



UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

**Relationship between electricity markets in
the Spanish system**

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Madrid, July 2018

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Abstract

Since electricity markets were implemented in the 70's and 80's around the world, it has always existed the uncertainty about prices. This uncertainty not only affects the short-term problem, when to produce, but also the long-term decisions, when and where to install a power plant.

In addition, in the last years, renewable energies have experienced a huge development in terms of technology and installation all over the globe. The introduction of this technologies into the different electric systems has added to price uncertainty, production uncertainty, which finally increase the uncertainty in prices too.

In this context of high uncertainty about electricity prices, this thesis aims to provide a reliable tool to forecast and relate prices for the different electricity markets that take place in the Spanish system, basically the day-ahead and intraday markets and some reserve markets managed by REE.

Based on statistical methods and using different types of inputs, for instance, demand or production by technology, it has been developed a day-ahead price simulator which is able to provide with an adequate level of reliability prices for the day-ahead market, which is the most important, in terms of energy traded, in the Spanish system.

Afterwards, and based on this day-ahead predictions, it has been developed a simulator for the most important markets in the system: all six intraday markets, secondary and tertiary reserve market and technical constraints market. The thesis pays especial attention to this last technical constraints markets, which a very particular market of the Spanish system with few singularities. To begin with, this is not a marginal market, it is cleared as a pay-as-bid mechanism.

The final objective of the thesis is to offer reliable forecasts of the different markets in order to provide a global view of the system for a given day to planned properly the strategies of a company based on the unit portfolio.

TABLE OF CONTENTS

Abstract	5
Chapter 1. Introduction.....	15
1.1 Preliminary works and motivation of this thesis. Why this problem is relevant?	15
1.2 Objectives. Keep in mind one main research question but organize it around three objectives	16
1.3 Structure of the report.....	16
Chapter 2. State of the art	18
2.1 A survey of the literature on the areas relevant to the research question	18
2.2 Original conclusions from such review. Identification of gaps to be overcome with this master's thesis	20
Chapter 3. Iberian electricity market	21
3.1 OMIE markets. Day-ahead and intraday markets	21
3.1.1 Day-ahead market.....	21
3.1.2 Intraday markets	24
3.2 REE markets. Secondary and tertiary reserve markets and technical constraint market	27
3.2.1 Secondary reserve market	28
3.2.2 Tertiary reserve market.....	29
3.2.3 Technical constraints market	30
Chapter 4. Day-ahead market price simulator.....	32
4.1 Introduction.....	32
4.2 Relevant input	32
4.3 Different approaches	38
4.3.1 Single variable models.....	38
4.3.1.1 Forecast based on a discrimination by days	40
4.3.1.2 Forecast based on a discrimination by hours.....	46
4.3.2 Two variables models.....	50
4.3.2.1 Forecast based on a discrimination by days	52
4.3.2.2 Forecast based on a discrimination by hours.....	56
4.4 Conclusions and comparison of results between simulations.....	59
Chapter 5. Relationship between different markets	62
5.1 Intraday market price simulator	62
5.1.1 First intraday market.....	62
5.1.2 Rest of intraday markets	65
5.1.3 Preliminary conclusions about intraday markets.....	70

5.2 Reserve markets price simulator.....	70
5.2.1 Secondary reserve market price simulator	70
5.2.1.1 Simulation based on the day-ahead thermal gap	71
5.2.1.2 Simulation based on the day-ahead price.....	74
5.2.2 Tertiary reserve market price simulator	76
5.2.2.1 Upward tertiary reserve market	77
5.2.2.2 Downward tertiary reserve market.....	81
5.2.3 Preliminary conclusions about reserve markets	84
Chapter 6. Technical constraints market	86
6.1 Introduction.....	86
6.2 Power plants.....	87
6.3 Analysis.....	91
6.3.1 Zone5.....	92
6.3.2 Zone7.....	99
6.3.3 Zone8.....	105
6.3.4 Zone9.....	109
6.3.5 Zone12.....	111
6.3.6 Zone13.....	115
6.4 Technical constraints price simulator	117
6.5 Preliminary conclusions	119
Chapter 7. Conclusions.....	121
Chapter 8. References.....	124
ANNEXES	125
ANEX 1. List of abbreviations	125

List of figures

Figure 1. Aggregate curve for electricity. Source: www.omie.es	24
Figure 2. Timetable for the different markets managed by OMIE. Source: [OMIE17]	25
Figure 3. Aggregate curve for electricity for an intraday market. Source: www.omie.es	27
Figure 4. Demand vs market price. Source: own elaboration from [ESIO17]	33
Figure 5. Thermal gap vs market Price. Source: own elaboration from [ESIO17].....	34
Figure 6. Thermal gap 2 vs market price. Source: own elaboration from [ESIO17].....	35
Figure 7. Thermal gap 3 vs market price. Source: own elaboration from [ESIO17].....	36
Figure 8. Renewable vs market price. Source: own elaboration from [ESIO17]	37
Figure 9. Forecasted renewable vs market price. Source: own elaboration from [ESIO17].....	37
Figure 10. Weekly behavior of market prices. Own elaboration from [ESIO17].....	39
Figure 11 Seasonal behavior of market prices. Own elaboration from [ESIO17]	40
Figure 12. Thermal gap 2 vs market price for a single day. Source: own elaboration from [ESIO17].....	41
Figure 13. Thermal gap 2 vs market price for five consecutive days. Source: own elaboration from [ESIO17]	43
Figure 14. Thermal gap 2 vs market price for two consecutive non-working days. Source: own elaboration from [ESIO17]	45
Figure 15. Thermal gap 2 vs market price for ten consecutive hours. Source: own elaboration from [ESIO17]	47
Figure 16. Forecasted wind vs market price. Source: own elaboration from [ESIO17]	51
Figure 17. Seasonal behavior of wind power for the year 2.015 and the year 2.016. Source: Own elaboration from [ESIO17].....	52
Figure 18. Forecasted wind vs market price for one day. Source: own elaboration from [ESIO17]	53
Figure 19. Day-ahead market price vs intraday market prices. Source: own elaboration from [ESIO17] and [OMIE17]	63
Figure 20. Day-ahead market price vs intraday market price for complete days. Source: own elaboration from [ESIO17] and [OMIE17]	64
Figure 21. Day-ahead market price vs intraday market price for hour 1. Source: own elaboration from [ESIO17] and [OMIE17]	64
Figure 22. Day-ahead market price vs second intraday market price. Source: own elaboration from [ESIO17] and [OMIE17].....	66
Figure 23. First intraday market price vs second intraday market price for complete days. Source: own elaboration from [OMIE17].....	67
Figure 24. Day-ahead market price vs third intraday market price. Source: own elaboration from [ESIO17] and [OMIE17].....	67
Figure 25. Second intraday market price vs third intraday market price for complete days. Source: own elaboration from [OMIE17].....	68
Figure 26. Thermal gap vs Secondary reserve market price for two whole years. Source: own elaboration from [ESIO17]	71
Figure 27. Thermal gap vs Secondary reserve market price for five consecutive days. Source: own elaboration from [ESIO17]	72
Figure 28. Thermal gap vs Secondary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]	72

Figure 29. Thermal gap vs Secondary reserve market price for complete days. Source: own elaboration from [OMIE17] and [ESIO17]	74
Figure 30. Day-ahead market price vs Secondary reserve market price for five consecutive days. Source: own elaboration from [OMIE17] and [ESIO17].....	75
Figure 31. Day-ahead market price vs Secondary reserve market price for ten consecutive hours. Source: own elaboration from [OMIE17] and [ESIO17].....	75
Figure 32. Day-ahead market price vs Upward tertiary reserve market price. Source: own elaboration from [OMIE17] and [ESIO17]	78
Figure 33. Day-ahead thermal gap vs Upward tertiary reserve market price. Source: own elaboration from [ESIO17]	78
Figure 34. Secondary reserve market price vs Upward tertiary reserve market price. Source: own elaboration from [ESIO17]	79
Figure 35. Day-ahead thermal gap vs Upward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]	79
Figure 36. Day-ahead market price vs Upward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17] and [OMIE17].....	80
Figure 37. Day-ahead market price vs Downward tertiary reserve market price. Source: own elaboration from [OMIE17] and [ESIO17]	82
Figure 38. Day-ahead Thermal gap vs Downward tertiary reserve market price. Source: own elaboration from [OMIE17] and [ESIO17]	82
Figure 39. Day-ahead market price vs Downward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]	83
Figure 40. Day-ahead thermal gap vs Downward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]	83
Figure 41. Location of Spanish power plants. Source: [WIKI18]	87
Figure 42. Day-ahead market bids for the year 2.017 for the power plants in Zone5. Source: own elaboration from [ESIO17]	93
Figure 43. Technical constraints market bids for the year 2.017 for the power plants in Zone5. Source: own elaboration from [ESIO17]	93
Figure 44. Day-ahead and technical constraints market bids versus MIBGAS price for PP8 from Agent1. Source: own elaboration from [ESIO17].....	94
Figure 45. Day-ahead and technical constraints market bids versus MIBGAS price for PP9 from Agent1. Source: own elaboration from [ESIO17].....	95
Figure 46. Day-ahead and technical constraints market bids versus MIBGAS price for PP10 from Agent1. Source: own elaboration from [ESIO17].....	96
Figure 47. Day-ahead and technical constraints market bids versus MIBGAS price for PP11 from Agent2. Source: own elaboration from [ESIO17].....	98
Figure 48. Day-ahead and technical constraints market bids versus MIBGAS price for PP12 from Agent2. Source: own elaboration from [ESIO17].....	98
Figure 49. Day-ahead market bids for the year 2.017 for the power plants in Zone7. Source: own elaboration from [ESIO17]	99
Figure 50. Technical constraints market bids for the year 2.017 for the power plants in Zone7. Source: own elaboration from [ESIO17]	100
Figure 51. Day-ahead and technical constraints market bids versus MIBGAS price for PP7 from Agent3. Source: own elaboration from [ESIO17].....	101
Figure 52. Day-ahead and technical constraints market bids versus MIBGAS price for PP11 from Agent1. Source: own elaboration from [ESIO17].....	101
Figure 53. Unavailability of production and generation units. Source: [ENTS18].....	104

Figure 54. Day-ahead market bids for the year 2.017 for the power plants in Zone8. Source: own elaboration from [ESIO17]	105
Figure 55. Technical constraints market bids for the year 2.017 for the power plants in Zone8. Source: own elaboration from [ESIO17]	105
Figure 56. Day-ahead and technical constraints market bids versus MIBGAS price for PP9 from Agent3. Source: own elaboration from [ESIO17].....	106
Figure 57. Day-ahead and technical constraints market bids versus MIBGAS price for PP12 from Agent3. Source: own elaboration from [ESIO17].....	107
Figure 58. Day-ahead and technical constraints market bids versus MIBGAS price for PP13 from Agent3. Source: own elaboration from [ESIO17].....	107
Figure 59. Day-ahead and technical constraints market bids versus MIBGAS price for PP14 from Agent3. Source: own elaboration from [ESIO17].....	109
Figure 60. Day-ahead market bids for the year 2.017 for the power plants in Zone9. Source: own elaboration from [ESIO17]	110
Figure 61. Technical constraints market bids for the year 2.017 for the power plants in Zone9. Source: own elaboration from [ESIO17]	110
Figure 62. Day-ahead and technical constraints market bids versus MIBGAS price for PP14 from Agent3. Source: own elaboration from [ESIO17].....	111
Figure 63. Day-ahead market bids for the year 2.017 for the power plants in Zone12. Source: own elaboration from [ESIO17]	112
Figure 64. Technical constraints market bids for the year 2.017 for the power plants in Zone12. Source: own elaboration from [ESIO17]	112
Figure 65. Day-ahead and technical constraints market bids versus MIBGAS price for PP3 from Agent5. Source: own elaboration from [ESIO17].....	113
Figure 66. Day-ahead and technical constraints market bids versus MIBGAS price for PP21 from Agent1. Source: own elaboration from [ESIO17].....	114
Figure 67. Day-ahead and technical constraints market bids versus MIBGAS price for PP14 from Agent2. Source: own elaboration from [ESIO17].....	115
Figure 68. Day-ahead market bids for the year 2.017 for the power plants in Zone13. Source: own elaboration from [ESIO17]	116
Figure 69. Technical constraints market bids for the year 2.017 for the power plants in Zone13. Source: own elaboration from [ESIO17]	116
Figure 70. Day-ahead and technical constraints market bids versus MIBGAS price for PP22 from Agent1. Source: own elaboration from [ESIO17].....	117
Figure 71. Technical constraints market bids versus MIBGAS price for different power plants. Source: own elaboration from [ESIO17]	118

List of tables

Table 1. Results of the basic approach for Thermal gap 2. Source: own elaboration from [ESIO17].....	38
Table 2. Results of the basic approach for Thermal gap 3. Source: own elaboration from [ESIO17].....	39
Table 3. Results of the day before approach for Thermal gap 2. Source: own elaboration from [ESIO17].....	41
Table 4. Results of the day before approach for Thermal gap 3. Source: own elaboration from [ESIO17].....	41
Table 5. Results of the seventh day before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	42
Table 6. Results of the seventh day before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	42
Table 7. Results of the five days before approach for Thermal gap 2. Source: own elaboration from [ESIO17].....	44
Table 8. Results of the five days before approach for Thermal gap 3. Source: own elaboration from [ESIO17].....	44
Table 9. Results of the two days before approach for Thermal gap 2. Source: own elaboration from [ESIO17].....	45
Table 10. Results of the two days before approach for Thermal gap 3. Source: own elaboration from [ESIO17].....	46
Table 11. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17].....	47
Table 12. Results of the ten hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17].....	47
Table 13. Results of the fifteen hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	48
Table 14. Results of the fifteen hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	48
Table 15. Results of the twenty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	48
Table 16. Results of the twenty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	48
Table 17. Results of the twenty-five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	48
Table 18. Results of the twenty-five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	48
Table 19. Results of the thirty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	48
Table 20. Results of the thirty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	48
Table 21. Results of the five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17].....	49
Table 22. Results of the five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17].....	49

Table 23. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	50
Table 24. Results of the five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	50
Table 25. Results of the day before approach for a quadratic function for Thermal gap 2. Source: own elaboration from [ESIO17]	53
Table 26. Results of the day before approach for a quadratic function for Thermal gap 3. Source: own elaboration from [ESIO17]	54
Table 27. Results of the day before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]	54
Table 28. Results of the day before approach for a linear function for Thermal gap 3. Source: own elaboration from [ESIO17]	54
Table 29. Results of the seventh day before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]	55
Table 30. Results of the seventh day before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]	55
Table 31. Results of the five days before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]	55
Table 32. Results of the five days before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]	55
Table 33. Results of the two days before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	56
Table 34. Results of the two days before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	56
Table 35. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	57
Table 36. Results of the ten hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	57
Table 37. Results of the fifteen hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	57
Table 38. Results of the fifteen hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	57
Table 39. Results of the twenty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	57
Table 40. Results of the twenty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	57
Table 41. Results of the twenty-five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	58
Table 42. Results of the twenty-five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	58
Table 43. Results of the thirty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	58
Table 44. Results of the thirty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	58
Table 45. Results of the five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	59
Table 46. Results of the five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	59

Table 47. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]	59
Table 48. Results of the ten hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]	59
Table 49. Best result approaches for working days. Source: own elaboration from [ESIO17] ...	60
Table 50. Best result approaches for non-working days. Source: own elaboration from [ESIO17]	60
Table 51. Results of the five days before approach for working days. Source: own elaboration from [ESIO17] and [OMIE17].....	65
Table 52. Results of the ten hours before approach for working days. Source: own elaboration from [ESIO17] and [OMIE17].....	65
Table 53. Results of the five days before approach for non-working days. Source: own elaboration from [ESIO17] and [OMIE17]	65
Table 54. Results of the ten hours before approach for non-working days. Source: own elaboration from [ESIO17] and [OMIE17]	65
Table 55. Results of the five days before approach for working days. Source: own elaboration from [OMIE17]	68
Table 56. Results of the ten hours before approach for working days. Source: own elaboration from [OMIE17]	69
Table 57. Results of the two days before approach for non-working days. Source: own elaboration from [OMIE17].....	69
Table 58. Results of the ten hours before approach for non-working days. Source: own elaboration from [OMIE17].....	69
Table 59. Results based on the day-ahead thermal gap for working days. Source: own elaboration from [OMIE17] and [ESIO17]	73
Table 60. Results based on the day-ahead thermal gap for non-working days. Source: own elaboration from [OMIE17] and [ESIO17]	73
Table 61. Results based on the day-ahead market price for working days. Source: own elaboration from [OMIE17] and [ESIO17]	76
Table 62. Results based on the day-ahead market price for non-working days. Source: own elaboration from [OMIE17] and [ESIO17]	76
Table 63. Results based on the ten hours before approach for working days. Source: own elaboration from [OMIE17] and [ESIO17]	81
Table 64. Results based on the ten hours before approach for non-working days. Source: own elaboration from [OMIE17] and [ESIO17]	81
Table 65. Results based on the ten hours before approach for working days. Source: own elaboration from [OMIE17] and [ESIO17]	84
Table 66. Results based on the ten hours before approach for working days. Source: own elaboration from [OMIE17] and [ESIO17]	84
Table 67. Power plants participating in the technical constraints market by agents and by zone for the year 2.016. Source: Own elaboration from [ESIO17] and [WIKI18].....	90
Table 68. Power plants included in the study by agents and by zone for the year 2.016. Source: Own elaboration from [ESIO17] and [WIKI18].....	91
Table 69. Technical constraints market bids for Zone5. Source: own elaboration from [ESIO18]	97
Table 70. Day-ahead and technical constraints market bids for Zone7. Source: own elaboration from [ESIO17].....	103

Table 71. Day-ahead and technical constraints market bids for Zone8. Source: own elaboration from [ESIO17]	108
Table 72. Results based on the five and ten hours before approach. Source: own elaboration from [ESIO17]	119

Chapter 1. Introduction

1.1 Preliminary works and motivation of this thesis. Why this problem is relevant?

Not so long ago, between twenty and thirty years back, the electric industry was a regulated business in every country in the world, in fact, in many countries still is. Under these circumstances every income and expense were approved by governments, therefore the electric business was a risk-free business, but also a non-evolving industry where overruns occurred.

In many countries, the electric business was run by few or even one big state-owned company. These companies were responsible for managing the whole electric industry, generation, transmission, distribution and retail; in consequence, they set their prices for their services. If the government considered this price excessive for consumers, the company was remunerated with subsidies. As it can be deduced, electric companies had no incentive to be efficient or innovative since they were recovering every cost at a reasonable interest rate.

However, this situation was unstable because electricity is an essential good and, furthermore, one of the basic pillars of the competitiveness of a country. Under these premises, governments start to liberalize electric business, the first country in the world was Chile in 1977 [RUDN01]. The aim was to divide the industry into different part, the ones that were susceptible of liberalization (generation and retail); and the ones that needed to remain regulated (transmission and distribution).

After Chile, many countries in the world followed its path, and they started to liberalized the electric business. It was at this point when a new word appeared in the electric power industry: Market.

In a market environment, the price for electricity is fixed by the law of supply and demand. Generation is paid the price fixed by the market and supply has to pay this price, and it obtains its revenues by charging their customer for the electricity supplied.

The problem for generation and retail companies lies in the ignorance of the electricity price in advance. They need to make its forecast of production and consumption on one hand, and the forecast of price on the other hand, and according to them, they have to make their profit and loss account. In addition, these companies normally have capital intensive investments in big power plants, so they need to do the calculations as accurate as possible, because a small deviation could lead to huge losses.

In this context, it appears relevant to have the most accurate estimation as possible. This master thesis aims to be a small tool to help understand the Iberian market and its functioning, and to provide information about the future prices of the different markets.

In the field of forecasting prices, one of the most relevant references followed to develop this thesis is “Modeling and Forecasting Electricity Loads and Prices” by R. Weron [WERO06]. In this book, the author treats the topic of forecasting loads and prices from a pure statistical perspective, not taking into account the actual structure or mix of the electric system.

For all of the reasons stated above, this thesis is considered of relevance in an environment of liberalized electric systems. Despite there are works about the same topic, this one is important because it pretends to analyze on one hand the situation of Spanish electric system, but also because it pretends to analyze not only the day-ahead market but also the Spanish ancillary service markets, and in particular, the technical constraints market. This market is particularly relevant in Spain because of the impact it has on the revenues for the CCGT power plants. Which are the most active technology in this market and receive most of their income from it.

1.2 Objectives. Keep in mind one main research question but organize it around three objectives

The present master thesis aims to formulate a mathematical relationship between the different electric market in the Iberian Peninsula. The main objective is to obtain a price market simulator with a reasonable accuracy.

The first step of the thesis is to be able to predict the price for the day-ahead market, the most important market due to the energy volume traded. It has been used a statistical approach, the simulator is based on historical data about prices and other inputs developed below; but it is not based on an actual representation of the electric system, which would be called a fundamental approach.

Once an estimation for the day-ahead market is known, the second step is to build a simulator for the rest of the electric markets. The markets analyzed in this thesis are the six intraday markets (managed by the Iberian market operator OMIE and common for Portugal and Spain), the secondary and tertiary reserve markets, and the technical constraints market (managed by the Spanish Technical system operator REE, and specific for the Spanish system). To achieve this second objective, the idea is to use the information obtain in the elaboration of the day-ahead market simulator and develop the simulators for the other markets to predict the price based on the actual price of the day-ahead market.

Finally, this thesis pretends to deepen in the study of the technical constraints market. The third objective is therefore, to analyze the relationship between the day-ahead market price and the technical constraints market price, and which are the main drivers for this last market.

1.3 Structure of the report

The report is organized in seven differentiated parts. The first chapter is the introduction and objectives of the thesis, where it is explained the main topic of the project, electricity market prices, and the principal objectives of it, the relationship between the different markets in the Iberian system.

After that, the second part is about the state of the art of the topic, this is a review of previous thesis, studies or papers; and which can be the gaps that this thesis could fill in the literature.

The third chapter is an introduction about the Iberian electricity market. Before entering into the main issues of the project, it is necessary a little introduction to the Iberian electric system. This third chapter offers a brief explanation of the electric system and the functioning of the different markets.

With the fourth chapter starts the core part of the thesis. This part is about the day-ahead market price simulator. It is explained the different stages of the process to create the simulator and the different strategies to achieve an accurate and reliable price.

The fifth chapter relates to the relationships between the day-ahead market and the rest of the markets excluding the technical constraints market, which will be treated in the next part of the document. In this point, it is explained the different simulators to obtain the price for the intraday markets and the secondary and tertiary reserve markets, and how they interact according to the day-ahead market price.

As it has been stated above, the technical constraints market is analyzed in higher detail than the other in this report, therefore the whole sixth chapter is about this particular market of the Spanish system. There are only a few power plants that are allowed to participate in this market, so the first step is to define these plants and explain a few details about them. Then, it is explained the mission and functioning of this market, which has a few complicated details. The last point of the chapter related to the simulator and the relationships between this and the day-ahead market price.

The seventh and last chapter is the conclusions chapter. Here are explained the conclusions about the results of the different simulators, and global results of the master thesis.

Chapter 2. State of the art

2.1 A survey of the literature on the areas relevant to the research question

The main reference followed in this report is the “Modeling and forecasting electricity loads and prices” [WERO06]. This study analyzes the problem of forecasting both, loads and prices, from a statistical perspective. From this report, it has been useful only the topic about prices, since the present thesis only relates to prices and not loads.

The book of Weron presents in an understandable language the most common methods to predict and estimate prices for any electric system, not taking into account the actual structure of its mix. This is the methodology wanted to be implemented in this thesis. Weron names at the beginning of the chapter the most common approaches employed to predict the behavior of electric markets but focuses only on the statistical methods. These six approaches are: production cost models, equilibrium models, fundamental methods, quantitative models, statistical approaches (the one explained in detail in the book) and artificial intelligence-based techniques.

Weron emphasizes that, despite the importance of employing a robust statistical algorithm, it is also necessary to take into account some exogenous factors within the electric markets. For instance, the historical and forecasted loads, since they are the most influential input for price variation; time factors, since electricity prices presents a strong relation to the time of the year and the day of the week; and finally, the fuel prices because in the short-term prices are highly influenced by them, moreover when a coal or CCGT power plant sets the marginal price.

Other important issue to be handled when predicting prices is the spikes. Spike prices are very high prices that appear very few hours during very few days, even during just one day. The problem, says Weron, is that they are difficult to predict but they also disturb future forecast if not properly taken into account.

The next important point highlighted by Weron is the problem of assessing the quality of price forecasting. It is proposed a series of different statistical parameters, the most important and the ones used further in the thesis are the mean absolute error (MAE) and the mean absolute percentage error (MAPE). The first one assesses about the distance between the forecast and the actual price of electricity for a given data set. When comparing two different data set, it is preferred the percentage error. However, this method could be misleading for analyzing prices, especially when they drop to zero, says Weron.

At the end of the chapter, Weron proposes a couple of cases of study about the CalPX, the market operator of California.

Apart from Weron´s book, it has also been used a series of thesis related to market costs and prices. The first of these thesis is from Á. García [GARC13]. This thesis develops a tool for analyzing the situation of electric system of the Iberian Peninsula.

García begins by describing and explaining the Iberian market and the process it follows every day until the final program is formed for every power plant. It also explains a few basic concepts about the electric market, for instance the marginal price or some specific characteristic about the Iberian system.

Afterwards, García starts explaining the concept of marginal price and its characteristics, particularly three specific features about the price of electricity. The first one, says García, is that the demand, although in the short term can be considered inelastic, in the long term may be influenced by different variables, such as the price of electricity.

Secondly, García explains that almost all of the nuclear energy generated in the Spanish system is traded by bilateral contract, therefore it does not affect the price, except when a power plant triggers and it has to rebuy its energy in the intraday market.

The last important remark is about renewable energy, a high developed technology in the past years. García explains that renewable power plant, considering only wind and solar power, send their bids at price zero since, by the time of his thesis they were remunerated by a feed-in-tariff scheme. Nowadays, it would be also correct to assume that their bids are, if not zero, close to it, because their variable costs are low and they are going to produce if there is wind or sun.

For the present thesis, the inelastic demand will be an important fact when designing the price simulator, and it will be explained in detail later. Moreover, the fact that nuclear energy and renewable energy does not bid in the spot market or bid at close to zero prices, will have a huge effect in the final result of the price, and it will be taken into account in the design too.

The second thesis, “Análisis del Mercado eléctrico en España”, is a tool to analyze the Spanish electric market, and specifically to compute the cost of every technology in the Spanish system [SALV10]. As the thesis before, Salvador starts its thesis by explaining the situation of the Spanish electric system.

Afterwards, it is explained the hypothesis used to compute the cost of electricity for each technology. The methodology chosen to compute costs is called LCOE or Levelized Cost of Electricity, it is the equivalent unitary cost of a power plant, and it allows to compare different technologies, not taking into account associated risks as economics or regulatory, according to Salvador. The LCOE is computed with the investment cost plus the operation and maintenance cost plus the fuel cost and other cost associated with a power plant and divided by the hours of production of the power plant.

Salvador explains later the tool developed for the thesis and its functioning. In simple terms, the tool needs different types of inputs, for instance financial or technological; or about the properties of the fuel. Then, the tool applies the formula for the LCOE adapted to each technology and calculates the different factors.

Finally, the thesis elaborates a series of conclusions about the estimated cost of every technology and the actual price of electricity in the market. However, since the report is from 2010, its results are obsolete and cannot be applied to the present day because the market and market rules have change since then. For this reason, it is considered that it is not of relevance to explain these conclusions from Salvador’s thesis.

Apart from these three pieces of literature about electric markets, there are several studies of relevance also that have been considered during the development of the present thesis. However, as a general review and introduction to the topic, these have been considered appropriate representatives of the different works about electric market and prices.

2.2 Original conclusions from such review. Identification of gaps to be overcome with this master's thesis

In the literature about electric market and market prices there are many texts and studies of interest, a few of them have been stated above. Many of these studies are related mainly to market analysis and market costs.

The first impression from the present literature is that when assessing and designing a price simulator for electric market it is important to bear in mind few basic but remarkable tips. According to Weron the main driver for price estimation is the load [WERO06], therefore before designing a robust price simulator, it would be advisable to have a robust load simulator or at least a good provider of information. However, says García that for the Spanish case, with a huge penetration of renewable energy, this energy plus the nuclear should not be taken into account when assessing future prices [GARC13].

The second preliminary conclusion would be that, despite how good is are model, each electric system is completely different, hence, each model should be adapted specifically for each one. In addition, it is necessary to keep in mind that Weron book dates from 2006, when renewable energy was not as implemented as in 2013, when the thesis from García is written and renewable energy was at its peak in Europe. Thus, despite the location of the system, it is important to consider the date when the model is design because as technology evolves, electric systems evolve with it, and the way electric prices behave in consequence.

The first interesting conclusion specific for the Spanish system, and very applicable for this thesis is about the influences in the price. It is of relevance that, although every technology participates in the market together, not everyone has the same impact on price. For instance, nuclear energy in the Spanish market has few impact since their power plants go by bilateral contracts; and the same applies for renewable power plants that bids at close to zero price [GARC13].

Despite the extensive and useful knowledge acquire from the existing literature, it has also been found some gaps that this master thesis could fill. It exists several studies and papers about electric markets, about their behavior under different circumstances, about their main drivers. It also exists numerous analysis specifically about the Iberian or Spanish system.

However, it has been identified an absence of literature about specific price simulator for the Iberian market, and a tool that allows to predict and relate the different markets in the Spanish system. This may be because of industry interest, each company can have different tools to use and apply for their daily offers, and the know-how is confidential for competitive interests. Whatever the case may be, this thesis could add new knowledge about price estimation for the Iberian market and the specific markets of Spain.

It aims also to analyze the technical constraints market and connects it with the day-ahead market. This market is very specific for the Spanish system, and very exclusive since only a few power plants in the system are allowed to participate. It has also very concrete and specific conditions. All of these, make this market barely known and sometimes it may seem opaque. With this thesis, it is pretended to clarify the conditions and the functioning of this market, and also to try to estimate its price, whenever this is possible as it will be seen further.

Chapter 3. Iberian electricity market

The purpose of the present thesis is to analyze and build a tool to predict electricity prices for the Iberian market. Before explaining the different markets and their functioning, it is important to state the differences between the Iberian markets and make clear which market are in the scope of this report.

What are called Iberian market refers only to day-ahead and intraday market. These markets are managed by the Spanish market operator OMIE, and they are common for both countries Spain and Portugal. All of the markets managed by OMIE are physical, agents that trade energy must sell or buy that energy according to their transactions in the market.

On the other hand, markets for ancillary services are managed by the Spanish Technical system operator (TSO) REE. REE manages the primary, secondary and tertiary reserve markets, the reserve of additional power to upload market, the imbalances market and the technical constraints market [ESIO17].

This thesis pretends to analyze all markets managed by OMIE, and the secondary and tertiary reserve markets. Additionally, it aims to analyze in deep the technical constraints market. When in this thesis is written about the Iberian market, it is made reference therefore, to every market managed by OMIE, however, when it only speaks about Spanish market, it made reference to the markets managed by REE.

3.1 OMIE markets. Day-ahead and intraday markets.

As it has been stated before, OMIE is the entity in charge of managing the Iberian electricity market, this includes Spain and Portugal. OMIE is a regulated private company. This means that its investors are private entities, but the company and its activities remain regulated by the Government [OMIE17].

OMIE began to operate Spanish market in the year 1.998. At this time, the company only managed the Spanish market under the name of OMEL. It was in the year 2.007 when the Spanish and Portuguese Governments arrived to the agreement to create the Iberian market. They defined the new market with two poles, the Spanish in charge of managing spot markets; and the Portuguese in charge of managing the future markets, OMIP. The content of this thesis comprises only spot market, therefore OMIP would be exclude of any future explanation except for clarification purposes when needed [OMIE17].

In the Iberian system, any transaction apart of bilateral contracts have to go through the spot market managed by OMIE. This means that this entity is in charge of managing more than 80% of the total energy transacted in the Iberian Peninsula. In terms of energy 270 TWh, which are approximately 21 % of the electricity of the European market [OMIE17].

With all these data, it can be concluded that OMIE is a liquid market, where most of the energy of the region it manages goes through it. This assures competitiveness and a truly reliable price for electricity in the area.

3.1.1 Day-ahead market

The main market and the most liquid that OMIE manages is the day-ahead market. Through this market is traded the energy for the 24 hours of the next day. In the day-ahead market, it is traded each hour independently resulting in 24 prices, one for each hour.

In the day-ahead market, every agent has to attend and present their bids for their units, if the unit is a bidding unit, they present a bid offer; if it is a selling unit, the offer would be to sell energy. For selling units is compulsory to attend and present an offer for the whole power of the unit, except if the unit is unavailable or if it has a bilateral contract [OMIE17].

Agents may present their bids for any day they desire; the market is open for any future day. However, at 12 am the market for the following day is closed, and OMIE runs, in coordination with the PX's of Europe, the algorithm Euphemia to compute the price of electricity and assign the energy to each unit according to their bids.

The bids to buy energy are simple bids, this means that they only contain the quantity of energy desired and the price the agent is willing to pay for this energy. The offer is structure in blocks of up to 24 hours, the 24 hours that are going to be traded for the following day [OMIE17]. This block allows to set different prices for different steps of energy willing to be bought. This price of the different blocks must have an increasing order.

The previous characteristics are common for buying and selling bids, but, in contrast with bidding offers, for selling bids it exists also what is called complex conditions. In addition to simple bids, selling offers are allowed to include complex conditions that reflect the technical limitation of the power plant behind the selling unit. These conditions are: minimum income condition, the ramp limits or gradient condition, the indivisibility condition and scheduled stop condition.

One addition remark is that for the day-ahead market is only allowed to present one bid per unit of production or consumption. This bid must also be consequent with the sign of the unit, if it is a producer, it has to be a selling bid and vice versa.

Minimum income condition

This condition allows selling unit to set the minimum quantity they are willing to accept for their energy. They present their 24 bids, one for each hour, with energy and price. In addition, they may include in the bid a fix term of money and a variable term, in €/MWh.

When the algorithm is run, it first looks at the quantity and price offered as a simple bid and set the price for each hour. After that, it checks if for that price, the minimum income condition is fulfilled, if not, the bid is rejected and a new price is computed without the bid of this unit [OMIE17].

The purpose of this condition is to avoid the fluctuations of prices throughout the 24 hours of the day. With this condition, units have the possibility to offer a low price and assuring their bid is in the marginal price for each hour, but they also have the assurance that their cost is going to be recovered through the minimum income condition. This way, they make sure that they are going to be committed the 24 hours, and they will not have to stop the power plant in the middle of the day, which would result in higher and inefficient costs.

Load gradient condition

The load gradient condition allows to limit the differences in energy matched in two consecutive hours. The agent may include in their bids what is the maximum power its plant can increase or decrease in one hour. It is important that this term is actually given in MW/min, therefore it is necessary to make a little calculation to transform the term to MW/hour [OMIE17].

This condition allows the agent to reflect the physical limits that each power plant has to vary its energy in a given time.

Indivisibility condition

Before explaining this condition, it is important to clarify that when more than one bid remains in the marginal price, the algorithm executes a distribution of the energy. The indivisibility condition allows to power units to express explicitly its desire for their energy bid to not to be divided.

However, to apply this condition, it is also necessary to fulfill a few extra terms. First of all, this condition is only applied when the price of electricity falls to zero. Secondly, only one indivisible part of the bid per each hourly scheduling period is allowed and must be the one with the lowest price. Finally, this condition only may be employed if no other condition has been selected. In addition, if the indivisible amount is higher than the demand, the bid may be divided [OMIE17].

This condition is especially relevant for those units that cannot produce below a given power. For example, nuclear units in Spain always produce at its nominal power, therefore, they would use this condition to make sure their energy will not be distributed.

Scheduled stop condition

The name of this condition is because it allows power plant to schedule a stop in case the plant is not committed for the next day.

The condition of scheduled stop can only be used along with the minimum income condition. In this case, if the bid is rejected because of incomes, the bid is wholly rejected. However, the scheduled stop condition allows to keep the first step of up to the first three hours. This energy bid must decrease, since it is a power plant stop.

The purpose of this condition, as mentioned above, is to allow power plants to stop in case they are not committed. This is necessary because power plants, especial any thermal type, cannot stop its production from one hour to the next, they need a stepped shut down.

Now it has been explained in general terms the functioning of the day-ahead market and the bid process with all of its complex conditions. With all the bids and taking into account both, simple and complex conditions, the algorithm computes the price for electricity and builds the electricity curve. In the following image, it can be seen the curve for a given day and hour:

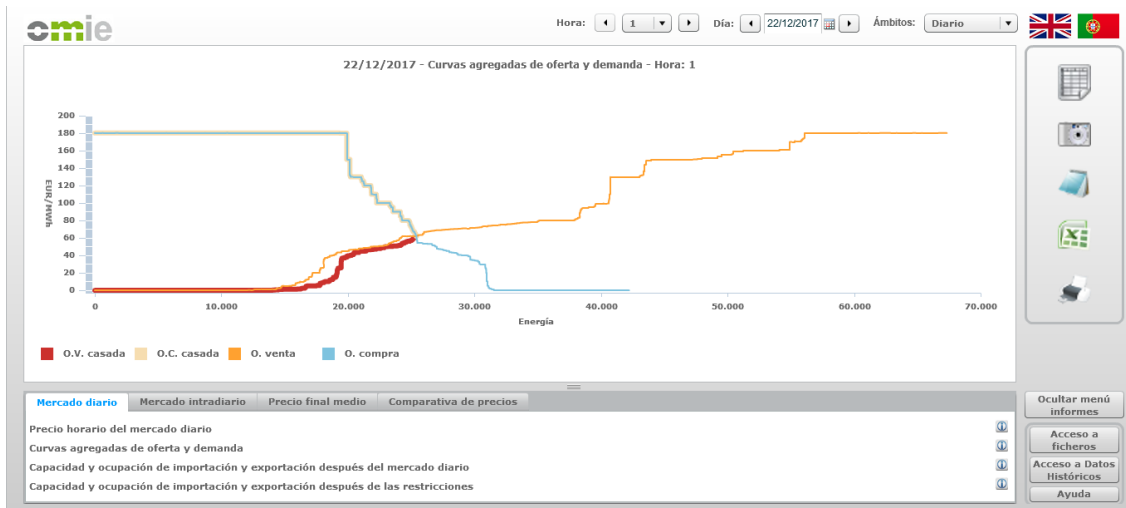


Figure 1. Aggregate curve for electricity. Source: www.omie.es

In this curve is relatively visible the minimum income condition. While the blue line refers to the bid offers and the orange one to selling offers, the red line refers to those selling offers that have been accepted in the matching process. The part of the orange line to the left of the crossing point refers to those offers rejected because of the minimum income condition. Other conditions are more complicated to observe since they do not have a specific impact on the curve.

3.1.2 Intraday markets

Once the day-ahead market has been cleared and the price set, every producer and consumer know its program and they must fulfill this program, otherwise they will be penalized. However, unexpected events may happen, for instance the boiler of a power plant breaks or there is a strike in an industry and its consumption drops.

These events change the actual production or consumption of the plants and force them into deviation from the initial program. therefore, it should exist a mechanism to change the program without being penalized. This mechanism are the intraday markets.

There are six intraday markets and their functioning is similar to the day-ahead market, but their meaning is different. These markets are meant to be balancing markets, each one of them allows to renegotiate the same hours that the day-ahead market, so agents can change their programs in case they foresee they will not be able to fulfill the day-ahead program. However, each one of them allows to renegotiate less hour than the previous one, since they approach the real time. In the next image it is resume the timetables for the day-ahead market and the six intraday markets:

INTRADAY SESSIONS Timetable

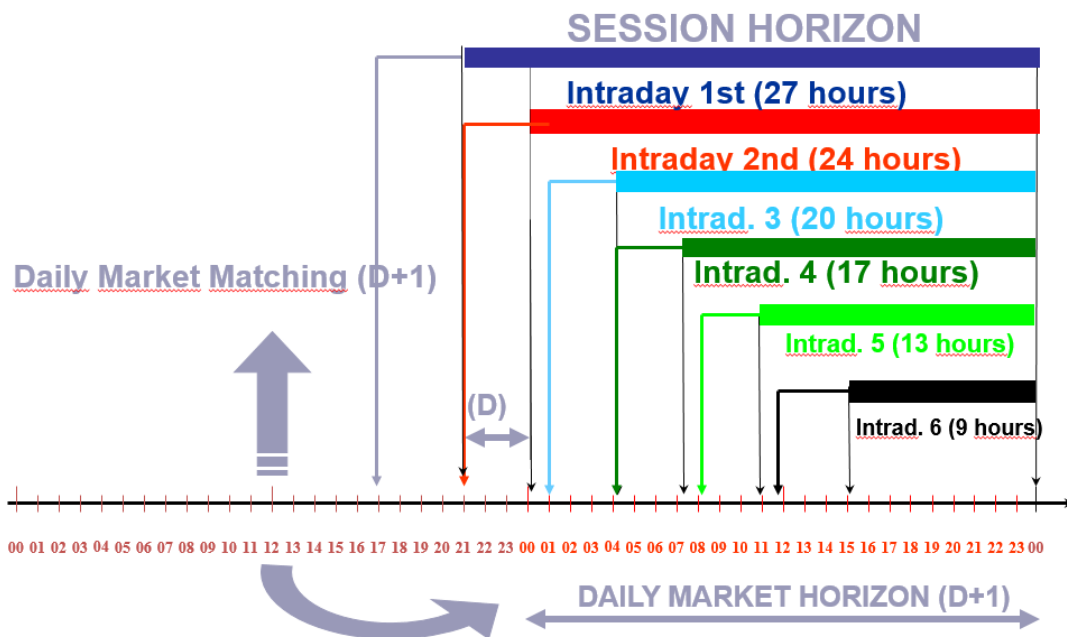


Figure 2. Timetable for the different markets managed by OMIE. Source: [OMIE17]

One difference between the day-ahead market and the intraday markets is that, while the first one is carried out in coordination with other European PX, the intraday markets are managed by OMIE alone for Spain and Portugal.

Additionally, the purpose of these markets is to serve as a balancing mechanism, therefore their liquidity is considerable less than the day-ahead market. This situation makes difficult for agents to come to these markets with the whole power of their plants in case they would not be committed in the day-ahead market. Furthermore, since the markets are for balancing purposes, these are not mandatory as the day-ahead is.

In terms of bids, there are also few difference between both type of markets. While in the day-ahead market is only allowed one bid per unit, in the intraday markets are allowed more than one bid. Moreover, this bid may have the opposite sign of the unit, this is, producer may buy energy with production unit and vice versa. However, this is only possible if the unit has a previous program, to say it clearer a power plant is only allowed to buy as much energy as it had sold in previous markets, and the same applies for consumption units. The final program of every unit has to be in consequence with its sign, selling units can only produce energy and consumption units are only allowed to consume energy [OMIE17].

In the case of intraday markets, it is possible to include complex conditions for the buying bids as the maximum payment condition. The list of the complex condition that may be used in the intraday markets is as follows [OMIE17]:

- Minimum income
- Maximum payment
- Complete acceptance of the first block of the bid

- Complete acceptance per hours of the first block of the bid
- Maximum energy
- Minimum number of consecutive hours with complete acceptance of the first block
- Load gradient condition

For simplification purpose, it will be explained below those conditions that are specific for the intraday market only. Those conditions in common with the day-ahead market have the same functioning in the intraday market.

Maximum payment condition

This condition is the opposite to the minimum income. Its purpose is to limit the amount of money that the agent has to pay in case its bid is matched. As the minimum income condition, this one consist in a fixed term of money and a variable term in €/MWh.

The existence of this condition in the intraday markets and not in the day-ahead market is because in these markets, power plants can also buy energy and not only sell it as mentioned above. This condition applies the same principles that the minimum income in terms of unifying the price of the bid so the whole bid has the possibility to be accepted [OMIE17].

Complete acceptance of the first block of the bid

This condition applies for both sale or purchase bids. In this case, if the first block of the bid is not fully accepted, the algorithm rejects the whole bid. This way the agent has the assurance that at the in the first block, the whole if the hours negotiated would be accepted [OMIE17].

Complete acceptance per hours of the first block of the bid

As the previous condition, this one also applies for sale and purchase bids. This condition allows that if one hour of the first block is not fully matched, that hour is fully rejected, but the rest of the block may still be accepted [OMIE17].

Maximum energy

Also, applicable for both types of bids. If this condition is active, the energy matched will be lower or equal to the declared value. Additionally, this condition can only be used without the load gradient condition, and it will only allow to send one bid per unit [OMIE17].

Minimum number of consecutive hours with complete acceptance of the first block

As the previous condition, this one also applies for sale or purchase bids. This condition allows to declare the number of hours that need to be matched so the whole bid is not rejected.

For example, if the declared value is 4, whenever there is a block of less than 4 consecutive hours of energy matched, the whole bid is rejected [OMIE17].

These are the complex conditions specific for the six intraday markets. Once the market is closed and the algorithm is run, it validates all the previous conditions for all of the bids inserted and compute the price for the market. It also draws the curve, which is similar to the day-ahead curve.

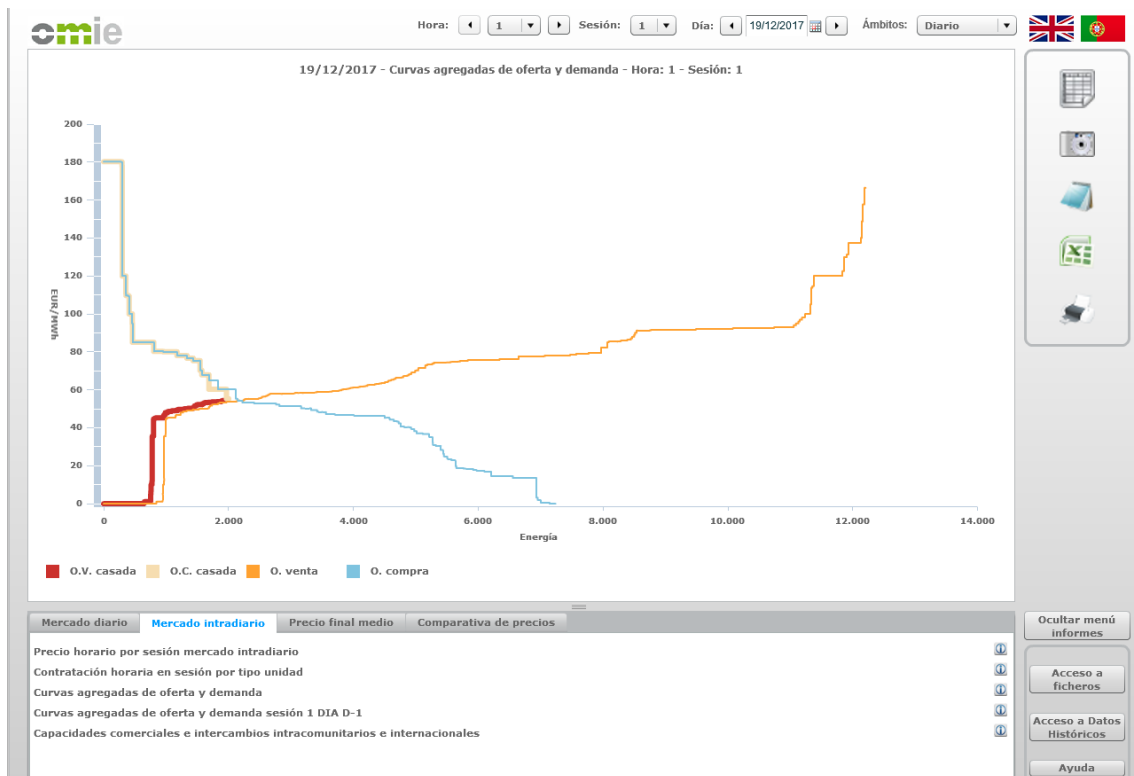


Figure 3. Aggregate curve for electricity for an intraday market. Source: www.omie.es

In this curve, in addition to the effect of the minimum income condition, it is possible to observe the effect of the maximum payment one.

3.2 REE markets. Secondary and tertiary reserve markets and technical constraint market

REE is the technical system operator (TSO), is at the same time the entity in charge of managing the grid and also the owner of it. As OMIE is a regulated company, but in contrast with the market operator, REE is partially owned by the government. 20% of the company is owned by the government while the 80% remaining belongs to private investors. REE also is an enlisted company in four Spanish stock Exchanges including the IBEX35[REE_17].

REE was founded in 1985, it was the first company in the world exclusively dedicated to the transmission of electricity and the operation of the electric system.

In the beginning, the company was created with a majority of public capital, made up of capital contributions of a group of public electric utilities but also private ones. At this time the company was in charge of 10.500 km of high voltage electricity [REE_17].

Although the company was mainly public when it was born, in the year 1.999 and important share capital of the company was privatized. Is in this year and the following when the company set its current structure of 20% public and 80% private [REE_17].

In technical terms, the company created the Control Centre of Renewable Energies (CECRE) in 2.006, a pioneering center for the control and integration of renewable energy in the electric grid. The company becomes a world leading company in the integration and managing of renewable energy in the grid [REE_17].

Is in this year, 2.006, when the company starts its role as operator of the electric systems in the Canary Island, the Balearic Island, Ceuta and Melilla. And in the year 2.007, REE becomes the sole transmission agent and operator of the Spanish electricity system because of the Law 17/2007 [REE_17].

Is in this period of the years 2.000s when the company undertakes some major international interconnection projects, for instance, the submarine interconnection with Morocco or the creation of the company INELFE (a joint venture co-owned with the French system operator), to carry out new electricity interconnection with France [REE_17].

In conclusion, REE is responsible for operating the electricity grid and assuring the electrical functioning of the Spanish system. It has to supervise the program builds by OMIE with pure economic criteria and check its technical viability. To carry out this task, REE employs some market mechanisms too [REE_17].

REE employs market mechanism to assure the stability and functioning of the grid. Between this market managed by REE are the secondary and tertiary reserve market and the technical constraint market. As it has been explained before, REE is in charge of more ancillary services markets, such as the imbalance market, however, from now on it will be only explained the markets studied in the present thesis.

3.2.1 Secondary reserve market

Before entering in the explanation of the different markets, it is important to clarify what are the reserves of the system and how REE uses them.

Between other mechanisms, REE uses a system of reserves for assuring the stability of the system and its functioning between appropriate levels. The system is divided into three reserves: primary, secondary and tertiary.

According to REE, the primary reserve is a mandatory ancillary service and not remunerated, provided by all the generators connected to the grid. The purpose of this service is to correct automatically instantaneous imbalances between generation and consumption. It is provided through the variation in power from the turbines of the generation through frequency variations mechanisms [REE_98].

After this first mechanism that correct instant deviations, it enters into action the secondary reserve. This reserve is not mandatory and therefore is remunerated, however, any agent willing to participate in this market must obtain a certificate for its production units, provided by the system operator.

The system is divided into regulation areas, and agents are requested to offer a regulation band for its units. In other words, each power plant may offer a band of variation of its power, to increase and to decrease its power. The TSO will assign these bands for each area based on economics criteria, and if it is necessary, it request agent to effectively provide that energy [REE_98].

As an extra backup mechanism, it is established the tertiary reserve. According to REE, the tertiary reserve is a voluntary ancillary service remunerated. The purpose of this reserve is to recover the energy provided by the secondary reserve. This reserve has to enter into action in a maximum of 15 minutes and must be producing energy for at least 2 hours [REE_98].

With these three levels of reserves, REE is able to ensure the service of electricity between a certain quality margins.

The secondary reserve market is a market with only one buyer, REE, and several sellers, those agents with power plants certified to provide the service. In this market REE compute the need of secondary reserve and ask agent to present their offers to provide the service.

The offers presented must contain the band that the power plant is able to provide with the price they are willing to sell it, in €/MW. Offers must contain the reserve of upload power, the reserve of download power, the price, the deviation of energy necessary from the existing program and the code of indivisibility. Companies are allowed to present different offer for the same plant, but only one with the indivisibility condition [REE_98].

In the assignment of energy, the TSO will take into account two terms, on one hand that in every area is possible to fulfill the security criteria; on the other hand, the economic term. The TSO will assign those offers which would represent the lowest cost to the system. In case of two offers with the same price, the TSO will carry out a proportional distribution of the energy assigned. Finally, the price paid for the band will be the marginal price resulting from the last offer assigned [REE_98].

In addition to the band provided, the TSO will pay if that energy from the band is finally requested. The price for that energy will be the marginal price of the tertiary reserve energy necessary to replace the secondary reserve. The method to compute this tertiary reserve price will be explained in the following point.

To sum up all of the concept above, the secondary reserve market is a marginal market where several sellers (agent) sell their services to one single buyer (REE). Although actual energy provided is remunerated in addition to the remuneration of the band, this thesis will analyze the behavior of the price regarding only the band, since the price for the energy supply will be analyze in the tertiary reserve market.

3.2.2 Tertiary reserve market

As the secondary reserve, the tertiary reserve is an optional and remunerated service by market mechanisms. The purpose of this service is to restore the energy of the secondary reserve employed.

The definition of REE about tertiary reserve is: “the maximum programmed power variation that one unit is able to accomplish in a maximum time of 15 minutes and keep during at least 2 hours” [REE_98].

As in the secondary market, this service will only be provided by those agents certified by the TSO. Which will give the authorization to those units that demonstrate their technical capability to fulfill the service [REE_98].

The offers presented by agents are similar to the secondary reserve offers. They must contain, for each hour, the maximum reserve available, both upload and download energy, with the price requested in €/MWh. The energy will be requested by the TSO in an economic order, but it will be paid to all of the providing agents at the same price, the price of the last used plant [REE_98].

In the case of the tertiary reserve there is only one remuneration, and is for the actual energy provided, and not for the band. There is also one more difference with the secondary reserve,

in this case, there is a distinction between the price paid for the upload and download energy. While the price paid for upload energy is the described above, the offer for the download energy has the character of the price of rebuying the equivalent energy not produced [REE_98].

3.2.3 Technical constraints market

This is probably the most complex market of all of the market analyzed in this thesis in its functioning. First of all, this market is mandatory for every production unit. This is not a marginal price market every unit is paid what they request for the service. In addition, in the assignment of units for this market will intervene not only economic criteria, but also technical one. The technical constraints will be related to specific areas, so just few units will compete in each area, and not the whole of the system, or a great percentage of it at least as in the other markets.

All of the issues mentioned above, and more that will be explained in the following paragraphs make of this market a very complex market to understand. This thesis aims to explain and clarify the functioning of this market, that is specific for the Spanish system, and try to investigate and analyze the main drivers of the price of this market.

The principal purpose of this market is to solve the technical constraints created in the program of the day-ahead market, which a pure economic dispatch. The TSO will analyze the resulting program from the day-ahead market and identify the possible restriction that would appear in the grid if no action is taken.

Once the final program from the day-ahead market is communicated to the agents, the TSO opens the period of reception of offers for the technical constraint market.

As said before, all selling unit has the obligation to present their selling offers. This obligation will apply over the total energy available of the correspondent unit after the energy programmed in the day-ahead market or in a bilateral contract [REE_15].

In addition, the same selling units have the obligation to present purchasing offers for the energy programmed in the previous market [REE_15].

The offers will be, generally, simple bids. The offer must contain for both, upload and download energy, the energy offered and the price. The offer may be divided into up to ten different blocks with different prices. These blocks will have an increasing price for selling offers and vice versa for purchasing ones [REE_15].

For selling unit corresponding to thermal power plants is allowed to present complex bids. These complex bids will have four terms: incomes for maintaining the plant coupled to the grid for one hour, incomes for unit of energy produced, incomes for a cold start-up (more than five hours after the plant stopped), incomes for a hot start-up (less than five hours after the plant stopped) [REE_15].

These complex conditions will only be taken into account when the correspondent unit have no previous program, this is, the power plant is shut down.

The process of technical constraints will consist in two different phases: phase 1, modification of the previous program for security criteria; and phase 2, rebalance of production and demand [REE_15]. It is important to explain that the analysis carried out in this thesis will refer

only to phase 1, since this is the phase where power plants are assigned and paid for providing the service.

In the technical constraint assignment process, the first term taken into account is the technical. In case of more than one valid technical solution, the TSO will assign the one that represent the lowest cost to the system. In case the cost is the same, the criteria are the lowest movement of energy. After that, renewable and cogeneration will have preference before thermal plants [REE_15].

It is important to remark that the economic criteria and therefore, the remuneration, is not marginal, but for the whole offer presented. In consequence, it is relevant not only the price offered, in €/MWh, but also the energy offered, because the final cost will be the product of multiplying both terms.

In the process of technical constraints, the ones with major economic impact are those related to increments of energy. This thesis will focus only on the increment of energy process of phase 1, since it has been considered this as the most important in economic terms.

Now it has been explained briefly the different markets that will be analyze in the present thesis, it is time to move on to the next topic of the report, the day-ahead market simulator.

Chapter 4. Day-ahead market price simulator

This is the first chapter of the three core topics of the thesis. As it has been stated above, the day-ahead market is the most liquid one and is the one that has the highest impact on the final price of electricity.

Due to the importance of this market, there is more literature about this topic than about the rest of the markets analyzed. However, it has been considered relevant to carry out a study about this market to offer a complete vision about the different market processes and mechanisms.

4.1 Introduction

As said in the introduction chapter, there are many approaches to build a market price simulator. In this thesis, the approach chosen has been the statistical, based on historical data about prices, distribution of the energy supplied into technology or fuel prices.

The statistical approach, as any other technique, has its pros and cons. In the cons side is the fact that some information is lost, for instance details about power plants or interconnections, since they are not needed in contrast with fundamental models. It also required of complex statistical models and a high degree of investigation to obtain an accurate model. However, the statistical model simplicity when presenting the data makes them easy to understand, and a very interesting option to make studies about behavior of different markets.

Throughout this chapter it will be explain the process to obtain the simulator, the different inputs and its level of impact on the price. It also will be explained the different approaches taken to obtain the simulator, since there is not a unique way to predict correctly the price, but each situation requires an adaptation of the model. And finally, the exposition of the different results obtained with the different models and a brief explanation of them.

4.2 Relevant input

The first step in the way of building a price simulator was to decide which ones were the input to be taken into account. It was necessary firstly to identify the different drivers of the market and secondly the different levels of impact that they had.

It is obvious that, as in any other market, the first rule followed by it was the law of supply and demand. This means that the higher the demand, the higher the price. And this is true up to a point. In the following images are represented graphs with the demand in the x-axe and the price of electricity in the y-axe for the year 2.016.

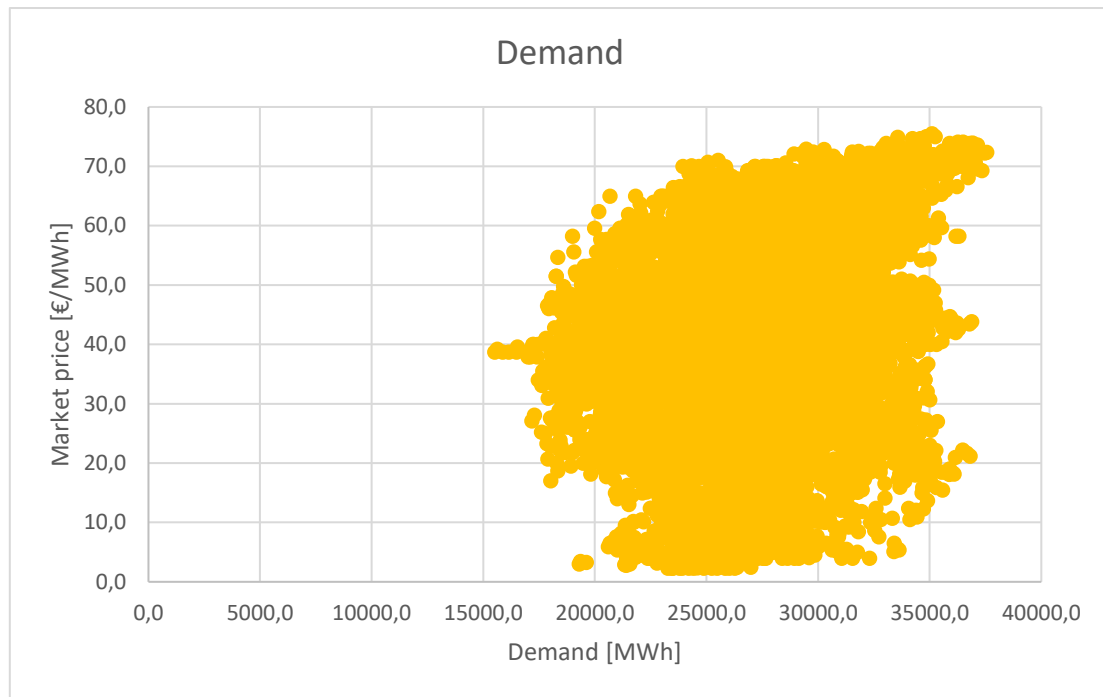


Figure 4. Demand vs market price. Source: own elaboration from [ESIO17]

As it can be seen in the figures above, there is a certain relationship between demand and price, however, the connection is not strong enough to make a simulator only based only on demand data. The reason for such a dispersion is in the fact that electricity is a complex commodity, with a complex technical infrastructure behind that makes less obvious the drivers of the price.

While the side of the demand is more or less homogenous, with a predictable behavior; the side of the supply is more complex in structure and functioning. First of all, there are different technologies supplying the same good, each technology with their own structure of costs and its operation complexities. From the renewable energies with free fuel but inconsistent production, to thermal power plant which main cost is the fuel price, that has its own drivers.

It was necessary to drive a study about the different technologies and their behavior in the market, to be able to discriminate between those that have high impact in the price, and those that have few impact. For instance, renewable energy has zero variable cost or very low at least, on the other hand, is a very intermittent energy. For this reason, renewable energy rarely sets the price, this makes that although its impact on price is very huge, this energy gives no information to predict the market price. With this reasoning it was decided to subtract renewable energy from the demand and see if the correlation was strong. This graph shows the demand minus the renewable energy in contraposition with the market price. It has been considered as renewable energy wind and solar power, since hydro power has other different characteristics.

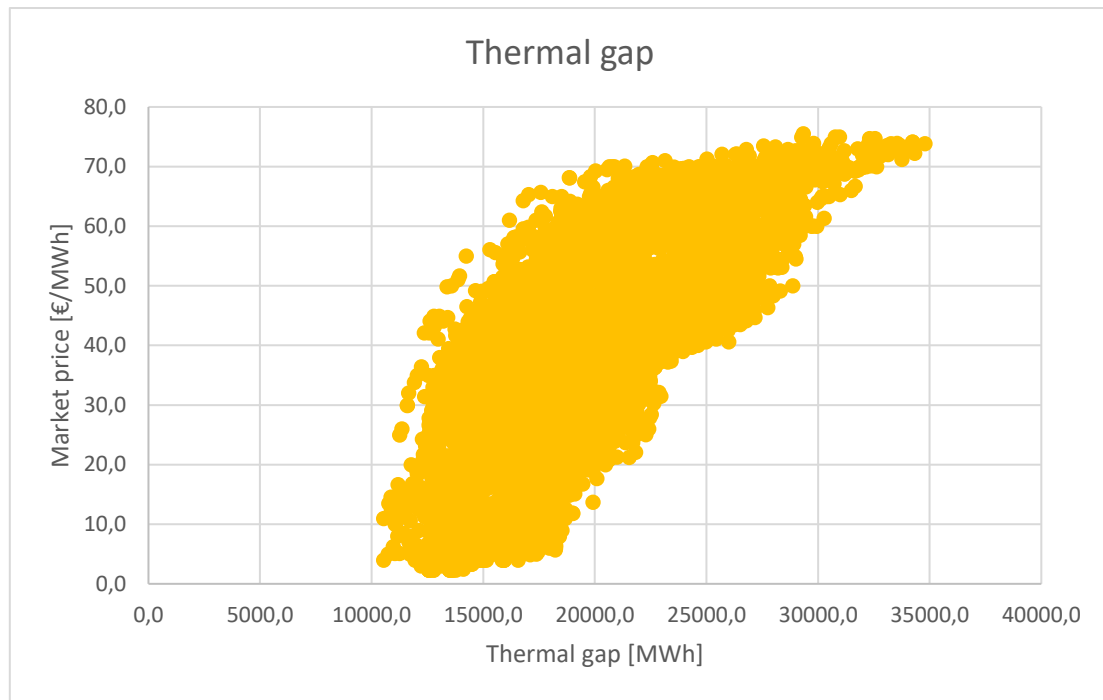


Figure 5. Thermal gap vs market Price. Source: own elaboration from [ESIO17]

This remaining energy has been called thermal gap, in reference to the energy that comes from thermal power plants.

Another technology to study separately was the nuclear energy. This type of power plants has very low variable cost, although is higher than renewable, and would set the marginal price in many hours along the year. But this technology has the particularity that, for security reasons, must always work at its nominal capacity. This peculiarity makes the agent that manage these plants to bid to zero prices, since they need to ensure that the power plants are committed. Another option would be to compromise these plants into bilateral contracts. The results either ways are that nuclear technology has no impact in the price of electricity, since it is not bidding at its real cost.

For this specific reason, it was decided also to subtract the energy produced by nuclear technology from the load and see if the relationship was even stronger.

There is a technology in a situation similar to nuclear energy, these are the cogeneration power plants. These devices are installed by industries with a huge necessity of heat, to produce electricity with the exhausted heat as a by-product. The main activity of these industries is not the production of electricity; hence, their bids are not driven by electric market behavior. For this reason, as in the case of nuclear energy, this technology has little impact on the price of electricity, and it was decided to subtract also from the demand. In the following graph is possible to see the results.

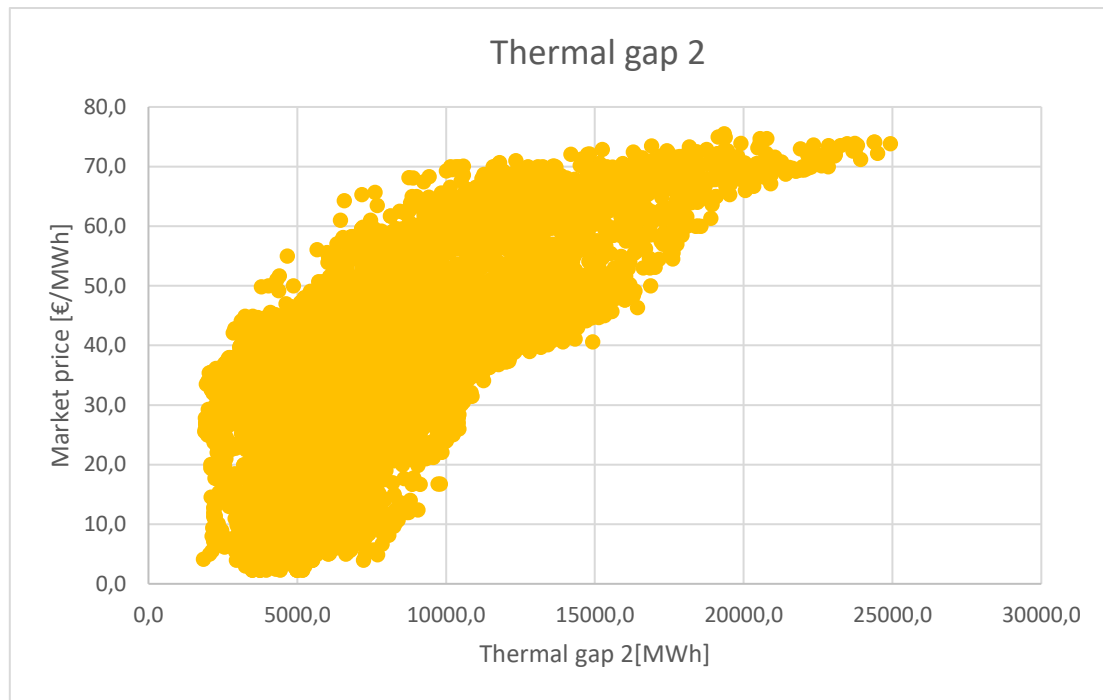


Figure 6. Thermal gap 2 vs market price. Source: own elaboration from [ESIO17]

In this graph the dispersion curve formed is more stylized, moreover for high values of the Demand. However, it still exists a huge dispersion in the relationship, the reason why this data is still not valid to start building the simulator. It has been decided to call this new energy thermal gap 2, in order to make manageable the different terms.

Nevertheless, it is important to remark one basic statement, agents bid based on predictions. Until now every data considered were taken from actual demand and production, but agents do not have the real-time information when designing their bid strategy, they can only use predictions. In consequence with this reasoning, the next step was to compare the price with prediction data.

REE publishes in its website www.esios.ree.es predictions of demand, wind and solar power. On the other hand, nuclear power plants always work at the same rate, so it is possible to compute and estimation of their production for the day ahead. Finally, the cogeneration works based on industrial schedule, which is also relatively constant and predictable. For the nuclear and cogeneration energy it has been assumed that their estimations will coincide with their actual production for simplicity purposes.

In the following graph is possible to see the relationship between market prices and the demand³ of the previous figure, but with prediction data.

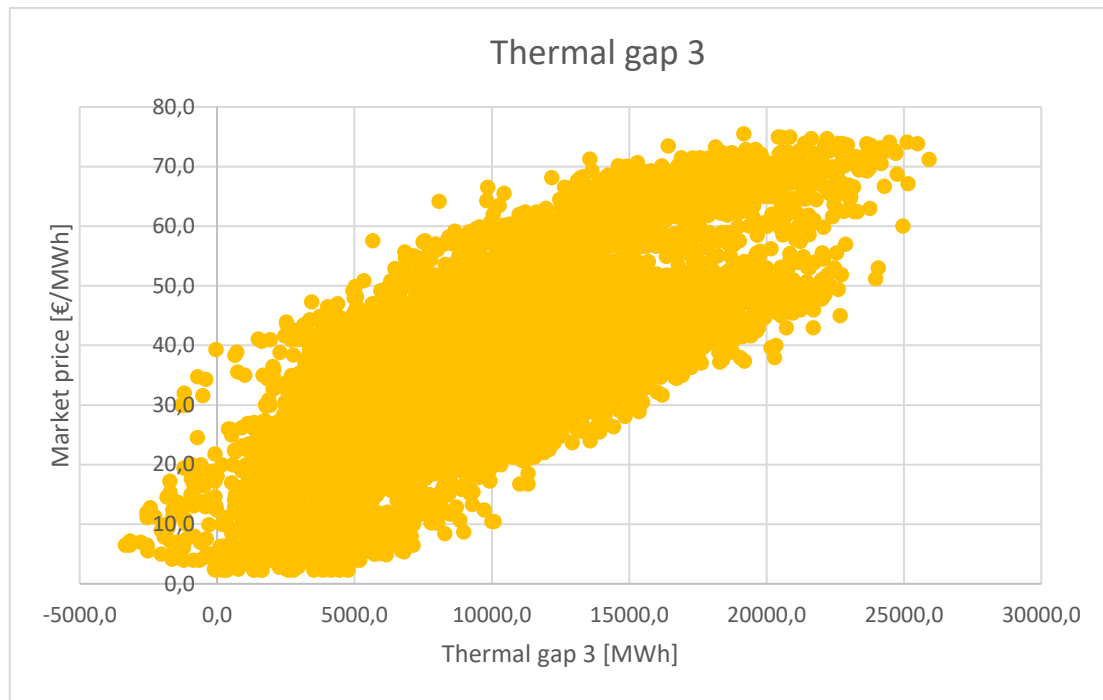


Figure 7. Thermal gap 3 vs market price. Source: own elaboration from [ESIO17]

In this case, the relationship is even more linear than in the previous assumptions. It is remarkable a zone with negative values for the x-axis, this is simply because of forecasting errors in the demand that makes those values useless, and they will be treated properly when designing the simulator.

When it has been subtracted the technologies mentioned above, it only remains three major types of energy: Coal, CCGT and hydro. For coal and CCGT it is not necessary to explain in much detail, these are the two most expensive technologies, their costs mainly depend on fuel and they will set the marginal price in most cases.

On the other hand, the reason that hydro remains in the function and the relationship becomes that linear is not that obvious. It is important to clarify that hydro means only big hydro power plants. This type of technology has the ability to store water and produce at any desired time. In addition, this is one of the cheapest technologies, since the infrastructure is built, and the cost of the fuel is almost zero, because it is water that comes from the rivers. Nevertheless, this combination of storage and cheap fuel has a price, what is called “water value”, this means that in a market environment water will be used to replace the most expensive technology, therefore it will be most time in the marginal price. For all of the reasons explained, it is not possible to take off hydro power from the demand.

An additional point that it is worth analyzing in this report is the direct influence of the renewable energy in the price. As it has been demonstrated above, when these technologies are subtracted from the demand, the relationship with prices becomes a lot clearer, therefore, it would be interesting to check its direct influence in the price. In the graph below, it is shown the relationship between renewable and market price for one year.

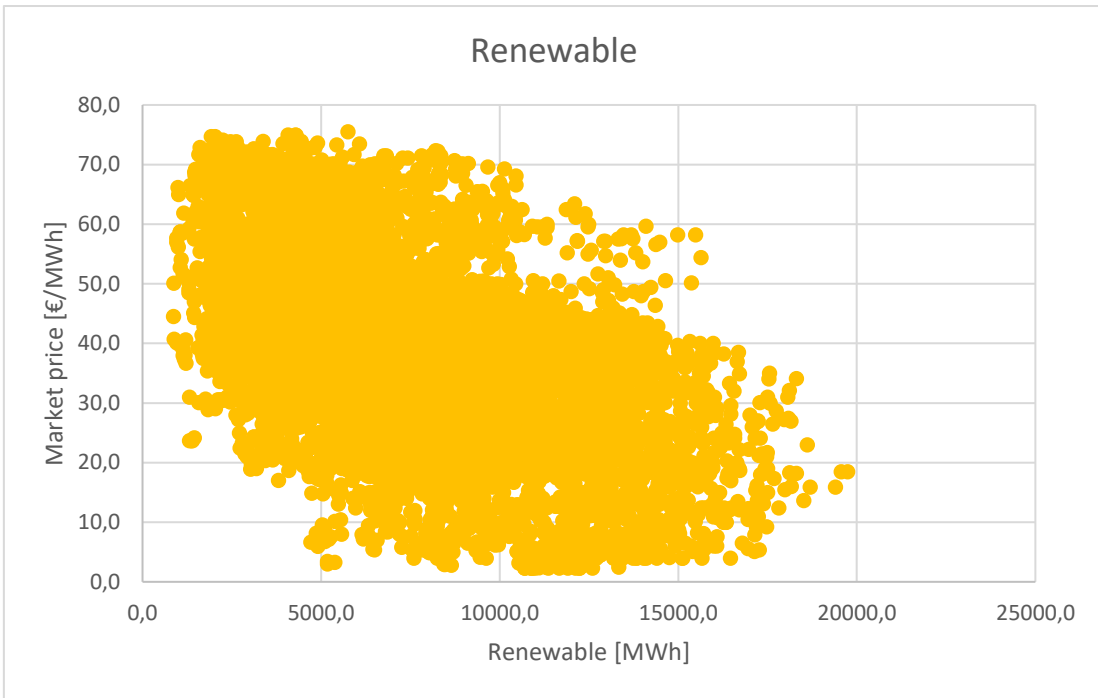


Figure 8. Renewable vs market price. Source: own elaboration from [ESIO17]

As expected, the relationship is just the opposite as with the thermal gap, the more the renewable the lower the price. However, the dispersion is higher because electricity markets are influenced by other factors with higher impact. In consequence this will not be used as a drive alone, but with other inputs like the thermal gap.

Now it is shown the relationship when the values of renewables are forecasted values instead of actual production.

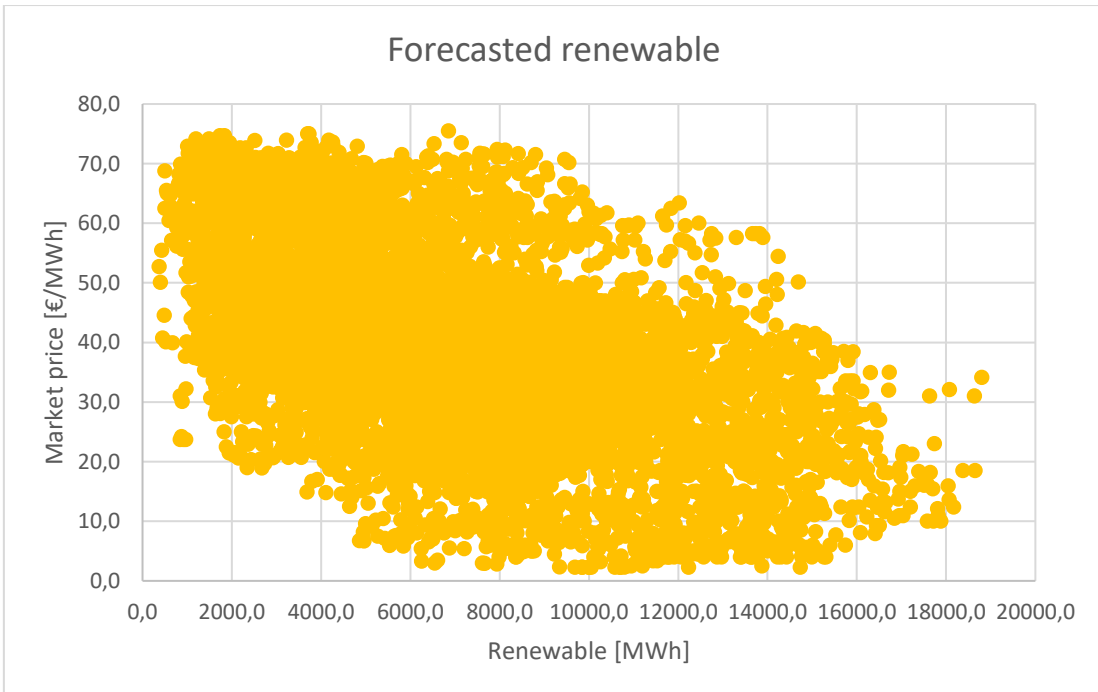


Figure 9. Forecasted renewable vs market price. Source: own elaboration from [ESIO17]

In this case the relationship remains almost the same. It can be concluded that the amount of renewable produced has a notable impact in prices, but it is not the higher influencer, and it cannot be used alone to construct a market price simulator.

With the studies shown above is now possible to start investigating and designing the simulator and the relationships between inputs and market prices, it would be taken into account the forecasted values but also what has been called Thermal gap 2. With these two sources, it would be possible to compare results and see the behavior of the simulation in both cases. The task now would be to find the methods to forecast prices with the given information.

For the study carried out to develop the simulator has been used data from the year 2.015 and 2.016. It has been considered that the length of two years is enough to have a reliable model. The process was to use the data to the develop the forecasting tool and testing it with the actual results to evaluate the quality and reliability of the model.

4.3 Different approaches

In this report it has been developed two major approaches subdivided into different theories and studies. These two major ideas are the analysis with one variable, only thermal gaps inputs, and the analysis with two variables, thermal gaps plus renewable inputs.

It has been considered to employ the mean absolute error (MAE) and the mean absolute percentage error (MAPE), following Weron's recommendations [WERO06]. It is also remarkable to expose the maximum error to know how far from the actual solution it the prediction may be. In order to not to saturate the report with unnecessary data about all the forecasted prices and their errors, it will only be showed the most relevant features of each approach.

4.3.1 Single variable models

Once the most important drivers of market price have been analyzed, is now time to find the way to properly connect the inputs with the price. As a first step, it was decided to obtain a unique equation for the whole year from the graph above and apply that formula to the whole next year. The equation employed will be based on a logarithmic approach computed by the software Excel.

In the following table it is observable the MAE, MAPE and the maximum error if the basic approach is taken. The year 2.015 will be used to obtain the equation, and the year 2.016 to test its effectiveness. To clarify, for the prediction made with forecasted values, it has been deleted those invalid values, considered as invalid a value lower than a thousand.

Parameters of the equation		MAE	MAPE	Maximum error
m	n			
23,38	-162,3	13,40567954	51%	42,74036067

Table 1. Results of the basic approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Parameters of the equation		MAE	MAPE	Maximum error
m	n			
	19,73	-130,48	12,25392642	49%
				40,91098871

Table 2. Results of the basic approach for Thermal gap 3. Source: own elaboration from [ESIO17]

As it can be seen, the results are quite far from the ideal results desired. The problem lays on the fact that there is a lot of dispersion applying the whole year at the same, it is necessary to discriminate the year into different groups and apply the correct group to forecast each day.

As expected, the set of forecasted data provides a better solution, although the difference is minimum. This is due to the fact stated before that agents bid based on predictions, not on actual production. Obviously, this is not relevant since both approaches are not precise enough and more investigation must be carry out.

If it is plot the behavior of the price it can be seen a few patterns that should be taken into account when constructing the model. The same way that demand varies with the year, the seasons, the days of the weeks or the hours, the price would change with those factors. It is not the same a Monday, when the society starts its weekly activity than a Friday, when the case is just the opposite. The same thing happens with a Monday in January, during the cold season, and a Monday in August, with the hot season and the majority of the society in vacation. In the two following figures can be seen the seasonal behavior of prices, as much as the weekly behavior.



Figure 10. Weekly behavior of market prices. Own elaboration from [ESIO17]

Here it is represented three consecutive weeks of February 2015. It can be observed the difference between the weekdays and the weekends, when prices go down following the demand tendency. Even between the days of the weeks exist few differences, for instance, prices start growing from Monday to Wednesday and then dropping until Friday.



Figure 11 Seasonal behavior of market prices. Own elaboration from [ESIO17]

In this figure it is represented the prices of the electric pool for the year 2.015 and 2.016, it is important to clarify that the curve has been smooth to make it more comprehensible. Although both years are completely different respect to price behavior, there are some patterns that may be observable. For instance, prices tend to be lower during spring and higher in cold months, despite year 2.015 was more expensive than year 2.015. This behavior should be taken into account when developing the model, and a season coherence would be useful in the model design.

4.3.1.1 Forecast based on a discrimination by days

After trying the basic approach, forecasting one complete year with one unique equation based on one whole year of data, it was decided to carry out a forecast based on a discrimination by days.

During the present part of the thesis will be presented different approaches base on a discriminatory model by days. As shown above, market prices present two major behaviors, the seasonal and the weekly, with this type of method it is pretended to capture that effect on price to get a better approximation to real prices.

Forecast based on the day before

In the introduction has been tried to predict a whole year with the year before, as a whole, in consequence the results were not accurate enough. The next step is to reduce the length of the input data, as much as the scope of application. In this case it will be use the day before to forecast the next one.

Due to the considerable difference between weekdays and weekends, it does not seem wise to employ Fridays to predict Saturdays or use Sundays to forecast Mondays; results will not be valid at all. For that reason, this simulation has been divided into two types of days: working days and non-working days, including in this category festive days. Non-working days will be analyzed apart in a specific section for them.

For working days, it has been used the method of the day before. Although for Mondays the inputs would not be the most desirable, this will allow to test the performance of this supposition.

Before a methodology is employed, it is important to check properly the relationship between the thermal gap and market prices in the short term. This is, when it is plot the relationship for a single day, it is possible that the function changes from a logarithmic to any other. In the following figure it is shown the dispersion graph for a typical single day.

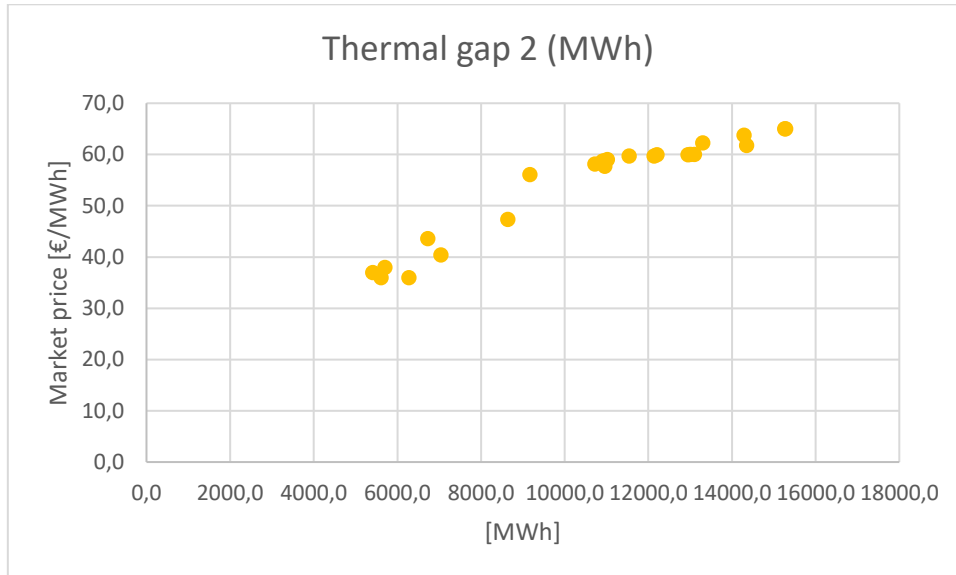


Figure 12. Thermal gap 2 vs market price for a single day. Source: own elaboration from [ESIO17]

In order to not to fill the report with numerous graphs that would prevent from a correct understanding, it will only be shown the relationship with values of actual production, since both types of results are similar.

As it can be seen in the graph, the relationship changes when it is only taken into account a single day. Now it can be observed a more linear relationship, therefore, it will be taken a linear formulation. It has been decided to approximate the curve by a quadratic function to adapt it better to the values.

With the previous reasoning, it has been performed the forecast for the year 2.015 and 2.016 with the method of the day before. In the following table are shown the results for working days using as input data the Thermal gap 2 and 3.

MAE	MAPE	Maximum error
7,75727768	22%	588,868585

Table 3. Results of the day before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,6231436	10%	85,00275895

Table 4. Results of the day before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

As it can be seen, the improvement is notably with the new methodology. Both MAE and MAPE have been reduced considerably for both types of input data. When data used to build the forecast, equation is brought near to the data that is going to be predicted, forecast is

more accurate. The reason is that the farther day of the input data from the day predicted, the more obsolete that information is going to be, in consequence, the less accurate the prediction.

On the other hand, there is an indicator that has increased its value, this is the maximum error, although the increment between the results of thermal gap 2 is quite higher than for thermal gap 3. The explanation for this increment is simple, when approximating the input data to the forecast day, less data is used as a model, therefore it is more likely that a value forecasted lays outside the equation and the result it gives, would not be valid. To solve this problem, the next methodology tested will contain five days instead of just the day before, there would be more data to form the equation.

There is another interesting fact, despite the increment for the maximum error is notably with both types of data, it is considerably lower for thermal gap 3 data. As it has been said in the previous paragraph, if a point to forecast lays outside the input data, the prediction will not be good. However, a data of production, like the ones taken for thermal gap 2, will deviate more frequently and in a higher proportion than a forecasted date, like the thermal gap 2, since predictions are based on previous information.

As a primary conclusion for this methodology, it can be affirmed that it improves the results in terms of MAE and MAPE but it increases the maximum error. In other words, it provides better solutions in general but the dispersion of the extreme is highly increased. It is proposed to solved this issue by taking a wider range of input data.

Additionally, in order to capture the weekly effect, the next methodology will take as input data only data from the same day of the week: Mondays for Mondays, Tuesdays for Tuesdays...

Forecast based on the seventh day before

This methodology aims to capture the weekly effect but also to reduce the maximum error, in consequence, it will take two days as input data and will use the same day of the week only. It has been considered to take only two days because more days in the past could not be useful, since the situation of the system may have change enough to invalid the data.

In addition, it has been changed the type of equation taken to forecast prices. Instead of employing a second order equation, it will be used a first order equation. With this change, the forecasted curve will lose precision in the points in between the input data, but for those data outside the inputs, the solution will not be as far as in the case before. In the following table can be seen the solution for this methodology.

MAE	MAPE	Maximum error
7,13931517	19%	84,69182846

Table 5. Results of the seventh day before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
4,21645807	12%	35,69808644

Table 6. Results of the seventh day before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

It can be seen that the purpose of this methodology has been achieved, the maximum error has been reduced for both types of data considerably. It is remarkable also that the tendency

is maintained, the set of forecasted data gives a more accurate solution and more reduced maximum error. This indicates which will be the final set chosen to forecast prices in the future.

One more interesting fact, while MAE for actual production data has been reduced in more than 0,5 points, which is a considerable number at this point of the study; MAE for forecasted data has been increased almost the same amount. The reason may lay on the usefulness of predicted data. While production is a fact, prediction may be obsolete with time, and a two weeks old forecast may not be as valid for the computation of prices.

Since this methodology does not improve MAE factors in a notable number, a new methodology is needed. The next theory will try to compute more accurate prices while keeping the maximum error under acceptable levels.

Forecast based on the five days before

Previous methodologies were based on just one or two days to elaborate the predictions for market prices. In one case it was by taking only the day before to the forecasted, on the second one it was based on two days before but of the same type (Mondays would serve only for Mondays and so on). Since the second approach employed does not seem as useful as expected, this new methodology will be based on previous days, without considering the day of the week.

Before computing any forecast, it is important to plot the relationship between thermal gap and market prices, because it may change for a five days of data input. In the following figure it is shown the relationship with thermal gap 2. As before it will be only shown for one set of input for simplicity purposes.

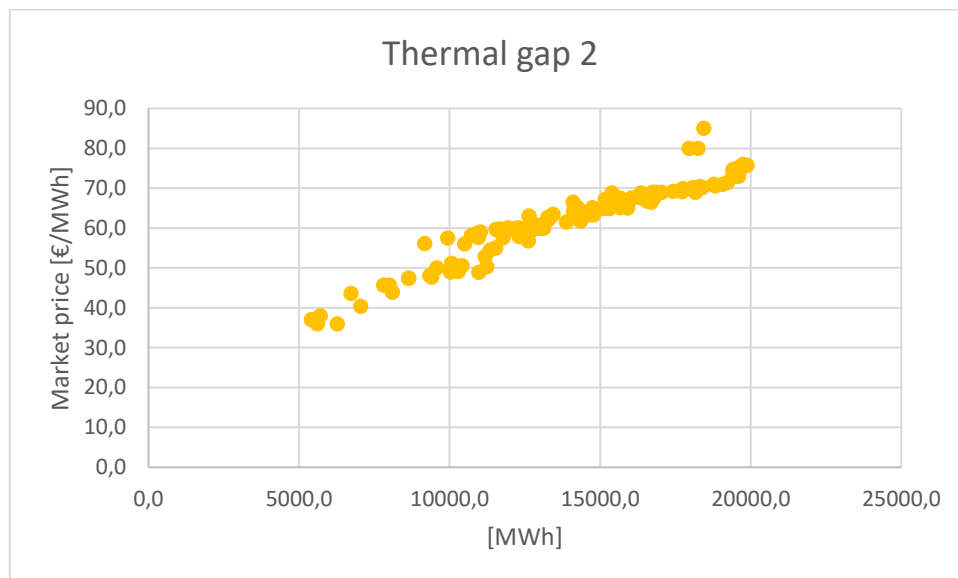


Figure 13. Thermal gap 2 vs market price for five consecutive days. Source: own elaboration from [ESIO17]

As it can be seen, the relationship remains quite linear, however, it will be employed a second order function to compute the model. This new hypothesis will take into account the five previous days to the one desired to be forecasted, therefore this will be enough to reduce the maximum error, and a linear approximation will not be needed. The purpose is to use a wider range of input data to keep the maximum error in a reduced number, but also use this bigger set to adjust better the forecast and capture the effect of a whole previous week.

As in the two cases above, this study will only apply to weekdays, weekend day will be analyzed apart. In the following tables may be seen the results for the new hypothesis.

MAE	MAPE	Maximum error
5,42829108	15%	98,55949333

Table 7. Results of the five days before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,19715265	9%	34,67125521

Table 8. Results of the five days before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

In this case, MAE factors have been reduced in a considerable amount, for thermal gap 3 the value is close to 3 €/MWh, which it may be considered a relatively good value at this point. The new methodology has been able also to maintain maximum error under the same values, although for thermal gap 2 is still a high value.

With this last theory, it is finished the section of approaches based on a whole day and single variable. As preliminary conclusion, MAE factors have reached interesting level to be the first step, however, maximum error parameter should be reduced in the following sections if a reliable forecast method is desired.

Before introducing the next set of approaches proposed, it must not be forgotten the so called non-working days. The next point of the report will analyze briefly an approach to forecast this type of days, which have some peculiarities that should be taken into account.

Non-working days forecast method based on a discrimination by days

Non-working days have been considered those days corresponding with weekends and festive days also. These days have some specific conditions that required them to be analyzed separately.

The first reason to study them apart is their load. This type of days has a very low demand with respect to their predecessors and successors, therefore, it is not wise to use ones to forecast the others.

Additionally, the behavior of their load is notably different with respect to working days, so employing them to predict non-working days will provide not valid solutions. For the previous reasons, it has been considered to analyze these days separately.

Once it is clear why these days should be treated differently, it is time to analyze their behavior and propose a method to analyze them. The three methodologies proposed for working days were: the day before, the two seventh days before and the five days before.

The first one cannot be applied in this case, since in most cases it would be used a Saturday to forecast a Sunday, and between the two days there exist a lot of differences. There also some festive days with their particularities, and one of these days would be used as input for a Saturday for example, which is not completely correct either.

The second one would be interesting since it would allow to use the same type of day to make the prediction. However, there are not a proper previous day for festive days, included also in this category.

The third methodology does not appear a bad choice at first, since it takes into account the last five days, it would include a wide range of data and at least one day of the same type as the one forecasted. However, five days back, when it is only considered non-working days, may be too much time in the past, and some data must not be valid for the prediction.

In conclusion, it appears that previous formulas are not good enough for this kind of days. It has to be elaborated a new methodology for this particular days. The conditions are to have at least one day of the same type in the input set and to have a wide range of input data but not too big that data will be obsolete. To fulfill these two terms, it is proposed to use the last two days, this way it will be available at least one day of the same type and the range will be wide enough but not too much to be obsolete.

Now that the methodology has been decided, it has to be chosen the type of equation that will be employed to elaborate the forecast. To do that, it is important to see the behavior of market prices with respect to thermal gap, as seen in previous studies. The simplest method to observe how market price relate to thermal gap is to plot in a dispersion graph as it has been done before. In the following figure it is shown the relationship between thermal gap 2 and market prices for two consecutive non-working days.

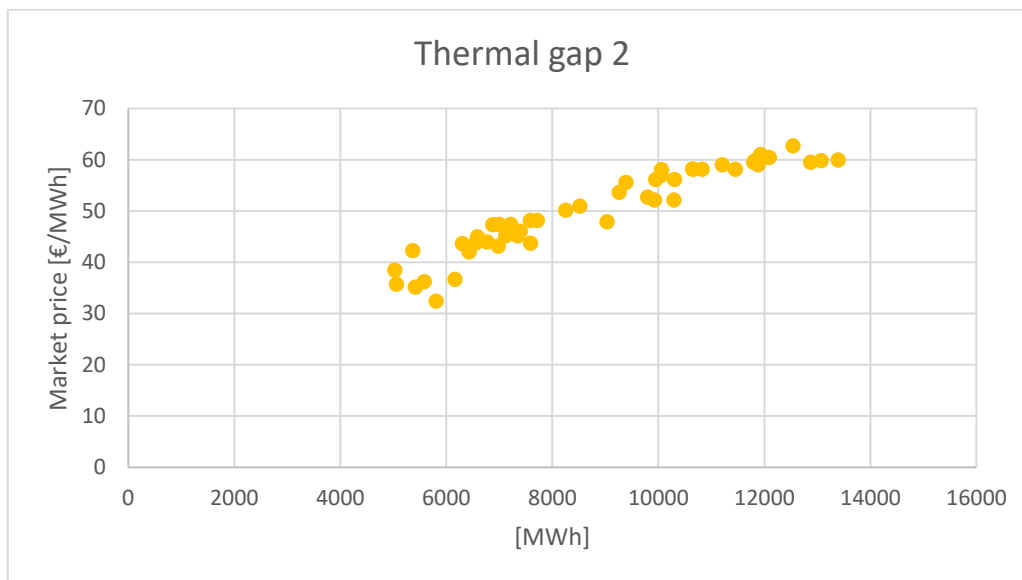


Figure 14. Thermal gap 2 vs market price for two consecutive non-working days. Source: own elaboration from [ESIO17]

It can be seen that the relationship between thermal gap 2 and market prices is similar to a linear function. Although for small values of thermal gap it more remarkable the dispersion of the data, the approximation function chosen will be a linear one, since it has worked well in the studies before. This type of approximation also is able to provide less fluctuation when the data forecasted is on the limit of the input range.

In the following tables may be seen the results for this new methodology applied to non-working days.

MAE	MAPE	Maximum error
8,41413919	32%	131,9210047

Table 9. Results of the two days before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
4,00742421	10%	21,39648823

Table 10. Results of the two days before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

As expected, results are less accurate than for working days. It has been explained above the difficulties when forecasting this type of days, therefore, results expected were less precise. Despite the particularities of non-working days, it can be affirmed that results are quite good and very similar to the best results obtained for working days. MAE for thermal gap 3 stays close to 4 €/MWh, which is only one points above than for working days. While maximum error remains below 25 €/MWh, which is even lower than the value obtained for working-days.

With the results provides by this methodology, it can be affirmed that it will be used just one methodology. Since it is considered the solution accurate enough based on the experience of previous studies. Also, these types of days are complicated and it is believed that a better solution will not be possible with these current techniques.

Now it can be considered the last approach used taking into account a discrimination by days. The next step will be to analyze the problem from a different perspective but taking advantage of the previous knowledge and conclusions. For instance, it is important to remind both the seasonality of market prices and the weekly effect. These two issues should be taken into account in the following approach if a proper model is desired.

4.3.1.2 Forecast based on a discrimination by hours

As explained in the section before, it is important to capture the seasonality and the weekly effect of market price in any methodology employed. Additionally, it has been observed remarkable differences between the hours of the day. These new set of methodologies will exploit these differences between hours to try to obtain a better output.

The discrimination by hours' methodology means that, for example, to forecast the first hour of a given day, it will be used only the firsts hours of previous days. The model will be able to capture the different behavior that have the different hours during a day.

The different methodologies will increase the number of hours taken as input data, but not as much that the seasonality effect is lost. So as to say, the first propose methodology will take ten hours back from the forecasted hour, and this number will be increased by five up to thirty hours back. It is considered thirty as a good number to not to be affected by seasonality.

Before showing results, it is important to remark that, as in the previous scenarios, the methodology will be applied separately for working day and non-working days.

Forecast based on the ten hours before

The first approach will take as input data the ten previous hours to the one forecasted. But before computing forecast, it is important to find the best function that approximates price, as done before. In the next figure it is shown the relationship between market prices and thermal gap 2 for ten consecutive hours, in this case hour 1.

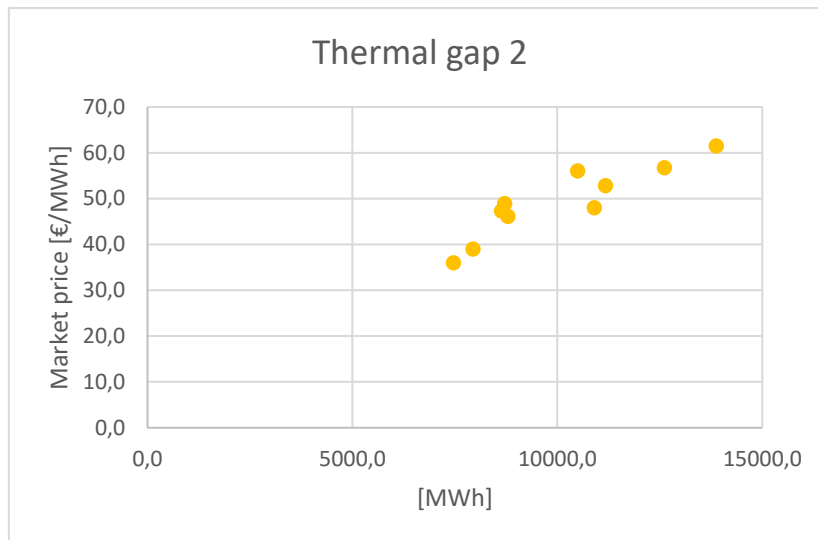


Figure 15. Thermal gap 2 vs market price for ten consecutive hours. Source: own elaboration from [ESIO17]

Although it is remarkable the few points represented in the graph, it is also noticeable the almost straight line they form. Although it may seem that a quadratic or even a third-degree formulation will adjust better to the shape of the line describe in the graph, based on the previous studies with discrimination by days, the formulation employed will be a linear one, since it gave accurate results and a low maximum error.

In the following tables are shown the results for this hypothesis for the two set of inputs of the study, thermal gap 2 and 3.

MAE	MAPE	Maximum error
5,4428965	15%	67,29804182

Table 11. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,29778086	10%	27,50222322

Table 12. Results of the ten hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

The first interesting fact is that it is kept the tendency that thermal gap 3 data provides more accurate results than thermal gap 2, as it was deduced at the beginning of the report. It is remarkable too that results for the first methodology proposed are quite accurate, and near to the results of the best approach of the previous set.

For thermal gap 3, MAE remains close to 3 €/MWh and the maximum error obtained is the lowest for any working days methodology. It can be affirmed that the discrimination by hours seems efficient at first sight.

In the next hypothesis, the range of input data will be increased by five hours each consecutively. Since following approaches pursue only to increase input data and provide better results by doing it, it makes no sense to explain each one separately, but to show all the results and analyze them together.

Forecast based on the fifteen hours before

MAE	MAPE	Maximum error
5,27006752	14%	47,95777067

Table 13. Results of the fifteen hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,43150324	10%	29,97946936

Table 14. Results of the fifteen hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the twenty hours before

MAE	MAPE	Maximum error
5,28709538	14%	40,28467497

Table 15. Results of the twenty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,57814483	10%	29,1720499

Table 16. Results of the twenty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the twenty-five hours before

MAE	MAPE	Maximum error
5,3126915	14%	39,44527217

Table 17. Results of the twenty-five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,76464008	11%	28,26987307

Table 18. Results of the twenty-five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the thirty hours before

MAE	MAPE	Maximum error
5,35194545	15%	35,15672098

Table 19. Results of the thirty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
3,98973174	12%	28,39397001

Table 20. Results of the thirty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

It is interesting that thermal gap 2 and 3 follow similar tendencies when the range of input data is increased. The wider the range of input data, the worse is the results given by the model. However, while thermal gap 3 achieve its best result in the first attempt, thermal gap 2 provides best results when fifteen hours are taken as input data.

In the case of maximum error, thermal gap 3 maintains the same tendency and is able to achieve the minimum value for the first hypothesis. On the other hand, thermal gap 2 keeps a

downward trend, and achieve its best result when it is used thirty hours to elaborate the equations. In this case, is thermal gap the one that follows the logic path, it is assumed that with more input data, it is more likely that the forecasted values will fall inside the layer. Nevertheless, for thermal gap 3 the maximum error finds its best value with just ten hours, which may seem contradictory.

Despite the beginning of the section looked promising in terms of accuracy, its final results did not improve the previous theory, with discrimination by days. It appears necessary to try a new different theory to see if results can be improved.

Before entering into a new section, it will be analyzed this methodology for non-working days and see if in this case, this new approach works better than for working days.

Non-working days forecast method based on a discrimination by hours

As in the discrimination by days' methodology, for non-working days, it does not worth taking into account an excessive number of hours as input, since data will be obsolete and results not valid at all. For this type of days, it will be considered two hypotheses, employing five and ten previous hours, and see if results are acceptably good.

In the first case, taking into account the five previous hours to the hour forecasted, it will be important to choose a linear relationship. Since there are only five points to elaborate each equation, it is likely that the forecasted point lay outside the input set, consequently a linear approximation will avoid excessive errors.

In the following tables are shown the results for both set of input data for the five hours before approach.

MAE	MAPE	Maximum error
8,18920994	36%	141,7245919

Table 21. Results of the five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
4,75179004	18%	129,6650326

Table 22. Results of the five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

As expected, results provided are less accurate than for working days, given the particularities of the days of study. Additionally, the maximum error for both type of thermal gap is far from a desired one, proven that the range of input data is so small.

In order to solve the deficiencies of the previous approach, it will be tries to use a wider range of input data, in this case ten hours before the forecasted one. With more data as input, it will be reduced the maximum error because it is reduced the possibility of a point to lay outside the range. In addition, ten hours wide range has proven to be the one that provides the most accurate results for working days, and it may be expected the same for this type of days.

In the following tables are shown the result for thermal gap 2 and 3 when a ten hours' range is taken as input.

MAE	MAPE	Maximum error
6,96587636	30%	57,73009244

Table 23. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

MAE	MAPE	Maximum error
4,44823916	14%	36,78672858

Table 24. Results of the five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

It is worth remark that results have been improved with respect to the previous approach. However, as expected, they are less accurate than for working days and less accurate than for the discrimination by day methodologies too.

A good point is that the maximum error has been reduced for both set of input data, although it is still too high to be considered a good value.

With this last attempt, it is finished the first set of approached based on a single variable equation. As a primary conclusion, it can be affirmed that discrimination by day methods provides more accurate results and lower maximum deviations. This could mean that it is more relevant to maintain the coherence of the day, than trying to capture the hour effect in market prices.

On the other hand, it has been manifested that both, seasonality and weekly effect, are quite important when creating a model to forecast prices. However, it has been revealed to be more influential the seasonality effect, since the most accurate forecast was the one that used five days, without bothering about which day of the week they were.

In the following section will be analyzed the different approaches explained during the present one but employing a two variables approximation. It will be explained which these two variables will be and how they relate one with each other. It will be seen additionally, if it is possible to improve the results of the previous studies.

4.3.2 Two variables models

It has been made clear the huge effect of what has been named thermal gap, up to the point that based only on this term, it is possible to build a basic model with notably good results. However, it is also evident that there are more variables that have an important impact on market prices. This second set of models will be based on the effect of this additional term plus the before mentioned thermal gap.

When analyzing models based on thermal gap, it was mentioned the different effects that should be taken into account, for example, the seasonality of prices or the weekly effect. Additionally, there is one more particularity that needs to be considered. It is obvious that the higher the thermal gap, the higher the price, but for same thermal gap may not be same prices exactly, even notably differences between those two prices. It has been mentioned the seasonality or weekly effect, but there is also the possibility that for the same value of thermal gap, there are a lot more of renewable because demand is higher. This difference in renewables must be the cause for the difference in prices, combined with previous factors. The new set of approaches would develop models that take into account thermal gap and renewable and elaborate an equation with the combination of both.

Nevertheless, not all renewable has the same impact on the Spanish electric system, and not the same behavior either. For instance, it was explained in previous chapters the behavior of agent with respect to hydro, using it as a substitute of thermal power plants, and in consequence, this technology was included as thermal gap.

The two main renewable technologies remaining are the solar and wind, and there are plenty of difference between them. The most relevant is the fact that solar will only produce during certain hours, while wind is able to provide electricity the whole time as far as wind blows. Another difference is their predictability, solar is based on solar cycles, which are repetitive and simple to forecast; on the other hand, wind depends on air streams which depend on more variable at the same time and so on. In other words, solar energy is simple to forecast and wind is extremely complicated.

Additionally, as explained in previous sections, the Spanish system has a very low amount of solar energy installed with respect to other technologies; while wind power represents one of the principal sources of electricity in the system. Both, the uncertainty and the importance of wind make this the most interesting variable to analyze along with thermal gap, and its influence in prices may be easily proved. In the following graph it is shown the effect of wind on prices.

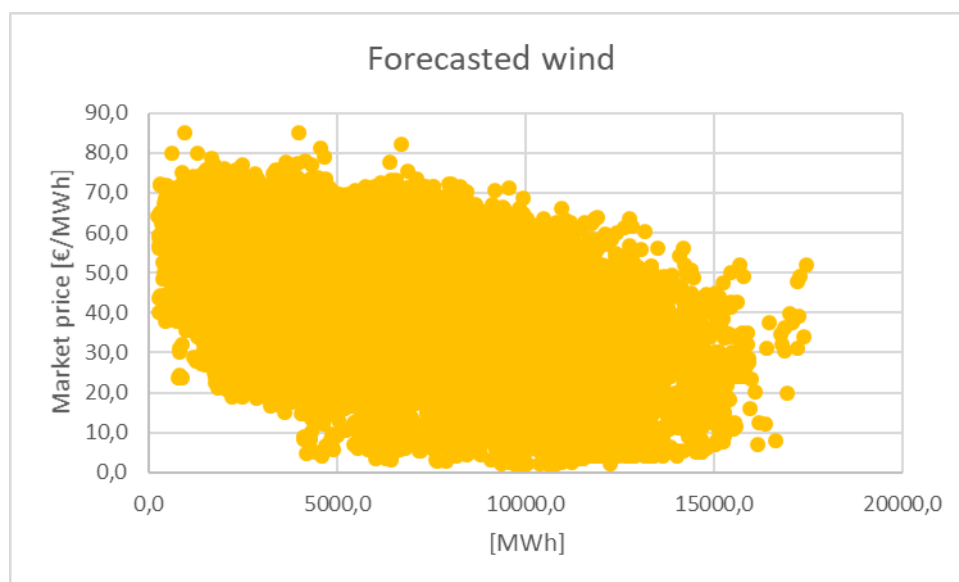


Figure 16. Forecasted wind vs market price. Source: own elaboration from [ESIO17]

It is only shown the relationship between forecasted wind and market prices for simplicity purposes, although the picture is similar with actual wind production. In the figure can be observed the connection between both terms, similar to with all renewable; the higher the wind, the lower the price. It must be said also that the relationship is not as simple nor clear as with thermal gap, but it is strong enough to allow wind to be considered the second variable.

In addition, it would be interesting to check the behavior of wind throughout the year and see if there are some pattern to take into account in the following studies. In the figure can be seen the evolution of wind production along the year 2.015 and 2.016.

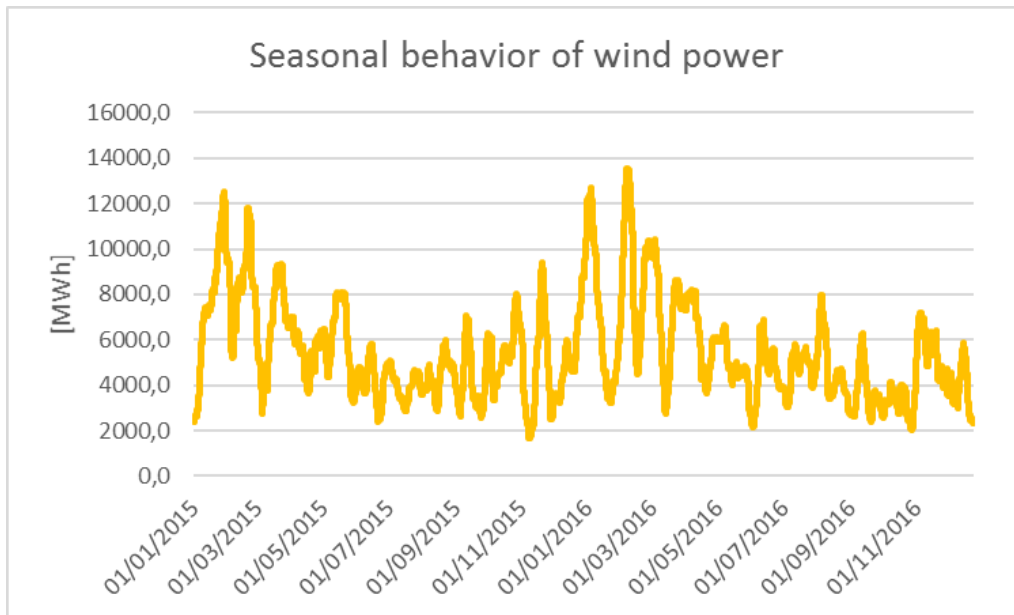


Figure 17. Seasonal behavior of wind power for the year 2.015 and the year 2.016. Source. Own elaboration from [ESIO17]

In the figure above may be seen some patterns for the behavior of wind production. As it could be implied, the time of higher production of wind correspond with colder months, from January to May approximately. While for warmer months, as July or August, the power produced by wind turbines is quite lower. Despite this seasonal term, it is notable that wind has a high volatile character, and for two same months, the difference can be quite considerably.

In conclusion, wind is a very variable term and quite complicate to estimate, however, it follows some small patterns of behavior that will be taken into account in the forecasting methods applied. These patterns are expected to have an impact on the results for each approach.

4.3.2.1 Forecast based on a discrimination by days

As in the previous section, with methods based in one single variable, in this new set of approached will be used the same methodologies but changing the input data and the equations employed to predict prices.

The first group of approaches will be based on a discrimination by day. These methodologies gave good results before and are expected to provide the same or better quality with the new input data.

The advantage of this method lies in its ability to capture the effect of the weekly behavior, as much as the seasonal behavior because it uses few days to elaborate the equation, and it can represent the current environment of the forecasted day.

Forecast based on the day before

The first approach used is the one based on just the day before. This methodology was demonstrated as a very simple and basic in previous studies, but it became an interesting starting point for the following approaches.

In contrast with single variable methodologies, two variables ones will be based on linear relationships only. It is important to remember that, when introducing quadratic equation, maximum error was increased highly when the data forecasted was outside the input range. If a quadratic system were implemented, it may result in high values of maximum errors, invalidating the solution. In consequence, all equation applied for two variables approaches will be based only on linear equation.

Although the equation used will be based on linear equation, it is important to see how wind and market prices relates between each other to know if a linear system is valid. In the following picture may be seen this relationship.

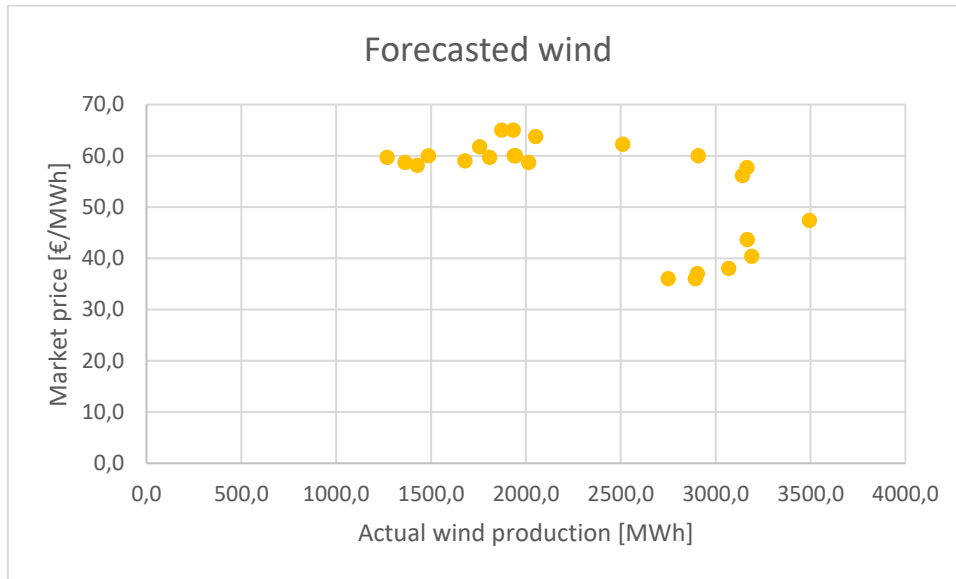


Figure 18. Forecasted wind vs market price for one day. Source: own elaboration from [ESIO17]

As done before, for simplicity purposes, it is only shown the relationship for forecasted wind. It can be observed that, when plotting just one day, the relationship is not as linear as with thermal gap, as expected though. The relationship shown is not even clear, and it may not follow a function, since for two same values of production, the difference in price is higher than 20 €/MWh. This characteristic may become a source of noise in the forecasting equation, and it is possible that results would not be as accurate as desired.

In order to show the possible consequences of using a quadratic system to build the forecasting equations, it has been run the simulation for the day before approach with these equations. In the following table are shown the results given.

Thermal gap 2

MAE	MAPE	Maximum error
18,40974618	44%	987,8045395

Table 25. Results of the day before approach for a quadratic function for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
6,85068103	17%	133,5628249

Table 26. Results of the day before approach for a quadratic function for Thermal gap 3. Source: own elaboration from [ESIO17]

As it can be seen, both the MAE and maximum error have high values, and they do not improve or, at least, approximate to results provided by single variable methods. For the set of input data thermal gap 2, the maximum error takes a value close to 1.000, which cannot be considered a valid information at all.

Now it has been proved that quadratic functions are not a good option for multivariable approaches, it is time to show the results provided by linear approximations. In the following tables are shown the results for the same method but employing only linear equations.

Thermal gap 2

MAE	MAPE	Maximum error
7,23883825	18%	80,4594465

Table 27. Results of the day before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
4,068006472	11%	49,49667773

Table 28. Results of the day before approach for a linear function for Thermal gap 3. Source: own elaboration from [ESIO17]

This method has provided lower values of the parameters used to measure the accuracy of the forecast, which means the forecast in this case may be considered better. It can be observed that MAE for both sets of data have taken values in between the range of previous approaches, and the maximum errors have been reduced to more acceptable values. However, it is also remarkable that these values have not been improved as expected, and they are closer to values of previous studies.

At the end of the section will be shown a comparison between results provided by single variable and multivariable methodologies. It will be analyzed then which one provides better results, and the reasons behind the efficiency of each approach.

In the following paragraphs will be evaluated if other approaches with these set of data are able to provide a better forecast, or on the contrary, they reveal worse results than previous methodologies.

Forecast based on the seventh day before

As in single variable section, the next step is to analyze the effect of employing the same day of the week as input data to predict the market price. Since the reasons to use this method were explained in the previous section, there is no need to fill the report with duplicated information. In the following tables are shown the results for the methodology employed.

Thermal gap 2

MAE	MAPE	Maximum error
7,26184872	19%	117,8998779

Table 29. Results of the seventh day before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
4,80542763	14%	33,09907232

Table 30. Results of the seventh day before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]

In this case, as it happened with the equivalent single variable approach, the results have been worsened and do not overcome the previous methodology. One preliminary conclusion may be the fact that, with independency of the input data employed, results provided by different approaches seems to follow the same tendency. That is to say that if the approach provides good results, it will be effective no matter the input data.

Forecast based on the five days before

This methodology proved to be the one providing best results for single variable methods. Following the reasoning explaining above, it is expected to be the one improving the results of the two previous approaches. In the tables below are shown the results.

Thermal gap 2

MAE	MAPE	Maximum error
6,00041613	16%	54,94895798

Table 31. Results of the five days before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
3,38114098	10%	30,0364947

Table 32. Results of the five days before approach for a linear function for Thermal gap 2. Source: own elaboration from [ESIO17]

As expected, the results provided by this approach are the best of the three methodologies based on a discrimination by day. Despite it cannot overcome results provided by single variable method, it has been able to reduce the maximum error below the values set by the same single variable methodology.

With the forecast based on the five days before, it has been concluded the three approaches used to forecast market prices that are based on a discrimination by days. Before changing to a discrimination by hours' methodology, it is important to evaluate the behavior of multivariable approaches when applying to non-working days.

Non-working days forecast method based on a discrimination by days

As it happened with single variable methods, it has been divided the days of the weeks into two groups, working and non-working, applying different approaches to each set of days. It has been enumerated before the several reasons for this division, for instance, the fact that demand falls drastically these non-working days.

Now that it has been shown the results of multivariable approaches to weekdays, it is time to apply the theory to weekends and festive days.

As explained in previous sections, it makes no sense to apply the same methodologies to these especial days, since they would not work properly. In consequence, it is going to be applied the same theory than in single variable section, this theory consists in employing the two days before to elaborate the equation for the forecast. This theory is based on the fact that non-working days occur from time to time and using many days in the simulation would mean to use very past days with no useful information for the prediction.

Once the reasons of the methodology for this simulation has been explained, it is time to show the results of it, which may be seen in the following tables.

Thermal gap 2

MAE	MAPE	Maximum error
9,497035105	36%	144,2780594

Table 33. Results of the two days before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
4,88613071	22%	111,5485433

Table 34. Results of the two days before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Following the trend revealed in the previous point, the results are similar to single variable methods. However, a new trend may be observed, this is the increment in maximum error values, which are considerably high with respect to previous methodologies. This could mean that, when introducing wind, the simulator is able to capture the effect combined of thermal gap and wind, but this introduce distortion that generates high values of maximum errors when the forecasted data are outside the layer of input values. This will be analyzed in higher details in further sections.

With this last simulation, it has finished the set of approaches based on a discrimination by days for multivariable input. Now it is time to enter into the simulation based on a discrimination by hours and see if the trend is broken and these new methodologies applied to multivariable approaches are able to improve the results given by single variable ones.

4.3.2.2 Forecast based on a discrimination by hours

After studying each methodology based on a discrimination by days, it is time to evaluate the effectiveness of the multivariable approaches with a discrimination by hours. At first sight, it may be assumed that these simulations will not be able to improve results provided by the set of approaches above. As deducted above, it may seem that every methodology follows the same trend, in consequence, as it happened with the single variable methods, discrimination by days' methodologies will be better than discrimination by hours' ones.

In addition, there is a specific effect of wind that will not be accounted for in these simulations. This is the effect of the continuity of wind, to say it simple, wind will blow in the following hour similar as to the hour before. This continuity is lost in these simulations, since same hours belongs to different days, and wind may be varied enormously.

Despite these negative preliminary assumptions anticipated, it is important to run all the simulation and see if results can be improved and study the reasons whichever may be the case. As in previous section, single variable approaches, the results will be shown together, and it will be explained at the end of the last approach's results. The simulations will take into account from the ten hours before the forecasted one, to the thirty previous hours. In the following tables can be seen all the results.

Forecast based on the ten hours before

Thermal gap 2

MAE	MAPE	Maximum error
4,78597561	13%	59,38461447

Table 35. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
3,40293778	10%	29,30444971

Table 36. Results of the ten hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the fifteen hours before

Thermal gap 2

MAE	MAPE	Maximum error
4,59261165	13%	45,66359702

Table 37. Results of the fifteen hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
3,39913383	10%	26,91328977

Table 38. Results of the fifteen hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the twenty hours before

Thermal gap 2

MAE	MAPE	Maximum error
4,65661777	13%	34,92140834

Table 39. Results of the twenty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
3,57206955	10%	27,000305

Table 40. Results of the twenty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the twenty-five hours before

Thermal gap 2

MAE	MAPE	Maximum error
4,78098993	13%	30,07922237

Table 41. Results of the twenty-five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
3,76231291	11%	28,90686997

Table 42. Results of the twenty-five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Forecast based on the thirty hours before

Thermal gap 2

MAE	MAPE	Maximum error
4,85539514	14%	28,55885162

Table 43. Results of the thirty hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
3,94002161	11%	30,56438364

Table 44. Results of the thirty hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

As expected, these simulations are not able to improve the results provided by single variable methods. However, they stay very close to results provided by multivariable methods based on a discrimination by days, in contrast with what occurred in single variable approaches.

It was said at the beginning of the point that these approaches are not able to capture the effect of continuity of wind. When this property is lost, input data cannot provide a proper relationship between the wind and market price for the hour forecasted, in consequence, results are worsened with respect to previous studies.

After these studies, it only remains to analyze the results of a discrimination by hours' methodology applied to non-working days.

Non-working days forecast method based on a discrimination by days

The last set of simulation carry out to forecast day-ahead market prices, will be to applied a multivariable approach based on a discrimination by hours to non-working days, these are weekends and festive days.

In contrast with working days, the loss of continuity of wind will not be as important since it was lost in the discrimination by days' section. Because usually input data belongs to days different to the previous day to the forecasted one. Nevertheless, this is expected to affect the results, which are not expected to be better than single variable ones.

The studies have been performed using the five previous hours and the ten previous too. It has been explained before the uselessness of employing excessive data in the past for this type of days, which will mean to use very past data with invalid information.

In the following tables are shown the results taken into account five hours before the hour forecasted.

Thermal gap 2

MAE	MAPE	Maximum error
8,38349441	38%	132,8951878

Table 45. Results of the five hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
6,30268269	27%	192,5322939

Table 46. Results of the five hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

Now it is shown the results for the ten hours before simulation.

Thermal gap 2

MAE	MAPE	Maximum error
6,43114483	29%	113,942231

Table 47. Results of the ten hours before approach for Thermal gap 2. Source: own elaboration from [ESIO17]

Thermal gap 3

MAE	MAPE	Maximum error
5,38372873	25%	125,2529084

Table 48. Results of the ten hours before approach for Thermal gap 3. Source: own elaboration from [ESIO17]

With the results visible are confirmed all the preliminary assumptions, these methodologies were not a good option to forecast non-working days. They completely cannot capture the effect of continuity of wind, which affect considerably to the accuracy of predictions. Additionally, although is only employed five and ten hours before the forecasted one for non-working days, this could mean up to three weeks before the day of simulation, in consequence, this input data has no valid information at all.

Finally, it can be concluded the section of simulation for the day-ahead market. It has been shown several approaches with different results. In the next section will be shown a comparison between the results of the different simulations, with an explanation of them and the reasons for the accuracy or their maximum errors.

4.4 Conclusions and comparison of results between simulations

This section pretends to offer few preliminary conclusions about the price simulator of the day-ahead market and serve as the closure of the chapter related to it. The aim of the section is not to substitute the chapter of conclusions at the end of the report, but to put together and organize all the theories and ideas expressed during the present chapter, that may not be completely clear for the reader.

In order to compare properly the different results of the simulations carried out during the chapter, it has been created a table with the best approaches of every set of them. In the following table are displayed the results of this methodologies.

		Thermal gap 2			Thermal gap 3		
		MAE	MAPE	Maximum error	MAE	MAPE	Maximum error
Single variable	Five days before	5,43	15,36%	98,56	3,20	9,43%	34,67
	Ten hours before	5,44	14,93%	67,30	3,30	9,90%	27,50
Multivariable	Five days before	6,00	15,96%	54,95	3,38	9,92%	30,04
	Ten hours before	4,79	13,11%	59,38	3,40	10,00%	29,30

Table 49. Best result approaches for working days. Source: own elaboration from [ESIO17]

As it could be deduced during the previous sections, best results in absolute terms are provided when the input data comes from thermal gap 3, this is, from forecasted values. As explained at the beginning of the chapter, when agents elaborate their strategies to bid, all the information they have is predictions of load, wind or solar, but not actual values, even from past days, since actual data is only available ninety days after the time of production [OMIE17]. For this reason, if the objective is to predict the market price based on the behavior of agents, it is important to take into account properly this behavior and note that is based on predictions and not on actual production or consumption.

In terms of MAE, best results are provided by single variable methodologies, while multivariable approaches are able to delimit better the maximum error. The reason may be that, while the introduction of wind in the equation generates useless noise which affect the quality of simulations. On the other hand, this introduction of a new variable is able to reduce the maximum error when the forecasted value is out of the input range, compensating when the value outside belongs only to thermal gap or to wind, the other value inside the range adjusts the price. This is only possible when a wide enough range of data is taken to compute the forecasting equation.

With the previous reasons stated, it can be affirmed that the introduction of more variables to the system, do not bring more accurate results, but it reduces the maximum error committed by the simulation.

The next table shows the results for non-working days, it would be interesting if, for this type of days the behavior of approaches changes with respect to working days.

		Thermal gap 2			Thermal gap 3		
		MAE	MAPE	Maximum error	MAE	MAPE	Maximum error
Single variable	Two days before	8,41	31,97%	131,92	4,01	9,79%	21,40
	Ten hours before	6,97	30,10%	57,73	4,45	13,94%	36,79
Multivariable	Two days before	9,50	36,45%	144,28	4,89	22,11%	111,55
	Ten hours before	6,43	28,98%	113,94	5,38	24,54%	125,25

Table 50. Best result approaches for non-working days. Source: own elaboration from [ESIO17]

It can be seen firstly the trend between thermal gap 2 and 3, being the latter the one providing best results for any type of methodology.

Among approaches applied to thermal gap 3, the trend is maintained in terms of MAE, and the best approach to compute market prices are the ones based on a single variable, specifically the one based on the two days before (it is important to remember that for non-working days it was employed a different methodology but based on the same principle of continuity between days). The reason may be similar to the previous type of days and could be related to the introduction of noise in the equation by wind, instead of adjusting better the price.

The interesting remark about non-working days' approaches is that, for maximum error, it is not multivariable methodologies the ones providing the lowest values, but single variables ones. As it has been explained above, the multivariable system is able to control the error, but it needs a wide range of input data to do so; otherwise, the system is just not able to reduce the maximum error and even it creates bigger ones. And for non-working days, the range of input data could not be very large, since it would imply to use very past days, which have not adequate information to elaborate the forecast.

With this last conclusion it has been finished the chapter related to day-ahead market, the most important in terms of volume of energy and price, in the following section it will be analyzed in detail the relationship between this and other different markets managed by OMIE and REE.

Chapter 5. Relationship between different markets

Despite the high importance of the day-ahead market, there are several markets in the Spanish system which have an impact on final price of electricity and are worth of taking into account. The markets analyzed in this thesis have been defined previously, they are the six intraday markets, the secondary and tertiary reserve markets, and the technical constraints market. During this chapter will be analyzed and studied all of the aforementioned markets except for the technical constraints market, that will be analyzed alone in chapter 6 due to its importance for this thesis.

5.1 Intraday market price simulator

From all of the markets analyzed in this chapter, the six intraday markets are the ones managed by OMIE and, therefore, they affect both Spain and Portugal. These markets were designed as balancing markets for the agents, the purpose is to allow market agents to adjust their positions when real time is approaching.

As balancing markets, their price is strongly and inherently related to day-ahead market price. As far as not any big position is undone, the price of this markets can be easily related to day-ahead price. In consequence, as a balancing market, the liquidity of these markets is not as high as the day-ahead, being the first intraday market the one with highest volume of energy, which is usually 10% of volume traded in the day-ahead market [OMIE17].

As explained in chapter 3 there are six intraday market, each one closer to real time than the previous one. As it may be deduced, each market will renegotiate less hours than the previous, since there are less hours in the day to be negotiated.

It is important to explain that it will be employed only the methodologies that provided the best results in the previous chapter, unless they are not able to produce a result with an appropriate accuracy. These methodologies are the five days before based on discrimination by days for working days, and the two days before for non-working days; and the ten hours before based on a discrimination by hours for both types of days. It will be taken into account only single variable methodologies, since they have proven more effective.

5.1.1 First intraday market

The first intraday market is five hours after the day-ahead market, and it concentrates the highest volume of energy after this. It has also some structural particularities, for instance, it has a duration of an hour and forty-five minutes, while the rest of intraday markets only last forty-five minutes. It also negotiates twenty-seven hours, including three hours of the previous day.

In order to simplify the calculation, the simulator of this first intraday market will only take into account the twenty-four hours of the following day.

The next step is to select the best input to forecast intraday prices, and also to choose the best system of equations that will used in the simulation. In terms of input data, it is possible to use the same variable as in the day-ahead market, however there are few issues that prevents this.

In terms of input data, it has to be taken into account that intraday market is a balancing market, in contrast with day-ahead market where agents want to match as much energy as possible; in this case, the objective is just to adjust positions of units previously committed. In consequence, the idea of thermal gap loses relevance, since it is possible that the majority of agents want to adjust the positions of renewable energy, or nuclear energy, and these technologies will be the drivers of price instead of the thermal gap. It appears the necessity to find a new drive for market prices.

It is thought the belief that intraday market price is strongly related to day-ahead market price; one good starting point will be to use the results of day-ahead market to compute a simulation for intraday prices. To see if this relationship is actually true, it can be plotted a dispersion graph with day-ahead prices in the x-axis and intraday prices in the y-axis. In the following figure may be seen this relationship for the year 2015 and 2016.

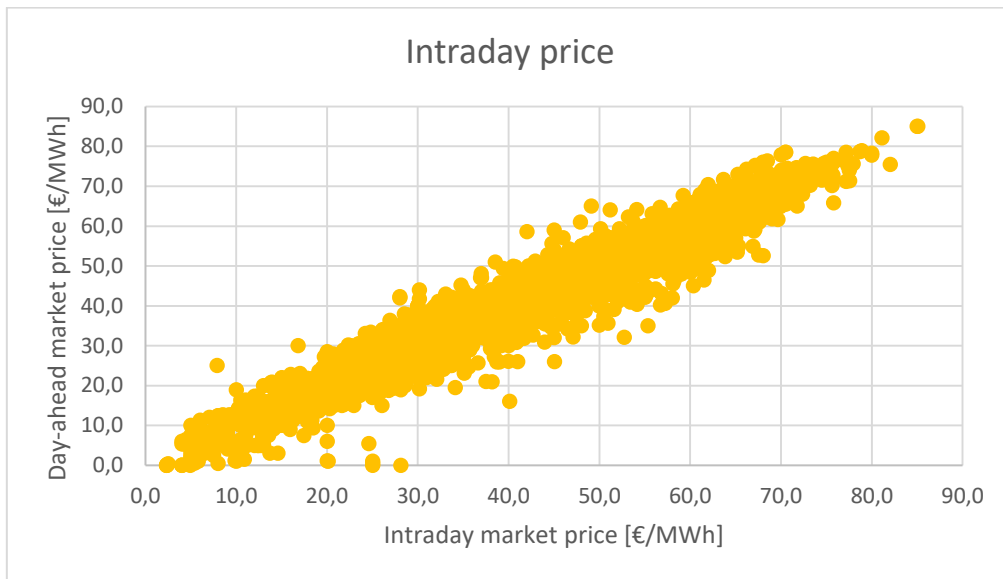


Figure 19. Day-ahead market price vs intraday market prices. Source: own elaboration from [ESIO17] and [OMIE17]

As it can be seen in the graph the relationship between the daily market and the first intraday is quite strong, and almost linear. Consequently, it seems appropriate to use the price of the day-ahead market to forecast the intraday market.

Once the main driver has been chosen, it has to be select the type of equations that will be followed to elaborate the simulations. It is going to be used two types of methodologies, one based on a discrimination by days, and the other by hours; therefore, it will be important to see the relationship when the whole day is considered, and when it is considered each hour separately. In the following pictures are plot both type of data to see the most adequate equation for the prediction.

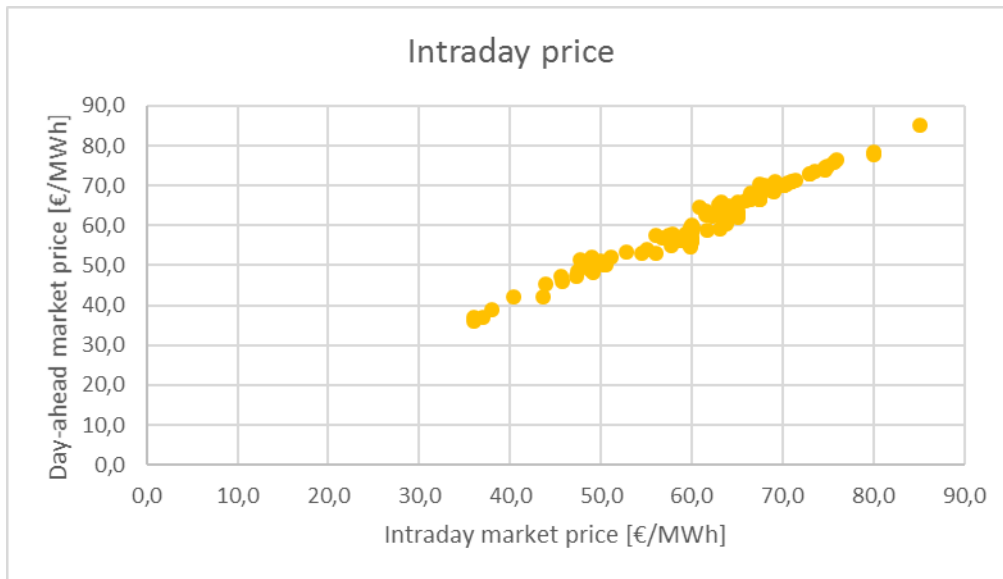


Figure 20. Day-ahead market price vs intraday market price for complete days. Source: own elaboration from [ESIO17] and [OMIE17]

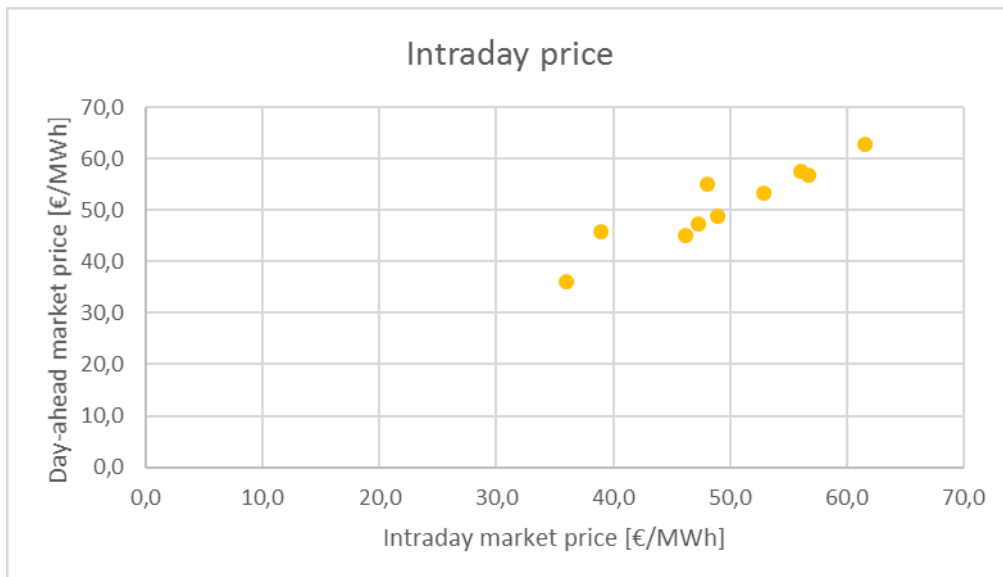


Figure 21. Day-ahead market price vs intraday market price for hour 1. Source: own elaboration from [ESIO17] and [OMIE17]

In the first picture is easy to observe a linear relationship between prices of both markets. In consequence, it will be employed a linear equation to elaborate forecast based on a discrimination by days.

In the second graph it has been plotted the relationship only for hour 1, and it will be used to select the type of equation for the rest of hours. However, it will be change if results are not adequate. Despite the few data plotted, only the ten hours that will be used, it can be observed the linear relationship that this data followed. Summing up, it will be used a linear equation for both type of simulations.

Finally, before showing the results, it has to be remarked that, following the procedure used in the previous chapter, days have been divided into two groups, working and non-working. Now it will be presented results for the two methodologies used for working days.

MAE	MAPE	Maximum error
1,9	30%	28,3

Table 51. Results of the five days before approach for working days. Source: own elaboration from [ESIO17] and [OMIE17]

MAE	MAPE	Maximum error
2,1	29%	27,2

Table 52. Results of the ten hours before approach for working days. Source: own elaboration from [ESIO17] and [OMIE17]

As it can be seen in the tables, results have been improved in terms of MAE with respect to day-ahead market for both types of methodologies. The maximum error is also under acceptable levels, although its improvement is not as remarkable as MAE values.

As a preliminary conclusion, it can be affirmed that the input data employed has worked well, and the type of equation chosen to forecast price is adequate.

In the following tables are shown the results for non-working days.

MAE	MAPE	Maximum error
2,6	24%	27,1

Table 53. Results of the five days before approach for non-working days. Source: own elaboration from [ESIO17] and [OMIE17]

MAE	MAPE	Maximum error
2,6	27%	28,2

Table 54. Results of the ten hours before approach for non-working days. Source: own elaboration from [ESIO17] and [OMIE17]

As expected, results have been worsened with respect to working days, however the values of MAE remain lower than in the case of day-ahead market for both types of approaches.

With all results presented, it can be say that both the main driver of intraday market and the type of relationship with it has been chosen correctly. It is remarkable the high connection between both, the day-ahead market and the first intraday market, which allows to elaborate accurate price predictions of the latter.

In the following section will be analyzed the results of the simulation for the rest of intraday markets. It will be studied whether this strong relationship remains or not, and it will be offered few conclusions about the relationship between day-ahead market and the different intraday markets. The five intraday markets will be studied together, since they have several characteristics in common, and the procedure to build their simulations will be similar.

5.1.2 Rest of intraday markets

In this section it will be developed the simulators for the five intraday markets that remains. The first issue to consider will be, which is the most appropriate driver to elaborate the forecast, as in the previous section.

Day-ahead market price has been proven as a good connector to forecast intraday prices, it has been discovered the strong link between prices of both markets. The challenge will be to evaluate whether day-ahead market prices remains as an appropriate input for the rest of intraday markets or if it is necessary to find a new one.

On the other hand, despite the relationship between prices, it is also true that day-ahead price has been tested with first intraday prices, which are consecutive markets. However, there are five more intraday markets after the first, and the last one, the sixth intraday, is one day after the day-ahead market has been cleared. For this reason, it may occur that day-ahead market prices lose importance while the previous intraday prices become more relevant.

With the previous considerations taken into account, it will be wise to analyze the relationship between day-ahead market prices against the rest of intraday markets, and against each other. If day-ahead price proves not to be as effective as the previous intraday market, it would be advisable to use the latter to develop the different simulations.

In the first place, it is going to be shown the dispersion graphs for the second intraday market, comparing it to the day-ahead market and the first intraday.

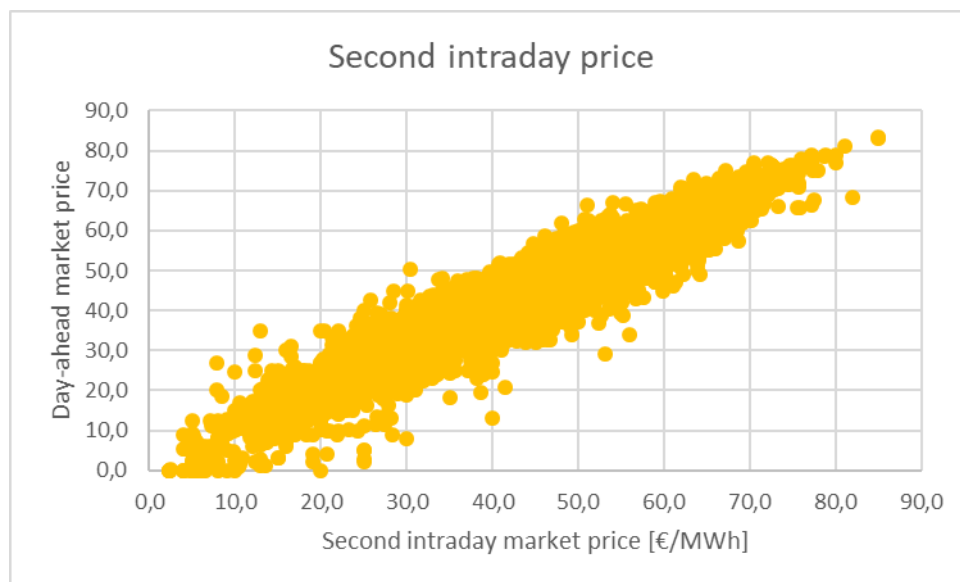


Figure 22. Day-ahead market price vs second intraday market price. Source: own elaboration from [ESIO17] and [OMIE17]

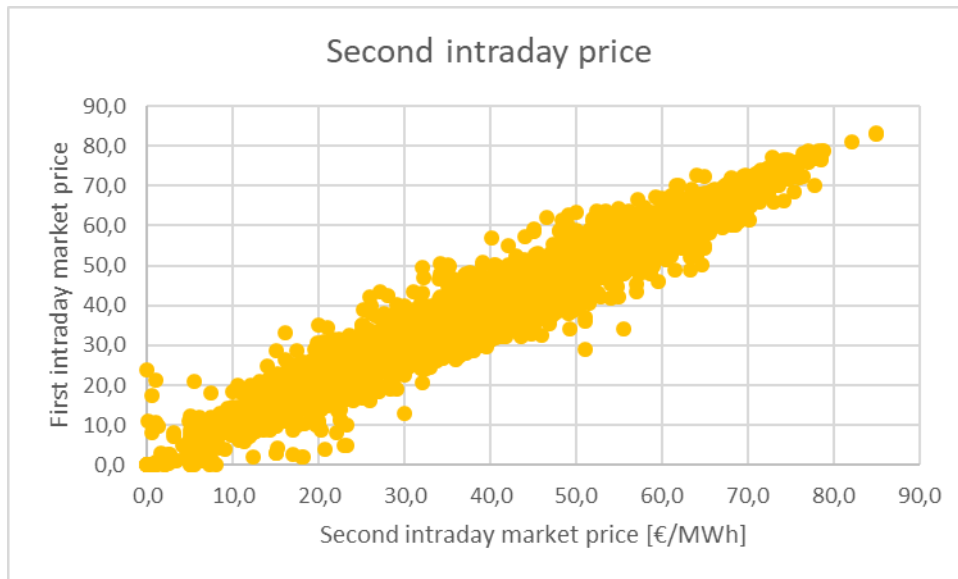


Figure 23. First intraday market price vs second intraday market price for complete days. Source: own elaboration from [OMIE17]

At first sight, it appears the second intraday market price is highly connected to both, the day-ahead and the first intraday market. When a deeper look is taken, it may seem that the relationship is a slightly stronger with first intraday market, since the dispersion is lower, despite barely noticeable.

It cannot be concluded if it is better to use day-ahead prices or previous intraday ones with just the information above, the three markets are relatively closer between each other, and they can be strongly linked. It is going to be plotted the same pictures for the third intraday, which is further from the day-ahead market, and see if the connection with day-ahead market is maintained.

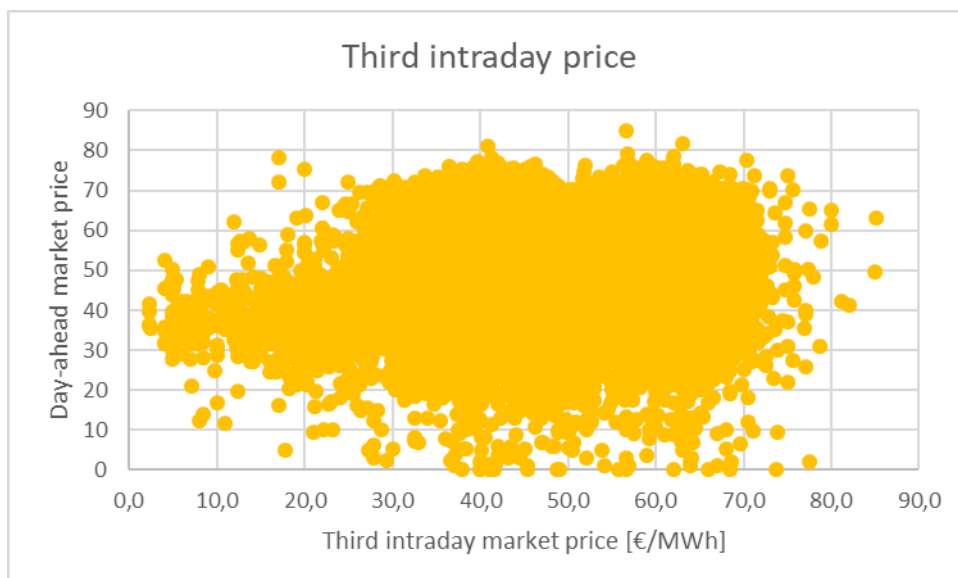


Figure 24. Day-ahead market price vs third intraday market price. Source: own elaboration from [ESIO17] and [OMIE17]

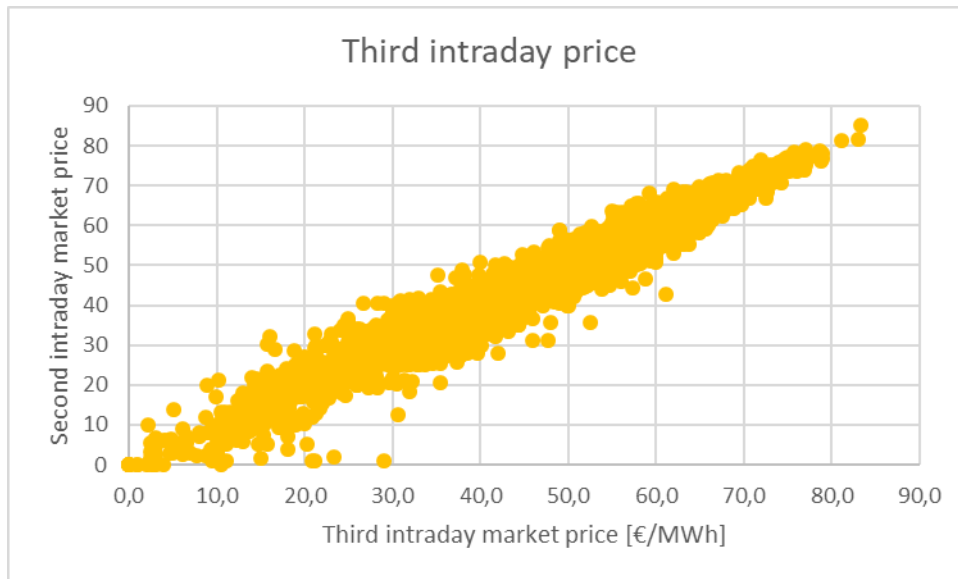


Figure 25. Second intraday market price vs third intraday market price for complete days. Source: own elaboration from [OMIE17]

In this case, the relationship remains quite linear when comparing with previous intraday market, however, when the comparison is made with day-ahead market dispersion grows considerably. It has become evident now the deduction made above, about the closeness between the market of study and the market used as input data. It can be assumed this dispersion will only grow when comparing other market further away in time, such as the fourth, fifth or sixth.

In conclusion, it may be used the day-ahead market to forecast the second intraday market, but only this one, and not any more intraday market. In consequence, in order to avoid distortion and to create a logic procedure, it will be used previous market to forecast the next one.

Now that it has been made clear the appropriate input data, it is time to show the results of every simulation. The type of equation chosen has been the linear, following the good results it provided for the first intraday market. Since the procedure followed has been the same for the remaining five intraday markets, and no further considerations have been taken into account, it will be shown results for five intraday markets together in the same table.

	MAE	MAPE	Maximum error
Intraday 2	1,9	13%	23,77
Intraday 3	1,8	7%	27,58
Intraday 4	1,7	4%	17,02
Intraday 5	2,3	5%	18,65
Intraday 6	2,8	6%	18,84

Table 55. Results of the five days before approach for working days. Source: own elaboration from [OMIE17]

	MAE	MAPE	Maximum error
Intraday 2	2,0	14%	17,05
Intraday 3	1,9	8%	22,53
Intraday 4	1,8	5%	20,69
Intraday 5	2,3	5%	17,20
Intraday 6	2,8	6%	22,36

Table 56. Results of the ten hours before approach for working days. Source: own elaboration from [OMIE17]

The first table shows results for the discrimination by days' approach, while the second contains results for the discrimination by hours. It may be observed, in first place, discrimination by days is able to provide slightly better results, following the same trend along the thesis. Despite the small difference, it is also remarkable the low values of MAE and Maximum error parameters, which inform about the good quality of the results.

Additionally, it is noticeable the increase in MAE value for the fifth and sixth intraday markets. It has to be taken into account they are the last two intraday markets traded, and a series of circumstances occur at the same time. Firstly, they contain mostly peak hours, which volatility is usually higher than base hour, in consequence, its forecast is more difficult. Secondly, they are traded the almost the next day than day-ahead, therefore, the probability to modify a unit program is higher than in other markets. Finally, the sixth intraday market is traded the last, but also farther away from the fifth than any other intraday (six hours away), which obstruct its connection, and consequently, its accuracy.

In the next tables will be shown results for the non-working days following the usual procedure.

	MAE	MAPE	Maximum error
Intraday 2	2,5	42%	26,84
Intraday 3	2,2	20%	24,13
Intraday 4	2,2	15%	18,14
Intraday 5	2,9	24%	21,68
Intraday 6	3,1	31%	24,29

Table 57. Results of the two days before approach for non-working days. Source: own elaboration from [OMIE17]

	MAE	MAPE	Maximum error
Intraday 2	2,4	38%	34,54
Intraday 3	2,5	8%	27,50
Intraday 4	2,1	19%	19,33
Intraday 5	2,7	17%	20,62
Intraday 6	3,0	27%	24,25

Table 58. Results of the ten hours before approach for non-working days. Source: own elaboration from [OMIE17]

In the tables above might be seen the same trend for non-working days than for working days. Simulation based on a discrimination by days offers better results because of the reasons provided in chapter 4 for the day-ahead market. Additionally, intraday market 5 and 6 seems to be the worst market to be forecast because of the particularities commented above. In conclusion, general results seem to be more accurate for intraday markets, whether they are referred to working or non-working days, despite little differences between intraday markets.

5.1.3 Preliminary conclusions about intraday markets

The main preliminary conclusion about intraday markets could be their relatively easiness to be forecasted, with a considerable level of accuracy, due to the strong relationship between prices of different markets. The cause lays on the nature of intraday markets, they are balancing markets for the day-ahead market, therefore, agents will operate these markets using the reference of the big day-ahead market strategy, prices will be, consequently, highly linked between each other.

Following the same reasoning may be explained the linear relationship between different markets. As balancing markets, agents use them to adjust their positions with respect to day-ahead market and previous intraday markets, consequently, their bids are highly linked one to each other. It is reasonable that prices are similar, forming a linear trend, since bids to adjust position will have similar prices. In other words, agents will want to rebuy energy at the price they sold it or cheaper, but on the selling side, agents will be willing to receive the same amount they paid or more, resulting in an intermediate position, so as to say, in a very similar price for every market.

With these conclusions it is finished the section about intraday markets, now it will be analyzed the first markets managed by REE, or ancillary services markets. These markets have some particularities that make them different from the ones analyzed until now. In first place will be studied reserve markets.

5.2 Reserve markets price simulator

5.2.1 Secondary reserve market price simulator

This is the first study about REE's markets, despite they are called markets, their main function is not to dispatch energy or set a price for it, but to provide market mechanism for system security services. As explained in the introduction, these markets are not managed by the market operator but the TSO, additionally, they are only applicable for the Spanish territory, and not in Portugal.

There are three reserve market, primary, secondary and tertiary, aimed to balance the system when production and demand are not matched. The first one is a mandatory service for every generator, therefore, there is no remuneration for providing the service [REE_98]. The secondary and tertiary reserve, on the contrary, are not mandatory for every generator, consequently, they are remunerated, which is the case of study.

During this section it will be studied the secondary reserve market, or to be precise the secondary band market. The secondary reserve is based on two terms, one is the band provided by generators committed to provide the service, the other one is the actual energy produced as secondary reserve [REE_98].

TSO invites all agents with generators certified and available to provide secondary reserve, to present their bids, in terms of energy and price. The energy term consists in the band of energy that those generators are able to upload or download in a determined range of time. The price term is what they are willing to receive to provide the service.

Additionally, when real time comes and generators are required to provide that energy, they also receive a remuneration for actual energy produced. This energy is remunerated at the

marginal cost set for tertiary reserve [REE_98]. Which will be analyzed in the next section of this chapter. The case of this study will be the secondary band price.

The first step will be to define the principal drivers that will be used to forecast price. This market is a different type of balancing market, while intraday markets were meant to be a balance for agents, this market is designed as a balance for the TSO, as a control to keep the system safe. In addition, not all generators are able to participate, only those certified by the TSO, however, in practice, just few thermal generators are willing to provide the service. In conclusion, it is a very thermal market, which may indicate a relationship with the day-ahead thermal gap.

In the same line that the previous reasoning, only those generators committed during the day-ahead market are allowed to participate in the secondary reserve market, since they need to be up and running to provide the service. Consequently, both markets will be definitely related. What will be interesting to analyze is if the relationship will be stronger with respect to thermal gap, as said before, or if the relationship in terms of prices will provide better results.

5.2.1.1 Simulation based on the day-ahead thermal gap

Firstly, it would be helpful to see the global relationship between both terms: day-ahead thermal gap and secondary reserve price. In other words, the dispersion graph for the two years of study employed in this report. The following graph shows the relationship between both data.

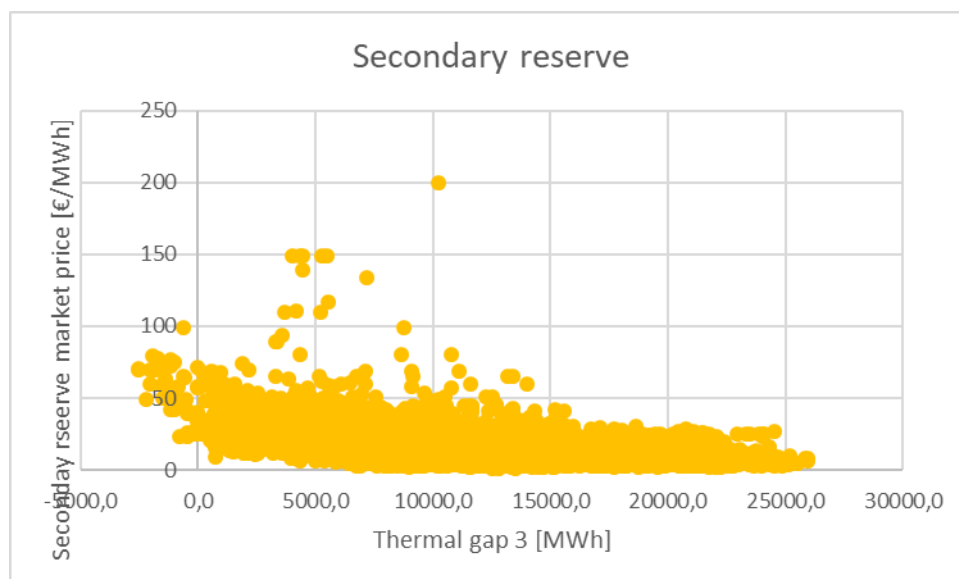


Figure 26. Thermal gap vs Secondary reserve market price for two whole years. Source: own elaboration from [ESIO17]

It must not be taken into account negative values of thermal gap, they correspond to erroneous values of load provided by ESIOs, and they have been removed from any simulation. In the graph, the tendency seems to be inversely proportional, the higher the thermal gap, the lower the price. This trend will be analyzed below, after the simulation results are shown.

One additional fact from the graph are the spike prices. It has to be remark that reserve markets have no cap price, therefore, from time to time appear extremely high prices with no previous warning. As Weron says, these spike prices are difficult to predict [WERO06], and out

of the scope of this thesis. Spike prices will not be treated specifically and will be analyzed as the rest of values of secondary reserve price, however, they are going to represent a source of distortion in the final results.

Once the relationship with the proposed drive has been proved, it is time to analyze the type of relationship for the different approaches employed, in order to choose the best adjustment possible for the forecast. As in intraday markets, it will be employed the best hypothesis of the day-ahead market, adjusted to the particularities of secondary reserve market. These approaches used are the five days before and the ten hours before for working days, and the two days before plus the ten hours before for non-working days.

The following picture contains only data for five consecutive days.

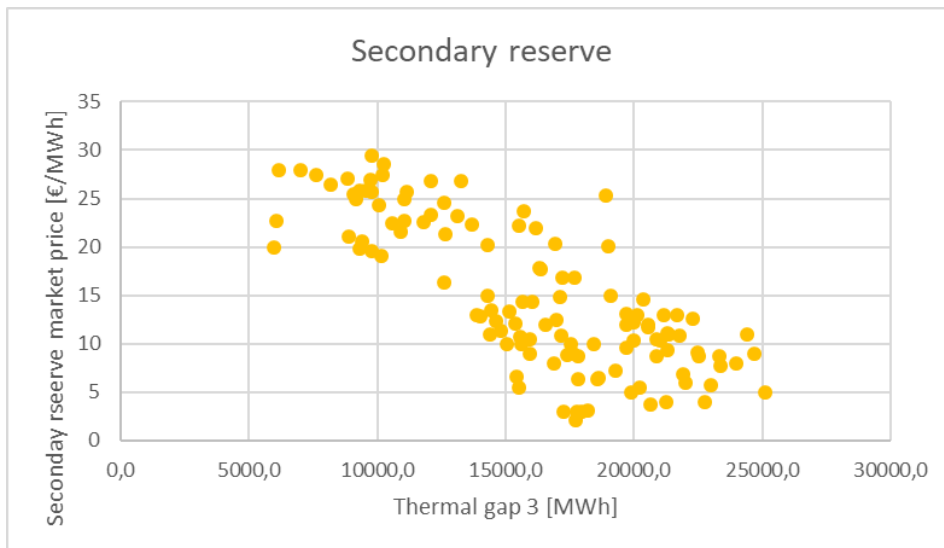


Figure 27. Thermal gap vs Secondary reserve market price for five consecutive days. Source: own elaboration from [ESIO17]

And the next picture shows the same relationship but for ten consecutive hours of the same type.

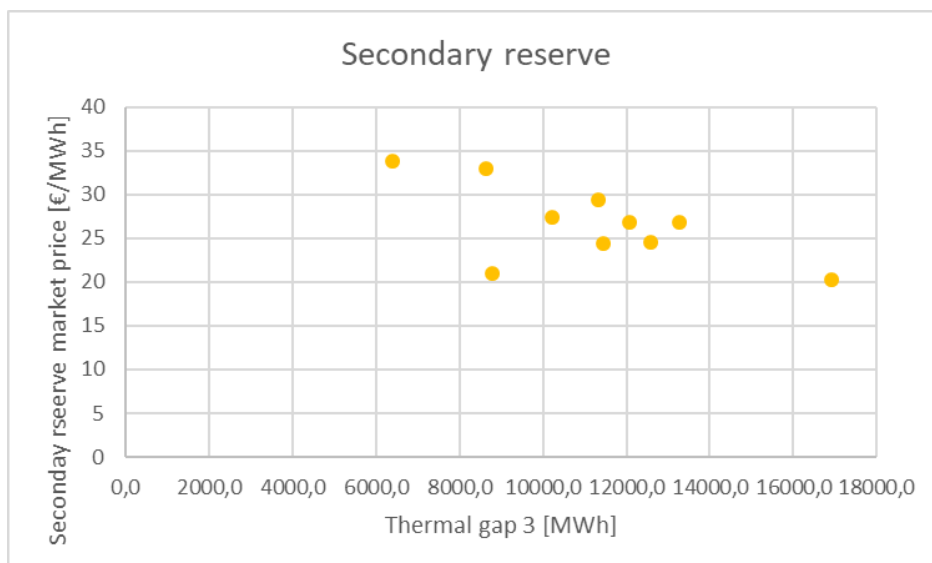


Figure 28. Thermal gap vs Secondary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]

As it can be seen in the images, the relationships, though linear in both cases, have a remarkable difference in their dispersion. While the relationship is quite linear for ten consecutive hours, the relationship is not as precise for thermal gap. This difference may be an indicator of future results; it may be expected more accuracy for the discrimination by hour approach than the discrimination by days one.

Since everything has been explained about the different methodologies used during this thesis, results will be shown together for the different approaches followed, and then, results will be analyzed and commented. In the following table may be seen results for hypothesis stated.

	MAE	MAPE	Maximum error
Five days before	4,88	38,08%	168,95
Ten hours before	4,62	34,02%	211,84

Table 59. Results based on the day-ahead thermal gap for working days. Source: own elaboration from [OMIE17] and [ESIO17]

In the first place, it is noted the high values of MAE and maximum error with respect to intraday values, which is easily explained taking into account the relationship between secondary reserve market and day-ahead market; and the relationship between intraday and daily markets, which is notably stronger. However, MAE values are manageable for this type of markets, which have very low liquidity and high volatility. On the opposite, maximum error values are extremely high, and future approaches should be able to reduce this value, to provide the simulation with less volatility. Additionally, as predicted above, the discrimination by hours' approach has been able to provide more accurate results.

It can be affirmed that, despite the disadvantages mentioned above about liquidity, and the absence of cap prices, which increases uncertainty, the simulation is able to provide convergent results with a reasonable quality. The high values of maximum error can be explained because of spike prices, out of the range of the thesis, which generates high value of error because of difficulty to be predicted and estimated.

In the following table have been plotted results for non-working days methodologies.

	MAE	MAPE	Maximum error
Two days before	6,29	32,55%	91,31
Ten hours before	6,78	35,87%	91,78

Table 60. Results based on the day-ahead thermal gap for non-working days. Source: own elaboration from [OMIE17] and [ESIO17]

As expected, for non-working days, results have been worsened, however, maximum error value has been reduced considerably. The explanation may be found, once again, in spike prices, which may have occurred during working days, resulting in higher values of maximum error for working days than for non-working days.

It has been finished the section about simulation based on thermal gap, in the following section it will be analyzed forecast based on daily prices. The objective is to check if the

relationship is stronger in prices than in thermal gap terms, and if price as input is able to reduce maximum error values.

5.2.1.2 Simulation based on the day-ahead price

The other driver considered of importance was the day-ahead market price. As in the previous section, the first step will be to observe the dispersion graph between both data, and check if an observable relationship occurred, otherwise, the assumption of market price as input data would not be valid. In the following figure may be seen the mentioned relationship.

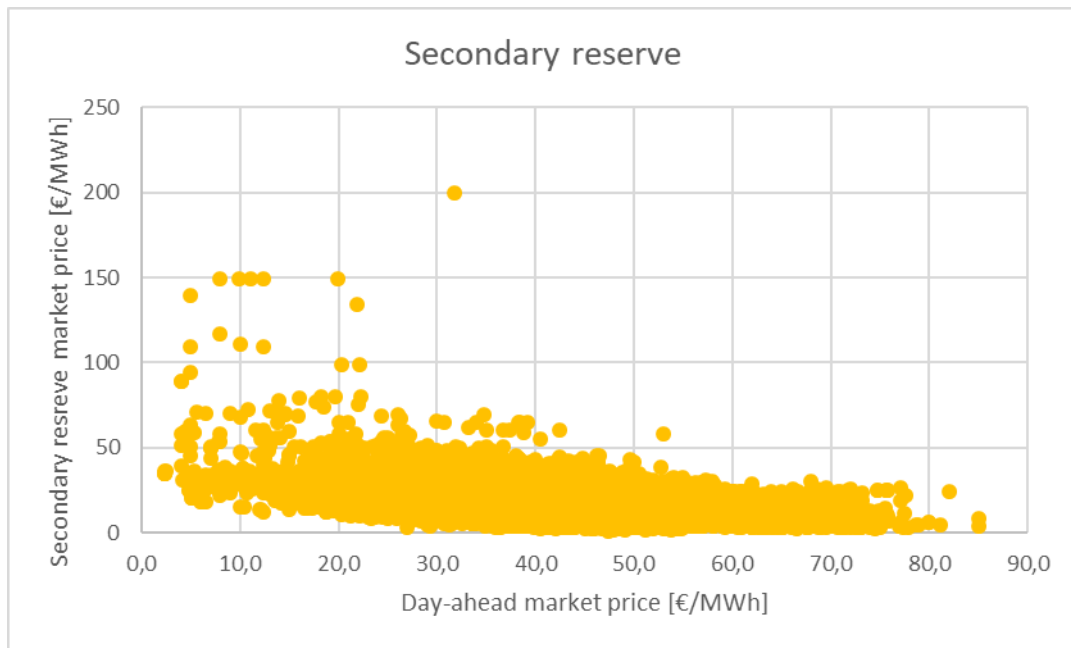


Figure 29. Thermal gap vs Secondary reserve market price for complete days. Source: own elaboration from [OMIE17] and [ESIO17]

At first sight, the tendency is maintained with respect to thermal gap, the relationship is inversely proportional. This is logic, taking into account that thermal gap and day-ahead price have a direct proportional relationship, therefore, secondary reserve price should have the same relationship with both type of input data.

Once it has been demonstrated day-ahead market price as a driver of secondary reserve price, it has to be defined the type of equation employed to elaborate the simulations. The approaches employed will be the same than in the previous section. In the following images may be seen the dispersion graphs for five consecutive days and for ten consecutive hours of the same type.

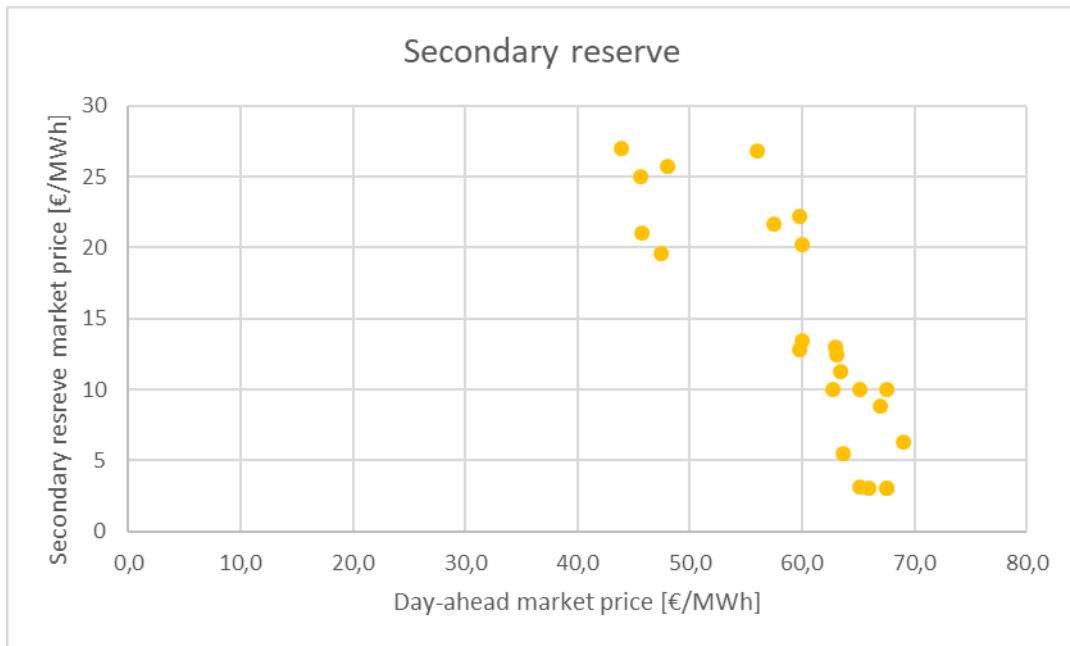


Figure 30. Day-ahead market price vs Secondary reserve market price for five consecutive days. Source: own elaboration from [OMIE17] and [ESIO17]

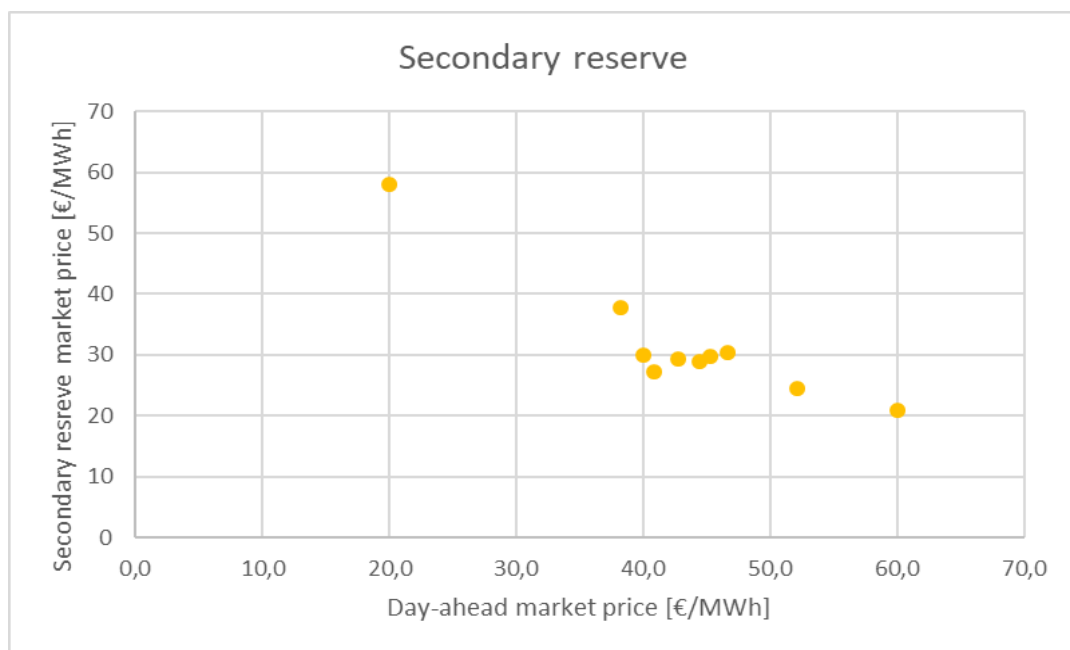


Figure 31. Day-ahead market price vs Secondary reserve market price for ten consecutive hours. Source: own elaboration from [OMIE17] and [ESIO17]

For a day-ahead market price driver, it seems the relationship is clearer than for thermal gap, which may imply better results in terms of forecasting. Additionally, as it happened in the previous section, the relationship becomes stronger for the discrimination by hours' graph, which would indicate better results for this approach too.

As in the section before, the equations employed to forecast prices will be adjusted to a linear. In the case of a discrimination by hours' approach seems logic, taking into account the dispersion graph. Although it may not seem as obvious to choose the linear equation for the

discrimination by days' approach, it is the one preferable, since the secondary reserve price is volatile enough, and this methodology would stabilize results.

Results for the different approaches employed for working days are summarized in the following table.

	MAE	MAPE	Maximum error
Five days before	4,50	34,82%	172,13
Ten hours before	4,30	31,73%	173,20

Table 61. Results based on the day-ahead market price for working days. Source: own elaboration from [OMIE17] and [ESIO17]

As predicted, results have been improved with respect to thermal gap driver section. It has been proved day-ahead market price as a more effective driver of secondary reserve price, however, the instability of this market makes difficult to improve the maximum error committed into a reasonable value. It can be affirmed, consequently, that the volatility of secondary reserve prices has a high impact on its ease to be forecasted.

Following the procedure, it has been computed prices also for non-working days using day-ahead market price as input data. In the following table may be seen the results.

	MAE	MAPE	Maximum error
Two days before	5,65	29,28%	78,46
Ten hours before	5,89	30,81%	72,94

Table 62. Results based on the day-ahead market price for non-working days. Source: own elaboration from [OMIE17] and [ESIO17]

As expected, results obtained using day-ahead market price as input data, are improved for both types of days, working and non-working days. As it occurred in the previous section, when it was computed the simulation for non-working days, maximum error values are much reduced with respect to working days. The reasons that explained this situation would be the same than in the section before.

With these two last simulations, it can be concluded the secondary reserve market section, in the following will be explained and analyzed the tertiary reserve market. After both reserve markets simulations have been studied, it will be offered few preliminary conclusions for this TSO's markets.

5.2.2 Tertiary reserve market price simulator

After the secondary reserve, it enters into action the tertiary reserve. Their main function is to recover actual energy provided by the secondary reserve, in order to free these generators to provide secondary reserve in case it is needed again.

The tertiary reserve market is the closest to real time of all studied markets. Additionally, in contrast with daily markets or secondary reserve markets, this is not a market traded for every hour of the day, only for those hours when tertiary reserve is required.

The process of the tertiary reserve market starts when the TSO identifies the necessity of extra reserve because secondary reserve needs to be replaced. REE summons all agents with generators able to presents their bids, and between them it selects the most suitable at the lowest price. It has to be remarked that the tertiary reserve price, is the price at which actual secondary reserve provided will be paid [REE_98]. Tertiary reserve is not a band, as secondary reserve market was, but real energy that has to be served when required, consequently, it makes sense that secondary energy produced will be paid at the same price, since one replace the other.

It is important to remind that tertiary reserve is not traded for every hour of the day, but only for those when reserve is required, in consequence, it would have to be forecasted not only the price of reserve, but also the hours this reserve is going to be traded. However, it is out of the scope of this thesis to develop a simulator of the electric system, which would provide information about when the system is going to need that tertiary reserve energy, therefore, this will not be included in the simulation. In order to simplify the calculus, in the study will be simulated the past two years with the same hours when tertiary reserve was required. Although this simplification will not provide useful information in terms of forecast tertiary reserve, it would allow to analyze the behavior of tertiary reserve market and sketch the ideas for future proper simulators.

For the tertiary reserve market, it will be used only the discrimination by hours' approach. The main reason it the fact that tertiary reserve is not traded every hour, as mentioned above, consequently, the discrimination by days' approach would have many difficulties to be run, since it is not possible to introduce whole days in the simulator.

Before the forecast is carried out, it is important to defined the main drivers of tertiary market. In this case, it will be used the same input data as for secondary reserve market, since the conditions of both market are very similar. To sum up, the driver introduced in the simulator will be the day-ahead thermal gap and market price.

Finally, it is important to remember that tertiary reserve has two sides, the upward reserve and the downward; as secondary reserve was a band of energy, tertiary reserve may be required to increase the energy of generators or to decrease it.

5.2.2.1 Upward tertiary reserve market

The first type of tertiary reserve studied will be the upward reserve. Once it has been defined the inputs used to simulate prices, it is time to analyze how they are related to tertiary prices and define the equation that best fits to forecast prices.

As it was done in every study before, the first step is to see global relationship between the objective variable and the data used as input, in this case tertiary reserve prices and day-ahead thermal gap and market prices. The following pictures shows the relationship between tertiary prices and day-ahead market price and day-ahead thermal gap respectively.

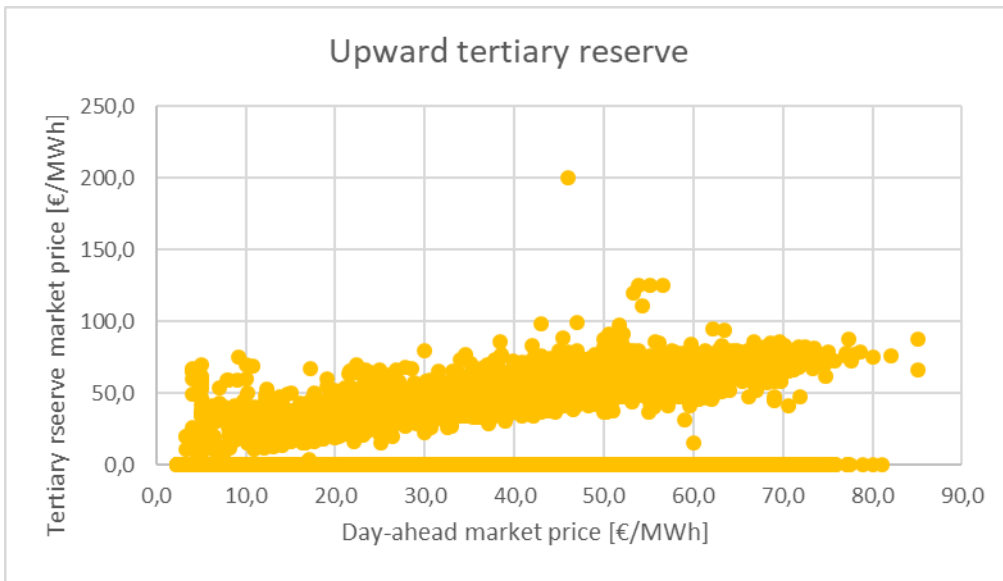


Figure 32. Day-ahead market price vs Upward tertiary reserve market price. Source: own elaboration from [OMIE17] and [ESIO17]

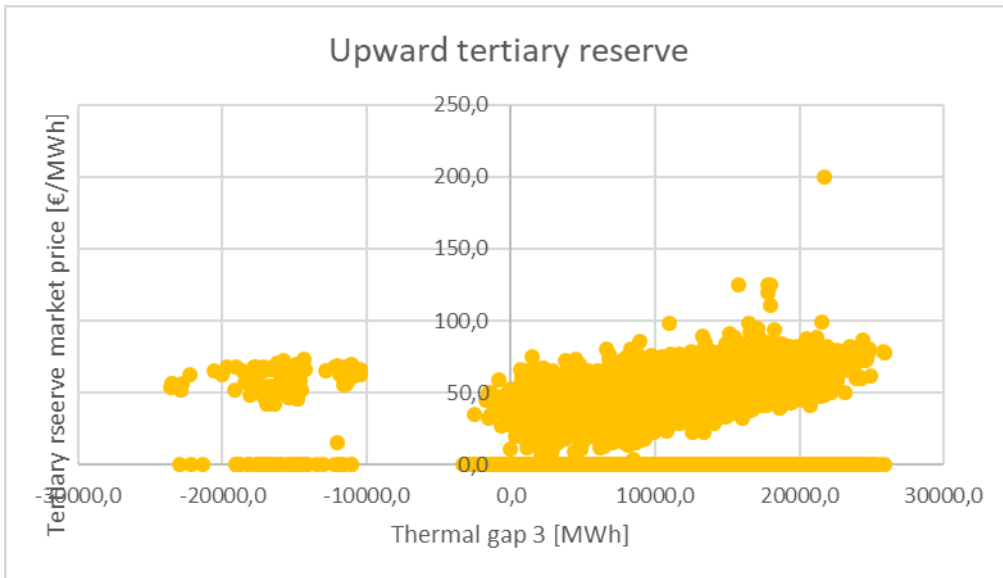


Figure 33. Day-ahead thermal gap vs Upward tertiary reserve market price. Source: own elaboration from [ESIO17]

As it may be seen, the relationship seems directly proportional, the higher the thermal gap or the day-ahead price, the higher the tertiary reserve price. It has to be explained that all values at the x-axis correspond with those hours when there is no price for tertiary reserve, therefore, the value is not valid and will not be used in the simulation. In the same line, negative values of thermal gap correspond with invalid data provided by ESIOS, consequently, it will not be useful in the study.

This direct relationship may indicate, on the other hand, an inversely proportional relationship between secondary and tertiary reserve markets. The reason may be the amount of energy available in the system, it is logic to think that if several generators are committed in the day-ahead market (high value of thermal gap and market price), more energy will be available for secondary reserve, therefore, prices will decrease and TSO will have an incentive to overbuy reserve; however, less tertiary energy will be available, consequently, prices for tertiary

reserve will increase; and vice versa if day-ahead price is low. In the following picture has been plotted the relationship between secondary and tertiary reserves market price.

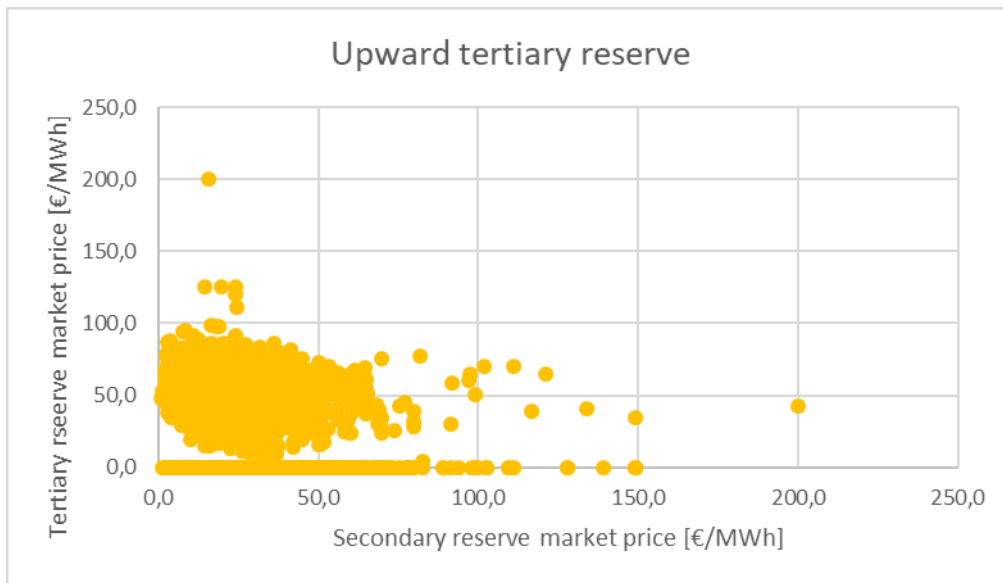


Figure 34. Secondary reserve market price vs Upward tertiary reserve market price. Source: own elaboration from [ESIO17]

Despite the relationship is not as clear as with day-ahead values, it may be seen a vague inversely proportional relationship between prices of both market, as it was expected following the previous reasoning.

Once the drivers of reserve prices have been identified and verified, the next step is to defined the type of equation that best adjust prices. To do so, it is important to observe the relationship for the type of data employed in the simulation, in this case, ten consecutive hours of the same type. In the following curve, it may be seen the relationship for ten consecutive hours 1, for thermal gap and day-ahead market price.

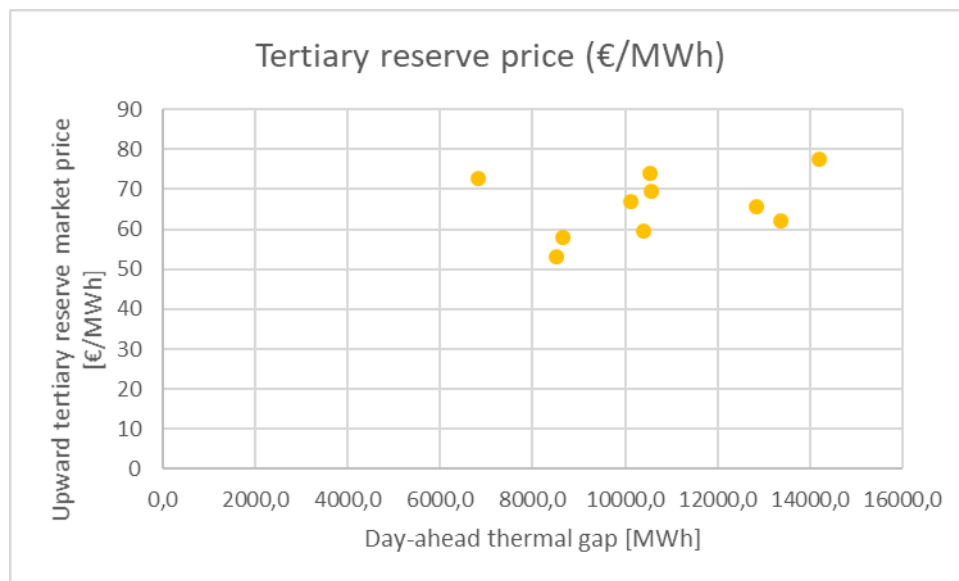


Figure 35. Day-ahead thermal gap vs Upward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]

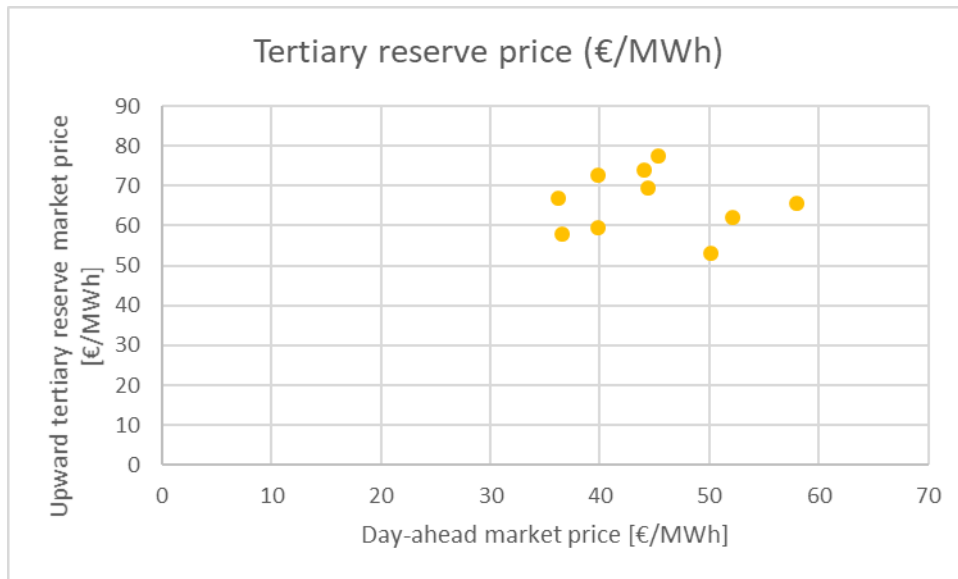


Figure 36. Day-ahead market price vs Upward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17] and [OMIE17]

In both cases the relationship, when few data are taken into account, becomes less clear, which may be an indicator of the difficulty to forecast this type of market by statistical methods. It is interesting, however, the stronger relationship that may seem with thermal gap instead of day-ahead price, this could anticipate better results for this type of driver, in contrast with the trend for secondary reserve simulator, where day-ahead market price provided more accurate results.

Another interesting fact with respect to relationship between prices is the slope in the graph. Either when representing two years or just few days, this slope is higher than 1, which means that the price of tertiary reserve will always be higher than the price of day-ahead market. Despite obvious, it may be an indicator of the competitive behavior of this market. Tertiary reserve market set a price for actual energy produce after the day-ahead market is cleared, and when the real time requires it in order to sustain the balance in the system. If only the service can be provided by energy not committed in the day-ahead market, it is logic the higher price of this market, although the relationship between both should be directly proportional as observe in the dispersion graphs.

Independently of the strength of the relationship of the different driver with the objective function, it has been decided to use a simple linear simulation to compute the forecast equation. Since by looking at the graphs it is not possible to decide the most appropriate type of equation, it has been chosen the linear because of its simplicity, this type of equations is able to reduce maximum errors, additionally, it has been proven before as the most effective type of equation forecasting prices of different markets.

Once the type of equations employed has been defined, it only remains to run the simulation and show the results it provides. In the following tables are shown the results for working and non-working days for the ten hours' approach, using as input data the thermal gap and the day-ahead market price.

	MAE	MAPE	Maximum error
TG	4,99	81,69%	141,84
DAMP	5,54	10,25%	150,08

Table 63. Results based on the ten hours before approach for working days. Source: own elaboration from [OMIE17] and [ESIO17]

	MAE	MAPE	Maximum error
TG	6,92	15,99%	117,94
DAMP	6,53	15,47%	48,51

Table 64. Results based on the ten hours before approach for non-working days. Source: own elaboration from [OMIE17] and [ESIO17]

Results for upward tertiary reserve reveals several interesting conclusions. First of all, results are worse than for secondary reserve simulation, which, as it has been explained in the introduction, refers to the difficulty to forecast price for this specific market.

This has been said, there are some conclusion worth analyzing. For instance, for working days, the best approach is the one using thermal gap as input data, as it was predicted above. The relationship seemed stronger, and it has been able to provide more accurate results. Nevertheless, for non-working days the results are just the opposite, and day-ahead market price provide better results.

As it has happened before, non-working day' simulations provide lower values of maximum error, however, the approach using day-ahead market price is able to provide a much lower value. There are two possible explanations, on one hand the possibility that day-ahead market price is able to reduce the error considerably with respect to other approaches; on the other hand, and more likely, the simulation may have failed and results are not valid, since the reduction is high enough to be considered an anomaly.

In line with this reasoning, may be explained the high value of MAPE for thermal gap approach for working days. It has to be remembered that MAPE is the same value of MAE, expressed as a percentage. In this case, it has been confirmed that there is no error in the simulation, but the abnormal value is produced because of the maximization of values when percentages are used. Actually, this is the effect why Weron advise against this indicator as a proper guide of the quality of results.

With all the reasoning above give, it may be concluded what it was predicted at the beginning of the section, tertiary reserve market is one of the most complex of all, it is close to real time, and all this makes more difficult to elaborate quality simulations.

In the following section will be analyzed the downward tertiary reserve, it will be studied if the trend is maintained with respect to upward reserve, or if it is a completely different market in terms of forecasting.

5.2.2.2 Downward tertiary reserve market

The downward tertiary reserve is the energy that the TSO needs to retire from the system in order to match actual production of energy with demand in real time. In the same way upward tertiary reserve functions, when the secondary reserve band is used and needs to be replaced, the downward tertiary reserve enters into action and some generators decrease their production to replace the secondary band. To do so, the procedure is also the same as in

upward reserve, the TSO publishes the amount of energy needed for tertiary purposes and agents have to submit their offers, then, REE chooses the most appropriate in technical and economic terms.

It is important to explain the character of downward tertiary reserve bids, they are considered as rebuying bids, or to say it simpler, the price an agent is willing to pay for reducing the production of energy. Therefore, in this market, it is not the TSO who is going to pay for the energy, but agents which are buying energy from the TSO.

Despite the differences explained above between upward and downward tertiary reserve, it is going to be assumed the same drivers for both type of markets, since the purpose of both is the same, to maintain the balance in the system. In consequence, in the following graphs is represented the relationships between downward reserve price and day-ahead prices and thermal gap.

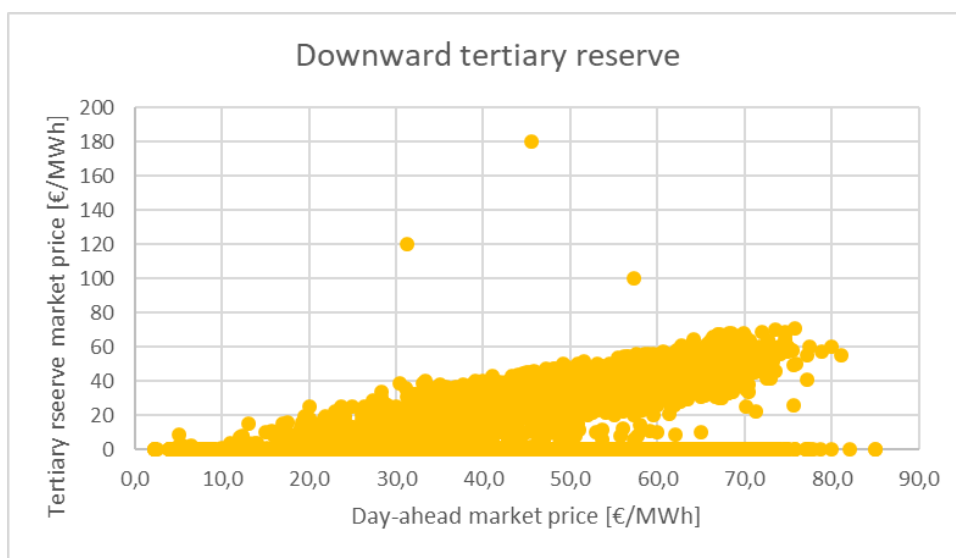


Figure 37. Day-ahead market price vs Downward tertiary reserve market price. Source: own elaboration from [OMIE17] and [ESIO17]

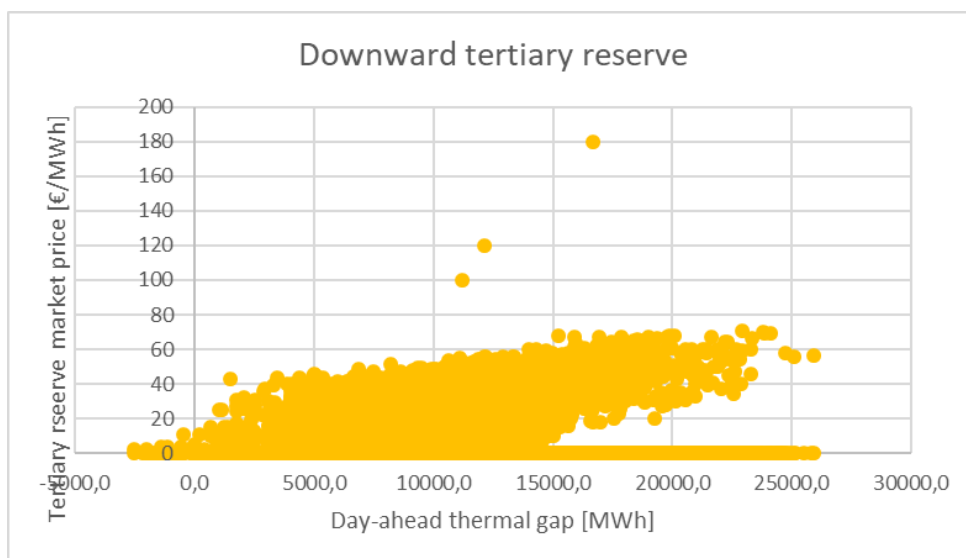


Figure 38. Day-ahead Thermal gap vs Downward tertiary reserve market price. Source: own elaboration from [OMIE17] and [ESIO17]

As it was expected, the relationship between downward tertiary reserve and its drivers is directly proportional, as for upward reserve. This may indicate that the approaches employed before, in the upward reserve section, are valid also for downward reserve.

One interesting difference between tertiary reserves, which may be seen in the graphs above, is about the relationship in terms of prices. While for upward reserve the slope was higher than 1, which meant that upward reserve will always be more expensive than day-ahead market; in this case, the slope is almost 1. It has been explained the character of downward reserve about rebuying energy from the agent side, this energy is energy sold in the day-ahead market, therefore, agents will be willing to pay at least what they have received previously in the daily market, consequently, the slope of the graph is logic.

Although it seems that upward and downward reserve may share the same approaches to be forecasted, which implies the same type of equation, it has been plotted the dispersion graphs for just few hours of data, in order to be completely sure about the equations chosen.

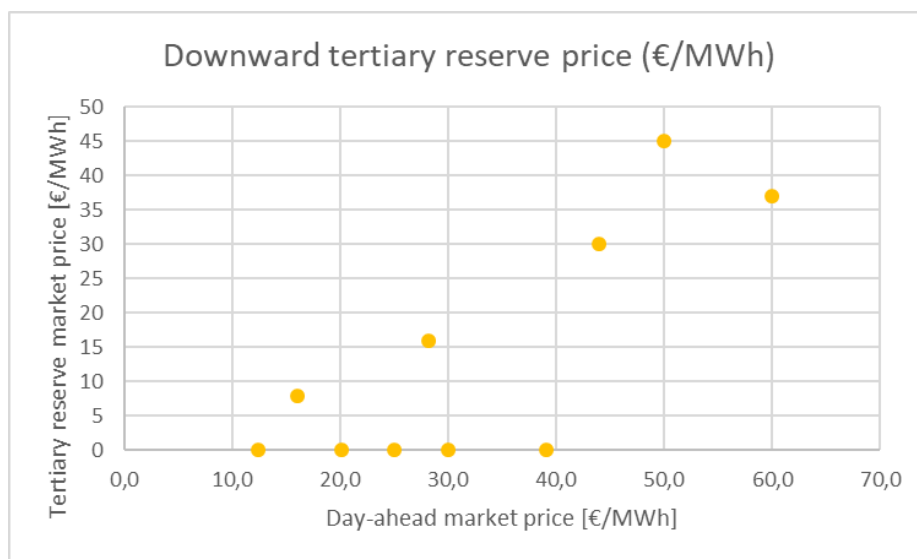


Figure 39. Day-ahead market price vs Downward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]

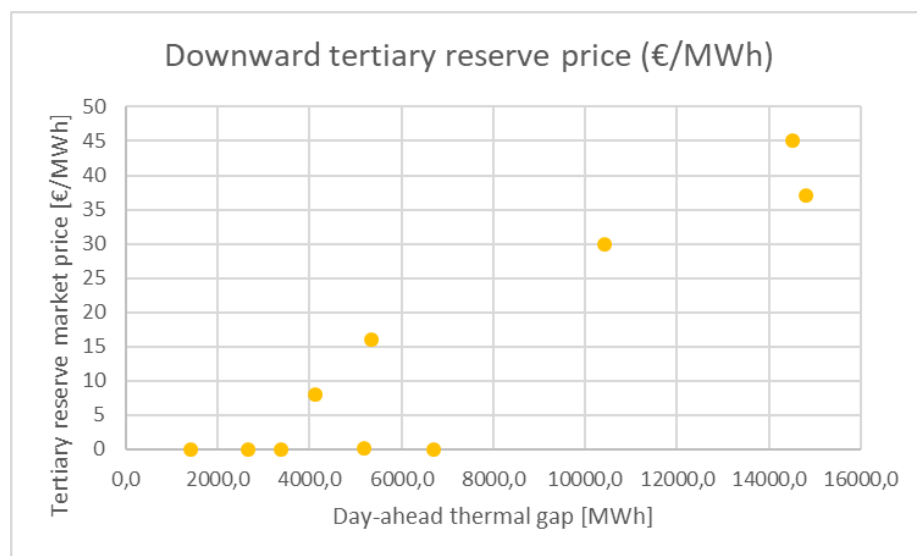


Figure 40. Day-ahead thermal gap vs Downward tertiary reserve market price for ten consecutive hours. Source: own elaboration from [ESIO17]

Except for those hours when there was no price for tertiary reserve, because there was not necessary downward tertiary reserve, the relationship appears to be linear, consequently, it will be employed linear equation to elaborate the forecast in both cases.

Now that it has been checked that both types of tertiary reserve are similar, and the procedure for downward reserve can be the same than for upward reserve. It is time to run the simulator and plot the results obtained.

	MAE	MAPE	Maximum error
TG	7,87	1893,17%	142,16
DAMP	7,63	2106,47%	151,28

Table 65. Results based on the ten hours before approach for working days. Source: own elaboration from [OMIE17] and [ESIO17]

	MAE	MAPE	Maximum error
TG	9,68	3563,18%	141,05
DAMP	8,66	2995,21%	45,92

Table 66. Results based on the ten hours before approach for working days. Source: own elaboration from [OMIE17] and [ESIO17]

It can be seen that results are even worse than in the case of upward reserve, MAPE values cannot be considered valid since their values are in the range of thousands. Despite results seem discouraging, some conclusion can be obtained.

In first place, approaches based on day-ahead market price have provided better results than those using thermal gap as input data, in contrast with the results obtained for upward reserve.

The other interesting fact is related to maximum error values. In this case, the behavior of results remains similar to upward reserve, while the approach of day-ahead market price for non-working days is stabilized at about 45, for the rest of approaches used it seems that maximum errors take high values. This indicate that the anomaly supposed before may not be correct, and day-ahead market price input is able to reduce the maximum error committed by the simulation much better than the other driver.

5.2.3 Preliminary conclusions about reserve markets

Once all the simulations have been run for the reserve markets studied, this section will analyze results obtained and will offer few preliminary conclusions about them. First of all, it is important to remember that there have been studied two different markets, secondary and tertiary reserve markets, in consequence, results have been, although similar at some points, slightly different, and so are the conclusions for them.

The first market simulated in this market was the secondary reserve market, this was a market where no energy was actually traded but a band of energy, or to say it otherwise, the possibility to provide energy. This means that agents are not offer real production, but they are offering the possibility to increase their production, which also means, that they are not producing at their maximum rate yet, this will be taken into account in their bids, and will be reflected in the behavior of price of this market.

It was considered as the main driver of this market the daily thermal gap and market price, since it was said that agents are offering remaining energy from their generators, but these generators must be up and running, it is logic to think that the relationship with day-ahead market should be strong enough to be used as input data.

The most important conclusion about secondary reserve market is related to the input data, although both approaches considered were valid at first, results confirmed day-ahead market price as a better drive of secondary reserve price. The reason may be, despite the obvious and strong relationship with day-ahead thermal gap, that agents are not only influence by the amount of energy that can participate in this market, but also by price of day-ahead market. To say in other words, it has been made clear that the higher the price or the thermal gap from day-ahead market, the lower the price of secondary reserve, and also have been explained the reasons; however, it may be possible that for the same amount of thermal gap, but different day-ahead market price, agents decide to change price in order to maximize their profits.

With respect to tertiary reserve markets, the most relevant conclusion is about results in general. It can be affirmed that results are not as good as in other market simulators, which may advise against the validity of the study for tertiary reserve markets. When forecasting electricity prices for any markets, there are several issues which difficult the task of predicting the price, in the case of tertiary reserve, there are even more difficulties because of its particularities. First of all, it is the closest market to real time, which increase highly its volatility, because agents need to bid with little information about their competitors with very few time to prepare the strategy, consequently, prices vary significantly. Additionally, in this market can participate just a small number of generators, those with available energy after every market has been cleared, therefore, the competitiveness is reduced considerably, and reflected again in the volatility of prices. Summing up, despite there is a relationship between day-ahead data and tertiary reserve price, this is not enough to build a quality price simulator because of the disadvantages mentioned above, at least not by statistical methodologies employed in this thesis.

Apart from the differences between both reserve markets, there is a common point between the two of them, this is related to maximum error values obtained. For every study carried out for reserve markets, maximum errors have taken huge values above one hundred, except for two approaches. The reason why these high values have appeared in reserve markets and not before has to be, consequently, in the characteristic of reserve market. An important difference between OMIE markets and REE reserve markets is the absence of floors and caps in the latest. When no limits are set to the price of the bids of agents, from time to time appears what Weron call spike prices [WERO06], these are very difficult to foresee and complex to forecast, in consequence, the maximum error committed sometimes takes very high values.

Chapter 6. Technical constraints market

6.1 Introduction

The technical constraints market may be, by far, the most complex market of all studied in this report, which means also the most difficult to elaborate forecast. Initially, it will be explained, studies and analyzed the market in depth, afterward it will be evaluated if any forecast is possible and the quality and accuracy of it.

The technical constraints market, as indicated by its name, aims to solve any technical issue that may appear in the grid after the day-ahead market is cleared. Since day-ahead market is a purely economic market, it does not optimize or even take into account the grid, therefore, it is common that the initial dispatch is technically non-viable and REE needs to solve it by the technical constraints market and more tools at its disposal.

It has to be explained that the TSO uses only generation to solve the constraints, therefore, as it happened before with the other REE markets studied, this is a one-sided market, when the purchasing part role is played by REE, and agents just bid their willingness to sell energy from their power plants. It has to be made clear also, that not every generation technology can provide the service, only those which can guarantee firm power, in the end, thermal generation. Additionally, the technical constraints market has some specific characteristic which make it completely different from every other market studied in this report, these differences are explained in the following paragraphs.

The main difference between this market and all of the markets studied before in this report, is how it is cleared. While every other market before was based on marginal prices, the price of the last offer accepted is the one setting the price for every bid accepted in the market, the technical constraints market is based on a pay as bid system. To say it in other words, every agent or power plant is remunerated according to what it has been requested in the bid, with independency of what other agents or power plant may do. This particularity complicates considerably the task of forecasting, because there is no single price to forecast but the price of every unit in the system. This is, instead of modelling the behavior of a large group, it is necessary to model the behavior of individuals, which is, logically, much more complex.

The other relevant difference is related to the criteria when assessing the assignment of power plants to provide the service. While in other markets, including REE market, one of the first considerations were economical (once the power plant was certified by REE), in this case the most important remark is related to the ability of the power plant to solve the constraint. Only if there are two or more plants which can solve the issue, the TSO takes into account economic conditions.

Normally, the ability of a power plant to solve the problem is related to the location of the power plant. Usual issues in the constraints market is the control of voltage level in a specific line, in consequence, only power plants located near that line can guarantee voltage level. The technical constraints market is, therefore, a zonal market, where the location of power does affect the output of the market.

Summing up, it has been said the technical constraints market is a pay as bid market and a zonal market too, provided mainly by thermal power plants. It will be important to carry out an analysis on the power plants which are able to participate in the market, study their location

and identify the possible plants in competition in each area, before the studying and development of a price simulator.

6.2 Power plants

It has been said in the previous section that only generation able to provide firm capacity are allowed to participate in the constraints market. It is excluded, consequently, all intermittent renewable generation, like wind and solar, but also other technologies such as cogeneration and river-of-the-run hydro. Additionally, nuclear energy does not attend to this market since it produces at nominal values all the time, so it cannot solve any constraint. In the end, the technologies that can participate in the technical constraints market are the coal, the CCGT, and the manageable hydro, including pumping.

From the technologies mentioned above, in practice, only coal and CCGT participate actively in the technical constraints market, at least for the period of the study. In conclusion, only thermal power plant fueled by coal or gas will be taken into account in the present report. In the next paragraphs will be named and analyzed the different power plants which are able to participate in the constraints market. At the time of this study there were 89 power plants registered in the Spanish system from which only 79 were available to produce electricity [OMIE17].

As explained in the introduction, the location of the power plant is relevant when assigning the constraint, in consequence, it will be important to locate power plants in the map of Spain and defined the areas where competition between different power plants is possible. Despite the data from the following map is from the year 2012, the number and location of power plants has not change remarkable since then, and it will be useful to establish the preliminary zones of study.



Figure 41. Location of Spanish power plants. Source: [WIKI18]

It is excluded from the study any power plant located in the different islands of Spain, it will be only taken into account peninsular power plants. Considering the location of power plants showed by the map, it has been established 15 different zones, defines in the table below. It has to be explained, additionally, that not every defined zone is regularly committed in the technical constraints market, therefore, those areas with a low number of hours of production in the technical constraints market will be excluded also from the study, since it will not be representative to analyze them.

In the following table are divided the different power plants into the fifteen different zones defined, they are shown along with the number of hours of production in the technical constraints market for the year 2.016. It has been taken into account active power plants for the year of the study.

Zone	Agent	Name of power plant	Code of power plant	Number of hours of production
Zone1	Agent1	Power plant 1	PP1	155
		Power plant 2	PP2	479
	Agent2	Power plant 1	PP1	414
		Power plant 2	PP2	710
		Power plant 3	PP3	1.289
		Power plant 4	PP4	734
Power plant 5	PP5	10		
Zone2	Agent4	Power plant 1	PP1	2.007
		Power plant 2	PP1	3.816
		Power plant 3	PP3	264
		Power plant 4	PP4	119
		Power plant 5	PP5	267
	Agent3	Power plant 1	PP1	120
		Power plant 2	PP2	0
		Power plant 3	PP3	32
	Agent1	Power plant 3	PP3	30
		Power plant 4	PP4	0
		Power plant 5	PP5	0
		Power plant 6	PP6	30
	Agent2	Power plant 7	PP7	30
		Power plant 6	PP6	0
Power plant 7	PP7	0		
Zone3	Agent6	Power plant 1	PP1	219
	Agent7	Power plant 1	PP1	854
	Agent3	Power plant 4	PP4	11
		Power plant 5	PP5	0
	Agent4	Power plant 6	PP6	48
Power plant 7		PP7	36	
Zone4	Agent6	Power plant 2	PP2	0
	Agent7	Power plant 2	PP2	0
	Agent5	Power plant 1	PP1	0
	Agent2	Power plant 8	PP8	0
		Power plant 9	PP9	0
Power plant 10	PP10	2		
Zone5	Agent1	Power plant 8	PP8	7.650
		Power plant 9	PP9	1.803
		Power plant 10	PP10	2.125
	Agent2	Power plant 11	PP11	3.532
Power plant 12		PP12	3.961	
Zone6	Agent6	Power plant 3	PP3	248
		Power plant 4	PP4	189
	Agent3	Power plant 6	PP6	1.139
Agent5	Power plant 2	PP2	0	
Zone7	Agent3	Power plant 7	PP7	613
	Agent1	Power plant 11	PP11	2.148
Zone8	Agent3	Power plant 8	PP8	185
		Power plant 9	PP9	1.600
	Agent1	Power plant 12	PP12	2.076
		Power plant 13	PP13	2.880
Power plant 14	PP14	1.411		

Zone9	Agent1	Power plant 15	PP15	2.299
		Power plant 16	PP16	295
		Power plant 17	PP17	959
	Agent6	Power plant 5	PP5	0
		Power plant 6	PP6	3
		Power plant 7	PP7	609
Agent3	Power plant 10	PP10	126	
Zone10	Agent2	Power plant 13	PP13	18
	Agent1	Power plant 18	PP18	0
		Power plant 19	PP19	64
		Power plant 20	PP20	0
Zone11	Agent3	Power plant 11	PP11	0
		Power plant 12	PP12	0
		Power plant 13	PP13	550
Zone12	Agent5	Power plant 3	PP3	3.288
		Power plant 4	PP4	4.844
	Agent6	Power plant 8	PP8	0
		Power plant 9	PP9	174
	Agent1	Power plant 21	PP21	2.299
	Agent2	Power plant 14	PP14	1.596
Zone13	Agent1	Power plant 22	PP22	3.567
Zone14	Agent5	Power plant 5	PP3	0
Zone15	Agent2	Power plant 15	PP15	850
		Power plant 16	PP16	819

Table 67. Power plants participating in the technical constraints market by agents and by zone for the year 2.016.
Source: Own elaboration from [ESIO17] and [WIKI18]

Because of the pay-as-bid characteristic of this market, power plants have to be treated separately in the study. In order to maintain the anonymity of every agent and power plant, it has been decided to change every name from every zone, agent and power plant, therefore, it will be named as zone1, zone2 ... and the same for the rest.

The number of hours of production refers to those hours when the generator is ordered to produce energy and not to reduce it, since the technical constraints market may be to increase or decrease power. As explained in the introductory chapter, this study will be based only on the phase of increase power to solve the constraint, in order to analyze the price for producing energy in this market.

As a general rule, it has been decided to study every power plant with a number of hours of production above 1.000 hours, however few exceptions have been made. For instance, power plant 7 from Agent3 in Zone7 has been included for comparison purposes; while others above the thousand hours of functioning have been eliminated from the study if they were the only ones producing, as in the case of power plant from Agent1 in Zone1. For clarifying purpose, in the following table are shown all power plants included in the present study:

Zone	Agent	Name of power plant	Code of power plant	Number of hours of production
Zone2	Agent4	Power plant 1	PP1	2.007
		Power plant 2	PP1	3.816
Zone5	Agent1	Power plant 8	PP8	7.650
		Power plant 9	PP9	1.803
		Power plant 10	PP10	2.125
	Agent2	Power plant 11	PP11	3.532
		Power plant 12	PP12	3.961
Zone7	Agent3	Power plant 7	PP7	613
	Agent1	Power plant 11	PP11	2.148
Zone8	Agent3	Power plant 9	PP9	1.600
	Agent1	Power plant 12	PP12	2.076
		Power plant 13	PP13	2.880
		Power plant 14	PP14	1.411
Zone9	Agent1	Power plant 15	PP15	2.299
Zone12	Agent5	Power plant 3	PP3	3.288
		Power plant 4	PP4	4.844
	Agent1	Power plant 21	PP21	2.299
	Agent2	Power plant 14	PP14	1.596
Zone13	Agent1	Power plant 22	PP22	3.567

Table 68. Power plants included in the study by agents and by zone for the year 2.016. Source: Own elaboration from [ESIO17] and [WIKI18]

From the 79 active power plants in Spain, the list has been reduced to 24 power plants to be studied in the present thesis. In the following section will be studied in depth every power plant by zone.

6.3 Analysis

This section will study, by zones, every power plant participating in the technical constraints market. The principal idea is to analyze their bidding and competitive behavior, as far as to establish a trend in their bids in order to develop a price simulator, whenever this is possible.

The study will be divided into the different zone defined in the previous section. Since there are areas with several power plants competing at the same time, while in others there is just one, it would be interesting to analyze if this fact affects the behavior of agents in their bids, and the possibility to develop a price simulator in those areas.

The last fact to take into account is the fuel used by every power plant. In this chapter, the study is done power plant by power plant individually, therefore, the main driver for their prices should be fuel prices. There are two types of power plants in the constraints analysis, coal and gas, and it will be important to define the price reference for them.

In the case of gas prices, the reference in Spain should be the price of gas sets by MIBGAS, this market started to operate at the end of the year 2.015, for this reason the study is done only for the year 2.017, when it is belief the market will be more mature.

On the other hand, there is not a local organized market for coal, which makes difficult to stablish a reference price, since there is no public reference for it. Additionally, there are only three coal power plants selected for the study which fulfill the requirements exposed above, two of them are not even situated in the transmission grid, but in the distribution grid, which means that it is not REE, the TSO, who selects them for the technical constraints market, but

the local distributor. In conclusion, two of the three power plants selected do not actually compete, and for the remaining power plant has been considered not worth it to carry out the process of obtaining a good indicator of coal price, since there is not an organized public one in the Spanish system.

6.3.1 Zone5

In the case of Zone5, all of its power plants actively participate in the technical constraints market, additionally, all of them use also the same type of technology, CCGT, from two different agents. This could be the perfect scenario to analyze the behavior of CCGT power plants in the technical constraints market.

Because all power plants used natural gas as fuel to produce electricity, it is assumed that the main driver of their bids should be the price of it. In Spain, there is an organized market for natural gas, MIBGAS, which started to operate at the end of the year 2.015. Since this is the only organized market for natural gas in Spain, and the only source of a public price for the commodity, this will be used as the reference and driver for CCGT bids in every market, and especially in the technical constraints market.

It has to be made clear that it makes sense to use the MIBGAS reference, despite every agent, especially the big ones, would acquire a portion of its gas by bilateral contracts with private prices. To say it clearer, if the gas price for MIBGAS is higher than the one any agent is paying, they would go to MIBGAS to sell their gas instead of burning it with lower profits, or at least they would equate the bid of their power plant to the price of MIBGAS to maximize their profits. If, in contrast, the price of MIBGAS is lower than the one of their bilateral contracts, they would go to buy gas to MIBGAS, and introduce this price in their bids to be more competitive. In any case, since there is a public reference for the price of gas, and the market is liquid enough, one way or another, agents would use it to be more competitive. In order to ensure the liquidity of the market, it has been decided to make the study for the year 2.017, when it is expected MIBGAS to be more mature and therefore, more liquid.

The main purpose of this technical constraints analysis is to assess the possibility to develop a price simulator, in order to do so, the first step is to find and define a pattern in the bid building process. This pattern would appear easily if every agent behaves in a competitive way, which would mean that they link their bids to some reference, in this case the normal reference would be the MIBGAS price reference. To assess the competitive behavior of the power plants, it has been studied the bids of every power plant in the technical constraints market plus the bids in the most liquid market, and therefore the most competitive, the day-ahead market; and compared both cases with the price of natural gas sets by MIBGAS. If the behavior of agents observed can be considered competitive, it will be possible to establish the principles of a price simulator, otherwise, there will be no trend in the bid construction and no simulator will be possible.

In the first place have been plotted the bids of the five power plants of Zone5 for the day-ahead market and the technical constraints market. With this first analysis, it will be possible to observe if both types of bids follow the same trend throughout the year, which will be the logic and expected behavior. In the following pictures are shown the bids for the day-ahead market and the technical constraint market.

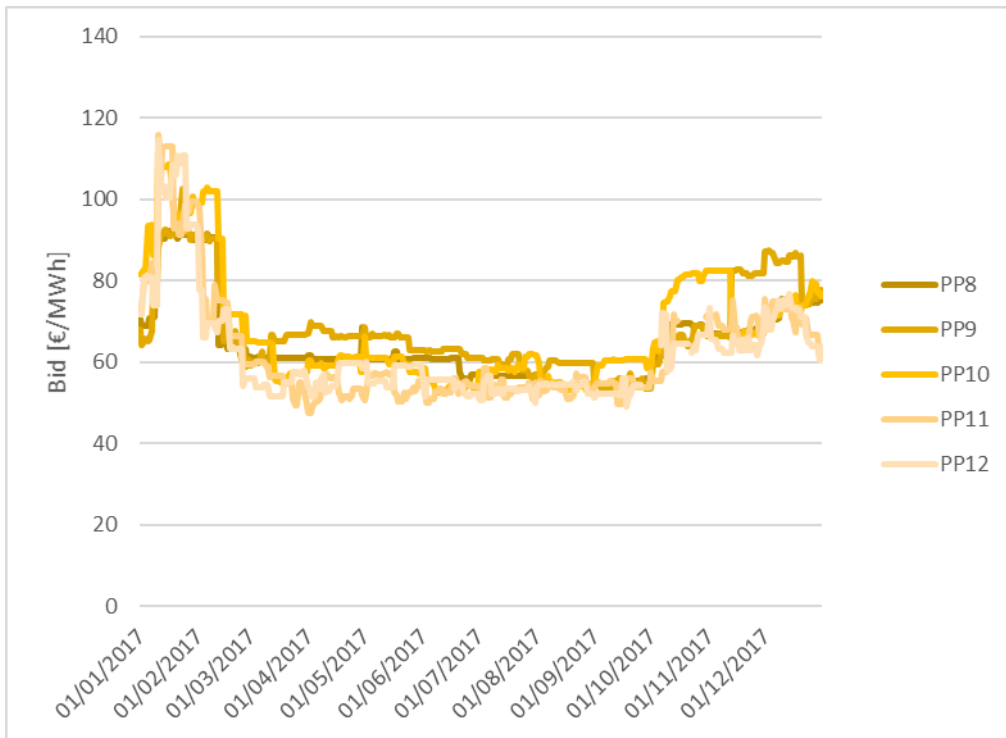


Figure 42. Day-ahead market bids for the year 2.017 for the power plants in Zone5. Source: own elaboration from [ESIO17]

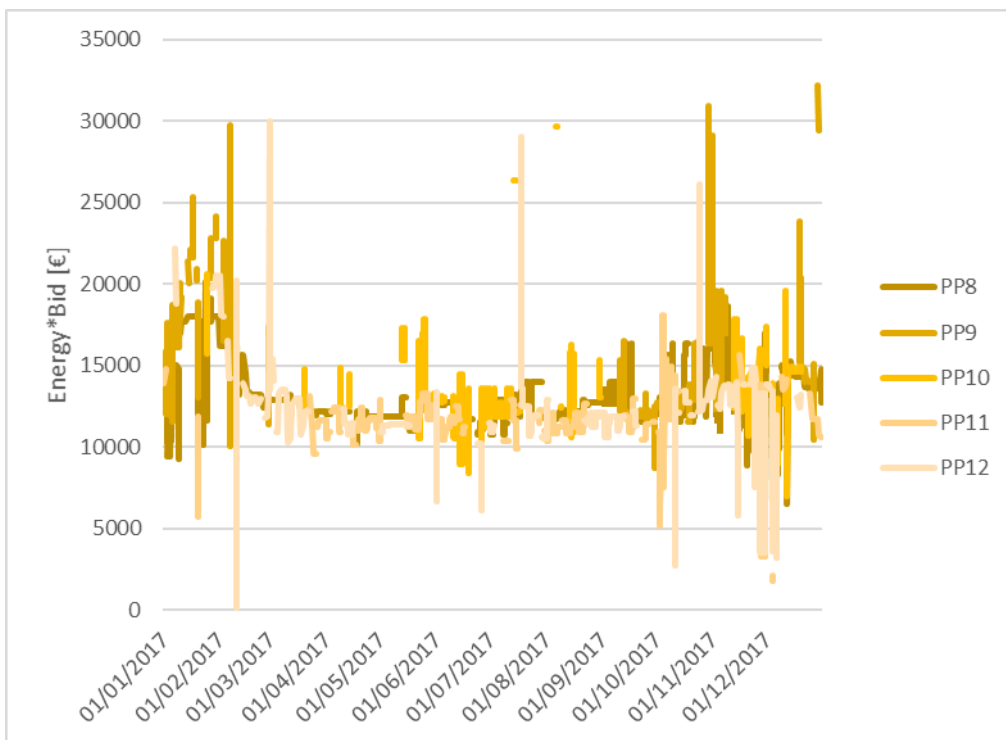


Figure 43. Technical constraints market bids for the year 2.017 for the power plants in Zone5. Source: own elaboration from [ESIO17]

Before analyzing the trend shown in the pictures, it is important to explained the terms used. In the case of day-ahead market it has been plotted the variable term included in the bid, this term should reflect the cost of fuel, and is in the end what agents need to recover from the market to produce electricity. In the case of technical constraints, it has been shown the

product of the variable term of the bid by the energy bid. It has to be reminded that in the technical constraints market, the selection of units is done by a pay-as-bid system, therefore it is taken into account the whole amount of money asked.

Looking carefully at both pictures it is possible to observe that bids follow a similar natural trend in the two markets, with higher prices at the beginning and at the end of the year, corresponding with seasons of higher demand. It is also normal the higher volatility of prices in the technical constraints, something usual for low liquid markets.

Although the images are not extremely clear, it is possible to observe that those power plants situated at the lowest position in the day-ahead market, meaning the cheapest ones, are also at the same position in the technical constraints chart, and the same happens with those situated at the higher positions, the most expensive. This may be an initial indicator about the competitive behavior of the power plants situated in Zone5, however further analysis is going to be implemented below.

To assess if power plants are following a pattern in their bids, and therefore, a price simulator is possible, it has been decided to compare the behavior of each power plant individually. It has been plotted at the same time the dispersion graph for the bids of the day-ahead market and the technical constraints markets, with respect to the MIBGAS price reference for the day ahead. In the following picture may be seen the graph for PP8 from Agent1.

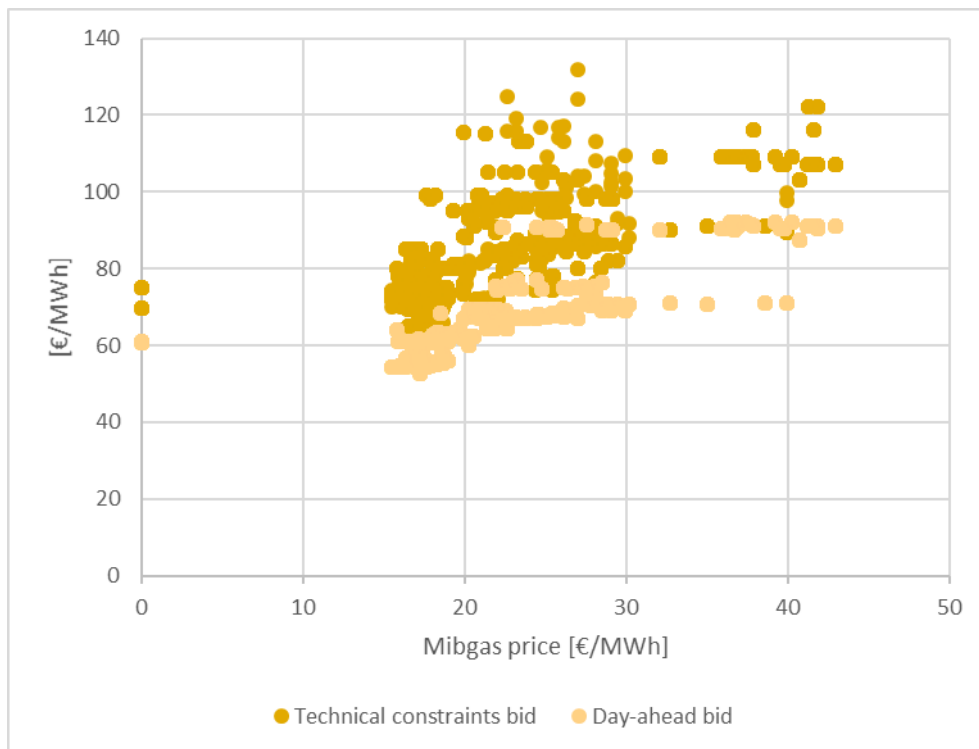


Figure 44. Day-ahead and technical constraints market bids versus MIBGAS price for PP8 from Agent1. Source: own elaboration from [ESIO17]

In this case it has been plotted for both markets the variable term for comparing purposes. The present image can provide some interesting details, for instance, as expected, bids for the technical constraints market are higher than for the day-ahead market. The explanation may not be necessarily related to competitive behavior, but to the amount of energy committed in each market. Although, in principle, in the technical constraints market agents have to bid the

remaining amount of energy from the day-ahead market, in practice, REE usually commits only the minimum technical, which is the minimum amount of energy a power plant can permanently produce. This situation provokes that agents have to increase the variable term for the energy committed in the technical constraints market, since functioning at the minimum technical consumes more gas, hence it is more expensive.

It is possible to observe for the day-ahead charter the strong relationship between the day-ahead bid and the gas price, except for some points when the price may be justified by other external factors. It is possible to see that for prices of gas below 20 €/MWh, electricity price remains around 60 €/MWh; while for 40 €/MWh the price of electricity is increased up to 80 €/MWh, which is the same increase in both markets.

However, for the technical constraints charter, the cloud of data is fuzzier. The reason may be competitive issues or the complexity of building a bid when it is known that only a small portion of energy is going to be committed. Additionally, it has to be reminded the absence of cap and floor price for REE markets, which may increase the uncertainty in price and therefore the volatility of bids. Whichever is the case, it is obvious the relationship between gas prices and electricity prices, and it does appear to be a possible trend to be used in a price simulator.

The following picture correspond to PP9 and PP10 from Agent1.

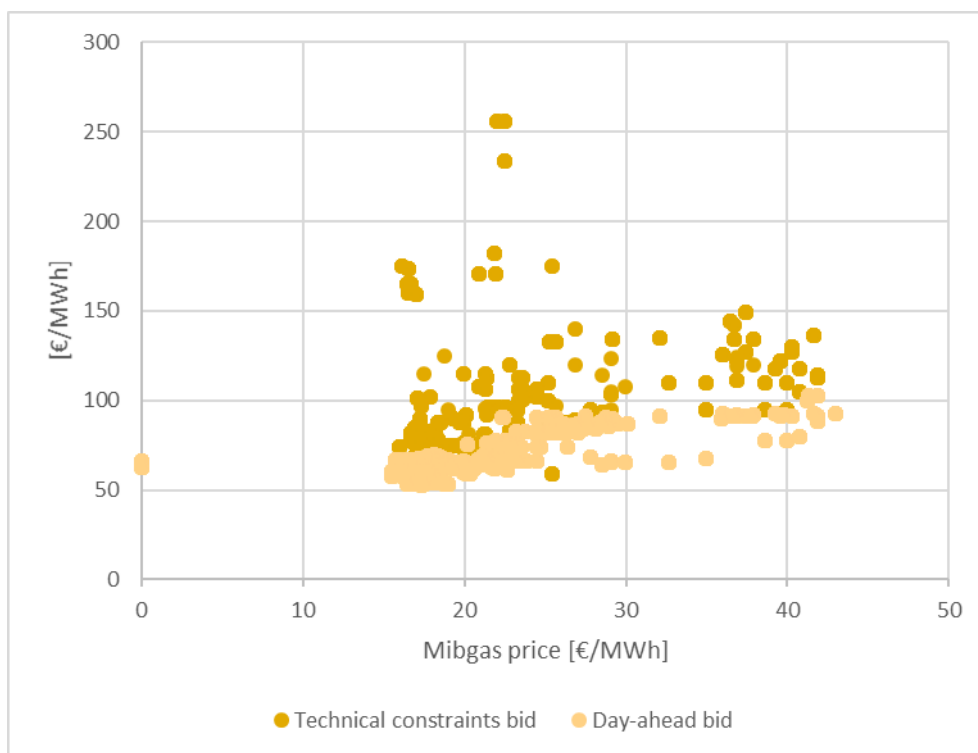


Figure 45. Day-ahead and technical constraints market bids versus MIBGAS price for PP9 from Agent1. Source: own elaboration from [ESIO17]

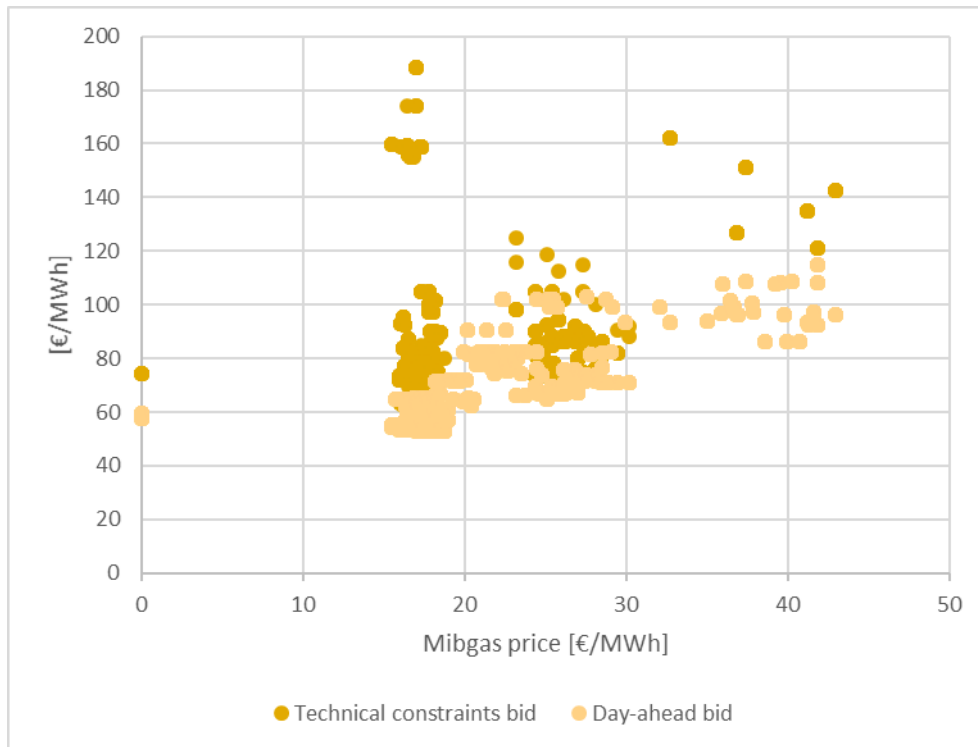


Figure 46. Day-ahead and technical constraints market bids versus MIBGAS price for PP10 from Agent1. Source: own elaboration from [ESIO17]

It has been decided to analyze these two power plants together because of the similarity in their graphs. For the day-ahead bid the behavior is similar than in the case of PP8, which was expected, since there is no doubt about the strong relationship between both markets and the competitive behavior in the day-ahead market because of its liquidity.

However, the behavior of these two last power plants is slightly different with respect to PP8 in the technical constraints market. In the three cases, the dispersion for technical constraints is higher, this could have different explanations, but in addition to this situation, for PP9 and PP10 there are few points with extremely high prices and outside the general trend. This could mean a non-competitive behavior and could not allow to create a price simulator for these two power plants. However, if looking specifically to those points, it is possible to relate them to days when almost every power plant was committed, hence, it was necessary for the agent to acquire extra gas, more expensive. In the following table may be seen some of those days when a high number of power plants were committed at the same time.

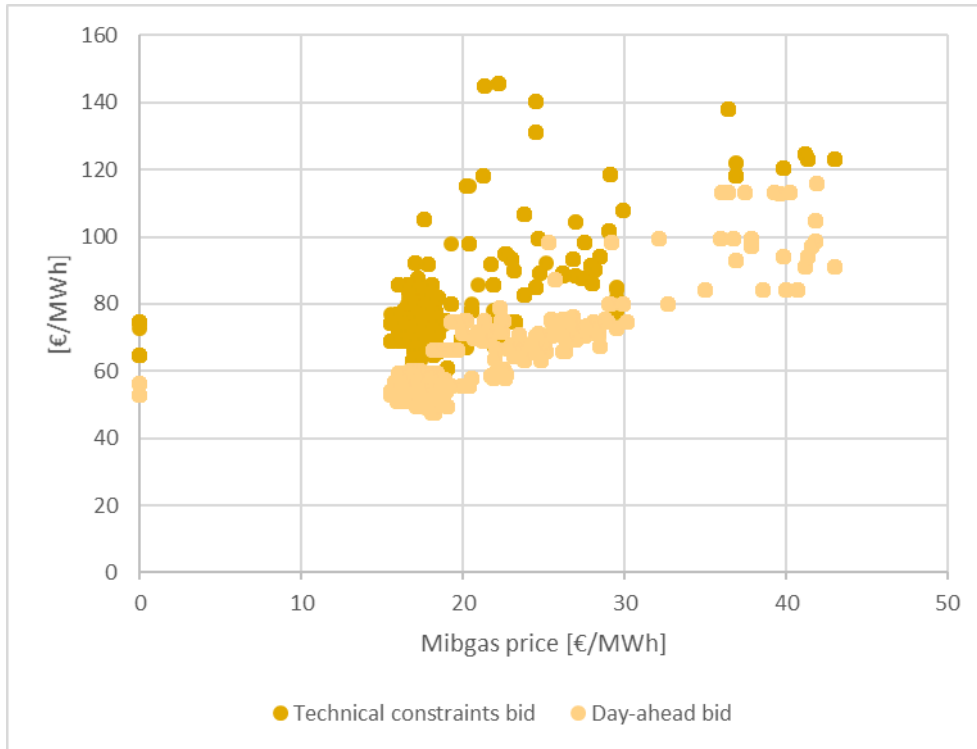


Figure 47. Day-ahead and technical constraints market bids versus MIBGAS price for PP11 from Agent2. Source: own elaboration from [ESIO17]

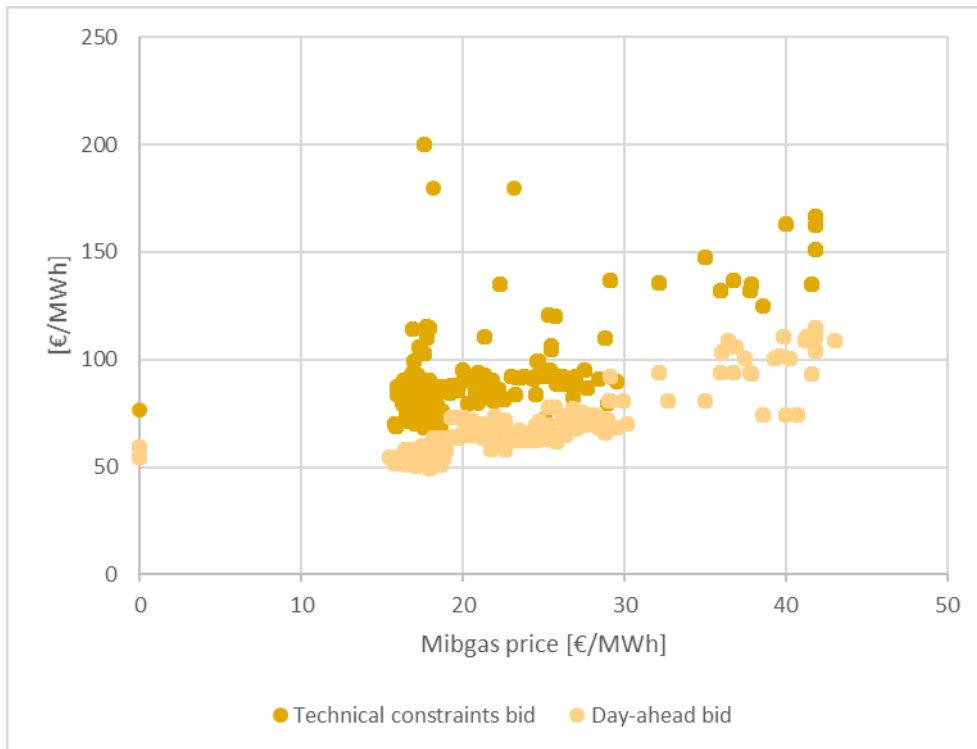


Figure 48. Day-ahead and technical constraints market bids versus MIBGAS price for PP12 from Agent2. Source: own elaboration from [ESIO17]

The previous three power plants belonged to the same agent, while these last two belong to a different one, for this reason this last two are analyzed separately from the three first. As in the other three cases, the trend for the day-ahead market is observable and similar to other

power plants. It is important to see the trend for the technical constraints market, which in both cases is very observable also and remains very close to the line of the day-ahead market, except for a few points out of the general line, something similar as in the PP9 and PP10 from Agent1.

Once every unit in Zone5 has been studied and analyzed, the main conclusion obtained is the presence of a competitive behavior in the area. The existence of several power plants, at least for a very specific market as this, with different agents also guarantee a competitive situation in the market, which may enable the construction of a price simulator.

6.3.2 Zone7

In Zone7 there are two CCGT power plants, as all studied in this chapter, these two power plants also belong to two different agents, which in principle should guarantee a minimum quantity of competitiveness and a trend in price to develop a simulator.

As in the section above, the first step will be to see the behavior of their bids throughout the year of study. The first graph corresponds to bids for the day-ahead market, while the second refers to the technical constraints market. It is important to remind that, while the day-ahead market includes the variable term in €/MWh, the technical constraints picture shows the product of the variable term by energy, in order to show the total amount of money asked, and what the TSO takes into account to assign a plant.

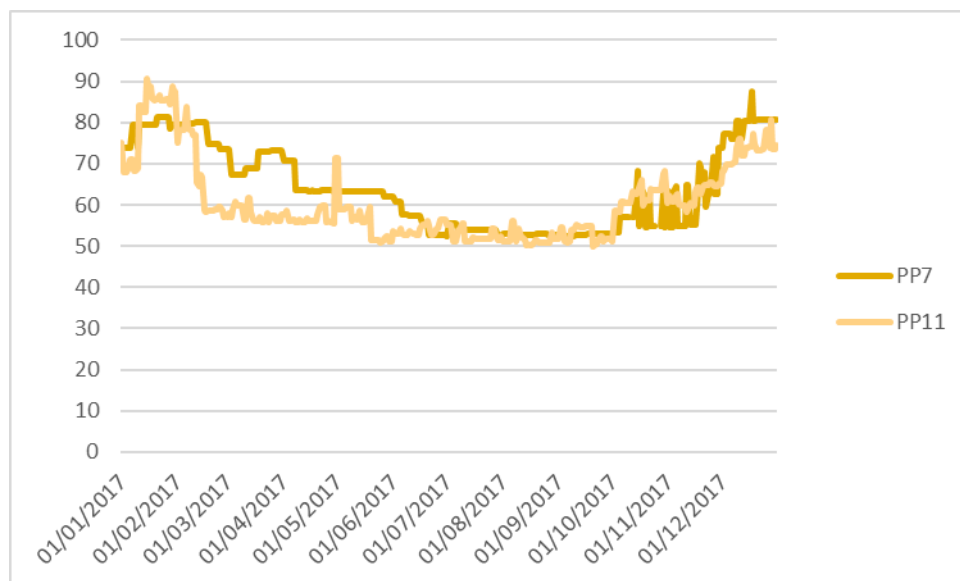


Figure 49. Day-ahead market bids for the year 2017 for the power plants in Zone7. Source: own elaboration from [ESIO17]

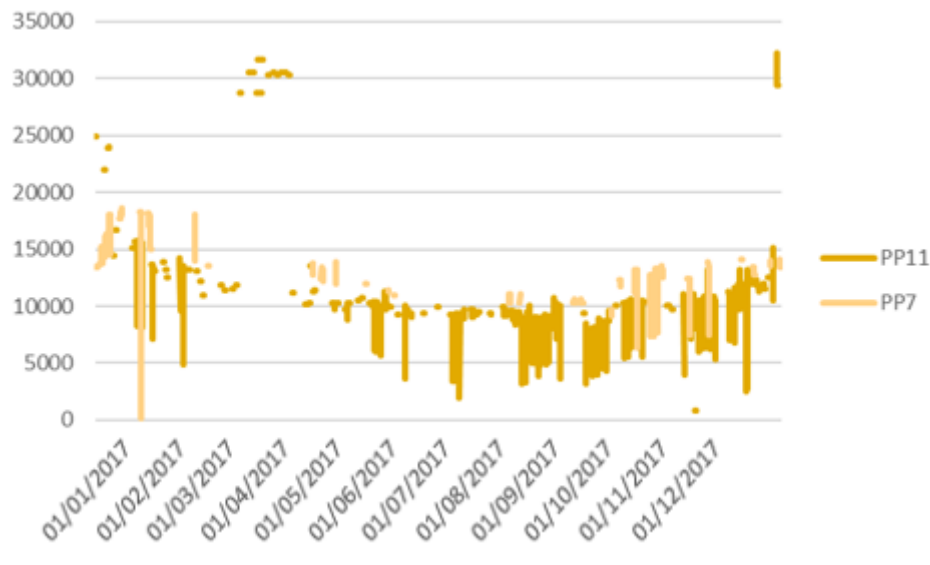


Figure 50. Technical constraints market bids for the year 2.017 for the power plants in Zone7. Source: own elaboration from [ESIO17]

With respect to the market bids charter, it is possible to observe a similar trend as in Zone5, where the bids are according to the demand at every season. It is important to see also that normally, when PP11 is cheaper in the day-ahead market, this unit is also the one committed in the technical constraints market, meaning that it is more competitive in both market, which in principle is logic.

On the technical constraints graph, it can be seen most of the time the color of PP11, as it was seen in the introductory section, PP7 did not even achieve the minimum number of hours required to be studied, however, since there were only two power plants, it was considered important to include unit 7 for comparison purposes. Additionally, there are some hours for PP11 when prices are extremely high, it would be interesting to study carefully these hours and find the reason for the high values.

In order to find the trend of each power plant, it is going now to be analyzed the dispersion graphs of their day-ahead and technical constraints bids with respect to gas prices. The first picture shows the data for PP7 from Agent.

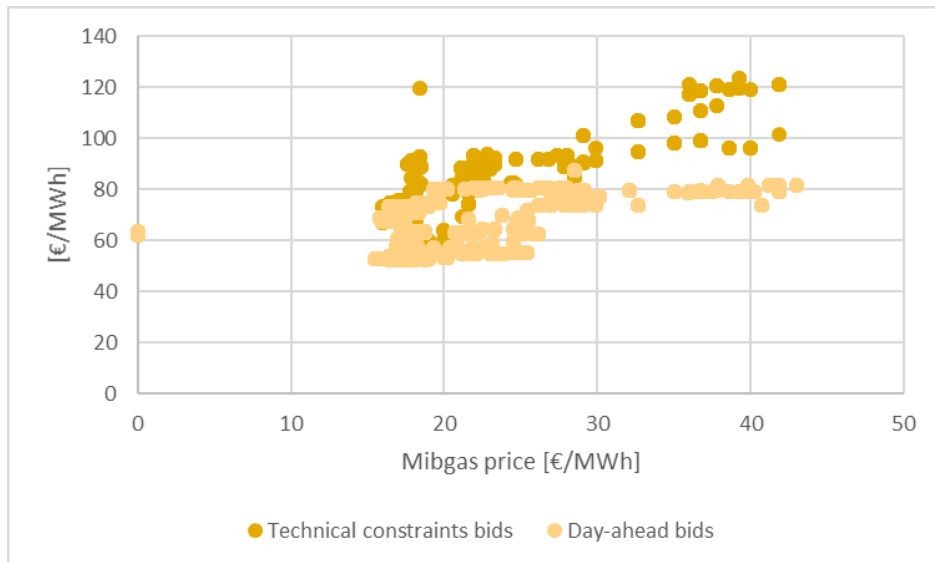


Figure 51. Day-ahead and technical constraints market bids versus MIBGAS price for PP7 from Agent3. Source: own elaboration from [ESIO17]

As in every previous power plant chart, the line of data corresponding to day-ahead bids is below the technical constraints one, meaning the day-ahead market bid is expected to be cheaper, as explained before.

It is interesting to notice the difference in the slope of both clouds of points, while for the day-ahead bids it stays smoother, it is a bit steeper for the technical constraints market, which could indicate the higher increase in price when the production decreases. The higher prices in the technical constraints market have been explained for Area5, however this bigger slope in prices may be a particularity of this power plant, which consumes much more gas at lower productions of electricity. However, the trends are well defined in both cases, especially in the technical constraints graph, which may imply a competitive behavior, therefore, as explained before, opens the possibility to develop a price simulator.

In the following graph it is shown the data for PP11 from Agent1.

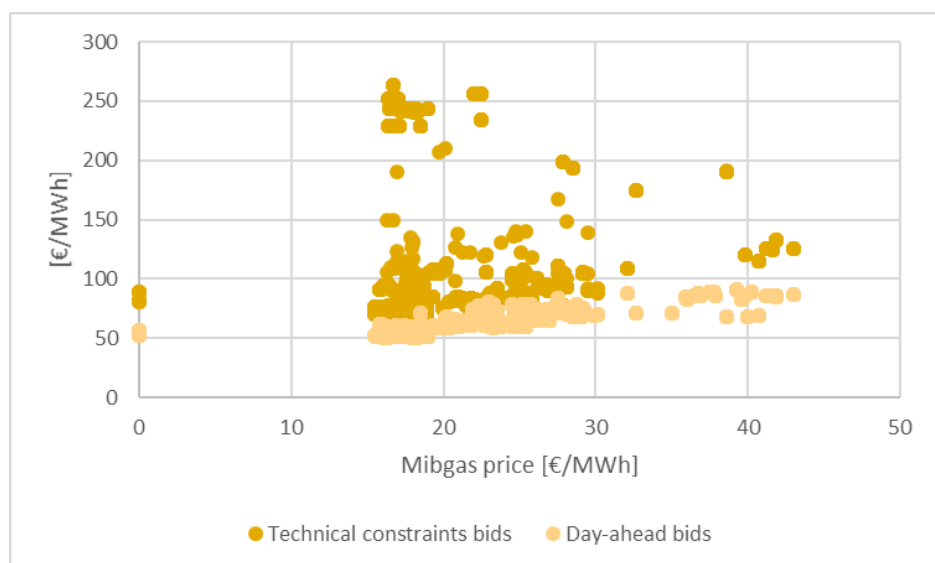


Figure 52. Day-ahead and technical constraints market bids versus MIBGAS price for PP11 from Agent1. Source: own elaboration from [ESIO17]

It is remarkable that the dispersion graph for PP11 is slightly different to the previous one studied. While for day-ahead bids the trend in price is clear and well defined, there is a big cloud of points for the technical constraints bids, which probably correspond with those high prices observed in the previous graph.

It can be observed for prices of gas around the 20 €/MWh extreme prices in the bids for the technical constraints market, while for the day-ahead market it does not exist this out of range points. In order to assess if this a situation of lack of competitiveness, and no price simulator is possible, it will be important to analyze the situation of its competitor for those days.

It can be checked in the annexed table that most of these points correspond to the months of March and April. In the following table may be seen some of these examples.

Date	Mibgas price	Technical constraints bids						Day-ahead bids	
		PP7			PP11			PP7	PP11
		Energy	Price	Energy * Price	Energy	Price	Energy * Price	Price	Price
01/03/2017	17,59				125,6	100	12560	73,53	57,03
02/03/2017	17,58	151	89,85	13567,35				73,53	57,83
03/03/2017	16,86							67,26	56,99
04/03/2017	17,3							67,26	58,86
05/03/2017	17,4							67,26	60,92
06/03/2017	16,87							67,26	60,17
07/03/2017	16,99							67,26	59,75
08/03/2017	16,72							67,26	59,7
09/03/2017	16,36				125,6	94,66	11889,296	67,26	59,7
10/03/2017	15,98				125,6	92,08	11565,248	67,26	56,3
11/03/2017	15,87				125,6	90,5	11366,8	69	56,53
12/03/2017	15,77				125,6	90,5	11366,8	69	61,59
13/03/2017	15,96							69	61,59
14/03/2017	16,14							69	58,31
15/03/2017	16,52				125,6	92,05	11561,48	69	56,37
16/03/2017	16,44				125,6	94,04	11811,424	69	56,04
17/03/2017	16,07				125,6	94,04	11811,424	69	56,04
18/03/2017	16,68				125,6	90,3	11341,68	72,9	56,03
19/03/2017	18,5				125,6	229	28762,4	72,9	57,07
20/03/2017	16,54				125,6	229	28762,4	72,9	55,85
21/03/2017	16,8							72,9	55,85
22/03/2017	16,42							72,9	56,4
23/03/2017	16,68				125,6	263,66	33115,696	72,9	57,91
24/03/2017	16,42				125,6	243,16	30540,896	72,9	55,92
25/03/2017	17,29				125,6	243,17	30542,152	73,2	57,28
26/03/2017	19				125,6	243,17	30542,152	73,2	57,28
27/03/2017	17				125,6	243,17	30542,152	73,2	57,28
28/03/2017	16,84				125,6	229	28762,4	73,2	56,22
29/03/2017	16,77				125,6	229	28762,4	73,2	56,22
30/03/2017	16,4				125,6	229	28762,4	73,2	56,22
31/03/2017	17,12				125,6	229	28762,4	73,2	57,61
01/04/2017	18,25							70,86	57,61
02/04/2017	18,11				125,6	240,29	30180,424	70,86	58,11
03/04/2017	17,75				125,6	241,55	30338,68	70,86	58,75
04/04/2017	18,34				125,6	241,55	30338,68	70,86	56,25
05/04/2017	18,18				125,6	243,11	30534,616	70,86	56,07
06/04/2017	18,08				125,6	243,11	30534,616	70,86	56,4
07/04/2017	18,14				125,6	243,11	30534,616	70,86	56,4
08/04/2017	18,21				125,6	241,55	30338,68	63,46	55,9
09/04/2017	18,3				125,6	241,55	30338,68	63,46	55,9
10/04/2017	18,16				125,6	243,11	30534,616	63,46	56,56
11/04/2017	17,76				125,6	243,11	30534,616	63,46	55,74
12/04/2017	17,93				125,6	243,11	30534,616	63,46	55,74
13/04/2017	17,2				125,6	241,55	30338,68	63,46	55,7
14/04/2017	17,9				125,6	241,55	30338,68	63,46	56,67
15/04/2017	18	151	81,12	12249,12				63,42	56,23
16/04/2017	0				125,6	89,02	11180,912	63,42	56,23
17/04/2017	18,14				125,6	83,76	10520,256	63,46	56,21
18/04/2017	18,03				125,6	85,21	10702,376	63,42	56,21
19/04/2017	17,85							63,42	56,04
20/04/2017	17,8							63,42	57,66
21/04/2017	17,9							63,42	59,55
22/04/2017	18				125,6	91	11429,6	63,49	59,55
23/04/2017	18,2				125,6	81,39	10222,584	63,49	59,81
24/04/2017	17,8				125,6	88	11052,8	63,49	59,81
25/04/2017	17,51				125,6	81,49	10235,144	63,49	55,73
26/04/2017	17,81				125,6	90	11304	63,49	56,06
27/04/2017	18,14				125,6	90	11304	63,49	55,74
28/04/2017	18,06							63,49	55,74
29/04/2017	18,5							63,36	55,6
30/04/2017	18,5							63,36	71,21

Table 70. Day-ahead and technical constraints market bids for Zone7. Source: own elaboration from [ESIO17]

It can be seen in the table the bids submitted by agents for the day-ahead and the technical constraints market. In case of the technical constraints are shown values only when the unit has been committed for this market, meaning that the unit was not committed if no value is shown.

In the table may be observed that mainly was PP11 from Agent1 committed during those days of March and April. During those days, as explained above, there were many hours where the bids for the technical constraints market were remarkably higher than gas prices or even the bids for the day-ahead market. However, it is important to notice when PP7 starts to appear again the 15th of April, the following day the PP11's bids start to be lower again, reduced to logical values according to gas prices.

Additionally, it is interesting that the bids of PP11 for the day-ahead market were a lot lower than the ones from its competitor. It is interesting to analyze if PP11 was the only available power plant in the area those days. Attending to the ENTSO-E unavailability of production and generation units for those days, it is possible to see the following table.

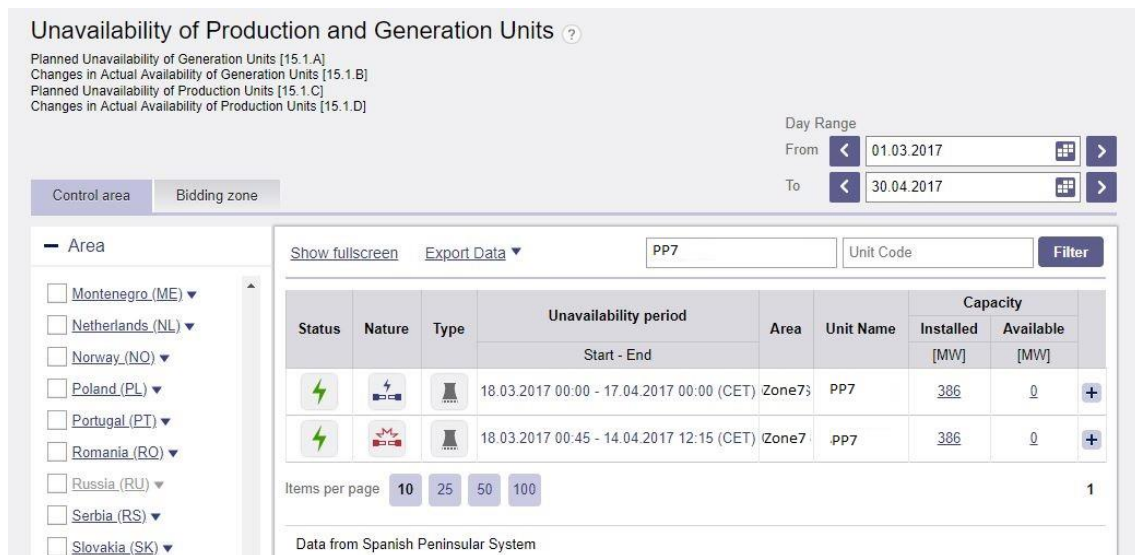


Figure 53. Unavailability of production and generation units. Source: [ENTS18]

The image has been taken directly from the ENTSO-E transparency platform, although modified to not to show any private information. It is notably to see, for the period indicated above, that PP7 starts to be unavailable the 18th of March, the day before the high bids starts, and these high bids finish the April 14th, just when the second unavailability ends.

In this context, it would be possible to explain a situation of lack of competitiveness, where bids were not driven by gas prices, but by pure profit-making purposes. In any case, it is not advised to implement a price simulator for this power plant, since there is a great period when prices did not follow a trend, therefore, it will result in useless results.

With this last conclusion it is finished the study of Zone7, which has demonstrated to be a very interesting zone despite the reduce amount of power plants located in the area. The following zone, Zone8, will be a completely different location, with four power plants and two different agents.

6.3.3 Zone8

There are four power plants in Zone8, which belong to two different agents. All of the power plants located in Zone8 are CCGT, as all studied in this chapter.

As the two sections before, the first step would be to analyze the annual behavior of bids for every power plants in both market, the day-ahead and the technical constraints. This situation may be seen in the two pictures below.

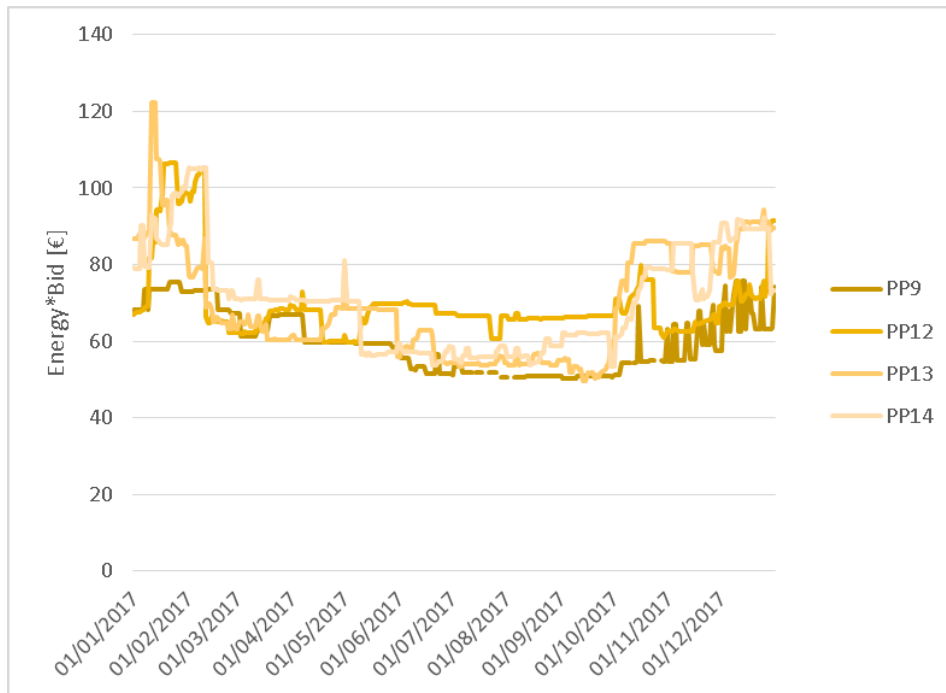


Figure 54. Day-ahead market bids for the year 2.017 for the power plants in Zone8. Source: own elaboration from [ESIO17]

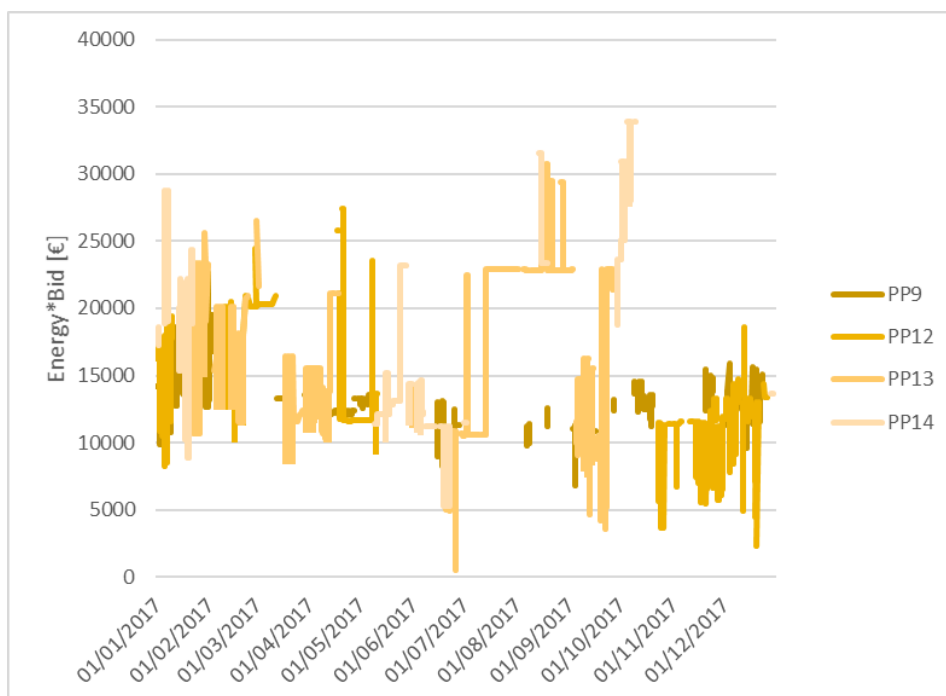


Figure 55. Technical constraints market bids for the year 2.017 for the power plants in Zone8. Source: own elaboration from [ESIO17]

As expected, the first image shows the normal behavior of bids for the day-ahead market throughout a year. In case of the technical constraints chart, it appears to have the usual shape, but with some high values for some units in the months of August, September and October, which, in principle, should not be expensive months. It will be necessary to take a deeper look into every individual unit to see the reasons for these peak prices.

The first unit analyzed will be PP9 from Agent8, which the only unit this agent has in this area. In the following graph will be shown the bids for the day-ahead market and the technical constraints market compared to gas prices.

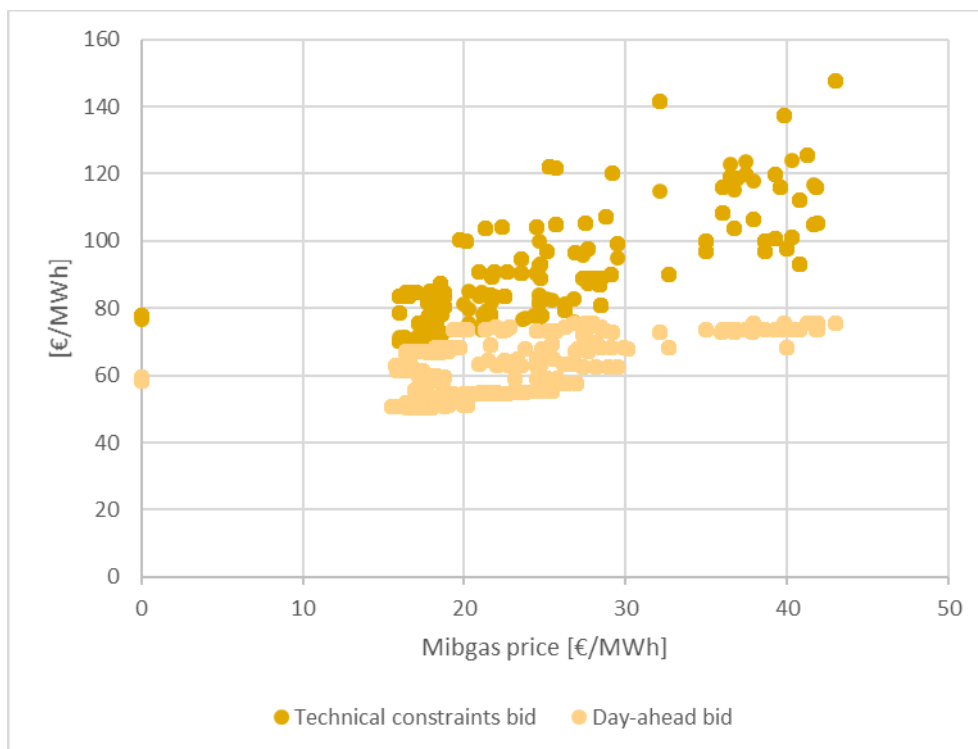


Figure 56. Day-ahead and technical constraints market bids versus MIBGAS price for PP9 from Agent3. Source: own elaboration from [ESIO17]

At first sight, it seems that bids from both market follow a trend, which in case of day-ahead bids is well defined and clear, as expected. It may be seen that the trend for the technical constraints bids is obvious, however, it does exist also a high level of dispersion for the same value of gas.

In principle, it would be advised to develop a simulator for PP9 and run it for the year 2.017 to see if the dispersion in the graph is due to seasonality, or it may be caused by other factors.

The next power plant studied will be PP12 from Agent3, which is also the owner of the rest of the power plants studied in this zone. As usual, the following graph shows data for day-ahead and technical constraints market compared to gas prices.

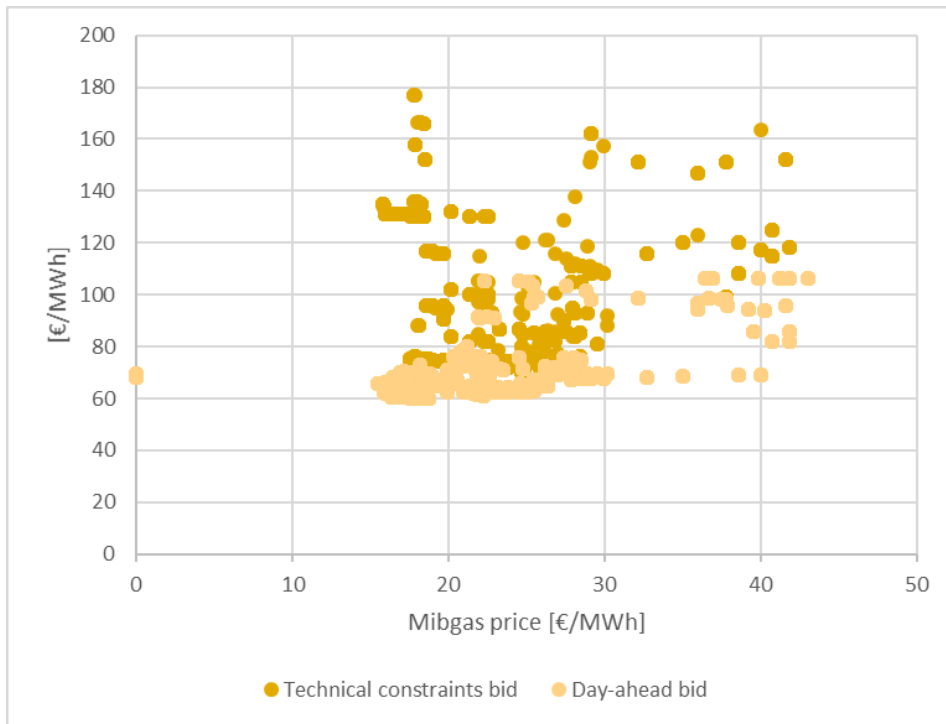


Figure 57. Day-ahead and technical constraints market bids versus MIBGAS price for PP12 from Agent3. Source: own elaboration from [ESIO17]

In this case, it may be observed a lack of relationship between gas prices and the two markets used in this study. There is not a specific group of high values, but a general dispersion of bids for different values of gas prices. There is, in principle, no doubt in terms of competitiveness, but it is clear that MIBGAS price is not the reference to build the bids. This lack of relationship makes impossible to develop a price simulator based on public prices of gas.

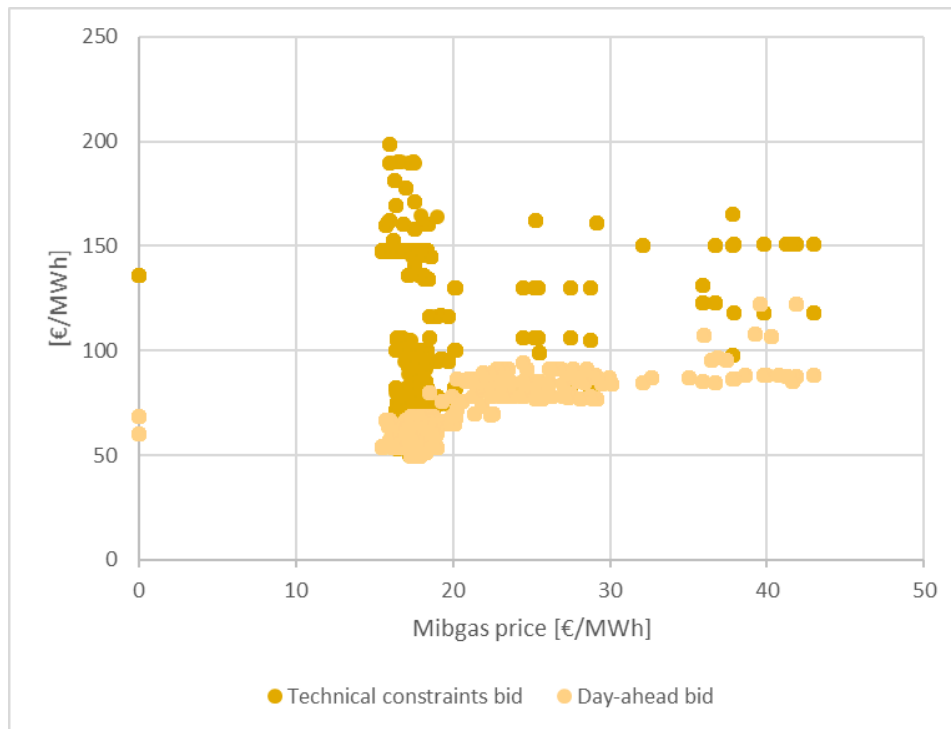


Figure 58. Day-ahead and technical constraints market bids versus MIBGAS price for PP13 from Agent3. Source: own elaboration from [ESIO17]

The graph above shows data for PP13, which belongs to Agent3. It may be observed a very clear trend for data for day-ahead market. However, there is not an observable relationship between the technical constraints bids and gas prices.

Despite there is no trend for the technical constrains bids, this case is different from PP12 because the majority of points for technical constraints market are situated in the range between 15 and 20 €/MWh for gas prices. It is going to be analyzed the days when those points occurred, in order to check if those days there were a great amount of power plants committed, or a number of outages, as in previous cases.

If attending to those days, it can be observed no apparent relations. These high prices occurred indistinctly at any month of the year, especially during summer time. It has been checked the ENTSOE transparency platform, as in Zone7, to see if the rest of power plants were out during that season, however, despite there were days when some unit were not available, it was few specific days, and did not always coincide with the days with high prices.

Once the option of competitor outages has been discarded, it is going to be checked if a lot of power plants were committed during those days, producing the same effect than in Zone5. If attending to those days, it may be seen that there were some hours when two power plants were producing at the same time, however, this is not the usual case, and two power plants is not much when there are five in the area, and four actively participating. Nevertheless, it has been discovered a remarkable situation, shown in the following table.

Date	Mibgas price	PP9				PP12			PP13			PP14		
		Technical constraints energy bid	Technical constraints bid	Energy * Price	Day-ahead bid	Technical constraints bid	Energy * Price	Day-ahead bid	Technical constraints bid	Energy * Price	Day-ahead bid	Technical constraints bid	Energy * Price	Day-ahead bid
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66	162	25110	76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66	162	25110	76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66	162	25110	76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66	162	25110	76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66			76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66			76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66			76,6			105,12
02/02/2017	25,29	160	121,92	19507,2	73,06			96,66			76,6			105,12
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
10/03/2017	15,98				61,2	131	20305	62,11	162,11	25127,05	63,85			70,97
18/08/2017	15,97				50,73			66,12			56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12			56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12			56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12			56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12	198,54	30773,7	56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12	198,54	30773,7	56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12	198,54	30773,7	56,88	146	23360	54,68
18/08/2017	15,97				50,73			66,12	198,54	30773,7	56,88	146	23360	54,68

Table 71. Day-ahead and technical constraints market bids for Zone8. Source: own elaboration from [ESIO17]

In the previous table may be seen some days when the bids of PP13 for the technical constraints market were high, while the price of gas was around the range 15-25 €/MWh. It is interesting to observe for some days despite there were not an elevated number of power plants committed, and gas was not expensive, for some reason, all technical constraints bids were high for every power plant. For any reason, most of this days, the most committed power plant was PP13 from Agent1, hence the curious shape of its dispersion graph.

In any case, as it occurred with PP12, since there is not a defined trend that would allow the development of a price simulator, this power plant is out of the simulation process.

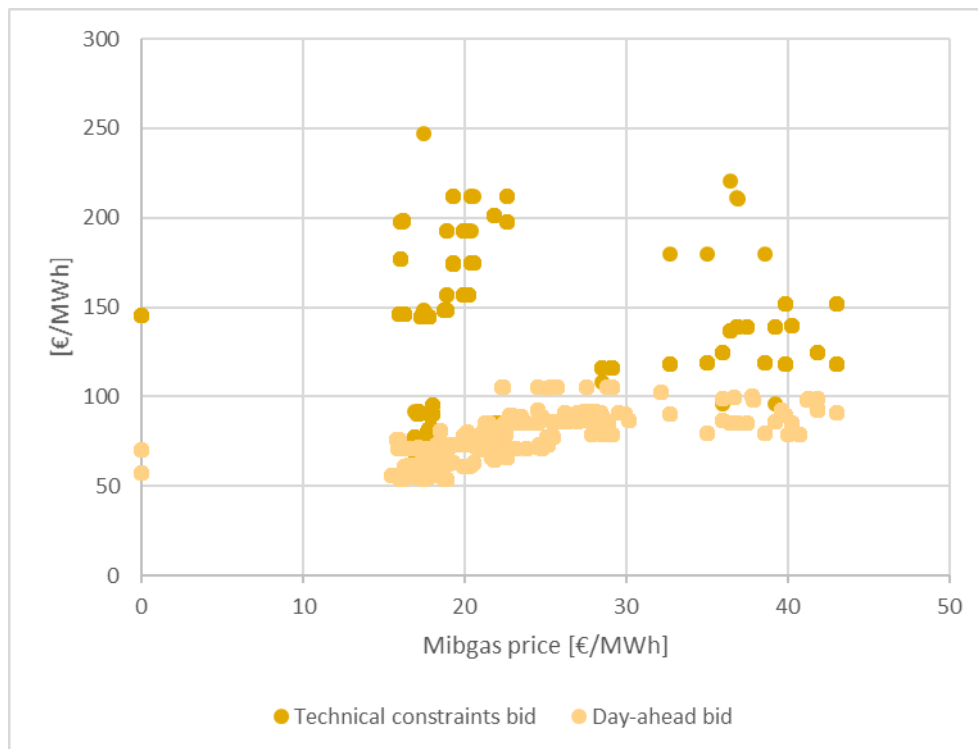


Figure 59. Day-ahead and technical constraints market bids versus MIBGAS price for PP14 from Agent3. Source: own elaboration from [ESIO17]

As it happened with PP12, it is clear the absence of any relationship between technical constraints bids and gas prices. Consequently, it is impossible to use this power plant data to develop and implement a price simulator.

With this last power plant, it is finished the Zone8. Despite the promising presence of four power plants with different owners, finally, there are just one power plant which may be eligible to implement a price simulator, since the other three did not follow any trend in their technical constraints market bids.

6.3.4 Zone9

This section will analyze the only power plant which produced the hours required to be present in the study, despite there are five more power plants in the area. It would be interesting to analyze the behavior of its bids when the rest of power plants were hardly producing and see if any price simulator is possible.

In the first place, it may be observed the graphs for day-ahead bids and the technical constrains bids throughout the year of study.

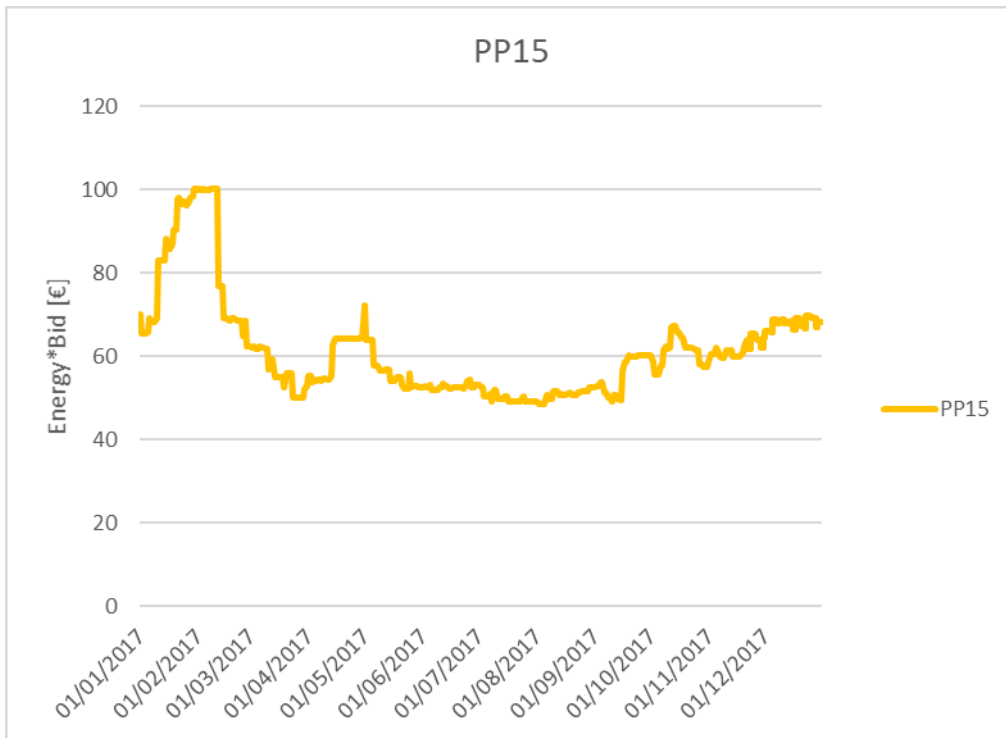


Figure 60. Day-ahead market bids for the year 2.017 for the power plants in Zone9. Source: own elaboration from [ESIO17]

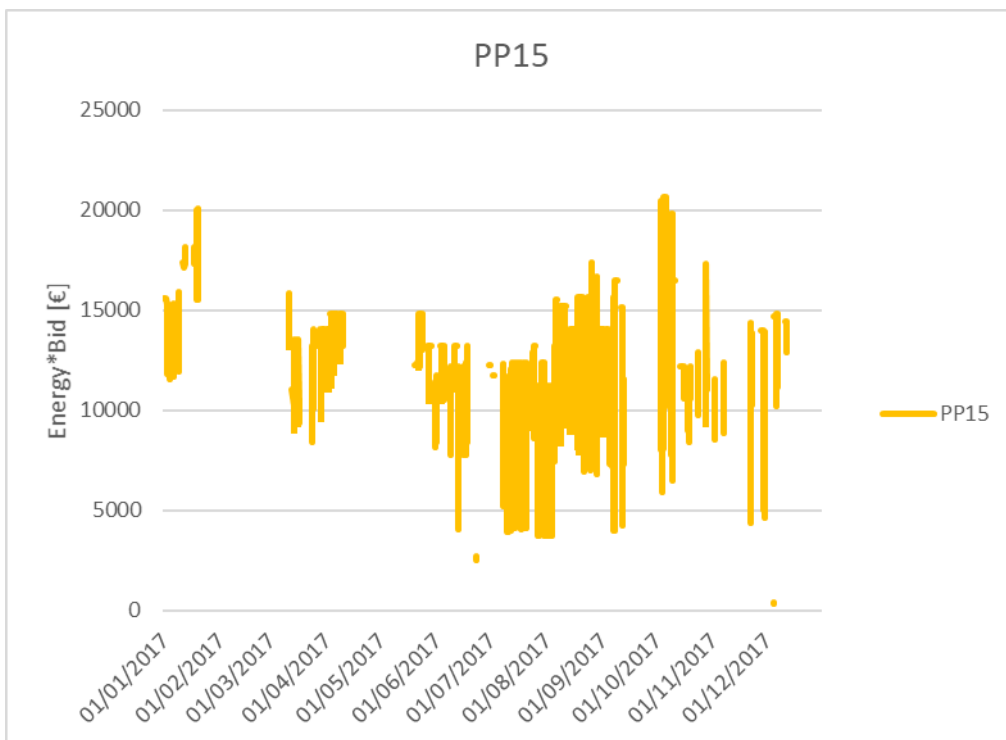


Figure 61. Technical constraints market bids for the year 2.017 for the power plants in Zone9. Source: own elaboration from [ESIO17]

The first graph, the day-ahead market bids, seems to have the natural shape of bids for a whole year, with more expensive periods during cold months, and cheaper bids for those warmer. The second picture shows a slightly different trend, it still exists the expensive periods

during the first months of the year, but there is also an expensive period during the end of the summer, in the months of August, September and October.

In the next graph, it will be shown the relationship between gas prices and electricity market prices, and it will be possible to see if those high prices of summer are the result of high prices during the summer.

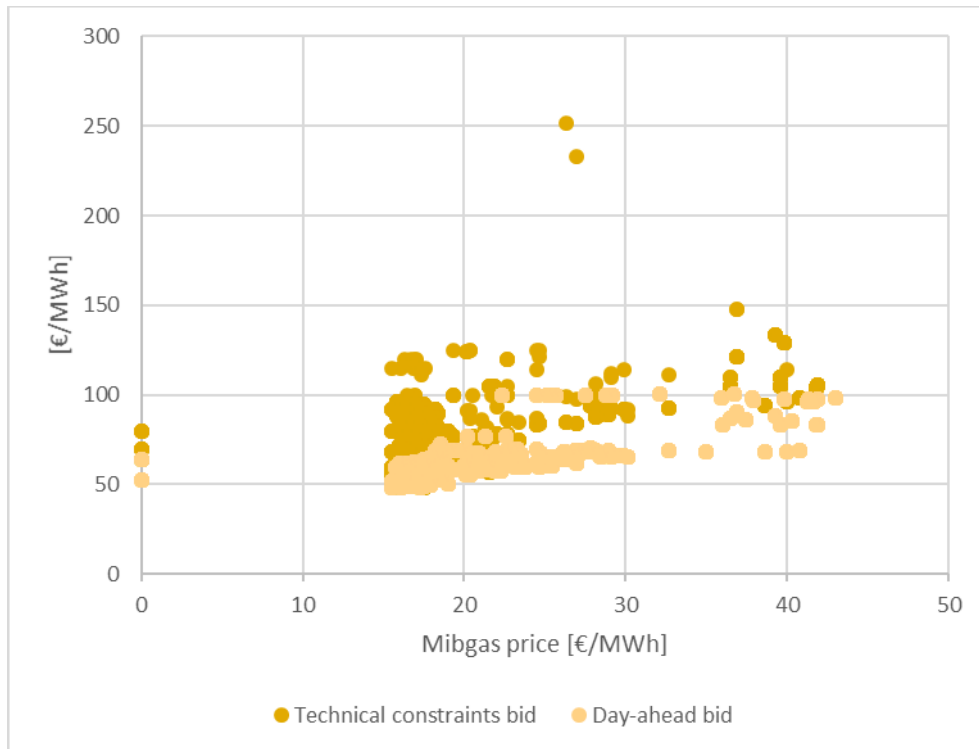


Figure 62. Day-ahead and technical constraints market bids versus MIBGAS price for PP14 from Agent3. Source: own elaboration from [ESIO17]

In the picture is possible to see, despite some high values out of the trend, that the majority of values follow a clear trend driven by gas prices. It can be assumed the possible to apply a price simulator to this power plant.

It may be concluded, though there is only one power plant which produce the minimum number of hours, the mere existence of several power plants and different agents in the area is enough to make it competitive, and it has allowed the development of a price simulator.

6.3.5 Zone12

Zone12 is the zone with highest diversity in terms of agents of all studied, there are four different agents in the area, with six different power plants. However, it is going to be studied only three power plants belonging to three different agents, since only four of the six reached the required hours of functioning, and one of them was a coal power plant. This characteristic may guarantee a minimum level of competition, which may allow the creation of a price simulation for these power plants.

In the following graphs are shown the data of bids for the day-ahead and technical constraints markets for the year 2.017.

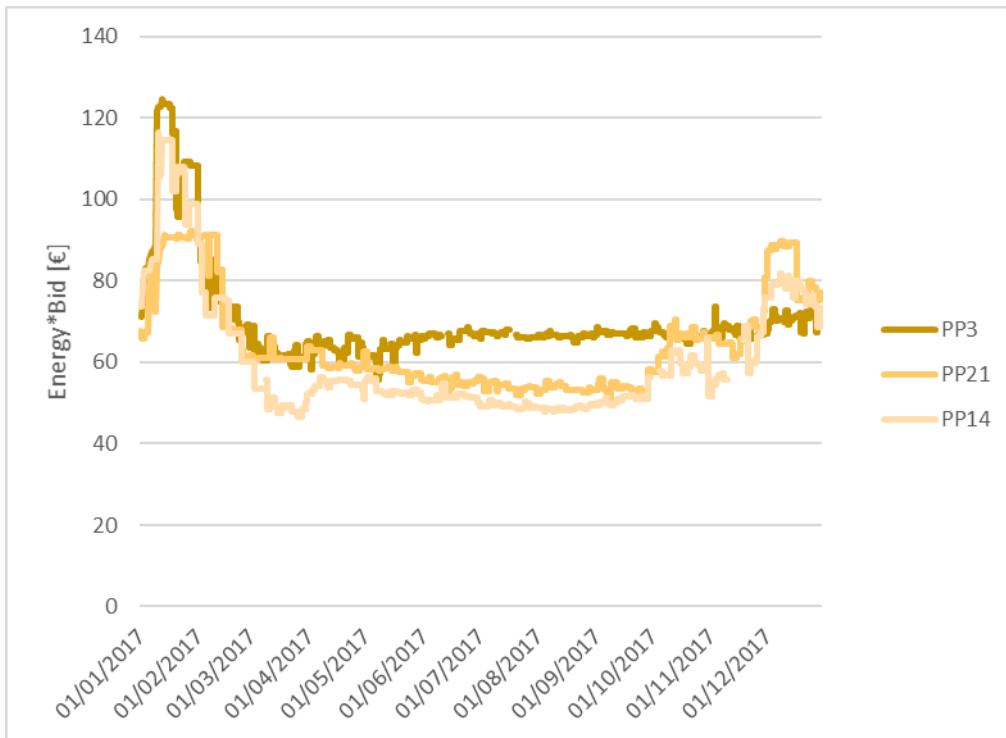


Figure 63. Day-ahead market bids for the year 2.017 for the power plants in Zone12. Source: own elaboration from [ESIO17]

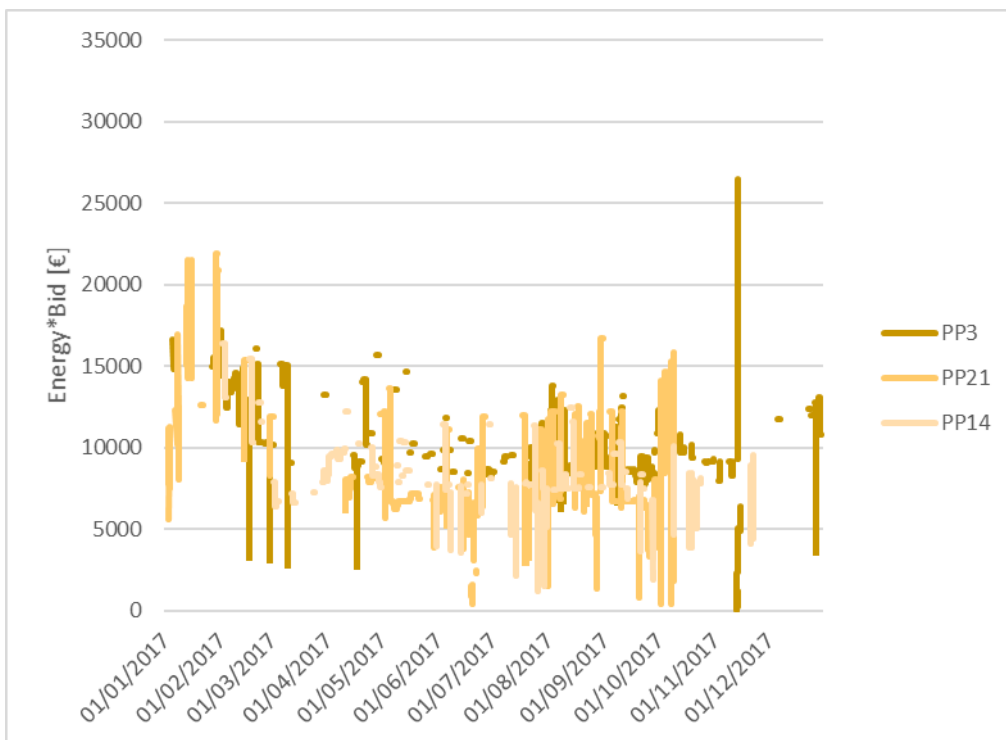


Figure 64. Technical constraints market bids for the year 2.017 for the power plants in Zone12. Source: own elaboration from [ESIO17]

The first graph, related to the day-ahead market, shows the typical shape of bids during a natural year, as observed in the rest of zones. It is interesting the fact that the technical constraints chart also has a similar shape to the day-ahead, despite the usual volatility of this

market. It will be interesting to analyze if this apparent trend is maintained in the behavior of every power plant, and a price simulator is possible.

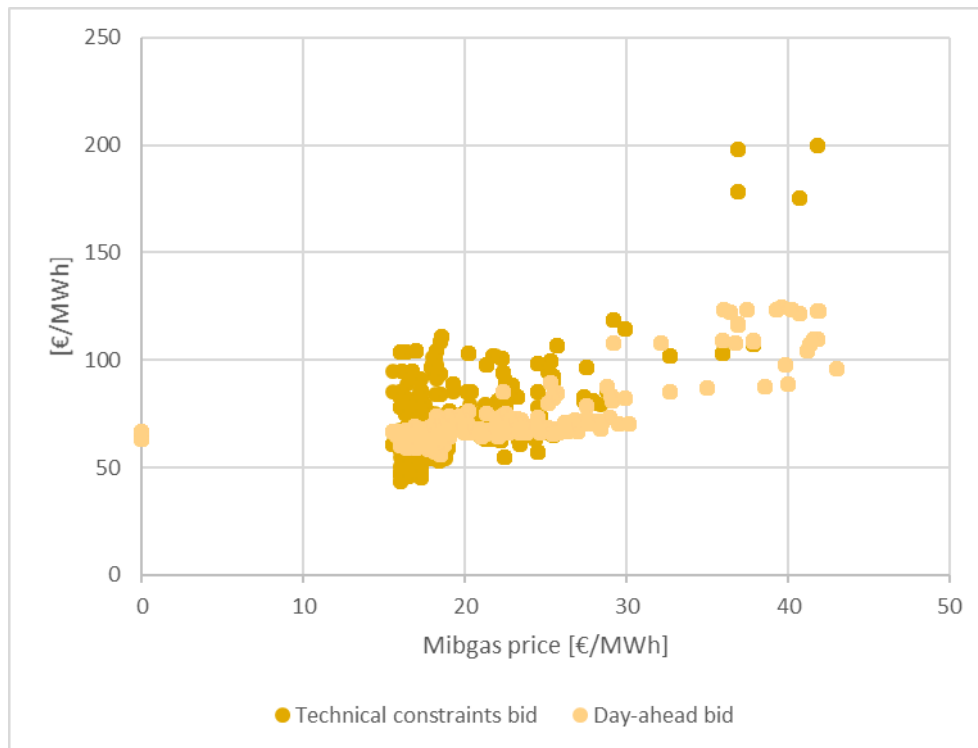


Figure 65. Day-ahead and technical constraints market bids versus MIBGAS price for PP3 from Agent5. Source: own elaboration from [ESIO17]

This first dispersion graph corresponds to PP3 from Agent5, in it is possible to appreciate a clear trend for the day-ahead market, as it has been normal in almost every power plant analyzed. It is remarkable to observe that the trend is maintained for the technical constraints market, but with a higher level of dispersion. One additional fact is the proximity of both curves, where, sometimes, the technical constraints curve is even below the day-ahead one. In principle, this does not represent any issue in terms of building a price simulator, it just means the agent is valuing both markets equally for any reason related to gas prices or the characteristics of its power plant.

At first sight, it seems to be verified the competitive theory, since the dispersion graph for the first power plant seems to follow a more or less clear path. It going to be analyzed the following generation unit.

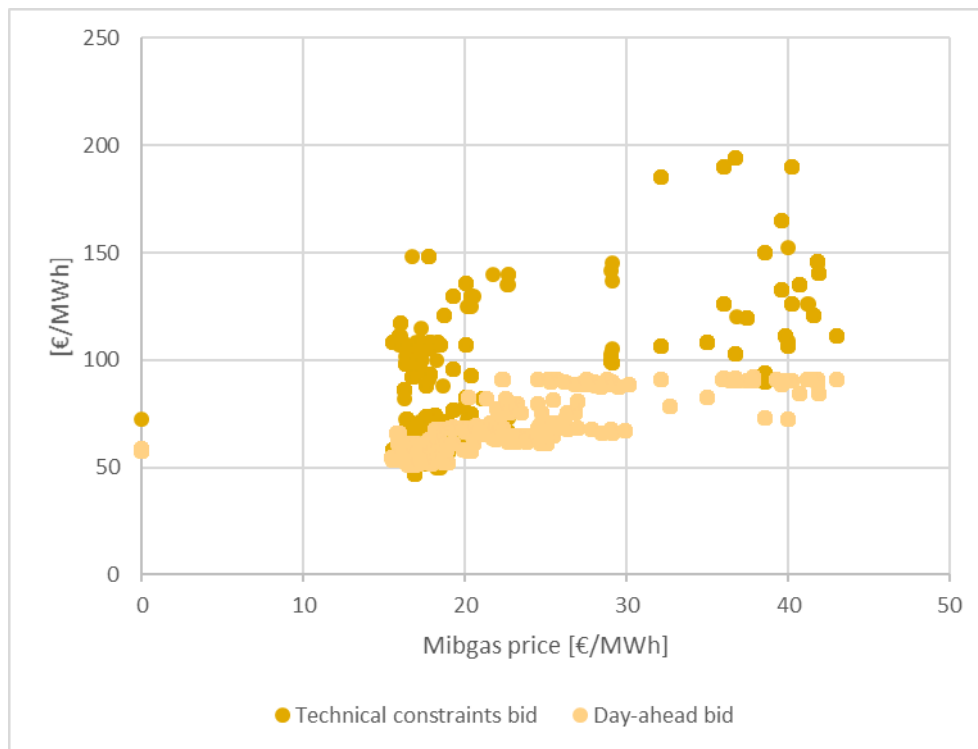


Figure 66. Day-ahead and technical constraints market bids versus MIBGAS price for PP21 from Agent1. Source: own elaboration from [ESIO17]

In this case, it is possible to see a similar shape in the case of the day-ahead market curve, however, the situation is quite different for the technical constraints market.

The technical constraints chart has a high level of dispersion, although the general shape of the curve follows a logical trend, with higher bids for the electric market for higher prices of gas. The wide range of values may be due to season effects on the electric market, and it is possible that prices are correctly correlated with gas market.

It can be concluded for this power plant, despite the high dispersion, that there is a trend in the technical constraints market, and it is possible to apply the price simulator.

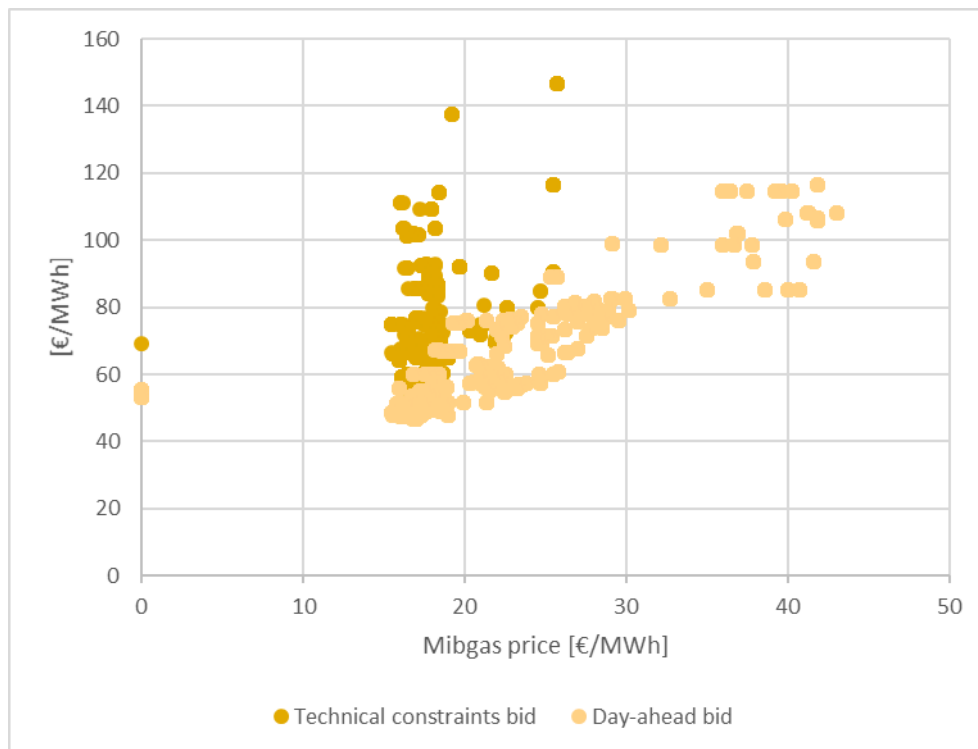


Figure 67. Day-ahead and technical constraints market bids versus MIBGAS price for PP14 from Agent2. Source: own elaboration from [ESIO17]

As usual, the graph for the day-ahead market presents the normal shape, with higher bids in electric market for higher prices of gas.

It is interesting to analyze the technical constraints curve, it may be observed a small trend for prices below 25 €/MWh, however, there is no bid for upper prices. The two most probable options are the unit was not committed during those periods of high gas prices; or the unit was already committed in the day-ahead market. In this case, it may seem that the unit was simply not committed in the technical constraints market, since there is no day-ahead energy committed for it.

In any case, although just for a small range of prices, it seems the present unit follow a trend, which could allow the appliance of a price simulator. As expected at the beginning of the section, this area has demonstrated to be a competitive one, where all of its power plants show a trend in their technical constraints market bids.

6.3.6 Zone13

With Zone13 it is concluded the analysis section, and it will be shown the simulator and some of its results. Zone13 is a complete different zone from all the others studied, in this area is only studied one power plant, but not because there is only one power plant with the minimum hours of production required, but because there is only one power plant located in the area. It would be interesting to analyze the behavior of this power plant in such a particular environment and see if a competitive behavior can allow a price simulator, or if this is not possible.

The first step is to show the yearly bids for the day-ahead and technical constraints market.

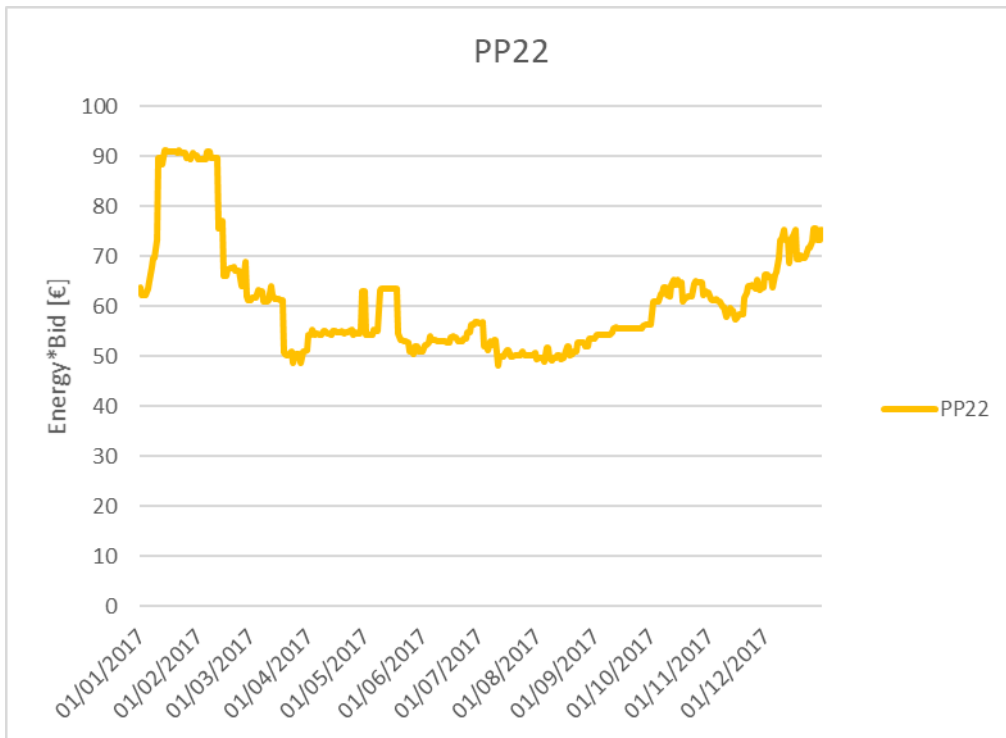


Figure 68. Day-ahead market bids for the year 2.017 for the power plants in Zone13. Source: own elaboration from [ESIO17]

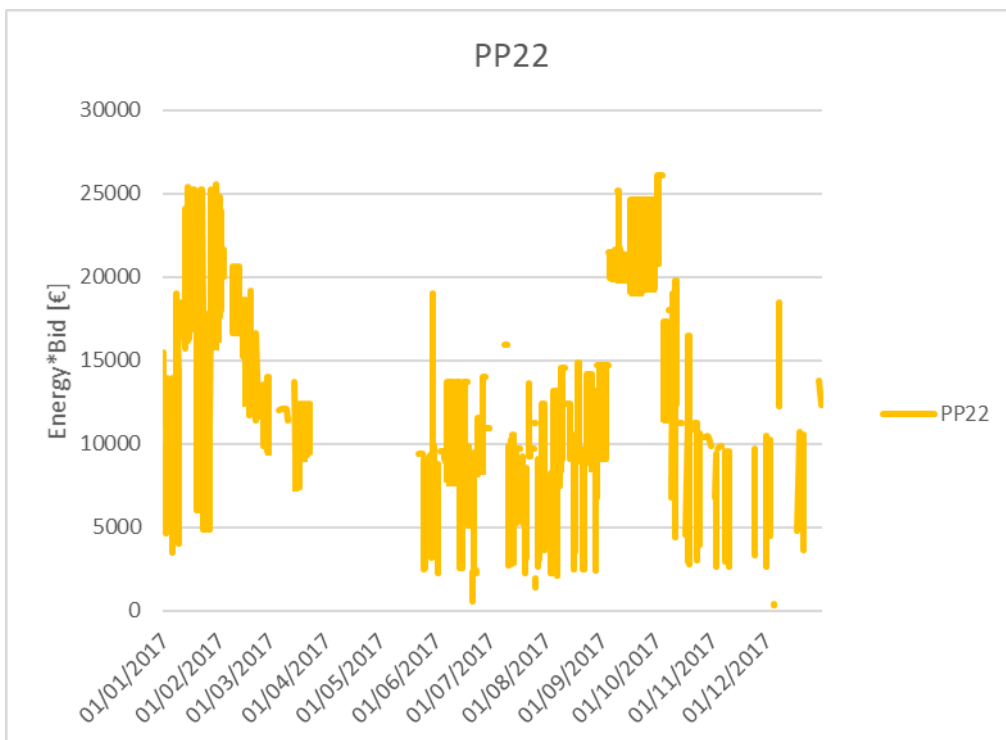


Figure 69. Technical constraints market bids for the year 2.017 for the power plants in Zone13. Source: own elaboration from [ESIO17]

The first picture shows, as expected, the usual trend for the day-ahead market bids, despite the solitary location of this power plant, this situation is not applicable in the daily market since every power plants compete as if they were in the same node of the grid.

The second graph, on the contrary, shows a very irregular curve, indicating the high volatility of a very low liquid market. It would be interesting to analyze if this irregularity means lack of correlation with prices, or if this relationship is possible. In order to carry out the analysis, it is plot the dispersion graph of both electric markets bids with respect to gas prices.

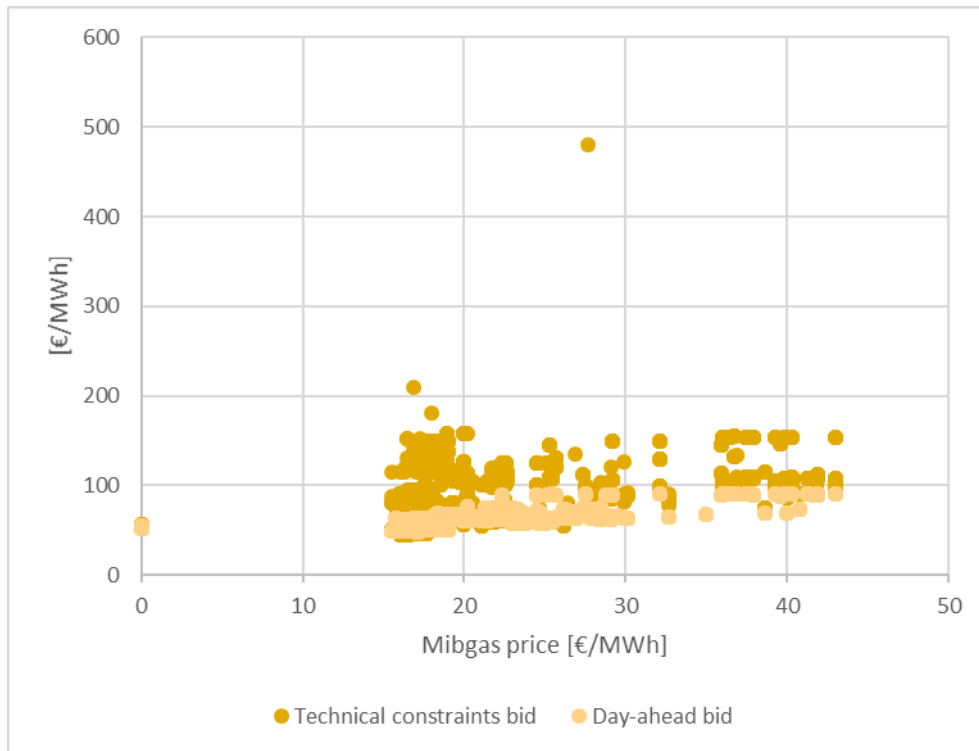


Figure 70. Day-ahead and technical constraints market bids versus MIBGAS price for PP22 from Agent1. Source: own elaboration from [ESIO17]

It is possible to see in the picture above how the electric markets bids correlate with respect to gas prices. It is possible to see a clear trend in both curves, with the exception of a very high points, which could be simply an eventual spike in price.

With no further analysis may be affirmed the clear trend for the technical constraints market, despite the usual variability of price in this market. It is interesting to observe, despite the monopoly situation of this power plant in the technical constraints market, what seems a competitive behavior, or at least a trend in their bids which will allow a price simulator.

It is concluded now the section about power plant analysis, the next step will be to develop the basic of a price simulator for this market and apply it to different power plants in order to see if the analysis is correct and is possible to forecast prices for such a particular market as the technical constraints one.

6.4 Technical constraints price simulator

During this section will be explained the steps followed to develop a price simulator for the technical constrains market. It has to be explained that the difficulty of this simulator is not its construction, but to see if it is able to produce a proper forecast with good quality results. It has to be taken into account the difficulties of making a forecast for a single unit, which mean to model the behavior of a single agent with a single power plant, and results may be not as accurate as desired.

The first step in every simulator development process was to define the driver for the market of study, in this case, this step is simple and quick, since it has been used gas price for the analysis, and it has been demonstrated an adequate relationship between this input and technical constraints bids. In conclusion, it is going to be used the gas price reference sets by MIBGAS, since it is believed to be the most appropriate public reference that anyone can access.

The next task is to define the type of approach employed, so it can be defined afterwards the equation to adjust the price curve. Since this is a market where not every hour there is a price, because units may only produce for a few hours of the day, the discrimination by days' approach can be discarded, as in the tertiary reserve market. It only remains to use a discrimination by hours' approach from the models used during the thesis.

Once the approach has also been defined, it is time to choose the best type of equation to adjust the price curve to forecasts. It is going to be used two approaches, with five and ten hours before the hour simulated, therefore, it is going to be plotted the dispersion graph for a few power plants for just few hours, and it will be analyzed the best system of equations.

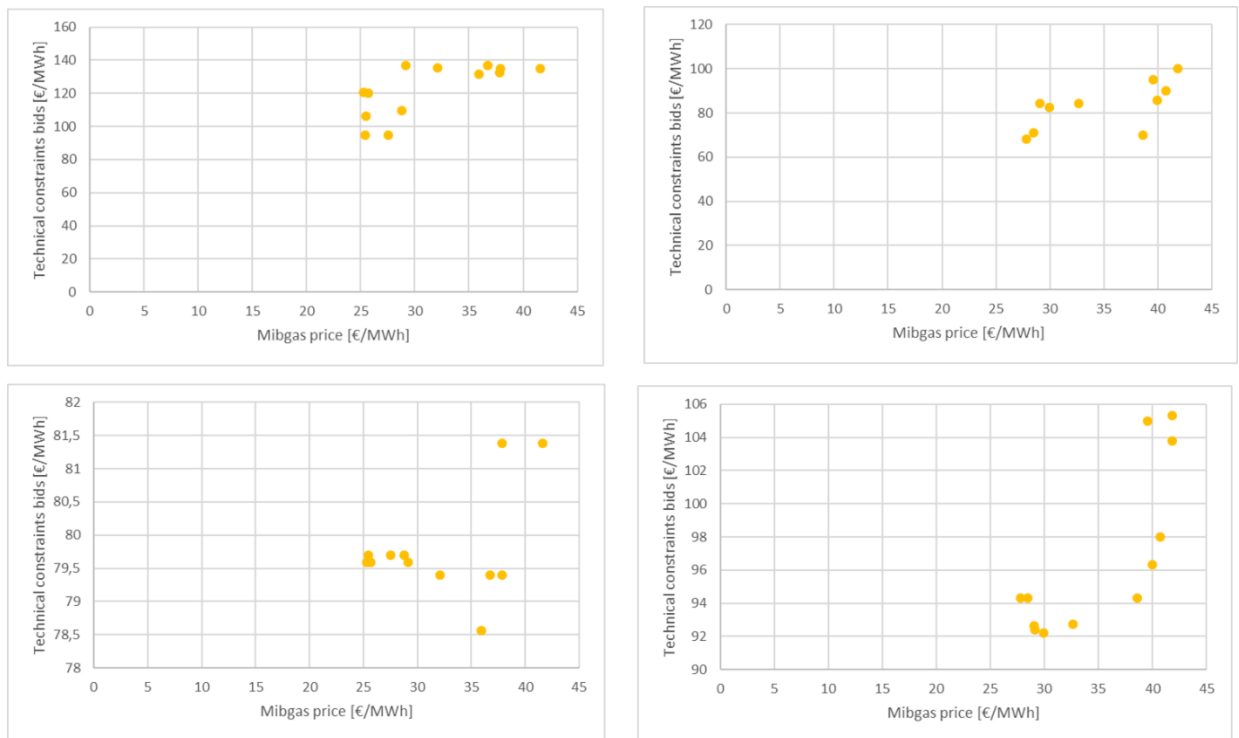


Figure 71. Technical constraints market bids versus MIBGAS price for different power plants. Source: own elaboration from [ESIO17]

In the previous images may be seen the relationship of different technical constraints bids with respect to market prices, for a few hours for different periods of time and different power plants.

The most remarkable conclusion is the lack of unanimity in the type of curves. It has to be taken into account the elevated differences between power plants, but also between agents or even between the different seasons of the year. These many differences indicate the necessity to treat each power plant individually and create a complete different price simulator for each one of them. However, the aim of the present thesis is to create a common set of mathematical rules to correlate the different electric market.

In order to create a common simulator to forecast every power plant, the most appropriate choice would be to employ a linear system of equations to adjust price curves and elaborate the forecast.

It has been used this linear system to elaborate the simulator. This simulator has only been applied to some power plants and calculated the results for exemplification purposes. In the following table may be seen the power plants chosen and the results for this power plants.

	H-5		H-10	
	MAE	Maximum error	MAE	Maximum error
PP12	7,205139097	118,673871	4,904740763	25,28052342
PP7	1,4017908	18,99187149	1,578906612	40,98428127
PP15	4,027103782	55,2190835	1,612361272	5,403185069
PP22	7,130397263	243,0322581	6,315907302	126,193981

Table 72. Results based on the five and ten hours before approach. Source: own elaboration from [ESIO17]

It has been chosen power plants from different agents, and from locations with different particularities. PP12 is located in an area with a high number of power plants and different agents, in the area of PP7 there are only two power plants from two different agents. Finally, PP15 and PP22 are alone in the analysis, but while PP15 is in an area with more power plants, PP22 is completely alone in its area.

The principal conclusion about results is the high variability between them. As expected, there are high differences between results for different power plants. It is interesting to verify that, the clearer was the trend between the technical constraints market and gas prices, the more accurate are the results. In this line, the best results correspond to PP7, which had a defined curve for the dispersion graph; while in contrast, worst results correspond to PP22, the one with a higher dispersion in its graph.

6.5 Preliminary conclusions

After the analysis about the technical constraints market has been concluded, it has been made clear the high difficulty that represents a market with such particularities as this.

The first issue to solve was the geographical distribution of power plants, since the technical constraints market intends to solve constraints at local level, only those power plants located in the affected zone of the grid will be able to solve the problem. In consequence, it was important to locate all power plants, and define the areas where they could compete to solve the same problems.

This geographical issue impacts directly on the competitiveness of the market therefore, it could affect significantly the possibility to find trends in bids and to develop the price simulator. However, after the analysis was carried out, it was verified for the majority of power plants analyzed a more or less clear tendency in their bids, indicating possibly a competitive behavior.

It was challenging to analyze the behavior of different power plants in different locations, for instance, there were locations with an elevated number of power plants from different agents, while in other there was just was unit which can solve the constraint. There were even locations where, despite the high number of generation plants, only one was being committed regularly. It has been interesting to see, despite the presence of few power plants or even just

one, their behavior was mostly competitive and it has been possible to apply the price simulator to every location.

From the results obtained from the price simulator, the most interesting conclusion explained in the section before was about the differences in the results. It was explained that the accuracy in results depends notably on the trend definition. Additionally, it is remarkable to see the high differences in maximum error values, this is clearly related to the high volatility in price of the technical constraints market, which sometimes produce spike prices, which, as explained in previous sections, are difficult to predict and forecast.

Finally, it is important to conclude by explaining that, despite the initial difficulty that a complex and specific market, such as the technical constraints is, it has been possible to demonstrate the relationships between it and day-ahead and gas market prices. It has been also possible to develop a price simulator, which in some cases, has been able to produce accurate and quality results.

Chapter 7. Conclusions

Throughout the different chapters of the present report, it has been analyzed the various electric markets of the Spanish system. With each market analysis, it has been calculated a series of data from which it is possible to obtain different information and conclusions about them.

In the first place, it was analyzed few previous studies and literature about statistical methods and electric prices forecasting. The main book named during the review was “Modeling and Forecasting Electricity Loads and Prices” by Weron [WERO06], in this book it was explained and applied some statistical techniques to predict and forecast electricity loads and prices. However, since this thesis is focused on prices, it was analyzed deeply this issue of the book. The most important reference about electricity prices that Weron provide is the difficulty to be computed, due to the high quantity of inputs that affect prices and the volatility of them. Weron also studies spike prices, extremely high prices that appears for short period of time, and concludes about the complexity to forecast them, since they appear suddenly and disappear with the same speed. This particularity was experienced and analyzed during some sections of the thesis and they will be reviewed in this chapter.

The first market analyzed in the report was the day-ahead market, because of its importance and its liquidity. It was analyzed several types of approaches based on different input data, different discriminations of data and different number of variables. In the end, the approach which used the whole five previous days to elaborate the forecast, was the one that provide the best results. This is also a single variable approach and uses forecasted data as input.

As it has been said, it was tested models with different number of variables, actually, with a single variable a two. In any case, single variable models were able to provide better results. As Weron had said, electricity prices are the results of multiple variables, and its prediction is a difficult task, but for this precise reason, the simpler the method the less noise it introduce in the simulator. In order to achieve a simple methodology, but with as many information as possible also, it was defined and computed a particular variable, the “thermal gap”. This thermal gap is the results of subtracting from the demand, the wind, solar and nuclear production (the generation whose production can be estimated), this type of generation also bid at very low prices, therefore it hardly sets the marginal price.

In contrast with single variable, the two variables methodologies also include the amount of renewable energy as the second variable. This pretended to increase the accuracy of the prediction by capturing in the simulation the direct effect of renewable energy. However, it created more dispersion instead of improving the prediction, and these methodologies were not able to improve results. As explained above, the simplicity of single variable methods did not create noise in the forecast, and was able to provide better simulations.

In addition to different number of variables, it was tested models with different type of input data. The one called “thermal gap 3”, was computed using the estimated load and the forecasted wind, solar and nuclear production provided by REE, which is public data. For comparison purposes, this model was tested together with “thermal gap 2”, which employs the same terms, but with actual production instead of estimated one. Finally, results proved thermal gap 3 models as better estimator of prices. Since agents bid based on predictions,

because actual data is published after 90 days, it may be concluded that simulators should be based on forecasted data too, in order to simulate properly the behavior of agents.

Finally, it was used input data with different discriminations, in particular with a discrimination by hours and by days. In other words, on the one hand it was used same hours to forecast same hours, on the other one it was used the whole day to estimate the price. The idea is to capture the effect of the same hour, or to capture properly the curve of prices for one day. In the end, models based on a discrimination by days provided better results, proving that it is more important to have the coherence of days, instead of the similarities of the same hour.

The best model uses a single variable, the thermal gap 3 and a discrimination by days. It employed exactly the five previous days, which has been assumed as a proper amount of data to forecast adequately electricity prices. Less days have not enough information, but more data introduce more oscillations into the forecasted prices.

The next chapter is related to intraday markets, their purpose is to allow agents to balance their units in case they need to be readjusted. At first sight, it appeared to exist a strong relationship between these markets, this was seen in the preliminary graph, especially when comparing consecutive markets.

As subsidiary markets of the day-ahead, the connection had to be strong, for this reason it was decided to use directly price of the previous market to forecast the following. It seems to be a correct assumption since results are more accurate than for the day-ahead market. It may be concluded, since these markets are balancing markets of the day-ahead, that the relationships are strong, prices of intraday markets are highly dependent on the day-ahead price.

After pure economic markets, it was studied the first technical market managed by the TSO, the secondary reserve market. It has to be remembered the absence of cap and floor prices, in contrast with day-ahead and intraday market. In this case was tested two types of input data, the thermal gap of the day-ahead market and the day-ahead market prices, trying to identify which one provided better results. The first one took advantage of the thermal generation committed during the day-ahead market, while the second one just employed monetary results. Finally, the system based on prices provided more accurate results, indicating that agents are normally more influenced by prices than by actual production, and they bid consequently.

However, in any case results were not better than for economic markets and the values of maximum error were considerably higher than in the previous chapter. This absence of cap prices may be the main driver of this situation, indeed, spike prices appeared in this market while there were none for other markets, and were not predicted nor forecasted, verifying the theory of the difficulty to be predicted and forecasted of Weron.

The next market analyzed was the tertiary reserve, in this market could only be applied the discrimination by hours' methodologies, since the market did not have a price for every hour, and the model by days failed. Results were worse than for secondary reserve market, motivated by the less liquidity and higher volatility of this market. It is not possible to provide valid conclusions about tertiary reserve since results do not have enough quality.

In addition, as a general conclusion for economic and technical markets, it is interesting the issue of spike prices. It was demonstrated, as Weron said, their complexity and difficulty to be predicted and forecasted. However, it is interesting the absence of them for economic markets

(prices were not even close to higher limits), while they are present in technical markets, being the most significant difference between them the existence of price limits. If there is a limit in prices, the possibility of spike price is reduced, and they do not appear easily, while the absence of these limits increase the possibility of spike prices, since agents do not have this references to elaborate their bids.

The final market analyzed was the technical constraints market. It was explained at the beginning of the chapter the complexities and particularities of this market, which was organized by zones, since agents and power plants competed only in those areas where a constraint appeared.

The first difficulty when analyzing this market was to discriminate those zones where agents really compete, to do so it was analyzed the national map with every power plant. Once the areas were assigned, it was observed that not every area really participate actively in the technical constraints market, since the excessive amount of generation did solve every issue with grid in the daily market. In conclusion, constraints only appeared in those areas where there where low quantity of generation programmed in the day-ahead market, to say it otherwise, in those areas where only few expensive power plants were located and were not committed by economics procedures. In the end, those power plants were CCGTs and in the area there were installed just a few of them.

In order to carry out a simulator development, it was necessary to verify a competitive behavior, therefore a trend in prices. Since it was analyzed particularly every power plant, the drive for their bids was clear, the price of natural gas they use as fuel, and the national reference for gas price is MIBGAS. It was demonstrated, for the majority of power plants, MIBGAS reference as the main driver for power plants bids, in consequence, it was possible to develop a price simulator for most of them. It was interesting to discover, despite the lower level of liquidity and competitiveness, how most power plants had a trend linked to their bids, indicating in principle a competitive behavior.

Finally, the price simulator was applied to some power plants as example. The main conclusion about their results was the high difficulty to forecast prices for one single unit, and the variability in results. Those power plants with a better-defined trend line in bids with respect to gas prices were the ones with better results in the forecast, as expected.

As a general conclusion about the thesis, it may be assumed the high difficulty of forecasting electricity prices. However, it is easier for those markets with a high volume of energy traded, or more competitive; while for those markets with less volume and without price caps, the price simulation process becomes harder and results are less reliable.

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ANNEXES

ANEX 1. List of abbreviations

CCGT. Combined Cycle Gas Turbine

ENTSO-E. European Network of Transmission System Operators for Electricity

LCOE. Levelized Cost of Energy

PX. Power Exchange

TSO. Transmission System Operator