average Generator Costs (Entire Study Period)

The below graph represents a frequency analysis of the changes noted in the daily average System Marginal Price. It demonstrates that small variances have been observed in the daily average System Marginal Price in each instance

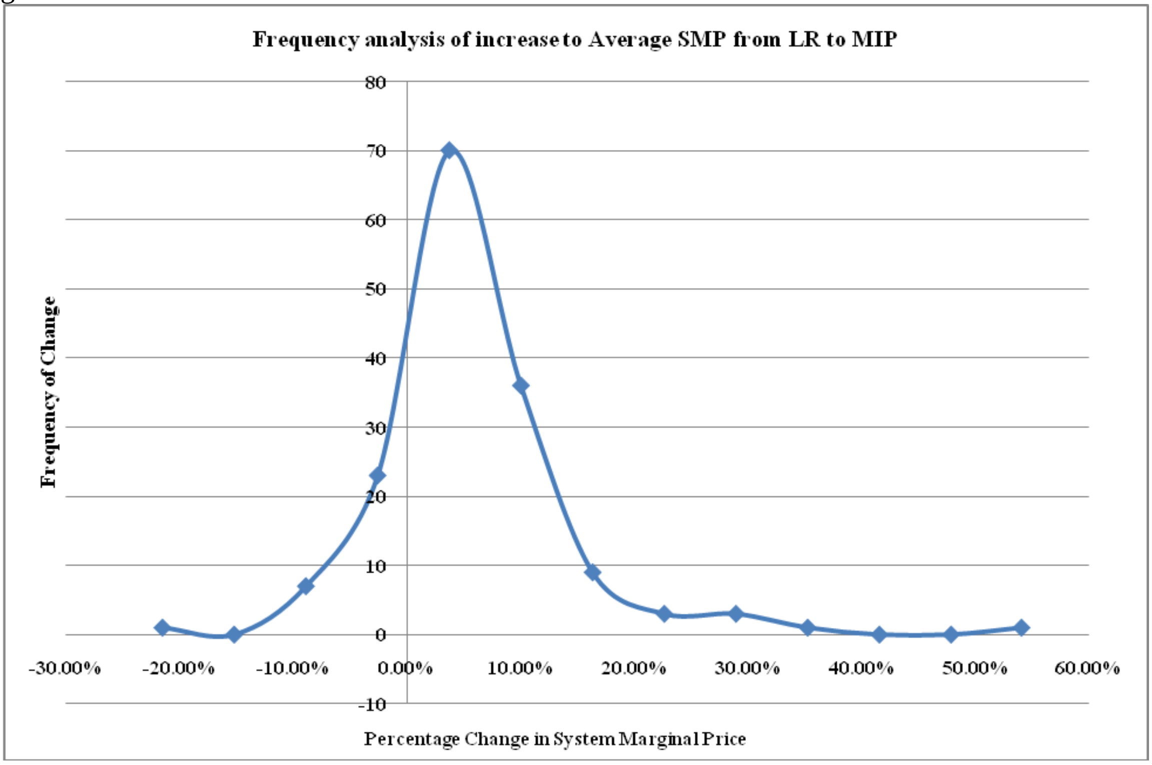

Figure 68 - Changes in System Marginal Price from LR and MIP

Looking at these variances, 81 study cases show an increase in the daily average System Marginal Price of between 0% and 20% when using the MIP solver over the LR.

We also reviewed the Maximum System Marginal Price & Maximum Shadow Price as observed for each Trading Day. We have divided these into 3 categories as follows:

- Peak Prices (> €500)
- High Prices (>= €300 & <= €500)
- Low Prices (< €300)

Tables 18 and 19 below summarise the distribution of the Maximum System Marginal Price values across the all study cases. As above, the data is separated relating to System Marginal Price values from before the change in the economic climate and those Trading Days from after this.

System Marginal Price *(%) per category over Total Period (116 Trading Days)*	*LR*	*MIP*
Peak System Marginal Price	4.31%	3.45%
High System Marginal Price	22.41%	19.83%
Low System Marginal Price	73.28%	76.72%

Table 18– System Marginal Prices Pre Economic Downturn (December 2007 – January 2009)

System Marginal Price *(%) per category over Total Period (38 Trading Days)*	*LR*	*MIP*
Peak System Marginal Price	0%	0%
High System Marginal Price	2.63%	5.26%
Low System Marginal Price	97.37%	94.74%

Table 19 – System Marginal Prices Post Economic Downturn (February 2009 – August 2009)

Peak System Marginal Price were observed in a total of 9 study cases, 5 of which used the LR solver and 4 used the MIP solver. In only one case, the Peak System Marginal Price was identical in both the LR and MIP runs. This occurred on Trade Date the 21st August 2008. This was caused when both solvers scheduled the Dual Rated generator unit registered in the SEM into its oil price band for two Trading

Periods. These coincided with the peak system load for the Trading Day as well as a time of lower generator availability. More generators became available in the next immediate Trading Period and the solvers were able to move the Dual Rated generator back into its coal price band. This is demonstrated in the graph below.

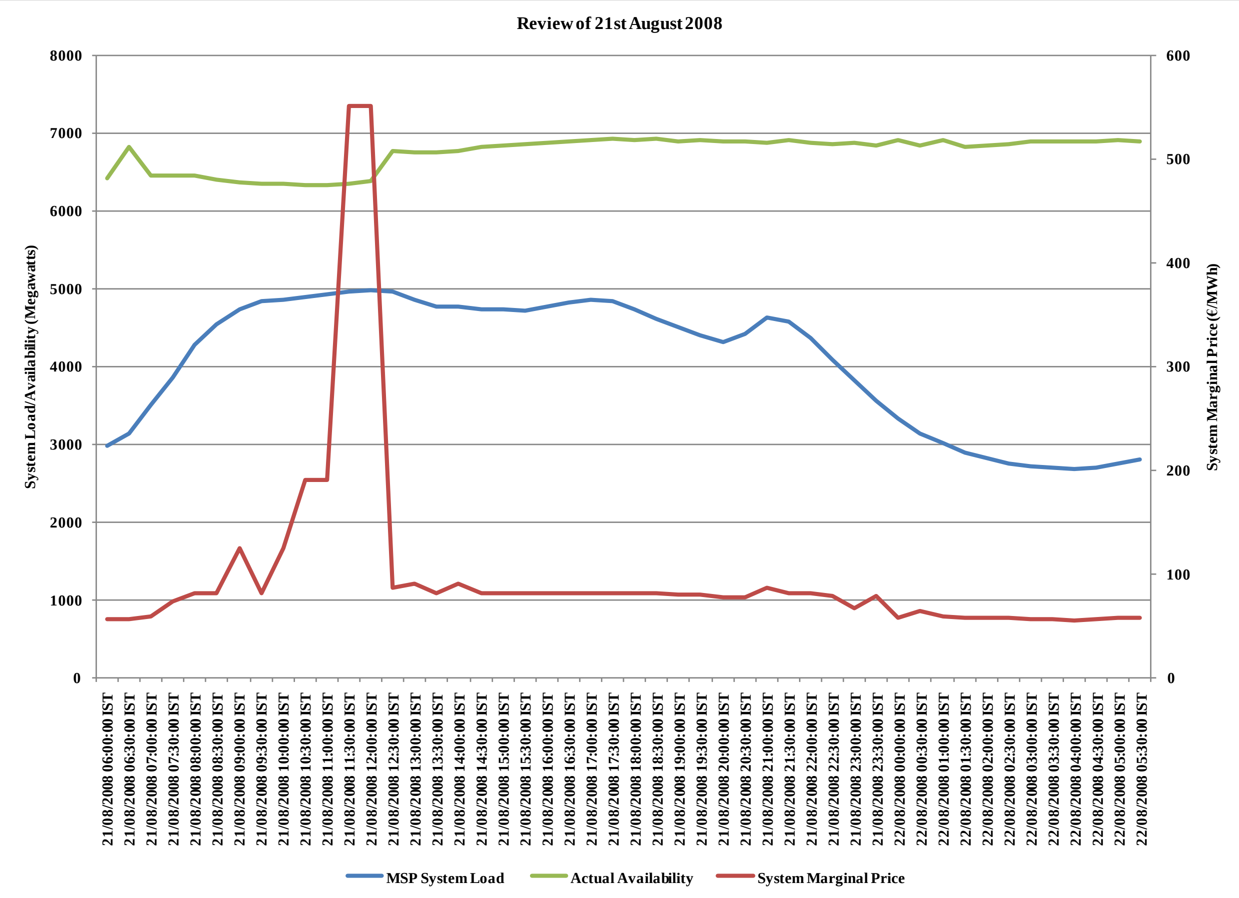

Figure 69 - Review of System Load, Availability and System Marginal Prices (21st August 2008)

There were no Peak Prices observed in the dates following the economic downturn.

From December 2007 to January 2009, the MIP solver produced a Maximum System Marginal Price below €300 in 3.45% more cases than LR. However, in the study cases following the downturn this reversed with LR producing 2.63% more than MIP. Over the entire study period, MIP produced a Maximum System Marginal Price below €300 in 81.17% of cases where LR was slightly lower with 79.22%.

In contrast to the Daily Average System Marginal Price, in 80 cases (51.95%) the Maximum System Marginal Price was higher in the LR study cases than MIP demonstrated below.

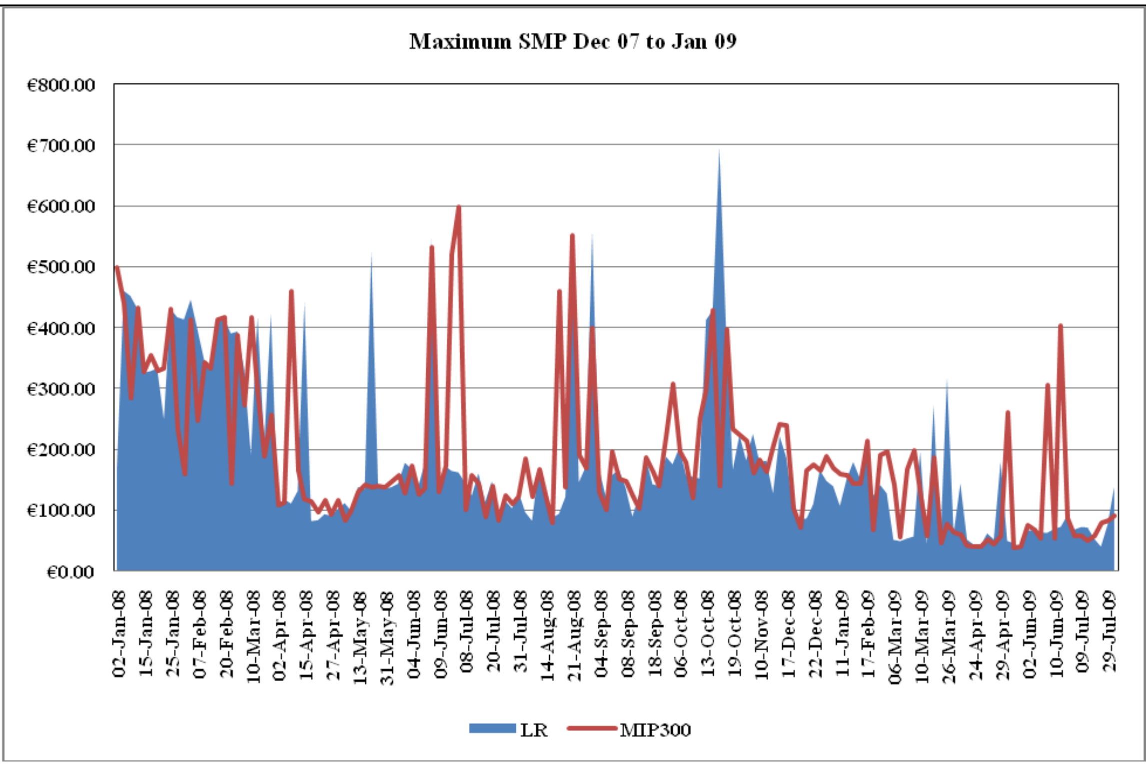

Figure 70 - Maximum System Marginal Prices (December 2007 – January 2009)

Of this total, 59 of these cases occur in the pre economic downturn phase and 21 in the post economic downturn phase. The highest Peak System Marginal Price noted in the study is €696.46, observed in the outcomes of the LR solver for the Trading Day of 15th October 2008. This System Marginal Price corresponds to the solution published in live operation in respect of this Trading Day. This was largely made up of Uplift, which was incurred when the solver de-committed an expensive generator at the beginning of the Trading Day. This reduced the overall MSP Production Costs but caused the remaining carried forward start up costs of this unit to be recovered through Uplift in these two Trading Periods.

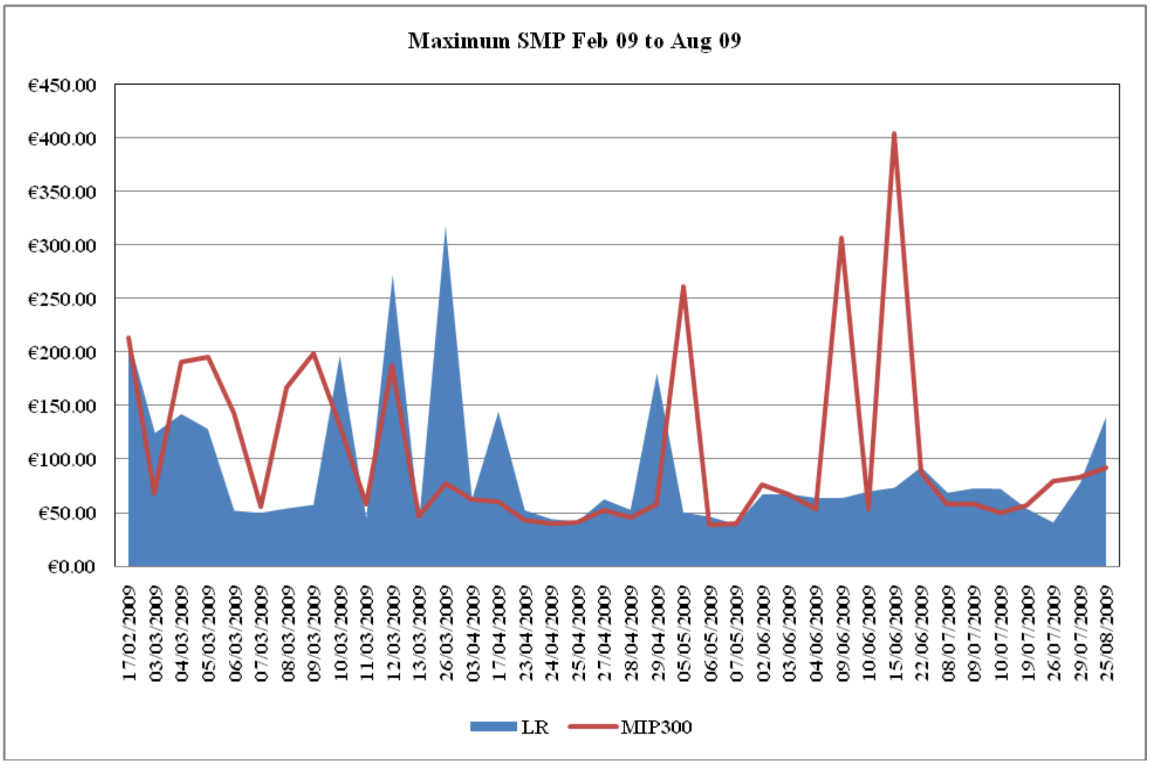

Figure 71 - Maximum System Marginal Prices (February 2009 – August 2009)

In eight of the 154 cases studied, the Maximum System Marginal Price was the same in both the LR and MIP runs. The dates are as follows:

Trading Day	*Maximum System Marginal Price*
10/01/2008	€432.52
15/01/2008	€326.66
25/01/2008	€430.96
16/02/2008	€332.26
20/02/2008	€415.95
10/06/2008	€173.53
21/08/2008	€551.46
16/10/2008	€397.91

Table 20 - Maximum System Marginal Prices

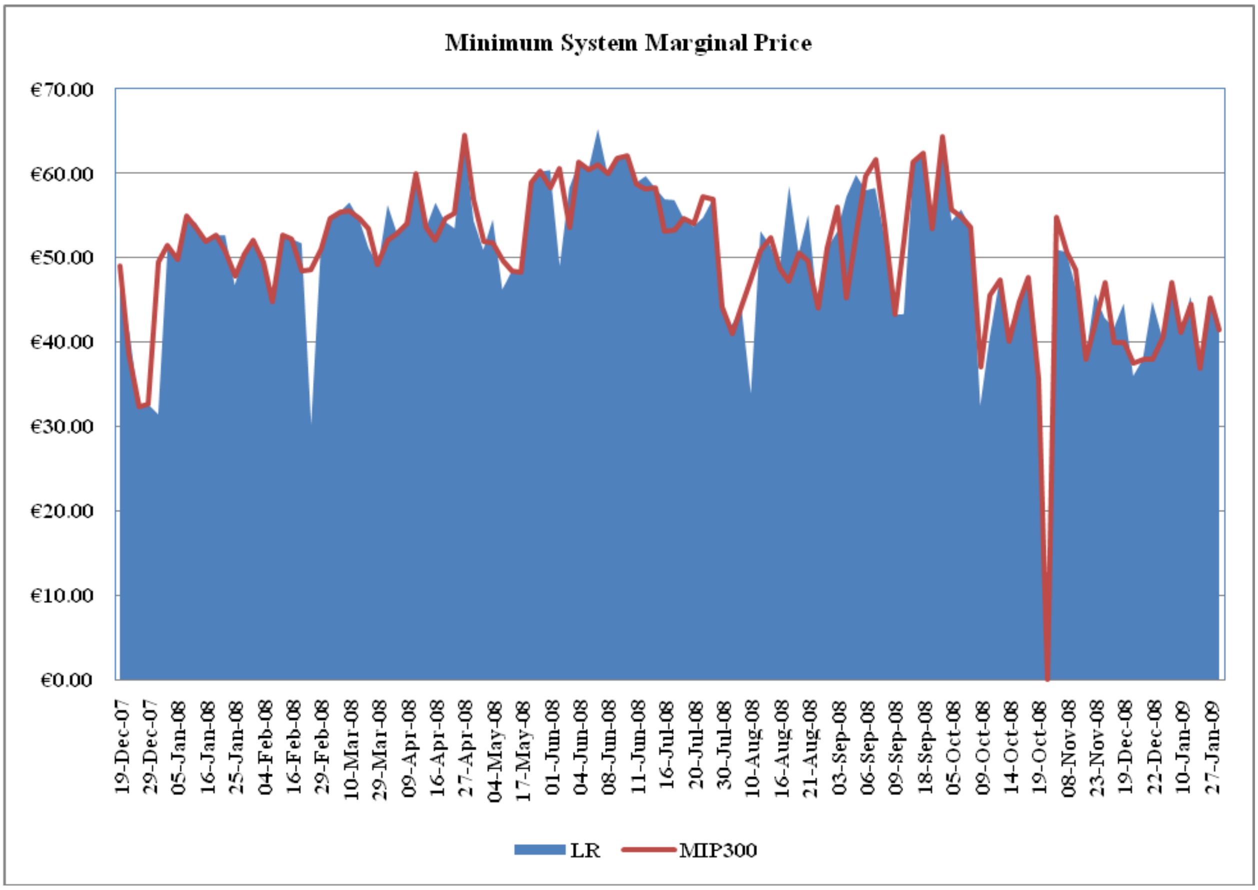

Figure 72 - Minimum System Marginal Prices (December 2007 – January 2009)

The above graph identified one Trading Day with an extremely low Minimum System Marginal Priceas follows:

Trade Date (Specific Interval)	*LR*	*MIP*
22-Oct-08 (23.10.08 Interval 04:00)	€3.26	€0.00

Table 21 - Minimum System Marginal Price

On the 22nd October 2008, the Shadow Price in both the LR and MIP solutions dipped to zero. Upon further investigation it would seem that this is possibly due to a large number of units being committed. When the load was low, the solver took the step of moving a large number of units to their Minimum Stable Generation position. Appendix N to the Trading and Settlement Code states the following:

> **"Appendix N: Derivation of Price Quantity Pairs**
>
> **N .47 (2) For** Price Maker Generator Units that are not Under Test, other than Interconnector Units and Pumped Storage Units, the relevant Price Quantity Pairs for each Trading Period in the Optimisation Time Horizon shall apply only over the range from the Minimum Output to the Availability in Trading Period h, where for each Trading Period h in the Optimisation Time Horizon"

Therefore, when a unit is at its Minimum Stable Generation, the units Price Quantity Pairs are no longer considered in the Economic Dispatch. Although these generator units are not free and are considered in the MSP Production Cost calculation, they no longer impact on the price. As there were 13 generator units in this position, this left only Hydro units in marginal positions. As the Price Quantity Pairs for Energy Limited units are zero, the marginal generator set the Shadow Price to its bid price of €0. This outcome was also observed in the published Ex Post Initial Market Schedule for this date. This scenario was driven by higher quantities of wind generation coupled with a low night valley system load. Similar results were observed in the outcomes of both solvers in this case.

Price volatility is measured through standard deviation of the System Marginal Price. The graph below shows the standard deviation of the System Marginal Price in all 154 study cases. We have presented all cases together to demonstrate that while individual days may yield markedly different levels of volatility, neither solver can be said to perform better than the other in any significant way. Very large peaks of over €120 have been found in study cases from both solvers though in both cases norms can be observed of around the €30 level in study cases from before the economic downturn to under €20 in the cases after.

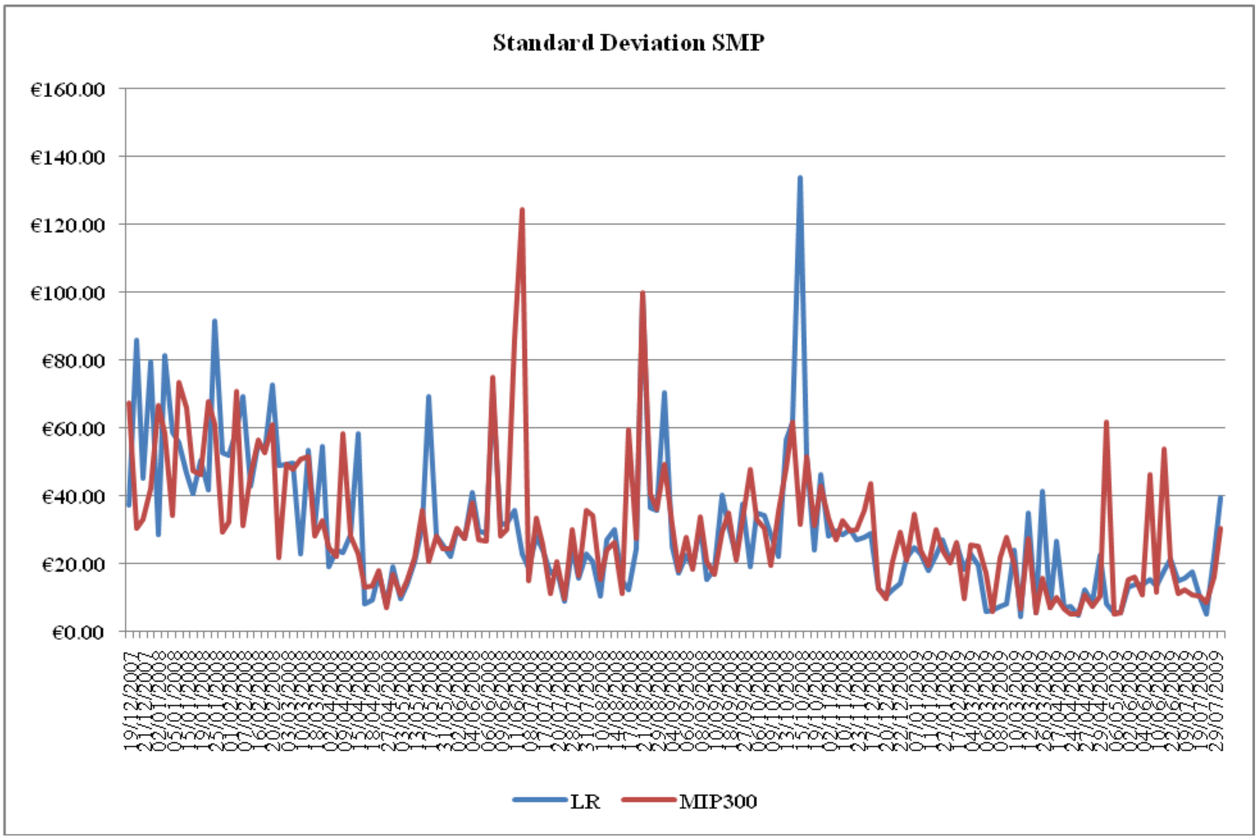

Figure 73 - Standard Deviation of System Marginal Prices (All Study cases)

We have also completed a frequency analysis of the values of standard deviation noted for each study case. This is presented in the two graphs below.

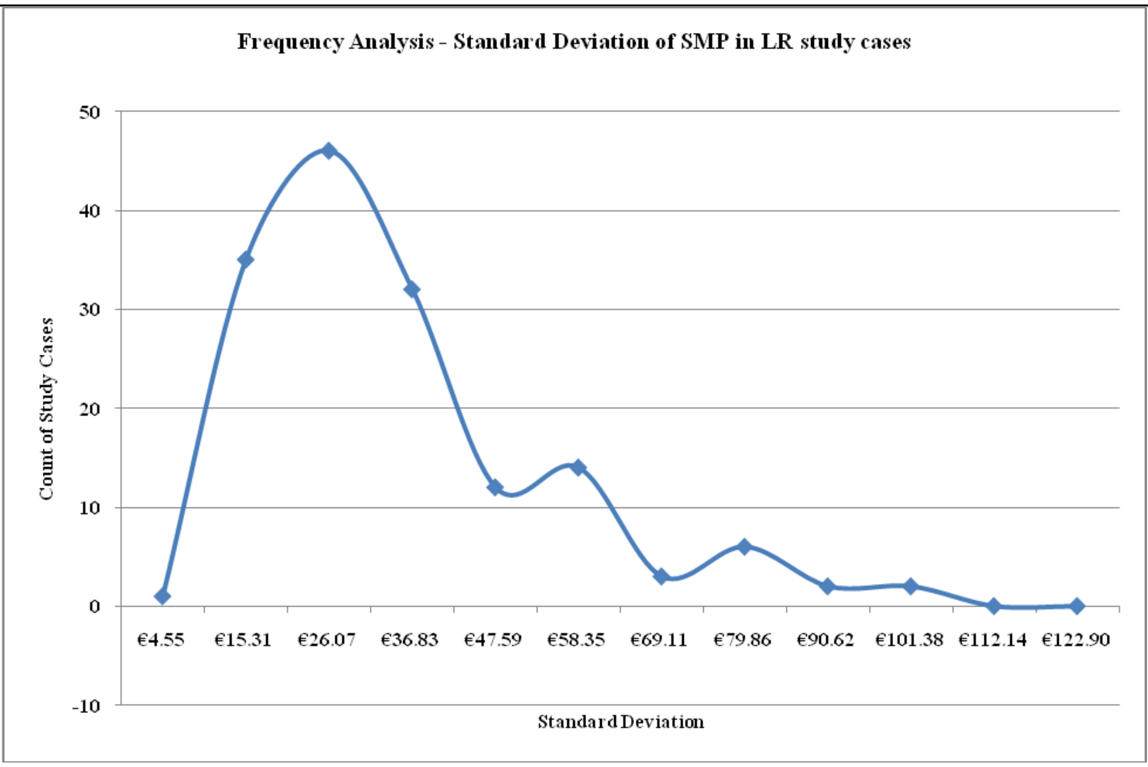

Figure 74 - Standard Deviation of System Marginal Prices in LR

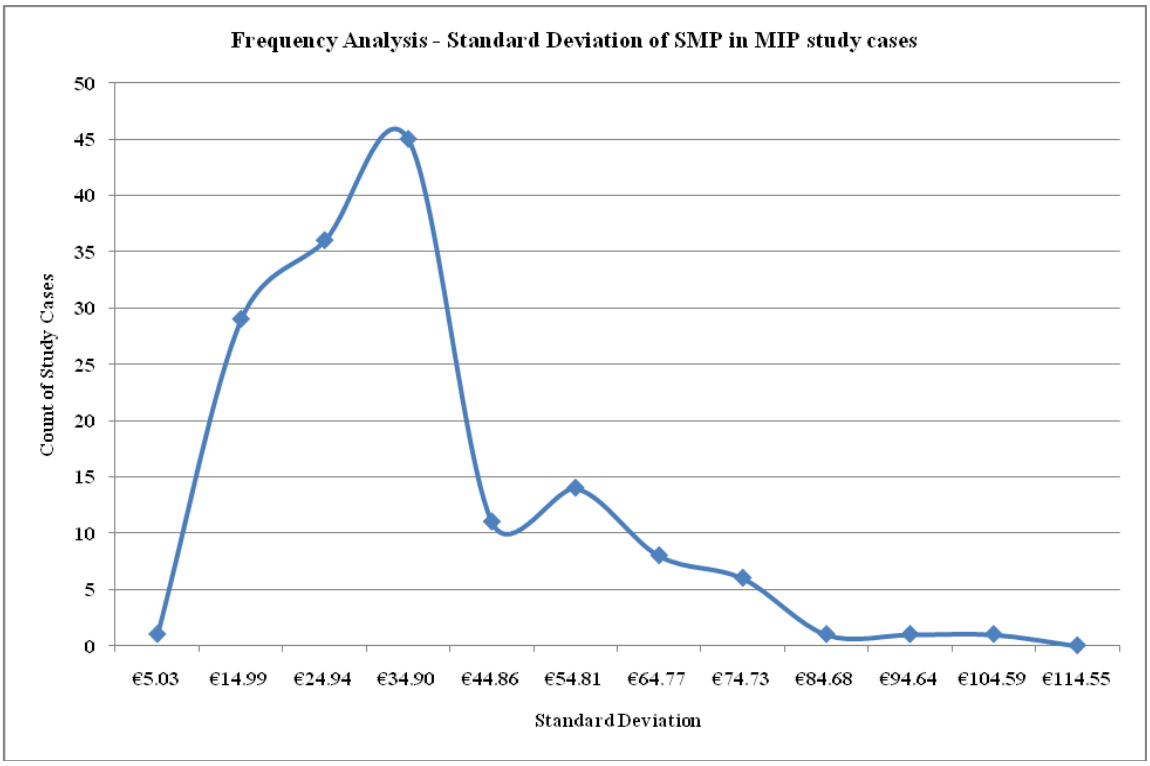

Figure 75 - Standard Deviation of System Marginal Prices in MIP

Again, a similar pattern is observed in the volatility of the price outcomes from each solver with no clear indication of one solver performing better than the other. This is particularly true when considering the difficulty that is encountered when trying to measure what level of volatility is best of an energy market.

6.4.2 Shadow Prices

The chart below represents a frequency analysis of the changes noted in the daily average Shadow Price. As demonstrated in percentage terms there are small changes in all cases. Of the 154 cases, we observed an increase in the daily average Shadow Prices in the outcomes of the MIP solver in 104 cases. The increases ranged from just above 0% to 25%. The largest change in monetary terms was €47.95.

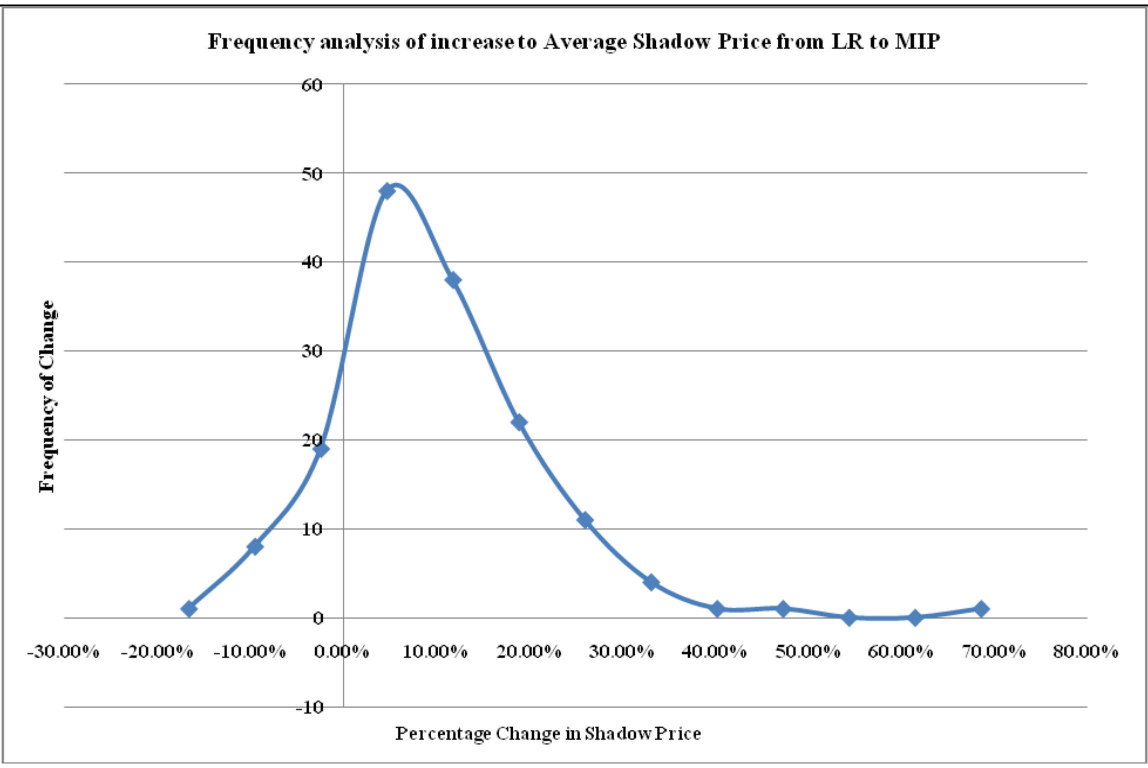

Figure 76 - Changes in Shadow Price from LR and MIP

Below Tables 22 and 23 summarise the distribution of daily average Shadow Price values across the full study. Both pre and post the economic downturn MIP has a higher % of Shadow Prices in the low price category.

Shadow Prices (%) per category over Total Period (116 Trading Days)	*LR*	*MIP*
Peak Shadow Price	3.45%	3.45%
High Shadow Price	22.41%	15.52%
Low Shadow Price	74.14%	81.03%

Table 22 – Shadow Prices Pre Economic Downturn (December 2007 – January 2009)

Shadow Prices (%) per category over Total Period (38 Trading Days)	*LR*	*MIP*
Peak Shadow Price	0%	0%
High Shadow Price	2.63%	0%
Low Shadow Price	97.37%	100.00%

Table 23 – Shadow Prices Post Economic Downturn (February 2009 – August 2009)

6.4.3 Uplift

In terms of Uplift, there is a general trend of reduction in the Average Daily Uplift calculated in the MIP runs. In 121 of the 154 cases, Uplift was calculated in both the LR and MIP runs. Of these 121 cases in percentage terms, 66.94% (81 studies) had smaller values of Average Daily Uplift when using the MIP solver than in the corresponding studies completed using LR. In monetary terms, the largest change was noted on the 4th September 2008 when the Average Daily Uplift calculated in MIP is lower than LR by €19.75. Of these 81 cases, 58 occurred in the pre economic downturn phase and 23 in the post economic downturn phase.

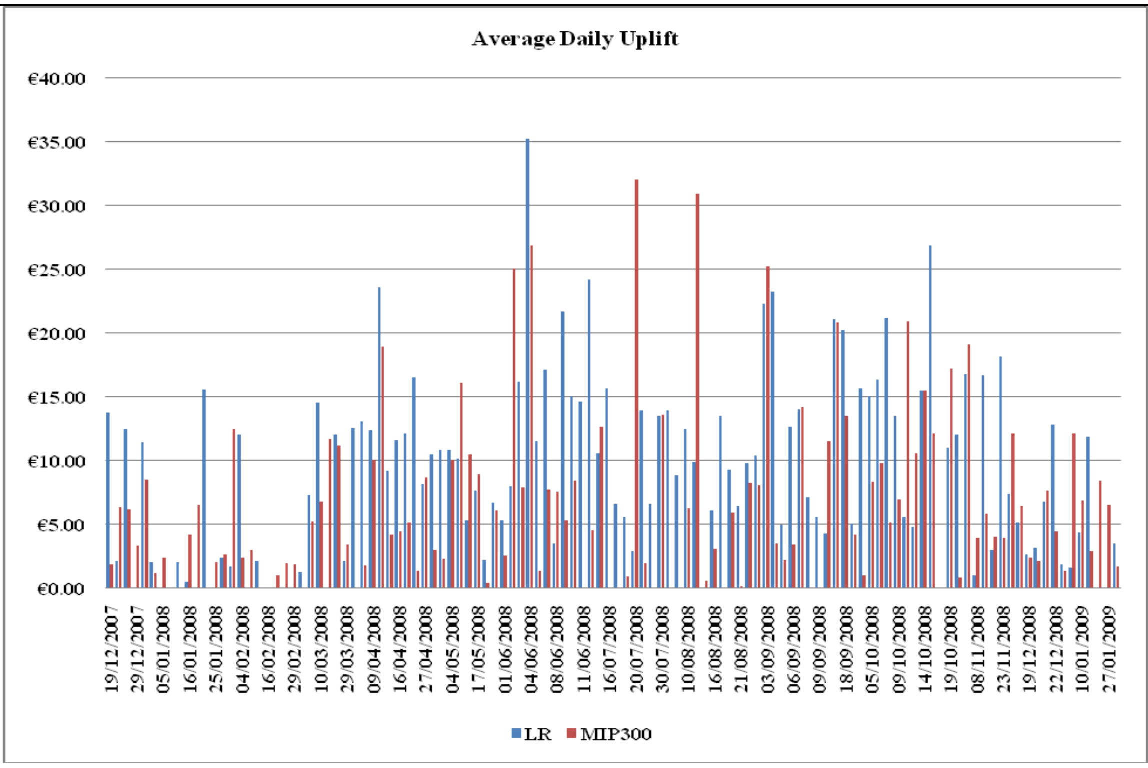

Figure 77 - Average Daily Uplift in System Marginal Price Pre Economic Downturn (December 2007 – January 2009)

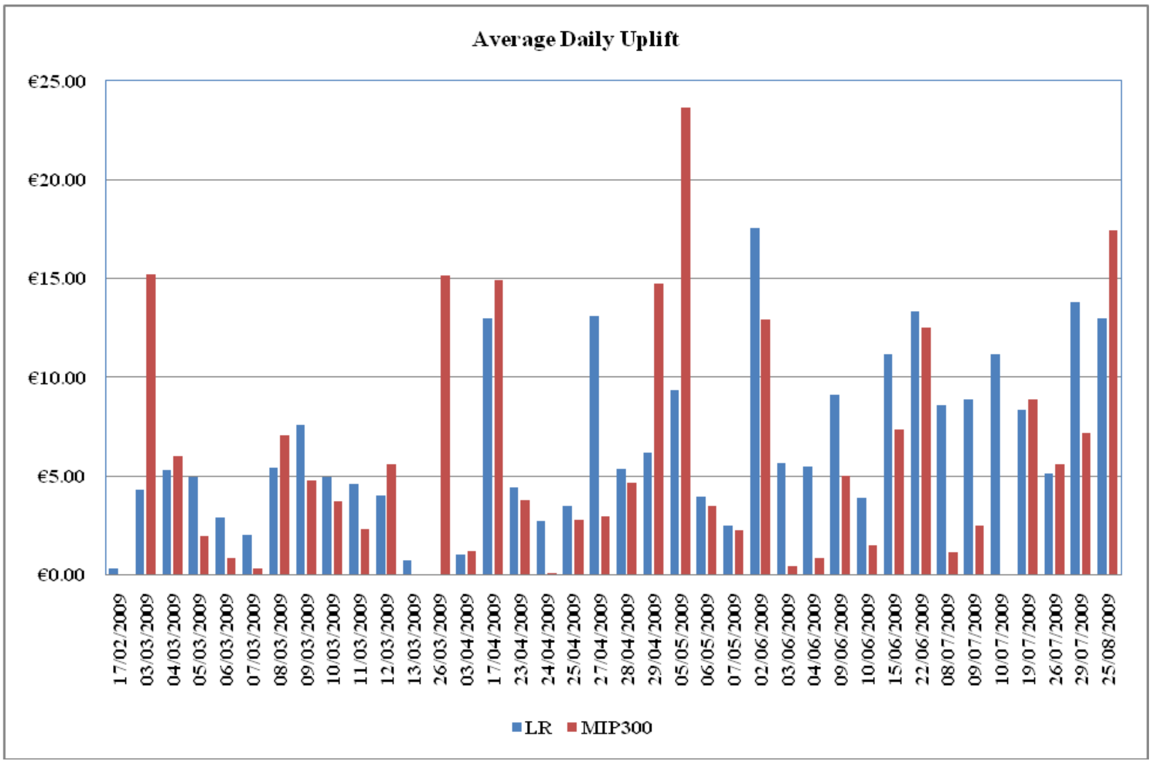

Figure 78 - Average Daily Uplift in System Marginal Price Post Economic Downturn (February 2009 – August 2009)

Of the remaining 33 study cases, Uplift was calculated by the LR or MIP solver but not both in 30, which breaks down as 17 when using LR and 13 when using MIP.

In three cases (1.95%), no Uplift was calculated in either the LR or MIP runs. These dates were the 10th January 2008, 16th February 2008 and 16th October 2008.

This is in line with the observations made in the report on generator commitment and starts. While there is a significant increase in generator starts by the MIP solver, the tendency is to commit the unit for longer contiguous periods and therefore reducing the need for Uplift. LR will commit a unit for a single period if required resulting in an increased volume of Uplift.

6.5 Shadow Price Calculation

The rules for the calculation of the Shadow Price in the SEM are set out in Appendix N of the Trading & Settlement Code, specifically in paragraph N 18.6. This requires that the Shadow Price is determined from the €/MWh change caused by an infinitesimally small increase or decrease to the Schedule Demand in a Trading Period. In general, this can be equated directly to an offer price bid in by a single generator who is said to be in the marginal position; that is, if there were a small increase or decrease to the Schedule Demand, this would be reflected in an increase or reduction the Market Schedule Quantity for this generator. Therefore, the offer price of this generator at this level of megawatt output (defined as the Market Offer Price in the T&SC) would determine the Shadow Price for the change to the Schedule Demand.

Pumped Storage generators do not submit bids into the SEM. Therefore, the Shadow Price calculation where a Pumped Storage generator is marginal becomes dependent on the offer price of other generators. Generally, the Shadow Price for a Pumped Storage generator is based on the cost of the water in the reservoir, that is, the Shadow Price when the reservoir was being filled.

However, the calculation of the Shadow Price can be more complex in other circumstances. This is because of the nature of the SEM design where the objective function is to minimise MSP Production Costs across a period of thirty hours. This can create inter-temporal dependencies where the cost of an increase in the output of a marginal generator in one Trading Period will have an impact on that generator's output in another Trading Period. To maintain energy balance, the change in the output of the generator in the other impacted Trading Period will also lead to a further change in the output of the marginal generator in that Trading Period. We refer to prices calculated in this manner as inter-temporal prices.

In this circumstance, the Shadow Price is calculated by taking the offer price of the marginal generator based on their output level and adding the cost of the increase minus the cost of the decrease in output for all other affected Trading Periods. This is most frequently observed when the marginal generator is operating under a ramp rate constraint and in the case of prices determined when Energy Limited Generators are marginal.

During periods of steep change in the system load, such as the ramp up to the morning or evening peak, the Shadow Price can become dependent on a generator that may be constrained by ramp rates in adjacent periods. As noted in these Trading Periods, the Shadow Price is made up of the offer price of the generator that is in a marginal position at the time and will include further costs from these constrained Trading Periods. In essence, the Shadow Price is calculated by taking account of the cost of the increase in the immediate Trading Period as well as the cost of the increase in output required in the adjacent Trading Periods due to the ramp rate constraint while also considering the reduction in cost for the marginal generator in these adjacent Trading Periods. The formula for this calculation is as follows

$$SPh = MOPuh + \sum_{hint} (MOPh - SPuh)$$

Where

1. SPh is the Shadow Price in Trading Period h;
2. MOPuh is the Market Offer Price of Generator Unit u in Trading Period h, calculated as per paragraph 4.133 of the Trading & Settlement Code;
3. the summation $\sum_{hint}$ is over all Trading Periods h in Trading Day t which are affected by Generator Unit u being under a ramp constraint.

We should note that this formula is a representation of how the Shadow Price is determined based on paragraph N 18.6 when the marginal generator is constrained by ramp rates in adjacent Trading Periods.

While we consider this kind of Shadow Price to be a result of ramp constraints on a given generator, the real cause is the requirement to maintain energy balance in all Trading Periods. For example, where the generator is ramp constrained across three Trading Periods and becomes marginal in the fourth, a change of 0.5MW to the MSQ in the Trading Period where the generator is marginal means that the output must be higher in the three previous Trading Periods while the unit was ramp constrained. As a result, the marginal generator in each of these Trading Periods would also need to change to output, reducing by 0.5MW to maintain the balance.

Generator	*Study Case*	*MSQ - 06:30:00*	*MSQ - 07:00:00*	*MSQ - 07:30:00*	*MSQ - 08:00:00*
GU_400272	EP2	142.59	185.55	228.5	271.45
	EP2 +0.5mw	143.09	186.05	229	271.95
	EP2 -0.5mw	142.09	185.05	228	270.95
GU_400323	EP2	237	237	439.81	453
	EP2 +0.5mw	237	237	439.31	453
	EP2 -0.5mw	237	237	440.31	453
GU_400480	EP2	283.63	316	316	316
	EP2 +0.5mw	283.13	316	316	316
	EP2 -0.5mw	284.13	316	316	316
GU_500130	EP2	113	189.53	230	230
	EP2 +0.5mw	113	189.03	230	230
	EP2 -0.5mw	113	190.03	230	230

Table 24 - Example of MSQ output with ramp up constraints

This is demonstrated in the table above. This shows how the generator GU_400272 while marginal at 08:00AM is ramp constrained in the previous three Trading Periods. Study cases completed with increases and decreases of 0.5MW are reflected in this generator's MSQ output while in the adjacent Trading Periods, the MSQ output while ramp constrained is increased. This leads to changes in the output of the marginal generator in each of these Trading Periods.

In these cases, the cost of a change to the megawatt output of the generator operating under a ramp constraint is no longer simply a product of the generator's incremental offer price but the cost of maintaining the energy balance in all other affected Trading Periods.

Energy Limited Generators in the SEM are Hydro stations. These submit a zero bid price into the SEM. As a result, when these generators become marginal their own contribution to the Shadow Price is zero. However, we must also consider the requirement for energy balance as noted above in connection with generators under ramp constraints. Because the Hydro stations are Energy Limited, this means that their output across the entire Trading Day must be balanced to not exceed a certain total level of output. As a result, an increase in the megawatt output of an Energy Limited generator can require a corresponding decrease in output for the same generator in another Trading Period in some other part of the Trading Day. This is the case when the Energy Limit is binding, that is the full Energy Limit has been used by the MSP software. When the full Energy Limit has not been used, the increase in output in one Trading Period may not require an increase in another. However, when the full Energy Limit has been used, the increase must have a decrease elsewhere. This decrease in output will require another generator to increase its output in that Trading Period.

The formula for this calculation is as follows

$$SPh = MOPuh + \sum_{hint} (SPh - MOPuh)$$

Where

4. SPh is the Shadow Price in Trading Period h;
5. MOPuh is the Market Offer Price of Generator Unit u in Trading Period h, calculated as per paragraph 4.133 of the Trading & Settlement Code;

6. the summation $\sum_{h\,in\,t}$ is over all Trading Periods h in Trading Day t which are affected by Generator Unit u being under an Energy Limit constraint.

As noted above, this formula is a representation of how the Shadow Price is determined based on paragraph N 18.6 when a Hydro generator is marginal while the Energy Limit constraint is binding. It can be noted that the variables in the addition are reversed from their order when we represent how Shadow Price is calculated when the marginal generator is operating under a ramp rate constraint. This is because when dealing with the ramp rate constraint, the output and therefore the costs of the marginal unit must increase in all affected Trading Periods while the output and therefore the costs of the marginal generator in the affected Trading Periods must decrease. However, when dealing with the Energy Limit constraint, the reverse is true – the output and costs of the marginal generator in the affected Trading Period must increase while the output and costs of the Energy Limited generator must decrease.

This means that when an Energy Limited generator is marginal while its own bid price is zero, we add the cost variance from the other affected Trading Period. Because of the zero bids, this gives the appearance that Hydro generators take the bid price of another thermal generator when marginal. Because Energy Limited generators are scheduled to maximise their impact across peak energy times, this means that the energy cost associated with Energy Limited generators frequently arises from generation that is more expensive.

As we note in the section on Generator Commitment, the MIP algorithm makes better use of Energy Limited generators with the Energy Limit constraint more frequently being binding. As a result, it is more common to find Energy Limited generators in marginal positions in the MIP schedules setting the Shadow Price according to the methodology above.. This is demonstrated in the graphs below which match the system Shadow Price to the marginal generator at that time.

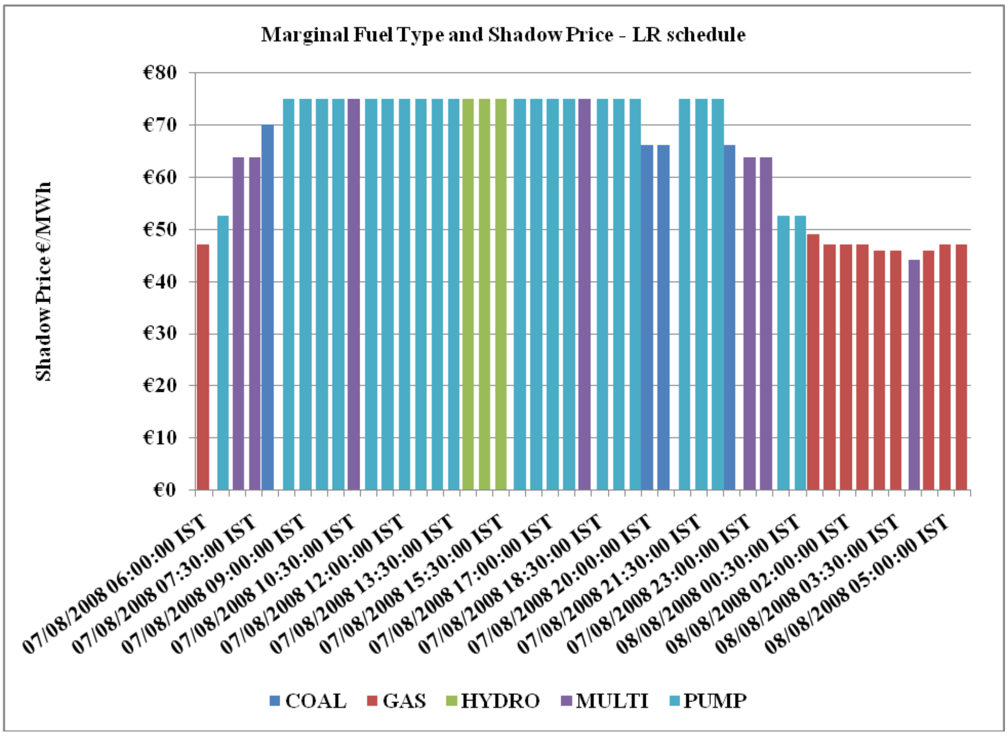

Figure 79 - Shadow Price Setting Fuel - LR

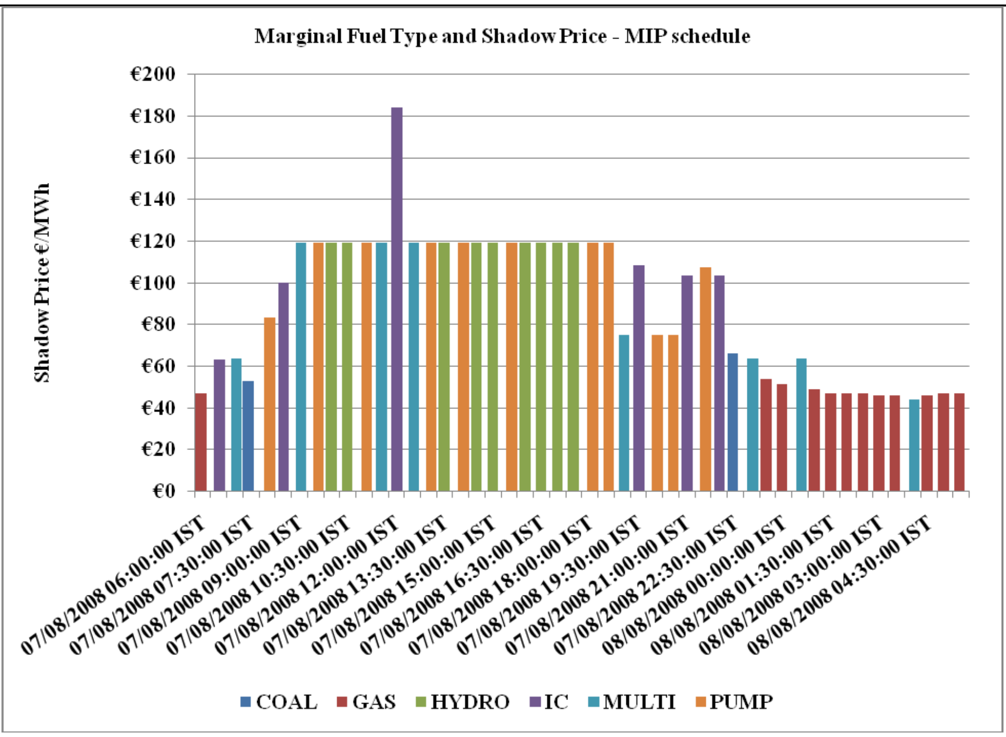

Figure 80 - Shadow Price Setting Fuel - MIP

As can be noted in this example, Hydro generators are more frequently marginal in the MIP case. This results in the marginal cost of a gas generator which is used to maintain the Energy Limit balance at 12:30 which then persists throughout the schedule. This is because the first Hydro generator whose Energy Limit balance is maintained by the gas generator is used elsewhere in the schedule to balance another Hydro generator. This is also reflected in the costs of Pumped Storage generation which is also used to maintain the Energy Limit balance for a Hydro.

In the LR schedule for this Trade Date, Pumped Storage generators are the marginal plant for the bulk of the day and set the Shadow Price based on their pumping cost. Interestingly, in this schedule when Hydro generators become marginal during the afternoon, because they cause changes to Pumped Storage generators elsewhere in the schedule, this price then becomes the marginal cost of an increase in Hydro generation.

6.6 Conclusion

Overall, the Average Daily System Marginal Price has increased in MIP, with the highest average daily increase observed on the 5th May 2009 (€54.11). This study case has also been reviewed in the Consumer Costs section where it was observed that the higher System Marginal Price in the MIP schedule resulted in the largest percentage change in Consumer Costs observed in the complete study.

In the majority of cases the increase in the daily Average System Marginal Price is within -10/+20% of the System Marginal Price from the results of the LR study case. With respect to the daily Maximum System Marginal Price, the opposite has occurred with a higher daily Maximum being observed in the results of the LR solver. With Average daily Uplift, we observed that of the 121 cases when Uplift was calculated in both the LR and MIP runs, the daily Average is higher in 66.95% of the study cases run with the LR solver. This ties in with the patterns observed in the commitment section where we noted that the LR solver is more likely to incur frequent starts and their respective costs than the MIP solver. This appears to relate to the behaviour of the MIP solver where generators once started are kept on for longer periods of operation. This longer period of operation makes it more likely for the generator to recover its costs at Shadow Price rather than needing Uplift when they are shut down after shorter periods, a behaviour sometimes noted in the solutions from the LR solver.

While it may be expected that the reductions in Uplift, incidence of Peak Prices and the lower daily Maximum System Marginal Prices would produce lower prices, this is not the case as the daily Average shows. It can also be noted that the daily Minimum System Marginal Prices in the results of the LR solver were more frequently lower than those observed when using MIP. This means that while reducing Peak Prices and Uplift, the Shadow Prices in the MIP solutions are generally higher than those in LR. We have noted that the increased commitment of Hydro generators is a factor in the resulting higher Shadow Prices.

We also noted comparable levels of standard deviation in the System Marginal Prices between the two solvers.

As noted earlier, while the System Marginal Price and Uplift calculations are not part of the objective function of the SEM rules and therefore not strictly influenced by the solver choices, the changes in how generators are committed impacts on the choices that can be made in the Economic Dispatch phase of the MSP software. As such, we can only conclude that we have observed more incidents of higher prices with the MIP solver than the LR solver; however, we cannot conclude positively that the MIP solver will always produce higher prices.

7 Commitment of Generators

7.1 Introduction

The key aim of this report is to provide a comparative analysis between the LR and MIP solvers with regard to the commitment of Price Maker Generator units. We first focused on generator starts, to determine if there was a notable increase or decrease in these in the outcomes of the MIP solver compared with the LR. Secondly, we reviewed the number of commitments by generator technology type[19] across the outcomes of the two solvers. The Price Maker technology types reviewed were Pumped Storage, Energy-Limited (Hydro), Combined Heat and Power (CHP), Open Cycle Gas Turbines (OCGT), Combined Cycle Gas Turbines (CCGT) and Steam based generators. Price Takers were excluded from this review as their commitment decision is not made by the Unit Commitment software.

7.2 Executive Summary

The main findings were that the MIP solver shows a significant increase for both generator starts and levels of commitment particularly for Pumped Storage and Hydro. The largest overall percentage increase in unit commitment of 30% over the entire Trading Day was observed on the 7th March 2009.

We have observed that LR has a tendency to commit a single generator unit for one Trading Period to meet a portion of the Schedule Demand when MIP will commit a combination of units. One effect of this is a larger volume of Uplift in the LR runs. However, because MIP schedules more generators, in particular Hydro as noted above, the overall Shadow Price in the MIP runs tends to be higher than with the LR.

7.3 Background

In accordance with Appendix N of the Trading and Settlement Code, section N.16 on the Operation of the MSP Software reads

> **“**Operation of the MSP Software
>
> N.16
>
> For each Trading Period h of the Trading Day, the MSP Software shall be used to calculate System Marginal Price (SMPh), and the Market Schedule Quantity (MSQuh) for each Price Maker Generator Unit u that is not Under Test, as follows:
>
> Step 1
>
> Determine the Unit Commitment Schedule for each Price Maker Generator Unit that is not Under Test, including for each Pumped Storage Unit whether or not it is scheduled to pump or generate, in each Trading Period in the Optimisation Time Horizon;”

The Unit Commitment program is the module within the MSP software, which determines the unit commitment schedule. It supports both Mixed Integer Programming and Lagrangian Relaxation methods. The initial stage in the running the MSP software is unit commitment phase which is the decision to commit a generator unit on or off for each Trading Period in the Optimisation Time Horizon. The Unit Commitment program simply outputs 1 or 0 (to signify on or off respectively) for units. The next phase of the program, the Economic Dispatch, sets the level of megawatt output for each generator. This is their Market Schedule Quantity. In addition, this phase sets the Shadow Price in the SEM. However, the Economic Dispatch phase is limited to solving the market using the commitment decisions from the Unit Commitment program. As such, the behaviour of the commitment engine is an important factor in the calculation of the market price.

[19] See Appendix 5 for the breakdown of how generators were classed for this study.

Unit commitment may find local optima, as there may be various commitment solutions with similar costs. When making commitment decisions, the solver considers the generators Commercial Offer Data (Price and Quantity pairs, No Load Costs and Start Up Costs), while respecting the generators technical operating characteristics (ramp rates, minimum on times, minimum off times, and warmth state etc.) to meet the load to be delivered by Price Maker Units (referred to as the MSP Schedule Demand) at the least cost.

The objective function of unit commitment is to minimise the sum over all periods of the following:

- Start Up Costs,
- No Load Costs,
- Generator and Interconnector usage costs, and
- Cost of slack variables

7.4 Analysis

Comparative analysis was carried out between the LR and MIP solvers on both the degree of commitment across technology types and the frequency of generator starts. The commitment analysis focused on the number of committed generator units rather than the Market Schedules Quantities for each unit in the Trading Day. The main emphasis was placed on technology type rather than classification type (i.e. Baseload, Mid Merit etc). The reason for this is that the classification type is linked to the generators Commercial Offer Data. If a generator reduces its bids and offers it may fall into a different classification category.

This analysis was completed on the Trading Day (06:00am to 06:00am) not the Optimisation Time Horizon (06:00am to 12:00pm) for Price Maker Generator units across all 154 study runs.

For the consecutive run dates, the initial conditions for each case, in terms of generator status and output, were set based on the end conditions of the previous Trading Day's Ex-Post Initial Market Schedule. The initial status for each resource shows the following data:

1. Status flag (On/Off)
2. Initial MW value
3. Last status change time, i.e. the time when the last status change occurred. It is used to calculate how long the unit has been on/off.

Please note that in all graphs by Trading Day/Trading Period in this report, the interval mapping is as follows time period 1 is the Trading Period starting at 06:00am, the start of the Trading Day and time period 24 is the Trading Period starting at 05:00am, the end of the Trading Day.

The graphs in Section 1 (a) & (b) below, demonstrate the overall commitment by each solver, by technology type for periods both pre and post the economic downturn. It is evident from the graphs that MIP has a tendency towards committing a larger number of generators. This is particularly for two technology types, Pumped Storage and Hydro. However, as Pumped Storage generators do not submit Commercial Offer Data, these extra commitments will have no impact on the final prices in the SEM.

Of the 154 days studied, MIP committed more units in 151 cases (98%). On the 25th January 2008 and 20th December 2008, LR showed greater commitment. There was only one case, the 23rd November 2008 when both solvers demonstrated the same number of total commitments; however, the commitment by technology type did vary.

There was only one technology type that showed no change in commitment between the solvers in all cases and this was CHP. This is because there are only two generators of this type registered in the SEM for the periods we have studied. The unit's position in the merit order would be reasonably consistent resulting in a common commitment pattern across the two solvers. The following table gives a summary of the commitment comparison by technology type for the entire study period:

Technology Type	*Cases with Higher Commitment in LR*	*Cases with Higher Commitment in MIP*	*Cases with Equal Commitment in LR & MIP*
CCGT	80	38	36
CHP			154
Hydro		154[20]	
OCGT	73	50	31
Pumped Storage	31	107	16
Steam	61	61	32

Table 25 – Commitment Comparison by Technology Type (All 154 study dates)

7.4.1 Section 1 (a): Commitment Comparison by Trading Day (Pre Economic Downturn)

In the graph below, we review the first 45 Trading Days in this period. We can see that the technology types that demonstrated the greatest increase in commitment with MIP were Pumped Storage in 30 cases and Hydro in all 45 cases. Steam based generators demonstrated a greater commitment with LR in 25 of these cases and no change in eight.

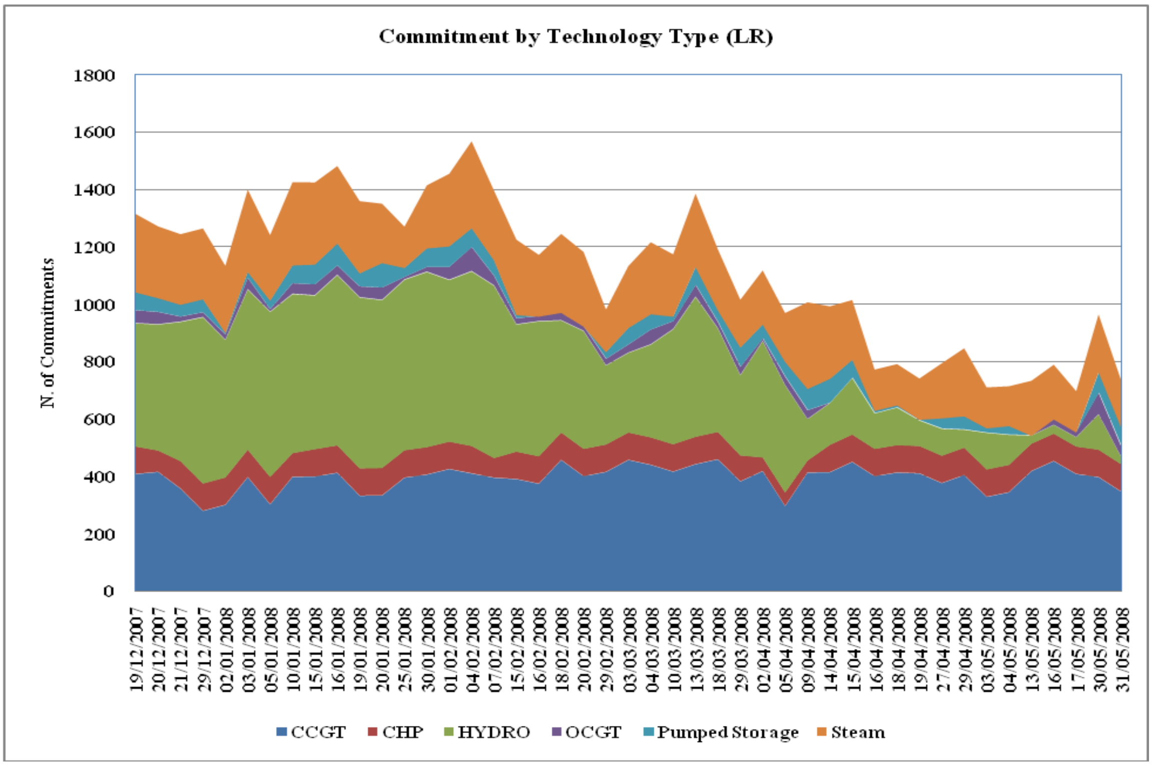

Figure 81 – Total Commitment in LR by Technology Type (December 2007 – May 2008)

[20] The Energy Limited Generators section of this report investigates this outcome further.

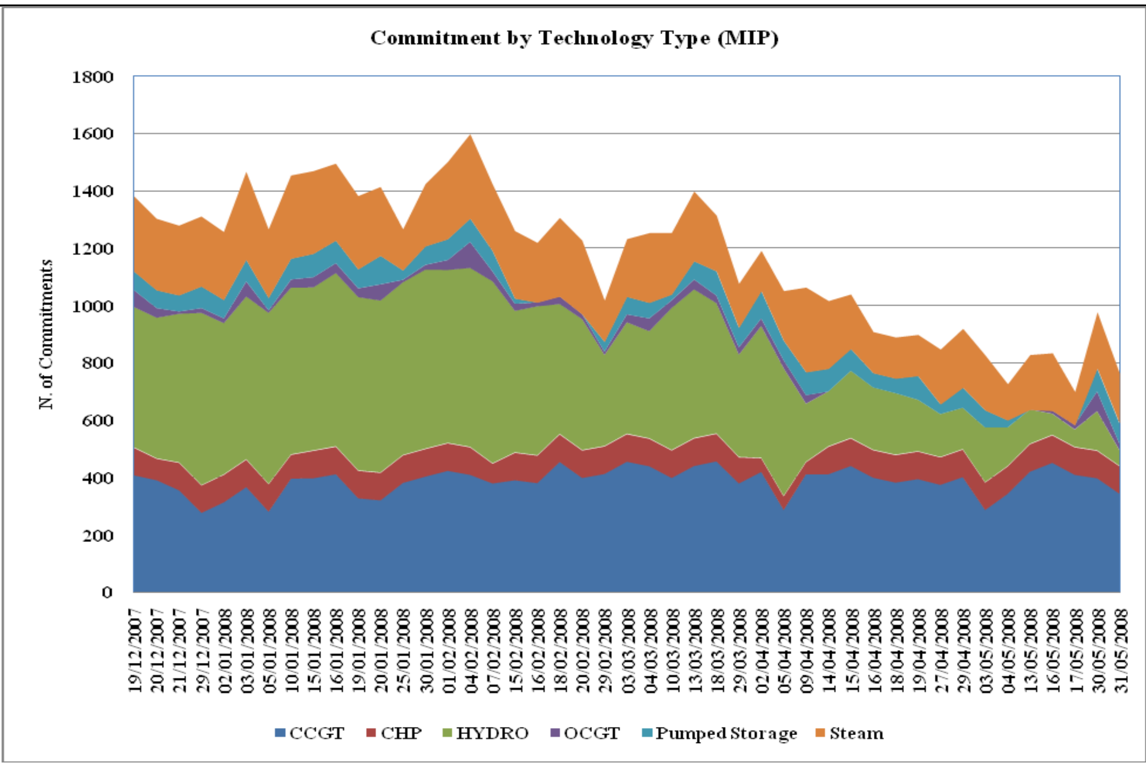

Figure 82 – Total Commitment in MIP by Technology Type (December 2007 – May 2008)

The next period of 64 Trading Days reviewed below followed a similar pattern as above with Pumped Storage showing increased commitment in 45 out of 64 cases and no changes in four cases. Hydro units' commitment increased in all cases. Steam based generators demonstrated a greater commitment with LR in 25 cases, a greater commitment in MIP in 25 cases and no change in 14.

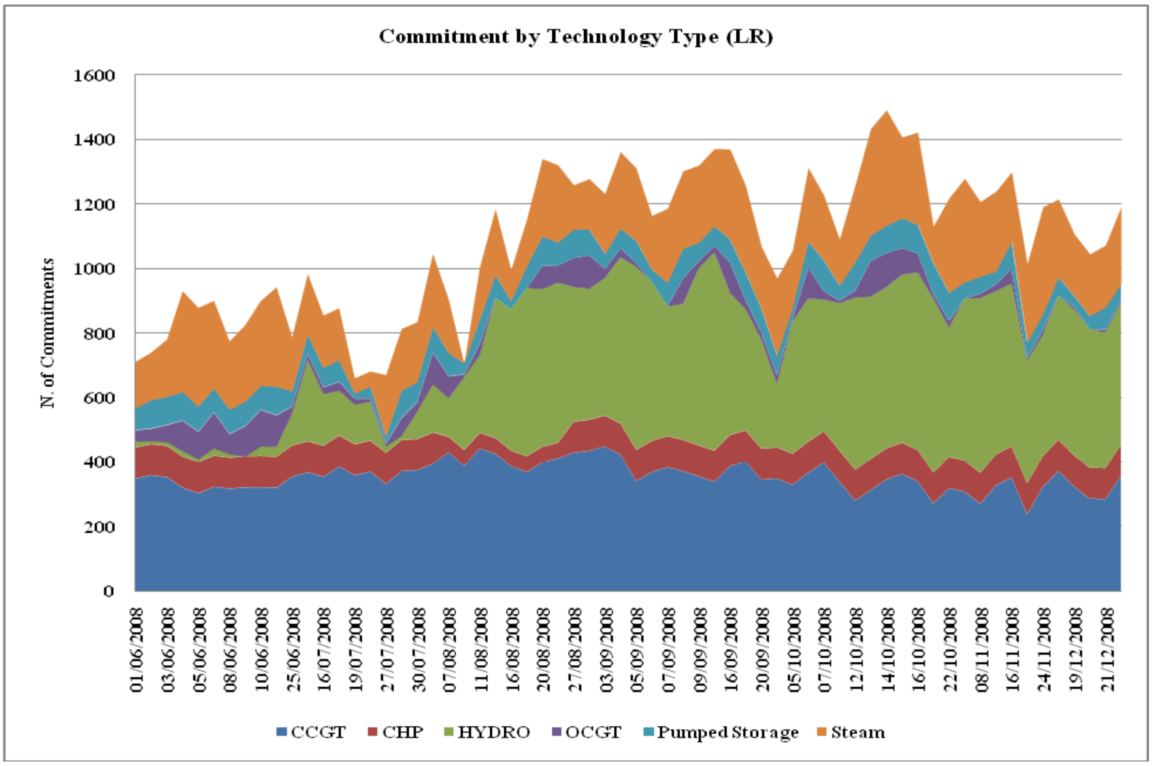

Figure 83 – Total Commitment in LR by Technology Type (June 2008 – December 2008)

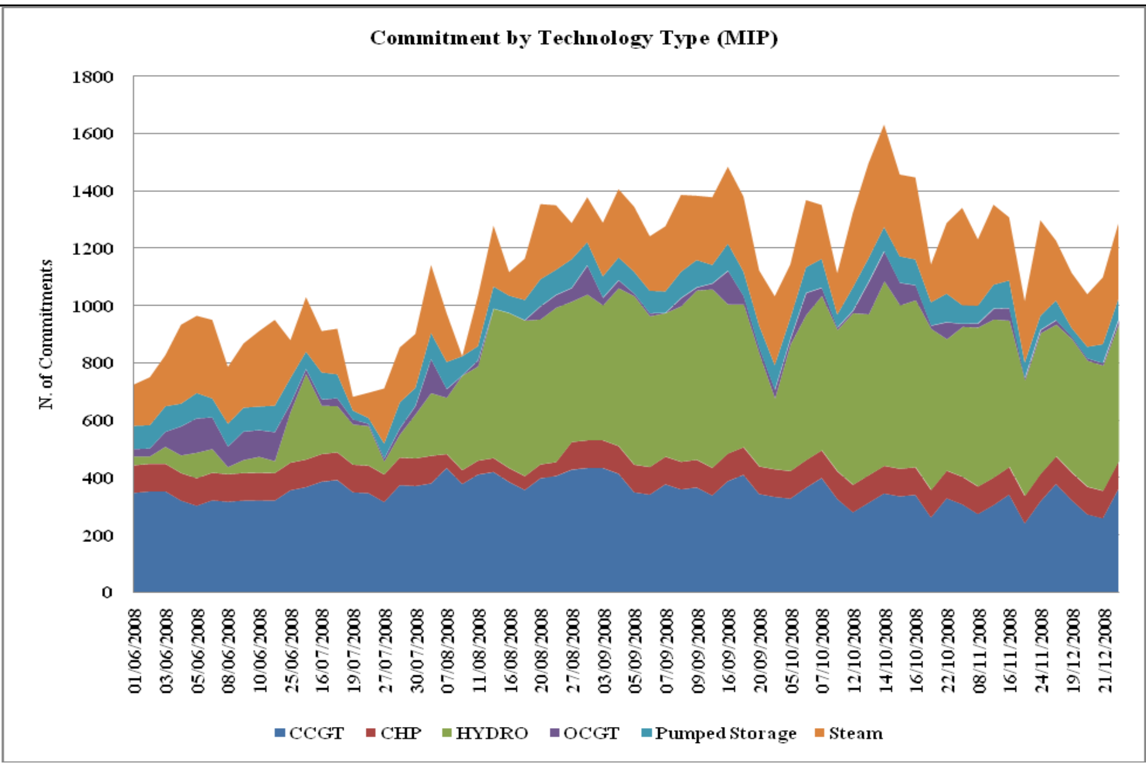

Figure 84 – Total Commitment in MIP by Technology Type (June 2008 – December 2008)

7.4.2 Section 1 (b): Commitment Comparison by Trading Day (Post Economic Downturn)

Following the economic downturn there was a decrease in Schedule Demand, which is evident from the following graphs. However, a similar trend was observed in commitment as is noted with the Trading Days from before the economic downturn. Pumped Storage showed an increase in commitment in 32 out of 45 cases and Hydro in all cases. Steam based generators demonstrated a greater commitment with MIP in this period in 24 cases and no change in 10 cases. OCGT demonstrated a greater commitment with LR in this period in 27 cases and no change in five cases.

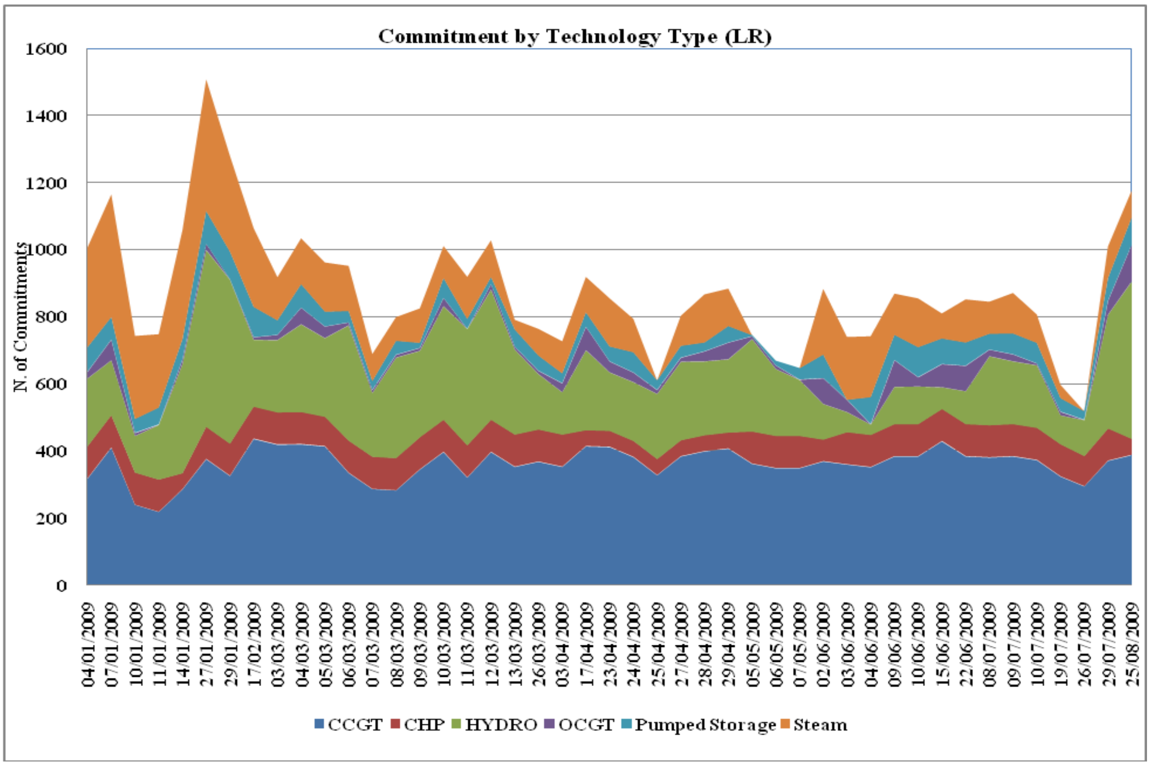

Figure 85 – Total Commitment in LR by Technology Type (January 2009 – August 2009)

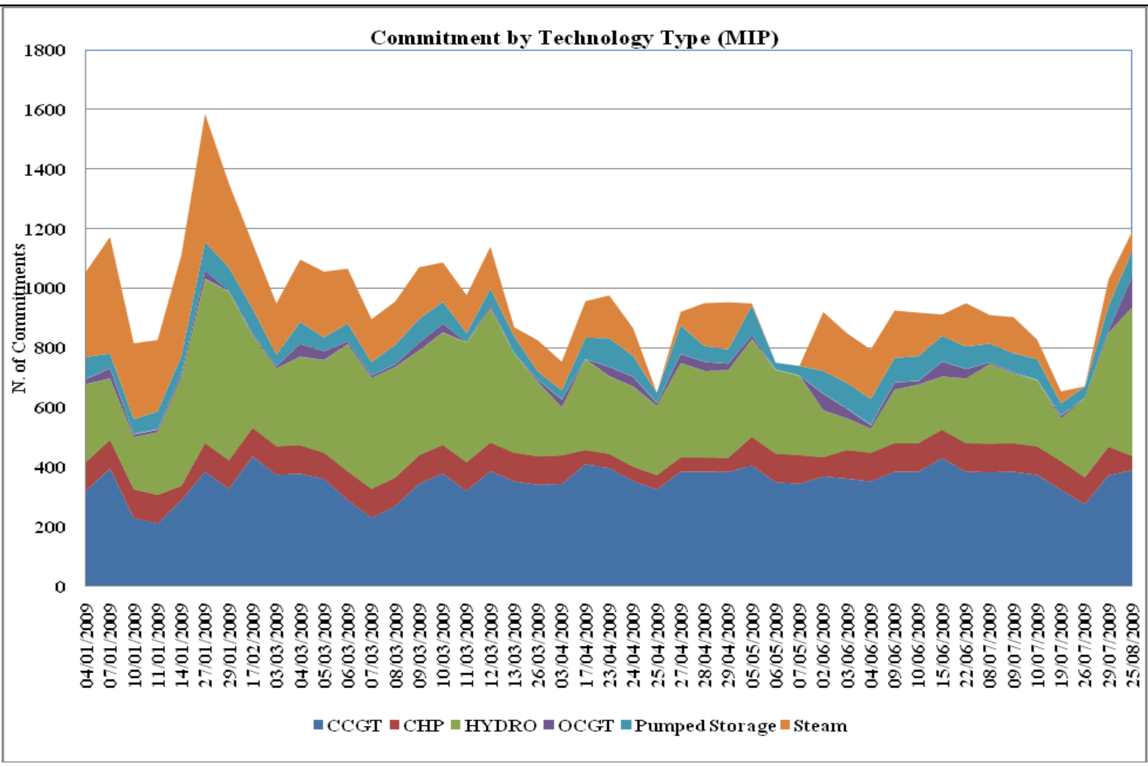

Figure 86 – Total Commitment in MIP by Technology Type (January 2009 – August 2009)

There is a notable reduction from March 2009 in the total level of commitment when compared with the same period in 2008 as shown in the table below.

Trading Day	*Average System Load*	*Total LR Commitment*	*Total MIP Commitment*
03/03/2008	5189.70	1134	1233
04/03/2008	4785.05	1217	1254
10/03/2008	5071.11	1175	1255
13/03/2008	5211.95	1386	1399
		918	949
03/03/2009	4969.63		
04/03/2009	4675.35	1034	1097
10/03/2009	4526.23	1011	1087
13/03/2009	4255.12	791	869

Table 26 – Total Commitment Comparison (March 2008 & March 2009)

7.4.3 Section 2 (a): Commitment Comparison by Trading Day/Trading Period for Consecutive run Dates (Pre Economic Downturn)

The graphs in Section 2 (a) and (b) below demonstrate the commitment variances on a per Trading Day/Trading Period basis. This gives us an opportunity to drill down into the general trend data that we have reviewed throughout Section 1. The increase in commitment for Pumped Storage and Hydro is evident in both Consecutive periods.

In turn, the increased commitment of Hydro generators has a knock on affect on other generators. We can see in the graphs below a noticeable reduction in the commitment of steam-based generators across this set of days. Rather than being related to their technology type, these units are displaced in the schedule here by the Hydro generators because of their high bid cost. (We have calculated the average cost per exported megawatt for these generators €85 using the measure of their Price multiplied by the absolute megawatt quantity, divided by the total offered energy.)

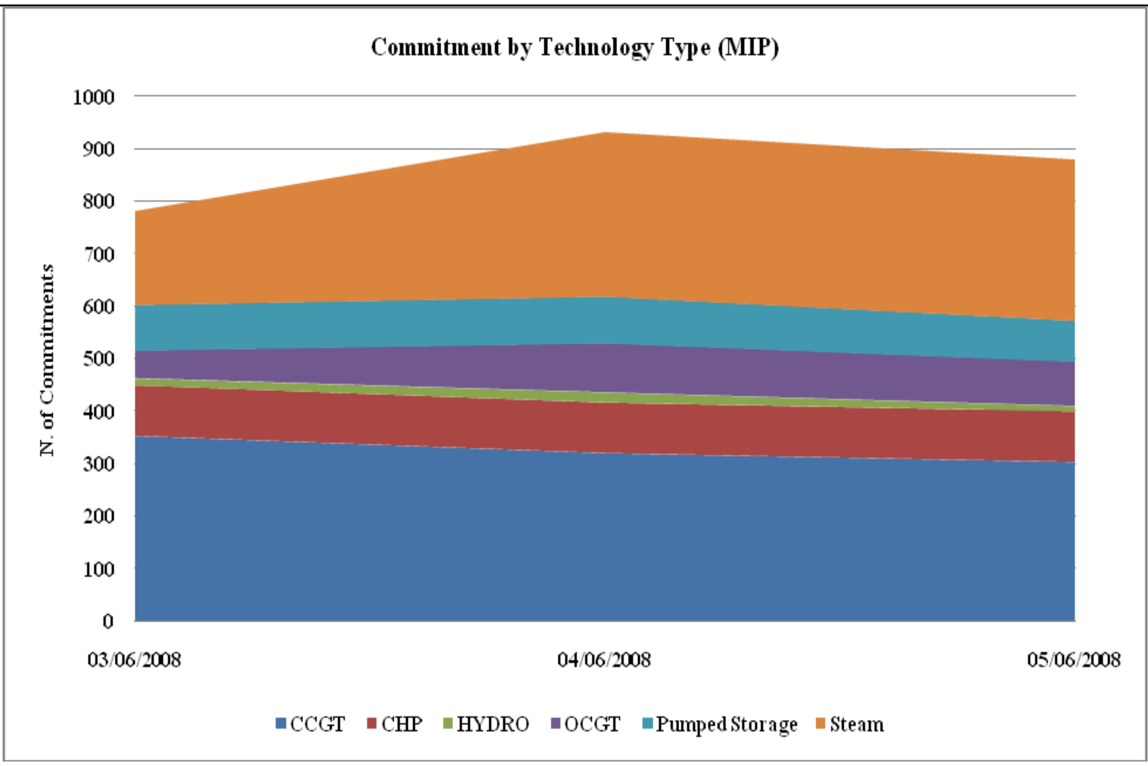

Figure 87 – Total Commitment in LR by Technology Type (June 2008)

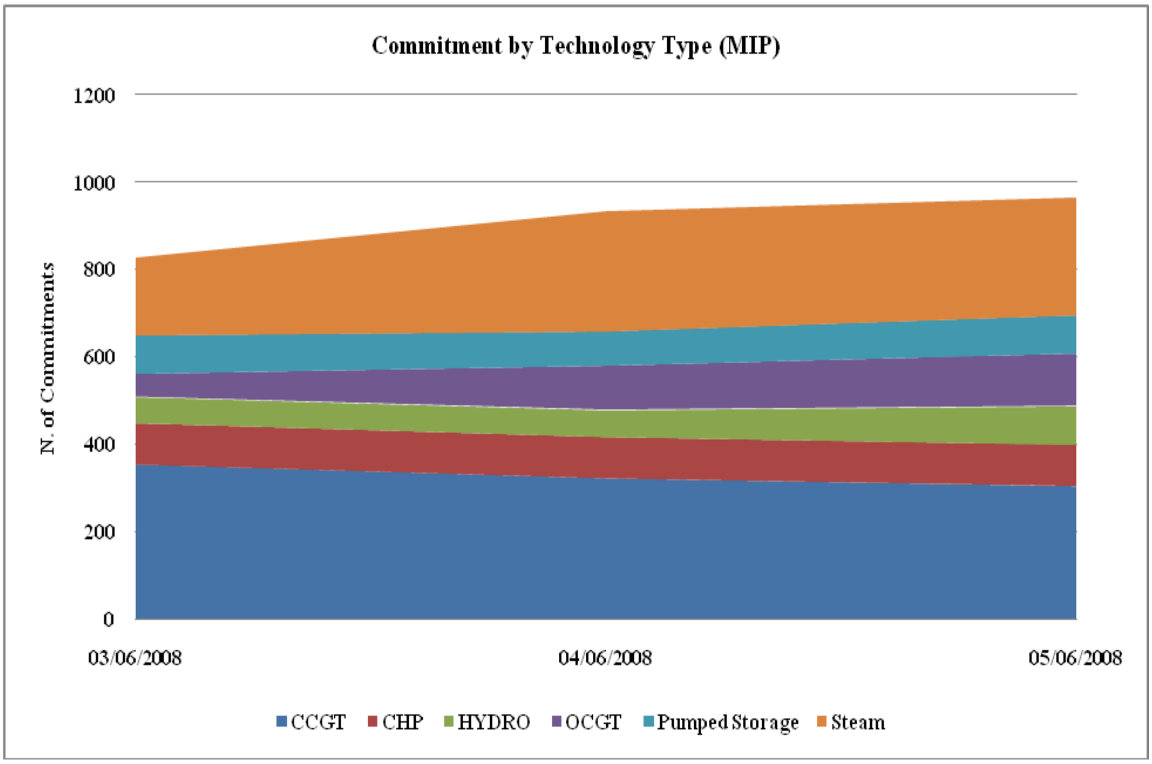

Figure 88 – Total Commitment in MIP by Technology Type (June 2008)

The following graphs demonstrate the increased commitment by Technology Type across this same three-day period.

Hydro generators are subject to Energy Limits across a Trading Day. They also submit very low start up costs. Normally, they are run across the day and de-committed during the night value in place of conventional generators. These are kept on at minimum stable generation and are used to meet the sharp increase in system load to meet the morning peak, when the Hydro generators are committed back on.

MIP significantly increases the commitment of Hydro while respecting the submitted Energy Limits. Energy Limited units are covered in more detail here.

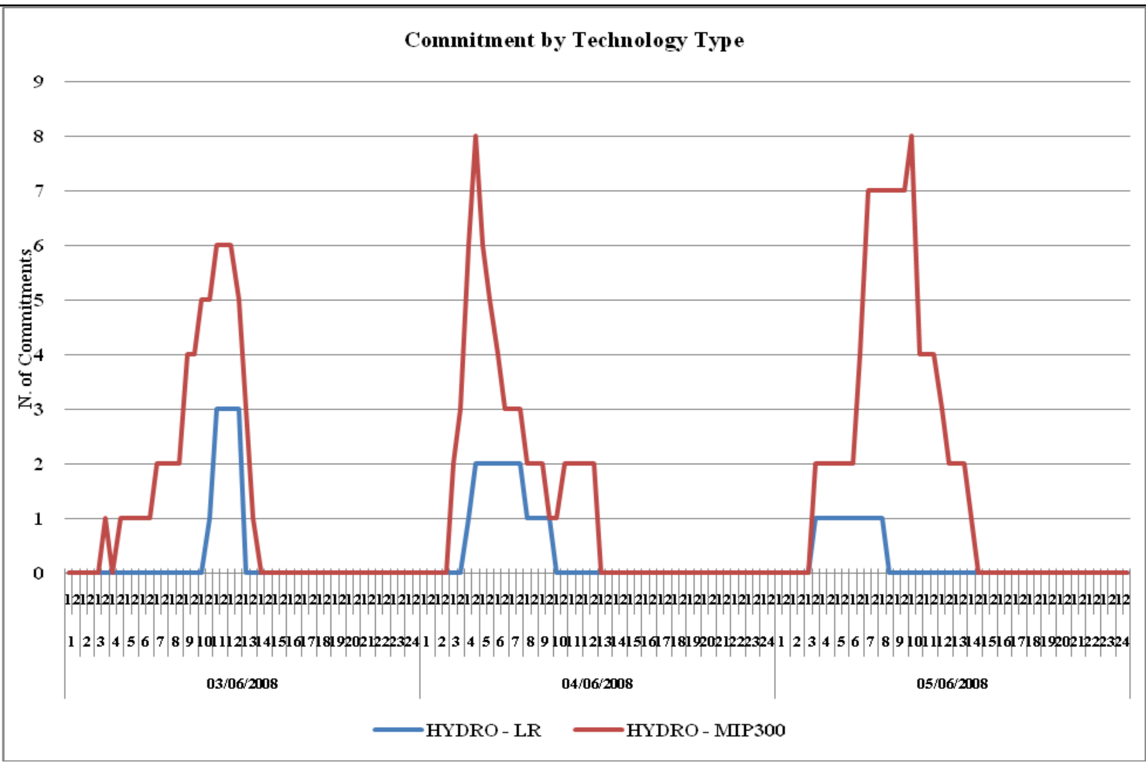

Figure 89 – Commitment Comparison by Technology Type (June 2008)

For Pumped Storage, the main changes occur right across the Trading Day. MIP again significantly increases the commitment of Pumped Storage, generating during the day and pumping at night.

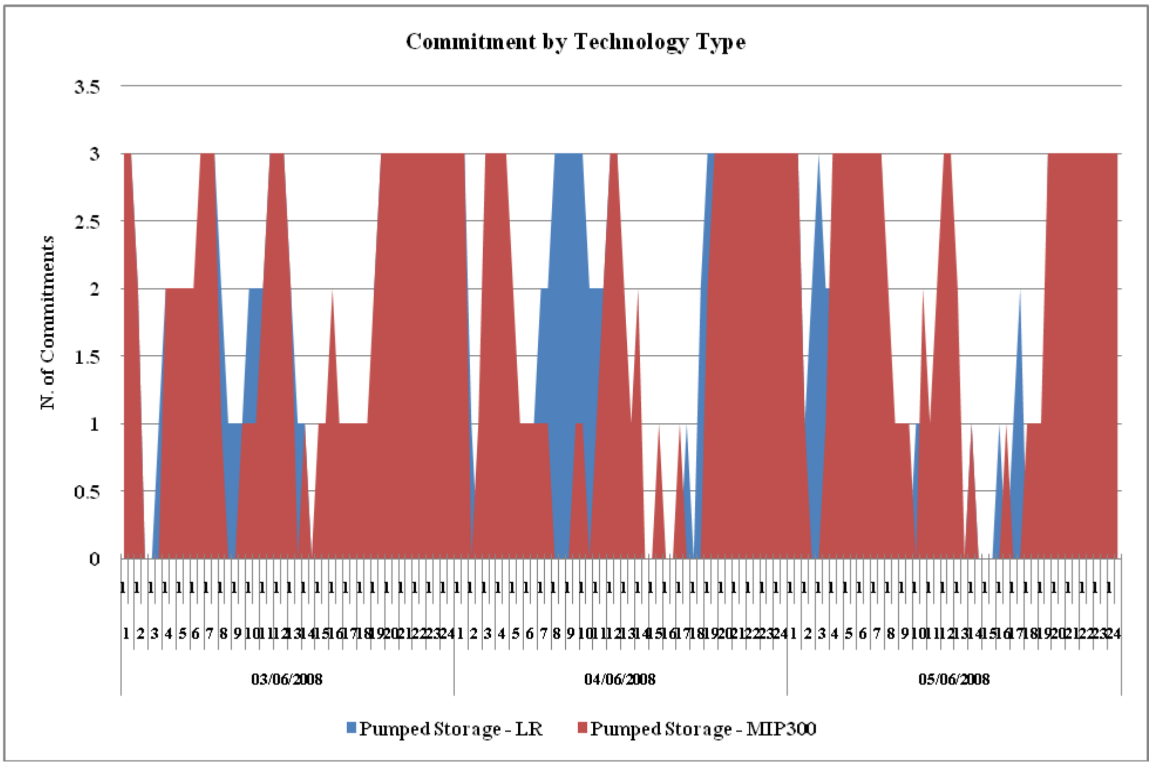

Figure 90 – Commitment Comparison by Technology Type (June 2008)

For Open Cycle Gas Turbine generators, these are mainly scheduled between hour 3 (08:00am) and hour 18 (23:00) of the Trading Day. Both solvers seemed to commit these units in a similar manner with variances only in start or stop times. The largest change was observed on the 5th June 2008 when the MIP solver committed one more unit than the LR solver resulting in higher MSP Production Cost across the Optimisation Time Horizon.

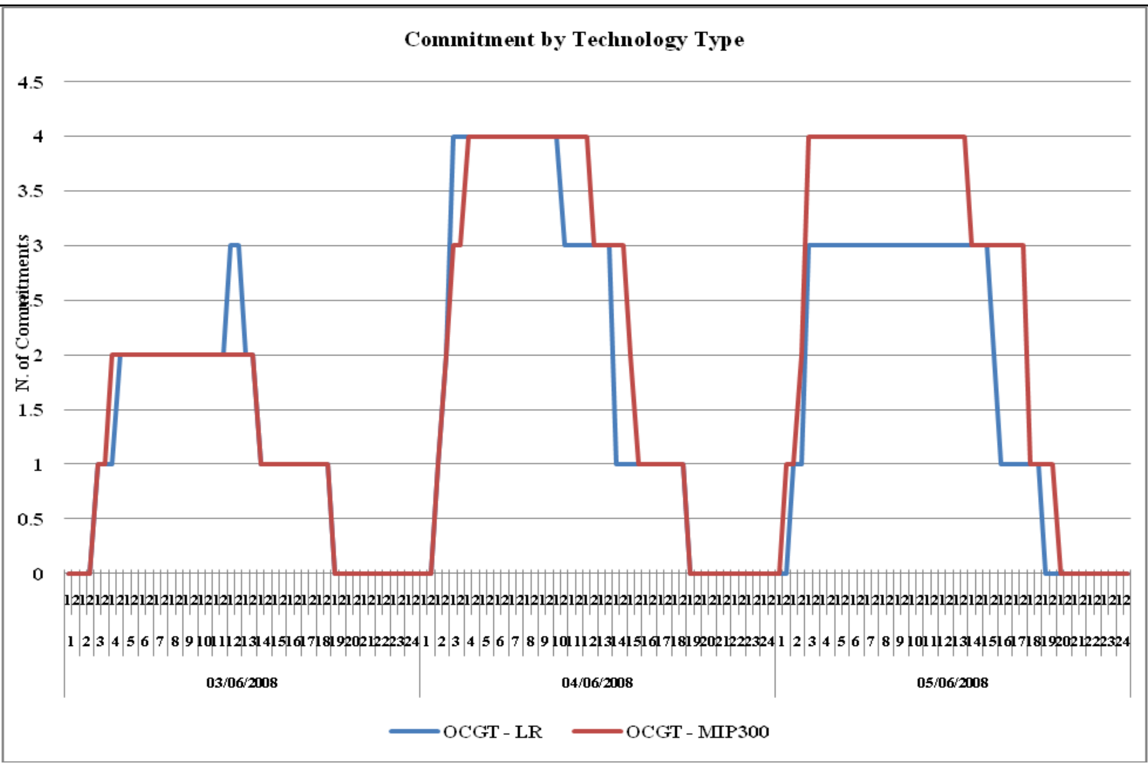

Figure 91 – Commitment Comparison by Technology Type (June 2008)

Considering Start Up costs when reviewing the above increases, MIP on the 4th June 2008 committed significantly more generators in the "Inexpensive" start cost bracket while LR had greater commitments in the "Dear" bracket. As stated earlier the LR program, in conjunction with the ALTCOM functionality, has a tendency to commit a generator unit for a single trading period to provide the required extra MW's than a combination of units. In this set of sample cases, the LR solver committed Steam based generators 313 times in total in contrast with 275 by MIP. MIP made 42 more Hydro commitments than LR over the same period.

	Free	*Inexpensive*	*Mid-Range*	*Dear*	*Very Dear*	*Grand Total*
LR						
03/06/2008	87	13	396	162	123	781
04/06/2008	89	19	473	214	136	931
05/06/2008	78	10	439	208	144	879
	254	**42**	**1308**	**584**	**403**	**2591**
MIP						
03/06/2008	89	59	388	168	123	827
04/06/2008	79	61	477	180	136	933
05/06/2008	88	88	454	190	144	964
	256	**208**	**1319**	**538**	**403**	**2724**

Table 27 – Commitment Comparison by Start Cost (June 2008)

The labelling of a generator's costs as Inexpensive, Mid-Range, etc was based on a simple review of commercial offer data submitted to the SEM. These labels are simply to assist in highlighting other factors which affect the running of the solvers.

	Free	*Inexpensive*	*Cheap*	*Mid Range*	*Dear*	*Very Dear*
Average Bid Cost	€ -	€ -	€ 0 - 30	€31 - €60	> €61	€ -
No Load Cost	€ -	€ -	€0 - €500	€501 - €2K	> €2K	€ -
Average Start Cost	€ -	€0 - €500	€501 - €2K	€2K - €40K	€40K - €80K	> €80K

Table 28 - Classification of Commercial Offer Data

7.4.4 Section 2 (b): Commitment Comparison by Trading Day/Trading Period for Consecutive run Dates (Post Economic Downturn)

As above, the greatest increase in commitment is observed for Pumped Storage and Hydro.

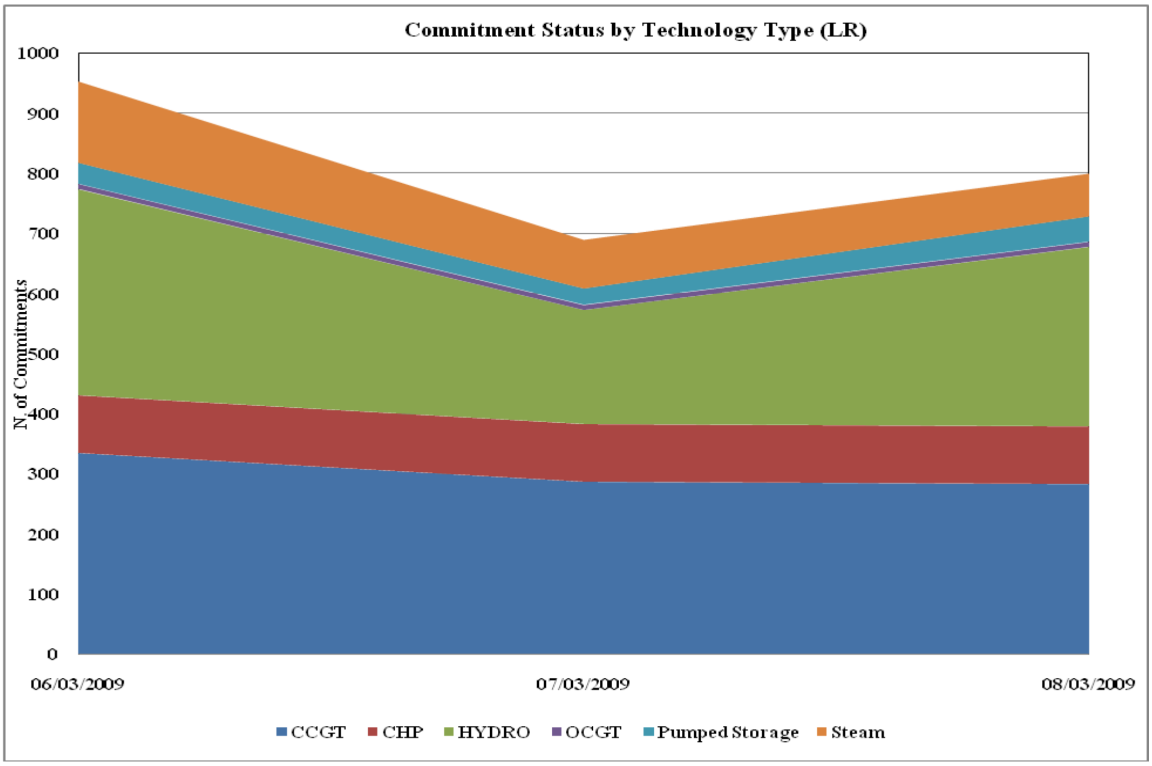

Figure 92 – Total Commitment in LR by Technology Type (March 2009)

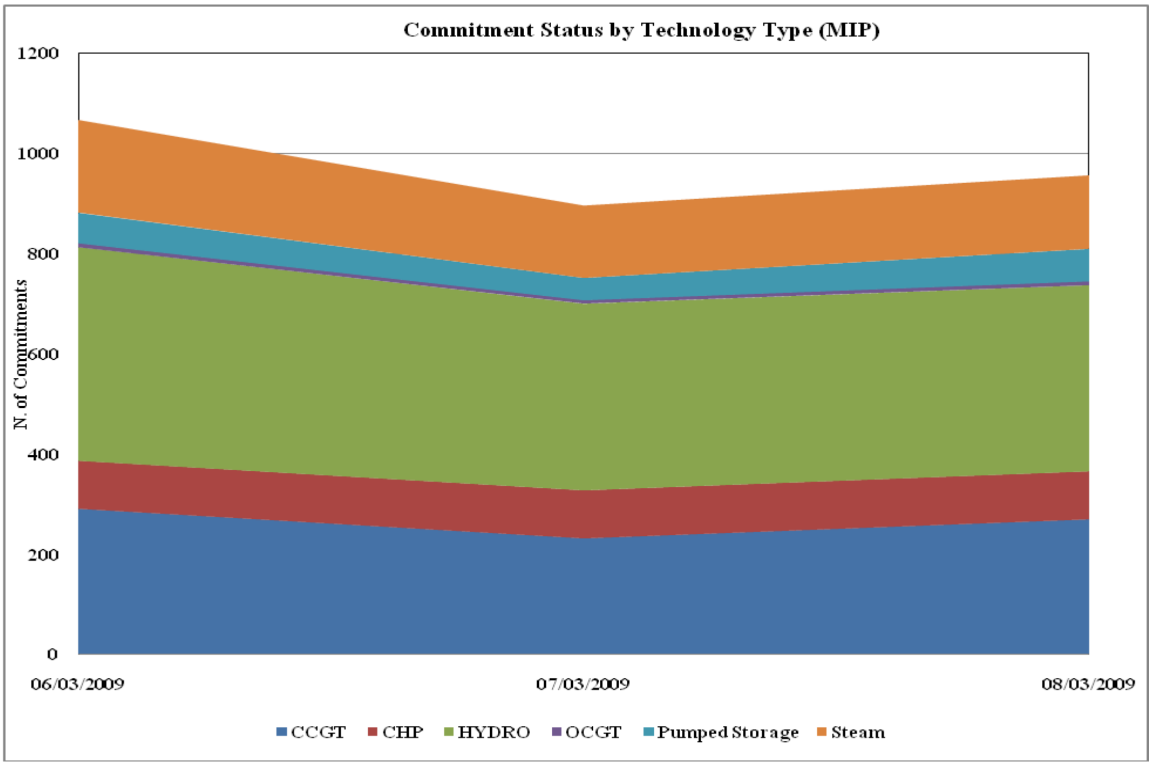

Figure 93 – Total Commitment in MIP by Technology Type (March 2009)

The following graphs demonstrate the increased and decreased commitment by Technology Type across this three day period.

As noted before, the commitment of Hydro generators is increased in the study cases completed using the MIP solver over those from the LR. While the LR commitment of Hydro in this period is better, there is still a significant variance in the usage of these generators with the MIP solver committing more generators per Trading Period in all but a few hours, including keeping two Hydro generators committed across the night valley while the LR solver de-commits all of them.

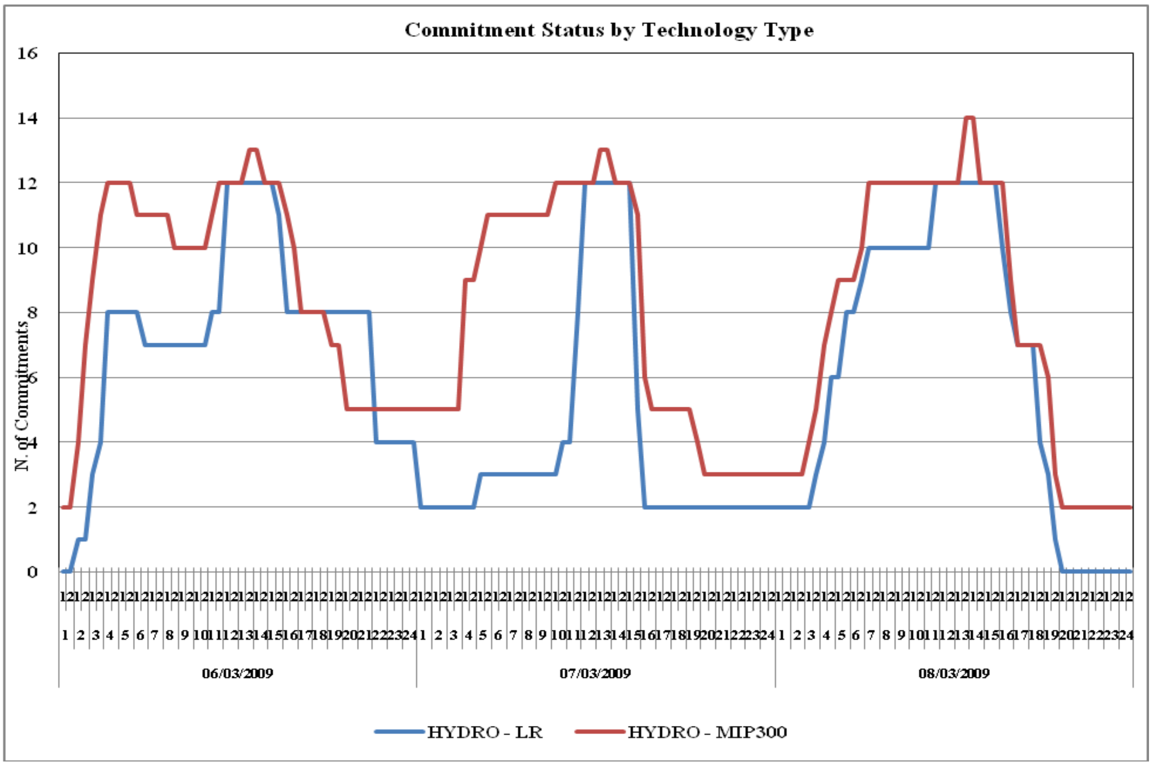

Figure 94 – Commitment Comparison by Technology Type (March 2009)

As previously noted, there is a high variance in the running of Pumped Storage generators in the MIP schedules over those from the LR solver. The overall higher commitment of other generators appears to contribute to a more flexible approach to this kind of generator in the schedules from the MIP solver.

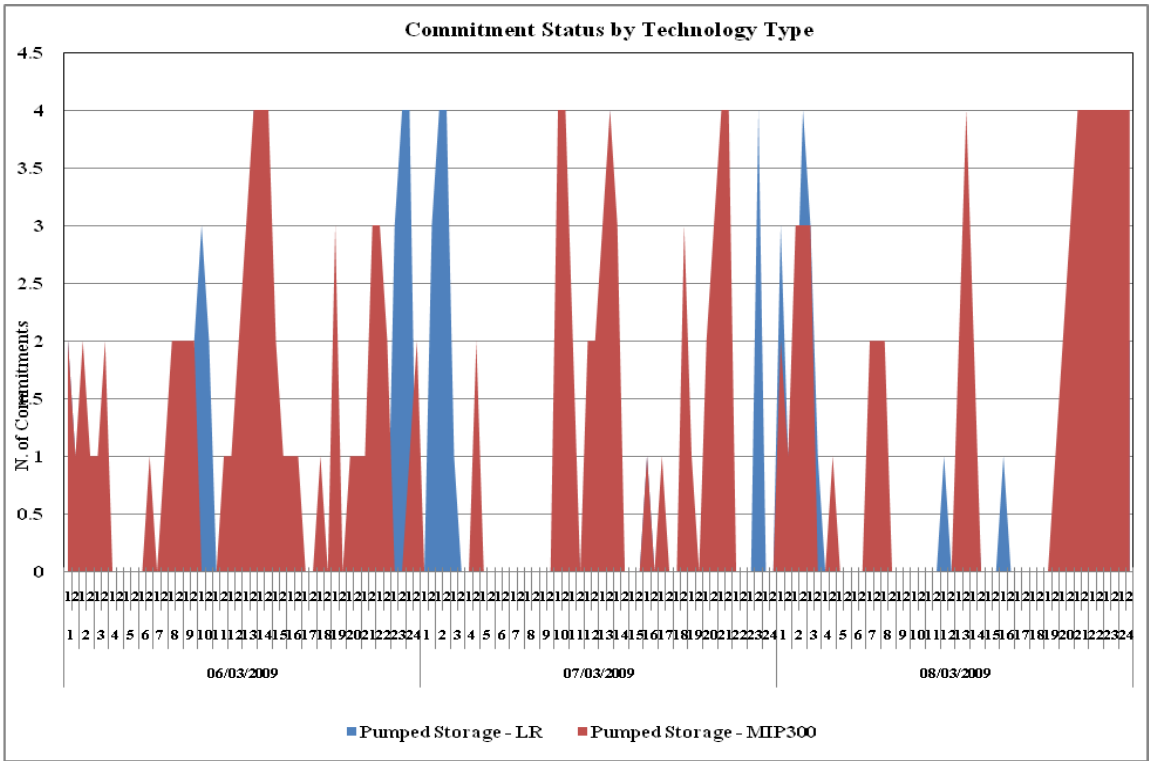

Figure 95 – Commitment Comparison by Technology Type (March 2009)

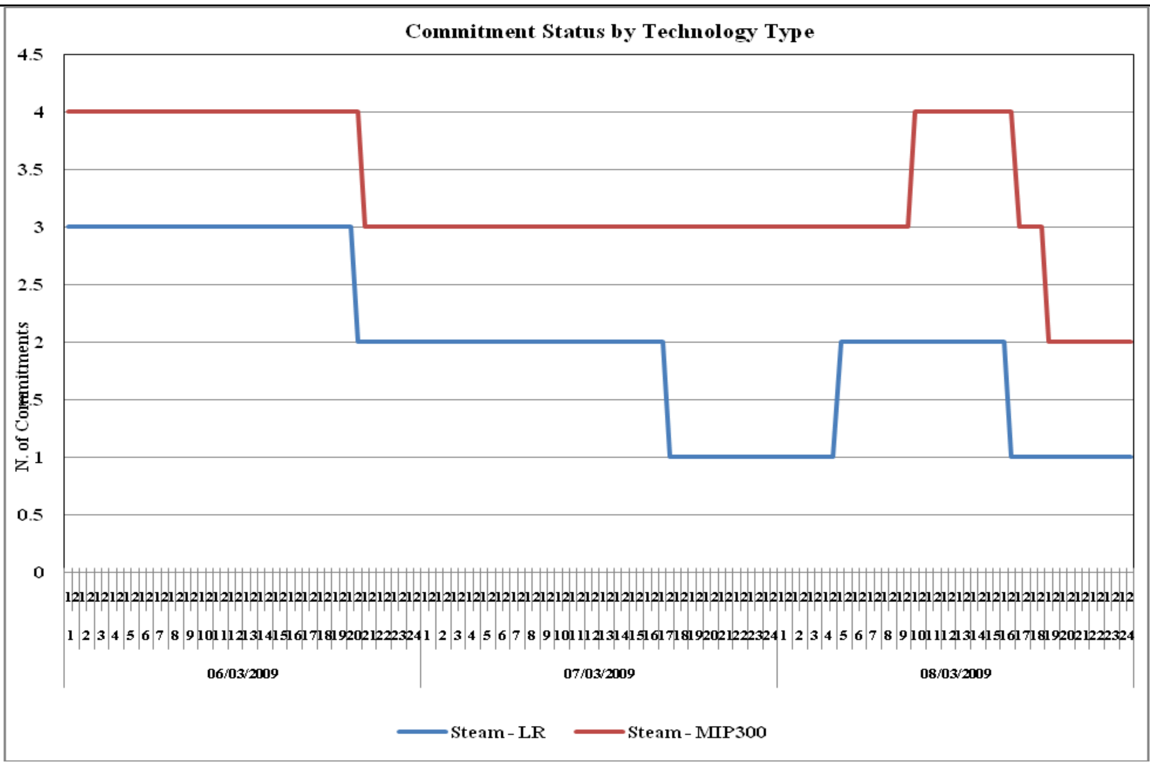

Figure 96 – Commitment Comparison by Technology Type (March 2009)

Small increases are noted in the commitment of steam based generators during this set of study cases. In contrast to the increases noted in the graph above, we saw a decreased commitment of CCGT units across the same dates, as demonstrated in the graph below.

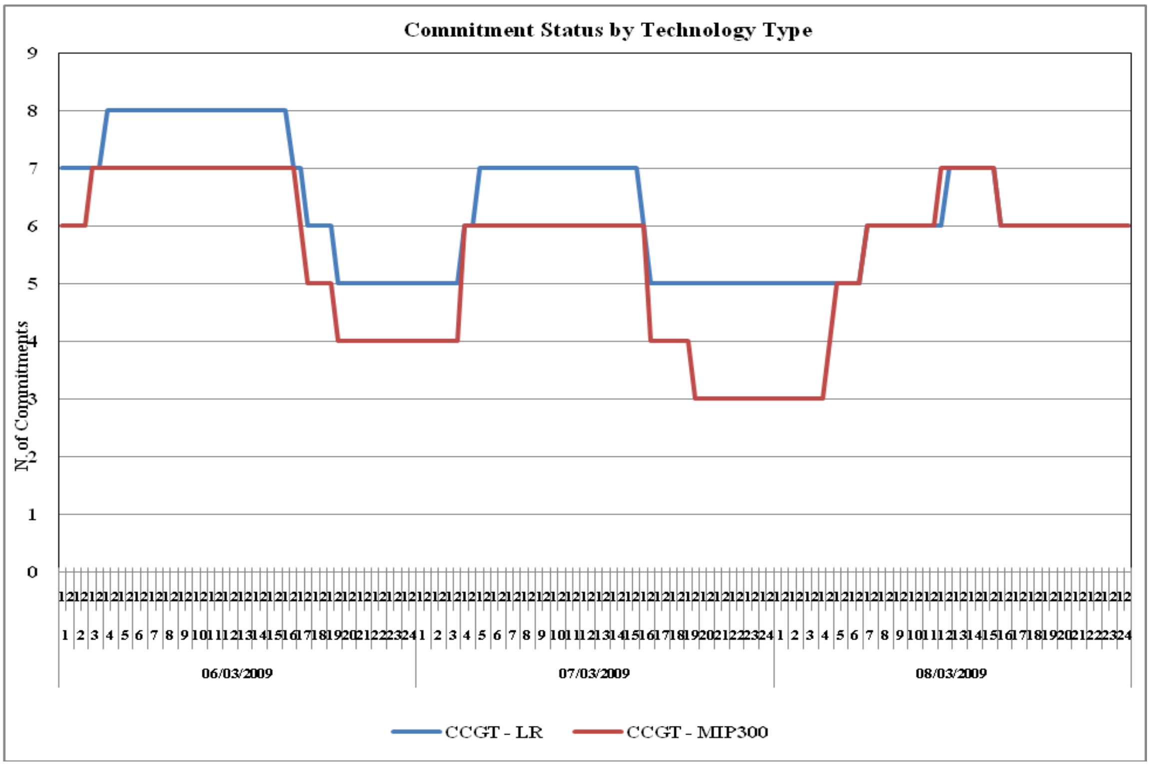

Figure 97 – Commitment Comparison by Technology Type (March 2009)

There are significant differences between the commitment decisions made by LR and MIP solvers in March 2009. Using the MIP solver, there was a large increase in the commitment of Steam based generators and a corresponding reduction for CCGT units. Of the ten CCGT units, five had start costs which fell into the Dear and Very Dear categories. While they had low unit cost bids, they also had Dear No Load costs.

In comparison of the nineteen Steam based generators, only seven had start costs falling into the Dear bracket. With a combination of inexpensive unit cost bids and mid range No Load costs, this would have made the Steam based generators a more economic choice.

	Free	Inexpensive	Mid-Range	Dear	Very Dear	Grand Total
LR						
06/03/2009	35	343	210	183	181	952
07/03/2009	27	190	199	129	144	689
08/03/2009	42	299	195	119	144	799
	104	**832**	**604**	**431**	**469**	**2440**
MIP300						
06/03/2009	61	427	213	232	133	1066
07/03/2009	45	372	202	192	85	896
08/03/2009	65	371	308	164	48	956
	171	**1170**	**723**	**588**	**266**	**2918**

Table 29 – Commitment Comparison by Start Cost (March 2009)

7.4.5 Section 3: Largest Variance for Pumped Storage

The largest change for Pumped Storage over the entire study period was on the 5th May 2009. In the LR run there were two Pumped Storage units committed from Trading Period & Interval 12,1 (17:00) to 13,1 (18:00). In MIP, all four units were scheduled across the Trading Day. This variance is demonstrated in the graph below.

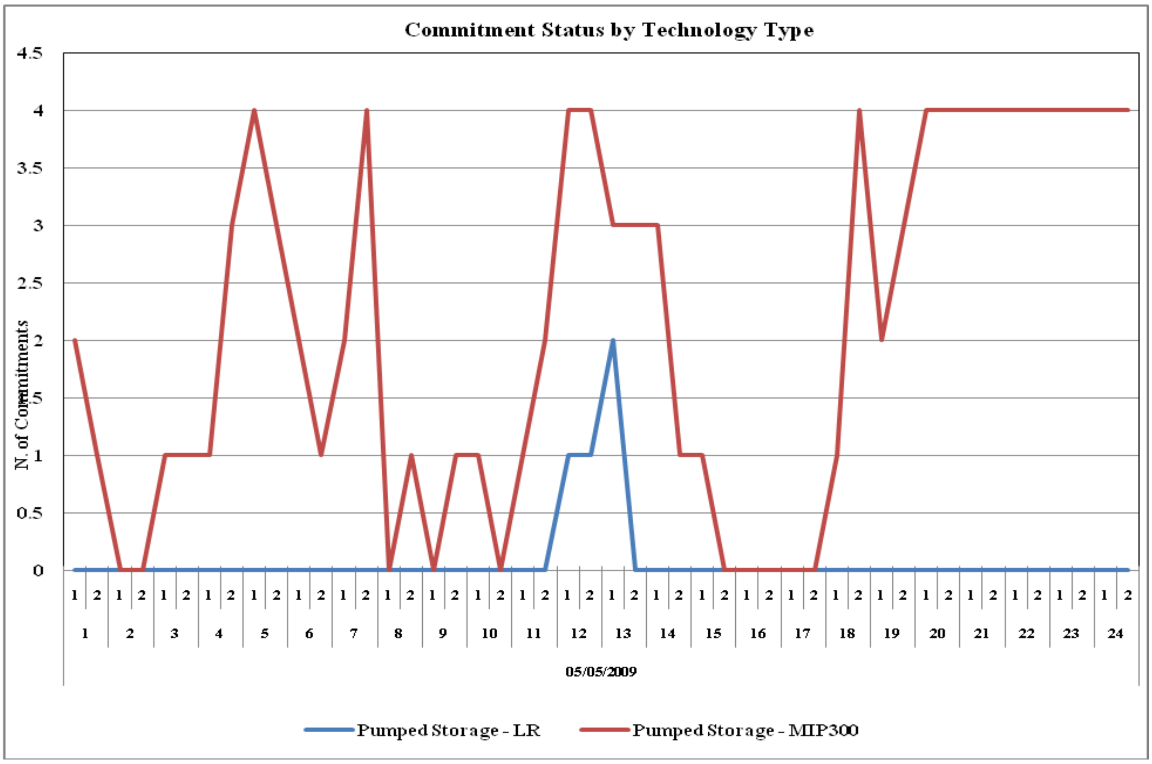

Figure 98 – Pumped Storage Commitment Comparison by Trading Period (May 2009)

Note that this Trading Day has come under scrutiny elsewhere in this report. We have observed that this day contained the single largest percentage increase in Consumer Costs (60.643%) in the outputs of the MIP solver over the LR. We have also noted the MIP solution stopped due to its timeout limits without reaching the Optimality Gap. The recorded MIP gap for this study case was 3.12% using the MIP300 setting. Increasing this to 600 seconds did not improve on the solution. A MIP gap of 0.95% was achieved when the study case was run for 1853 seconds. In real terms, this amounted to a 2.17% improvement in MSP Production Costs. This is also one of the Trading Days where the LR solver produced a schedule with cheaper MSP Production Costs than the MIP solver though only by 0.17%, or just over €6,000.

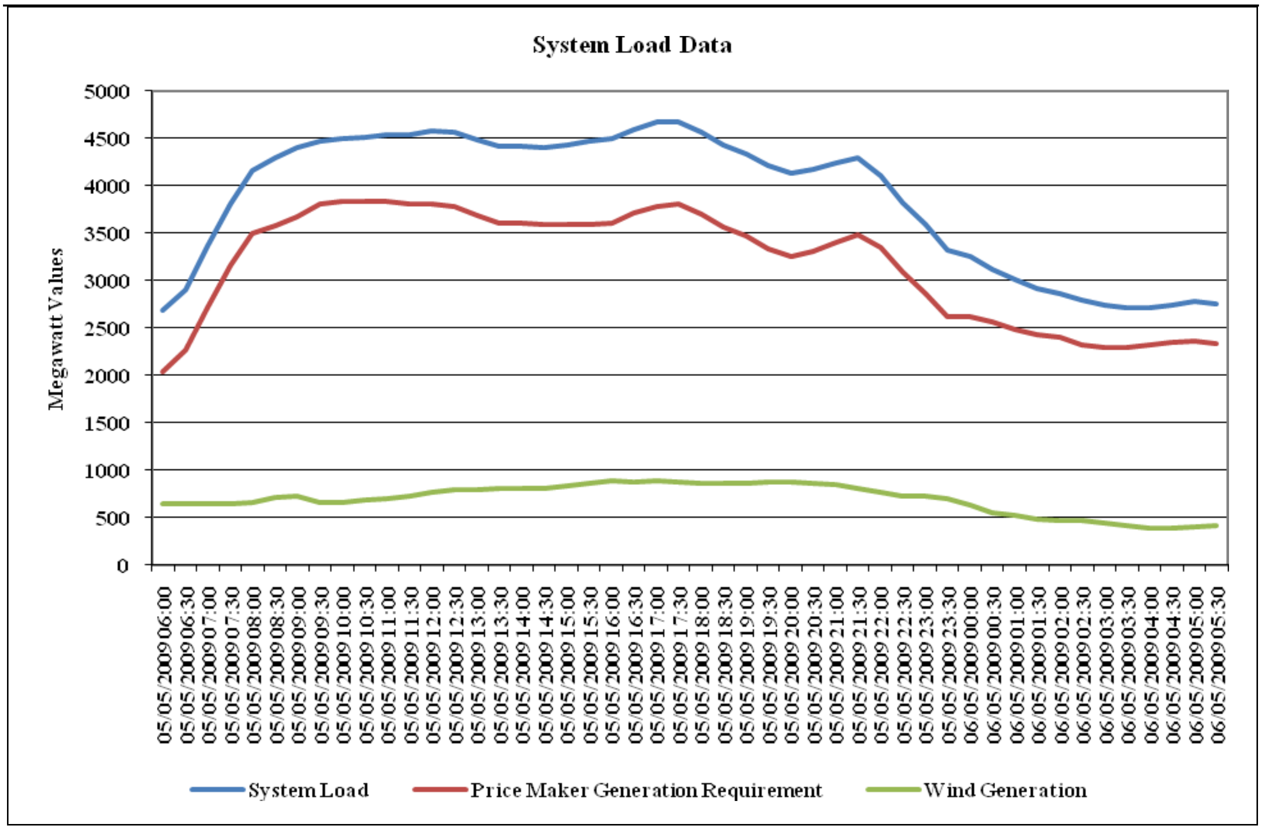

Figure 99 - Comparison by Trading Period (May 2009)

Pumped Storage generation acts as a peak-shaving unit. The idea of this is to shift load about the day, by pumping at night when prices are low, they increase the system demand to provide this back as generation and reduce the demand across the peak. When the wind generation quantity is taken from the overall System Load on this Trading Day, this has a similar “peak shaving” impact on the load, with the Price Maker generation requirement being reduced more considerably at the peak times while off-peak, particularly the night time is changed least. This flattening of the system load contributes to the difficult that the solvers will have in optimising the use of Pumped Storage units.

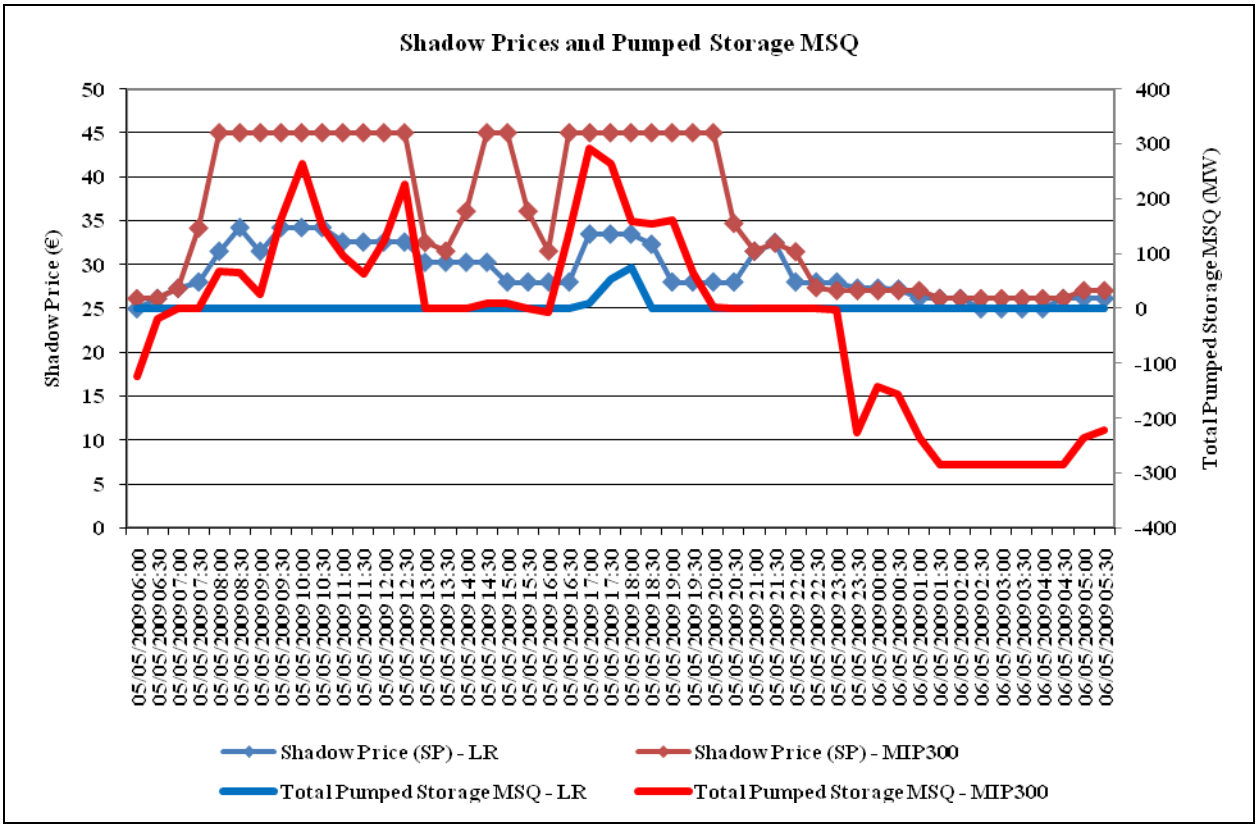

Figure 100 - Shadow Price and Pumped Storage Market Schedule Quantity Comparison by Trading Period (May 2009)

It must also be considered that Pumped Storage units run on a kind of price arbitrage basis; that is to run economically they need generation prices that must exceed their pumping prices by their cycle efficiency rating. Though not essential, a higher level of volatility in the Shadow Price increases the opportunity for optimum usage of pumped storage generators. In the study cases for May 5th 2009, there was little arbitrage opportunity in the Shadow Price for the LR run. The standard deviation of Shadow Prices on this day was only €2.98 while in the MIP run we see a standard deviation of €8.34. The graph above demonstrates the Shadow Prices from each study case compared with the Market Schedule Quantities for the Pumped Storage generators. This gives the impression that the smaller deviations in the Shadow Price observed in the LR study case have made Pumped Storage scheduling more difficult than in the MIP schedule.

We do have to note that the megawatt schedules and the Shadow Prices are outputs of the Economic Dispatch function and not of the unit commitment phase. Therefore, these outcomes are not directly attributable to the choice of solver. However, the commitment decisions made across the entire portfolio of generators in the SEM is a key factor in the decisions available to the Economic Dispatch program. The reviews completed here indicate that the commitment decisions made by the MIP solver allow for more efficient running of Pumped Storage generators than those made by the LR solver in most study cases reviewed.

7.4.6 Section 4: Frequency of Starts

The graph below shows the frequency trend of the increase in generator start ups when using the MIP solver over the LR. In general, across the 154 study cases, we have observed more generator start ups when using the MIP solver.

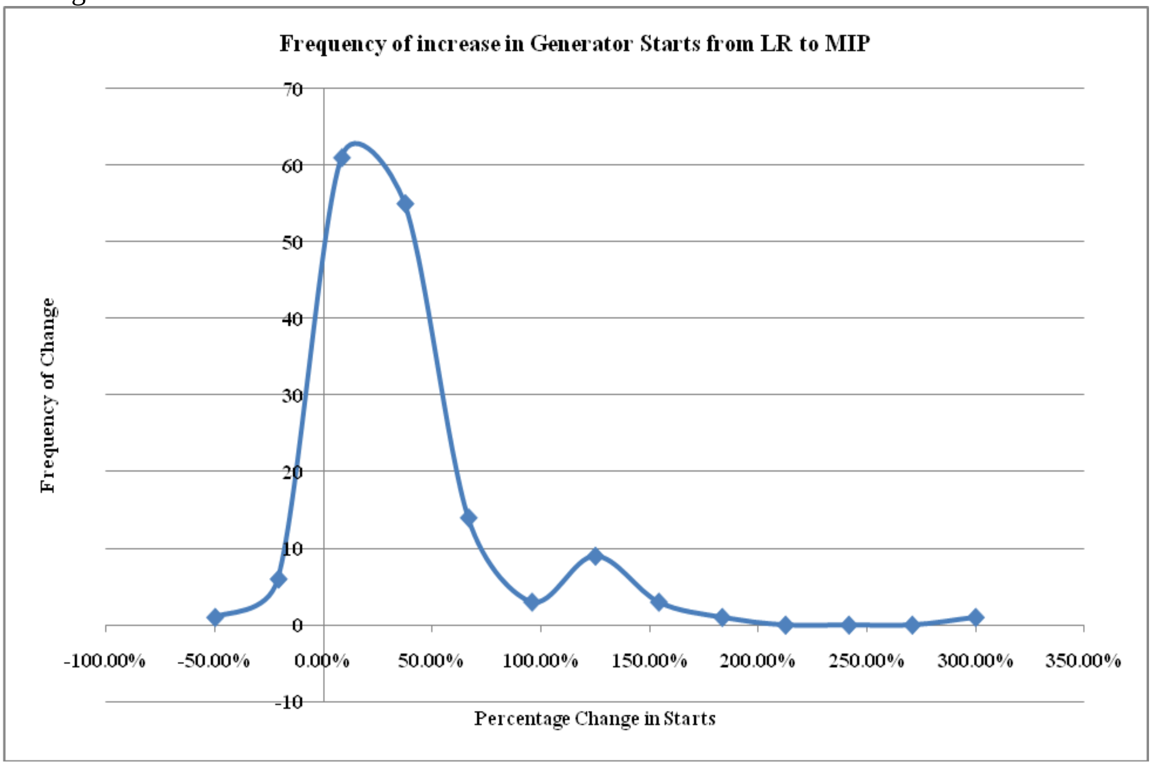

Figure 101 – Change in Starts from LR and MIP (Excluding Pumped Storage)

In 77 of the 154 cases, the percentage increase in generator starts excluding Pumped Storage[21] ranged between 5% and 60%. The largest increase was occurred on the 13th May 2008 with an increase of 300%, which breaks down as 5 starts in LR compared with 20 in MIP. As highlighted earlier in this report the technology type showing the greatest increase was Hydro which was used to a greater extent on this Trading Day by the MIP solver than by the LR. Of the twenty starts noted above, sixteen related to starting Hydro generators.

There was no overall percentage change in the number of generator starts observed in 53 study cases.

[21] We are presenting graphs here excluding Pumped Storage generators because their lack of Start Up Costs in the MSP software makes the commitment/start decision markedly different from that of other generators.

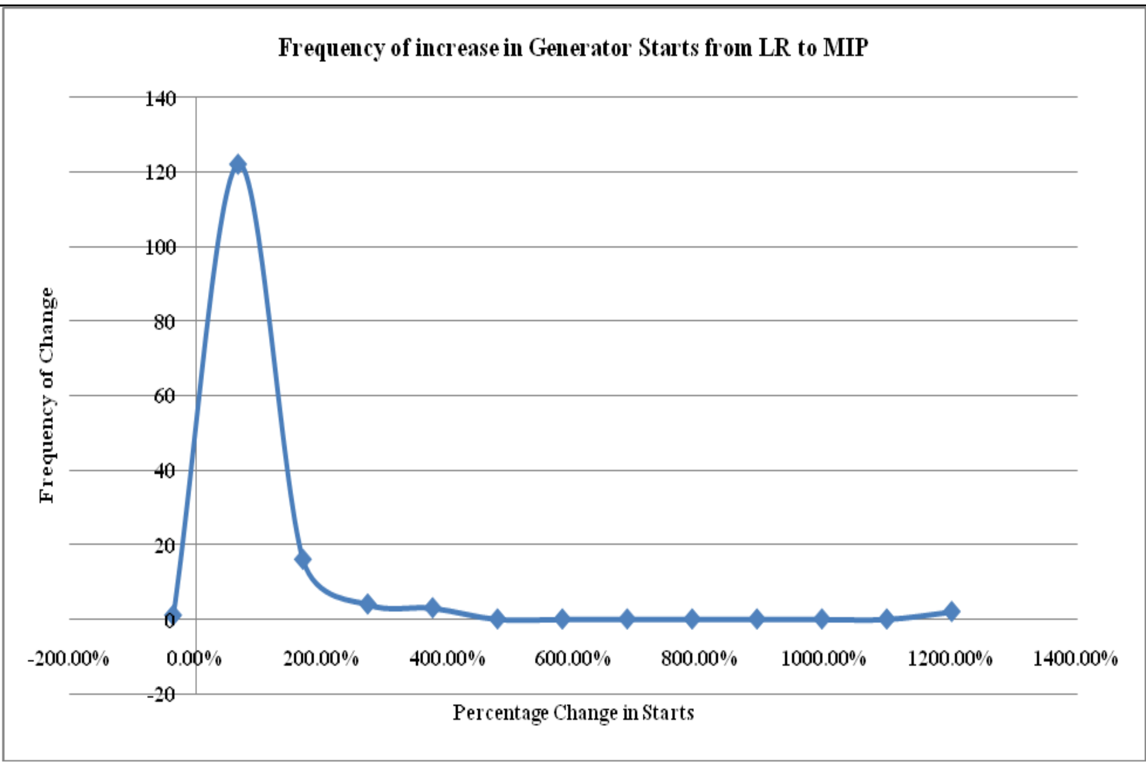

Figure 102 – Change in Starts from LR and MIP (Pumped Storage only)

In 83 cases, the percentage increase ranged between 6% and 120%.

There was no overall percentage change in 15 cases.

As Pumped Storage units are a "Free" resource effectively, they do not submit Commercial Offer Data they consequently incur a greater number of starts and stops to help minimise the total overall Production Cost over all scheduled Generator Units across a given Optimisation time Horizon.

7.4.7 Analysis of Ex Ante runs and Interconnector User Nominations

A number of Ex-Ante runs have been carried out to verify the impact of the choice of solver on IUNs, in particular to show whether the commitment of Interconnector units shows considerable changes.

A comparison of Commitment of Price Maker Units from each solver, has been completed by technology type, similar to the one carried out on the Ex-Post Initial outputs. The emphasis was placed on Commitment rather than Market Schedule Quantity, as the latter are finalised in Economic Dispatch where the solver has no direct impact other than providing an initial input.

This analysis was completed by Trading Day (06:00am to 06:00am), excluding the end overlap period of the Optimisation Time Horizon (06:00am to 12:00pm) across all 16 study runs.

Please note that, unless specified, all graphs by Trading Period in this section will show the interval mapping as follows: time period 1 denotes the hour starting 06:00am, the start of the Trading Day and time period 24 denotes the hour starting05:00am, at the end of the Trading Day.

In all 16 cases, MIP committed more Price Maker units than LR. This is represented graphically in the two figures below showing the overall commitments of all technology types for both solvers. MIP has a higher total commitment in every Trading Day, mainly driven by Hydro and Pumped Storage.

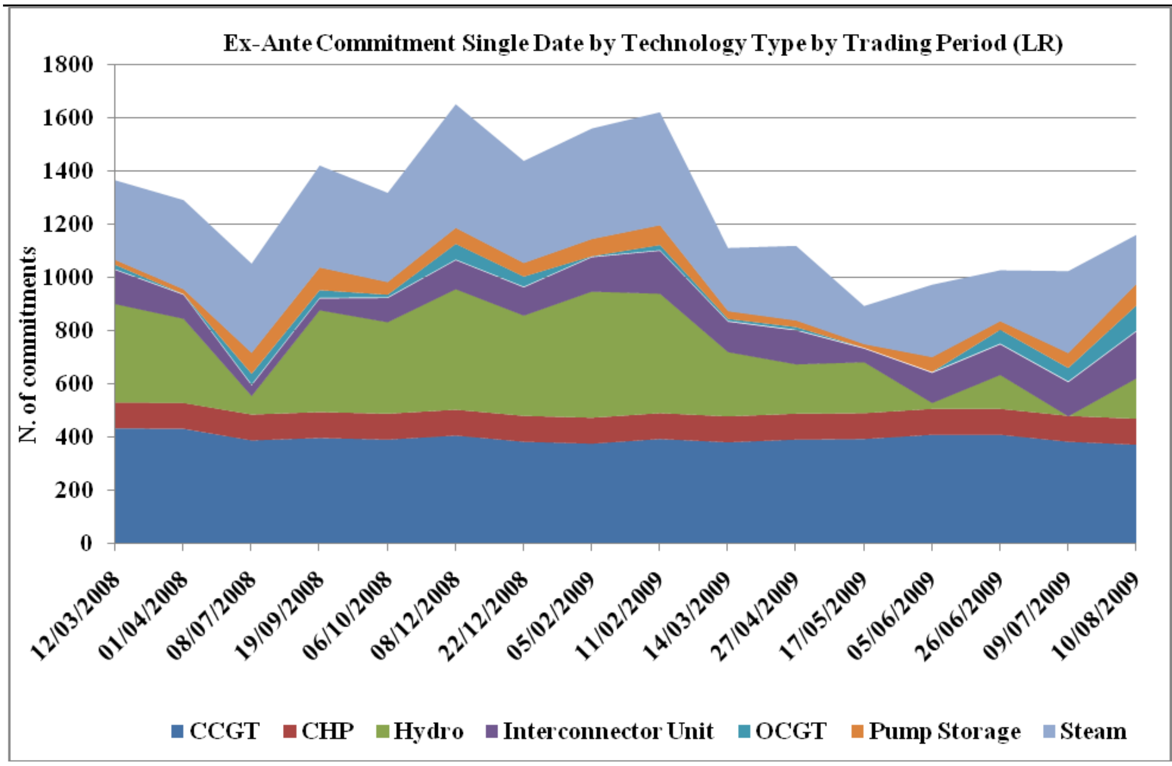

Figure 103 - Ex-Ante Commitment - LR

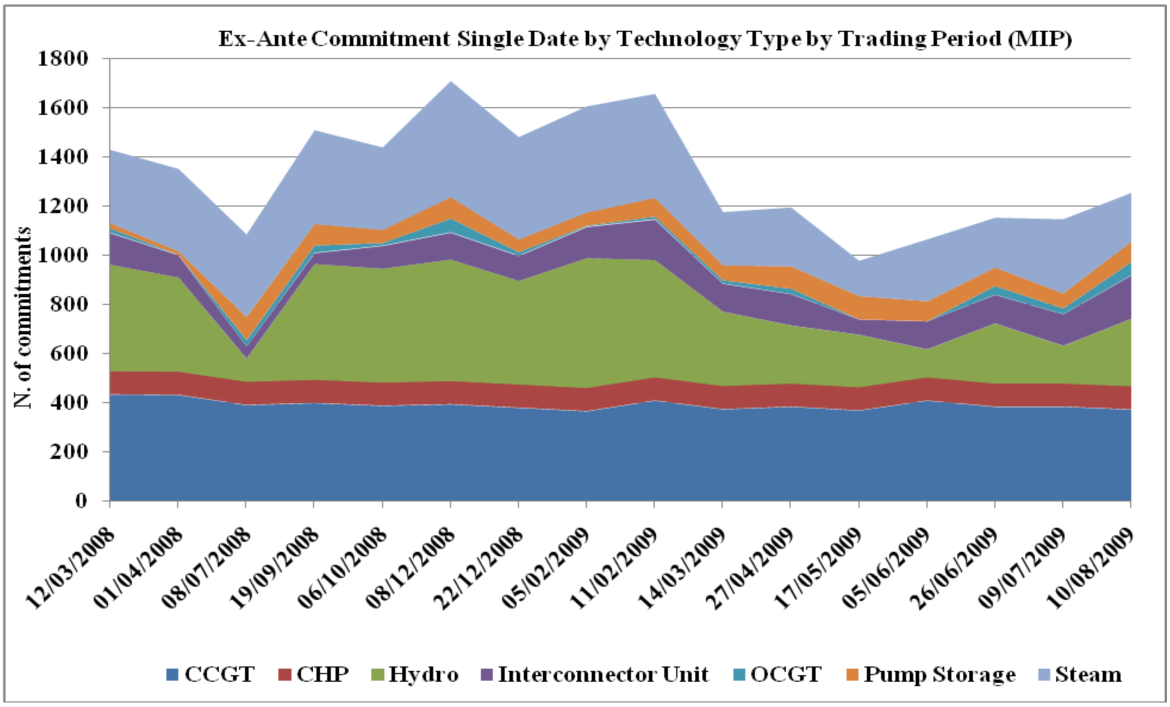

Figure 104 - Ex-Ante Commitment - MIP

The following table gives a summary of the commitment comparison by technology type for these study cases:

Technology Type	*Cases with Higher Commitment in LR*	*Cases with Higher Commitment in MIP*	*Cases with Equal Commitment in LR & MIP*
CCGT	9	3	4
CHP			16
Hydro		16	
OCGT	7	3	6
Pumped Storage	3	12	1
Steam	7	4	5
Interconnector	3	5	8

Table 30 - Changes in Ex-Ante Commitment

It can be noticed that, in line with the finding on the Ex-Post Initial runs, CHP type maintained the same commitment in both solvers, while all Hydro units were consistently committed more in all MIP runs. Pump Storage have the next largest instance of greater commitment in MIP, while other technology types closely followed the same pattern observed on the Ex-Post Initial runs with CCGT, OCGT and STEAM all achieving slightly higher commitment in LR, while having a large number of dates with no change between the two solvers.

Looking at the graph below, representing Interconnector units only, we can see that out of the 16 Trade Dates analised, eight had the same number of commitments, while the other eight dates have minor differences in either direction.

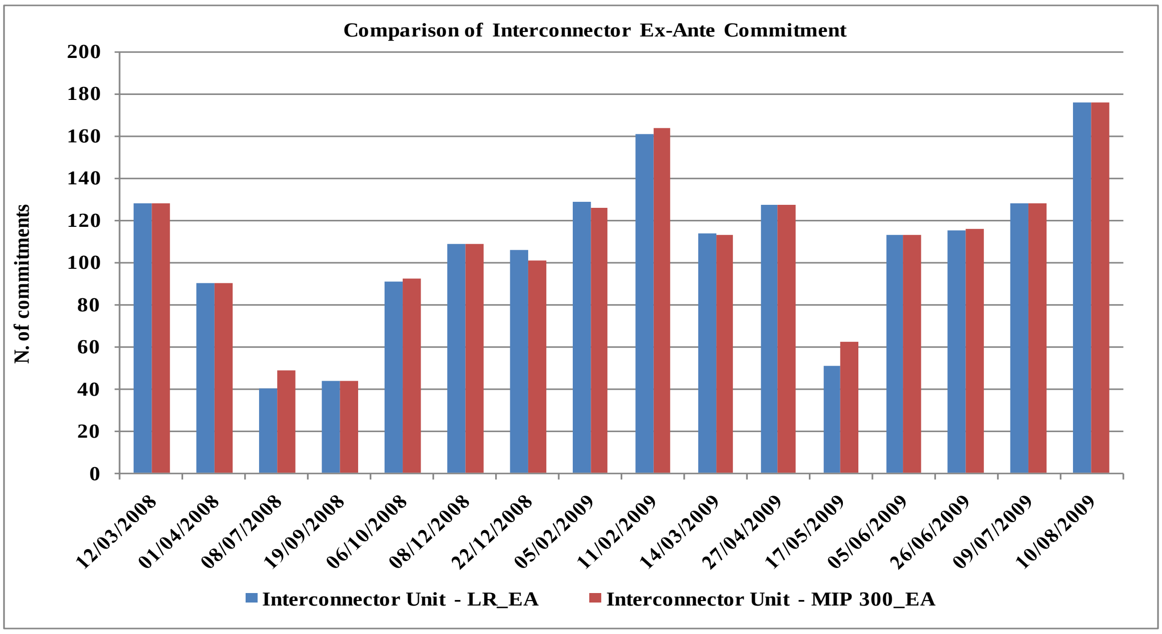

Figure 105 - Comparison of Ex-Ante Interconnector Commitment

It has to be noted that two of the dates that saw the same total commitment, in reality had a different distribution over the Trading Day, therefore the number of the dates with the exact same commitment for Interconnector Units from both solvers, is in fact six. By looking at all dates by Trading Period we can see that these differences are confined to a small number of Trading Periods across the Trading Day. The following two graphs show all ten dates with differences in either the total commitment or the distribution of commitment across the Trading Day, divided according to the relevant year.

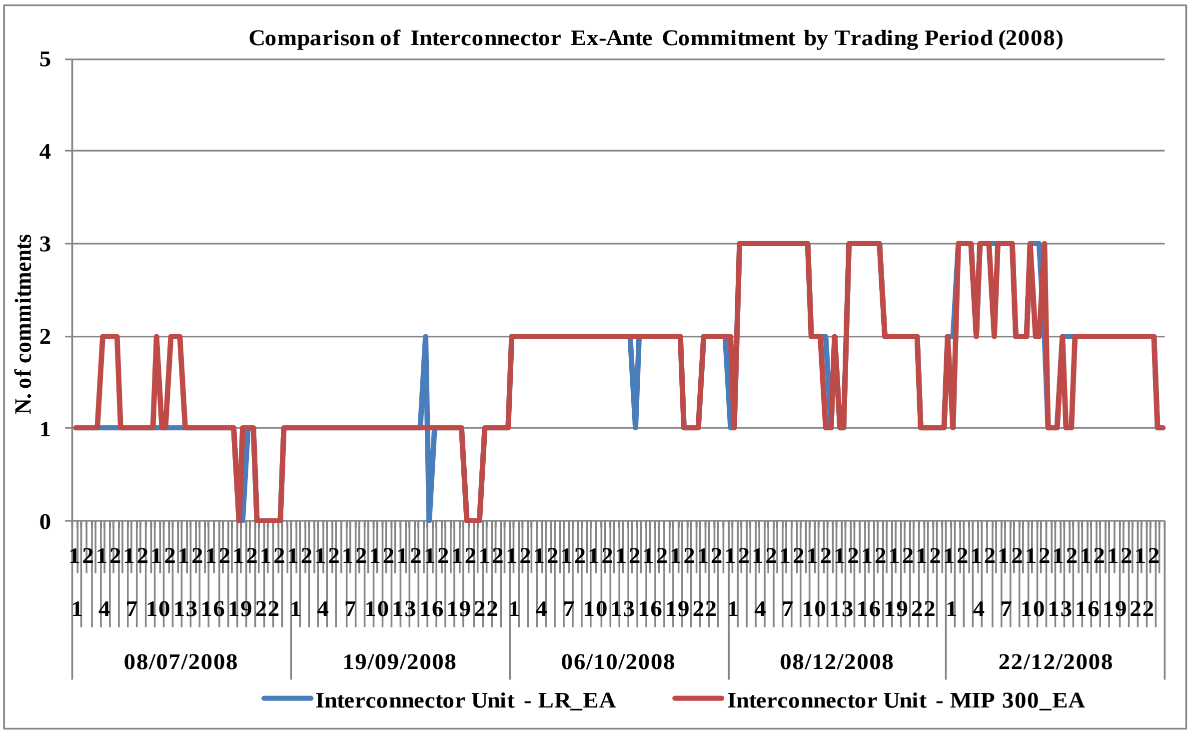

Figure 106 - Interconnector Ex-Ante Commitment by Trading Period

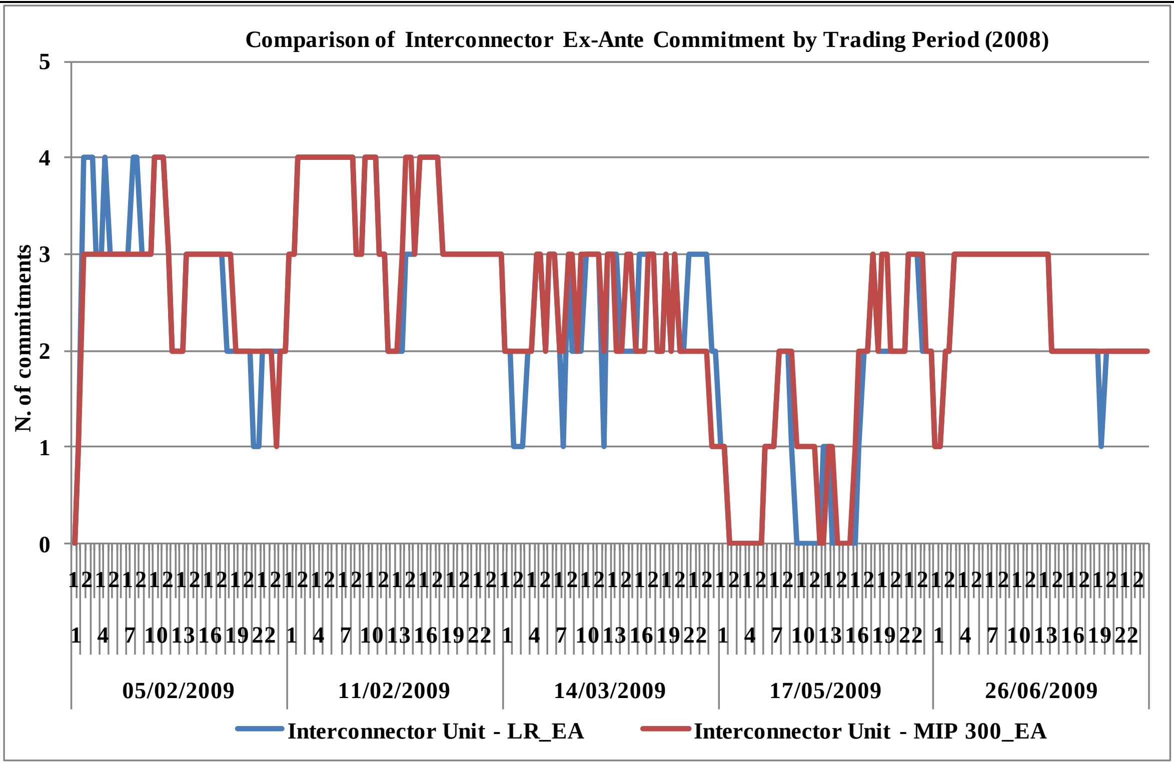

Figure 107 - Interconnector Ex-Ante Commitment by Trading Period

This shows only small differences, in particular in the 2008 dates. There are just two dates (14th March and 17th May 2009) with differences just over more than 50% of the Trading Periods.
The same two Trade Dates also show the largest differences in terms of total IUNs (Or Market Schedule Quantities) as per graph below. For all other dates, the changes in commitment translate into minor differences in the MSQ for Interconnector Units, while 3 dates had the exact same schedule in both run types.

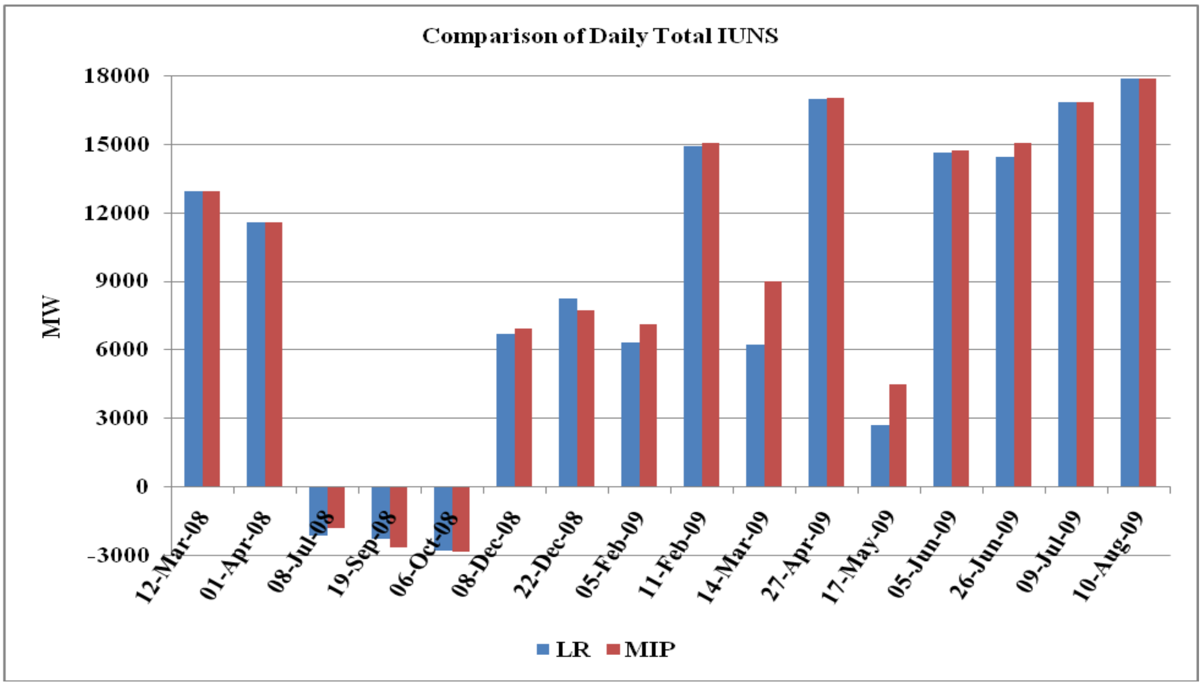

Figure 108 - Comparison of Daily Total IUNs

The two dates with the largest changes in both commitment and total IUN amounts (14th March and 17th May 2009), have been analised further to compare if the alternative schedule of Interconnector Units in MIP, might have impacted significantly on other unit types.

On the 14th March 2009 we can see from the comparison of the two graphs below that Pump Storage and Hydro have been committed more in MIP. This happened in particular during the night or early morning traing periods (when Pump Storage normally has a negative output) and over the peak.

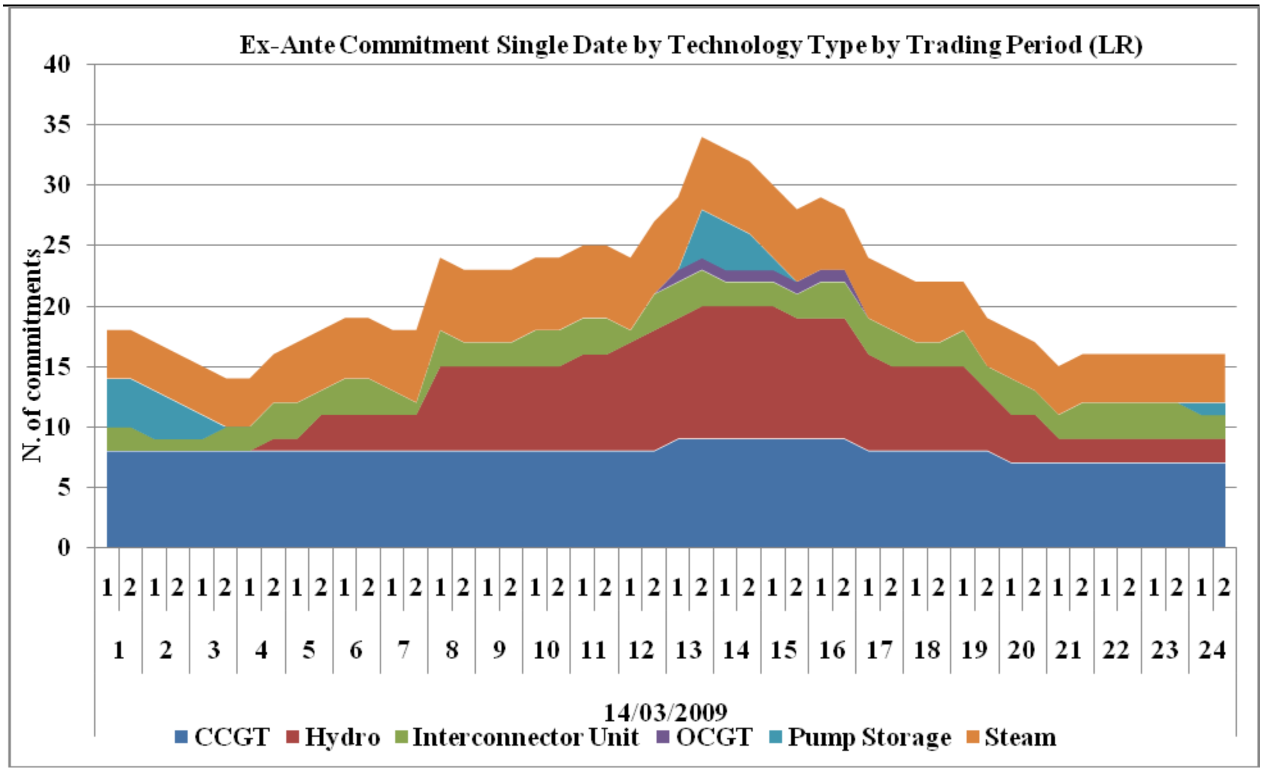

Figure 109 - Ex-Ante Commitment for 14th March 2009, LR

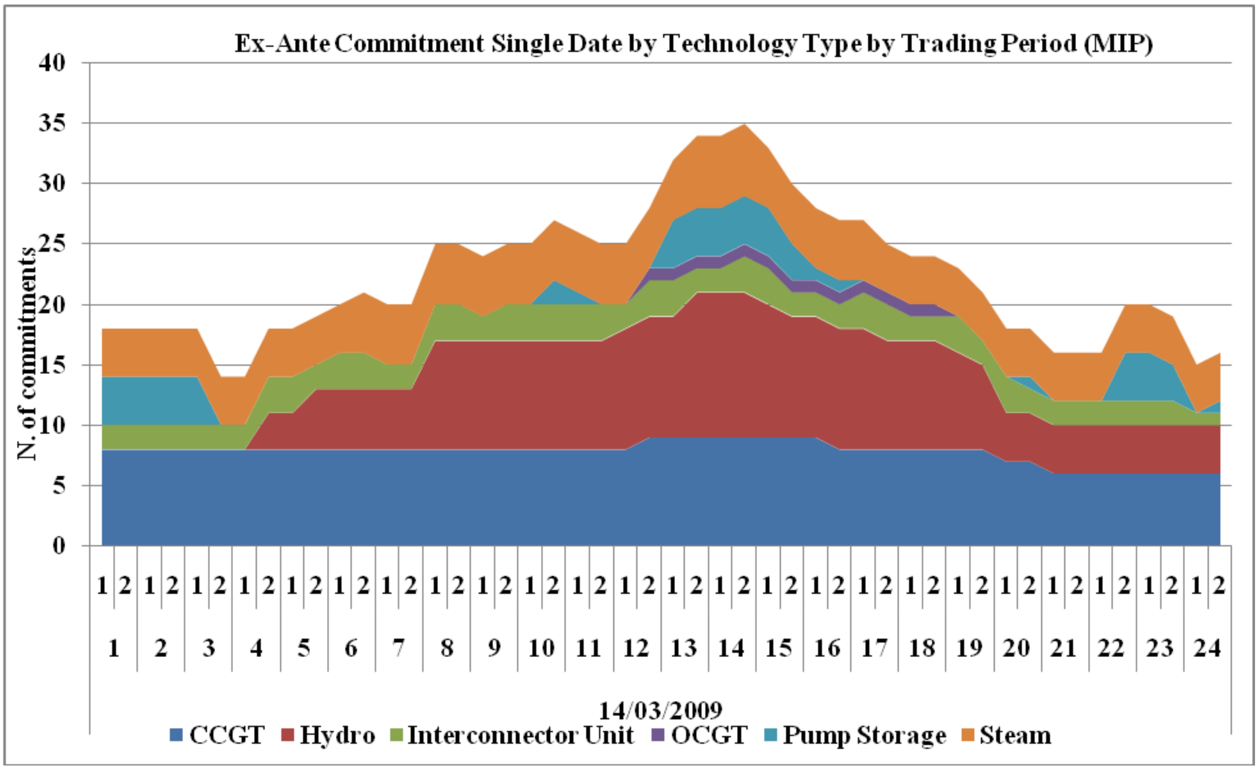

Figure 110 - Ex-Ante Commitment for 14th March 2009, MIP

At night time, MIP has committed less CCGTs while during the day and up to peak time Steam units have been committed less. On the other hand OCGT units are committed for longer time over the peak.

This might seem counterintuitive given that CCGT are normally more efficient and less expensive units than OCGT. However when looking at the actual shedule's MW amount the scale of OCGT plants contribution to the schedule is small and has no significant impact overall.

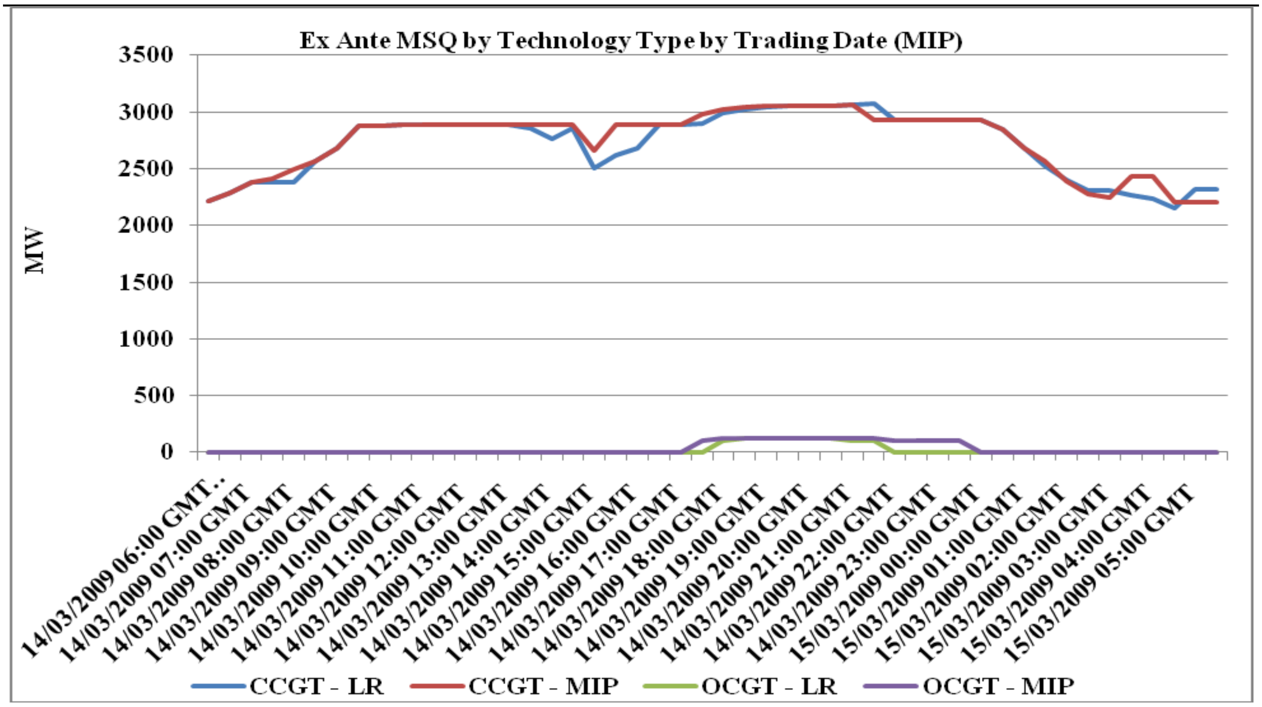

Figure 111 - Ex-Ante MSQ by Technology Type, MIP

Similarly on the 17th of May, the higher level of generataor commitment in MIP is again driven by Pump Storage units. Only small differences are noticed on other technology types: no changes in Steam and OCGT units and slightly higher number of commitments for CCGT and Hydro units.

Therefore, even in this case, there has been no major impact on the spread of other units as a result of the larger commitment of Interconnector Units in MIP, other than the increase of Hydro and Pump Storage observed in MIP and discussed elsewhere.

These changes again reflect the same observations made for the commitments of units in Ex-Post Initial runs and are illustrated in the two graphs below.

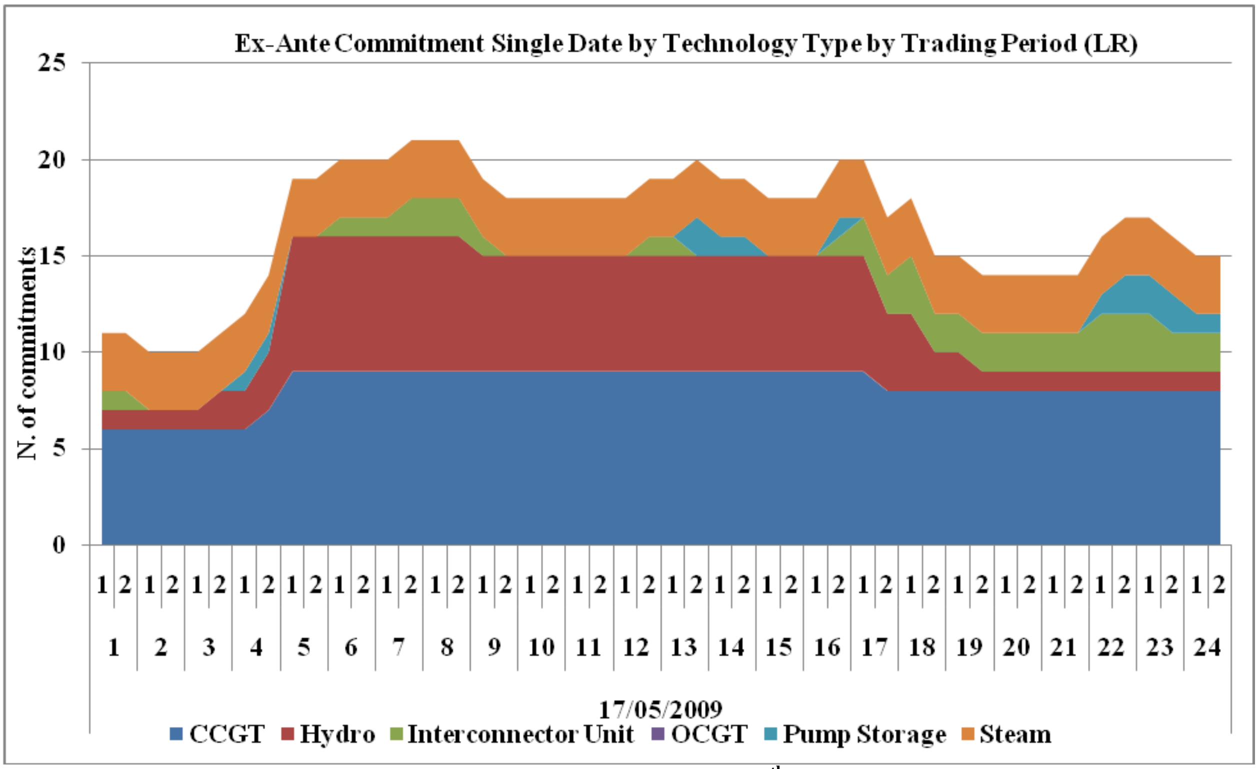

Figure 112 - Ex-Ante Commitment for 17th May 2009, LR

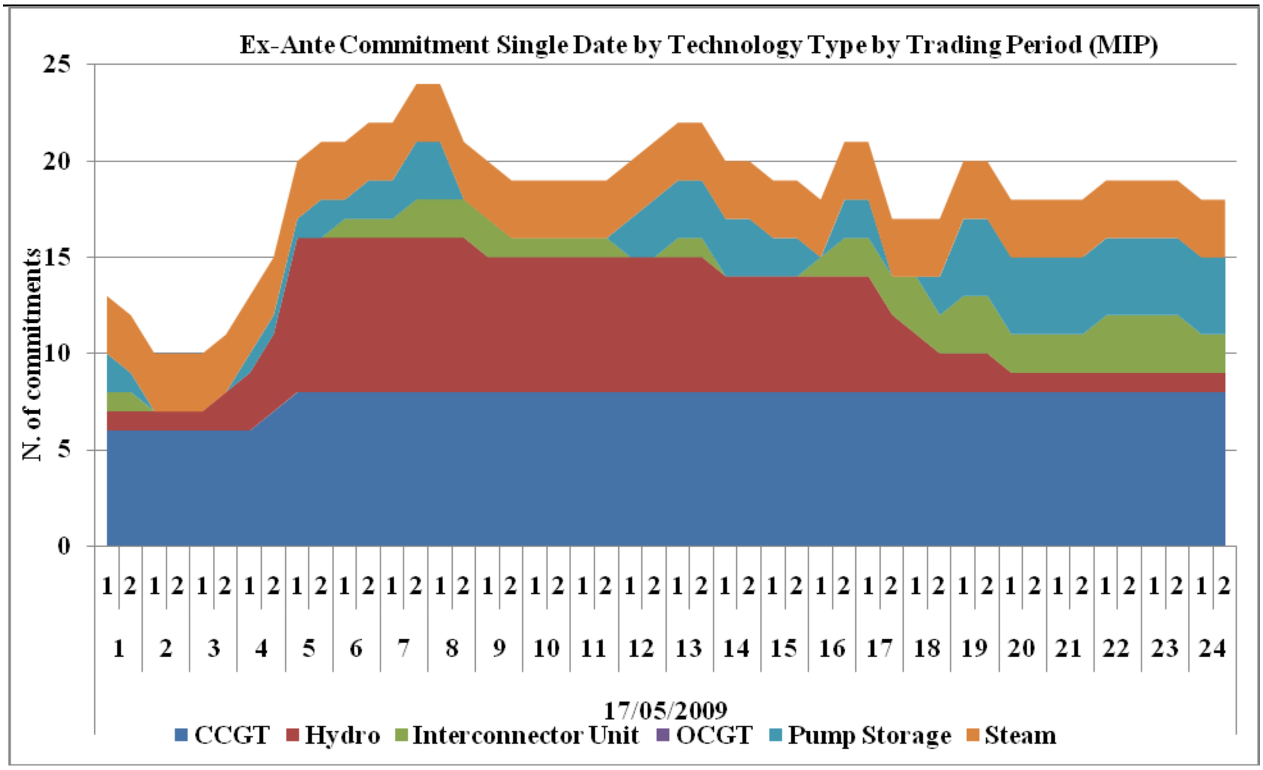

Figure 113 - Ex-Ante Commitment for 17th May 2009, MIP

Finally 15 out of the 16 MIP runs have a reduced Production Cost and we can see from the table below, that although the Shadow Price is higher in MIP, the final SMP is lower due to the higher level of uplift in the results of the LR solver. This is again in line with observations of the EX-Post Initial runs outputs where a larger volume of uplift was noted.

	Shadow Price			*SMP*			*Production Cost*		
	LR	*MIP 300*	*% difference*	*LR*	*MIP 300*	*% difference*	*LR*	*MIP 300*	*% difference*
12-Mar-08	€70.75	€66.08	-7%	€70.75	€70.13	-0.87%	€7,196,845.20	€7,176,260.34	-0.286%
01-Apr-08	€53.35	€53.30	-0.10%	€62.74	€62.78	0.07%	€6,638,595.91	€6,626,194.83	-0.187%
08-Jul-08	€88.35	€94.66	7%	€93.91	€94.66	0.79%	€7,865,434.63	€7,838,438.29	-0.343%
19-Sep-08	€106.40	€95.33	-10%	€106.40	€95.71	-10.05%	€7,800,006.24	€7,760,206.11	-0.510%
06-Oct-08	€71.44	€68.42	-4%	€77.89	€76.72	-1.50%	€7,290,614.87	€7,245,386.13	-0.620%
08-Dec-08	€66.48	€68.29	3%	€71.25	€75.56	6.04%	€6,756,130.61	€6,732,852.13	-0.345%
22-Dec-08	€60.99	€60.11	-1.4%	€62.02	€65.71	5.94%	€6,358,882.69	€6,354,158.62	-0.074%
05-Feb-09	€60.14	€58.09	-3%	€63.17	€66.50	5.27%	€7,175,311.60	€7,173,720.87	-0.022%
11-Feb-09	€65.86	€73.23	11%	€72.31	€75.44	4.32%	€3,465,120.57	€3,435,098.59	-0.866%
14-Mar-09	€30.44	€32.10	5%	€37.11	€36.03	-2.91%	€3,647,647.11	€3,594,103.35	-1.468%

	Shadow Price			*SMP*			*Production Cost*		
	LR	*MIP 300*	*% difference*	*LR*	*MIP 300*	*% difference*	*LR*	*MIP 300*	*% difference*
27-Apr-09	€30.90	€33.61	9%	€47.16	€34.09	-27.71%	€6,396,502.49	€6,396,321.01	-0.003%
17-May-09	€31.83	€34.19	7%	€36.50	€36.13	-0.99%	€3,227,446.94	€3,210,537.72	-0.524%
05-Jun-09	€33.97	€34.50	2%	€42.67	€42.31	-0.83%	€3,548,949.98	€3,519,301.67	-0.835%
26-Jun-09	€33.05	€37.14	12%	€44.45	€51.51	15.89%	€3,366,267.46	€3,394,304.73	0.833%
09-Jul-09	€35.67	€38.96	9%	€42.67	€41.75	-2.15%	€3,709,305.32	€3,639,713.53	-1.876%
10-Aug-09	€32.18	€39.91	24%	€56.49	€51.07	-9.59%	€3,155,821.13	€3,105,151.44	-1.606%

Table 31 - Ex-Ante MSP Software runs, summary

We therefore note that results from the Ex-Ante study runs are similar to those in the Ex-Post Initial: higher commitment of units (in particular Hydro and Pump Storage) and lower MSP Production Costs.

The schedule of Interconnector Units does not vary significantly and has no significant effect on the commitment of other units.

7.5 Conclusion

MIP demonstrates greater commitment of Price Maker Generator units than LR. While the solvers do not make decisions based on technology type, they do make decisions based on cost taking the technical capabilities of the generator units into consideration. The overall objective of the MSP software is to produce a solution with the lowest MSP Production Costs which we have observed that MIP produces overall. This matches the trend shown for greater commitment of units with little or no running costs i.e. Pumped Storage and Hydro and a reduced commitment of more expensive generation plant like CCGT and OCGT.

The overall trends across the entire period are as follows:

- CCGT – These show greater commitment in LR in 77% of cases.
- CHP – Commitment remained the same across both solvers
- Hydro – These show greater commitment in all MIP cases.
- OCGT – There is no clear pattern. We have observed higher commitment with MIP in 32% of cases, LR in 47% and remained the same in 20% (or 31 cases).
- Pumped Storage – These show greater commitment in 69% of MIP cases
- Steam – Commitment was marginally higher in LR in 39.5% of cases and in MIP in 39.5% of cases. There was no change in 21% of cases.

8 Energy Limited Generators

8.1 Introduction

Energy Limited Generators are Generator Units which have a Trading Day Energy Limit; that is, while subject to Availability values on a per Trading Period basis, a separate Trading Day Energy Limit applies, in effect placing a cap on the number of MWs that the Generator can produce across a Trading Day. This in turn limits the number of Trading Periods in which an Energy Limited Generator can be committed. These limits are applied to Hydro generators in the SEM.

One impact of this on the MSP software is the requirement to balance Energy Limited Generators across a full Trading Day to ensure limits are not breached. This introduces an inter-temporal element to the problem faced by the unit commitment software where the decisions made in one Trading Period for a given generator would limit the decisions that are available for this generator in any other Trading Period in the Trading Day. Normal thermal generators are not subject to such inter-temporal constraints in their commitment.

Since market "go live", it was observed that when using the LR solver, Energy Limited Price Maker Generators appear to have been under utilised in a number of schedules in that while energy limits are not breached, a large quantity of unused capacity remains.

LR produces sub-optimal solutions and this has widely been documented academically. One manifestation of the sub-optimal nature of LR solutions noted in the SEM is that Energy Limited Generators might not be scheduled to their full capability. While the market rules set the daily limits as just that and not targets, because water is bid in at zero under the Bidding Code of Practice, inclusion of as much as is available could provide for a lower MSP Production Cost in the schedule.

Because these Generators are generally used to the full of their Energy Limit in actual dispatch, we have included this issue within the scope to consider if the MIP version of the UUC will make better use of the Energy Limited Generators while delivering lower MSP Production Costs.

8.2 Executive Summary

It is clear from the analysis carried out, with regard to the specific scheduling of Hydro units that the MIP solver is scheduling them closer to their full potential in all 154 cases studied and fully achieving the total Energy Limit in 22 of these cases. When using the LR solver, we did not observe the Energy Limits being fully used in any case.

The average difference between total schedule for Hydro units and Energy Limits amounts to 493MW in LR and just 38MW in MIP.

The additional utilisation of the Energy Limited Units with the MIP solver occurs during the night valley as the LR solver keeps conventional generators on, while the MIP solver has a more flexible approach and does not refrain from switching generator off and on again.

A higher total schedule does not guarantee a higher economic return for these units. In 21 cases the revenue of the units fell by an average of €18,000 as the overall System Marginal Price was lower throughout the day (also see section on Consumer Cost).

In addition, a larger amount of scheduled virtually free energy, does not guarantee lower Production Cost as 15% of MIP runs have higher Production Cost than LR however all MIP have higher Hydro schedule total (see section on Production Cost).

We have also observed that LR performances is not greatly improved by adding positive Price/Quantities and No Load costs or by removing Hydro units from the schedule. We completed this extra analysis to assess if the scheduling decisions from the LR solver were driven by Hydro bidding patterns in the SEM[22]. Because the LR solver applies Lagrange Multipliers to the generation costs based on submitted Commercial Offer Data, where the bid and No Load Cost is zero, this could affect how the LR solver commits these units. We ran these study cases to assess if the addition of extra Commercial Offer Data would lead to better scheduling.

8.3 Background

The functional objective of the MSP software is to minimise generation MSP Production Costs, by creating a merit order based on the prices and characteristics of each unit and taking into consideration the MSP Schedule Demand requirements over the full optimisation horizon.

This implies that cheaper generators will be scheduled before ones that are more expensive; however, as the Unit Commitment Engine assesses the costs over the full optimization horizon and not just a single trading period, considerations are given at the consequences of each commitment decision over the longer term.

Hydro units provide very low cost energy with zero bid cost per MW of generation, zero No Load Cost and relatively small Start Up costs. However, like Pump Storage units, a decision to schedule a Hydro unit at a certain level would have implication on start up and schedule of all other units.

The MSP software then considers multiple possible scenarios. These could result in a more efficient schedule across the Optimisation Horizon. This would be achieved by keeping Hydro units at a lower level thereby enabling an overall saving on more expensive generation at peak times. While this is a possibility, it cannot be ignored that the LR total schedule for Hydro units is constantly below the energy limits for the unit indicating that the software may not be using these generators as efficiently as possible.

LR produces very accurate results, but rely on simplifying assumptions and heuristic procedures (Streiffret, Philbrick, Ott, 2005) and there is no practical measure of the actual quality of the solution found; that is, where MIP solvers produce an Optimality Gap to give a measure of how close the solution came to global optimality, LR solvers do not.

Considering the results found when reviewing the commitment decision made by the different solvers (see here), we decided to carry out some further investigation into the possible differences between the two solvers in handling Hydro units in particular.

8.4 Analysis

The analysis for Hydro units has been divided into three sections:

- the regular LR/MIP for all study dates
- a limited number of runs where additional No Load and bid costs have been added, and
- a limited number of runs where Hydro units have been made unavailable.

For all 154 study cases based on Ex-Post Initial runs of the MSP software, a comparison has been carried out between the total MSQs for all Price Maker Hydro sets in LR and MIP.

One of the 154 runs completed breached the energy limit constraints in MIP resulting in the total schedule for Hydro being higher than the actual limit by 34MW. We have raised this with our vendor who has identified a defect, which is currently being corrected[23].

MIP has consistently ensured that Energy Limited Generators are scheduled closer to their daily limits than the LR solver, as demonstrated by the figure below (the whole series has been divided in 3 graphs for ease of illustration - Graph1 2007 to May 2008; graph2 June 2008 to Dec 2008; graph3 Jan 2009 to Aug 2009).

[22] Noted above, Hydro generators bid in zero price in their Price Quantity pair, zero No Load Cost and small Start Up Costs.

[23] This affects the study case for the 29th March 2008. It has been investigated by the software vendor who has confirmed that there is a defect. This was linked to the application of Energy Limits on the short day when using the MIP solver. This has not impacted on any other day in this study and has never occurred in Production, as it has never been necessary to run MIP on the short day.

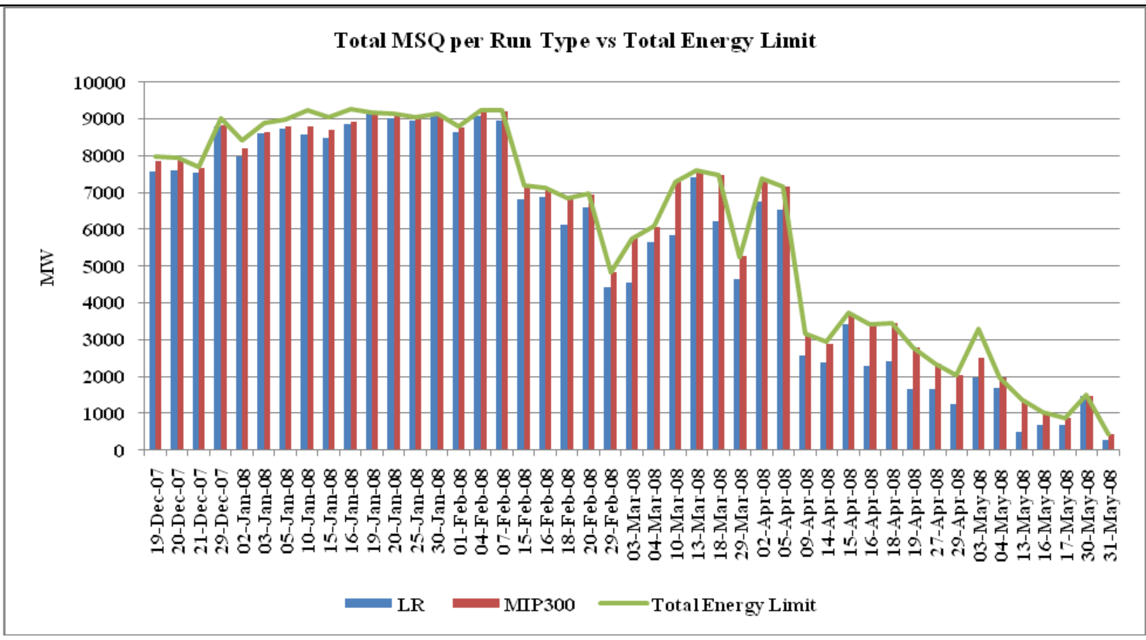

Figure 114 - Total MSQ and Energy Limit, 2007 to May 2008

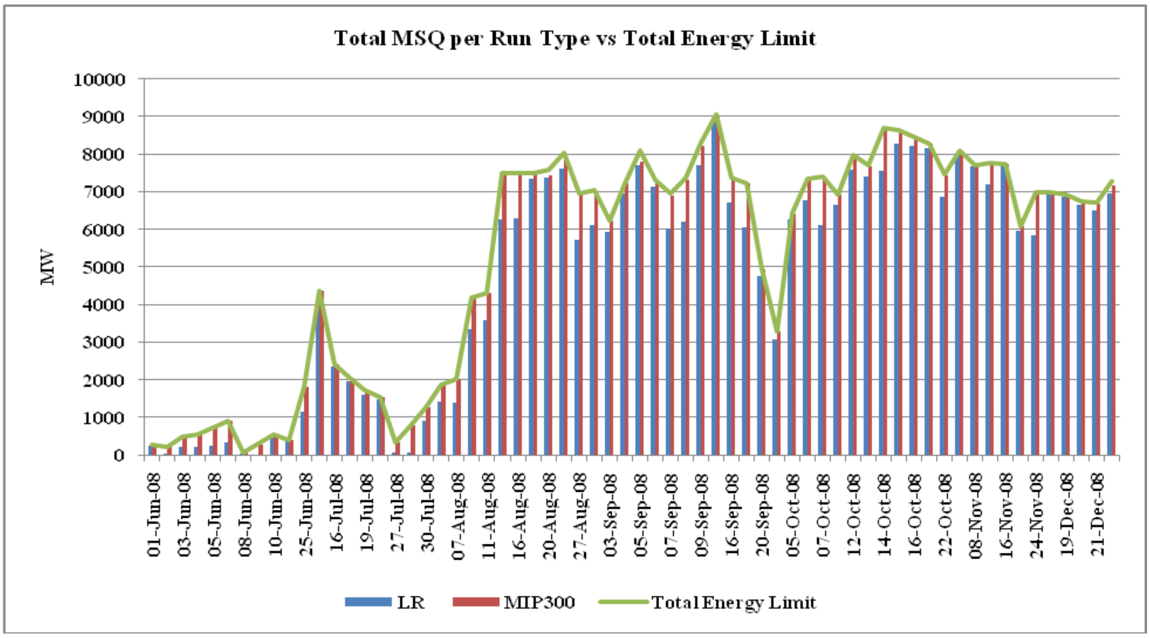

Figure 115 - Total MSQ and Energy Limit, June 2008 to December 2008

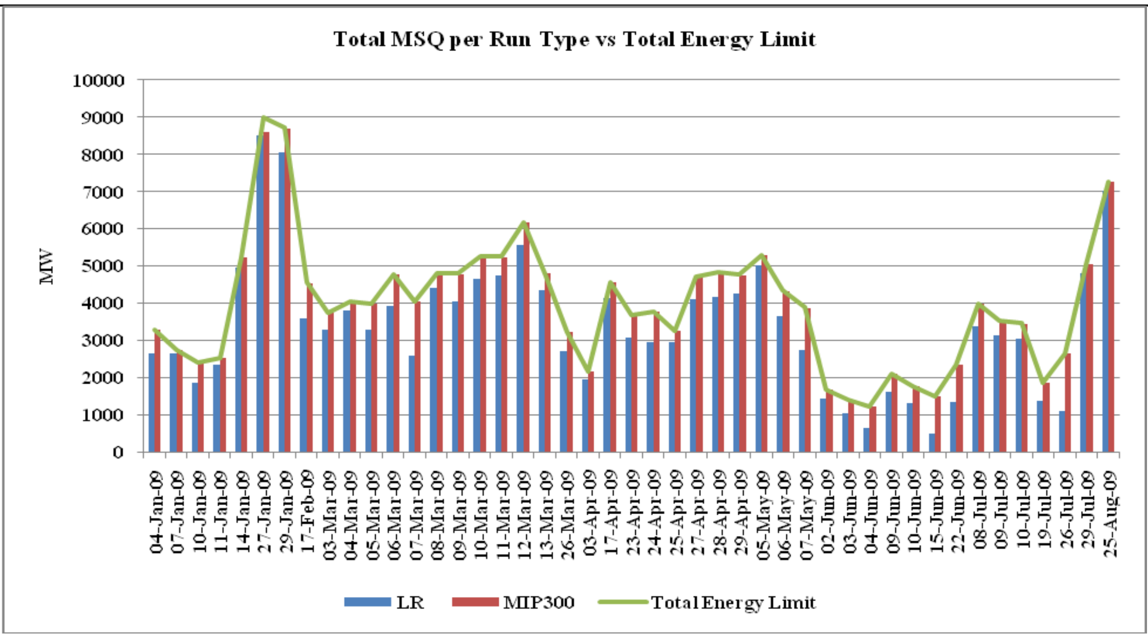

Figure 116 - Total MSQ and Energy Limit, 2009

In all study cases, MIP has scheduled more Hydro generation than LR. In the vast majority of cases (97%) out of a total of 154 Trading Days, the total Hydro schedule in MIP was within 96% of the Energy limit. The graph below illustrates this by visually representing that the vast majority of study cases completed using MIP produced a total schedule for Hydro units which was within 20MW of the Energy Limits with just 25 instances with differences above 100MW.

However, in the study cases using the LR solver, the vast majority of runs have a difference of about 500MW between the total Market Schedule Quantities and the Trading Day Energy Limits. This represents the quantity of unused energy from these Hydro generators. The schedules from the LR solver were within 20MW of the Trading Day Energy Limits in only three study cases.

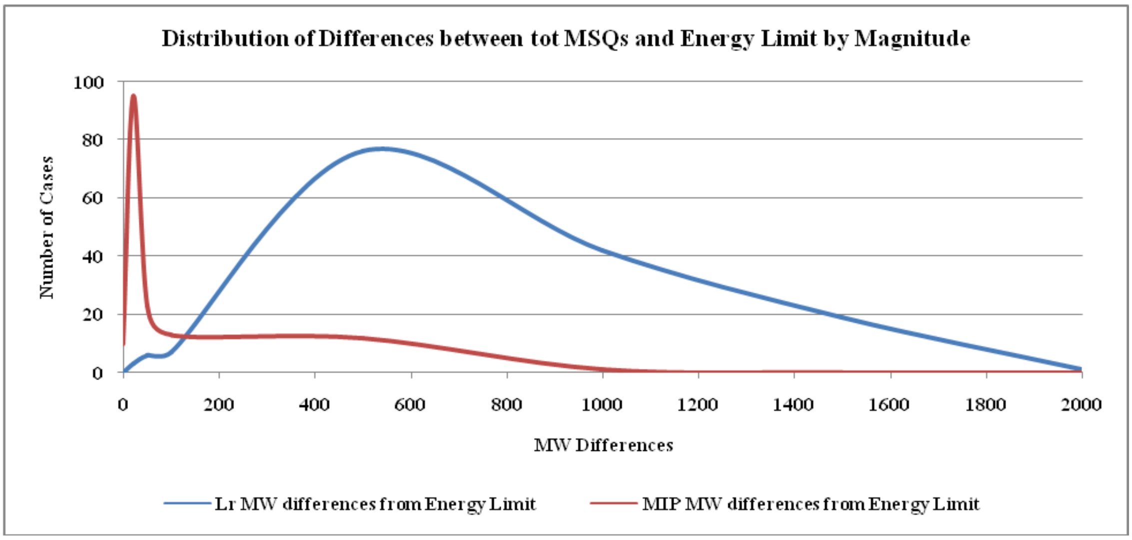

Figure 117 - Distribution of differences

Looking into more details at MIP performances, it has been noted that MIP has scheduled an average 454MW higher MSQ than LR which represents a 10% increase on the average daily LR MSQs.

In only 13 MIP cases did we observe unused energy limit quantities of greater than 100MW. These are mostly concentrated in the first few weeks of the study period. Eight out of ten Trading Days up to mid Jan 2008 are showing differences between total Hydro schedule amount and Energy Limit of this magnitude. The remaining five Trading Days are scattered with no particular order between Feb 2008 and Jan 2009.

No Trading Day after Jan 2009 shows the same issue with most runs achieving total Market Schedule Quantities very close to the full limit. The maximum difference observed in this set is 35MW and only three cases, out of the 39 of this period, had variances above 15MW.

The breakdown by Trading Period also shows that the larger increase of Hydro schedules in MIP actually happens at night-time as shown in the graph below.

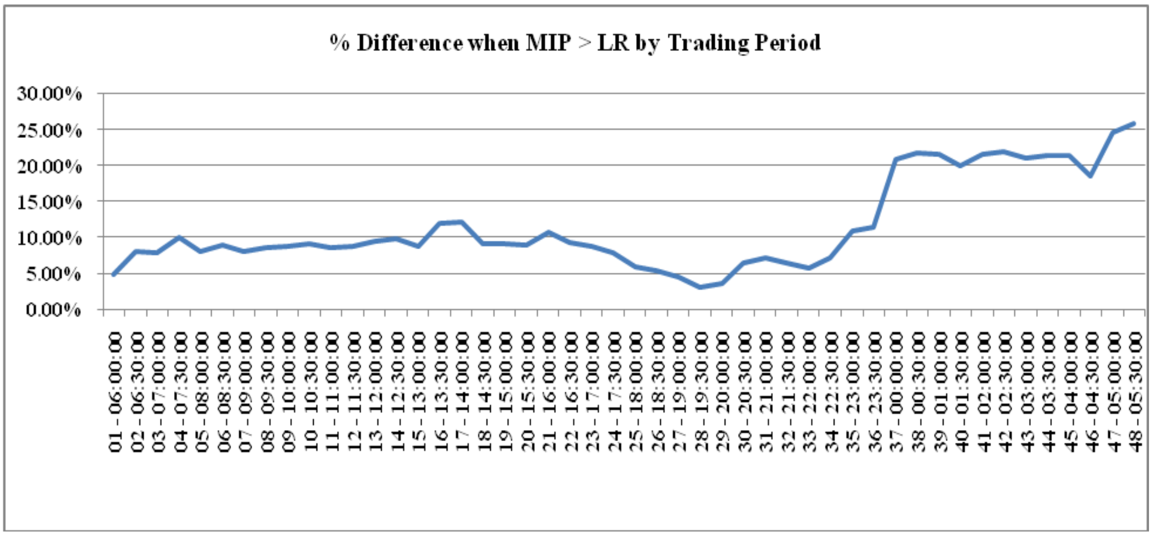

Figure 118 - Percentage Difference, per Trading Period

This could be because LR has a tendency to commit units in long blocks to avoid incurring Start up costs. As Hydro have relatively low Start up costs they are turned off during the night instead of conventional generators and put back on for the morning peak, while MIP has a more flexible approach and achieves its objective function with a more complex arrangement of units.

While MIP is scheduling more megawatts of Hydro generation than LR, only 22 dates out of the 154 achieve the full Energy Limits. This confirms that fulfilling Energy Limits is not part of the function of the MSP Software and, although the bid price is zero per MW of generation, it does not mean that instructing Hydro to their maximum reduces the overall MSP Production Costs of the schedule. This is also reflective of the fact that both MIP and LR solvers as used in the SEM and in this study produce sub-optimal solutions and not the global optimal solution.

It is important to note that, although a higher total schedule is achieved with MIP, this does not guarantee a higher economic return for these units. In 21 cases the revenue of the units fell by an average of €18,000 as the overall System Marginal Price was lower throughout the day (also see section on Consumer Cost)

Other considerations come from Hydro units only submitting Start Up Costs and the impact that this could have. It has been demonstrated that the LR software encounters problems in handling steep cost curves, as discussed during the consultation for the Dual Rated Modification proposal (Mod_34_08) and in the Market Operator User Group held on the 26th August 2008[24]**.** Unusual bidding patterns are known to create a search space which can be described as multimodal and rugged, what SEMO have previously referred to as a discontinuity in the solution space where the optimal solution lies (Thomas Weise, 2009). It has also been stated that Start Up is a costly characteristic that introduces inefficiencies in the Unit Commitment problem (Stoft).

For a subset of 14 Trading Days, further analysis has been carried out by adding a nominal price to Hydro units (€5 for the first Price Quantity pair and the No Load Cost), to verify if any variance is produced.

We observed a decrease in the difference between LR schedule for Hydro and Energy Limits in 8 out of 14 LR cases. Therefore adding a price did marginally improve the scheduling of Hydro Units; however, all study runs have still produced a lower total Market Schedule Quantity than the MIP solutions for the same Trading Days with still significant quantities of unused energy.

[24] http://allislandmarket.com/general_publications/publication/?id=8c6a302b-9a31-4358-9ca7-7003a8ceaa3f&categoryId=604f0183-1f1a-4a98-a7af-200a948c758b

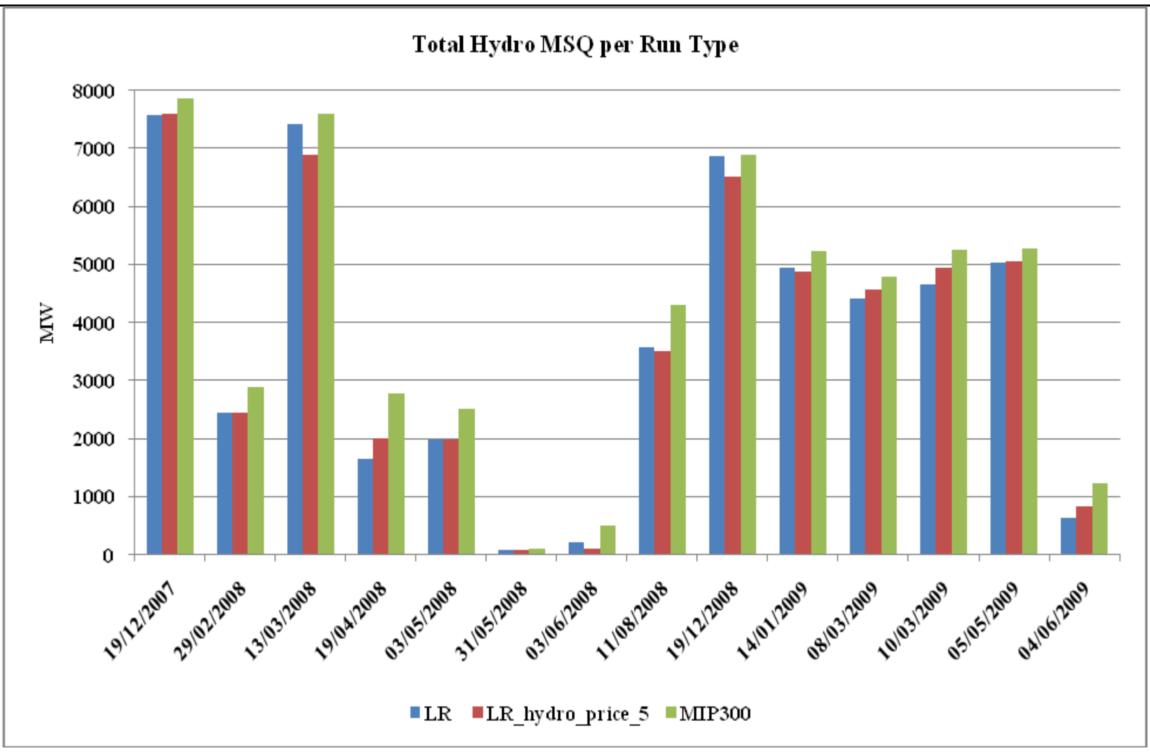

Figure 119 - Total MSQ per Run Type

It is interesting to note that even by introducing an extra cost in the problem, the solver achieved a lower Production Cost (even if just marginally lower) in 5 out of 14 cases as illustrated in the graphs below. Four of these dates had a combination of lower Production Cost and higher MSQ total for Hydro units than the regular LR.

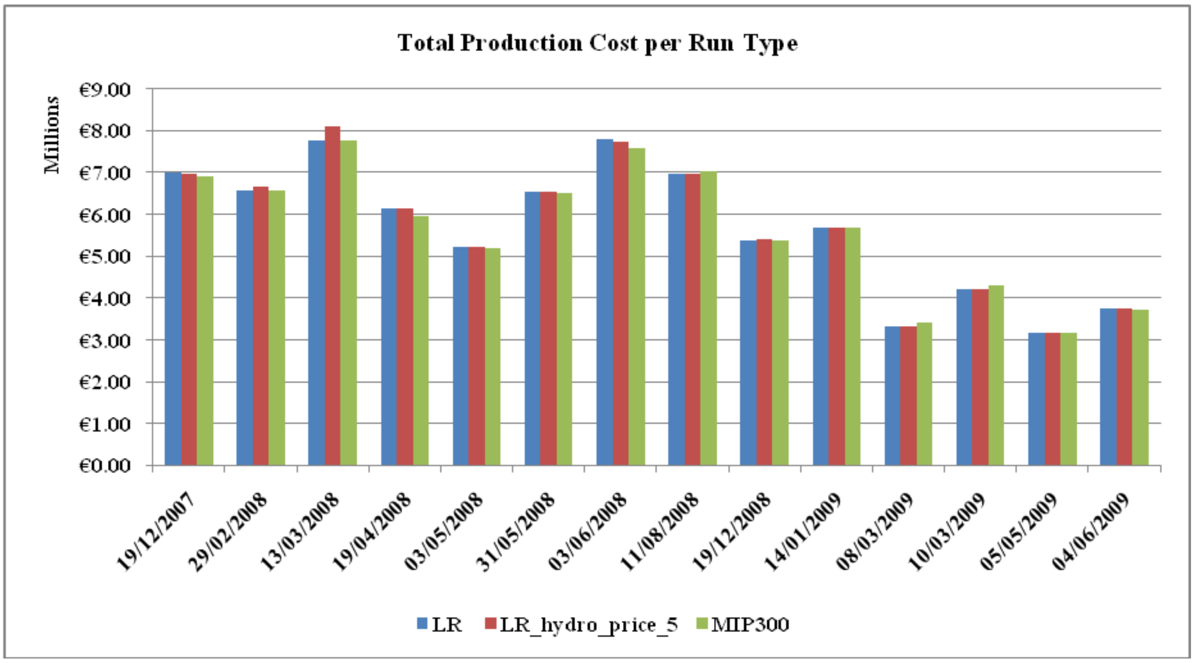

Figure 120 - MSP Production Cost per Run Type

There is no observed trend in this analysis and hence, these study cases with modified input data do not offer conclusive evidence that with the introduction of an additional cost, the schedule of Hydro units is improved. By adding an extra cost to the problem function, a fundamentally different problem is presented to the MSP solver therefore the results will be different.

Finally, a number of study runs were carried out where we made the Hydro units unavailable. This was done to verify whether, by removing this particular unit type with the inter-temporal element that this brought to the problem, a more efficient LR schedule, comparable to the outcome of the MIP solver, is obtained.

Based on MSP Production Costs differences, a sample of Trading Days was identified. The selection looked for study cases, which had minimal, large positive or large negative variances.

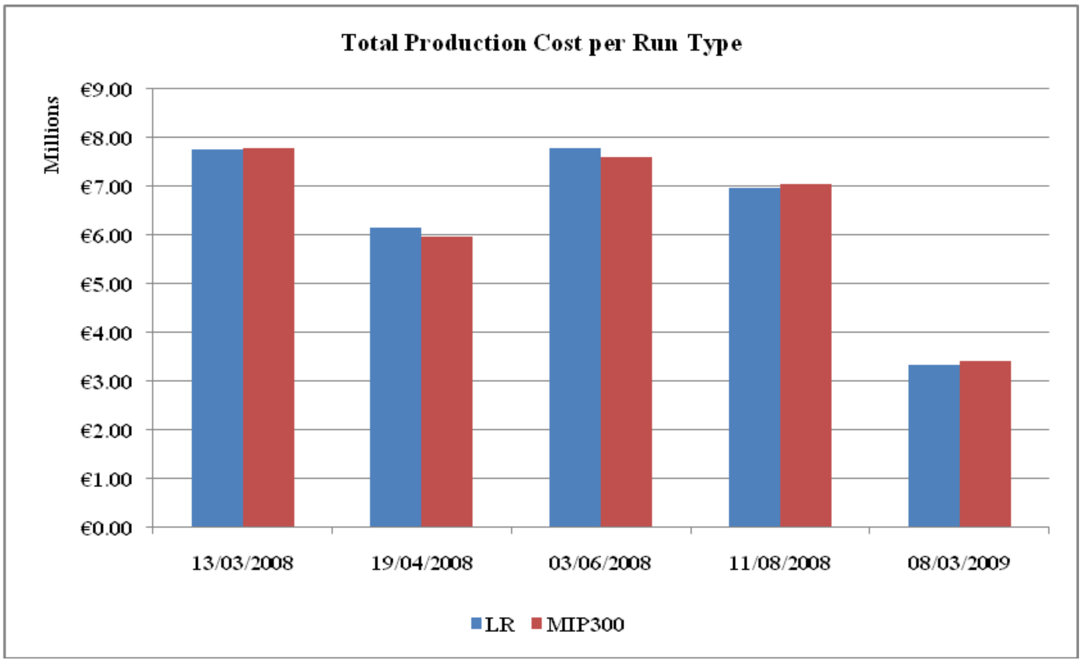

Figure 121 - MSP Production Cost per Run Type

After Hydro units have been made unavailable, no improvement was noticed in the LR performances. In fact, the MSP Production Costs in LR are consistently higher than MIP.

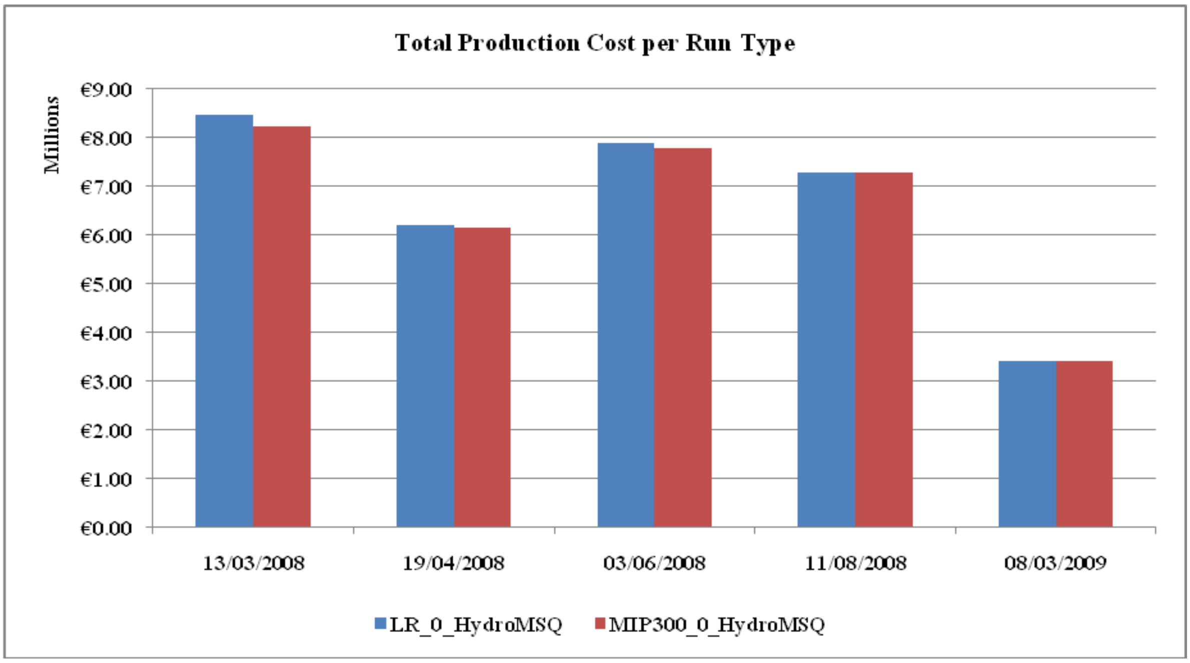

Figure 122 - MSP Production Cost per Run Type

8.5 Conclusion

With regard to the scheduling of Hydro units, it is evident that MIP schedules these units closer to their energy limit in all study runs and achieves the full limit in 14% of the cases. The average increase in MIP total Hydro schedule is 454MW per trade date.

This does not always result in cheaper production cost as for approximately 15% of dates (23 out of 154 study cases - see section on MSP Production Costs) the LR solution has a cheaper MSP Production Cost.

Therefore, the assumption that scheduling these Energy Limited Generator Units, which are price affecting, with zero bid and No Load Cost to their full would produce an overall lower Production Cost schedule is not supported.

The Energy Limits of these units are not targets that the solver needs to meet. These are just limits for a selected number of units and the full realization of these limits is not in the functional objective of the solvers.

By removing the Hydro problem from the unit commitment (by either applying conventional Commercial Offer data or making them unavailable), no improvement has been noticed over the original study cases in the comparison of these results with those seen from the MIP solver. The MIP solver still gives a lower MSP Production Cost and, where relevant, better scheduling of Energy Limited Units.

9 Constraint Costs

9.1 Introduction

Payments are made to Generators in respect of constraints in the SEM. These payments address the difference between how the unit is scheduled by the MSP software against how the unit is dispatched by the System Operator. The tool used by the System Operators to determine a dispatch schedule is known as RCUC (Reserve Constrained Unit Commitment) and is similar to the UUC software used in the SEM in a number of respects. Both tools seek to schedule generation while minimising MSP Production Costs. However, the RCUC takes account of a number of system constraints not considered in the UUC. In addition, the RCUC uses the MIP solver.

While recognising that constraint costs in the SEM are largely driven by the exclusion of any system constraints from the UUC, some consideration is given in this study to the possibility that some constraint cost may be driven by the use of two different solvers. Here we seek to compare the changes to the resulting Constraint Payments that may be observed in the SEM under the different solvers used in the UUC.

9.2 Executive Summary

This section intends to present the findings on how constraints costs compare when using the LR or the MIP solvers. The overall aim of the market is to schedule units which provide the best value in terms of production costs. This topic was of interest in this study as Constraint Payments are funded through Imperfections Charges on suppliers and, inevitably, all costs to the supplier will be passed on to the end user – the consumer. As a result, there are implications for the consumer if higher costs results from the choice of solver. It should be noted that the Dispatch Production Costs were fixed in these studies, as the data used was the same across all cases. Therefore, when the MIP solver reduces MSP Production Costs, this will increase Constraint costs.

In this section, we document the analysis completed with respect to Constraint Payments that may occur in the Settlement process based on the market schedules produced by the different solvers.

Market Production Costs for each generator are calculated and output from each run of the MSP software, regardless of the solver selected. These values have been used in this study. Dispatch Production Costs were calculated separately, making use of the real Dispatch Quantities and Commercial Offer Data from the live market. The dispatch schedule was consistent for both calculations.

A review of the results shows that Constraint Costs more frequently increase in the results calculated using the outcomes of the MIP solver.

For the study cases that relate to Trading Days from before the economic downturn notable from February 2009, the Constraint Payments are on average 17% higher when using the MIP solver. For the study cases after this time, the payments calculated using the MIP solver are 2% lower than the results from the LR solver. However, this post economic downturn finding is largely based on large changes on a small number of Trading Days.

Over the same period of time, the results from the MIP solver were more expensive in 65% of study cases. In relation to the study cases from before the economic downturn, the results from the MIP solver were more expensive 84% of the time.

The overall pattern of Constraint Payments was consistent between the solutions from the two solvers with the net daily total payments being either positive or negative in most study cases. In general, the variance in payments is in the +/-30% range.

We have also made observations with regard to the impact of improved Hydro generator scheduling on the net daily totals. This notes that the under utilisation of Hydro generators in the schedules from the LR solver are resulting in payments in from thermal generators while no payments are made out to the Hydro generators. This will result in a lower net daily total for Constraints.

9.3 Background

Constraint Payments fall into the category Trading Payments and Charges in relation to Generator Units. This class of payment also contains:

- Energy Payments, which are recovered through Energy Charges
- Constraint Payments,
- Uninstructed Imbalance Payments, and
- Make Whole Payments.

The last three payments listed above are recovered through Imperfections Charges

Constraints Payments are calculated to compensate for the difference between the economic solution and the dispatching reality. The Unit Commitment solver produces a Market Schedule which determines a megawatt value that a unit will produce. Ex-post, the real time dispatch instructions are received from the Transmission System Operators (TSOs) and when the Market Schedule Quantities (MSQ) do not equal the Dispatch Quantities (DQ), then Constraint Payments arise.

The Constraints Payments calculation is based on Dispatch Production Costs less Market Production Costs and can be either positive or negative.

A generator's production costs are primarily comprised of fuel costs; therefore, if a generator uses more fuel in dispatch than the market schedules it to use, the generator will be compensated for this additional fuel cost. If the generator does not use as much fuel as the market schedules it to then the generator pays back the avoided fuel costs, in the form of a negative Constraint Payment.

The formula for Constraints as per the Trading and Settlement Code is defined in paragraph 4.136 as follows:

$$CONPuh = TPD \times \begin{bmatrix} (DQLFuh \times DOPuh + DNLCuh + DQCCLFuh) \\ -(MSQLFuh \times MOPuh + MNLCuh + MSQCCLFuh) \end{bmatrix} + DSUCuh - MSUCuh$$

In essence, this calculation determines the Production Costs of a generator based on its position in dispatch and subtracts the Production Costs that would be calculated based on its position in the market schedule. This is because, the functions that calculate the market schedule and System Marginal Price are designed to ensure that each generator will meet their incurred Production Costs based on their market schedule position through the Energy Payment calculation (Energy Payments to generators are reviewed in the Consumer Costs section of the report). The Constraint Payment then offsets this amount against the Production Costs that were actually incurred by the generator in actual dispatch.

In preparation for analysing the Constraints, we used an Access database to replicate the calculation, which is done in the market Settlement System.

The inputs required for this calculation were as per the formula above:

- DQLF – Dispatch Quantity Loss Factored
- DOP – Dispatch Offer Price
- DQCCLF – Dispatch Quantity Cost Correction Loss Factored
- DSUC – Dispatch Start Up Cost
- MSQLF – Market Schedule Quantity Loss Factored
- MOP – Market Offer Price
- MNLC – Market No Load Cost
- MSQCCLF – Market Schedule Quantity Cost Correction Loss Factored
- MSUC - Market Start up Costs

However, as a key part of the unit commitment process is the calculation of the MSP Production Costs, which mirror the Production Costs based on market schedule, we took the results of each run of the MSP software and used the calculated generator Production Costs from this. Therefore, all that remained was to calculate the Production Costs based on the dispatch position.

Because the inputs for this calculation were not going to change because the dispatch schedule was fixed, values including Offers and Start Up Costs were extracted from the Market Systems Database. Production Costs for dispatch schedules were then calculated and were then offset against the market Production Costs extracted from the MSP solver for each study case.

Loss factors were excluded from our calculations for convenience. As such, the results observed represent trends in how the Constraint Payments would be calculated under each solver and will not be exact amounts.

9.4 Analysis

When looking at Constraints over the Trading Days included in the study, it appears that similar trends are produced when using the outputs of the LR solver and the MIP solver. This is to be expected as both solvers are attempting to minimise Production Costs while Constraints represent how far this economic ideal ranges from the real time dispatch, which is the same for both. The graphs below roughly follow the same pattern, with MIP appearing to have slightly higher Constraint Payments than LR when variances occur between the two. Apart from some anomalies throughout the study, the results are consistent with MIP solutions incurring more expensive payments in the majority of cases.

In the figures below as with elsewhere in this report, the whole series has been divided into 3 graphs for ease of illustration - –the first representing 2007 to May 2008, the second from June 2008 to Dec 2008, and finally showing from Jan 2009 to Aug 2009. The following graphs show a comparison between the Constraint Payments resulting from commercial decisions in the different solvers.

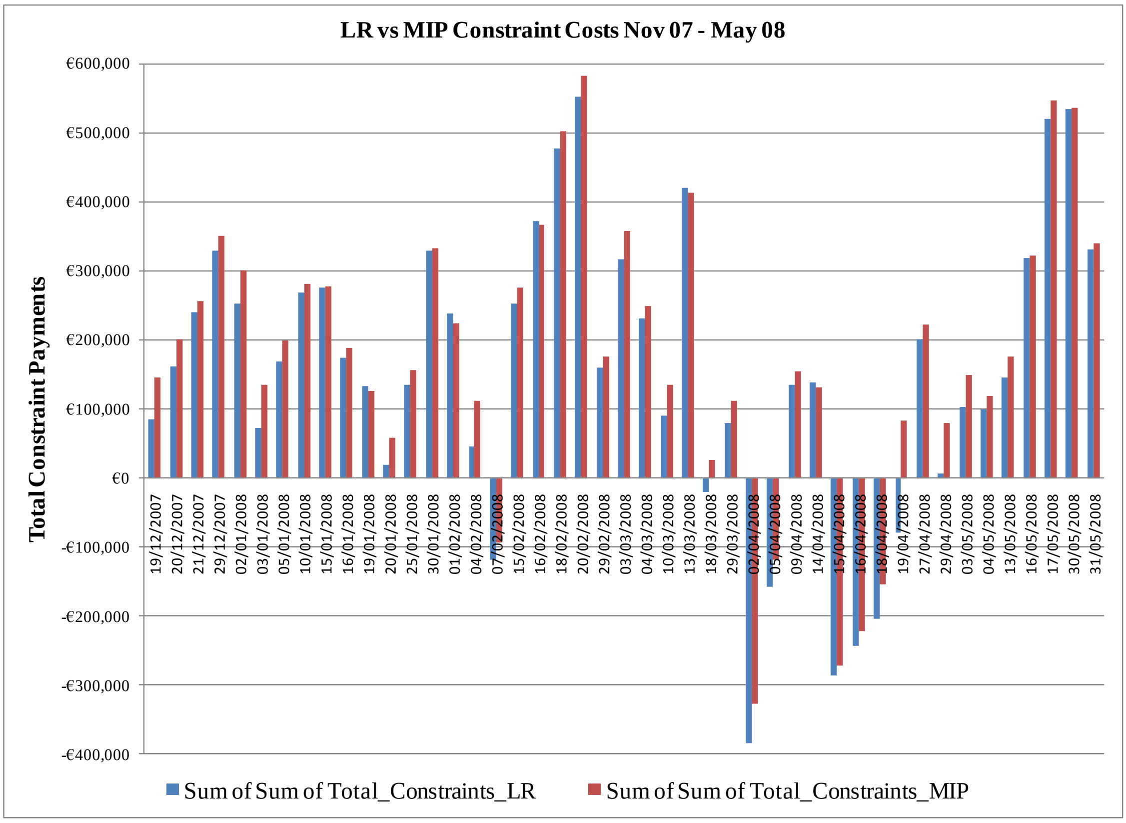

Figure 123 - Constraint Costs, 2007 to May 2008

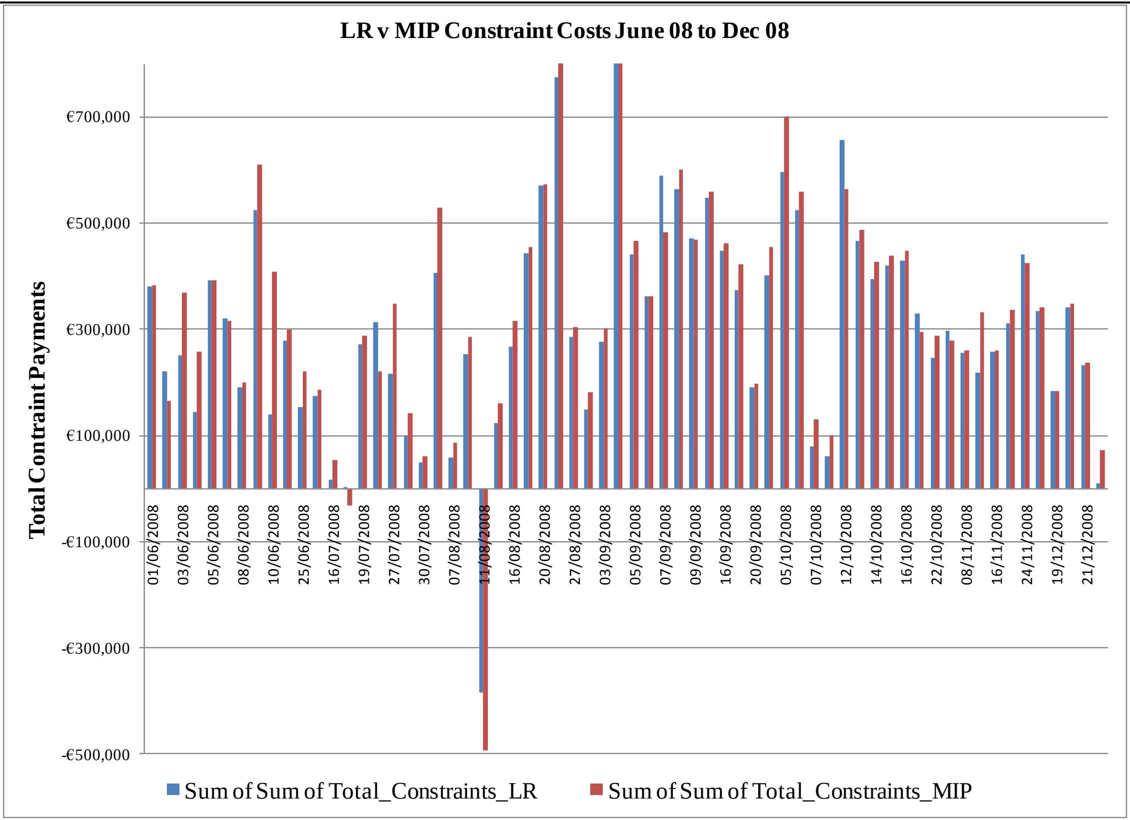

Figure 124 - Constraint Costs, June 2008 to December 2008

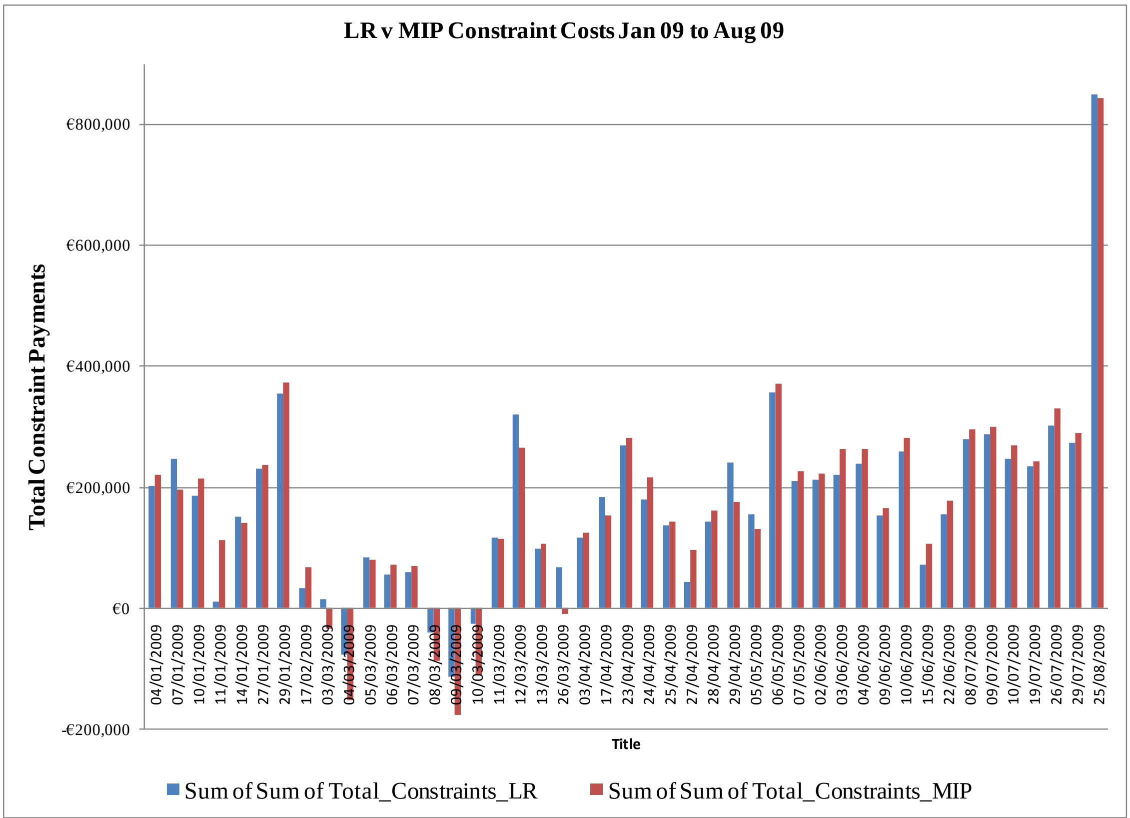

Figure 125 - Constraint Costs, 2009

The total Constraints Costs for the study cases completed using LR was € 34,359,359.63 and the total Constraints Costs for the study cases completed using MIP was € 37,252,716.15. The difference between the two solvers equates to an 8% increase with MIP. While we have noted that the system is dispatched based on the output of the RCUC program which uses the MIP solver, it must be remembered that the market program does not contain any reserve or system constraints. Therefore, we cannot expect that because we are using the same core MIP solver that we will get a similar result as the inputs are formulated differently.

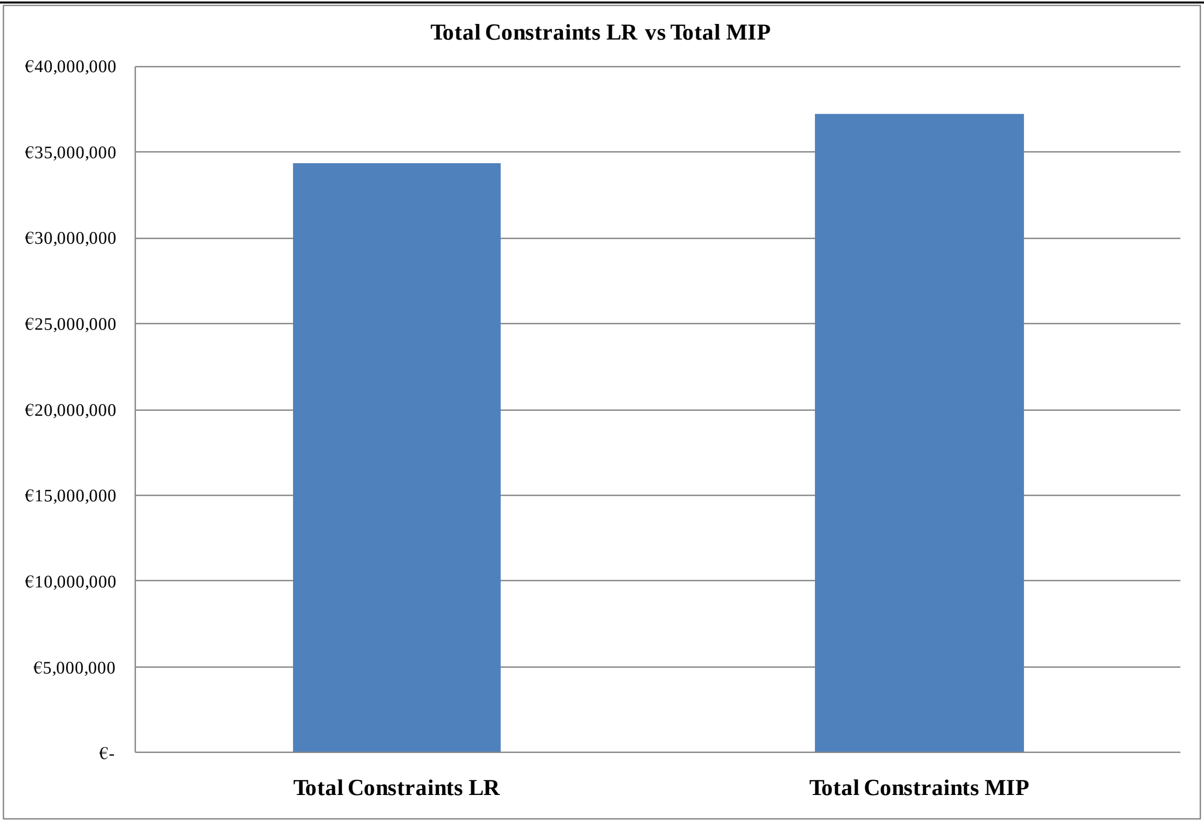

Figure 126 - Total Constraints

The Total figures from the point of view of pre/post economic downturn shows a significant drop when the two solvers are compared against each other. The difference pre economic downturn between the total figures is an increase with MIP of 11% in Constraint costs. Post economic downturn we can see that MIP is 2% cheaper than LR in Constraint Costs.

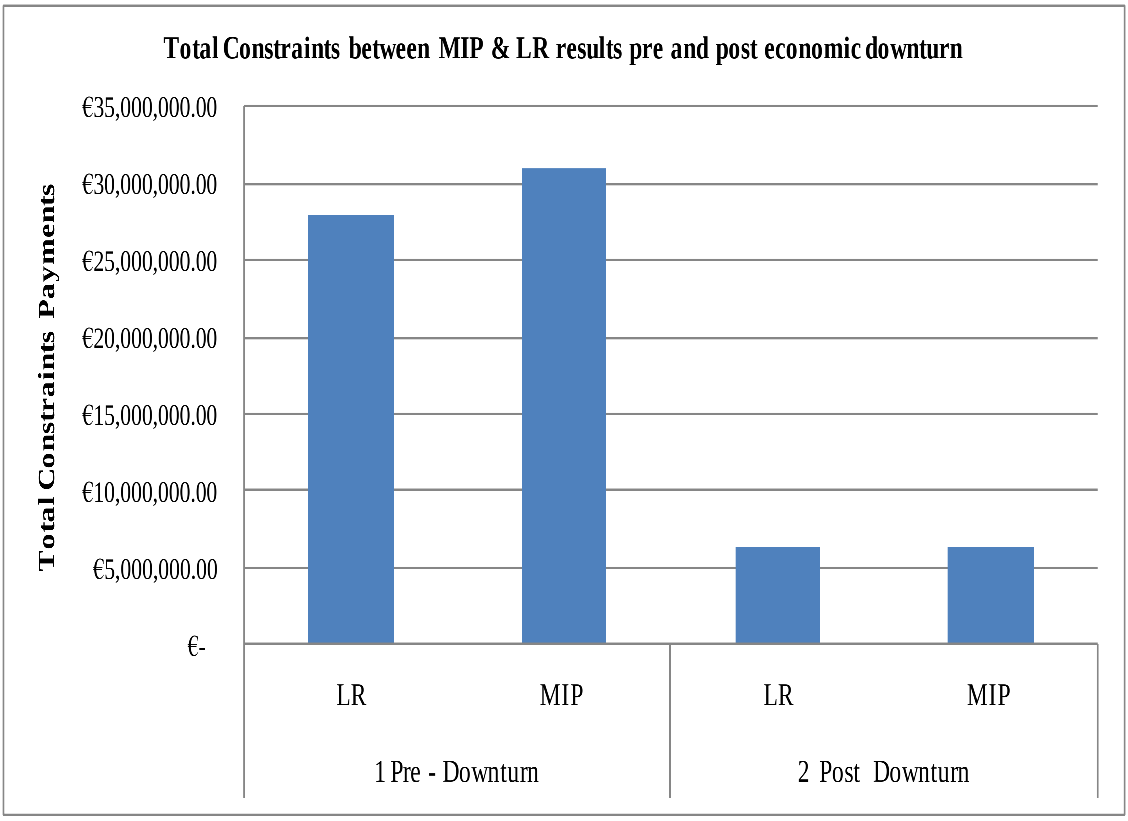

Figure 127 - Total Constraints, pre and post economic downturn

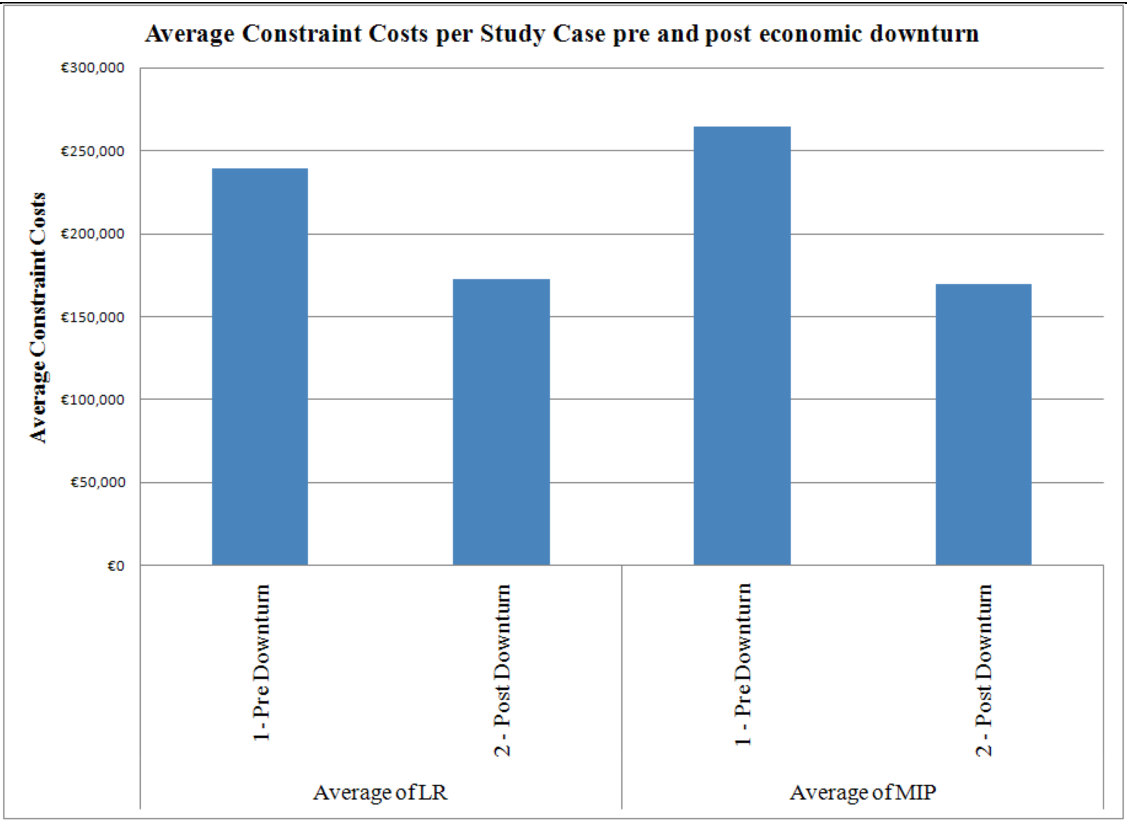

Figure 128 - Average Constraints, per and post economic downturn

It is clear to see that constraint costs have fallen since the start of the market. Looking at the average per study day, pre economic downturn, with LR, Constraint costs were €237,098.85 and after February 2009[25] LR Constraint costs were €172,562.00. The MIP Constraint costs before the economic downturn were €264,829.73 and afterwards dropped to €169,395.61. The cheapest average per study day is the MIP run (by only 2%) after the economic downturn. However, over the course of the study cases within that post economic downturn time period, LR is cheaper more frequently than MIP. LR is cheaper 65% of the time, compared to 35% with MIP. The constraints calculation is based on production costs and these have been reduced since the economic downturn, therefore constraint costs have also reduced during this time. (See the Production Costs section for further analysis.)

[25] February 2009 has been selected as a boundary of the economic downturn and is used elsewhere in this report when comparing monetary values across all study cases. This is based on the observed large drop in the load-weighted average daily System Marginal Price from this point onwards.

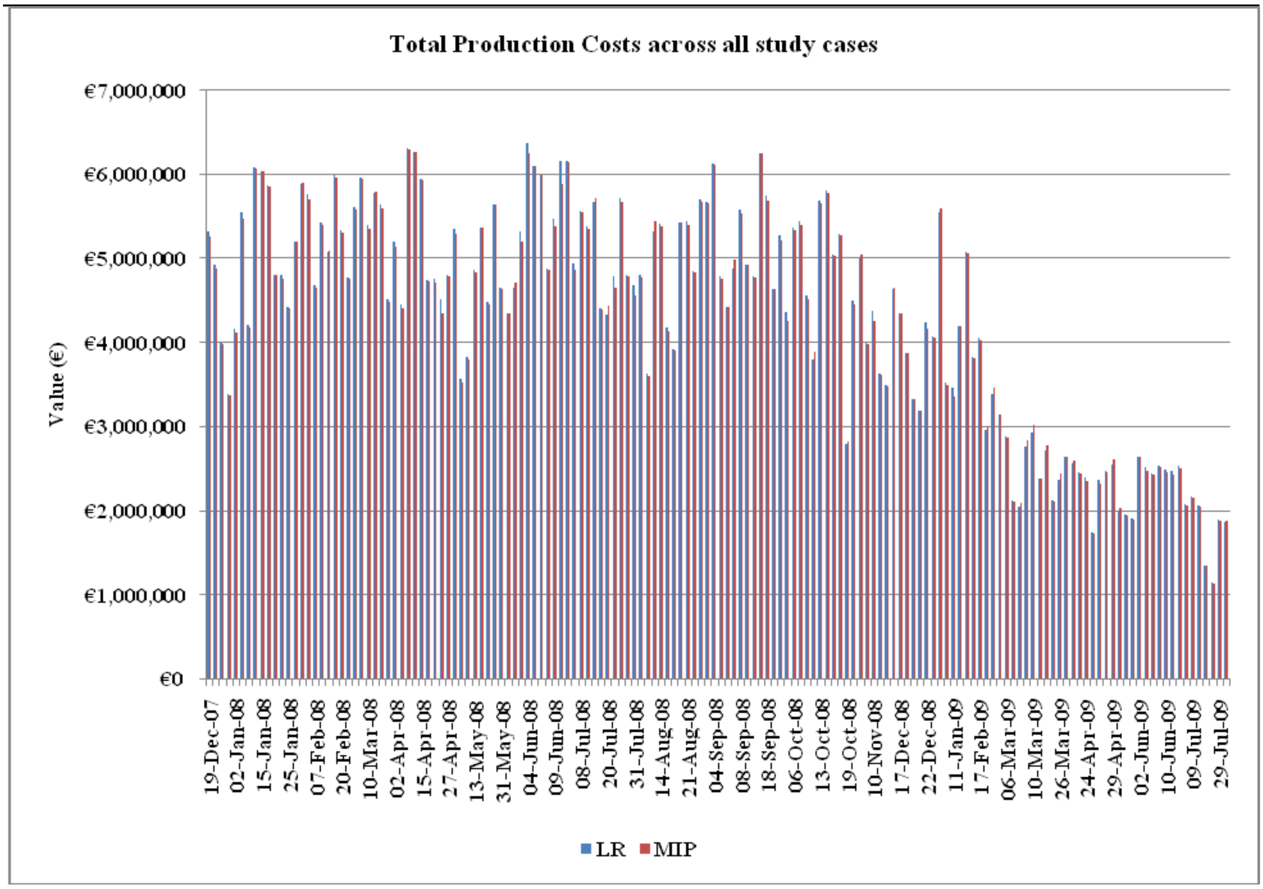

Figure 129 - Production Costs in study cases

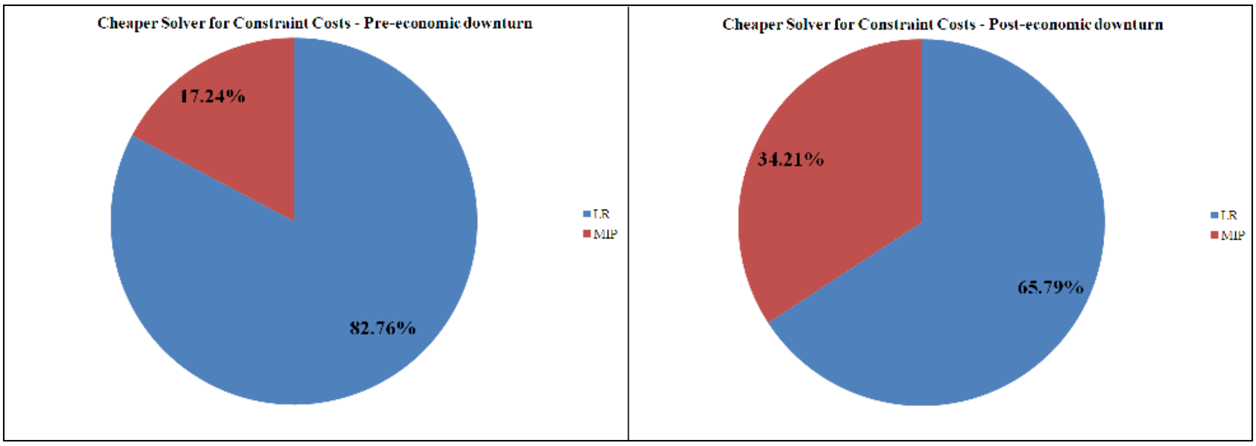

Figure 130 - Cheaper solver for Constraints, pre and post economic downturn

When looking at the overall breakdown of the solvers, Constraint Payments calculated on the outputs of the study cases using the LR solver are the cheapest over 121 days of the 154 study dates.

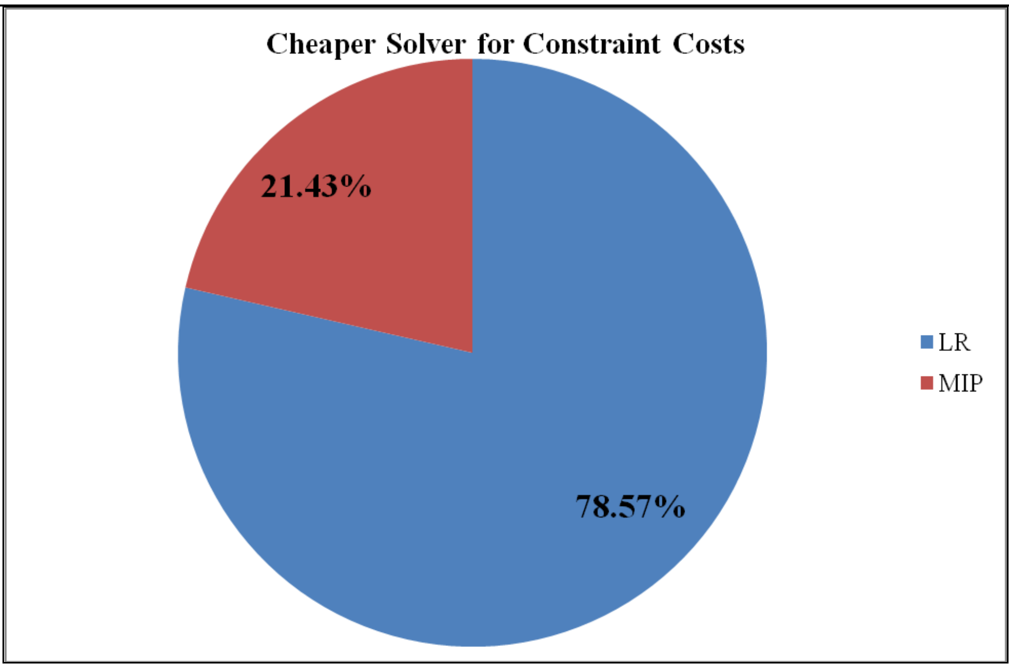

Figure 131 - Cheaper solver for Constraints

Analysing the figures further, out of the 154 Trading Days studied, both the LR and MIP runs of 138 study cases produced positive payments, 11 study cases produced negative payments in both runs. In two of the study cases, the LR runs produced negative payments while the MIP runs produced positive payments. There were three occurrences of LR producing positive payments where the MIP run produced negative payments.

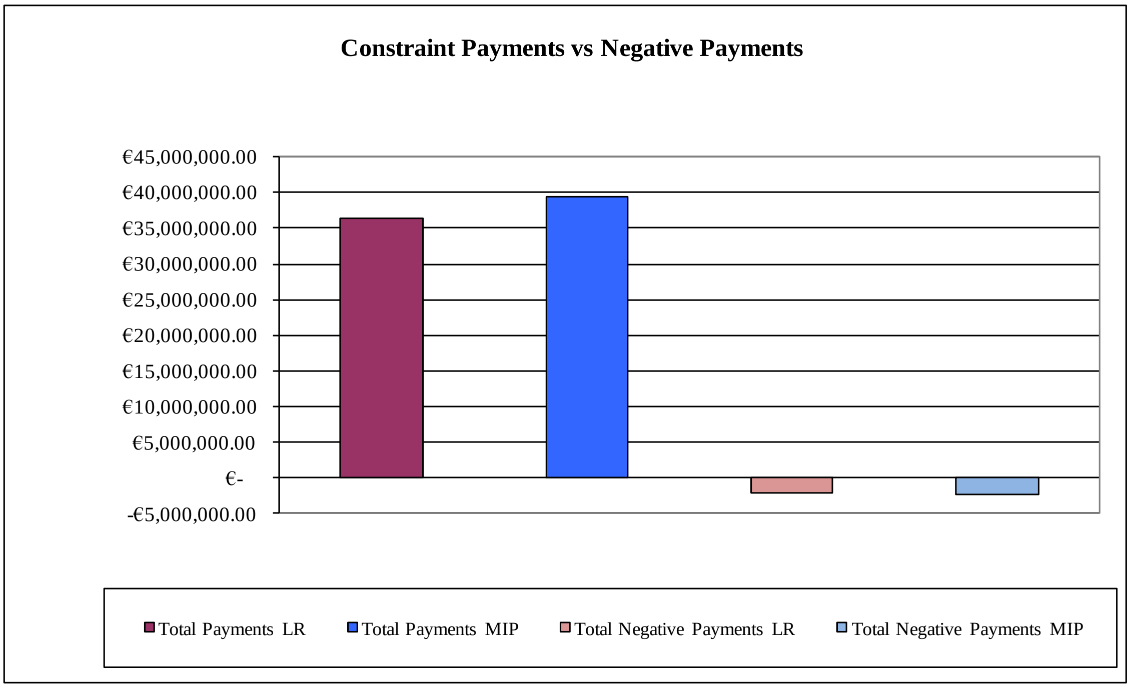

Figure 132 - Constraint Payments, positive and negative values

The total of the positive payments in monetary terms was €36,404,324.09 from the LR runs and €39,425,326.91 from the MIP runs. The total of the negative payments was -€2,030,578.58 from the LR runs and -€2,204,337.55 from the MIP runs.

	LR	***MIP300***
Total Payments	€ 36,404,324.09	€39,425,326.91
Total Negative Payments	-€ 2,030,578.58	-€ 2,204,337.55
Total Constraints	**€ 34,373,746.41**	**€37,220,989.37**

Table 32 - Constraint Payments, positive, negative and totals

The breakdown of Constraint Payments and Negative Payments is as follows:

	Number of Days
Payments (Both LR and MIP)	138
Negative Payments (Both LR and MIP)	11
Negative Payments (LR) v Payments (MIP)	2
Payments (LR) v Negative Payments (MIP)	3
TOTAL STUDY DAYS	**154**

Table 33 - Constraint Payments, positive and negative by study case

99 of the 138 days that had Constraint Payments from both runs had variations between LR and MIP within the 0% - 20% range. Of those 99 days, 75 fell within the 0-10% range. This is demonstrated in the frequency analysis graph below.

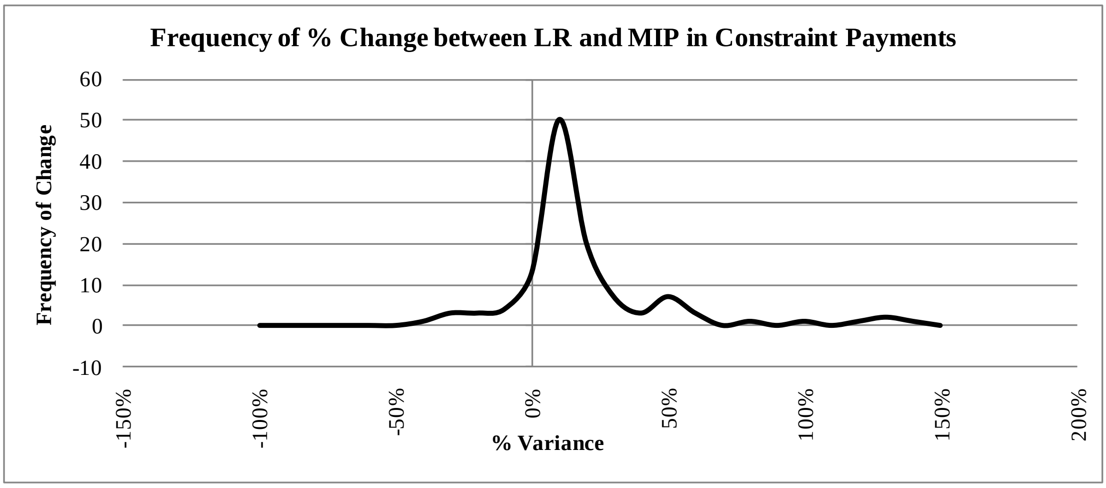

Figure 133 - Frequency of change in Constraint Payments

In terms of payments, the largest variance was 1081%. This occurred on the 29th of April 2008, when the LR run produced Constraint Payments of €6,680.24 and the MIP run produced Constraint Payments of €78,900.49, an increase of €72,220.07. This increase can be explained by a 100% change for one unit in the LR and MIP schedules. The LR run scheduled a mid range (in relation to average bid cost) price maker generator, which the MIP run did not commit at all; however, the unit was used in actual dispatch. This resulted in the unit receiving a Constraint Payment of €43,329 in the LR run and €124,377 in the MIP run. Along with small shifts between the two runs for other units, the increase for this one particular unit is the major contributor to the €72,220.07 variance.

Compared to the Negative Constraint Payments, six of the 10 days that had Negative Constraint Payments had variations between LR and MIP within the 0% to -20% range.

The maximum variance is an increase of Negative Constraint Payments of 343% from the LR run to the MIP run on the 3rd March 2009.

The minimum variance is -5% on the 15th April 2008 when the MIP run produced €271,242.032 of Negative Constraint Payments and the LR run produced €285,729.55.

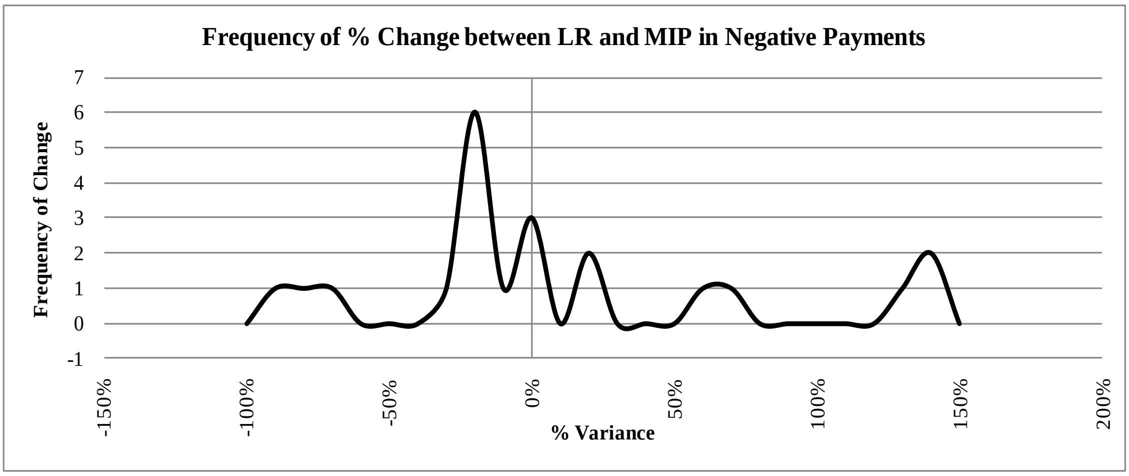

Figure 134 - Frequency of change in negative Payments

Large percentage variances occur when one solver produces payments and the other, negative payments. There are five days when this situation arose.

Trade Date	Total Constraints LR	Total Constraints MIP	% Difference between LR and MIP	Cheaper Solver
17-Jul-08	*€ 2,764.04*	*-€ 32,983.27*	*-1293%*	*MIP*
18-Mar-08	-€ 20,660.81	€ 25,229.02	-222%	LR
19-Apr-08	-€ 79,559.40	€ 82,613.65	-204%	LR
03-Mar-09	*€ 15,003.30*	*-€ 34,575.88*	*-330%*	*MIP*
26-Mar-09	*€ 68,066.09*	*-€ 8,556.74*	*113%*	*MIP*

Table 34 - Study Cases that changed from positive to negative

There were three occurrences from the 154 study dates, of the LR solver producing Constraint Payments and the MIP solver producing Negative Constraint Payments (highlighted in the table above). The other two dates have Negative Constraint Payments in the LR only. These variances are arising from different commitment decisions from both solvers.

Consecutive Days – 31st May 2008 – 6th June 2008

Consecutive Study Days were run with Initial Conditions reset from the 31st of May to the 6th of June. As commented on elsewhere, this was done to see if over time the solutions from the given solvers would evolve and improve. Here, we review the trend in Constraint Payments across these study cases

The analysis below is based on 67 generators. This is the total number of dispatchable generators running in the system. There is one exception, the 4th of June, when there were two additional interconnector units trading, which brought the number up to 69, for that day only.

Of the seven days ran, the calculated Constraint Payments from the results of the LR solver were the cheaper 4 times, while the results from the MIP solver were cheaper twice. One day had no percentage change at all.

The first two days (31st May 2008 and 1st June 2008) showed small increases with the MIP solver of 3% and 1% respectively, the payments then dropped significantly by 25% with the MIP solver on the third day (2nd June 2008). The next day (3rd June 2008) then increased by 48% in the outcomes from the MIP run. The largest increase occurred on the fifth day (4th June 2008) with Constraint Payments from the MIP run being 79% more expensive than LR. On the sixth day (5th June 2008), there was no change between the two solvers. On the final day (6th June 2008), the results from the MIP solver were 2% cheaper than those from the LR solver.

What this demonstrates is that using one solver consistently over another, over an extended time period does not necessarily produce cheaper Constraint Costs. Over the seven consecutive study days run, the LR runs had total constraint costs of €2,041,108.34 and MIP had total constraint costs of €2,224,392.60, a change of 9%. This would indicate a similar pattern in the overall totals where we saw an increase of 8% with MIP. In addition, as similar patterns are being seen with both solvers, this indicates that swapping from one solver to another out of sequence has no impact on the outcomes for the market; that is, although variances of up to 9% were noted in these consecutive studies, these variances would have occurred anyway. This corresponds to the observations made when the consecutive day blocks are reviewed in the Production Costs section.

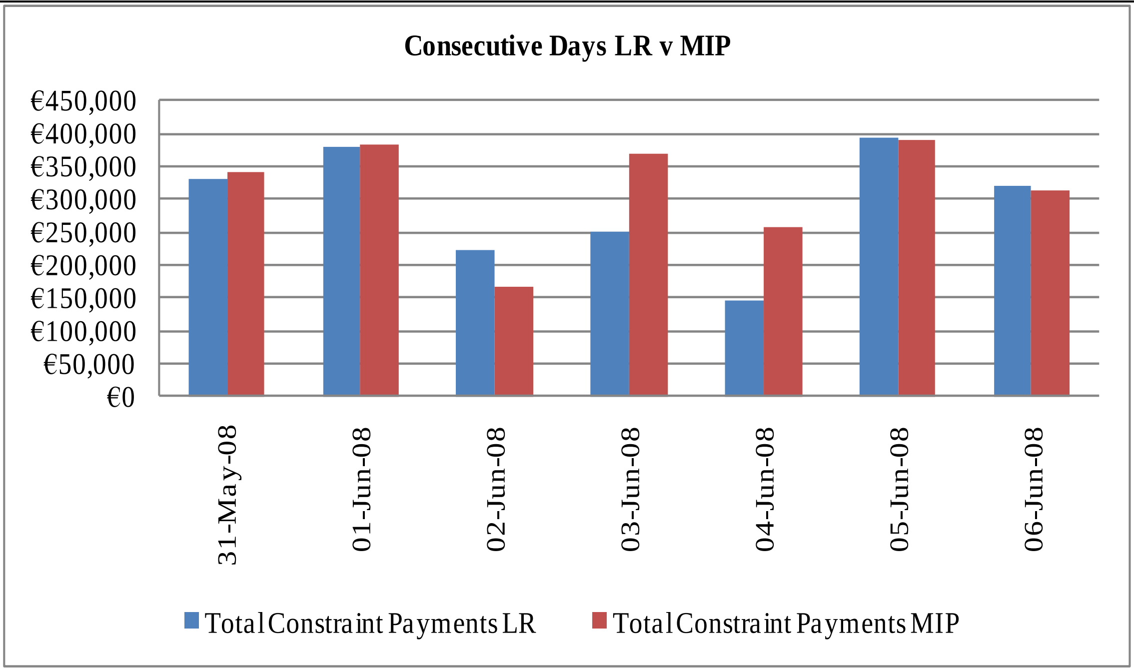

Figure 135 - Constraint Payments, on consecutive days.

9.5 Hydro Units

A further observation with regard to Constraint Payments can be made around the Hydro generators. As noted in the section on Energy Limited Generators, Hydro generators are better scheduled with respect to their daily limits when using the MIP solver rather than the LR. This artefact does have an impact on the total Constraint Payments made within the SEM.

While we have noted that Hydro generators are normally used to their full limit in the dispatch process, the LR solver does not always schedule these units to their full limit in the market. Therefore, the difference between their Market Schedule Quantity and their Dispatch Quantity should be compensated through the Constraint Payment calculation. However, as Hydro generators bid in a zero cost and zero No Load Cost, the Constraint Payment calculated would be zero with the exception of Trading Periods where a start is incurred in one schedule and not the other.

A hidden impact of this is that elsewhere in the schedule other generators with non-zero costs and No Load Costs will be used in the market but not in actual dispatch. Under the Constraint Payments, these generators will pay back their avoided fuel costs. This has an impact on the overall Constraint Payments as a negative payment is being made in respect of a certain megawatt quantity while no positive payment is made out for this.

We have been unable to accurately quantify this in monetary terms, as when reviewing the megawatt quantities by which Hydro units have been constrained down there is no direct pass off to another generator or generator type. The unused Hydro megawatts are effectively met by a number of other generators. We have been able to quantify the megawatt values and these are shown in the graphs below. The positive values visible here represent the reduction in the megawatt quantities by which Hydro units are effectively constrained in the MIP studies over the LR studies. While the daily value fluctuates across all schedules in the study, an average value of 450MW can be determined. It is also clear that there was no occurrence of a negative value. Therefore, in all study cases completed, the Constraint costs have been increased when using the MIP solver by the megawatt amounts below.

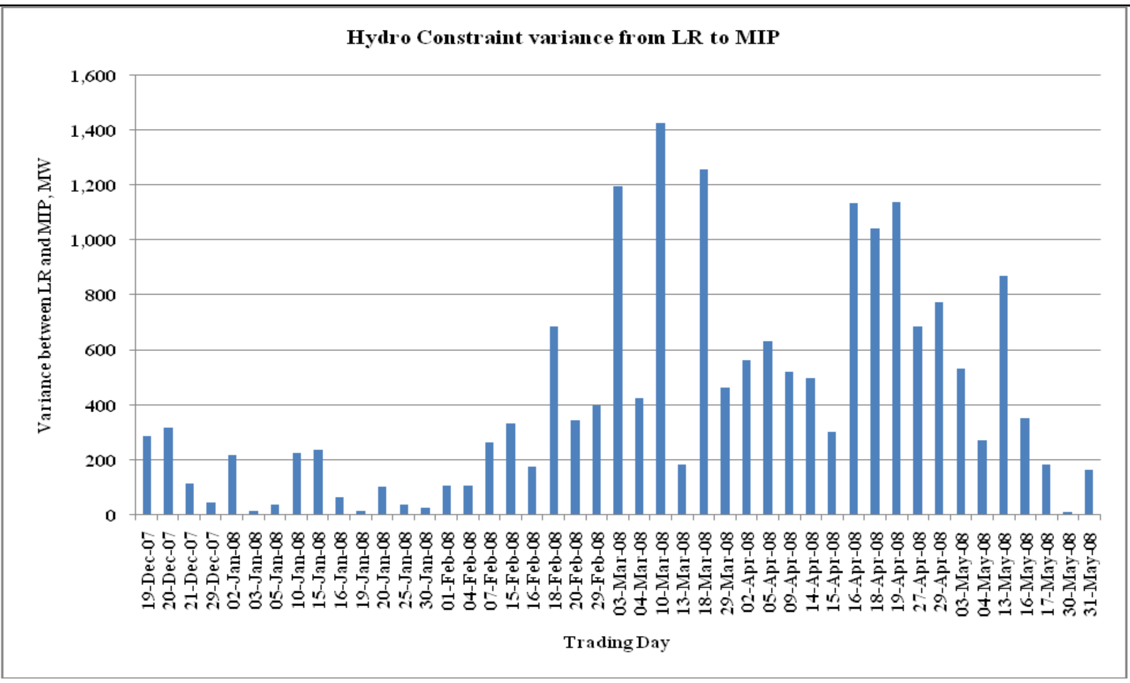

Figure 136 - Hydro Constraint variance, 2007 to May 2008

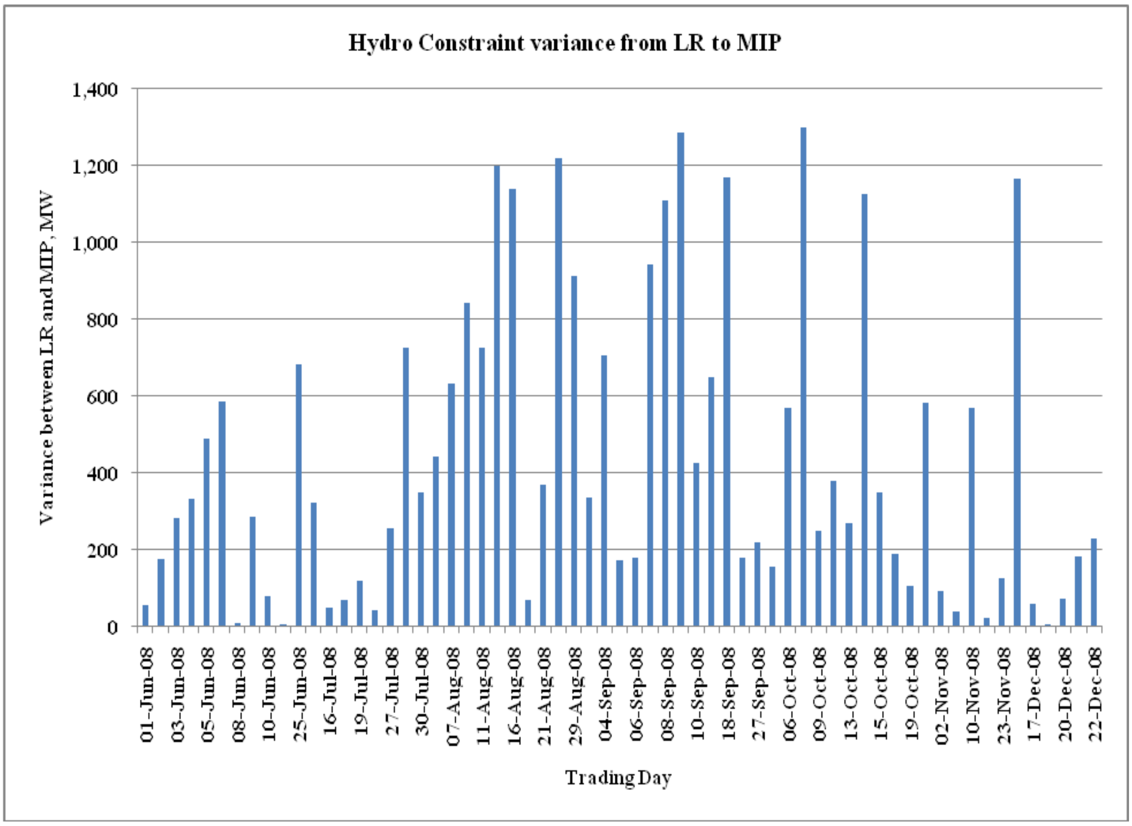

Figure 137 - Hydro Constraint variance, June to December 2008

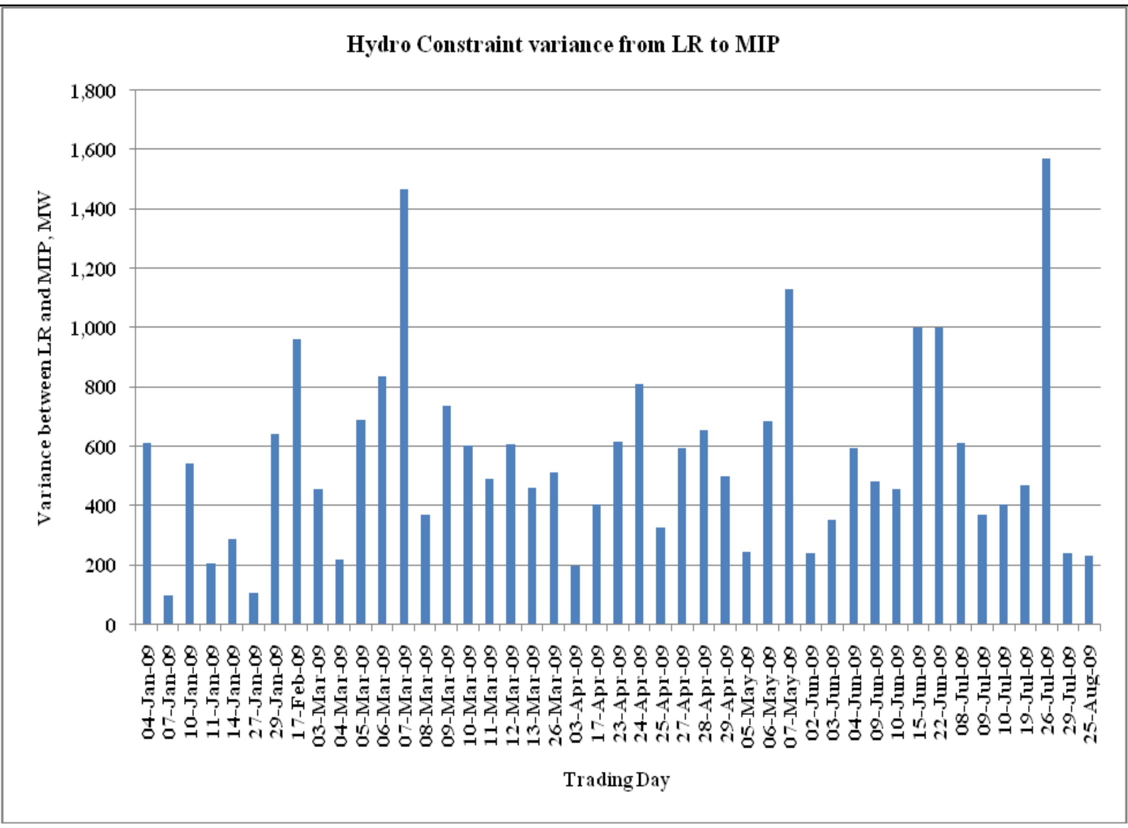

Figure 138 - Hydro Constraint variance, 2009

In an attempt to put a monetary value on this quantity, we applied the daily average Shadow Price to the quantities observed. Because these generators paying back their avoided fuel costs were used in the market schedule, we can state that their bid cost is no greater than the Shadow Price but could be less.

This approach would indicate that using the MIP solver, there would be a daily average reduction of €14,000 in negative Constraint Payments, separated in the graph below into pre and post economic downturn timeframes. Because of the crudeness of this estimation approach, there is no additional value is showing the daily figures.

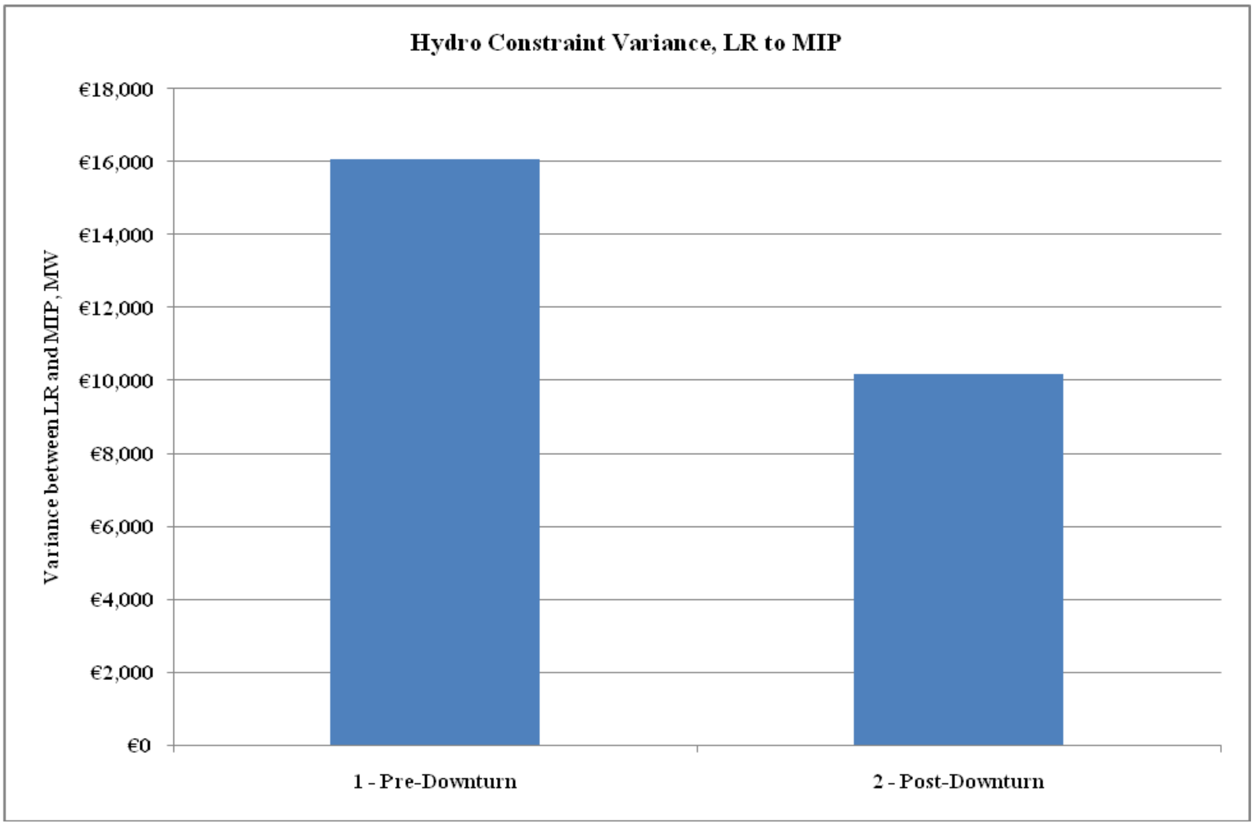

Figure 139 - Hydro Constraint variance, costs

9.6 Conclusion

In conclusion, it has been shown that over the course of the study dates both the LR and MIP solvers followed the same general pattern in regards to constraints. Overall, the Constraint Payments observed in the outcomes of the LR solver are cheaper than those from the MIP. The constraints calculation is based on commercial offer data and reductions in fuel costs based on external factors and the economic downturn have meant that Constraint costs have fallen since the start of the SEM. While constraint costs in both solvers have dropped, LR is still more frequently the cheaper solver. The LR and MIP solvers mainly produce the same trend in payments; i.e. they both result in payments or they both result in negative payments for generators. There are some anomalies in days that have extreme variances between the LR and MIP solver; however, the majority of variances occur within the +/-30% range.

One point that can be made is regarding Hydro units. We have seen in the Commitment and Energy Limited Generator section of this report that the Hydro generators are scheduled closer to their Trading Day Energy Limits in the outputs of the MIP solver. Therefore, other units are being scheduled in LR to compensate for the difference in mega watts. As Hydro units have zero incremental and no load costs, constraint payments to Hydro generators are very small, generally resulting in a net reduction in constraint costs when Hydro is scheduled less in the market than it is dispatched. This may require further analysis and investigation.

10 MSP Software Internal Parameters

10.1 Introduction

For this section, we have taken into consideration the Lagrangian Relaxation's two ALTCOM parameters and the Mixed Integer Programme's MIP Gap[26]. These are the only parameters that the Market Operator could amend if it so wished in the SEM implementation of the two solvers.

The purpose of this analysis is not to question the parameters that have been set as advised and tested by the vendor, but to verify that default values would not impact significantly on the outcome of each solver.

Only a limited number of sample dates have been deemed necessary to run for each scenario. A more comprehensive analysis might be carried out in future separate studies should the outcomes deserve further investigation.

10.2 Executive Summary

We modified the default parameters for both the LR and MIP solvers on a limited number of Trading Days.

In the LR implementation, we can change the ALTCOM parameters. The ALTCOM processing in the LR solver stands for Alternative Commitment. When the LR solver has completed its pass of committing generators, the Alternative Commitment phase reviews the results to see if the MSP Production Costs can be further reduced by making changes to the commitment decisions. This phase cannot commit generators who were not originally committed in the first pass but can only review the impact of individual generator commitments. It will assess if a cheaper MSP Production Cost can be achieved by changing the Trading Periods in which units are committed on or off.

This phase looks at a number of generators that cycle on and off across a schedule, and then at generators committed for short periods (where they are used as peakers) replacing other generators that were committed off. In the SEM, the first phase of ALTCOM examines a block of 60 generators and the second phase examines a block of five.

In our study cases, we first amended the parameters setting them both to zero and effectively turning off the ALTCOM process. The results we observed showed that MSP Production Costs were higher in all three Trading Days taken into consideration. A second set of study cases where we set the first parameter to zero but left the second at its original setting of five. This produced identical results to the outcomes observed when we turned the process off above.

In the next set, we amended the parameters setting them both to 90 which would ensure that the process was run on all generators. All runs in this group have produced lower MSP Production Costs, SMP and Consumer Costs are higher in one of the three Trading Days. A further set of runs with the first parameter at its default setting and the second parameter to zero produced the same results.

Changes on MIP GAP have resulted in the following outcome:

- by increasing the MIP Gap higher MSP Production Costs have been achieved with faster response time;
- by decreasing the MIP Gap, only marginally lower MSP Production Costs have been generated however with slower response times.

[26] As noted above, the MIP Gap is a configurable parameter in the Central Market Systems which is used as a convergence tolerance which allows the program to stop when it has achieved a solution with an Optimality Gap better than the tolerance, once time limits have not been reached.

This analysis has confirmed that there is limited value in modifying both the ALTCOM parameters in LR and the MIP Gap in MIP. We have observed incidents with both where the MSP Production Costs have been improved; however, full consideration should be given to all the other aspects impacted by such changes, like SMP, Consumer Costs and Generator revenue. This has not been done in sufficient detail for this report to reach any solid conclusions, as only a limited number of study cases have been considered.

We therefore recommend that the current settings continue to be used in SEM operations and further analysis be carried out in separate studies should this be required.

10.3 Background

The ALTCOM function is part of the proprietary Lagrangian Relaxation solution delivered by the vendors of the SEM Central Market Systems. This function is executed as part of each Unit Commitment run to further optimise the outcome of the first pass of LR. This is done by reviewing the schedule of peakers and two-shifting plants and considering if the generator requirement could be delivered at a cheaper MSP Production Cost by committing a given Generator Unit for a shorter or longer period of operation. Details of this function have also been presented at the Market Operator User Group on the 11th August 2009[27].

When SEMO originally proposed the study of MIP vs. LR in the SEM, the actual function of ALTCOM was not fully understood by us. This was included in the scope of the study as it was originally considered that this could be an LR tuning parameter and that this could be used to achieve better commitment outcomes. However, we have now learned from consultations with the vendors that this is not the case and it only serves to set the number of generators for which the ALTCOM process is run.

As such, altering the ALTCOM parameters in the Central Market Systems does not provide any insight into the different results reviewed elsewhere in this report.

Although this issue is considered as no longer relevant, we have included the results of our studies where the ALTCOM parameters were changed for completeness.

As for MIP the only variables that can be modified by the users are the run times (covered in section 'Comparison of the MIP Timeout Settings') and the MIP Gap, which sets a convergence tolerance target for the Optimality Gap which measures how close the solution found is to the global optimal[28]. It is academically recognised that given an infinite time to solve, MIP will eventually produce the global optimal solution with zero variation (Sioshansi, 2008); however, within the practical timelines available in SEM operations, this has never been achieved. By introducing limits on the time allowed for a run and a convergence tolerance, the solution achieved is likely to be sub-optimal. With this in mind, we have completed extra study runs with the convergence tolerance setting, known in our software as the Optimality Gap, adjusted to higher and lower settings to review the impact on the solutions delivered.

This analysis aims to confirm that a variation of the MIP Gap value would not have a significant effect on the quality of the solution in terms of MSP Production Cost.

10.4 Analysis

A small number of Trading days were selected to be run with modified parameters in each MSP solver.

10.4.1 ALTCOM parameters in LR

The ALTCOM function is the final stage of the LR Unit Commitment program and it is used to refine the initial LR commitment by providing a series of Alternative Commitments. These are driven by two parameters as follows:

- ALTCOM1, which analyses how by modifying the commit status of units cycling on and off during the run period, cheaper Production Cost could be achieved; and

[27] http://allislandmarket.com/general_publications/publication/?id=d0e66c1c-6094-4fd2-ab76-7bb4d58a2ce7&categoryId=604f0183-1f1a-4a98-a7af-200a948c758b

[28] As noted in the Summary Overview, the Optimality Gap is calculated as the percentage variance between the best current solution and the best lower bound from the first phase of the program where a relaxed version of the problem is solved.

- ALTCOM2, which is used to improve ALTCOM 1 scenarios in cases when there are units committed on very short times (peakers). Its function is to verify if the commitment of one peaker unit could replace multiple peakers achieving a cheaper Production Cost.

Currently these are set respectively at 60 and 5, these figures representing the number of units whose schedule will be considered on a Trading Period by Trading Period basis to verify if, by reducing or increasing the commitment of each unit, a lower production cost can be achieved. Only Alternative Commitment solutions, which improve the MSP Production Costs, are accepted. Therefore, the ALTCOM logic will only ever further improve the optimality of the LR solution by delivering cheaper MSP Production Costs.

In our analysis, three Trading Days have been selected and four different run types have carried out:

- ALTCOM1 = 0/ALTCOM2 = 0;
- ALTCOM1 = 0/ALTCOM2 = 5;
- ALTCOM1 = 90/ALTCOM2 = 90; and
- ALTCOM1 = 60 /ALTCOM2 = 0

Dates have been chosen in December 2007 and January 2008 when the System Load was at its highest. This was to observe the impact when more Price Maker generators and Peak units are more likely to be instructed on/off. This is when the ALTCOM logic would be used more effectively.

Based on the results obtained, we can divide the run type outcomes in two groups:

- the first group consists of the two runs types where parameters are set as follows ALTCOM1 = 0/ALTCOM2 = 0 and ALTCOM1 = 0/ALTCOM2 = 5, and
- the second group consists of the two run types where parameters are set as follows ALTCOM1 = 90/ALTCOM2 = 90 and ALTCOM1 = 60 /ALTCOM2 = 0.

Identical results were obtained in all Trading Days for the two run types in the first group, where the highest parameter (ALTCOM1 currently at a default value of 60) was set to zero. MSP Production Costs were higher than the original LR by a minimum of 0.04% to a maximum of 1.15% (which in monetary terms is equal to a minimum of €1,702 to a maximum of €68,649).

None of these runs achieved a lower Production Cost than MIP for the relevant Trading Day.

Trading day	*LR default parameters*	*LR Altcom1=0/Altcom2=0 & LR_Altcom1=0/Altcom2=5*	*MIP300*
20-Dec-07	€6,461,011.26	€ 6,466,292.83	€ 6,438,095.28
29-Dec-07	€4,294,023.00	€ 4,295,725.04	€ 4,259,123.87
02-Jan-08	€5,968,910.87	€ 6,037,560.39	€ 5,919,945.34

Table 35 - Results with ALTCOM1 set to 0

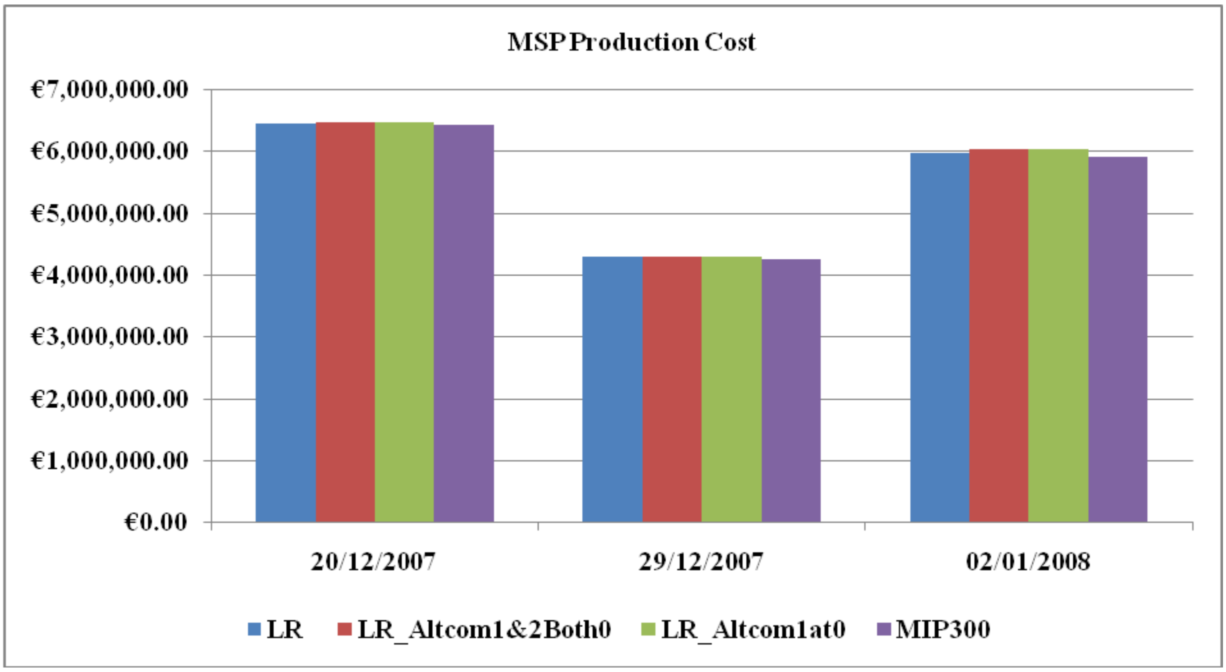

Figure 140 - Results with ALTCOM1 set to 0

In the second group of run types, identical results were also observed on all three Trading Days, although parameter settings vary significantly. For one run type both parameters were set to 90 while on the other ALTCOM1 was at 60 while ALTCOM2 (currently at a default value of 5) was set to zero. This is due to the fact that, although each schedule had unit committed on for short times, no alternative ALTCOM2 scenario proved cheaper, therefore changes have been driven by ALTCOM1 parameter only.

In all Trading days, a lower Production Cost than the original LR was achieved; however, by small margins**.** Differences vary from a minimum of 0.18% to a maximum of 0.38%, which in monetary terms are €11,029 and €16,442 respectively.

As with the previous batch, none of these runs produced lower MSP Production Costs than MIP for each relevant Trading day. The table and graph below show the summary for all Trading Days and run type.

Trading day	*LR*	*LR_Altcom1=90/ Altcom2=90 & LR_Altcom1=60/ Altcom2=0*	*MIP300*
20-Dec-07	€6,461,011.26	€6,446,688.59	€6,438,095.28
29-Dec-07	€4,294,023.00	€4,277,580.78	€4,259,123.87
02-Jan-08	€5,968,910.87	€5,957,881.87	€5,919,945.34

Table 36 - Results with ALTCOM1 set > 0

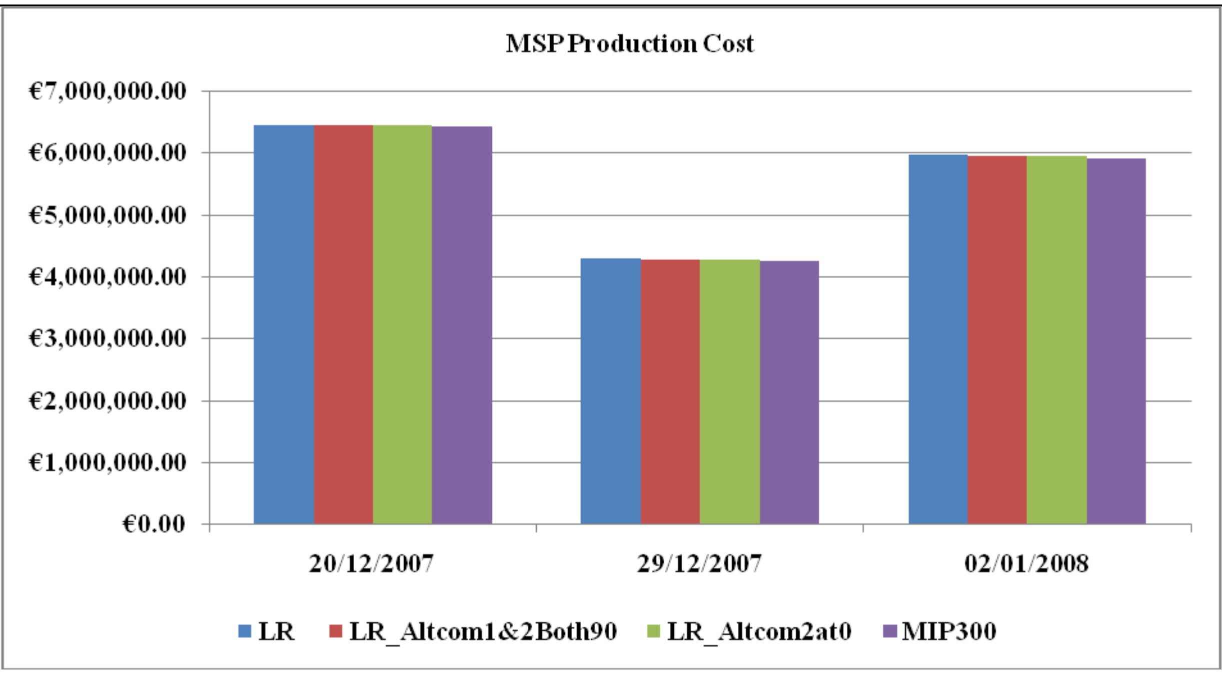

Figure 141 - Results with ALTCOM1 set > 0

The impact of changing ALTCOM parameters on the System Marginal Price has been to reduce prices in two out of the three Trading Days.

	LR	*LR Altcom1=0/Altcom2=0 & LR_Altcom1=0/Altcom2=5*	*LR_Altcom1=90/Altcom2=90 & LR_Altcom1=60/Altcom2=0*	*MIP300*
20-Dec-07				
AVG_SMP	€ 84.73	€ 71.59	€ 81.21	€ 78.47
MAX_SMP	€482.74	€ 314.58	€ 482.74	€ 144.16
MIN_SMP	€ 41.02	€ 41.11	€ 41.11	€ 38.56
29-Dec-07				
AVG_SMP	€ 67.63	€ 57.92	€ 58.75	€ 60.15
MAX_SMP	€435.63	€ 337.70	€ 435.63	€ 314.44
MIN_SMP	€ 32.58	€ 32.58	€ 32.58	€ 32.58
02-Jan-08				
AVG_SMP	€ 66.48	€ 66.86	€ 67.03	€ 75.23
MAX_SMP	€172.35	€ 109.99	€ 170.29	€ 498.27
MIN_SMP	€ 31.45	€ 49.42	€ 49.42	€ 49.42

Table 37 - Impact of ALTCOM changes on SMP

The distribution of SMP and MSQs is such that lower Consumer Costs have been achieved on two Trading Days with differences up to 17% of the original LR Consumer Costs. On the 2nd of January Consumer Costs fell by 0.30% on the runs that achieved a higher MSP Production Costs and increased by 0.63% in the runs with lower MSP Production Costs

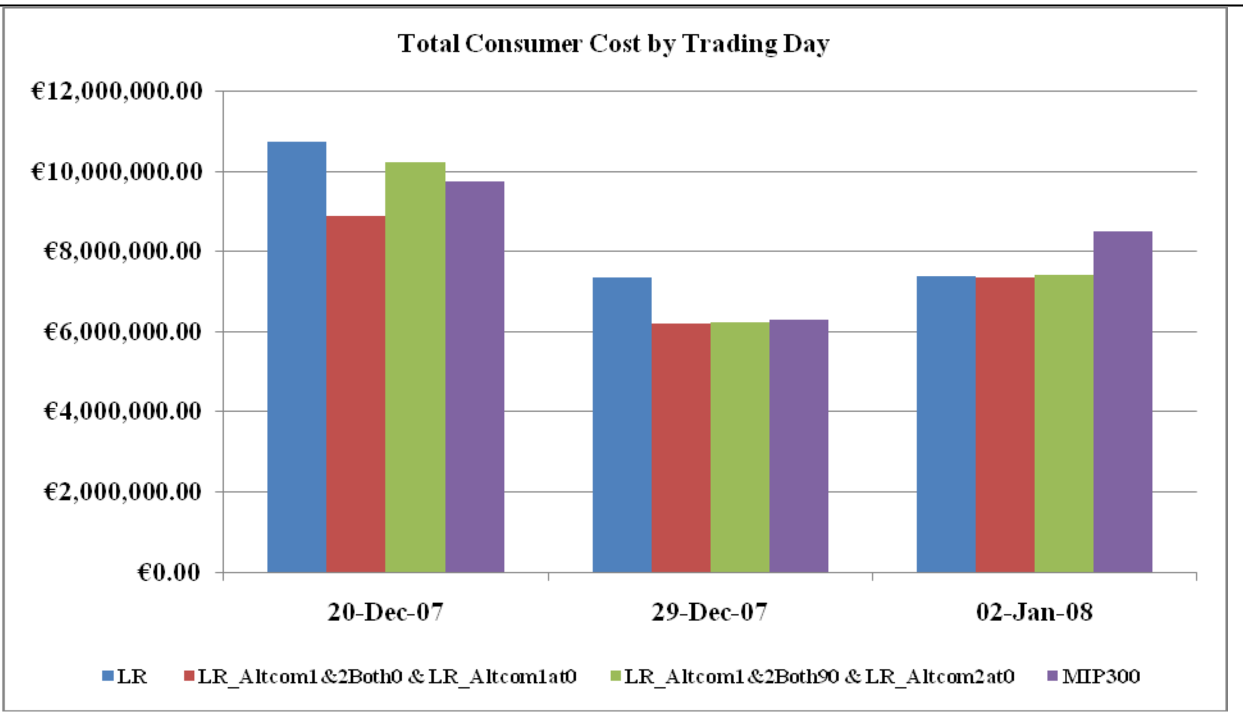

Figure 142 - Consumer Costs by Trading Day with ALTCOM changes

The outputs have also been analysed with regard to the scheduling of Hydro units. As these generators are expected to be utilised mainly for peak shaving and would be more often instructed on/off to allow reservoir re-fill, they could be impacted by the LR ALTCOM parameters should those be modified.

The results show that, although all three Trading Days show a marginally higher amount of Hydro scheduled than the regular LR, this is still lower than MIP.

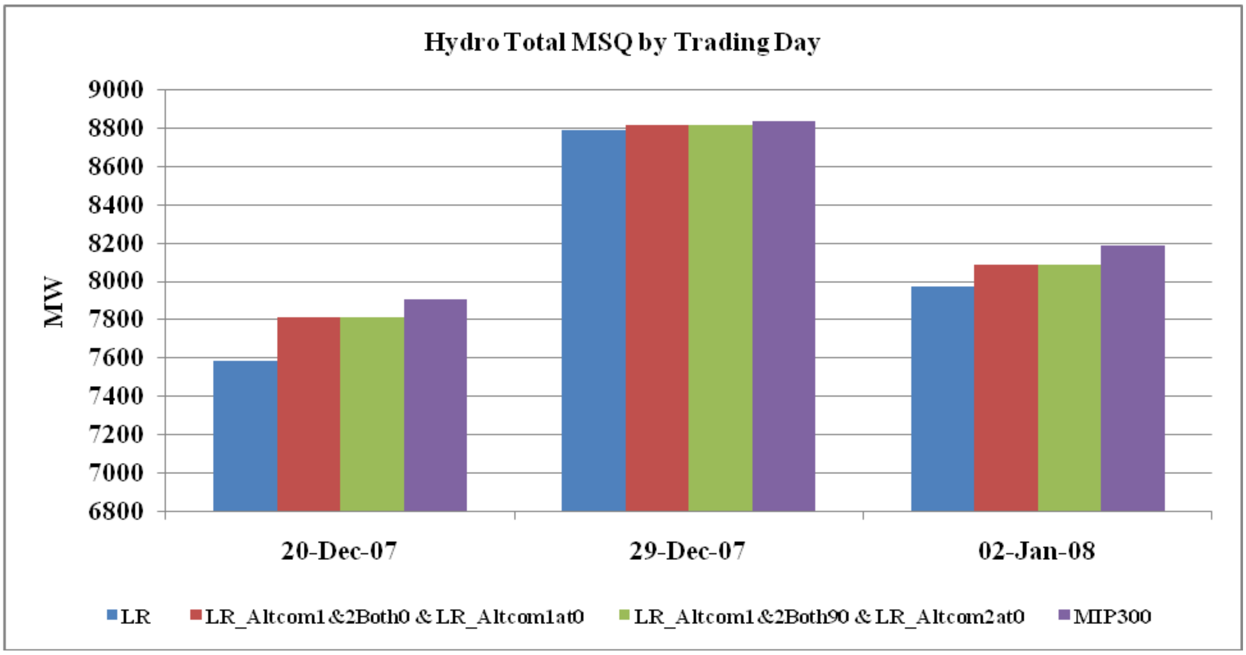

Figure 143 - Hydro MSQ across changed parameters

Differences are concentrated during the night valley, as shown by the following graph representing the average Market Schedule Quantities for Hydro generators by trading period for each run type over the five trading days studied. There is very little or no change in the LR runs regardless of the ALTCOM value, except for trading periods in the early hours of the morning (from midnight onward) where the total schedule is higher than the default LR and is closer to the MIP run.

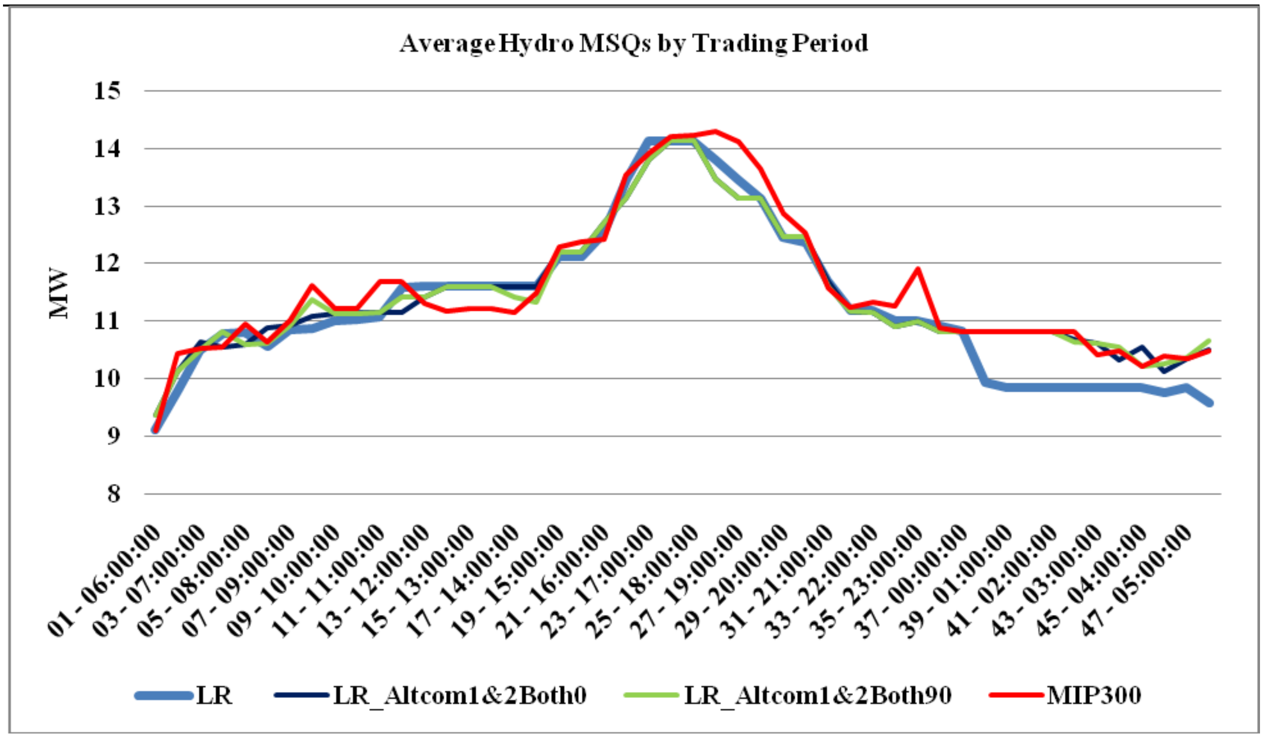

Figure 144 - Average Hydro schedule by Trading Period

The revenue for Hydro units do not always match the increase or decrease in MSQs as it is dependent on the value of SMP in the trading periods when they are scheduled. As shown below, revenue decreases substantially on two Trading Days (even though the total schedule quantities on those dates are higher). Only the 2nd of January show a marginal increase.

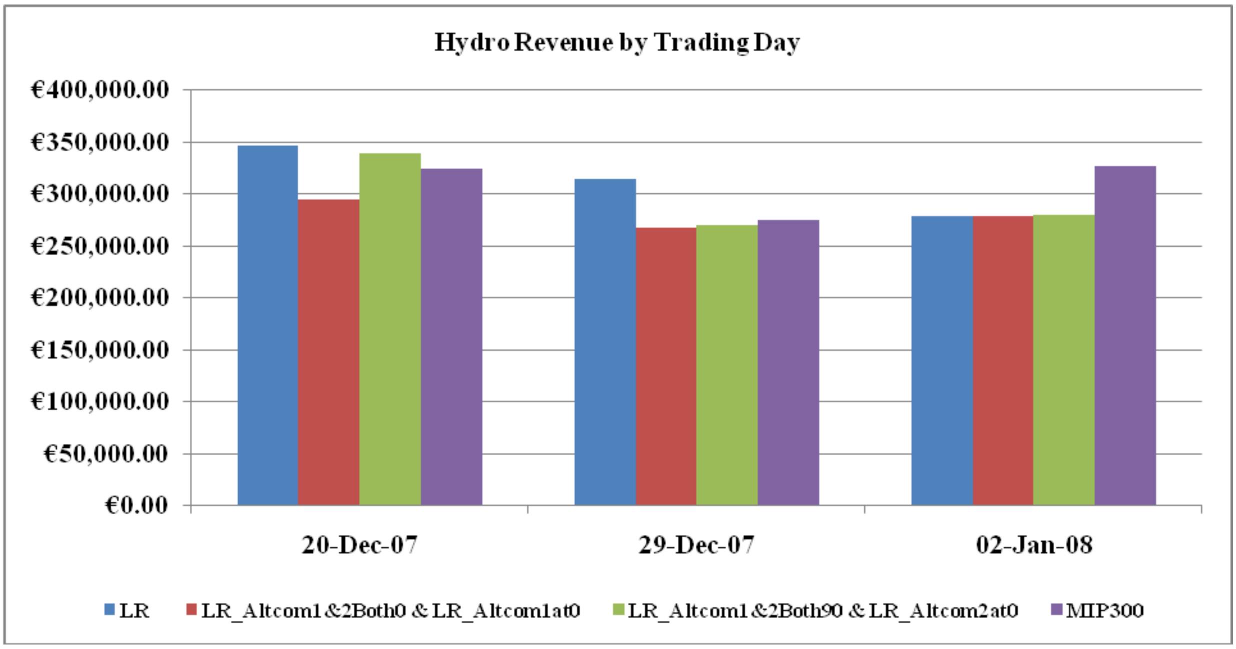

Figure 145 - Hydro revenue by Trading Day

These findings demonstrate that in the majority of cases the ALTCOM parameters, in their default setting, achieve the objective function of lessening MSP Production Costs while at the same time, maintain a lower level of Consumer Costs. However, differences are noted when modifying the parameters that would require more investigation. The limited number of Trading Days observed in this study does not offer any conclusive evidence and a more thorough analysis is necessary if the market so requires.

10.4.2 MIP Gap

In the version of Mixed Integer Program available to the SEM, the user has the ability to set the maximum time limit for each run and a convergence tolerance, which is known as the MIP Gap. If within the timelines assigned, the solver does not reach the set gap a solution is still produced with an indication of the deviation from the global optimal.

Currently the MIP Gap is set at 1%. For the purpose of these special study cases it has been changed as follow:

- on two Trading Days the gap has been increased to 2%,
- on the same two Trading Days the gap has also been increased to 5%,
- on two Trading Days the gap has been decrease to 0.5%, and
- on one Trading Days the gap has been decreased to 0.

2.1 Cases where the MIP Gap was increased

The increase in the gap was carried out on the 10th & 18th March 2008. These dates did not reach the default MIP Gap of 1% and the study aims to assess if there is a decrease in the quality of the outputs when this parameter is increased.

As expected, increasing the MIP Gap and maintaining the same run time of 300 seconds did not produce as good a solution as in the original run as demonstrated in the table below.

Trading Day	*MIP Solution Times*	*MIP GAP 1%*	*MIP GAP 2% Solution Times*	*MIP GAP 2%*	*MIP GAP 5% Solution Times*	*MIP GAP 5%*
10/03/2008	396 secs	1.23%	124 secs	1.24%	124 secs	1.24%
18/03/2008	413 secs	1.70%	382 secs	1.72%	150 secs	2.46%

Table 38 - Optimality Gaps and Solution Times

Although the time limit was the same, the larger MIP Gap allowed the MIP solver to end the run in a shorter time with a higher convergence value.

This is also evident in the increase in MSP Production Costs. On the 10th of March, there is only a €55 increase over the original run of the MIP solver with the default settings (both amended runs produced the same outputs) while on the 18th of March the increase is €1,497 in MSP Production Costs with the 2% target gap and €51,977 with 5% target gap. The highest increase still represents only 0.68% of the Production Cost from the run with the default value.

Trading Day	*MIP default Gap 1%*	*MIP Gap 2%*	*MIP Gap 5%*
10-Mar-08	€ 7,172,428.09	€ 7,172,483.03	€ 7,172,483.03
18-Mar-08	€ 7,659,901.33	€ 7,661,398.66	€ 7,711,878.24

Table 39 - MSP Production Costs for special run

This is mirrored in the SMP trend for the two days, which is seen to increase. This is illustrated by the graph below showing the average SMP over the two Trading Days by Trading Period. Although the larger increase is concentrated in the peak hours, it still leads to higher Consumer Costs.

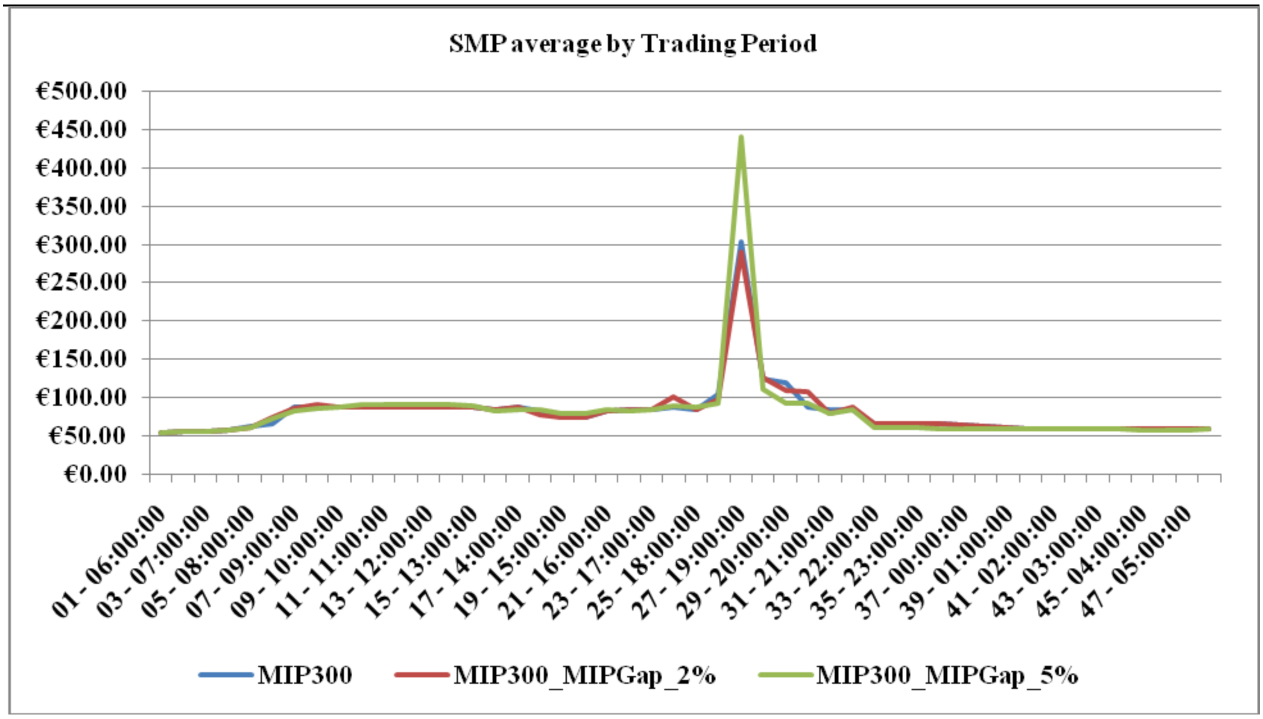

Figure 146 - Average SMP

2.2 Cases where the MIP Gap was decreased

The two dates run with a decrease in the MIP Gap to 0.5%, are the 13th and the 29th March 2009. The results show an improvement in the schedule as per table below; however, both required a longer processing time to achieve it.

Trade Date	*MIP Solution Time*	*MIP GAP 1%*	*MIP GAP 0.5% Solution Time*	*MIP GAP 0.5%*
13/03/2008	122 secs	0.62%	273 secs	0.38%
29/03/2008	154 secs	0.79%	398 secs	0.60%

Table 40 - Reduced Optimality Gap

Although the gap reached is noticeably lower, the variance in monetary terms is very small: 0.24% improvement on the 13th and 0.08% on the 29th. In monetary terms, this represents a lower Production Cost by just €18,334 and €4,481 respectively as shown in the table and graph below.

Trading Day	*MIP default Gap 1%*	*MIP Gap 0.5%*
13-Mar-08	€ 7,770,717.92	€7,752,383.38
29-Mar-08	€ 5,855,092.65	€5,850,611.00

Table 41 - Reduced MSP Production Costs

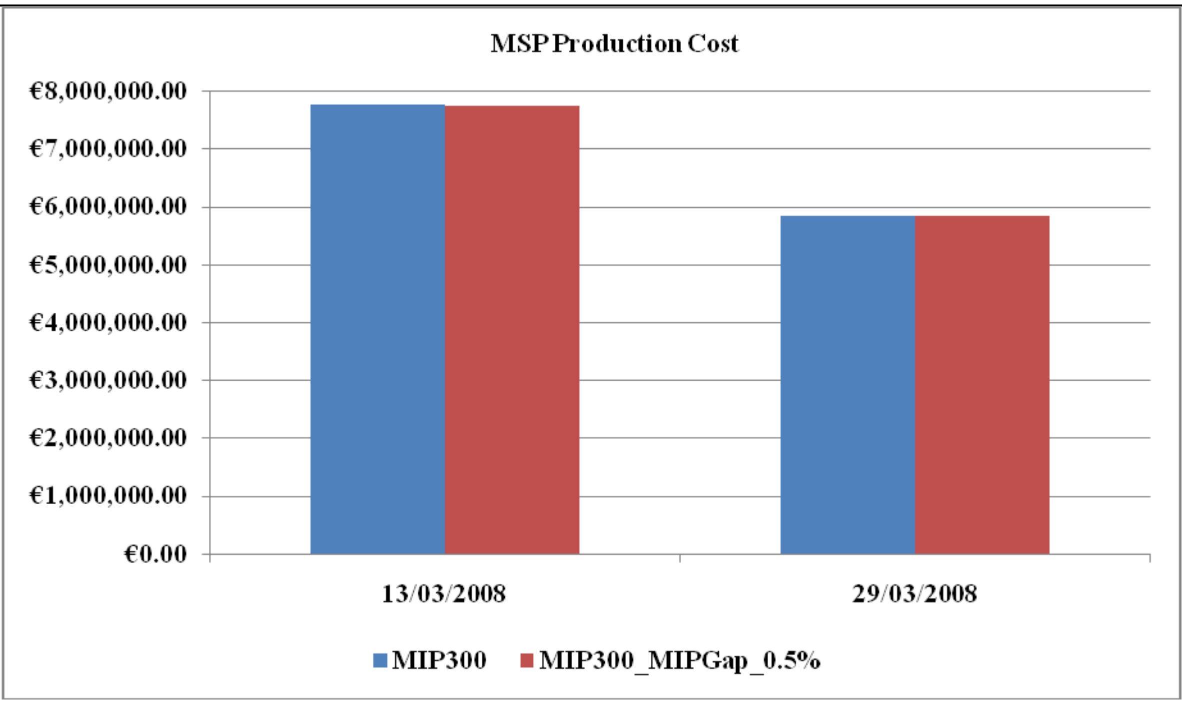

Figure 147 – MSP Production Costs

The System Marginal Price variance is also very small and overall the lower gap only achieves an average of €2 saving over the two trading days.

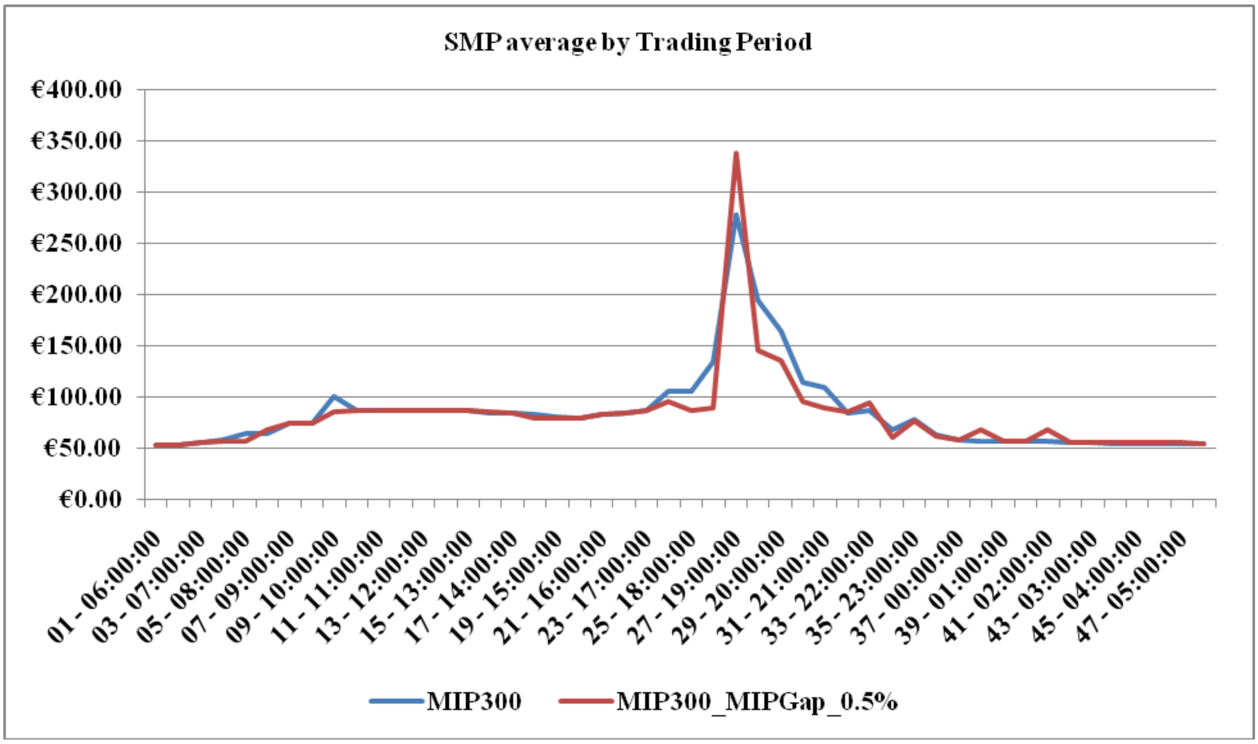

Figure 148 - Average SMP

As mentioned in section 'Energy Limited Generator Schedules', the 29th March 2008 MIP run has been affected by a software defect linked to the application of Energy Limits for the short day. Because only MIP runs are being compared in this section, we still consider the results relevant as both runs for the 29th March 2008 have been impacted in the same manner; however, this could be reviewed after the defect fix is implemented.

Finally, we have identified the day with the best Optimality Gap outcome in the study: the 20th February 2008, which reached a variance of just 0.04%. This has been re-run bringing the MIP Gap value down to 0% and increasing the run time to the maximum time of 1800 seconds allowed in this study, to maximise the chances to reach the full global optimal solution.

The results, as commented on in the 'MSP Production Costs' section, show very little improvement in the solution with MSP Production Costs lower by just €502 and a gap improvement of only 0.01%. The solver also was stopped by its time limit meaning that even this solution is still sub-optimal.

Study Type	*MSP Production Costs*	*MIP MSP Production Costs as a % of LR*	*Optimality Gap in MIP*	*Solution Time*
MIP300 1% Gap	€7,262,859.46	99.34%	0.04%	96 secs
MIP1800 0 Gap	€7,262,357.53	99.33%	0.03%	2081 secs

Table 42 - MSP Production Costs and Optimality Gap

10.5 Conclusion

It is not the purpose of this study to perform a review of the default parameter set in both MSP solvers. However, it is of interest to assess whether, by modifying those values, significant variations would be observed and that these could be further reviewed.

The ALTCOM parameters define the number of units that will be considered for alternative commitments in LR. The variations noted by modifying these parameters show that, when switching ALTCOM off by changing the parameters to zero, higher MSP Production Costs are achieved. This is expected as the ALTCOM function always improves the solution. Consumer Costs and prices fell substantially in two Trading Days while only marginally on the 2nd of January 2008.

An increase of the parameters to 90 resulted in small improvements in the MSP Production Costs; however, SMP and Consumer Costs were higher on one Trading Day.

Changes in the Trading Days studied have been driven by ALTCOM1 as ALTCOM2 which did not result in improved solutions in any of the sampled cases.

Although results may appear to be improving by modifying these parameters, the original LR with default values still achieved a combination of lower Production and Consumer Costs in the majority of cases.

The MIP solver has a number of distinct phases. First of these is to solve a relaxed version of the problem. This is completed to get the lower bound on the overall solution. The Optimality Gap is calculated as the percentage variance between the best current solution and the best lower bound from this phase. The MIP Gap is a configurable system parameter which sets the convergence tolerance for the solution’s Optimality Gap. An increase of the MIP Gap parameter allows the solver to end its search at a higher tolerance band, which can be achieved in a shorter time. In the two Trading Days observed this has resulted in higher MSP Production Costs. A decrease in the MIP Gap parameter pushes the solver to find better solution with cheaper MSP Production Costs; however, the longer run time required only yielded small benefits.

This analysis has confirmed that there is limited value in modifying both the ALTCOM parameters in LR and the MIP Gap in MIP. We have observed incidents with both where the MSP Production Costs have been improved; however, full consideration should be given to all the other aspects impacted by such changes, like SMP, Consumer Costs and Generator's revenue. This has not been done in adequate detail for this report to reach any solid conclusions, as only a small number of Trading Days have been considered.

We therefore recommend that the current settings continue to be used in SEM operations. Further analysis may be carried out in separate studies if it is considered that this is desirable.

11 Appendices

11.1 Appendix 1 - MSP Production Costs Summary Data

Trading Day	*LR MSP Production Costs*	*MIP Production Cost*	*MIP PC as a % of LR*	*Optimality Gap in MIP*
19-Dec-07	€ 6,991,642.29	€ 6,917,656.67	98.94%	0.67%
20-Dec-07	€ 6,461,011.26	€ 6,438,095.28	99.65%	1.60%
21-Dec-07	€ 5,265,462.77	€ 5,226,761.94	99.27%	0.37%
29-Dec-07	€ 4,294,023.00	€ 4,259,123.87	99.19%	0.67%
02-Jan-08	€ 5,968,910.87	€ 5,919,945.34	99.18%	0.68%
03-Jan-08	€ 7,550,550.00	€ 7,503,547.77	99.38%	1.27%
05-Jan-08	€ 5,880,263.20	€ 5,833,292.76	99.20%	0.39%
10-Jan-08	€ 8,482,316.76	€ 8,480,793.60	99.98%	0.65%
15-Jan-08	€ 8,296,331.62	€ 8,288,580.93	99.91%	0.55%
16-Jan-08	€ 7,977,023.57	€ 7,963,183.68	99.83%	0.52%
19-Jan-08	€ 6,486,905.28	€ 6,486,355.37	99.99%	0.71%
20-Jan-08	€ 6,757,324.61	€ 6,710,958.25	99.31%	1.25%
25-Jan-08	€ 6,082,529.67	€ 6,067,929.02	99.76%	0.37%
30-Jan-08	€ 7,199,808.26	€ 7,187,480.18	99.83%	0.26%
01-Feb-08	€ 7,706,785.82	€ 7,716,434.56	100.13%	0.64%
04-Feb-08	€ 7,732,607.10	€ 7,685,203.52	99.39%	1.38%
07-Feb-08	€ 6,414,549.08	€ 6,398,923.26	99.76%	1.27%
15-Feb-08	€ 7,391,740.16	€ 7,361,752.75	99.59%	0.38%
16-Feb-08	€ 6,909,734.13	€ 6,895,651.32	99.80%	0.27%
18-Feb-08	€ 8,307,436.85	€ 8,271,796.94	99.57%	0.14%
20-Feb-08	€ 7,311,464.50	€ 7,262,859.46	99.34%	0.04%
29-Feb-08	€ 6,579,718.09	€ 6,557,132.47	99.66%	0.16%
03-Mar-08	€ 7,807,168.38	€ 7,759,245.39	99.39%	0.68%
04-Mar-08	€ 8,017,073.52	€ 7,996,445.33	99.74%	1.19%
10-Mar-08	€ 7,225,844.06	€ 7,172,428.09	99.26%	1.23%
13-Mar-08	€ 7,767,033.51	€ 7,770,717.92	100.05%	0.62%
18-Mar-08	€ 7,723,503.18	€ 7,659,901.33	99.18%	1.70%
29-Mar-08	€ 5,882,034.31	€ 5,855,092.65	99.54%	0.79%
02-Apr-08	€ 7,347,856.45	€ 7,309,684.93	99.48%	1.09%
05-Apr-08	€ 6,143,567.27	€ 6,096,827.16	99.24%	0.64%
09-Apr-08	€ 8,673,006.76	€ 8,644,907.78	99.68%	0.54%
14-Apr-08	€ 8,433,771.68	€ 8,383,360.39	99.40%	1.01%
15-Apr-08	€ 7,751,010.21	€ 7,708,003.81	99.45%	0.92%
16-Apr-08	€ 6,780,360.66	€ 6,677,201.66	98.48%	0.52%
18-Apr-08	€ 6,491,417.09	€ 6,447,305.61	99.32%	0.68%
19-Apr-08	€ 6,135,721.03	€ 5,965,677.26	97.23%	0.27%
27-Apr-08	€ 7,002,578.06	€ 6,929,124.77	98.95%	0.39%
29-Apr-08	€ 7,497,745.86	€ 7,413,816.96	98.88%	0.14%
03-May-08	€ 5,225,713.04	€ 5,179,320.90	99.11%	0.52%
04-May-08	€ 5,544,374.28	€ 5,521,933.15	99.60%	0.47%
13-May-08	€ 7,167,812.97	€ 7,122,283.30	99.36%	0.70%
16-May-08	€ 7,121,494.59	€ 7,113,578.47	99.89%	0.63%

Trading Day	*LR MSP Production Costs*		*MIP Production Cost*		*MIP PC as a % of LR*	*Optimality Gap in MIP*
17-May-08	€	6,218,535.92	€	6,180,102.71	99.38%	0.19%
30-May-08	€	7,642,883.37	€	7,631,670.43	99.85%	0.20%
31-May-08	€	6,528,968.60	€	6,510,057.82	99.71%	0.55%
01-Jun-08	€	6,327,120.72	€	6,318,339.40	99.86%	0.26%
02-Jun-08	€	6,846,433.75	€	6,842,797.96	99.95%	1.22%
03-Jun-08	€	7,783,521.59	€	7,589,042.84	97.50%	1.81%
04-Jun-08	€	8,694,965.56	€	8,610,095.05	99.02%	2.53%
05-Jun-08	€	8,560,471.07	€	8,597,920.05	100.44%	0.97%
06-Jun-08	€	8,115,514.38	€	8,111,952.71	99.96%	0.66%
08-Jun-08	€	7,106,365.00	€	7,099,821.19	99.91%	1.71%
09-Jun-08	€	7,823,217.85	€	7,771,424.73	99.34%	0.77%
10-Jun-08	€	8,473,653.15	€	8,305,362.57	98.01%	0.97%
11-Jun-08	€	8,473,653.15	€	8,459,382.41	99.83%	0.66%
25-Jun-08	€	7,129,668.09	€	7,086,793.33	99.40%	0.80%
08-Jul-08	€	7,680,040.67	€	7,664,993.14	99.80%	0.32%
16-Jul-08	€	6,910,606.10	€	6,852,549.24	99.16%	0.31%
17-Jul-08	€	7,265,929.26	€	7,287,333.48	100.29%	0.61%
19-Jul-08	€	5,569,761.29	€	5,547,626.16	99.60%	0.35%
20-Jul-08	€	6,078,985.09	€	6,101,727.52	100.37%	1.87%
27-Jul-08	€	6,381,406.75	€	6,327,811.41	99.16%	0.49%
28-Jul-08	€	7,261,182.64	€	7,213,626.33	99.35%	0.37%
30-Jul-08	€	6,144,103.91	€	6,125,281.16	99.69%	0.30%
31-Jul-08	€	6,144,948.47	€	6,057,512.52	98.58%	0.63%
07-Aug-08	€	6,289,045.97	€	6,240,733.80	99.23%	0.44%
10-Aug-08	€	5,001,474.26	€	4,961,157.82	99.19%	0.36%
11-Aug-08	€	6,963,003.82	€	7,044,662.04	101.17%	4.60%
14-Aug-08	€	6,932,967.87	€	6,892,291.87	99.41%	0.26%
16-Aug-08	€	5,277,378.66	€	5,219,206.48	98.90%	0.34%
17-Aug-08	€	5,437,073.42	€	5,425,561.99	99.79%	0.98%
20-Aug-08	€	7,335,962.84	€	7,313,880.09	99.70%	0.60%
21-Aug-08	€	7,273,968.89	€	7,241,181.57	99.55%	0.36%
27-Aug-08	€	6,732,240.05	€	6,713,183.44	99.72%	2.86%
29-Aug-08	€	7,287,617.02	€	7,249,537.42	99.48%	2.03%
03-Sep-08	€	7,894,999.03	€	8,002,439.74	101.36%	3.67%
04-Sep-08	€	8,043,324.04	€	8,022,033.02	99.74%	1.74%
05-Sep-08	€	6,307,740.51	€	6,286,211.82	99.66%	0.27%
06-Sep-08	€	6,036,861.12	€	6,056,271.31	100.32%	0.27%
07-Sep-08	€	6,924,594.62	€	7,016,998.61	101.33%	0.99%
08-Sep-08	€	7,476,783.63	€	7,436,679.05	99.46%	0.62%
09-Sep-08	€	6,867,849.66	€	6,856,500.97	99.83%	0.23%
10-Sep-08	€	6,676,959.59	€	6,675,411.07	99.98%	0.34%
16-Sep-08	€	8,566,615.08	€	8,479,755.19	98.99%	1.90%
18-Sep-08	€	7,847,128.51	€	7,773,793.42	99.07%	0.56%
20-Sep-08	€	6,280,684.46	€	6,267,081.60	99.78%	0.39%
27-Sep-08	€	6,999,556.35	€	6,938,106.25	99.12%	0.31%
05-Oct-08	€	6,430,230.84	€	6,379,404.01	99.21%	0.90%
06-Oct-08	€	7,633,714.42	€	7,591,814.62	99.45%	0.85%
07-Oct-08	€	7,716,870.40	€	7,644,128.90	99.06%	0.28%
09-Oct-08	€	6,356,993.13	€	6,315,575.60	99.35%	0.85%
12-Oct-08	€	5,859,552.44	€	5,904,936.81	100.77%	1.66%
13-Oct-08	€	7,918,250.28	€	7,901,776.47	99.79%	1.62%
14-Oct-08	€	7,825,723.73	€	7,786,440.88	99.50%	1.15%
15-Oct-08	€	7,081,093.25	€	7,061,365.05	99.72%	0.63%
16-Oct-08	€	7,406,718.79	€	7,383,653.01	99.69%	0.95%
19-Oct-08	€	4,490,508.79	€	4,501,143.05	100.24%	1.17%
22-Oct-08	€	6,224,607.90	€	6,180,562.31	99.29%	1.41%
02-Nov-08	€	7,123,060.47	€	7,132,908.53	100.14%	1.26%

Trading Day	*LR MSP Production Costs*	*MIP Production Cost*	*MIP PC as a % of LR*	*Optimality Gap in MIP*
08-Nov-08	€ 5,391,190.61	€ 5,382,155.49	99.83%	0.51%
10-Nov-08	€ 6,043,599.16	€ 5,953,029.88	98.50%	0.66%
16-Nov-08	€ 5,043,873.48	€ 5,038,433.79	99.89%	0.35%
23-Nov-08	€ 5,169,035.72	€ 5,156,356.83	99.75%	1.91%
24-Nov-08	€ 6,529,391.20	€ 6,526,532.48	99.96%	2.12%
17-Dec-08	€ 6,020,876.19	€ 6,011,939.30	99.85%	0.49%
19-Dec-08	€ 5,376,465.29	€ 5,378,191.91	100.03%	0.48%
20-Dec-08	€ 4,540,922.03	€ 4,532,205.37	99.81%	0.59%
21-Dec-08	€ 4,906,836.02	€ 4,898,631.54	99.83%	1.96%
22-Dec-08	€ 5,938,174.72	€ 5,887,240.16	99.14%	1.93%
04-Jan-09	€ 5,859,363.49	€ 5,835,869.19	99.60%	0.42%
07-Jan-09	€ 7,561,787.94	€ 7,582,562.74	100.27%	1.10%
10-Jan-09	€ 4,780,378.67	€ 4,755,059.60	99.47%	1.10%
11-Jan-09	€ 5,378,226.46	€ 5,345,380.63	99.39%	1.96%
14-Jan-09	€ 5,676,522.43	€ 5,676,065.91	99.99%	0.96%
27-Jan-09	€ 6,666,612.76	€ 6,659,604.62	99.89%	0.59%
29-Jan-09	€ 5,438,492.71	€ 5,421,162.95	99.68%	0.48%
17-Feb-09	€ 5,542,205.26	€ 5,501,856.30	99.27%	0.93%
03-Mar-09	€ 4,375,284.52	€ 4,416,061.13	100.93%	1.57%
04-Mar-09	€ 4,784,022.60	€ 4,852,087.49	101.42%	1.22%
05-Mar-09	€ 4,576,234.99	€ 4,561,320.74	99.67%	0.72%
06-Mar-09	€ 4,034,227.35	€ 4,011,001.45	99.42%	0.50%
07-Mar-09	€ 3,183,558.82	€ 3,170,114.01	99.58%	0.64%
08-Mar-09	€ 3,328,483.32	€ 3,419,479.10	102.73%	1.33%
09-Mar-09	€ 4,119,977.67	€ 4,177,497.10	101.40%	0.92%
10-Mar-09	€ 4,205,118.02	€ 4,291,796.97	102.06%	0.68%
11-Mar-09	€ 3,663,833.18	€ 3,672,738.38	100.24%	0.55%
12-Mar-09	€ 3,967,789.50	€ 4,023,087.07	101.39%	0.97%
13-Mar-09	€ 3,175,987.70	€ 3,162,558.94	99.58%	0.46%
26-Mar-09	€ 3,616,719.17	€ 3,682,798.12	101.83%	2.99%
03-Apr-09	€ 3,780,809.43	€ 3,764,843.27	99.58%	0.16%
17-Apr-09	€ 3,572,958.95	€ 3,593,827.36	100.58%	3.71%
23-Apr-09	€ 3,572,709.18	€ 3,546,557.35	99.27%	0.32%
24-Apr-09	€ 3,325,541.34	€ 3,289,353.58	98.91%	0.32%
25-Apr-09	€ 2,805,150.21	€ 2,792,308.09	99.54%	0.32%
27-Apr-09	€ 3,636,896.33	€ 3,625,921.08	99.70%	1.85%
28-Apr-09	€ 3,798,288.68	€ 3,773,401.57	99.34%	0.35%
29-Apr-09	€ 3,855,590.66	€ 3,895,486.49	101.03%	2.54%
05-May-09	€ 3,169,615.00	€ 3,175,059.61	100.17%	3.12%
06-May-09	€ 3,119,366.57	€ 3,101,651.07	99.43%	0.79%
07-May-09	€ 3,063,258.83	€ 3,035,745.63	99.10%	0.67%
02-Jun-09	€ 4,003,059.03	€ 3,986,964.05	99.60%	2.46%
03-Jun-09	€ 3,875,357.75	€ 3,833,348.30	98.92%	0.61%
04-Jun-09	€ 3,755,521.58	€ 3,718,537.16	99.02%	0.56%
09-Jun-09	€ 3,882,023.53	€ 3,860,654.48	99.45%	1.21%
10-Jun-09	€ 3,800,000.17	€ 3,793,242.05	99.82%	0.85%
15-Jun-09	€ 3,746,655.07	€ 3,703,126.26	98.84%	0.82%
22-Jun-09	€ 3,777,562.92	€ 3,737,566.35	98.94%	3.06%
08-Jul-09	€ 3,274,964.40	€ 3,255,982.50	99.42%	0.12%
09-Jul-09	€ 3,371,673.38	€ 3,348,282.34	99.31%	0.27%
10-Jul-09	€ 3,094,446.63	€ 3,069,445.12	99.19%	0.16%
19-Jul-09	€ 2,553,980.87	€ 2,532,159.75	99.15%	0.96%
26-Jul-09	€ 2,239,168.21	€ 2,193,564.31	97.96%	1.05%
29-Jul-09	€ 3,123,956.59	€ 3,103,416.37	99.34%	0.88%
25-Aug-09	€ 2,527,710.37	€ 2,582,212.57	102.16%	4.90%

Table 43 – MSP Production Costs LR and MIP, Optimality Gap MIP only, and MIP MSP Production Costs as a percentage of LR

11.2 Appendix 2 - Sample System Summary File

Trading Period	*System Load (MW)*	*Non-Wind Gen (MW)*	*Wind Gen (MW)*	*Demand-Side Unit (MW)*	*Interconnector Flow (MW)*	*Total Gen Cost (€)*	*SMP (€/MWh)*	*Lambda (€/MWh)*
12/03/2008 06:00:00 GMT	3661.65	3187.27	474.38	0	84.85	88750	54.73	54.73
12/03/2008 06:30:00 GMT	3950.99	3470.22	480.77	0	84.85	94753	55.76	55.76
12/03/2008 07:00:00 GMT	4283.63	3796.64	486.99	0	406.88	99165	54.73	54.73
12/03/2008 07:30:00 GMT	4661.78	4170.38	491.4	0	406.88	107701	57.15	57.15
12/03/2008 08:00:00 GMT	4882.83	4387.54	495.29	0	406.88	112842	58.46	58.46
12/03/2008 08:30:00 GMT	5032.8	4538.13	494.67	0	406.88	116303	60.81	60.81
12/03/2008 09:00:00 GMT	5119.56	4625.52	494.04	0	406.88	135217	58.46	58.46
12/03/2008 09:30:00 GMT	5235.97	4741.4	494.57	0	406.88	122863	58.46	58.46
12/03/2008 10:00:00 GMT	5252.16	4757.07	495.09	0	406.88	123502	58.46	58.46
12/03/2008 10:30:00 GMT	5232.67	4742.18	490.49	0	406.88	123024	58.46	58.46
12/03/2008 11:00:00 GMT	5246.14	4760.26	485.88	0	406.88	123067	58.46	58.46
12/03/2008 11:30:00 GMT	5260.82	4776.41	484.41	0	406.88	123445	58.46	58.46
12/03/2008 12:00:00 GMT	5289.55	4806.94	482.61	0	406.88	123947	60.81	60.81
12/03/2008 12:30:00 GMT	5317.8	4837.07	480.73	0	406.88	124404	83.52	83.52
12/03/2008 13:00:00 GMT	5284.37	4822.19	462.18	0	406.88	124380	83.52	83.52
12/03/2008 13:30:00 GMT	5144.66	4683.44	461.22	0	406.88	120827	58.46	58.46
12/03/2008 14:00:00 GMT	5137.76	4697.5	440.26	0	406.88	120867	58.46	58.46
12/03/2008 14:30:00 GMT	5139.47	4700.76	438.71	0	406.88	121354	58.46	58.46
12/03/2008 15:00:00 GMT	5180.47	4716.65	463.82	0	406.88	122380	58.46	58.46
12/03/2008 15:30:00 GMT	5220.7	4742.81	477.89	0	406.88	123661	58.46	58.46
12/03/2008 16:00:00 GMT	5308.81	4807.22	501.59	0	406.88	124076	60.81	60.81
12/03/2008 16:30:00 GMT	5410.01	4917.03	492.98	0	406.88	129953	60.81	60.81
12/03/2008 17:00:00 GMT	5408.18	4923.82	484.36	0	406.88	128390	60.81	60.81
12/03/2008 17:30:00 GMT	5473.89	5004.53	469.36	0	406.88	129120	83.52	83.52
12/03/2008 18:00:00 GMT	5554.87	5100.82	454.05	0	406.88	176757	75.19	75.19
12/03/2008 18:30:00 GMT	5787.3	5345.32	441.98	0	406.88	140541	83.52	83.52
12/03/2008 19:00:00 GMT	5953.9	5525.8	428.1	0	228.61	165313	111.27	111.27
12/03/2008 19:30:00 GMT	5985.2	5571.86	413.34	0	228.61	158685	386.78	192.33
12/03/2008 20:00:00 GMT	5840.94	5443.27	397.67	0	228.61	152453	83.52	83.52
12/03/2008 20:30:00 GMT	5606.2	5226.38	379.82	0	228.61	144480	83.52	83.52
12/03/2008 21:00:00 GMT	5476.1	5112.81	363.29	0	228.61	142529	75.45	75.45
12/03/2008 21:30:00 GMT	5294.8	4950.9	343.9	0	228.61	136337	74.7	74.7
12/03/2008 22:00:00 GMT	5072.02	4747.68	324.34	0	228.61	128502	68	68
12/03/2008 22:30:00 GMT	4766.19	4457.98	308.21	0	228.61	120927	58.46	58.46
12/03/2008 23:00:00 GMT	4622.77	4330.52	292.25	0	84.85	119419	58.46	58.46
12/03/2008 23:30:00 GMT	4477.04	4196.88	280.16	0	84.85	115000	58.46	58.46
13/03/2008 00:00:00 GMT	4274.78	4006.63	268.15	0	84.85	112680	58.46	58.46
13/03/2008 00:30:00 GMT	4079.03	3812.34	266.69	0	84.85	104896	57.15	57.15
13/03/2008 01:00:00 GMT	3970.95	3705.43	265.52	0	84.85	102060	57.05	57.05
13/03/2008 01:30:00 GMT	3831	3565.62	265.38	0	84.85	98427	56.32	56.32
13/03/2008 02:00:00 GMT	3770.39	3505.04	265.35	0	84.85	96727	55.13	55.13
13/03/2008 02:30:00 GMT	3679.77	3413.32	266.45	0	84.85	98169	56.95	56.95
13/03/2008 03:00:00 GMT	3638.68	3371.09	267.59	0	84.85	93433	54.73	54.73
13/03/2008 03:30:00 GMT	3624.27	3370.73	253.54	0	84.85	93423	54.73	54.73
13/03/2008 04:00:00 GMT	3599.16	3359.73	239.43	0	84.85	93103	54.73	54.73
13/03/2008 04:30:00 GMT	3558.94	3329.62	229.32	0	84.85	95870	55.76	55.76
13/03/2008 05:00:00 GMT	3544.48	3325.5	218.98	0	84.85	92167	54.73	54.73
13/03/2008 05:30:00 GMT	3588.73	3377.23	211.5	0	84.85	93473	54.73	54.73
13/03/2008 06:00:00 GMT	3720.02	3387.65	332.37	0	84.85	94076	54.73	54.73
13/03/2008 06:30:00 GMT	3986.25	3662.5	323.75	0	84.85	100013	57.05	57.05
13/03/2008 07:00:00 GMT	4330.73	4032.12	298.61	0	406.88	105274	57.05	57.05
13/03/2008 07:30:00 GMT	4727.15	4433.61	293.54	0	406.88	112100	58.46	58.46

Trading Period	System Load (MW)	Non-Wind Gen (MW)	Wind Gen (MW)	Demand-Side Unit (MW)	Interconnector Flow (MW)	Total Gen Cost (€)	SMP (€/MWh)	Lambda (€/MWh)
13/03/2008 08:00:00 GMT	4979.37	4691.92	287.45	0	406.88	119314	60.81	60.81
13/03/2008 08:30:00 GMT	5141.95	4847.25	294.7	0	406.88	123273	81.89	81.89
13/03/2008 09:00:00 GMT	5232.19	4939.09	293.1	0	406.88	129096	74.7	74.7
13/03/2008 09:30:00 GMT	5369.31	5075.24	294.07	0	406.88	131039	111.27	111.27
13/03/2008 10:00:00 GMT	5376.07	5081.37	294.7	0	406.88	131149	111.27	111.27
13/03/2008 10:30:00 GMT	5360.38	5061.28	299.1	0	406.88	130834	75.45	75.45
13/03/2008 11:00:00 GMT	5352.54	5045.78	306.76	0	406.88	129997	75.45	75.45
13/03/2008 11:30:00 GMT	5380.15	5065.16	314.99	0	406.88	130734	75.45	75.45

Table 44 - Sample System Summary data

11.3 Appendix 3 - Consumer Costs per Trading Day

Trading Day	LR Consumer Costs	MIP300 Consumer Costs	Cheaper Solution in Consumer Costs
19-Dec-07	€11,268,174.97	€11,202,244.37	MIP
20-Dec-07	€10,737,350.76	€9,741,268.01	MIP
21-Dec-07	€7,807,493.59	€7,157,108.10	MIP
29-Dec-07	€7,346,985.71	€6,306,277.89	MIP
02-Jan-08	€7,382,418.66	€8,503,343.66	LR
03-Jan-08	€11,258,428.80	€11,287,696.42	LR
05-Jan-08	€7,355,369.23	€7,032,608.06	MIP
10-Jan-08	€10,577,018.95	€11,429,121.40	LR
15-Jan-08	€11,048,980.72	€12,340,728.77	LR
16-Jan-08	€9,740,990.28	€10,584,816.74	LR
19-Jan-08	€8,184,122.98	€8,532,460.51	LR
20-Jan-08	€8,727,841.25	€10,084,296.31	LR
25-Jan-08	€9,568,908.02	€8,513,136.58	MIP
30-Jan-08	€8,907,150.40	€8,643,454.20	MIP
01-Feb-08	€10,530,441.56	€11,151,182.27	LR
04-Feb-08	€11,418,765.66	€12,077,561.23	LR
07-Feb-08	€8,919,897.74	€8,165,421.68	MIP
15-Feb-08	€8,374,491.61	€9,873,783.42	LR
16-Feb-08	€7,722,805.68	€7,980,544.79	LR
18-Feb-08	€9,923,929.25	€9,812,292.33	MIP
20-Feb-08	€9,860,146.77	€10,083,851.21	LR
29-Feb-08	€8,481,951.95	€8,198,039.28	MIP
03-Mar-08	€9,666,413.34	€10,051,489.22	LR
04-Mar-08	€11,099,133.60	€11,508,119.85	LR
10-Mar-08	€9,469,907.42	€9,383,603.49	MIP
13-Mar-08	€10,774,515.69	€11,595,089.98	LR
18-Mar-08	€9,443,939.60	€9,448,393.26	LR
29-Mar-08	€7,507,544.76	€7,364,099.40	MIP
02-Apr-08	€8,919,735.77	€9,233,550.74	LR
05-Apr-08	€8,033,604.56	€7,921,697.66	MIP
09-Apr-08	€10,200,698.59	€11,144,030.79	LR
14-Apr-08	€11,627,838.95	€11,649,024.68	LR
15-Apr-08	€10,266,986.16	€9,125,323.78	MIP
16-Apr-08	€7,493,173.42	€7,345,283.07	MIP
18-Apr-08	€7,659,660.10	€7,743,621.29	LR
19-Apr-08	€7,355,068.21	€7,317,393.18	MIP
27-Apr-08	€6,451,660.74	€6,453,004.88	LR
29-Apr-08	€8,625,168.30	€8,078,195.30	MIP
03-May-08	€6,038,458.84	€5,859,269.57	MIP
04-May-08	€6,230,348.14	€6,145,434.70	MIP
13-May-08	€7,737,340.49	€8,210,509.38	LR
16-May-08	€8,553,622.59	€8,876,568.71	LR
17-May-08	€7,627,465.91	€6,544,581.14	MIP

Trading Day	*LR Consumer Costs*	*MIP300 Consumer Costs*	*Cheaper Solution in Consumer Costs*
30-May-08	€9,630,396.61	€9,796,046.06	LR
31-May-08	€7,725,177.76	€8,055,497.60	LR
01-Jun-08	€6,563,660.97	€6,649,605.17	LR
02-Jun-08	€7,758,235.42	€8,818,587.13	LR
03-Jun-08	€9,810,705.15	€9,197,576.77	MIP
04-Jun-08	€13,068,171.95	€12,354,393.48	MIP
05-Jun-08	€10,862,862.22	€10,708,766.93	MIP
06-Jun-08	€11,154,342.93	€11,111,821.40	MIP
08-Jun-08	€8,565,677.95	€8,812,962.76	LR
09-Jun-08	€11,299,035.33	€10,569,499.04	MIP
10-Jun-08	€11,016,865.33	€10,972,189.19	MIP
11-Jun-08	€11,476,725.66	€12,796,181.55	LR
25-Jun-08	€9,173,904.18	€12,089,930.90	LR
08-Jul-08	€8,475,738.15	€8,512,802.33	LR
16-Jul-08	€8,567,879.00	€9,093,762.49	LR
17-Jul-08	€8,216,976.14	€8,677,307.67	LR
19-Jul-08	€6,191,638.77	€5,943,271.51	MIP
20-Jul-08	€5,535,483.36	€7,611,117.45	LR
27-Jul-08	€6,187,811.96	€5,686,224.44	MIP
28-Jul-08	€8,467,580.49	€8,996,233.22	LR
30-Jul-08	€7,460,182.79	€7,453,142.55	MIP
31-Jul-08	€8,143,059.24	€8,751,831.00	LR
07-Aug-08	€7,431,061.38	€9,035,695.41	LR
10-Aug-08	€5,119,903.75	€5,132,735.69	LR
11-Aug-08	€8,606,438.60	€9,476,165.10	LR
14-Aug-08	€8,524,718.44	€8,412,598.20	MIP
16-Aug-08	€6,027,182.43	€6,001,785.47	MIP
17-Aug-08	€6,172,914.93	€6,297,545.83	LR
20-Aug-08	€8,507,488.68	€9,086,281.03	LR
21-Aug-08	€10,465,861.88	€10,687,902.84	LR
27-Aug-08	€9,942,730.08	€10,365,528.37	LR
29-Aug-08	€10,539,545.25	€10,540,926.53	LR
03-Sep-08	€10,444,667.69	€10,338,986.39	MIP
04-Sep-08	€10,300,109.03	€10,203,205.96	MIP
05-Sep-08	€7,992,944.71	€7,984,068.96	MIP
06-Sep-08	€7,687,583.95	€7,397,281.70	MIP
07-Sep-08	€7,441,375.60	€7,508,227.42	LR
08-Sep-08	€10,050,058.66	€10,447,420.45	LR
09-Sep-08	€7,585,643.63	€8,157,877.61	LR
10-Sep-08	€7,544,396.38	€8,421,628.21	LR
16-Sep-08	€12,737,669.14	€12,958,126.42	LR
18-Sep-08	€11,062,790.83	€10,840,344.12	MIP
20-Sep-08	€7,361,813.20	€7,107,927.98	MIP
27-Sep-08	€8,918,450.55	€9,194,097.42	LR
05-Oct-08	€7,028,769.18	€7,746,562.16	LR
06-Oct-08	€10,465,893.66	€10,196,877.22	MIP
07-Oct-08	€10,832,971.20	€9,839,975.82	MIP
09-Oct-08	€7,537,845.88	€7,204,003.88	MIP
12-Oct-08	€5,741,358.22	€7,416,979.33	LR
13-Oct-08	€10,708,353.95	€10,487,015.80	MIP
14-Oct-08	€12,503,454.37	€12,496,083.77	MIP
15-Oct-08	€11,745,509.81	€9,815,623.85	MIP
16-Oct-08	€9,805,842.98	€9,800,022.68	MIP
19-Oct-08	€5,596,799.19	€6,010,293.59	LR
22-Oct-08	€9,117,416.17	€8,736,406.04	MIP
02-Nov-08	€8,569,932.96	€8,873,056.89	LR

.

Trading Day	*LR Consumer Costs*	*MIP300 Consumer Costs*	*Cheaper Solution in Consumer Costs*
08-Nov-08	€6,655,661.69	€7,213,272.18	LR
10-Nov-08	€9,058,447.09	€9,377,260.57	LR
16-Nov-08	€5,857,703.22	€5,996,742.69	LR
23-Nov-08	€7,058,114.12	€6,190,023.43	MIP
24-Nov-08	€8,224,097.89	€8,873,243.40	LR
17-Dec-08	€7,824,914.96	€8,534,843.11	LR
19-Dec-08	€6,328,357.38	€6,326,906.46	MIP
20-Dec-08	€5,429,489.60	€5,422,860.06	MIP
21-Dec-08	€5,648,249.41	€6,063,202.22	LR
22-Dec-08	€6,996,617.12	€7,228,758.87	LR
04-Jan-09	€5,779,103.44	€5,770,019.00	MIP
07-Jan-09	€9,084,059.84	€10,255,524.35	LR
10-Jan-09	€6,636,476.84	€7,033,126.69	LR
11-Jan-09	€6,854,034.81	€6,315,984.05	MIP
14-Jan-09	€6,853,581.82	€7,634,819.63	LR
27-Jan-09	€8,490,297.80	€8,773,731.72	LR
29-Jan-09	€7,032,637.28	€7,091,101.65	LR
17-Feb-09	€6,170,030.61	€6,423,069.33	LR
03-Mar-09	€4,526,247.36	€5,666,101.81	LR
04-Mar-09	€5,588,254.06	€6,038,590.06	LR
05-Mar-09	€4,830,646.83	€5,051,914.13	LR
06-Mar-09	€4,126,498.77	€4,573,994.14	LR
07-Mar-09	€3,420,312.53	€3,452,974.70	LR
08-Mar-09	€3,455,920.40	€4,379,573.40	LR
09-Mar-09	€4,286,454.00	€4,749,587.58	LR
10-Mar-09	€4,425,213.53	€4,738,399.35	LR
11-Mar-09	€3,731,885.66	€3,689,380.09	MIP
12-Mar-09	€4,258,973.63	€4,645,930.68	LR
13-Mar-09	€3,369,861.25	€3,386,687.69	LR
26-Mar-09	€4,106,739.49	€4,841,207.25	LR
03-Apr-09	€3,724,738.45	€3,725,217.33	LR
17-Apr-09	€5,155,945.67	€5,002,894.21	MIP
23-Apr-09	€3,737,889.03	€3,721,289.20	MIP
24-Apr-09	€3,590,831.19	€3,569,052.12	MIP
25-Apr-09	€2,794,203.74	€2,792,813.18	MIP
27-Apr-09	€4,507,320.38	€3,986,716.65	MIP
28-Apr-09	€3,922,744.20	€3,847,570.70	MIP
29-Apr-09	€4,449,659.11	€5,011,520.07	LR
05-May-09	€3,706,089.71	€5,953,574.06	LR
06-May-09	€3,223,440.69	€3,222,823.25	MIP
07-May-09	€3,119,192.48	€3,139,609.69	LR
02-Jun-09	€5,173,784.22	€5,181,803.91	LR
03-Jun-09	€4,095,113.26	€4,333,358.89	LR
04-Jun-09	€4,021,915.02	€3,751,160.00	MIP
09-Jun-09	€4,538,416.83	€5,269,968.14	LR
10-Jun-09	€4,047,997.52	€4,042,493.81	MIP
15-Jun-09	€4,551,422.75	€4,661,107.17	LR
22-Jun-09	€4,947,430.61	€4,927,953.93	MIP
08-Jul-09	€3,869,254.44	€3,483,340.14	MIP
09-Jul-09	€4,116,671.55	€3,736,822.69	MIP
10-Jul-09	€4,144,237.11	€3,572,877.73	MIP
19-Jul-09	€2,573,520.53	€2,604,900.33	LR
26-Jul-09	€2,107,843.90	€2,140,721.84	LR
29-Jul-09	€4,330,556.42	€3,863,919.28	MIP
25-Aug-09	€5,017,169.70	€4,949,437.06	MIP

Table 45 - Consumer Costs per Trading Day

Run Date	*Production Cost Variance %*	*Optimality Gap*	*Consumer Cost Variance %*
19-Dec-07	1.058%	0.670%	-0.585%
20-Dec-07	0.355%	1.600%	-9.277%
21-Dec-07	0.735%	0.370%	-8.330%
29-Dec-07	0.813%	0.670%	-14.165%
02-Jan-08	0.820%	0.680%	15.184%
03-Jan-08	0.623%	1.270%	0.260%
05-Jan-08	0.799%	0.390%	-4.388%
10-Jan-08	0.018%	0.650%	8.056%
15-Jan-08	0.093%	0.550%	11.691%
16-Jan-08	0.173%	0.520%	8.663%
19-Jan-08	0.008%	0.710%	4.256%
20-Jan-08	0.686%	1.250%	15.542%
25-Jan-08	0.240%	0.370%	-11.033%
30-Jan-08	0.171%	0.260%	-2.961%
01-Feb-08	-0.125%	0.640%	5.895%
04-Feb-08	0.613%	1.380%	5.769%
07-Feb-08	0.244%	1.270%	-8.458%
15-Feb-08	0.406%	0.380%	17.903%
16-Feb-08	0.204%	0.270%	3.337%
18-Feb-08	0.429%	0.140%	-1.125%
20-Feb-08	0.665%	0.040%	2.269%
29-Feb-08	0.343%	0.160%	-3.347%
03-Mar-08	0.614%	0.680%	3.984%
04-Mar-08	0.257%	1.190%	3.685%
10-Mar-08	0.739%	1.230%	-0.911%
13-Mar-08	-0.047%	0.620%	7.616%
18-Mar-08	0.823%	1.700%	0.047%
29-Mar-08	0.458%	0.790%	-1.911%
02-Apr-08	0.519%	1.090%	3.518%
05-Apr-08	0.761%	0.640%	-1.393%
09-Apr-08	0.324%	0.540%	9.248%
14-Apr-08	0.598%	1.010%	0.182%
15-Apr-08	0.555%	0.920%	-11.120%
16-Apr-08	1.521%	0.520%	-1.974%
18-Apr-08	0.680%	0.680%	1.096%
19-Apr-08	2.771%	0.270%	-0.512%
27-Apr-08	1.049%	0.390%	0.021%
29-Apr-08	1.119%	0.140%	-6.342%
03-May-08	0.888%	0.520%	-2.967%
04-May-08	0.405%	0.470%	-1.363%
13-May-08	0.635%	0.700%	6.115%
16-May-08	0.111%	0.630%	3.776%
17-May-08	0.618%	0.190%	-14.197%
30-May-08	0.147%	0.200%	1.720%
31-May-08	0.290%	0.550%	4.276%
01-Jun-08	0.139%	0.260%	1.309%
02-Jun-08	0.053%	1.220%	13.667%
03-Jun-08	2.499%	1.810%	-6.250%
04-Jun-08	0.976%	2.530%	-5.462%
05-Jun-08	-0.437%	0.970%	-1.419%
06-Jun-08	0.044%	0.660%	-0.381%
08-Jun-08	0.092%	1.710%	2.887%
09-Jun-08	0.662%	0.770%	-6.457%
10-Jun-08	1.986%	0.970%	-0.406%
11-Jun-08	0.168%	0.660%	11.497%
25-Jun-08	0.601%	0.800%	31.786%

Run Date	*Production Cost Variance %*	*Optimality Gap*	*Consumer Cost Variance %*
08-Jul-08	0.196%	0.320%	0.437%
16-Jul-08	0.840%	0.310%	6.138%
17-Jul-08	-0.295%	0.610%	5.602%
19-Jul-08	0.397%	0.350%	-4.011%
20-Jul-08	-0.374%	1.870%	37.497%
27-Jul-08	0.840%	0.490%	-8.106%
28-Jul-08	0.655%	0.370%	6.243%
30-Jul-08	0.306%	0.300%	-0.094%
31-Jul-08	1.423%	0.630%	7.476%
07-Aug-08	0.768%	0.440%	21.594%
10-Aug-08	0.806%	0.360%	0.251%
11-Aug-08	-1.173%	4.600%	10.106%
14-Aug-08	0.587%	0.260%	-1.315%
16-Aug-08	1.102%	0.340%	-0.421%
17-Aug-08	0.212%	0.980%	2.019%
20-Aug-08	0.301%	0.600%	6.803%
21-Aug-08	0.451%	0.360%	2.122%
27-Aug-08	0.283%	2.860%	4.252%
29-Aug-08	0.523%	2.030%	0.013%
03-Sep-08	-1.361%	3.670%	-1.012%
04-Sep-08	0.265%	1.740%	-0.941%
05-Sep-08	0.341%	0.270%	-0.111%
06-Sep-08	-0.322%	0.270%	-3.776%
07-Sep-08	-1.334%	0.990%	0.898%
08-Sep-08	0.536%	0.620%	3.954%
09-Sep-08	0.165%	0.230%	7.544%
10-Sep-08	0.023%	0.340%	11.628%
16-Sep-08	1.014%	1.900%	1.731%
18-Sep-08	0.935%	0.560%	-2.011%
20-Sep-08	0.217%	0.390%	-3.449%
27-Sep-08	0.878%	0.310%	3.091%
05-Oct-08	0.790%	0.900%	10.212%
06-Oct-08	0.549%	0.850%	-2.570%
07-Oct-08	0.943%	0.280%	-9.166%
09-Oct-08	0.652%	0.850%	-4.429%
12-Oct-08	-0.775%	1.660%	29.185%
13-Oct-08	0.208%	1.620%	-2.067%
14-Oct-08	0.502%	1.150%	-0.059%
15-Oct-08	0.279%	0.630%	-16.431%
16-Oct-08	0.311%	0.950%	-0.059%
19-Oct-08	-0.237%	1.170%	7.388%
22-Oct-08	0.708%	1.410%	-4.179%
02-Nov-08	-0.138%	1.260%	3.537%
08-Nov-08	0.168%	0.510%	8.378%
10-Nov-08	1.499%	0.660%	3.520%
16-Nov-08	0.108%	0.350%	2.374%
23-Nov-08	0.245%	1.910%	-12.299%
24-Nov-08	0.044%	2.120%	7.893%
17-Dec-08	0.148%	0.490%	9.073%
19-Dec-08	-0.032%	0.480%	-0.023%
20-Dec-08	0.192%	0.590%	-0.122%
21-Dec-08	0.167%	1.960%	7.347%
22-Dec-08	0.858%	1.930%	3.318%
04-Jan-09	0.401%	0.420%	-0.157%
07-Jan-09	-0.275%	1.100%	12.896%
10-Jan-09	0.530%	1.100%	5.977%
11-Jan-09	0.611%	1.960%	-7.850%

Run Date	*Production Cost Variance %*	*Optimality Gap*	*Consumer Cost Variance %*
14-Jan-09	0.008%	0.960%	11.399%
27-Jan-09	0.105%	0.590%	3.338%
29-Jan-09	0.319%	0.480%	0.831%
17-Feb-09	0.728%	0.930%	4.101%
03-Mar-09	-0.932%	1.570%	25.183%
04-Mar-09	-1.423%	1.220%	8.059%
05-Mar-09	0.326%	0.720%	4.580%
06-Mar-09	0.576%	0.500%	10.844%
07-Mar-09	0.422%	0.640%	0.955%
08-Mar-09	-2.734%	1.330%	26.727%
09-Mar-09	-1.396%	0.920%	10.805%
10-Mar-09	-2.061%	0.680%	7.077%
11-Mar-09	-0.243%	0.550%	-1.139%
12-Mar-09	-1.394%	0.970%	9.086%
13-Mar-09	0.423%	0.460%	0.499%
26-Mar-09	-1.827%	2.990%	17.884%
03-Apr-09	0.422%	0.160%	0.013%
17-Apr-09	-0.584%	3.710%	-2.968%
23-Apr-09	0.732%	0.320%	-0.444%
24-Apr-09	1.088%	0.320%	-0.607%
25-Apr-09	0.458%	0.320%	-0.050%
27-Apr-09	0.302%	1.850%	-11.550%
28-Apr-09	0.655%	0.350%	-1.916%
29-Apr-09	-1.035%	2.540%	12.627%
05-May-09	-0.172%	3.120%	60.643%
06-May-09	0.568%	0.790%	-0.019%
07-May-09	0.898%	0.670%	0.655%
02-Jun-09	0.402%	2.460%	0.155%
03-Jun-09	1.084%	0.610%	5.818%
04-Jun-09	0.985%	0.560%	-6.732%
09-Jun-09	0.550%	1.210%	16.119%
10-Jun-09	0.178%	0.850%	-0.136%
15-Jun-09	1.162%	0.820%	2.410%
22-Jun-09	1.059%	3.060%	-0.394%
08-Jul-09	0.580%	0.120%	-9.974%
09-Jul-09	0.694%	0.270%	-9.227%
10-Jul-09	0.808%	0.160%	-13.787%
19-Jul-09	0.854%	0.960%	1.219%
26-Jul-09	2.037%	1.050%	1.560%
29-Jul-09	0.658%	0.880%	-10.775%
25-Aug-09	-2.156%	4.900%	-1.350%

Table 46 - MSP Production Cost, Consumer Cost variances and Optimality Gap

11.4 Appendix 4 - Hydro Generator data

Trading Day	***LR Total MSQs***	***MIP Total MSQs***	***Total Energy Limit***
19/12/2007	7570.4	7857.22	7989.564
20/12/2007	7587.4	7906.23	7933.528
21/12/2007	7547.57	7663.11	7686.15
29/12/2007	8792.36	8839.75	9014.526
02/01/2008	7973.4	8190.32	8426.146
03/01/2008	8613.07	8629.41	8888.68
05/01/2008	8741.4	8780.91	8993.868
10/01/2008	8582.82	8807.81	9225.028
15/01/2008	8471.4	8709.93	9045.73
16/01/2008	8858	8923.12	9251.496
19/01/2008	9133.59	9149.59	9175.464

Trading Day	*LR Total MSQs*	*MIP Total MSQs*	*Total Energy Limit*
20/01/2008	9020.41	9123.06	9126.622
25/01/2008	8956.34	8995.58	9037.116
30/01/2008	9075.42	9101.42	9154.382
01/02/2008	8646.98	8752.75	8801.958
04/02/2008	9063.73	9169.43	9239.054
07/02/2008	8938.01	9204.36	9238.764
15/02/2008	6807.91	7141.13	7198.606
16/02/2008	6885.99	7064	7123.286
18/02/2008	6113.44	6801.68	6843.824
20/02/2008	6601.4	6947.99	6960
29/02/2008	4438.64	4839.47	4843.236
03/03/2008	4540.96	5736.9	5737.636
04/03/2008	5634.49	6062.03	6076.048
10/03/2008	5845.89	7273.47	7277.08
13/03/2008	7417.25	7601.91	7604.074
18/03/2008	6206.94	7465.26	7486.114
29/03/2008	4658.77	5263.85	5229.844
02/04/2008	6739.89	7303.61	7391.478
05/04/2008	6542	7174.63	7174.636
09/04/2008	2570.78	3091.94	3157.444
14/04/2008	2389	2887.41	2933.788
15/04/2008	3408.3	3711.45	3740.002
16/04/2008	2271.73	3407.2	3419.106
18/04/2008	2415.4	3457.68	3462.672
19/04/2008	1644.4	2784.06	2790.256
27/04/2008	1651.4	2337.74	2337.736
29/04/2008	1240.85	2017.49	2021.836
03/05/2008	1974.4	2506.53	3306.506
04/05/2008	1692.64	1966.91	1967.02
13/05/2008	484	1354.1	1381.308
16/05/2008	669	1022.58	1022.894
17/05/2008	675.82	858.7	859.844
30/05/2008	1466.51	1476.71	1484.734
31/05/2008	271.4	436	436
01/06/2008	229.4	284.51	287.748
02/06/2008	39.4	215.51	215.524
03/06/2008	207.4	490.27	490.294
04/06/2008	215.4	547.31	553.466
05/06/2008	240	730.47	731.522
06/06/2008	324.12	909.33	910.99
08/06/2008	41.7	51.9	55.792
09/06/2008	0	286.97	293.512
10/06/2008	449.35	530.29	535.724
11/06/2008	391.9	397.6	400.874
25/06/2008	1131.23	1814	1818.354
08/07/2008	4043.54	4366.01	4368.91
16/07/2008	2348.29	2396.85	2398.034
17/07/2008	1970.01	2041.57	2043.5
19/07/2008	1590.71	1709.47	1709.512
20/07/2008	1484.8	1528.65	1529.26
27/07/2008	76.8	332.37	335.722
28/07/2008	48	775.36	780.878
30/07/2008	906.8	1256.99	1259.68
31/07/2008	1411.37	1856.07	1857.896
07/08/2008	1394.76	2028.83	2030.64
10/08/2008	3347.2	4189.79	4189.766
11/08/2008	3580.09	4306.54	4306.494

Trading Day	*LR Total MSQs*	*MIP Total MSQs*	*Total Energy Limit*
14/08/2008	6262.64	7464.23	7506.988
16/08/2008	6303.84	7445.26	7499.572
17/08/2008	7339.55	7448.22	7507.14
20/08/2008	7357.99	7428.58	7571.576
21/08/2008	7614.07	7982.87	8030.122
27/08/2008	5724.1	6943.68	6944.342
29/08/2008	6108.26	7022.59	7044.704
03/09/2008	5927.06	6241.4	6241.416
04/09/2008	6949.82	7210.25	7231.32
05/09/2008	7707.36	7785.37	8089.364
06/09/2008	7132.51	7257.22	7326.798
07/09/2008	6025.71	6888.7	6960.164
08/09/2008	6206.41	7298.16	7372.02
09/09/2008	7710.80	8209.96	8299.84
10/09/2008	8944.32	8995.2	9069.204
16/09/2008	6709.65	7358.3	7358.828
18/09/2008	6050.26	7219.2	7219.184
20/09/2008	4760.35	4939.91	4939.902
27/09/2008	3066.15	3285.04	3286.72
05/10/2008	6254.43	6411.04	6426.196
06/10/2008	6770.46	7340.11	7340.1
07/10/2008	6101.94	7402.42	7402.434
09/10/2008	6658.96	6907.63	6909.896
12/10/2008	7581.33	7961.6	7975.736
13/10/2008	7407.4	7677.77	7693.5
14/10/2008	7556.42	8683.53	8692.346
15/10/2008	8261	8610.12	8649.302
16/10/2008	8226.22	8415.8	8443.118
19/10/2008	8160.13	8268.27	8269.494
22/10/2008	6846.5	7431	7449.942
02/11/2008	7970.53	8065.52	8094.442
08/11/2008	7663.91	7702.95	7702.956
10/11/2008	7187.88	7758.32	7769.602
16/11/2008	7700	7721.94	7732.6
23/11/2008	5947.11	6072.86	6073.144
24/11/2008	5826.39	6992.32	6992.334
17/12/2008	6923.27	6982.94	6996.238
19/12/2008	6870.3	6878.3	6906.928
20/12/2008	6652	6726.73	6731.766
21/12/2008	6486.35	6668.25	6701.386
22/12/2008	6940.01	7170.52	7284.47
04/01/2009	2662.36	3273.16	3278.986
07/01/2009	2639.4	2738.71	2740.392
10/01/2009	1857.51	2399.6	2402.926
11/01/2009	2330.8	2537.48	2537.892
14/01/2009	4944.4	5232.53	5240.264
27/01/2009	8494.1	8601.78	8984.208
29/01/2009	8047.09	8690.05	8718.526
17/02/2009	3575.96	4539.32	4552.848
03/03/2009	3280.8	3740.33	3744.086
04/03/2009	3812.43	4030.9	4031.588
05/03/2009	3292.3	3982.24	3982.266
06/03/2009	3937.86	4773.34	4773.346
07/03/2009	2580.48	4049.66	4049.828
08/03/2009	4422.6	4795.46	4804.406
09/03/2009	4048.4	4785.28	4787.986
10/03/2009	4649.83	5254.68	5257.276

Trading Day	*LR Total MSQs*	*MIP Total MSQs*	*Total Energy Limit*
11/03/2009	4751.1	5241.21	5248.234
12/03/2009	5563.54	6174.19	6179.93
13/03/2009	4348.12	4808.82	4810.48
26/03/2009	2707.4	3221.91	3221.932
03/04/2009	1953.98	2151.68	2151.84
17/04/2009	4148.26	4552.91	4555.474
23/04/2009	3073	3690.14	3691.984
24/04/2009	2949.91	3761.03	3765.276
25/04/2009	2940.27	3268.76	3269.22
27/04/2009	4114.76	4710.32	4714.532
28/04/2009	4151.85	4807.55	4842.91
29/04/2009	4256	4756.92	4779.894
05/05/2009	5027.51	5273.95	5276.48
06/05/2009	3643.49	4328.88	4339.354
07/05/2009	2745	3876.94	3878.998
02/06/2009	1440.77	1682.59	1684.586
03/06/2009	1047	1399.65	1399.798
04/06/2009	635	1230.81	1236.724
09/06/2009	1625.47	2111.08	2115.064
10/06/2009	1311.58	1771.14	1771.748
15/06/2009	500.79	1503.35	1503.356
22/06/2009	1330.09	2331.43	2331.412
08/07/2009	3373.46	3985.76	3994.334
09/07/2009	3147.01	3517.98	3519.996
10/07/2009	3043	3449.62	3453.278
19/07/2009	1378.79	1850.26	1850.966
26/07/2009	1091.76	2662.42	2662.426
29/07/2009	4806.75	5050.23	5050.972
25/08/2009	7020	7251.44	7251.44

Table 47- Hydro Generator data

11.5 Appendix 5 – Generator Classification and Installed Capacity

The following graph and tables represent how generator units were classified within this study where they were broken down by Fuel Type and Technology Type.

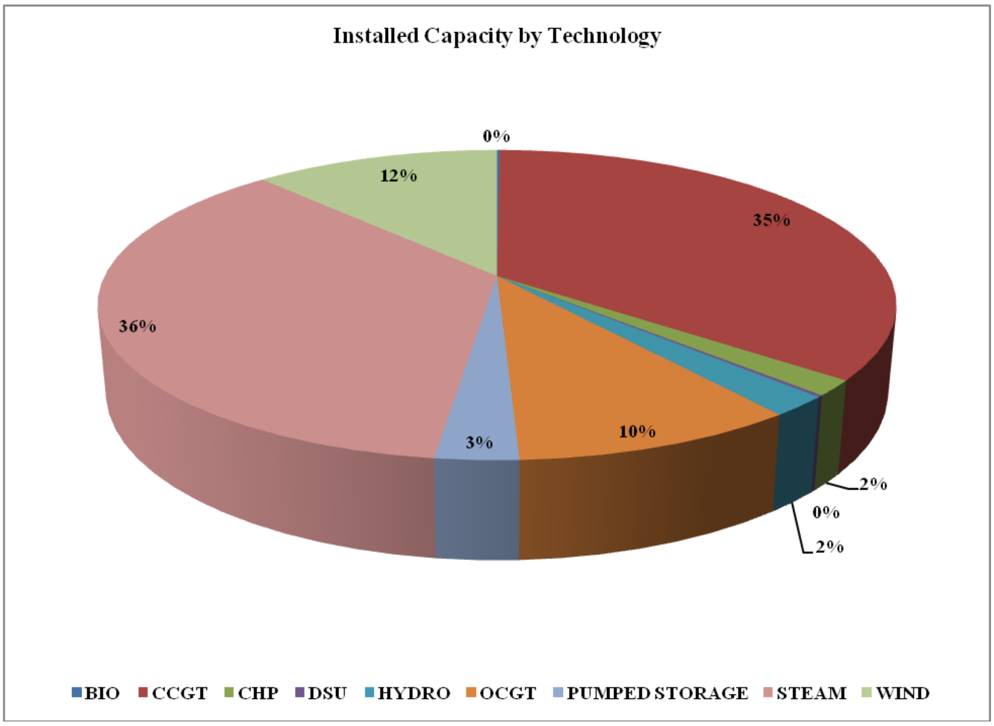

Figure 149 - Installed Capacity by Technology Type

Resource Name	*Fuel Type*	*Technology Type*	*Installed Capacity*	*EMS Unit Name*
DSU_500190	Demand Side Unit	DSU	20	DSU
GU_400020	WIND	WIND	25	Kingsmountain
GU_400030	WIND	WIND	11.88	Cuillagh
GU_400041	WIND	WIND	10.5	Gartnaneane
GU_400050	WIND	WIND	48	Bindoo
GU_400060	WIND	WIND	32.4	Midas
GU_400070	WIND	WIND	72.4	Meentycat
GU_400080	WIND	WIND	27	Richfield
GU_400110	WIND	WIND	25.6	Richfield
GU_400120	MULTI	CHP	83	SK3
GU_400121	MULTI	CHP	83	SK4
GU_400130	WIND	WIND	42	Ballywater
GU_400140	PEAT	STEAM	117.57	ED1
GU_400180	GAS	STEAM	258	AD1
GU_400181	MULTI	OCGT	95	AT1
GU_400182	MULTI	OCGT	95	AT2
GU_400183	MULTI	OCGT	95	AT4
GU_400200	HYDRO	HYDRO	21	AA1
GU_400201	HYDRO	HYDRO	22	AA2
GU_400202	HYDRO	HYDRO	19	AA3
GU_400203	HYDRO	HYDRO	24	AA4
GU_400210	HYDRO	HYDRO	10	ER1
GU_400211	HYDRO	HYDRO	10	ER2
GU_400220	HYDRO	HYDRO	22.5	ER3
GU_400221	HYDRO	HYDRO	22.5	ER4
GU_400240	PEAT	STEAM	91	LR4
GU_400250	HYDRO	HYDRO	15	LI1
GU_400251	HYDRO	HYDRO	15	LI2
GU_400252	HYDRO	HYDRO	4	LI4
GU_400260	HYDRO	HYDRO	4	LI5
GU_400270	COAL	STEAM	287.5	MP1
GU_400271	COAL	STEAM	287.5	MP2
GU_400272	COAL	STEAM	287.5	MP3
GU_400280	HYDRO	HYDRO	15	LE1
GU_400281	HYDRO	HYDRO	4	LE2
GU_400290	HYDRO	HYDRO	8	LE3
GU_400300	MULTI	OCGT	112	MRC
GU_400310	MULTI	CCGT	163	NWC
GU_400311	MULTI	OCGT	104	NW5
GU_400320	MULTI	STEAM	114.5	PB1
GU_400321	MULTI	STEAM	114.5	PB2
GU_400322	MULTI	STEAM	242	PB3
GU_400323	MULTI	CCGT	463	PBC
GU_400360	PUMP	PUMPED STORAGE	73	TH1
GU_400361	PUMP	PUMPED STORAGE	73	TH2
GU_400362	PUMP	PUMPED STORAGE	73	TH3
GU_400363	PUMP	PUMPED STORAGE	73	TH4
GU_400370	PEAT	STEAM	137	WO4
GU_400380	WIND	WIND	14	Beam
GU_400390	WIND	WIND	12.6	Beam
GU_400410	WIND	WIND	25.3	Taur

Resource Name	Fuel Type	Technology Type	Installed Capacity	EMS Unit Name
GU_400420	WIND	WIND	19.45	Booltiagh
GU_400430	WIND	WIND	42.5	Coomagearlaghy 1
GU_400440	WIND	WIND	60	Derrybrien
GU_400450	WIND	WIND	15	Barnesmore Gap
GU_400460	WIND	WIND	15	Cark
GU_400470	WIND	WIND	11.9	Carnsore Point
GU_400480	GAS	CCGT	352	HNC
GU_400490	WIND	WIND	15.18	Tursillagh 1
GU_400500	MULTI	CCGT	415	DB1
GU_400530	GAS	CCGT	404	TYC
GU_400540	GAS	CCGT	412	HN2
GU_400550	WIND	WIND	38.9	Sorne Hill
GU_400560	WIND	WIND	6.8	Tursillagh 2
GU_400570	BIO	BIO	4.239	Tursillagh 2
GU_400571	BIO	BIO	1.25	Tursillagh 2
GU_400580	BIO	BIO	8.652	Tursillagh 2
GU_400591	WIND	WIND	59.225	Coomacheo
GU_400600	WIND	WIND	17.2	Tournafulla 2
GU_400610	WIND	WIND	11.9	Meenachullalan 2
GU_400620	WIND	WIND	30.62	Mountain Lodge
GU_400630	WIND	WIND	22.5	Knockawirriga 1
GU_400640	WIND	WIND	15.3	Knockawirriga 1
GU_400650	WIND	WIND	19.55	Ballybane 1
GU_400660	WIND	WIND	37.85	Clahane
GU_400670	HYDRO	HYDRO	0.132	Clahane
GU_400671	WIND	WIND	3	Slievereagh 1
GU_400680	WIND	WIND	1.65	Beale Hill 1
GU_400700	WIND	WIND	4.62	Curabwee
GU_400730	WIND	WIND	8.5	Coomagearlaghy 2
GU_400731	WIND	WIND	30	Coomagearlaghy 3
GU_400750	OIL	STEAM	54	TB1
GU_400751	OIL	STEAM	54	TB2
GU_400752	OIL	STEAM	240.7	TB3
GU_400753	OIL	STEAM	240.7	TB4
GU_400754	OIL	STEAM	49	GI2
GU_400760	OIL	STEAM	54	GI1
GU_400761	OIL	STEAM	101	GI3
GU_400770	DISTL	OCGT	52	RP1
GU_400771	DISTL	OCGT	52	RP2
GU_400780	DISTL	OCGT	52	TP1
GU_400781	DISTL	OCGT	52	TP3
GU_400800	WIND	WIND	9.2	Flughland 1
GU_400810	WIND	WIND	18.7	Raheen Barr
GU_400840	WIND	WIND	55	Lisheen 1
GU_400850	MULTI	CCGT	431.6	AD2
GU_400880	WIND	WIND	1.8	Dunmore 2
GU_400890	WIND	WIND	1.8	Cronlea Upper 2
GU_400910	WIND	WIND	57	Boggeragh
GU_400920	WIND	WIND	28.5	Dromada
GU_500010	WIND	WIND	19.5	TAP
GU_500020	WIND	WIND	16.9	CAL

Resource Name	Fuel Type	Technology Type	Installed Capacity	EMS Unit Name
GU_500040	MULTI	CCGT	425	C30
GU_500060	MULTI	STEAM	238	K1
GU_500070	MULTI	STEAM	238	K2
GU_500080	DISTL	OCGT	23.6	KGT1
GU_500090	DISTL	OCGT	23.6	KGT2
GU_500100	GAS	STEAM	170	B4
GU_500130	GAS	CCGT	247	B31
GU_500131	GAS	CCGT	247	B32
GU_500140	GAS	CCGT	101	B10
GU_500150	DISTL	OCGT	58	BGT1
GU_500160	DISTL	OCGT	58	BGT2
GU_500170	DISTL	OCGT	53	CGT8
GU_500180	WIND	WIND	14	SNU
GU_500210	WIND	WIND	26	ALT1
GU_500211	WIND	WIND	11.7	ALT2
GU_500220	WIND	WIND	7.92	LEN1
GU_500260	WIND	WIND	5.28	LEN2
GU_500270	WIND	WIND	54	SLI2
GU_500280	GAS	STEAM	170	BPS6
GU_500281	GAS	STEAM	170	BPS5
GU_500720	WIND	WIND	15	GAR
GU_500740	WIND	WIND	30	SD1
GU_500790	WIND	WIND	25	GRU
GU_500820	DISTL	OCGT	41.61	KGT3
GU_500821	DISTL	OCGT	41.61	KGT4

Table 48 - Generators by Fuel, Technology and Installed Capacity

11.6 Appendix 6 - Works Cited

Bixby, Fenelon, Gu, Rothberg, Wunderling. (1999). *MIP: Theory and Practice - Closing The Gap.* ILOG CPLEX.
Johnson, Oren, Svoboda. (1996). Equite and Efficiency of Unit Commitm. *Power* .
Salam, S. (2007). Unit Commitment Solution Methods. *PWASET* .
Sioshansi, O. O. (2008). Economic Consequences of Alternative Solution Methods for Centralized Unit Commitment in Day-Ahead Electricity Markets. *IEEE Transactions on Power Systems, Vol 23, No 2* .
Streiffret, Philbrick, Ott. (2005). A Mixed Integer Programming Solution for Market Clearing and Reliability Analysis. *IEEE* .