Master's Thesis

MSc Environomical Pathways for Sustainable Energy Systems

Market Power Detection Analysis in the Iberian Wholesale Electricity Market: The Return on Withholding Capacity Index

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June 30, 2023

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Acknowledgements

This master's dissertation marks the end of the MSc program in Environomical Pathways for Sustainable Energy Systems, which was unquestionably both one of the most enriching and challenging chapters in my life.
First and foremost, I would like to express my sincere appreciation and gratitude to my supervisors, Maria Elena Martin Cañadas & Jordi de la Hoz for their time and counsel throughout the MSc program. The quality of this dissertation would not have been achieved without their assistance throughout the year.
Last but not least, I would like to express my gratitude towards my family and friends for their unconditional support. The accomplishment of this work would not have been possible without their encouragement over the past two enlightening years.

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Abstract

The liberalization of the electricity markets since the 1990s moved the electricity markets away from their traditional vertically integrated structure to a competitive market-based one. The objectives were clear: attract private investments, minimize government involvement, improve operational efficiency, foster innovation, and ultimately minimize electricity costs for customers. Several decades later, however, this market transformation is still ongoing and it has not been able to eliminate the potential to exercise market power.

Moreover, the detection or control of market power has shown to be particularly challenging. Several indexes and methods have been developed over time to measure or detect market power, although none of them have succeeded in establishing a standard for market monitoring endeavours.

For this purpose, this master's dissertation investigates a recently newly developed index named the Return on Withholding Capacity Index (RWC). The RWC Index measures the incentives generators experience to withhold capacity from the wholesale electricity market. The advantage of this methodology is that it can be readily calculated with publicly available data, and it takes into account demand elasticity and the specific nature of the generator's portfolio. Furthermore, the methodology can be easily standardized to apply across different markets, and across time.

The applicability of the RWC Index is demonstrated by applying the methodology to the Iberian electricity wholesale market in the year 2022. Overall, it can be concluded that market power potential in the Iberian wholesale electricity market was fairly low in 2022. Large generators seem to only experience incentives to withhold capacity during a limited amount of hours per year, while incentives for smaller generators are nearly non-existent. Furthermore, results show that the size, as well as the nature of the generator's portfolio have a strong impact on the RWC Index, and hence, on the market power potential. Last but not least, the results indicate that market power potential clearly exhibits temporal variability and incentives to withhold capacity are strongly positively correlated between generators, implying that when one generator experiences higher incentives during a certain period, incentives concurrently increase for other generators as well, and vice versa.

To conclude, by applying the RWC Index to the Iberian electricity wholesale market, its benefits and practicality have been demonstrated. The RWC Index provides rapid and valuable insights that can support market authorities to perform an initial screening to examine market power in a standardized way. This master's dissertation contributes to the limited and scarce literature of market power screening methods and tools.

Resumen

La liberalización de los mercados de la electricidad desde los años 1990 hizo que los mercados de la electricidad se apartaran de su estructura tradicional integrada verticalmente para convertirse en mercados competitivos. Los objetivos eran claros: atraer inversiones privadas, minimizar la participación del gobierno, mejorar la eficiencia operativa, fomentar la innovación y en última instancia, minimizar los costes de la electricidad para los consumidores. Sin embargo, varias décadas después, esta transformación del mercado sigue en curso y no ha conseguido eliminar el potencial de ejercicio del poder de mercado.

Además, la detección o el control del poder de mercado han demostrado ser especialmente difíciles. A lo largo del tiempo se han desarrollado varios índices y métodos para medir o detectar el poder de mercado, aunque ninguno de ellos ha logrado establecer un estándar para los procedimientos de control del mercado.

Con este fin, esta tésis de máster investiga un índice de reciente creación, denominado Índice de Retorno de la Capacidad Retenida (Return on Withholding Capacity Index, RWC). El Índice RWC mide los incentivos que experimentan los generadores para retener capacidad en el mercado mayorista de la electricidad. Las ventajas de esta metodología es que se puede calcular fácilmente con datos disponibles públicamente, tiene en consideración la elasticidad de la demanda y la naturaleza específica del portafolio del generador. Además, la metodología puede estandarizarse fácilmente para aplicarla en distintos mercados y a lo largo del tiempo.

La aplicabilidad del Índice RWC se demuestra aplicando la metodología al mercado mayorista de electricidad ibérico para el año 2022. En general, se puede concluir que el potencial de poder de mercado en el mercado mayorista de electricidad ibérico fue relativamente bajo en 2022. Los grandes generadores sólo parecen experimentar incentivos durante un número limitado de horas al año, mientras que los incentivos para los generadores más pequeños son casi inexistentes. Además, los resultados muestran que el tamaño, así como la naturaleza de la portafolio del generador tienen un fuerte impacto en el Índice RWC y por lo tanto, en el potencial de poder de mercado. Por último, pero no por ello menos importante, los resultados indican que el potencial de poder de mercado presenta una clara variabilidad temporal y que los incentivos para retener capacidad están fuertemente correlacionados de forma positiva entre los generadores, lo que implica que cuando un generador experimenta mayores incentivos durante un determinado periodo, los incentivos aumentan simultáneamente para otros generadores también, y viceversa.

En conclusión, la aplicación del Índice RWC al mercado mayorista de electricidad ibérico ha demostrado sus ventajas y su viabilidad. El Índice RWC proporciona información rápida y valiosa que puede ayudar a las autoridades del mercado a realizar un primer análisis para examinar el poder de mercado de forma estandarizada. Esta tésis de máster contribuye a la limitada y escasa literatura sobre métodos y herramientas de análisis del poder de mercado.

Resum

La liberalització del mercat elèctric des de la dècada de 1990 va traslladar els mercats elèctrics de la seva estructura tradicional integrada verticalment a una de competitiva basada en el mercat. Els objectius eren clars: atraure inversions privades, minimitzar la participació del govern, millorar l'eficiència operativa, fomentar la innovació i, en definitiva, minimitzar els costos elèctrics per als clients. Diverses dècades després, però, aquesta transformació del mercat encara està en curs, i no ha estat capaç d'eliminar el potencial d'exercir el poder de mercat.

A més, la detecció o el control del poder de mercat s'ha mostrat especialment difícil. Al llarg del temps s'han desenvolupat diversos índexs i mètodes per mesurar o detectar el poder de mercat, tot i que cap d'ells ha aconseguit establir un estàndard per als procediments de seguiment del mercat.

Amb aquesta finalitat, aquest treball de màster investiga un índex recentment desenvolupat, anomenat Return on Withholding Capacity Index (RWC). L'Índex RWC mesura els incentius que experimenten els generadors per retenir capacitat del mercat majorista d'electricitat. Els avantatges d'aquesta metodologia és que es pot calcular fàcilment amb dades disponibles públicament, té en compte l'elasticitat de la demanda i la naturalesa específica de la cartera del generador. A més, la metodologia es pot estandarditzar fàcilment per aplicar-la a diferents mercats i en el temps.

L'aplicabilitat de l'Índex RWC es demostra aplicant la metodologia al mercat majorista d'electricitat ibèric per a l'any 2022. En conjunt, es pot concloure que el potencial de poder de mercat al mercat majorista d'electricitat ibèric va ser força baix l'any 2022. Els grans generadors només semblen experimentar incentius durant un nombre limitat d'hores a l'any, mentre que els incentius per als generadors més petits són gairebé inexistents. A més, els resultats mostren que la mida, així com la naturalesa de la cartera del generador, tenen un fort impacte en l'Índex RWC i, per tant, en el potencial de poder de mercat. Finalment, però no menys important, els resultats indiquen que el potencial de poder de mercat mostra clarament una clara variabilitat temporal i els incentius per retenir la capacitat estan fortament correlacionats positivament entre els generadors, la qual cosa implica que quan un generador experimenta incentius més alts durant un període determinat, els incentius també augmenten simultàniament per a altres generadors. i viceversa.

Per concloure, amb l'aplicació de l'Índex RWC al mercat majorista d'electricitat ibèrica, s'han demostrat els seus beneficis i practicitat. L'Índex RWC proporciona coneixements ràpids i valuosos que poden ajudar les autoritats del mercat a realitzar un examen inicial per examinar el poder de mercat de manera estandarditzada. Aquesta tesi de màster contribueix a la literatura limitada i escassa de mètodes i eines de selecció de poder de mercat.

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List of Abbreviations

ADF	Augmented Dickey–Fuller
AVB	Virtual Storage Balance (Almacenamiento Virtual de Balance)
CAISO	California Independent System Operator
CCF	Contribution Congestion Factor
CCS	Carbon Capture and Storage
CNMC	National Commission of Markets and Competition (Comisión Nacional de los Mercados y la Competencia)
CR	Concentration Ratio
EEX	European Energy Exchange
ETS	Emissions Trading System
FD	First Differences
H1	First Half
H2	Second Half
HHI	Herfindahl-Hirschman Index
IV	Instrumental Variables
LI	Lerner Index
LP	Location Privilege
Mibel	Iberian Electricity Market (Mercado Ibérico de Electricidad)
MS	Market Share
MRR	Must-Run Ratio
MW	Megawatt
MWh	Megawatt-hour
NEIO	New Empirical Industrial Organisation
OLS	Ordinary Least Squares
PPA	Power Purchase Agreements

PP	Phillips–Perron Unit Root Test
PSI	Pivotal Supplier Index
PVB	Virtual Balance Point (Punto Virtual de Balance)
REMIT	Regulation on Wholesale Energy Market Integrity and Transparency
RSI	Residual Supply Index
RWC	The Return on Withholding Capacity Index
TSLS	Two Stage Least Squares
TVB	Virtual Balance Tank (Tanque Virtual de Balance)
VAT	Value Added Tax

Chapter 1

Introduction and Objectives

1.1 Introduction

The liberalization of the wholesale electricity markets started in the late 1990s and intended to move away from a vertically integrated model to a market-based, competitive model. This process is still ongoing and many liberalized electricity markets today are closer towards an oligopoly rather than a perfectly competitive market [1]. This can be explained by the specific traits of electricity markets being: the relative expensive storability of electrical energy; the existence of entrance barriers; market concentration and dominant privileges; network constraints; information asymmetry and low commodity differentiation with low substitution possibilities [1].

Efforts are ongoing to enhance competition but today market power potential and the exercise of it cannot be excluded. For this reason, market authorities continuously monitor electricity markets to prevent that manipulation practices alleviate prices above competitive levels. However, detecting and proving market power has been demonstrated to be particularly challenging and there is a lack of effective and standardized methodologies. There is a clear need for appropriate tools to detect market power potential or the exercise of it. Over the last decades literature has suggested several tools such as indices and simulation tools. Each of them have their specific characteristics, advantages and shortcomings.

1.2 Objectives and Scope

As the liberalization of the wholesale electricity markets only started from the late 1990s and is still an ongoing process, it is interesting to see to what extent market power is still present in the Iberian wholesale electricity market. As the three dominant market players together still possess a market share of over 50%, the Iberian market can be considered more as an oligopoly rather then a competitive market. Nonetheless, competition has increased over the last decade. As market power potential is more likely to be present and exercised by dominant generators with large multi-unit generation portfolios, this project will specifically focus on the three dominant market players in the Iberian market being Iberdrola, Endesa, and EDP.

Detecting market power potential and the exercise of it has demonstrated to be extremely difficult. Nonetheless, market authorities continuously monitor electricity markets as market power practices are illegal in order to protect consumers. To investigate market power potential in the Iberian wholesale electricity market, this project will make use of an index named *The Return on Withholding Capacity Index* (*RWC*). This is a recently new developed index that possesses some crucial advantages over more traditional market power detection tools. However, the RWC Index has not been applied to many different cases and is not yet a widely acknowledged market power detection tool. For this reason, the objective of this thesis is to examine to what extent this index can be insightful and to which extent it can be easily applied to different markets and periods in time.

The final objective is to demonstrate whether market power potential is still present in the Iberian wholesale electricity market and if so, which generators have the power to exercise it and during which periods. Furthermore, this thesis can demonstrate whether this recently developed RWC Index can be effectively applied in order to be a useful tool for market power detection. If this is the case, this work provides incentives for market authorities to include this RWC method in their market monitoring methodologies.

Chapter 2

Literature Study

2.1 Liberalization of Electricity Markets

Starting from the late 1990s, governments all over the world initiated the liberalization of the wholesale electricity markets, moving from a vertically integrated model to a market-based, competitive model. Some of the main steps of the reform included the unbundling of the traditionally vertically operated generation, transmission & distribution, and retail supply services [2]. The objectives were manifold: minimize government entanglement, attract private investment and new entrants, minimize costs for customers, foster innovation, and improve service quality [3].

However, despite all authority efforts during the last two decades, due to the specific traits of the electricity market, the current power markets might still be better characterised as oligopolies rather than perfectly competitive markets [1]. This implies that strategic behaviour, with prices above perfect competitive prices as a consequence, cannot be excluded, hence requiring the need for careful monitoring to avoid market players to exploit their market power. This implies that there is a clear need for appropriate tools to detect actual or potential market power. Over the last decades literature has suggested several tools such as indexes and simulation tools, each of which have their specific characteristics, advantages and shortcomings.

2.2 What is Market Power?

The most clear and concise definition of market power is given by [4] and follows: *"To raise its price above the competitive level by reducing output"*. Another definition is given by [5]: *"Market power refers to conditions where the providers of a service can consistently charge prices above those that would be established by a competitive market"*. Based on this, it can be concluded that in the case of market power exercise, the overall supplied output is lower than in the case of a competitive market, which explains the higher prices.

It is important to understand that this strategy must lead to a profitable outcome [6]. If not, it would not be a rational strategy to pursue, hence authorities should not worry about this. This latter criteria of profitability can be a good guideline during the investigation of potential market abuse practices to distinguish between strategic and non-strategic actions [3].

In [3], a distinction is made between *vertical* and *horizontal* market power. The former implies the execution of market power by a company operating several areas in the supply chain, through the manipulation of one part of the chain to raise overall profits made across the entire chain. The latter form implies the manipulation of a single part of the supply chain to shift prices above competitive levels. As the consequences of a vertically integrated system on market power potential are better understood, the remainder of this study will focus on horizontal market power of generation companies.

2.3 Market Power Causes

Specific features of the electricity market make the potential abuse of market power very likely compared to other commodity goods. The most important ones are: relative expensive storability; the existence of entrance barriers; market concentration and dominant privileges; network constraints; information asymmetry and low commodity differentiation with low substitution possibilities [1].

The lack of cost-effective storage opportunities [7], combined with the requirement to match supply and demand of electricity at all times to ensure grid balance, imposes severe challenges on managing the power grid. This, along with the relative inelastic demand and supply of electricity make the existence of market power particularly likely [3, 8]. Demand is rather inelastic in the short term due to a lack of alternatives and price-responsive technologies. Supply is rather inelastic due to limited capacities by market players and transmission congestion [9]. The latter might limit the amount of electricity that can be transported from low to high demand areas, increasing the slope of the supply curve.

Economic theory states that in a perfect competition, without the existence of entry barriers, new players will enter the market until the point where additional profits disappear. However, it is clear that some major entry barriers exist and they are an explanatory factor to why the electricity market is not a perfect competition [10]. Some of the entry barriers are: intensive capital requirements; sunk costs [11]; long lead times; political risk (i.e. priority dispatch regulations); and social barriers (i.e. public opinion risks) [3, 10].

Last but not least, the market structure will also determine the level of market power that can be exercised. Most power exchange markets are organized as uniform price auctions. This implies that all generators receive the same price, regardless of their true marginal costs or price bids. Another market structure is the pay-as-bid auction in which each generator submits a bid at the price they are willing to deliver electricity. If the bid is accepted, the generator gets paid the price they offered.

2.4 Consequences of Market Power

Market power abuse shifts market prices above competitive levels which leads to distorted price signals which in turn results in operational and investment inefficiencies [12]. These artificial prices shift trading surplus from costumers to suppliers and this wealth transfer creates overall social welfare losses [6]. These overall social welfare losses (also called *dead-weight losses*) might be limited due to the general low elasticity of demand [8] but might become more significant over time as new technologies (i.e. demand response technologies) should make demand more elastic over time. Nonetheless, inefficiencies are caused by these upward price shifts as they imply the replacement of more efficient (i.e. baseload) units (due to strategic purposes) for a more expensive marginal technology [8].

The effects of strategic bidding on the clearing price and their associated shifts in social welfare are well illustrated in Figure 2.1. This represents the market clearing mechanism in a uniform price auction which is the dominant market design worldwide. If all generators would bid at marginal cost, the market equilibrium would be at point E, with the market clearing price being λ and a market clearing quantity equal to Q [1]. If some generators exploit their market power by strategically shifting the supply curve (which in a perfect competitive market represents the marginal cost curve of the market) to the left side (and thus reducing supply), the new market equilibrium shifts to point E', at a higher price λ'. In this case, the producers' surplus grows from area λAE to area $\lambda' ABE'$. At the same time, the total social welfare surplus goes down from AED to area $ABE'D$, representing the dead weight loss $S-$ [1].[1] Note that Fig. 2.1 also shows that strategic bidding generates benefits for all generators, and not only by those strategic generators [3, 13]. However, [13] points out that the existence of market power might be more advantageous for those suppliers who do not exploit it, due to the high cost of doing so. Lastly, the figure also displays that market monitoring for market power should not only investigate marginal generators as other generators also have the ability to shift the supply curve upwards [3].

[1]Note the effect that demand elasticity has on the overall outcome of social welfare. The dead-weight loss reduces as demand becomes more inelastic [8].

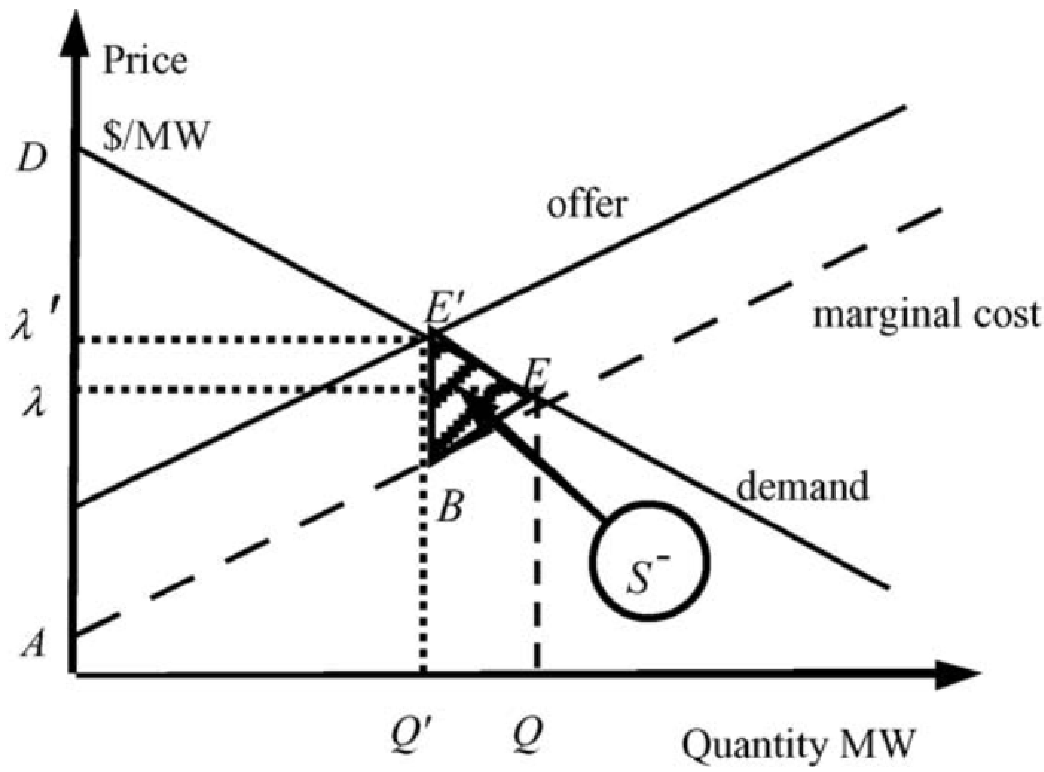

Figure 2.1: Effects of Strategic Bidding on Market Clearing. Source: [1].

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2.5 Market Power Strategies

Different practices to exploit market power exist, with *physical* and *economic withholding* being the most well-known and well understood ones in literature. Besides this, market power can also be exercised through strategic actions related to the transmission network or related to the strategic manipulation of ramp-rates. The latter case gained more attention in recent literature. Regardless of the type of market power, they all have the same effect: higher prices, higher generator profits, and withheld capacity [3].

Fig. 2.2 provides the reader with a well structured framework of how monitoring authorities must analyze several factors (including market structure, market price, performance) with detection tools that can expose any type of market power abuse.

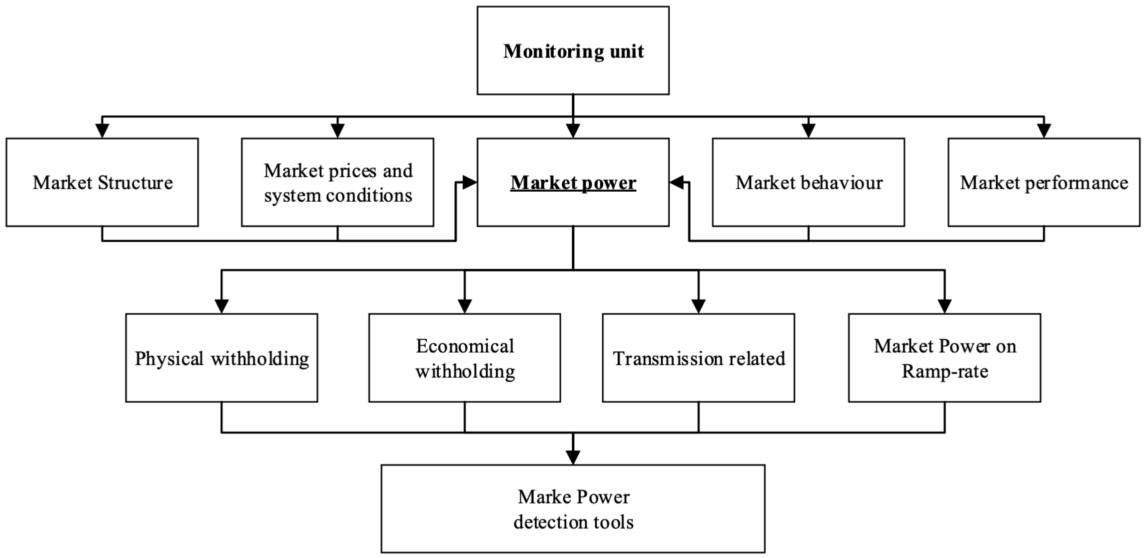


Figure 2.2: Market Power Monitoring framework. Source [10].

Physical withholding means strategically withholding a fraction of its capacity that has a lower or equal marginal cost than the current market price [3]. It is the most well known example of market power abuse.

Economic or *financial withholding* on the other hand implies offering its capacity at a higher price than the marginal price [3]. The key disadvantage of this strategy is that it is rather straightforward for the authorities to detect, simply by comparing the suspected operator's bids either over time or across different operators [8, 14]. For this purpose, literature seems to focus more on physical withholding which seems to be justified.

In the case of physical withholding, it is clear that only a fraction of the market power abuser's portfolio can be withheld. This, by definition, makes single-unit operators not suspicious for this kind of market power abuse practices. A single unit operator would typically have a relative low market share and thus, even reducing its output by a fraction would not have much impact on overall price levels, making the withholding of capacity a non-profitable strategy. This implies that market authorities should focus mostly on multi-unit generators. This is also supported by literature.

Another strategy to exploit market power is *transmission related*. By artificially manipulating power flows, generators can congest power lines, creating a segmentation of the market. In this way, local suppliers can become a pivotal player, being the only one able to deliver the residual demand, and thus creating market power which can allow those generators to raise prices. Furthermore, [1] demonstrate that even in the case of perfect competition, generators with identical marginal cost curves generate a different surplus in case of congested transmission lines. They highlight that the location of a generator in the network can give advantages or disadvantages in terms of surplus even in the perfect competition case without strategic behaviour. This clearly demonstrates the importance of understanding the consequences of transmission line congestions, especially if strategic behaviour is suspected. Unfortunately, very few indexes that have been used in literature are able to capture this form of market power and thus fail to completely address these types of abusive practices. Later on, some indexes will be explained that have attempted to address this type of market power.

Another strategy is exercising market power through manipulation of the *ramp rates* of generation units. This has gained more focus recently as this strategy might become more prevalent in the future due to unpredictable and intermittent behaviour of renewables. The intermittent nature of renewables will require units to provide additional flexibility which might be exploited by generators. For instance, generators could opt to lower the offered ramp rate so that they can maintain higher dispatch levels, generating additional profits [15]. [15] investigate the strategic behaviour of firms in terms of ramp rate manipulation of generators in a wind-integrated energy system. Next, [16] model the strategic manipulation of ramp rates of generators owning a portfolio with flexible power units (such as energy storage and hydropower units) and show how withholding the ramp rate can lead to additional non-competitive profits. The larger the market share of the strategic generator's portfolio, the larger the quantity of ramp rate being withheld from the market. They highlight it is therefore crucial to closely monitor the generators that are owning the flexible units in systems dominated by variable renewable power.

A potential issue that might create extra challenges to market power abuse investigation (and that is particularly related to ramp rates) is the plausible relationship between increasing penetration of variable renewable energy and an increased risk of failure for conventional power units [8]. Indeed, the increasing shares of variable energy sources such as wind and PV make the need for fast ramping balancing services more essential [16]. Therefore, it cannot be surprisingly that a higher frequency in shutdowns, restarts, and more flexible operations modes might lead to more unexpected outages [8]. For this reason, it might be more complicated in the future to classify plant failures as strategic or non-strategic, hence making it more complicated for authorities to prove and penalize abusive practices.

2.6 In What Markets is Market Power Abuse Likely?

Electricity markets are typically organized in separated markets. In most areas around the world there is a distinction between forward markets, day-ahead markets, intra-day markets, balancing markets, capacity markets, and ancillary service markets. While other types of market power cannot be excluded, market power abuse typically tempts to occur in the short-term. The explanatory reason for that is that a profitable strategy of market power abuse requires more accurate information that is not present in the longer term. This is good as a large part of electricity is traded based on long-term forward contracts. [8] define profitable market power strategies as actions that are based upon prior understanding of abrupt price surges and re-entering the market as soon as feasible after the price peak. They therefore conclude that the day-ahead markets in Europe are most likely the markets where most market power abuse is present. [8] also point out that they do not expect capacity withholding strategies in the intraday market as several intraday markets are organized as a bilateral market structure and only a limited amount of capacity is being traded there to balance short-term mismatches between supply and demand. For this reason, [8] and other studies typically focus on the day-ahead markets. For this purpose, the remainder of this work will focus on the day-ahead markets in the electricity market.

Last but not least, not only the time scale is important but also the type of market structure which defines the manner in which the market outcomes are obtained. Most wholesale electricity markets in countries around the world use uniform price auctions for electricity trading. However, pay as bid auctions are also possible, such as in the United Kingdom. In uniform price auctions, there is a single market clearing price which is obtained by matching demand and supply and it is the price all market players pay or receive [17]. In pay-as-bid auctions (also named *discriminatory price auctions*), all market agents receive or sell at their own submitted bid prices [17]. The conviction that uniform price auctions were more vulnerable to strategic market abuse than pay-as-bid auctions was one of the main factors behind the market reform in the United Kingdom [8, 18]. The pay-as-bid auction appears to evade the rational strategy of using market power, when present, because withholding capacity from one unit does not produce profits for the other units of a multi-unit generator [8]. However, this hypothesis has been rejected by [14] and [19] that show that withholding capacities can still be a profitable strategy under specific market circumstances. Notwithstanding, besides the greater potential for market power abuse in uniform price markets, other aspects such as transparency and efficiency of each market structure should be considered carefully.

Finally, literature finds that despite of the specific market and market structure, market power potential also varies depending on the specific demand level. It is generally accepted that there is little potential for market power abuse in off-peak hours. This makes sense as in those moments typically a large portion of the demand is served by must-run baseload capacity (e.g. nuclear, coal or run-of-the-river hydroelectricity) or by cheap renewables, having a large amount of unused generation capacity available. Additionally, transmission capacity might reach its limits during peak hours, creating additional market power potential,as discussed earlier. [20] agree with this hypothesis by stating that *"a single market can at times exhibit very little market power and, at other times, suffer from the exercise of a great deal of market power"*.

2.7 Market Power Mitigation

This section discusses some measures that can be taken to alleviate market power. As discussed before, it is clear that demand management can play a big role in alleviating market power abuse. Demand management increases demand elasticity which allows to shift demand from peak to off-peak hours, with associated lower costs. This makes it less likely for generators to exploit their market power. It can be expected that demand management will play a more significant role in the future because of flexible sources such as Internet of Things (IoT) and vehicle-to-grid technologies.

An additional measure to reduce market power incentives is the use of forward bilateral contracts to ensure long-term price contracts and to avoid future risks and volatility [21, 22]. This is also supported by the EU electricity market design reform, as part of their Green Deal Industrial Plan[2]. It aims to boost long-term forward contracts to ensure stable low prices.

Furthermore, a careful analysis must be executed to identify potential bottlenecks in the transmission system that might give rise to market power. A better connected transmission system that avoids market segmentation into smaller local markets dominated by one or a few generators should be considered if the benefits outweigh the costs of transmission expansion.

Finally, several other measures have been proposed to reduce market power. [8] suggest to investigate a system with price caps, along with potential additional capacity payments. Additionally, they deem it vital for generators to communicate more details on plant failures to enhance monitoring.

[2]https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en.

2.8 Market Power Detection Tools

2.8.1 Overview

The general distinction in market power detection tools is made between structural and market simulation approaches. A good overview of the different market detection tools that have been developed over time is provided in Fig. 2.3. Each of them will be addressed in detail below.

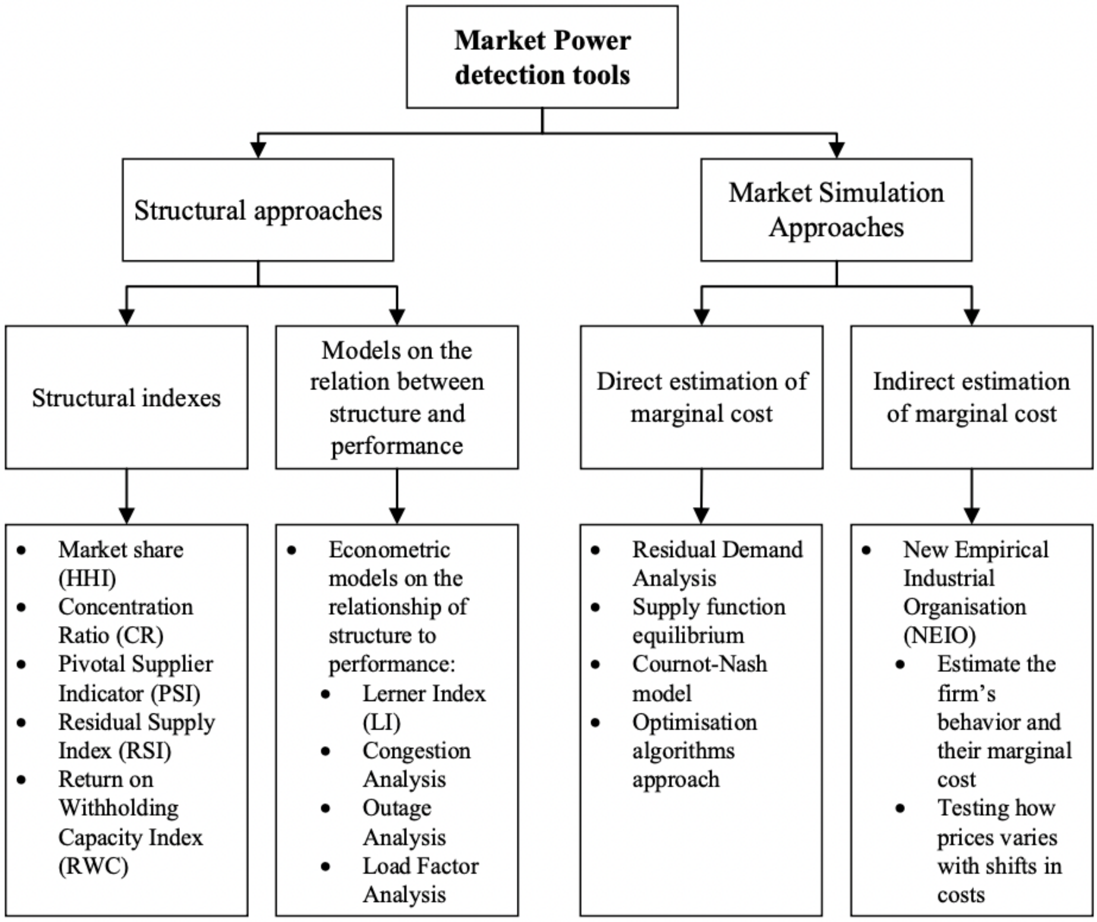


Figure 2.3: Market Power Detection Tools. Source: [10]. Based on information from [23] and [24].

2.8.2 Structural Approaches

Structural approaches are further divided between structural indexes and econometric models that investigate the relationship between structure and market performance. The structural indexes try to explain what factors cause market power [10]. The econometric models on the other hand utilize variables describing market structures and regress it on market performance variables such as profits or profit margins [3]. In this way, it is attempted to find out what structural variables actually cause market power [3]. This state-of-the-art review will mainly focus on structural indexes.

2.8.3 Structural Indexes

Over the last two decades an abundance of structural indexes has been proposed in the literature. The most common ones are *market shares*, the *Herfindahl-Hirschman Index* (*HHI*), the *Lerner Index* (*LI*), the *Residual Supply Index* (*RSI*), and the *Pivotal Supplier Index* (*PSI*). The Return on Withholding Capacity Index (RWC), which will be investigated in this master's dissertation, is a relatively new index in this category and will be explained in detail below.

Each of the structural approaches have their own characteristics, advantages and limitations. In order to precisely perform a market analysis to monitor market power, it would be advisable to use a combination of several indexes. Structural indexes are generally applied to carry out ex-ante analyses [3]. The most well-known structural indexes will be discussed in detail below.

Concentration Measures

Traditionally, concentration measures have been the most popular tool in the detection and prediction of market power [20]. Concentration indicators measure the concentration of the electricity generators in the market with the presumption that higher market concentrations make the exercise of market power by its actors more probable [25]. The most well known concentration indexes are market shares and the Herfindahl-Hirschman Index (HHI).

Market Share

Market shares or *Concentration Ratios* (*CRs*) have been used in many distinct markets to define market power. In general, an electricity market is said to be concentrated if any of the following criteria is met [3]:

- One single player has a concentration ratio (CR1) above 33.3%.
- The three biggest players have a combined concentration ratio (CR3) above 50%.
- The five biggest players have a combined concentration ratio (CR5) above 66.7%.

Herfindahl-Hirschman Index

The *Herfindahl-Hirschman Index* (*HHI*) is the sum of the squares of the market shares of all market participants. The equation is depicted below [26]:

$$HHI = \sum_{i}^{n} (MS)^2 \tag{2.1}$$

The HHI converges to 0 when there are an infinite number of small suppliers and is equal to 10,000 when there is only one player in the market [26]. Fig. 2.4 depicts how different market competitive levels can be defined by means of the HHI. The advantage of the HHI over concentration ratios is that they take into account all the generators in the market [27]. As a reference point it is assumed that a market is concentrated if the HHI exceeds 1,000 [3].

Unfortunately, a crucial issue with concentration measures (i.e. market shares and the HHI) is that they fail to take into account demand elasticity which is essential in determining potential market abuse [20]. The above-mentioned characteristics that explain the existence of market power (i.e. non-storability, congestion effects, limited production capacities) make demand elasticity a particular important factor explaining the actual level of market power [20].

Furthermore, [6] claims that the HHI is not an adequate index for market power appraisal as it, besides demand elasticity, also fails to take three other crucial factors into account: competition type, the existence of forward contracting, and geographic scope of the market. Therefore, they argue that Cournot modeling of the market is assumed to be a better indicator of market power compared to the HHI (cf. infra).

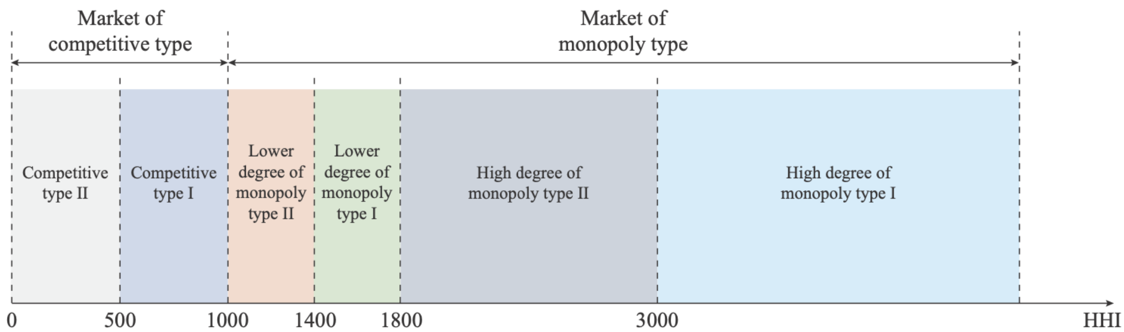


Figure 2.4: Different Market Structures Based on HHI. Source: [28].

The advantage of concentration measures is that they are simple to calculate with publicly available information and they can point into the direction of suspected market power [25]. However, another weakness is that these indexes only provide information about the suspected location where market power might occur but not how much power is actually exercised [10]. [29] indicate another weakness: the HHI does not include the effects of load variability, nor the effects that transmission constraints might have on market power. [30] also indicate that market actors can artificially create transmission congestion to gain additional profits, changing the HHI as a measure of market power while doing so. Similarly, congestions can create separate markets, influencing the calculations of the HHI.

To conclude, even though concentration measures can be good for an initial screening, they can never be sufficient to perform a proper market analysis. It cannot be excluded that price hikes can still be caused by generators with low market shares, as long as they are pivotal generators [16]. Other indexes such as the PSI and the RSI take this into account and give a better appraisal of potential market power.

Pivotal Supplier Indicator & Residual Supply Index

The Pivotal Supplier Indicator (PSI) and Residual Supply Index (RSI) are two of the most common structural indexes used in market power analysis. Both indexes can be calculated on an hourly basis and for every generator active in the market. The PSI is a binary variable that is equal to 1 for a generator if the generator is indispensable in order to meet demand (i.e. the generator is pivotal), and 0 if the generator is not [3].

The RSI on the other hand is equal to the ratio of all available capacity minus the specific firm's available production capacity, and the total demand [3]. The RSI is defined as [25, 28]:

$$RSI_i(t) = \frac{\sum_{g=1}^{N_T} P_g(t) - P_i(t)}{D(t)} \tag{2.2}$$

with $\sum_{g=1}^{N_T} P_g(t)$ being the total available generation capacity in the market at time t, $P_i(t)$ being the available generation capacity of generator i at time t, and $D(t)$ being the market demand at time t. The California Independent System Operator (CAISO) defines the market as competitive when the RSI value is between 120% and 150% [28]. In this case, there is sufficient capacity available in the market to meet demand, even upon excluding capacity from the investigated generator. When the RSI values are below 100%, the firm is pivotal to meet demand and its influence on market prices will be potentially significant [28]. According to [28], generators can be regarded as pivotal to meet market demand if they have PSI values equal to 1 for over 20% of the hours in a year, or when its RSI is below 110% for over 5% of the hours on a yearly basis.

The RSI provides more information than the PSI as the PSI is implicitly put equal to 100% when a generator becomes pivotal [25]. The RSI can provide an indication on the level of pivotality of a specific generator, and thus its capability to alter prices. However, both do not tell how much incentives each generator experiences to do so as these incentives depend on factors such as the generation technology [3]. The RWC Index does address this issue by taking into account the generation portfolios of generators.

The RSI and PSI are more informative indexes compared to the concentration measures as they include demand factors in their calculation, as well as it is possible to calculate them for every firm, for every time period [3]. However, the RSI and PSI still suffer from a similar matter as the concentration measures. Namely, they require a clear and concise definition of the specific product and the geographic market [3]. It is difficult to define whether every hour, or every 30-minutes period constitutes a new product and market.

Nonetheless, the RSI and PSI are still a popular market power analysis tool. For instance, the RSI was used by the German Monopolies Commission in their analyses on the German electricity sector(Monopolies Commission, 2013, 2015, 2017) [31]. Besides, [32] and subsequent research of [33] show that market structure, as measured by the RSI, significantly explains price-cost markups, even when other explanatory variables are taken into account. This shows the practicality of this index.

Return on Withholding Capacity Index

The Return on Withholding Capacity Index (RWC) is the index that will be utilized below to assess the market power potential in the Iberian day-ahead wholesale electricity market. The index is relatively new and was developed by [31]. The RWC Index attempts to measure the incentives that firms with a multi-unit generation portfolio experience to withhold one unit (i.e. 1 MW) of capacity. The RWC Index is calculated for every generator and can be calculated on an hourly basis. The higher this index during a specific period, the higher the incentive for generators to withhold capacity from the day-ahead market in order to increase profits [31]. The index takes into account the lost profit margin of withholding capacity and compares it with the gains attained from higher prices on its remaining generation. One of the advantages of this index is that it can be calculated with publicly available data and it takes certain factors into account such as demand elasticity and the specific portfolio of the generators [31]. This is often disregarded by other indexes. Another advantage is its general standardized form which allows to utilize the RWC Index in different kind of electricity markets, for different geographical areas, or for comparing indexes over time [31]. The exact methodology will be further explained in Chapter 4.

To conclude, complications for all structural indexes arise in the selection of the appropriate data (historical or simulation data, the use of either installed capacity or energy sold,...), as well as defining the appropriate markets in terms of geography and time-scale [3]. Due to interconnections between different areas or countries, it is challenging to define one market. Additionally, [3] also point out that transmission congestions can create smaller, local markets. However, transmission congestions depend on network conditions and vary over time and hence, so do these 'local' markets. Furthermore, [3] point out that it is hard to define a market in terms of time. As already pointed out, market power varies over time within the same market during peak and off-peak hours. Therefore, it is not appropriate to consider 24-hour periods to be a single market due to the need to continuously balance demand and supply and the lack of storage. However, the question is, what appropriate time period one should consider.

2.8.4 Models on the Relation Between Structure and Performance

Although this master's dissertation mainly focuses on structural indexes such as the RWC Index, some well-known tools in this category of econometric models will be briefly described in this section. As mentioned before, the econometric models utilize structural variables and regress them on market performance variables such as profits and profit margins [3, 10]. This should explain what factors play a big role in actually causing market power [3]. Most interesting here is that these structural models not only take into account the market structure from an economic point of view (market shares, HHI, and so forth) but also from a technical point of view (e.g. transmission related). This can include factors such as congestion, outages, and load factors. The additional consideration of transmission constraints is significant as literature is indisputable that transmission constraints have large effects on potential market abuse. For this purpose, several authors have introduced new indexes to take into account these constraints.

Unfortunately, [3] point out that the empirical evidence on the effects of market structure on market performance outcomes is very weak. This is due to the existence of endogeneity problems, measurement and calculation errors in the data, and invalid regression model selections [3]. This explains why these methods have not been wielded abundantly in literature. For this reason, this section will only briefly explain the most well-known approaches. Some of the better known analyses are the Lerner Index (LI), the Must-Run Ratio (MRR), the Location Privilege (LP), and the Contribution Congestion Factor (CCF).

Lerner Index

The Lerner Index (LI) assesses the proportional deviation of the price that generation units receive from the marginal cost of that unit [28]. It can be calculated as follows [21]:

$$LI_i = \frac{P_i - MC_i}{P_i} \tag{2.3}$$

with P_i and MC_i being the price and marginal cost of generation unit i, respectively. In a perfectly competitive market, the LI should be equal to 0. If the LI is greater than 0, some degree of market power is present. The larger the value of the Lerner Index, the larger prices deviate from marginal costs, and thus, the higher the market power of firm i.

One of the disadvantages of the LI is that it does not take into account the price reaction on demand [34] and it does not include potential effects from transmission line constraints on the price level [28].[3] Another disadvantage of indexes like the Lerner Index is that it shows how much the price deviates from the marginal cost of a certain unit i. However, a potential markup, indicating a price above the marginal cost does not necessarily mean that market power is being exercised. It actually often occurs in a uniform price market that prices rise above the marginal costs of the generation unit. This can even be the case for the marginal unit. This is to match supply with demand and it allows the marginal technology to recover fixed costs during those periods. If prices rise for a given marginal cost of generator i, the index could give the false impression that generator i is exercising market power, while it is not. Deeper analysis is therefore always required upon applying Lerner Indexes as a measure of market power abuse.

[3] For this purpose, the Lerner Index has been expanded to the Effective Lerner Index (ELI) by [35] in order to take into account vertical market power and congestion effects. More information can be found in [21, 35].

Must-Run Ratio

Unlike other indexes, the Must-Run Ratio (MRR) takes into account transmission related constraints. The MRR is used to investigate zonal market power and typical values vary between 0% and 100% [36].[4] The higher the MRR value, the larger the potential for locational market power [36].

The index is as calculated as follows [28, 36]:

$$MRR = \frac{P_d - P_l - (\sum_{j=1}^{N_g} Pg_{j,max} - \sum_{j=1}^{N_{gA}} Pg_{j,max})}{\sum_{j=1}^{N_{gA}} Pg_{j,max}} \tag{2.4}$$

with P_d and P_l being the total load and import limit of the specific zone under consideration, $P_{gj,max}$ is the output limit of generator j in the zone, N_g is the amount of generators in the zone, and N_{gA} is the number of generators that are owned by supplier A in the zone [28, 36]. The MRR can provide information on the amount of capacity that a generator should generate in order to supply a certain load through a congestion zone [21].

Contribution Congestion Factor Matrix

Another method is called the Contribution Congestion Factor Matrix (CCF) which assesses the effects of each specific generator on the transmission-constrained line [35, 37]. If the CCF value is positive, it implies there is a positive correlation between the power flow in the line and the specific generator's output [21]. Hence, this means that if the generator increases its generation, it will increase the power flow of the transmission constraint [21]. Likewise, if the CCF value is negative, there is a negative correlation between the power flow and the generator's output. An increase in generation from this specific generator will decrease the power flow in the constrained transmission line. Furthermore, [37] show that strategic behaviour can cause congestion constraints and thus can lead to the creation of local markets in which some generators exhibit market power. Last but not least, [37] illustrate that the geographical location of suppliers and customers lead to several levels of market concentration.

Location Privilege

The Location privilege (LP) measures the impact on the generators' surplus based on their location in the electrical grid and is defined as [1]:

$$\eta_i = \frac{S_{i,P}(F_l) - S_{i,Pu}}{S_{i,Pu}} \tag{2.5}$$

where η_i represents the LP Index for the specific power generator i; $S_{i,P}$ is the generator's surplus with network constraints; F_l is the limit of the transmission flow; and $S_{i,Pu}$ is the generator's surplus under the assumptions of unconstrained perfect competition [1]. If the LP Index is positive, the generator experiences an advantage on its surplus from the congested line because of its specific location. If the value is negative, the generator suffers a disadvantage due to its

[4] Values above 100% are not very informative.

location in the electrical grid [21]. The index compares the deviation in the generator surplus from the surplus that would occur in case of unconstrained perfect competition.

The LP Index is very interesting as it analyzes and measures the effects of the location of a generator on its surplus showing that a location can both reduce or increase its surplus. [1] show that even under perfect competition conditions, in which generators offer their bids as marginal costs, the location in the grid can increase of decrease the generators' surpluses. This index can be calculated for every line and for every generator.

Furthermore, an LP Index can be calculated for the entire power system. This global index is calculated as the sum of the absolute values[5] of all the specific LP Indexes [1]. In this way, this index represents the total effect of the network on the generator's surpluses, compared to the surpluses under the unconstrained perfect competition case [1].

In addition, [1] bear in mind strategic behaviors by taking into account the fact that generators might take advantage of the congestion of transmission lines. Last but not least, the LP Indexes can be used to rank transmission lines in order to detect lines that are more prone to congestions and thus potential market power abuse. This index could help market regulators to focus on the most important transmission lines during their monitoring analyses.

Several other indexes have been developed in literature but are less well-known. Some examples are the *System Interchange Capacity*, the *Variation Index*, the *Must-Run Share*, the *Nodal Must-Run Share*, and the *Expected Nodal Must-Run Share*. Most of these focus on transmission congestions and their effects on market power. More information on the above-mentioned indexes, as well as other indexes, can be found in [21, 28] which both provide an extensive overview on this topic.

[5]Absolute values are required to not cancel out the positive and negative values of the individual LP Indexes.

2.8.5 Market Simulation Approaches

Unlike the structural approach that attempts to figure out the reasons that might explain market power [10], market simulation approaches focus more on the amount of market power that is being exerted and try to measure it [3]. [10] prefer market simulation models over structural indexes as the latter ones fail to include crucial factors of the electricity market. As this master's dissertation mainly focuses on structural indexes as they are simpler and can be applied in a more standardized manner, less emphasis is put on these simulation approaches. Nonetheless, market simulation approaches are fundamental as they attempt to measure how much market power is exercised and they are better in including potential strategic behaviour of generators. For this purpose, a prompt overview of the most important approaches will be provided below. For a more in depth analysis on simulation approaches, [3] provide an excellent overview of the different tools that have been developed over time.

The most crucial decisions of market simulation models are the proper estimation of marginal costs of each generation unit and the determination of potential oligopoly equilibria in the market [3]. Regarding the estimation of marginal costs, two different methods are present: the direct and indirect estimation of marginal costs.

Direct Estimation of Marginal Costs

The direct estimation method utilizes costs of fuels and thermodynamic efficiency rates to determine marginal costs. In a next step, the price-quantity equilibrium is calculated based on some oligopoly model [3]. The following oligopoly models have been used in literature to investigate market power [3]:

- Linear Optimization Models
- Cournot-Nash Models
- Supply Function Equilibrium Models
- Agent-Based Simulation Models

Game theory models have been extensively used in modeling electricity markets, especially for oligopoly type models, as they allow to analyze various strategic interactions amongst participants in the market. The acknowledged models are Cournot-Nash, Betrand[6], Stackelberg, Supply Function Equilibrium (SFE), or collusion models. The SFE, the Cournot-Nash, and the agent-based models are strongly built on these oligopoly theories. They are highly flexible instruments to model strategic behavior in wholesale electricity markets [3]. However, these models also have several weaknesses. The three main drawbacks mentioned by [3] are:

- The abundance of assumptions create a significant modeling risk which might produce highly uncertain outputs.

[6]However, [28] note that Bertrand models may not be applicable to electricity markets because it assumes that any generator can capture the market by bidding prices below others while expanding its output to meet demand. However, this cannot be a valid assumption in any electricity market as the outputs of generation units are always constrained.

- The models focus on accurately estimating marginal costs. However, generators submit their bids based on opportunity costs rather than marginal costs. These opportunity costs might deviate substantially from the marginal costs.
- The models usually disregard other (marginal) costs that might influence generators' biddings. These costs are typically very difficult to estimate. An example is the degradation of equipment or the costs of operating reserves.

Indirect Estimation of Marginal Costs

Estimating marginal costs directly might be a very challenging and tedious undertaking. For this reason, the indirect estimation of marginal costs (also called the New Empirical Industrial Organisation (NEIO) Approach) attempts to overcome this difficulty by assessing market prices and any other cost and demand related factors [3]. By doing so, a generator's market power might be exposed when its generation explains price changes instead of any other shift in costs and demand factors [3].

This method can be divided into two different approaches. Each of them will be briefly explained below.

Approach 1

The first approach makes use of a structural model in order to forecast a generator's behaviour as well as marginal costs [3]. Again, oligopoly theories are applied to define the model equations [3]. This model is a simultaneous-equation model which is based on a demand and supply equation, along with three unknown sets of parameters: costs, demand and firm conduct [10].

Approach 2

Alternatively, a reduced form model can be used by examining how costs fluctuate with shifts in costs or any other relevant factors [3, 38]. This model investigates the market competitiveness by reviewing how market prices alter with cost shifts [10]. A generator is assumed to not possess market power if prices are entirely explained by shifts in costs rather than by the generator's output [3].

One of the advantages of this approach is that less data and assumptions are required compared to the structural models in approach 1 [3]. However, the disadvantage is that it tests only market competitiveness and does not really measure market power directly.

To conclude, the NEIO models for both approach 1 (structural form) and approach 2 (reduced form) have the advantage that they allow to calculate the level of market power without the need for data on costs or profits, as required by the direct estimation method [3, 10]. Furthermore, there is no need for market definitions which was a problem with the structural approaches as mentioned before [3]. Some of the disadvantages are the relatively limited flexibility to integrate assumptions and different generators compared to multi-agent models (i.e. direct estimation of marginal costs), the limited explanatory power to investigate which factors increase or decrease the market power level, and the sensitivity of NEIO estimates to the specific selection of the type of strategic behaviour between suppliers and the selected functional shape of the demand and cost functions [3].

More information on each of these models can be found in [3].

Chapter 3

Mibel Zone Wholesale Electricity Market

Before doing any effort to monitor and detect market power potential, it is fundamental to have a proper understanding of the market dynamics that are present in the specific market under investigation. In this case, this is the Iberian Electricity Market (also called the MIBEL or Mercado Ibérico de Electricidade) Zone wholesale electricity market, consisting of Spain and Portugal. More importantly, it is fundamental to gain initial insights on the general market structure and the level of competition in the MIBEL wholesale electricity market.

3.1 Market Structure

The MIBEL Zone wholesale electricity market is the result from the integration of the Portuguese and Spanish electricity market. This integration significantly contributed to the ongoing efforts to create an internal energy market at the European level [39]. The consolidation of the Portuguese and Spanish market initiated in 1998, and is a still ongoing process [39].

Fig. 3.1 provides information on the total installed capacities per generation technology consolidated for the entire Iberian market. It provides information on the installed capacities, as well as the respective market shares of the largest energy producers, being Iberdrola, EDP, and Endesa. It has to be noted that the market shares, as well as the specific energy technologies present in each of the generation portfolios of these generators, might have a significant impact on their potential to exercise market power. Fortunately, this is taken into account by the RWC Index.

Furthermore, it is crucial for the reader to understand that the MIBEL day-ahead wholesale electricity market is organized as a uniform price auction. This implies that all generators receive the same price, regardless of their true marginal costs and price bids. As already mentioned in Chapter 2, these uniform price auctions make market power abuse more likely, although other forms of price auctions cannot exclude strategic behaviour of generators either [8, 19, 14]. As the RWC methodology relies on the concept of uniform price auctions and utilizes the installed capacities of each generator, it was essential to examine and specify this. However, in order to perform an accurate and thorough market analysis, other information on market structure (such as transmission related information) is required. Nonetheless, this is not considered by the RWC Index[1] and it was therefore not deemed necessary to go further into detail in this chapter with regards to the Iberian market structure. More information can be extracted from the websites from MIBEL or National Commission of Markets and Competition (Comisión Nacional de los Mercados y la Competencia, CNMC), as well as from the national transmission system operators such as Rede Eléctrica Nacional for Portugal and Red Eléctrica for Spain.

Table 3.1: Installed Capacities Iberian Market 2022. Source: [40, 41, 42, 43].

Generation Type	**Total Installed**	**Iberdrola**		**EDP**		**Endesa**	
	[MW]	[MW]	[%]	[MW]	[%]	[MW]	[%]
Biomass	1,383						
Fossil Gas	34,447	5,695	16.53%	2,885	8.38%	5,445	15.81%
Fossil Hard coal	4,642			1,820	39.21%	1,644	35.42%
Fossil Oil	669						
Oil and Gas[a]	36,499					2,333	6.39%
Hydro							
Pumped Storage	8,522						
Run-of-River and Poundage	4,011	255	6.36%	57	1.42%		
Water Reservoir	20,702						
Water Reservoir + Pumped storage[b]	29,224	10,700	36.61%	5,470	18.72%		
Total Hydro[c]	33,235					4,746	14.28%
Nuclear	7,117	3,177	44.64%			3,328	46.76%
Renewables							
Solar	15,672	2,698	17.22%	136	0.87%	1,665	10.62%
Wind Offshore	25						
Wind Onshore	33,063	6,301	19.06%	3,314	10.02%	2,882	8.72%
Other renewable	272	19	6.99%				
Other and Waste	711	347	48.80%	23	3.23%		
Total Capacity	131,236	29,013	22.24%	13,682	10.43%	22,043	16.80%

[a] Note that Endesa only mentions oil and gas generation as one single division. For this purpose, their total installed capacity of 2,333 MW has been taken as a percentage of the total installed capacity of biomass, fossil gas and fossil oil. To calculate running capacities, this market share has been used appropriately. Similar approaches have been applied further. [b] Iberdrola and EDP only make a distinction between small hydro and big hydro. [c] Endesa only publishes numbers on total installed hydro capacity.

[1] This is also mentioned in Chapter 9 on the limitations and future work of the RWC Index.

3.2 Level of Competition

Information on the level of Competition in the MIBEL Zone is mainly provided by the CNMC. The CNMC is a competition regulator that promotes and sustains the proper functioning of all Spanish markets for the benefit of consumers and businesses [44]. They monitor and publish yearly reports on the functioning of the different electricity markets and on the evolution of the level of competition in the Iberian market. The CNMC provides information such as market shares, installed capacities, technical restriction resolutions, and their evolution over time. However, no in-depth analyses such as market power indexes or market simulation tools are provided, except for the calculation of market shares and the HHI Index. 3.1 provides an overview of the evolution of the market shares and the HHI Index between 2008 and 2021 in the MIBEL wholesale day-ahead electricity market. As can be observed, the three largest generators in the market have a market share of 53% in 2021, while the five largest generators have a combined market share of 67%. As mentioned in Chapter 2, this coincides with a combined concentration ratio (CR3) above 50% and a combined concentration ratio (CR5) above 66.7%. Hence, the market can be considered as concentrated. Fortunately, as can be observed, the HHI Index has been decreasing gradually since 2014 from 1,445, to 1,144 points in 2021 which implies that the level of market concentration has significantly decreased over the last few years. As can be observed in 2.4 in Section 2.8.2, the MIBEL day-ahead electricity market between 2014 and 2021 evolved from a lower degree of monopoly type 1 market to a market with a lower degree of monopoly of type 2. The HHI Index, and thus the level of competition should further decrease below 1,000 points to be classified as a competitive market of type 1. However, a strongly competitive market of type 2, with a HHI Index below 500 points is still far ahead from the current situation.

Besides the yearly reports published by the CNMC, there is a lack of additional publicly available information. Research into market power potential in the Iberian market has been scarce and more advanced indexes and tools than the HHI Index have not been widely examined. For this purpose, this project attempts to contribute something to the scarce literature.

YEAR	ENDESA	IBERDROLA	EDP	NTGY	VIESGO	AXPO	ACCIONA	REPSOL	ENERGYA VM	WIND TO MARKET	NEXUS	CEPSA	OTHERS	HHI
2008	27%	22%	13%	16%	1%	4%	3%	0%	1%	1%	1%	2%	9%	1,484
2009	20%	23%	13%	11%	4%	7%	3%	0%	2%	2%	1%	2%	11%	1,176
2010	19%	24%	12%	9%	3%	8%	5%	0%	2%	2%	2%	2%	11%	1,255
2011	23%	21%	12%	7%	2%	9%	5%	0%	3%	2%	2%	3%	11%	1,251
2012	23%	18%	16%	8%	2%	9%	5%	0%	3%	2%	2%	2%	9%	1,236
2013	21%	19%	20%	7%	1%	8%	6%	0%	3%	3%	2%	2%	7%	1,407
2014	22%	21%	20%	6%	1%	7%	5%	1%	2%	3%	2%	2%	7%	1,445
2015	22%	18%	19%	8%	2%	7%	5%	1%	2%	3%	2%	2%	8%	1,384
2016	19%	21%	19%	7%	2%	8%	5%	1%	3%	3%	2%	2%	8%	1,337
2017	23%	17%	18%	6%	3%	8%	6%	1%	3%	2%	2%	3%	9%	1,306
2018	20%	19%	20%	6%	3%	6%	6%	1%	3%	3%	2%	2%	9%	1,314
2019	17%	19%	19%	6%	0%	8%	5%	5%	3%	2%	2%	3%	11%	1,190
2020	16%	20%	18%	6%	0%	8%	5%	4%	3%	2%	3%	3%	11%	1,190
2021	16%	20%	17%	6%	0%	8%	5%	3%	3%	3%	3%	3%	14%	1,144

Figure 3.1: Market Shares and HHI in the MIBEL area for the day-ahead wholesale market. Source: [45].

3.3 Market Power Abuse Cases in the MIBEL Zone

Before applying the RWC Index to the Iberian wholesale electricity market, it is interesting to look whether there have been cases in the past in which market players have been suspected or even penalized by market authorities because of illegal market power practices. As already mentioned, detecting and providing evidence on the exercise of market power is extremely difficult. For this reason, it is not surprising that cases of market power conviction are very scarce. In 2015, Iberdrola was the first company being fined by the Spanish authority for market manipulation since the REMIT legislation (Regulation on Wholesale Energy Market Integrity and Transparency) came into force in 2011 [46]. The REMIT is a regulatory framework that was introduced in order to promote fair competition in the European energy markets [47]. The CNMC fined Iberdrola €25 million for artificially raising prices by reducing output of some of its hydroelectric plants between November 30 and December 23, 2013 [40]. The CNMC estimated that these actions caused an increase of €7/MWh in market prices, creating a benefit of €21.5 million for Iberdrola during that period [40]. Such strategic behaviour is prohibited by REMIT and hence provided a legal ground for the CNMC to convict and fine Iberdrola. At that time, this was the first national regulatory authority fining a company for market manipulation since the REMIT came into effect [46]. Consequently, it will be interesting to observe whether the RWC Index results indicate whether Iberdrola today still experiences incentives to withhold capacity from the market. Up to now, this remains the only case of market power abuse conviction in the Iberian market since the REMIT legislation came into place.[2]

[2]Note that there have been other convictions within the Iberian market for market players abusing their dominant position and restricting competition in the market. One example of this is the 48€ million fine for EDP in 2019 for manipulating allegedly second reserve services between 2009 and 2013 [48]. However, none of them were related to withholding capacity from the day-ahead wholesale electricity market.

Chapter 4

RWC Methodology

4.1 Overview

Fig. 4.1 below explains the main building blocks of the RWC methodology. This overview will support the reader to better understand each of the sections below that will explain each of the building blocks of the RWC methodology more in detail.

The RWC Index attempts to estimate the incentive of electricty generators to withdraw capacity from the day-ahead wholesale electricity market [31]. To do so, the expected gains and costs of capacity withholding have to be inspected. The costs represent the lost profit margins made on the electricty units that are not being generated. The gains represent the extra monetary benefits made from the price increase caused by withholding part of the capacity [31]. This price increase is being estimated as part of the RWC Methodology. Next, as the power plant portfolio has a profound impact on the ability to exercise market power, it is very advantageous that the RWC Index does take this into account, unlike many other indexes [31].

The methodology starts by estimating the relationship between (residual) demand, commodity prices (coal, natural gas, and CO_2 certificates) and the day-ahead wholesale electricty price. This is done by means of an Ordinary Least Squares (OLS) regression. Based on these regression results, the estimated price change in the wholesale electricty market can be calculated if one MW of capacity is withheld from the market. In a next step, the running capacity of the dominant market players for every hour during a certain period is calculated. Next, using the expected price change and the running capacity for each hour, the RWC Index can be calculated for each dominant market player separately, for every hour in a certain period. Based on the RWC Index values for each generator, it can be concluded if one of the generators has significant incentives to withhold capacity during certain periods. Based on that, a general conclusion on the level of market power and competition in the wholesale electricity market can be drawn.

Last but not least, another strength of the RWC Index is that in most developed wholesale electricity markets, it can be calculated solely based on publicly available data. Although several good indexes were mentioned in Chapter 2, many require a significant amount of data that is very often not publicly available, hence making the calculation of the index virtually impossible. The data requirements for the RWC Index and the procedures to obtain them will be discussed below.

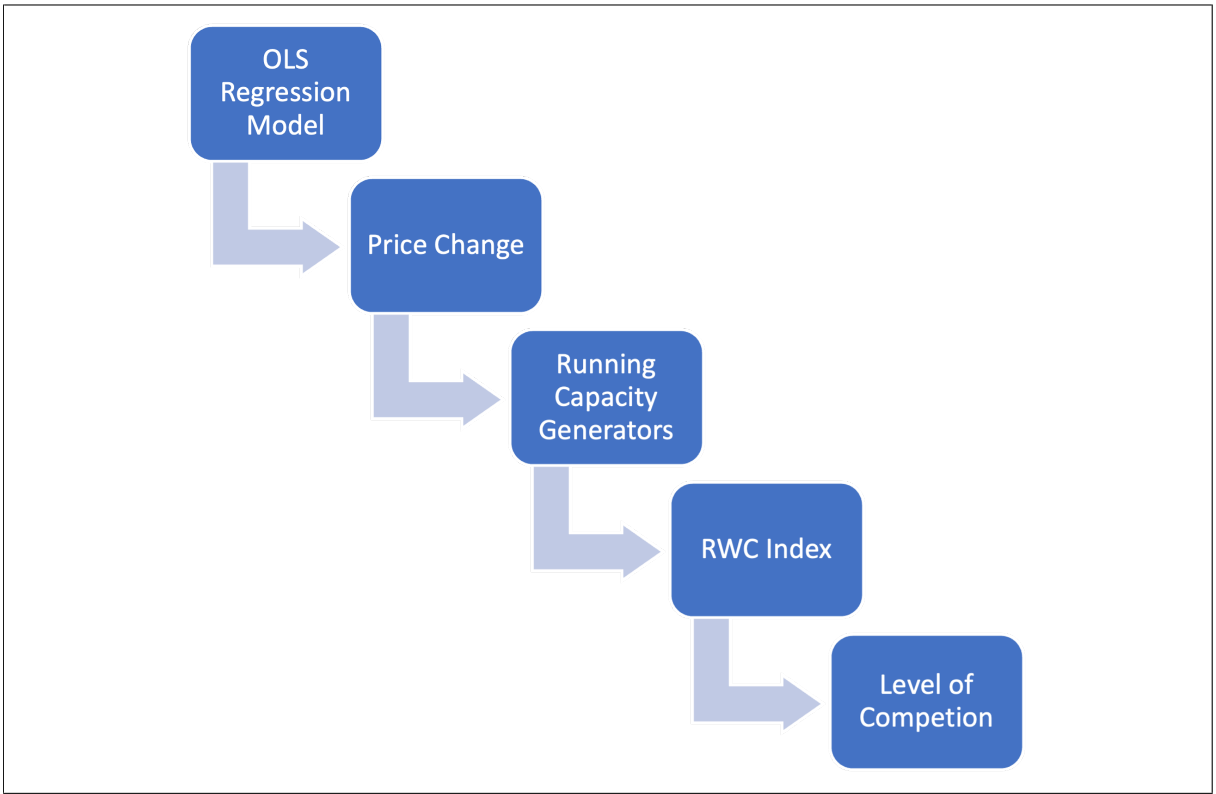


Figure 4.1: RWC Methodology

4.2 OLS Regression Model

The principle idea behind market power abuse is that by withholding capacity from the day-ahead wholesale electricity market, market prices will rise which generates additional profits for electricity generators. In order to assess this market power potential, it is important to be able to estimate how the wholesale electricity price responds when generation is withheld. Additionally, it is also good practice to understand how the prices relate to prices of energy commodities such as coal, natural gas, and CO_2 certificates. For this purpose, the first step is to estimate the following OLS model [31]:[1]

$$P_t = \beta_0 + \beta_1 \cdot ResL_t + \beta_2 \cdot {ResL_t}^2 + \beta_3 \cdot {ResL_t}^3 + P_{coal,t} + P_{gas,t} + P_{CO_2,t} + \epsilon_t \tag{4.1}$$

P_t and $ResL_t$ being the day-ahead market price and the (day-ahead) residual load, respectively. The residual load is the total load minus generation from inflexible energy resources, being volatile renewables [31]. Volatile renewables such as wind and solar energy produce nearly at zero marginal costs and production is typically subsidized (e.g. by feed-in tariffs) in many countries. For this reason, it is assumed that these units will produce regardless of the market price, hence they are not price-responsive. Consequently, they are typically categorized as a separate market by cartel officials [31]. Therefore, in the RWC methodology it is assumed that in order to estimate wholesale prices, the residual load is a better predictor than the total load, as it eliminates the volatile renewables. Conventional and other flexible (renewable) power plants will compete for the residual load, which in turn will affect the day-ahead price. Other authors such as [8, 49, 50] also use this concept of residual demand for either market power analysis or electricity price forecasts.

In this analysis, the day-ahead residual load is taken as the day-ahead total load minus volatile resources such as wind, solar and run-of-river generation. For solar and wind, not the actual generation but the day-ahead forecast is used. Although the difference between day-ahead and actual generation from renewables is rather small, it is considered to be more accurate to utilize day-ahead forecasts as the investigation is on the day-ahead wholesale electricity market. For run-of-river data, there is no day-ahead forecast available. For this reason, the actual generation has been used. As day-ahead forecasts and actual generation should not differ much, this should not pose any issue.

Next, $P_{coal,t}$, $P_{gas,t}$, and $P_{CO_2,t}$ are control variables and represent the energy prices for coal, natural gas and CO_2 certificates. They are used to control for supply shocks which might have an effect on the supply curve [31]. In this study, Eq. 4.1 will be estimated with and without the control variables to investigate if fundamental differences are present between the two models. The model will be programmed in RStudio.

[1] The properties of the Ordinary Least Squares Estimator will be explained below in Section 4.2.2.

4.2.1 OLS Data and Control Variables

In order to perform the OLS estimations to estimate the impact of one MW withdrawal of generation capacity on the day-ahead prices, it is crucial to collect accurate data. Table 4.1 summarizes all data that has been gathered, analyzed, processed and subsequently applied to the OLS regression model. This section describes the characteristics of the data and the sources used to extract the data.

The selected period is crucial for the estimation results of the OLS model. The period has to be at least several months to capture factors such as seasonal variations [31]. On the other hand, a period that is too long might be inappropriate as structural changes in the market (might be regulatory changes, but as well newly operating or dismantled generation units) might weaken the relationship between residual load and day-ahead prices [31]. On the other hand, longer periods result in larger data samples which in turn results in higher precision of the OLS estimates and more robust statistical inference.

Table 4.1: Summary Descriptive Statistics

Variable	Mean	Median	Std. Dev.	Min.	Max.
Day-Ahead Price (€/MWh)	167.65	163.58	69.32	0.00	693.03
Load (MW)	32,713.24	32,953.38	5,145.99	20,064.75	45,962.00
Solar (MW)	3,868.19	612.88	4,770.28	0.00	15,104.00
Onshore Wind (MW)	8,241.36	7,498.75	4,410.28	623.00	23,825.75
Offshore Wind (MW)	8.39	6.00	7.59	0.00	24.00
Run-of-river (MW)	1,227.22	1,038.50	689.32	298.00	3,592.00
Residual Demand (MW)	19,368.08	19,555.63	6,097.17	-2,271.00	40,354.00
Control Variables					
EU ETS Certificates (EUR/tCO_2)	80.35	80.76	7.55	57.91	97.51
Dutch TTF [EUR/MWh]	106.51	86.73	54.59	33.80	306.87
MIBGAS AVB Index [EUR/MWh]	75.61	77.00	39.96	30.50	154.00
MIBGAS Index [EUR/MWh]	98.88	90.81	36.65	25.59	225.03
MIBGAS LNG Index [EUR/MWh]	99.57	91.13	37.20	26.22	244.43
Daily Reference Price [EUR/MWh]	100.03	91.22	37.35	24.41	241.36
Daily Auction Price [EUR/MWh]	102.75	93.00	39.36	29.00	299.00
EOD Price [EUR/MWh]	99.16	91.52	36.27	27.78	240.00
API 2 [USD/mt]	289.39	319.00	74.03	135.00	438.35

Day-ahead prices, load, and other generation data of the Iberian Market was extracted from the ENTSO-E Transparency Platform[2] which is a publicly available source. This data was used to calculate the residual demand, as was explained before.

Data on EU Emissions Trading System (ETS) Certificates was taken from the European Energy Exchange AG (EEX). The data used is from the Primary Market Auction from the EEX Emissions Market.[3] The units are Euro per ton of CO_2 emitted. Next, seven different gas indexes were gathered. As generators have different trading strategies and thus therefore purchase gas differently with different risk profiles and terms, it is hard to estimate which gas index will have

[2]https://transparency.entsoe.eu/.

[3]The EEX is a European Energy Exchange platform for several energy commodities. More information can be found on https://www.eex.com/en/.

the most profound impact on the price. For this reason several indexes were used to compare results. All of the indexes are expressed in Euro per MWh.

Most of the indexes are defined by MIBGAS (also known as Iberian Gas Market or the Mercado Ibérico del Gas) which is the gas market operator of Spain and Portugal. As gas markets are more regionally organized, these indexes are assumed to be the most representative for the Iberian market and are expected to have the most profound impact on the biddings of gas-based power plants, and thus on day-ahead electricity prices. MIBGAS defines the following indexes: the MIBGAS AVB Index, MIBGAS Index, MIBGAS LNG Index, Daily Reference Price, Daily Auction Price, and the End of Day (EOD) Price. The MIBGAS AVB Index is the average weighted price of all products traded for delivery on the same gas day. This happens at the AVB (Almacenamiento Virtual de Balance). Next, the MIBGAS Index is the average weighted price of all transactions of all products that are delivered on the same gas day at the PVB (Punto Virtual de Balance). The MIBGAS LNG Index is the average weighted price of all products traded for delivery on the same gas day. This happens at the TVB (Tanque Virtual de Balance). Next, the Daily Reference Price is the weighted average of all transactions for a specific product, the product being natural gas with delivery on the next day. Likewise, the Daily Auction Price is the auction matching price for the same product. Finally, the EOD Price is the gas price based on an internal calculation by MIBGAS based on the trading session outcomes [51]. Besides the MIBGAS indexes, another index being the renowned Dutch TTF Natural Gas Future was taken as another control variable. This data was extracted from Intercontinental Exchange Inc.[4] This index represents contracts for physical delivery on the first day of the next month [52].

Besides several gas indexes, the API 2 Rotterdam Index was used a coal index. This index is one of the main benchmark price references for coal being imported into Northwest Europe [53]. The units are US Dollars per metric ton (USD/mt).

As a last step, all data on (day-ahead) prices, generation, and the control variables, was merged together into one overall time series data set (8,760 observations) for the MIBEL zone (Spain and Portugal) wholesale electricity market, for the entire year 2022.

[4]https://www.theice.com/products/27996665/Dutch-TTF-Gas-Futures/data?marketId=5577209.

4.2.2 OLS Estimator and Regression Model

As in [31], an OLS regression model is used to estimate Eq. 4.1. The OLS regression method is one of the most commonly used linear[5] estimators in multivariate regression analysis to investigate the relation between a dependent variable (typically denoted as Y) and one or multiple independent variables (typically denoted as X_i).

The OLS method estimates coefficients $\hat{\beta}_i$ to estimate the true unknown coefficients β_i in such a way that the sum of the squared differences between the estimated values ($\hat{Y}_i$) obtained by the OLS method and the actual values (Y_i) is minimized [54]. This can be summarized by the following equation:

$$\sum \hat{u}_i^2 = \sum (Y_i - \hat{Y}_i)^2 = \sum (Y_i - \sum (\hat{\beta}_i \cdot X_i))^2 \tag{4.2}$$

Here $\hat{u}_i^2$ represent the squared residuals which is equal to the difference between the actual value Y_i and the estimated OLS value $\hat{Y}_i$. Next, $\hat{Y}_i$ is estimated by estimating the coefficients $\hat{\beta}_i$. By minimizing Eq. 4.2, the desired coefficients $\hat{\beta}_i$ are obtained.

The OLS estimator is chosen here as it is the best linear unbiased estimator if the assumptions of the classical linear regression model hold [54].[6] The properties of the OLS estimator under these assumptions are also called the Gauss–Markov theorem [54]. Unbiased implies that the expected value of the estimated coefficient $\hat{\beta}_i$ is equal to the true coefficient β_i. It is called the "best" estimator as the estimated coefficient $\hat{\beta}_i$ has the lowest variance within the class of all linear unbiased estimators [54]. This implies that the estimated coefficients from the OLS estimator are on average closer to the true value.

The estimation model (such as the one in Eq. 4.1) should reflect the underlying market structure and its associated supply function. As in [31], a cubic shape has been depicted as the appropriate model. This is because of the different generation technologies that are present in the Iberian wholesale market. Large price spikes can be expected in both the lower (baseload) and higher (peak) end of the residual demand. This is because base load plants are rather inflexible, and thus will only adjust generation for large price changes [31]. Similarly, peak load demand is typically met by flexible units that have high marginal costs and short operating times, hence these units will only generate if they get properly remunerated for it. Consequently, higher price jumps are expected during baseload and peak periods while medium loads are characterized by lower price spikes [31]. As the Iberian market represents such as mix of different generation technologies, a cubic shape of the supply curve in the Iberian market is deemed appropriately.

Fig. 4.2 below depicts the relationship between the residual load and day-ahead prices for the Iberian wholesale electricity market. The figure highlights a clear positive relationship between the two variables. However, it is not very clear whether a cubic relationship is more appropriate to describe the relationship rather than a linear relationship. Hence, for this reason, a linear in

[5]Note that there are two forms of linearity. You have linearity in the parameters and linearity in the variables [54]. The OLS estimator is only valid under linearity in the parameters. It does not require the regression model to be linear in the variables. Eq. 4.1 is a linear regression model in the parameters (but not in the variables), hence the OLS method can be utilized.

[6]See [54] for more information on the classical linear regression model.

the variables OLS regression model will also be estimated. In this model the same variables are used but the square and cube term are eliminated.

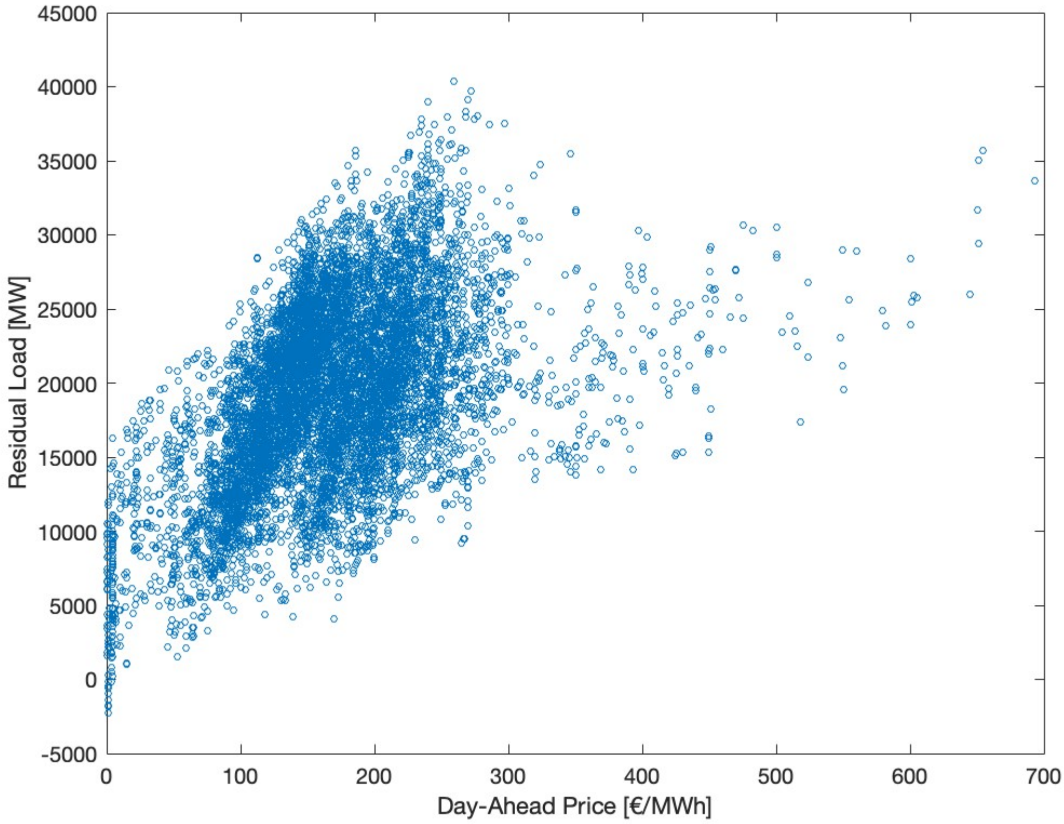


Figure 4.2: Relation Residual Demand and Day-Ahead Price Iberian Market (2022).

4.2.3 Unit-Root Tests

Unit root tests are used to test for the order of integration of all variables. A variable is called non-stationary or is said to contain a *unit root* when it is integrated of order one, I(1), or more. A non-stationary time series is characterized by a time changing unconditional distribution, in other words, the moments from the distribution of the variable, such as the mean and variance, shift over time. When non-stationary variables are included in a regression, the error term will adopt this non-stationary behavior. Non-stationary error terms in turn affect the properties of the OLS estimator, as some of its assumptions (from the classical linear regression model) are not satisfied anymore. OLS estimators will no longer be normally distributed, not even asymptotically, given that the asymptotic theory from which the distribution of estimators is derived, does not hold for non-stationary series. OLS estimations will no longer be consistent[7], and standard inference will be impossible. For this reason, stationarity must be induced in the variables. There is one exception to this scenario, which is when the non-stationary variables exhibit a common stochastic trend, which is referred to as a *cointegration relationship* between them. If the time series unit root tests provide evidence of the presence of non-stationary variables in the data, the concept of cointegration must be tested in a next step [54].

Two types of non-stationarity can be distinguished: *deterministic non-stationarity* and *stochastic non-stationarity*, both of which can be present in one time series[8]. The difference between the two is that in deterministic non-stationary time series, stochastic shocks have only transient effects, while in stochastic non-stationary time series, stochastic shocks will have a permanent impact on the series. Deterministic non-stationarity typically occurs when a linear trend is present in the series. Both types require different measures to achieve stationarity; deterministic non-stationary variables become stationary after trend removal, whereas stochastic non-stationary variables become stationary after a first-difference transformation [54].

In order to test the presence of unit-roots in our data, *Augmented Dicky Fuller* (*ADF*) tests developed by Dicky and Fuller will be performed. In contrast to the Dickey Fuller test, the ADF test additionally includes the possibility that the error terms might be correlated. This is taken into account by adding the lagged values of the dependent variable ΔY_t [54]. The amount of lagged values can be determined by an information criterion.[9] This work will make use of the Akaike Information Criterion.[10] The null hypothesis of the ADF test supposes the presence of a unit root in the data. If enough proof in the data, the null hypothesis will be rejected and it can be concluded that there is no unit root in the data. The ADF test estimates the following regression [54]:

$$\Delta Y_t = \beta_1 + \beta_2 \cdot t + \delta \cdot Y_{t-1} + \sum_{i=1}^{m} \alpha \cdot \Delta Y_{t-i} + \epsilon_t \tag{4.3}$$

[7]Consistency implies that as the sample size increases, the estimated coefficients converge to their true population values [54]. Very often it occurs that not all assumptions of the classical linear regression model are satisfied. This could make the OLS estimates biased. However, in various cases, even under these circumstances the estimator remains consistent implying that as soon as the sample size is large enough, the OLS estimates can be assumed accurate with a very slim bias.

[8]A time series is a data sample of a variable over a specific time period.

[9]Information criteria are used to select and compare different statistical models.

[10]See [54] for more information on the Akaike Information Criterion.

where Y_t is the variable to be tested for the unit root, ΔY_{t-1} is equal to $Y_{t-1} - Y_{t-2}$., and ϵ_t is a *pure white noise error term*. In this estimation formulation, Y_t is modeled as a *random walk* with drift around a deterministic trend. The drift term is represented by β_1 and the deterministic trend by $\beta_2 \cdot t$ [54]. The null hypothesis corresponds with the assumption that $\delta = 0$. If that were the case, there is a unit root present in the time series. The alternative hypothesis assumes that $\delta < 0$. In that case, the presence of a unit root can be rejected and the data can be assumed to be stationary, possibly with a deterministic trend included [54]. The ADF test uses the same asymptotic distribution as the *Dicky Fully statistic*, with is called the *τ statistic* [54]. The exact procedure of the ADF test is thoroughly explained in [54]. Note that also other unit root tests could be used to test for the presence of unit roots. Another popular unit root test is the *Phillips–Perron (PP) Unit Root Test*.

4.3 Expected Price Change

To estimate the price change from withholding one unit of generation capacity, the first derivative of Eq. 4.1 has to be taken with respect to the residual load [31]. The first derivative can be calculated as:

$$\frac{\delta P_t}{\delta ResL_t} = \beta_1 + 2 \cdot \beta_2 \cdot ResL_t + 3 \cdot \beta_3 \cdot ResL_t^2 \approx \Delta P \tag{4.4}$$

This first derivative will be used as an approximation of the price change that can be expected in the day-ahead market if one unit is to be withdrawn from the day-ahead market. In the next step, this expected price increase will be used along with the running capacities of each generator to calculate the RWC Index.

4.4 Running Capacity

As a next step, the running capacities of the dominant generators in the Iberian Market have to be calculated. As depicted before, the dominant players in the Iberian market are Iberdrola, EDP, and Endesa. In general, companies do not publish production data on an hourly basis but rather quarterly or yearly operational performances. This makes this part of the RWC Index calculation especially challenging. However, it is possible to approximate the running capacities from publicly available data. The same procedure as [31] is applied. Namely, by using generators market shares for each specific generation technology as companies generally publish installed capacities per technology.

Installed capacities for the entire Iberian market and for the three main generators are depicted in Table 4.2. Data for the total market was taken from the ENTSO-E platform, while company specific data was taken from their respective company specific websites and annual reports [40, 41, 42, 43]. Next, hourly production data for each generation technology is available on the ENTSO-E platform for the entire year. By multiplying each generators market share per type of energy technology by the total hourly running capacity for that specific generation technology, the running capacity of each generator can be derived. As pointed out by [31], marginal costs for similar generation technologies are very similar, hence the running capacities can be estimated approximately in this manner. Based on this, the hourly running capacities for Iberdrola, EDP and Endesa were determined for 2022.

Table 4.2: Installed Capacities Iberian Market 2022. Source: [40, 41, 42, 43].

Generation Type	Total Installed	Iberdrola		EDP		Endesa	
	[MW]	[MW]	[%]	[MW]	[%]	[MW]	[%]
Biomass	1,383						
Fossil Gas	34,447	5,695	16.53%	2,885	8.38%	5,445	15.81%
Fossil Hard coal	4,642			1,820	39.21%	1,644	35.42%
Fossil Oil	669						
Oil and Gas[a]	36,499					2,333	6.39%
Hydro							
Pumped Storage	8,522						
Run-of-River and Poundage	4,011	255	6.36%	57	1.42%		
Water Reservoir	20,702						
Water Reservoir + Pumped storage[b]	29,224	10,700	36.61%	5,470	18.72%		
Total Hydro[c]	33,235					4,746	14.28%
Nuclear	7,117	3,177	44.64%			3,328	46.76%
Renewables							
Solar	15,672	2,698	17.22%	136	0.87%	1,665	10.62%
Wind Offshore	25						
Wind Onshore	33,063	6,301	19.06%	3,314	10.02%	2,882	8.72%
Other renewable	272	19	6.99%				
Other and Waste	711	347	48.80%	23	3.23%		
Total Capacity	131,236	29,013	22.24%	13,682	10.43%	22,043	16.80%

[a]Note that Endesa only mentions oil and gas generation as one single division. For this purpose, their total installed capacity of 2,333 MW has been taken as a percentage of the total installed capacity of biomass, fossil gas and fossil oil. To calculate running capacities, this market share has been used appropriately. Similar approaches have been applied further.[b] Iberdrola and EDP only make a distinction between small hydro and big hydro. [c] Endesa only publishes numbers on total installed hydro capacity.

4.5 RWC Calculation

As defined by [31], the RWC Index is defined as:

$$RWC_{i,t} = \frac{\Delta P_t \cdot (RunningCapacity_{i,t} - 1)}{P_t} \tag{4.5}$$

With $RunningCapacity_{i,t}$ being the running capacity of firm i at time t, ΔP_t being the expected price increase at time t if one MW is withheld from the market, and P_t being the market price at time t. By calculating this index for every hour of the investigation period, an index is calculated for company i at every hour t. The level of the RWC Index during the investigation period gives insights if, and to what extent, generator i had incentives to withhold capacity from the market or not.

The interpretation of the RWC Index is as follows: if the RWC Index is higher or equal to 1, generator i has a powerful incentive to withhold capacity from the market because the costs (being the lost profit margin) are always lower then the potential gains (being the extra monetary benefits made from the price increase) [31]. However, if the RWC Index is smaller than 1, it is difficult to conclude anything as the incentive depends on the profit margins (which are unknown) being made by the generating units [31]. However, the RWC Index can still provide insights in the relative likelihood of withholding capacity by for instance comparing over time, between firms, or between markets [31]. In the next chapter the RWC Index will be calculated for the above-mentioned three dominant firms in the Iberian wholesale market and the results will be discussed accordingly.

Chapter 5

Results

This chapter commences by discussing the attained results from the baseline model (i.e. the OLS regression model without the control variables) which estimates the effect of a one MW withdrawal in generation capacity on the day-ahead wholesale electricity market in the MIBEL zone. Next, the chapter proceeds by adding control variables to the OLS regression model to investigate if and by how much the estimated coefficients change. Based on outputs from both regression models, the most appropriate OLS regression model will be utilized for further investigation and calculation of the RWC Index.

As discussed in Chapter 4, before executing the OLS regressions, ADF tests are executed to test the presence of unit roots in the data. ADF tests with both a drift and trend term are performed. Table 5.1 provides the F-Statistic and the associated p-value for each of the variables used in the regressions. The p-value is the probability to obtain an F-test statistic that is as extreme or more then the one obtained from the data (i.e. the one that is obtained), assuming the null hypothesis is true.

For all variables, the null hypothesis of unit roots can be rejected at the 10% level of significance or lower, except for the variables Dutch TTF (drift & trend), MIBGAS AVB Index (drift & trend), and MIBGAS Index (trend). To address this issue, a transformation was performed on the variables Dutch TTF and MIBGAS AVB Index. This transformation was done by taking the first differences (FD) of each of these two variables. This was not done for the variable MIBGAS Index as the probability of a type I error[1] was assumed to be low enough with a p-value of 0.1382. Table 5.1 also provides the results from the ADF tests for the first differences transformed variables. For both transformed variables, the null hypothesis of unit roots can be strongly rejected. Now that all variables are investigated, and/or transformed to remove the presence of unit roots, the OLS regression model can be performed in the next section.

[1]A type I error is an error that occurs upon falsely rejecting the null hypothesis, while it is correct.

Table 5.1: Augmented Dicky Fuller Tests: Drift and Trend

	Drift Term		**Trend Term**	
	F-Statistic	**P-Value**	**F-Statistic**	**P-Value**
Day-Ahead Price (€/MWh)	73.842***	<0.001	731.8***	<0.001
Residual Demand (MW)	7,426***	<0.001	4,982***	<0.001
EU ETS Certificates (€/tCO2)	3.525**	0.0295	2.533*	0.0552
Dutch TTF [€/MWh]	1.145	0.3183	0.7873	0.5008
Dutch TTF FD [€/MWh]	65.82***	<0.001	44.080***	<0.001
MIBGAS AVB Index [€/MWh]	1.495	0.2242	1.122	0.3390
MIBGAS AVB Index [€/MWh] FD	98.74***	<0.001	65.910***	<0.001
MIBGAS Index [€/MWh]	2.316*	0.0987	1.836	0.1382
MIBGAS LNG Index [€/MWh]	3.078**	0.0461	2.230*	0.0825
Daily Reference Price [€/MWh]	3.688**	0.0251	2.664**	0.0463
Daily Auction Price [€/MWh]	5.455***	0.0043	4.674***	0.0094
EOD Price [€/MWh]	4.674***	0.0094	3.274**	0.0202
API 2 [USD/mt]	3.168**	0.0421	3.796*	0.0720

Note: The F-test tests the null hypothesis of having the presence of a unit root. *, ** and *** signify significance levels at the 10%, 5% and 1% level, respectively.

5.1 Baseline OLS Regression Results

This section describes the obtained results from the baseline OLS regression model. Different regressions have been executed in order to obtain the most appropriate and standardized model.[2] Each of the executed regressions are presented and explained below.

Table 5.2 below displays the results of the different regressions that have been performed in this section. First, the OLS model (see Eq. 4.1) has been estimated without including any control variables. This is because the RWC Index only requires the coefficients of the residual load $ResL_t$ variable, hence it makes the calculation easier. It is true that this will result in a lower (adjusted) R-Squared[3] R^2 of the model but this is not of interest for the RWC Index calculation. However, this approach might lead to an omitted variable bias which might bias the estimated coefficients [56]. Later, this model will be compared with the model where control variables are included.

Results of the full sample are in line with [31] with a negative constant, positive coefficients for $ResL_t$ and $ResL_t{}^3$, and a negative coefficient for $ResL_t{}^2$. All of the coefficients are statistically significant[4] at the 1% significance level. Note that the coefficients of $ResL_t{}^2$ and $ResL_t{}^3$ are very small but are nonetheless important. This can depicted from Eq. 4.4 in Chapter 4 as the coefficient of $ResL_t{}^2$ is being multiplied by the residual demand level and the coefficient of

[2] A standardized model can support and promote the application of this methodology as a tool to monitor markets and market power manipulation.

[3] The R-squared measures how well the selected model fits the data. It measures the percentage of variance in the dependent variable (P_t in this case) that can be explained by the variance in the explanatory variables [55]. However, R-Squared values increase upon adding more variables in the model. For this reason, the adjusted R-Squared value will be used which penalizes overfitting the model with too many explanatory variables [55]. By using the adjusted R-Squared values, it is more appropriate to compare models with different amounts of explanatory variables.

[4] This implies that they are statistically significantly different from 0.

$ResL_t{}^3$ by the square of the residual demand level.[5] Based on the full sample, withdrawing one MW of capacity from the day-ahead market, on average, increases the price with 0.5599 Eurocents. Considering that Iberdrola and Endesa have a total installed capacity in the Iberian market of 29,013 MW and 22,043 MW, respectively, this price increase cannot be neglected.

Next, a distinction was made between peak and off-peak hours. As market power abuse is most likely during peak hours, as was discussed in Chapter 2, it could be interesting to depict the differences in estimated coefficients. During peak hours, demand intersects with the upper steeper part of the supply curve, hence making market power abuse more likely during those moments.

The specific peak hours were chosen in line with Endesa [57] which defines peak hours as hours between 10-14pm, and 18-22pm. Additionally, 8-10am and 22-24pm were also considered here as peak hours, which were defined as *"Mid-Peak Hours"* by Endesa [57]. The remainder of the hours were considered off-peak hours. Hence, the full sample is divided in two subsamples with each sample containing exactly 4,380 hours.

As earlier, ADF tests (trend and drift, Akaike's Information Criterion) were performed on the peak and off-peak sub-samples to test for unit roots, before executing the OLS regressions. The results can be found in Appendix A in Table **??**. As can be observed, the ADF Tests for each variable allow to strongly reject the null hypothesis of the presence of unit roots in the sub-samples at the 1% level of significance. This implies that each of the sub-samples can be used without any data transformation to estimate the model.

The OLS estimation results for each of the peak and off-peak hours can be observed in Table 5.2. In line with [31], both the peak and off-peak sub-samples provide a similar adjusted R^2, implying that the explanatory power of the residual load on the wholesale price is not very different between peak and off-peak hours. Wald Tests were performed to check whether there is any difference in the coefficients between the two models. Wald Tests can be used to examine whether there is a significant difference between the respective coefficients of each of the models. The Wald Test has as a null hypothesis that there is no significant difference between the coefficients of each of the explanatory variables. The alternative hypothesis is that the coefficients are different. Asymptotically, the test statistic of the Wald Test follows a *Chi-square distribution* [58].

In this case, the Wald Tests do not provide enough evidence to reject the null hypothesis for any of the coefficients, implying that it can be concluded that the coefficients of both models are the same. More specifically, when checking the difference between the two constants, the Wald Tests provide a p-value of 0.2942. For each of the coefficients of the residual load, p-values of 0.4359, 0.7370, and 0.7693 are obtained for $ResL_t$, $ResL_t{}^2$, and $ResL_t{}^3$, respectively. This implies that the null hypothesis for none of the coefficients can be rejected at the 10% significance level.

Last but not least, it is recognized that the data sample of year 2022 might have some structural changes due to the global energy crisis inflicted by the Russian invasion of Ukraine. As mentioned in Chapter 4, the investigation period has a fundamental impact on the results. Hence, it might be that the Russian-Ukrainian war inflicted a structural chance that attenuates the re-

[5] In Table 4.1, it can be observed that the average residual demand level in 2022 was 19,368.08 (MW). Taking the square of that gives 375,122,523 (MW^2).

lationship between price and residual load. For this purpose, the sample was divided in half, being the first 6 months (H1) and the last 6 months of 2022 (H2). Before the regressions were executed, similar ADF tests (trend and drift, Akaike's Information Criterion) for detecting the presence of unit roots were performed on each of the sub-samples. The results of the ADF tests can be found in Appendix A in Table **??**. As can be observed, all the ADF tests show no evidence for the presence of a unit root in the sub-samples and the null hypothesis of a unit root can be rejected for all sub-samples, for every variable in the baseline model. Next, each of the models were estimated. The results can again be found in Table 5.2. What strongly stands out is the large difference in explanatory power between H1 and H2, going from a modest 25.70% in H1 to a much higher explanatory power of 58.49% in H2. This implies that in the second half of 2022 the variation in residual demand explained the variation in day-ahead prices significantly better.[6] Note that in the H2 model, the square and cube term are not statistically significant anymore, implying that the relationship between prices and residual demand in H2 could be better described by a linear relationship.

In order to compare both H1 and H2 models and their estimated coefficients, a Wald Test was utilized again. The Wald Test provides strong evidence against the null hypothesis for all the explanatory variables, being $ResL_t$, ${ResL_t}^2$, and ${ResL_t}^3$ (i.e. with each of the p-values< 0.0001). Only the null hypothesis for the constant cannot be rejected (p-value = 0.931), implying that there is no statistical significant difference between the constants in both models. Based on this, it can be concluded that there is a significant difference in the estimated model between the first half and second half of the year. This might be a reason to alter the model (i.e. include variables to take into account factors such as cost shocks, seasonality, structural changes and so forth) or decide upon another investigation period. This highlights that the selected investigation period can have a strong impact on the estimated model and hence this should be further examined. For this purpose, a robustness check will be executed in Section 5.5 comparing results from the full 2022 sample with the H1 and H2 results.

Last but not least, a linear model (i.e. the square and the cube terms are omitted) was estimated to compare with the baseline model. The results can be observed in Table 5.2. Next, the coefficients of the linear model (i.e. the constant and the $ResL_t$ term) are compared with the coefficients of the full sample by means of a Wald Test to see whether there is any statistical significant difference. The Wald Tests for both coefficients provide evidence that the coefficients are significantly different at the 1% significance level (both p-values <0.0001). The results (the test statistic and associated p-values) of the Wald Tests can be observed in Table 5.3.

Furthermore, Wald Tests were performed to compare the full sample (FY) with each of the tested models (Peak & Off-Peak, H1 & H2, respectively). Table 5.3 below depicts the results of these Wald tests. Note that the test statistics and associated p-values in the table refer to the comparison between the coefficients of the full sample and each of the sub-samples. Based on these results, it can be observed that there is little to no difference between the FY and the peak, off-peak, and H1 models (except for the constant). However, as already discussed, the H2 model and linear model are clearly statistically different from the FY model. For this reason, it is extra interesting to examine the H2 model results in the robustness check in Section 5.5 below.

[6]Note, however, that this does not imply that the coefficients in H2 are more accurate. If both models have no unit roots (as the ADF Tests suggest), coefficients of both models are unbiased. The higher adjusted R^2 merely implies that variation in the explanatory variables (being the residual demand) explained the variation in day-ahead prices significantly better in H2. However, this does not tell anything about the accuracy of the coefficients of both models.

Table 5.2: Summary Baseline OLS Regression Results

Sample	Full	Peak	Off-Peak	First Half	Second Half	Linear
Constant	-24.6819***	-10.0084	-26.2154***	-3.2611	-4.2240	58.0780***
	(7.2100)	(12.1077)	(9.5974)	(9.6887)	(5.6060)	(2.1397)
$ResL_t$	0.0190***	0.0163***	0.0184***	0.0207***	0.0082***	0.00566***
	(0.0012)	(0.0020)	(0.0019)	(0.0016)	(0.0010)	(0.0001)
${ResL_t}^2$	<-0.0001***	<-0.0001***	<-0.0001***	<-0.0001***	<-0.0001	
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)	
${ResL_t}^3$	<0.0001***	<0.0001***	<0.0001**	<0.0001***	<-0.0001	
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)	
Observations	8,760	4,380	4,380	4,380	4,380	8,760
Adjusted R^2	0.2609	0.2530	0.2485	0.2570	0.5849	0.2475

Note: The standard errors are in parentheses. *, ** and *** signify significance levels at the 10%, 5% and 1% level, respectively.

Table 5.3: Wald Tests

	Peak Hours	Off-Peak Hours	First Half	Second Half	Linear Regression
Constant	1.0413	-0.1277	1.7736*	2.2399**	11.0031***
	(0.2977)	(0.8983)	(0.0761)	(0.0251)	(<0.0001)
$ResL_t$	-1.1822	-0.2667	0.8397	-6.6289***	-10.6704***
	(0.2371)	(0.7897)	(0.4011)	(<0.0001)	(<0.0001)
${ResL_t}^2$	1.2468	0.7071	-0.1069	6.2029***	
	(0.2124)	(0.4795)	(0.9148)	(<0.0001)	
${ResL_t}^3$	-1.1921	-1.2111	-0.7045	-5.4812***	
	(0.2332)	(0.2258)	(0.4811)	(<0.0001)	

Note: The p-values errors are in parentheses. *, ** and *** signify significance levels at the 10%, 5% and 1% level, respectively.

5.2 Extended OLS Regression Results

In this section, control variables will be added to our Baseline OLS Regression Model to control for supply shocks that might help to explain the day-ahead wholesale price. As mentioned in Chapter 4, several indexes will be employed to control for natural gas prices. Tables 5.4 and 5.5 summarize the regression results, using different control variables for the gas price.

As can be seen in Table 5.4, using the Dutch TTF and the MIBGAS AVB Index wield a high adjusted R^2 of 50.70% and 63.28%, respectively, showing that the model has a significant explanatory power which is in line with the findings of [31]. However, the ADF tests in Table 5.1 do not allow us to reject the null hypothesis of having unit roots in the data for these two variables. For this reason, OLS estimations might be biased, hence estimated coefficients cannot be interpreted. The fact that the coefficients for both gas indexes are negative is also proof that the coefficients might be biased as one would expect a positive relationship between the price of a fuel of a marginal technology and the day-ahead price. In order to remove the unit root, a first differences transformation was employed.[7] Again Table 5.1 shows that the null hypothesis of unit roots can be rejected for the first differenced variables. Unfortunately, a first differences approach removes variability in our gas indexes, hence making the variables less explanatory. This is observed in the lower adjusted R^2 for both the Dutch TTF FD and the MIBGAS AVB Index FD of 27.77% and 27.94%, respectively, which is very close to the baselines OLS regression adjusted R^2 of 26.09%.

Except for the Dutch TTF and MIBGAS AVB Index, which might both possess a unit root, the coefficients of all the other gas indexes are positive and significantly different from 0 at the 1% significance level. This stands to reason as a positive relationship between gas prices and day-ahead prices can be expected. For instance, the coefficient of the model using the MIBGAS Index points out that if the MIBGAS Index increases with 1€ per MWh, the day-ahead price on the wholesale electricity market will increase by 0.4178€ per MWh.

Next, what is interesting is that for the estimated extended OLS model, the coefficient on the EU ETC Certificates is always significantly negative. This is in line with [31], except for that they did not, in contrast to this case, find a statistically significant coefficient.

Regarding the residual load coefficients, all coefficients are statistically significant for every control variable used. Especially the coefficients for the $ResL_t$ variables are very close in line with each other which is favorable. The coefficients of $ResL_t$ (excluding the models with dutch TTF and MIBGAS AVB because of the potential presence of unit roots) range between 0.0197 and 0.0199, which is close to the FY baseline model coefficient of 0.0190.

[7] Note that other transformations such as logarithmic transformations can also be utilized. This was attempted by using the natural logarithm but ADF Tests could again not reject the null hypothesis of unit roots. Hence, this transformation could not be used.

Table 5.4: Summary Extended OLS Regression Results: Part 1

Sample	**Dutch TTF**	**Dutch TTF FD**	**MIBGAS AVB**	**MIBGAS AVB FD**	**MIBGAS**
Constant	70.8909***	-4.5223	-28.1248***	-0.1985	26.3581***
	(8.4351)	(10.1437)	(7.2151)	(10.1279)	(10.0411)
$ResL_t$	0.0179***	0.0197***	0.0159***	0.0197***	0.0198***
	(0.0010)	(0.0012)	(0.0009)	(0.0012)	(0.0012)
${ResL_t}^2$	<-0.0001***	<-0.0001***	<-0.0001***	<-0.0001***	<-0.0001***
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
${ResL_t}^3$	<0.0001***	<0.0001***	<0.0001**	<0.0001***	<0.0001***
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
EU ETS Certificates (€/tCO2)	-1.3339***	-0.6219***	-0.3276***	-0.6709***	-0.9722***
	(0.0705)	(0.0847)	(0.0602)	(0.0847)	(0.0847)
Dutch TTF [€/MWh]	-0.6820***				
	(0.0107)				
Dutch TTF FD [€/MWh]		0.0980***			
		(0.0957)			
MIBGAS AVB Index [€/MWh]			-1.2112***		
			(0.0131)		
MIBGAS AVB Index FD [€/MWh]				0.4598***	
				(0.0994)	
MIBGAS Index [€/MWh]					0.4178***
					(0.0221)
MIBGAS LNG Index [€/MWh]					
Daily Reference Price [€/MWh]					
Daily Auction Price [€/MWh]					
EOD Price [€/MWh]					
API 2 [USD/mt]	0.3019***	0.0997***	0.4238***	0.0976***	-0.0240**
	(0.0079)	(0.0087)	(0.0072)	(0.0087)	(0.0108)
Observations	8,760	8,760	8,760	8,760	8,760
Adjusted R^2	0.5070	0.2777	0.6328	0.2794	0.3057

Note: The standard errors are in parentheses. *, ** and *** signify significance levels at the 10%, 5% and 1% level, respectively.

Table 5.5: Summary Extended OLS Regression Results: Part 2

Sample	**MIBGAS LNG**	**Daily Reference Price**	**Daily Auction Price**	**EOD Price**
Constant	25.6777**	25.6356**	23.4780**	21.2309**
	(10.0458)	(10.0784)	(9.9298)	(10.1236)
$ResL_t$	0.0199***	0.0198***	0.01984***	0.0197***
	(0.0012)	(0.0012)	(0.0012)	(0.0012)
${ResL_t}^2$	<-0.0001***	<-0.0001***	<-0.0001***	<-0.0001***
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
${ResL_t}^3$	<0.0001***	<0.0001***	<0.0001***	<0.0001**
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)
EU ETS Certificates (€/tCO2)	-0.9757***	-0.9772***	-0.9228***	-0.9406***
	(0.0848)	(0.0852)	(0.0832)	(0.0858)
Dutch TTF [€/MWh]				
Dutch TTF FD [€/MWh]				
MIBGAS AVB Index [€/MWh]				
MIBGAS AVB Index FD [€/MWh]				
MIBGAS Index [€/MWh]				
MIBGAS LNG Index [€/MWh]	0.4035***			
	(0.0218)			
Daily Reference Price [€/MWh]		0.3812***		
		(0.0217)		
Daily Auction Price [€/MWh]			0.4411***	
			(0.0203)	
EOD Price [€/MWh]				0.3316***
				(0.0222)
API 2 [USD/mt]	-0.0221**	-0.0158	-0.0409***	0.0035
	(0.0108)	(0.0108)	(0.0107)	(0.0107)
Observations	8,760	8,760	8,760	8,760
Adjusted R^2	0.3049	0.3022	0.3145	0.2956

Note: The standard errors are in parentheses. *, ** and *** signify significance levels at the 10%, 5% and 1% level, respectively.

5.3 Final OLS Regression Model

Based on the results from Chapters 5.1 and 5.2, it has been decided to use the baseline regression results for further calculation of the RWC Index. This decision is based on several reasons: the potential presence of unit roots in the control variables, the potential non-linear relationship between control variables and prices, and standardization and objective of the RWC method.

Besides the potential presence of unit roots in the control variables, there is another reason to emit the control variables in the final model. It is clear that commodity prices of fuels used in power production influence the marginal cost of the plant, hence they should influence electricity prices. In the end, any supply curve is merely the result of aggregating marginal cost curves of all suppliers in the market. However, as [31] point out, the effect that fuel prices have on market prices is not linear but it depends on the load level. Due to the merit order, the ultimate impact a fuel has on the price depends on the extent a certain type of technology (natural gas, coal, etc...) is deployed at a certain load level. This implies a non-linear relationship between the control variables and prices. Hence, it might be better to not include fuel prices as control variables in the model as a linear relationship is assumed in Eq. 4.1.

For aforementioned reasons, the coefficients from the statistical model without the control variables are used. The fact that this model has a lower adjusted R-squared does not cause problems as the intention is not to forecast day-ahead prices, which would be achieved by a model with high explanatory power. The intention is to forecast the impact of (day-ahead) residual demand on day-ahead prices in an unbiased manner. Under these circumstances, the baseline OLS model yields the best appropriate estimate. This is also in accordance with [31], who mention similar reasons for leaving out the control variables. Another reason is uniformity, making this method easily accessible for different market analysis as different geographical markets would require to gather different data for the control variables, depending on the specific regulations and market design in terms of gas, coal and emission reduction certificates.

Fig. 5.1 represents the estimated relationship between residual load and the day-ahead price based on the baseline OLS regression model. The cubic form of the function can clearly be observed. Next, Fig. 5.2 provides the expected price jump estimated for different levels of residual load. As already mentioned in Chapter 5.1, the average expected price jump is 0.5999 Eurocents upon withholding one MW. Next, the results from Fig. 5.2 will be used to calculate the RWC Index for Iberdrola, EDP and Endesa, according to Eq. 4.5. The results of the RWC Index are presented below.

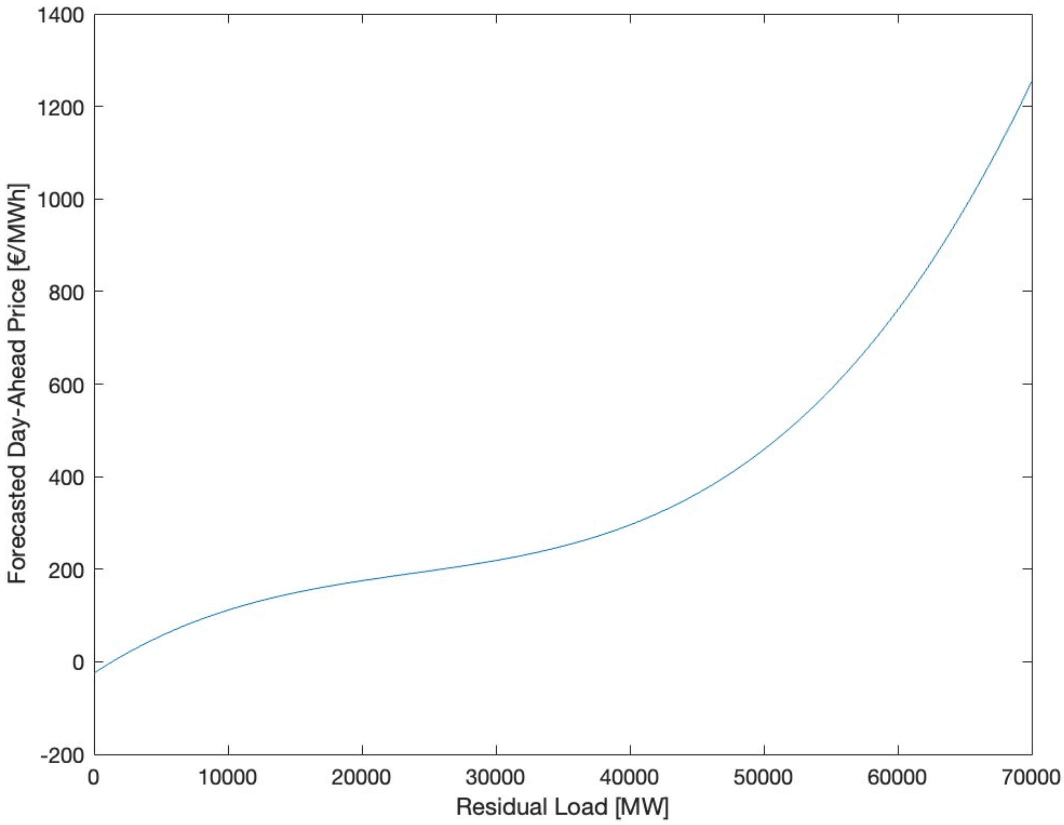


Figure 5.1: Estimated Relation Residual Demand and Day-Ahead Price Iberian Market (2022).

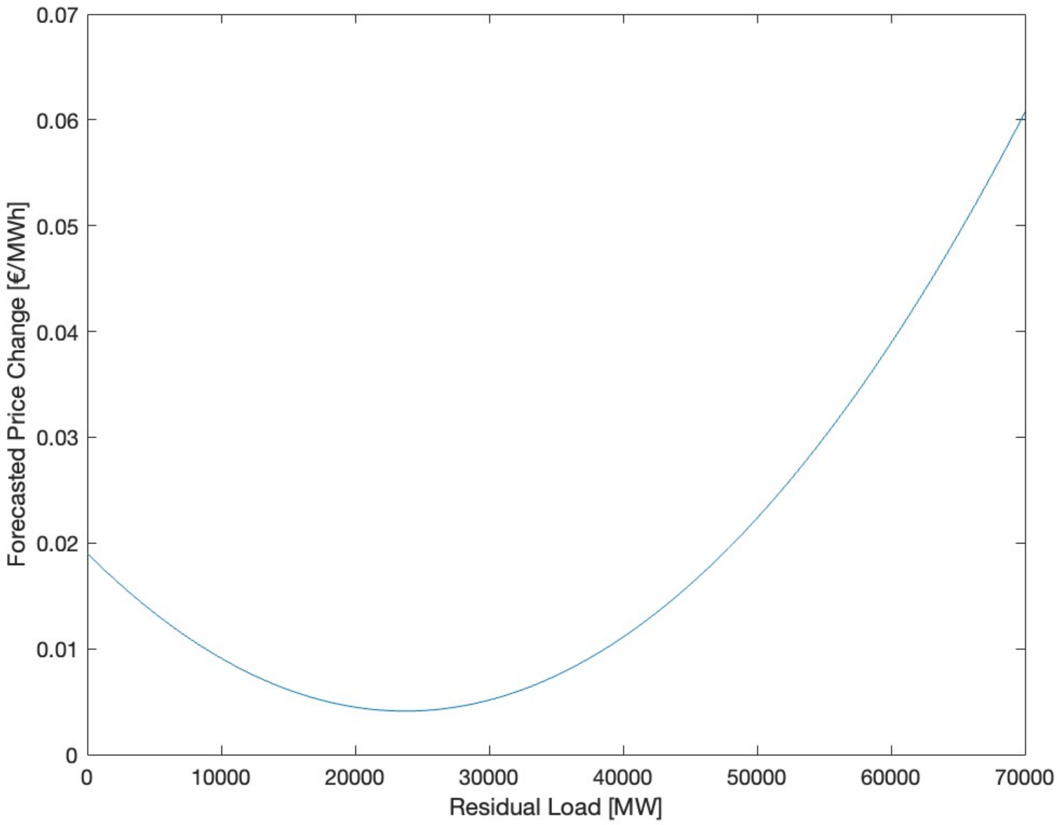


Figure 5.2: Forecasted Price Change

5.4 Company Results

As mentioned in Chapter 4, the companies' running capacities were derived, and together with the estimated expected price jumps, the RWC Index could be calculated for every hour for every generator. This is represented in Table 5.6 and Figs.s 5.3, 5.4, and 5.5. However, some remarks have to be made. First of all, the cubic function used to estimate the OLS regression model takes into account that higher price jumps are expected for lower load levels, compared to medium load levels. However, this implies that the RWC Index could be very high during off-peak periods. This would suggest that generators have high incentives to withhold capacity during off-peak periods. In reality, inflexible base load units are even willing to generate at negative prices because of technical reasons [31]. This implies that market power is typically low during those periods as the base load, inflexible units are dispatched in any case. For this reason, the RWC Indexes have to be adjusted. For this reason, the same method is used as in [31], putting the RWC Index values equal to 0 below a certain threshold. [31] chose a threshold of 21.67€. Here, thresholds of both 20€ and 30€ will be used. It has to be noted that the 30€ threshold is a more conservative estimation. RWC values at hours with prices lower than these thresholds will be set equal to 0, in line with [31]. This implies that for the 20€ and 30€ thresholds, the RWC Index is automatically set equal to 0 for 161 and 211 hours, respectively. For this reason, the average RWC values should always be lower in the 30€ threshold case.

Next, Chapter 4 explained the method to estimate each generator's running capacity. However, significant differences could be present due to geographical differences[8], due to shutdowns of generation plants (planned or unplanned), or due to differences in marginal costs. For this reason, two approaches will be followed. First of all, the RWC Indexes will be calculated using the estimated running capacities as explained in Chapter 4. In the second approach (hereafter named the "adjusted" case), the estimated running capacities will be adjusted per energy technology based on a correction. Although companies do not share hourly running capacities during the year, they typically do publish data on yearly production volumes specifically per generation technology type. Based on that, the estimated (according to the RWC methodology) and published company data are compared per generation technology on a yearly basis. Next, the percentage difference between the (according to the RWC methodology) estimated volumes and the actual published volumes for each technology is calculated. This percentage difference is used to adjust the previously estimated hourly running capacity per hour (according to the first approach) by this same percentage so that the total yearly estimated production volume per generation technology is equal to the real volume. This procedure was done for every company and the RWC Index was calculated again. Results are also demonstrated in Table 5.6 and Figs.s 5.3, 5.4, and 5.5.

Table 5.6 gives a summary of the mean RWC values, the 90% and 95% percentiles, and the amount of hours where the RWC Index is above 1.[9] What mostly stands out is that especially Iberdrola and Endesa, the two biggest generators have higher RWC Indexes and the highest amount of hours in which the RWC Index is above 1. For Iberdrola, this is 366 hours per year (4.18% of the year), while for Endesa this is 229 hours (2.61% of the year). Note that this amount is lower for the higher 30€ threshold but the picture remains the same: Iberdrola and Endesa seem to have the highest incentives to manipulate the market and increase prices. EDP on the

[8] Especially renewable energy related, but also transmission network related.

[9] Remember that in case the RWC Index is above 1, the generator has a clear incentive to withhold capacity.

other hand has very low RWC values, especially for the 30€ threshold case, and has a very limited amount of hours in which RWC values are above 1. Focusing on the adjusted running capacity case, it can be observed that in both the case of Iberdrola and Endesa, the RWC values are lower, as the initially (according to the RWC methodology) estimated running capacity over the entire year was overestimated compared to the real generation. The opposite is true for EDP, where the generation was slightly higher in reality, resulting in higher RWC values for EDP upon adjusting running capacities. The evolution over 2022 of the RWC Indexes for every company can be observed in Figs. 5.3, 5.4, and 5.5. Next, Figs. 5.6, 5.7, and 5.8 display the distribution of the hourly RWC values. A similar conclusion can be drawn here. Iberdrola and Endesa seem to have more incentives to withhold capacity compared to EDP, due to their larger market shares.

Fig. 5.9 provides a comparison of the evolution of the RWC Indexes between the three dominant players during 2022. Note that for all companies, there are clearly spikes in their RWC Indexes between hours 2,000 and 3,000 (between the March and April, shortly after the Russian invasion of Ukraine) and towards the end of the year. This clearly indicates that there are periods where generators have higher incentives to withhold capacity, and all generators experience this higher incentive. This could lead to various generators exercising their market power at the same time, creating a toxic situation which might have severe consequences. In Chapter 2, it was discussed that all electricity generators are better off even if only one generator exercises their market power. In this way, if all generators have incentives to withhold capacity, their strategic behaviour enforces each other's incentives, which might lead to more capacity withholding, higher prices, and so forth.[10]

As market power is more likely to occur during peak periods, it makes more sense to expect RWC values above 1 only during certain periods of the day. However, a day in which the average RWC Index is above 1 would indicate that generators experience days in which capacity withholding incentives are extremely high. In order to explore this, average daily RWC Indexes were calculated. These can be observed in Table 5.7. The evolution of the daily RWC Indexes during the whole year are depicted in Figs. **??**, **??**, **??**, in Appendix B. Again, a similar conclusion can be drawn: Iberdrola and Endesa have the highest incentives to withhold capacity. Iberdrola had 11 days in 2022 in which the average RWC Index was above 1. Endesa had only 5 days. If the 30€ threshold is applied and running capacities are adjusted, however, only 6 days remain for Iberdrola and none for Endesa.

Last but not least, a more visual comparison between the different dominant market players of the hourly and daily RWC values is represented in Fig. 5.10. Again similar conclusions can be drawn.

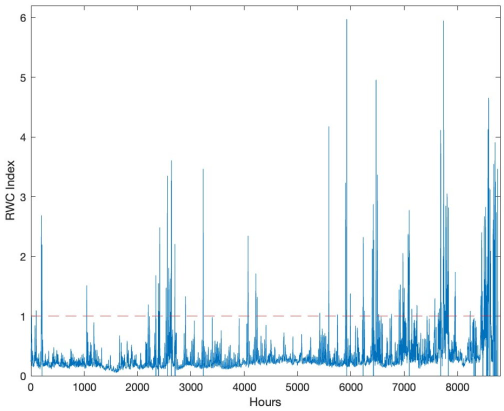
[10]Such a situation might have similarities to the most well-known market power abuse case: the California Electricity Crisis of 2000-2001 [59].

Table 5.6: Summary RWC Values Hourly

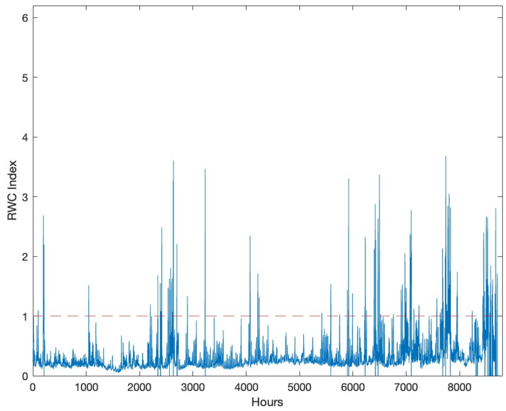
	Mean		**90% Percentile**		**95% Percentile**		**# Hours >1**	
	20€	30€	20€	30€	20€	30€	20€	30€
Iberdrola	0.346	0.327	0.623	0.602	0.911	0.859	366	315
Iberdrola Adjusted	0.273	0.257	0.492	0.477	0.739	0.688	253	202
EDP	0.113	0.107	0.199	0.191	0.299	0.280	38	12
EDP Adjusted	0.137	0.130	0.235	0.228	0.344	0.326	57	24
Endesa	0.298	0.284	0.510	0.494	0.711	0.682	229	178
Endesa Adjusted	0.288	0.275	0.483	0.469	0.665	0.642	198	147

Table 5.7: Summary RWC Values Daily

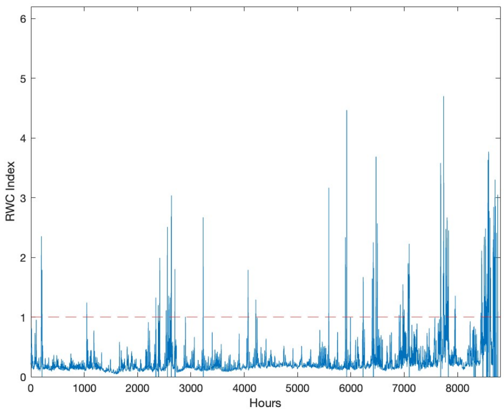
	Mean		**90% Percentile**		**95% Percentile**		**# Days >1**	
	20€	30€	20€	30€	20€	30€	20€	30€
Iberdrola	0.346	0.327	0.605	0.552	0.799	0.725	11	7
Iberdrola Adjusted	0.273	0.257	0.476	0.429	0.642	0.595	9	6
EDP	0.113	0.107	0.198	0.179	0.260	0.310	0	0
EDP Adjusted	0.137	0.130	0.231	0.212	0.244	0.285	0	0
Endesa	0.298	0.284	0.502	0.464	0.637	0.572	5	1
Endesa Adjusted	0.284	0.275	0.471	0.434	0.602	0.539	2	0



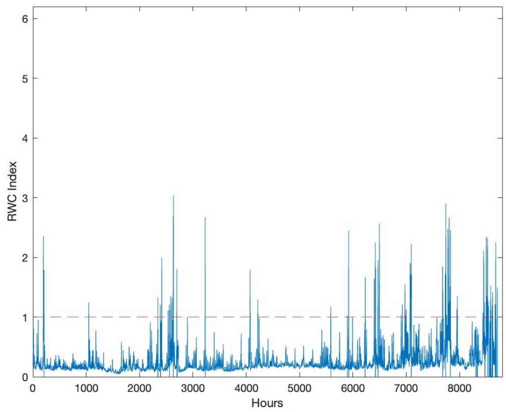
(a) Iberdrola (20€)



(b) Iberdrola (30€)

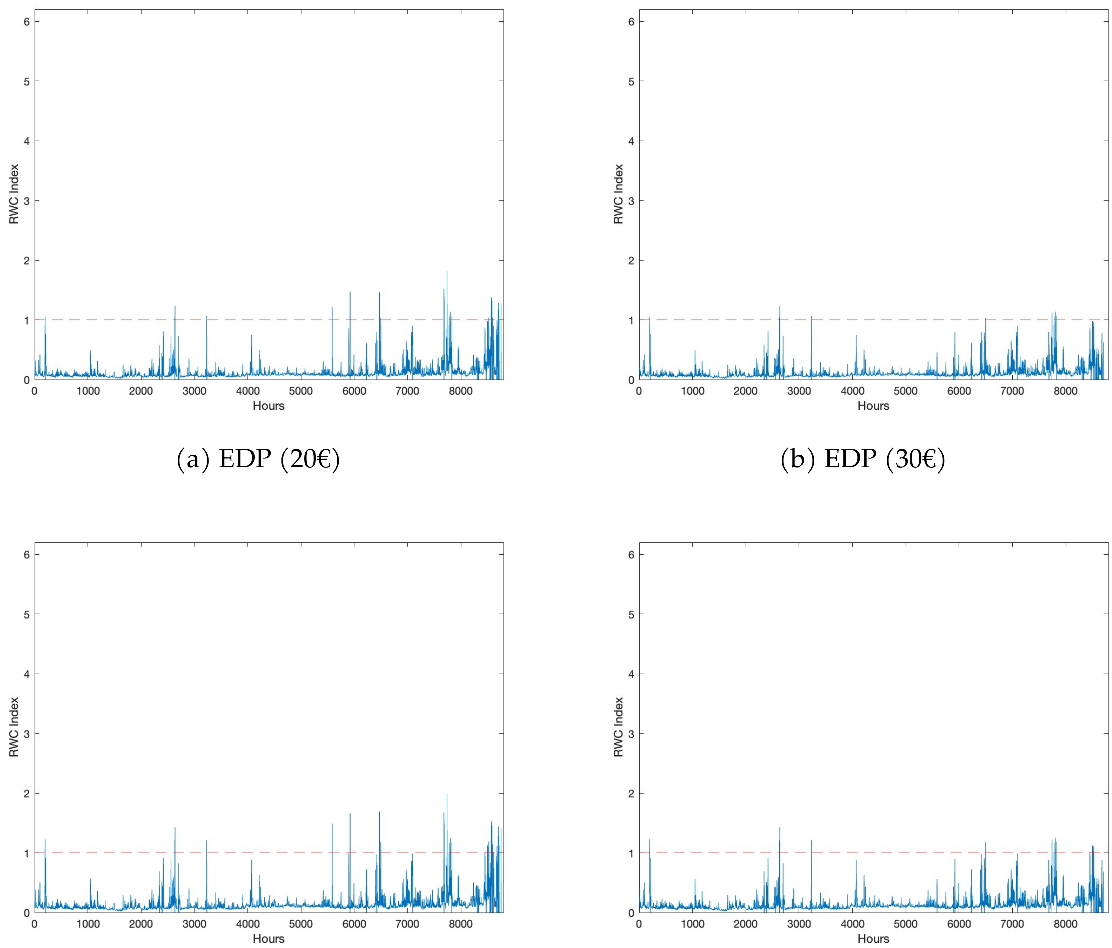


(c) Iberdrola Adjusted Production (20€)



(d) Iberdrola Adjusted Production (30€)

Figure 5.3: Iberdrola RWC Values (2022)



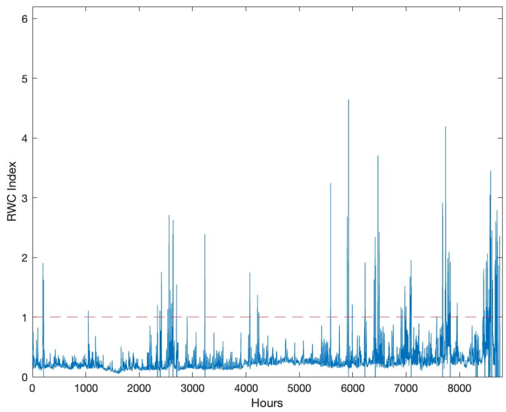
(a) EDP (20€)

(b) EDP (30€)

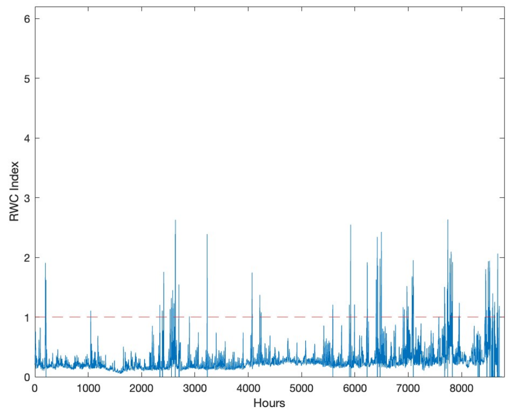
(c) EDP Adjusted Production (20€)

(d) EDP Adjusted Production (30€)

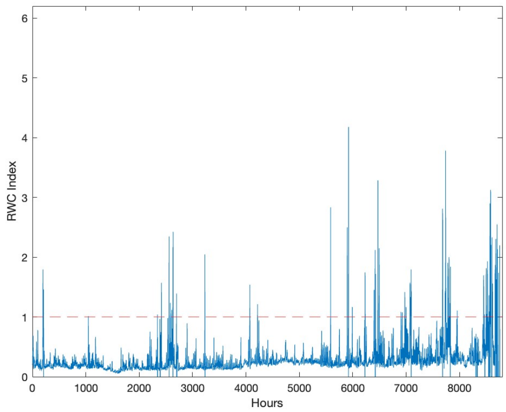
Figure 5.4: EDP RWC Values (2022)



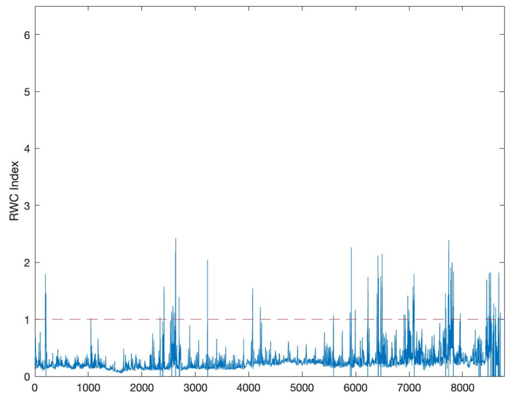
(a) Endesa (20€)



(b) Endesa (30€)

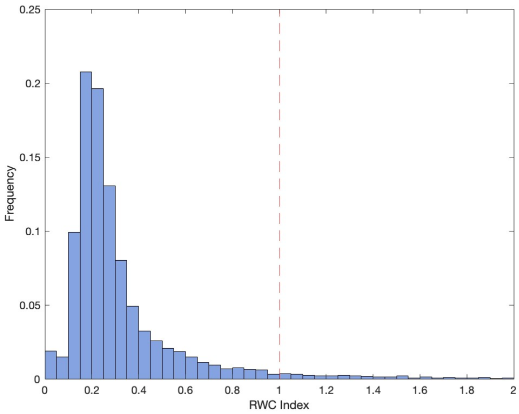


(c) Endesa Adjusted Production (20€)

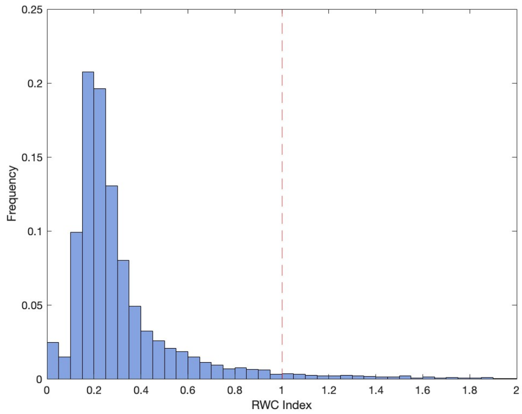


(d) Endesa Adjusted Production (30€)

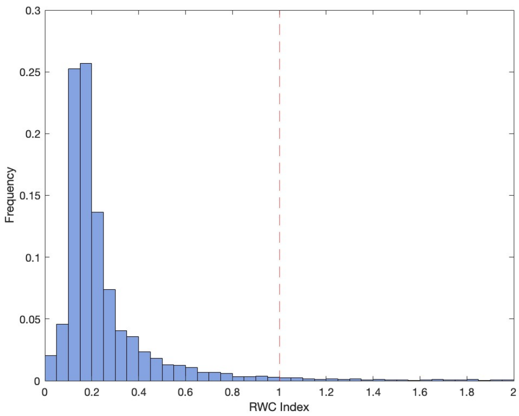
Figure 5.5: Endesa RWC Values (2022)



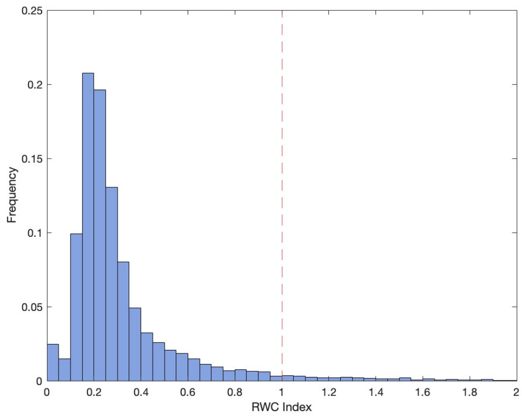
(a) Iberdrola (20€)



(b) Iberdrola (30€)

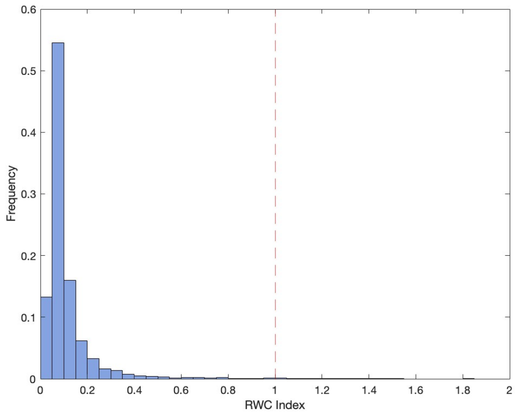


(c) Iberdrola Adjusted Production (20€)

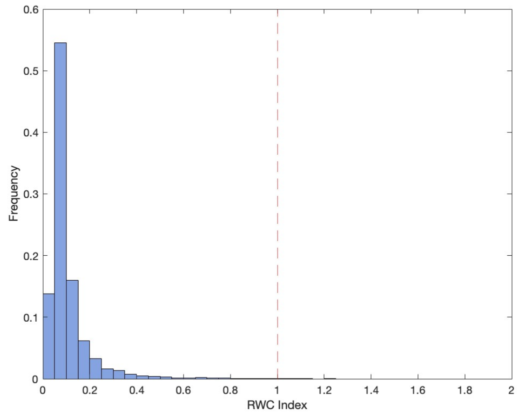


(d) Iberdrola Adjusted Production (30€)

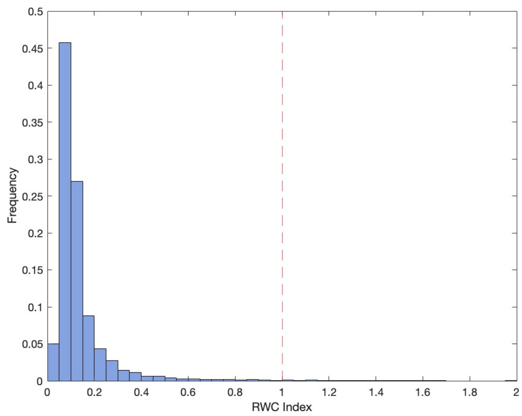
Figure 5.6: Iberdrola RWC Values (2022) Distribution



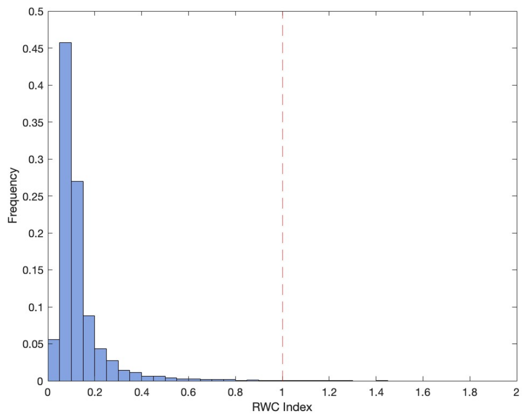
(a) EDP (20€)



(b) EDP (30€)

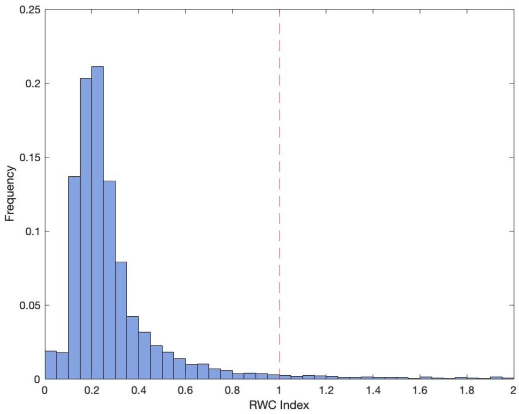


(c) EDP Adjusted Production (20€)

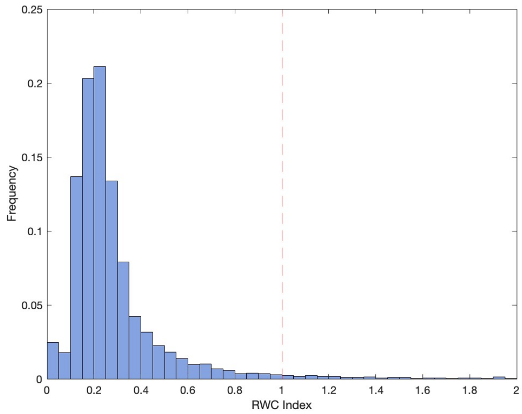


(d) EDP Adjusted Production (30€)

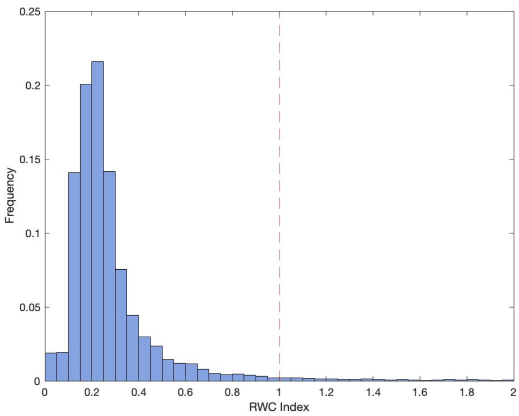
Figure 5.7: EDP RWC Values (2022) Distribution



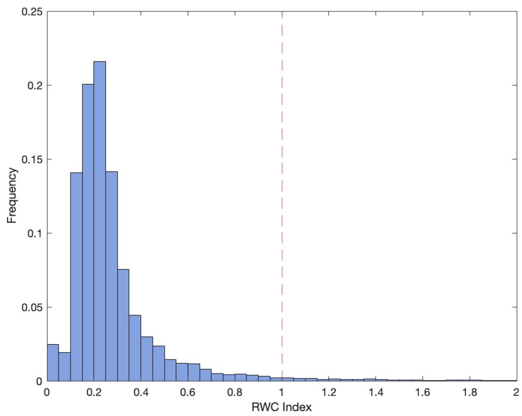
(a) Endesa (20€)



(b) Endesa (30€)

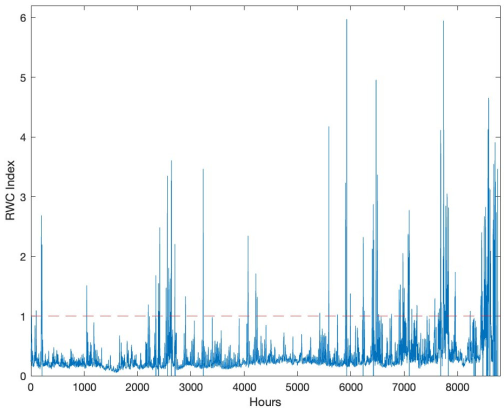


(c) Endesa Adjusted Production (20€)

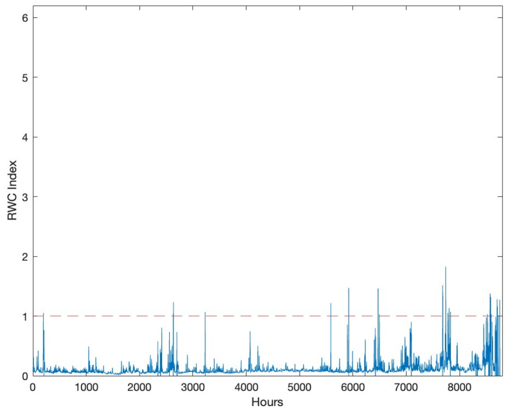


(d) Endesa Adjusted Production (30€)

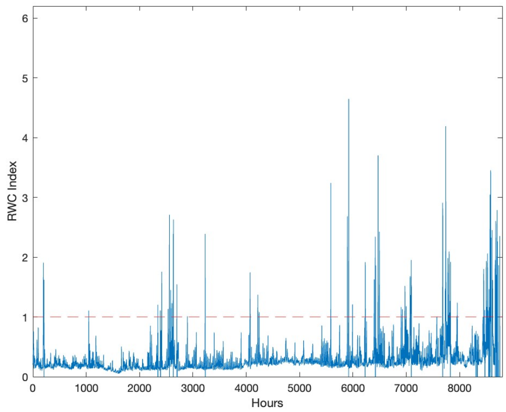
Figure 5.8: Endesa RWC Values (2022) Distribution



(a) Iberdrola (20€)

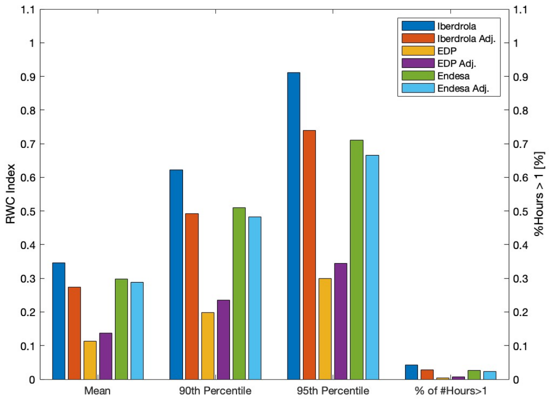


(b) EDP (20€)

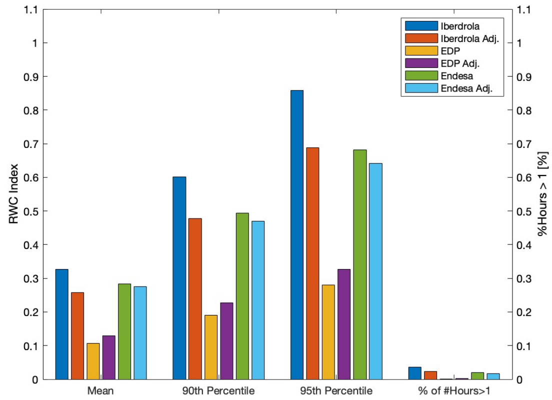


(c) Endesa (20€)

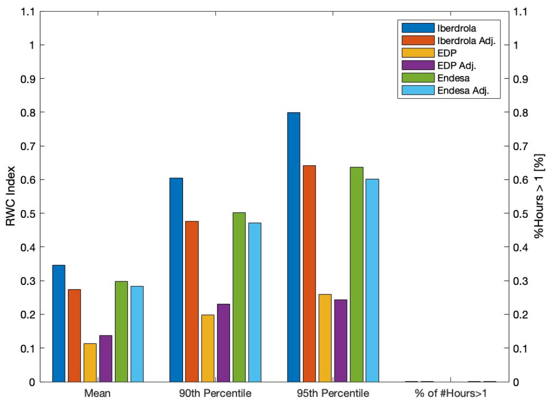
Figure 5.9: Comparison RWC Values Companies (2022)



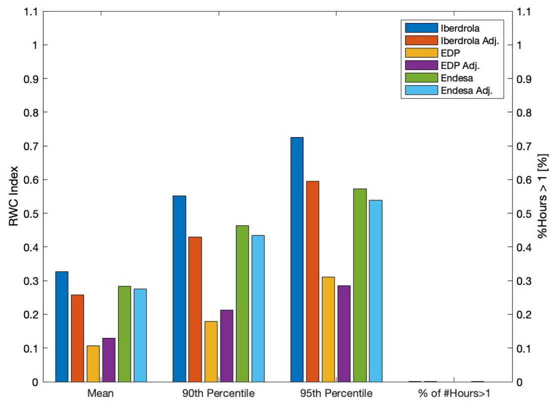
(a) RWC Results Hourly (20€)



(b) RWC Results Hourly (30€)



(c) RWC Results Daily (20€)



(d) RWC Results Daily (30€)

Figure 5.10: Comparison Between Companies

5.5 Robustness Check

In any statistical regression model, it is fundamental to perform robustness checks in order to assess the robustness and correctness of the results and the inferences that are made based on those results. For this purpose, it has been decided to use the baseline OLS regression results (see Table 5.2) where the statistical regression model was re-estimated using the H1 and H2 subsamples. As the Wald Tests pointed out that there is a significant difference between the coefficients in the full sample and the H2 subsample, a larger difference can be expected between the full sample and H2 subsample results, compared to the difference between the full sample and H1 results. This section will cover the results based on these H1 and H2 subsamples, and will compare them with the full sample results.

More specifically, to enhance comparison, the same procedure was followed as before. This implies that the regression model was estimated for both H1 and H2. The results from these regression models were subsequently applied to calculate RWC values for the whole year. Hence, the next step is to forecast the price difference that would have occurred if one MW of generation was withdrawn, for every residual load level that occurred during the whole year. In this way, the RWC values for each of the companies can be compared between the full sample (FY), the H1, and the H2 subsample.

Tables 5.8, 5.9, and 5.10 provide a summary of the RWC values for the H1, H2, and FY regressions. Next, a visual representation is provided in Fig. 5.11. More interesting is Fig. 5.12, in which per company, the results between H1, H2 and FY are compared. It can be observed that for every company the H1 results lead to higher RWC values for the 90% and 95% percentiles, as well as the number of hours in which the RWC Index is above 1. The opposite is true for H2 results, in which the RWC values for the 90% and 95% percentiles, as well as the number of hours in which the RWC Index is above 1 are lower compared to the FY sample.

Last but not least, the evolution of the RWC Index during the whole year is represented in Fig. 5.13 based on the result from FY, H1 and H2. This is only shown here for Iberdrola. The results for EDP and Endesa can be found in Figs. **??** and **??**, respectively, in Appendix C.

To conclude, although the H1, H2, and FY results are slightly different, they do point in the same direction. They all show that Iberdrola and Endesa are most likely to experience incentives to withhold capacity from the market. Moreover, the H1, H2, and full samples all depict that during certain periods of the year, incentives are higher to withhold capacity. This is positive as it shows that the approach points in the same direction, even though different subsamples are used. This shows the robustness of the RWC methodology and displays its multi-functionality to employ during different periods and markets.

Table 5.8: Summary RWC Values Hourly H1

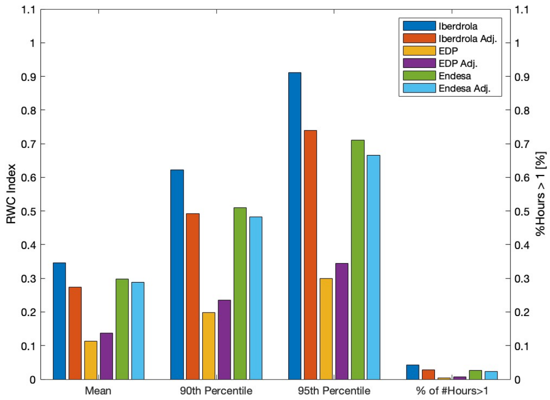
	Mean		**90% Percentile**		**95% Percentile**		**# Hours >1**	
	20€	30€	20€	30€	20€	30€	20€	30€
Iberdrola	0.337	0.316	0.677	0.654	1.006	0.952	448	397
Iberdrola Adjusted	0.267	0.249	0.537	0.515	0.812	0.760	302	251
EDP	0.109	0.103	0.214	0.208	0.332	0.306	54	21
EDP Adjusted	0.131	0.124	0.255	0.247	0.383	0.358	72	34
Endesa	0.286	0.270	0.556	0.538	0.787	0.756	280	229
Endesa Adjusted	0.274	0.260	0.525	0.511	0.740	0.705	240	189

Table 5.9: Summary RWC Values Hourly H2

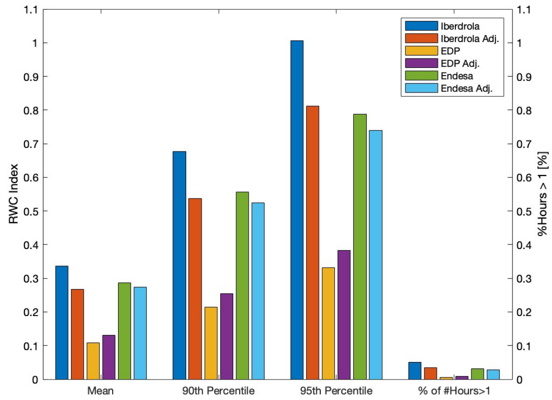
	Mean		**90% Percentile**		**95% Percentile**		**# Hours >1**	
	20€	30€	20€	30€	20€	30€	20€	30€
Iberdrola	0.348	0.332	0.579	0.564	0.769	0.729	239	188
Iberdrola Adjusted	0.273	0.259	0.453	0.443	0.610	0.577	160	109
EDP	0.114	0.109	0.186	0.182	0.251	0.240	14	0
EDP Adjusted	0.138	0.132	0.220	0.215	0.295	0.282	25	0
Endesa	0.305	0.293	0.479	0.471	0.604	0.582	130	79
Endesa Adjusted	0.296	0.285	0.458	0.450	0.569	0.550	100	49

Table 5.10: Summary RWC Values Hourly FY

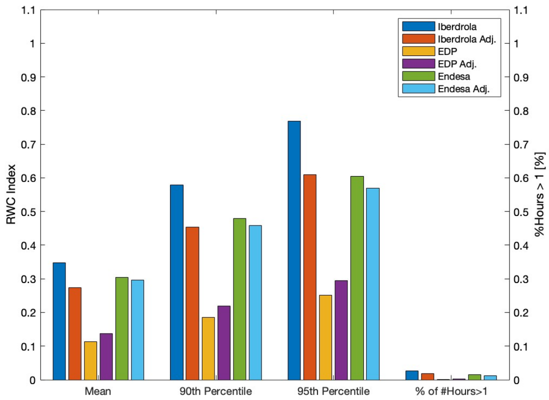
	Mean		**90% Percentile**		**95% Percentile**		**# Hours >1**	
	20€	30€	20€	30€	20€	30€	20€	30€
Iberdrola	0.346	0.327	0.623	0.602	0.911	0.859	366	315
Iberdrola Adjusted	0.273	0.257	0.492	0.477	0.739	0.688	253	202
EDP	0.113	0.107	0.199	0.191	0.299	0.280	38	12
EDP Adjusted	0.137	0.130	0.235	0.228	0.344	0.326	57	24
Endesa	0.298	0.284	0.510	0.494	0.711	0.682	229	178
Endesa Adjusted	0.288	0.275	0.483	0.469	0.665	0.642	198	147



(a) RWC Results FY

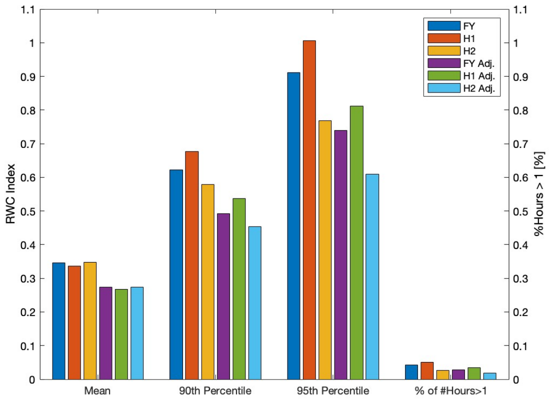


(b) RWC Results H1

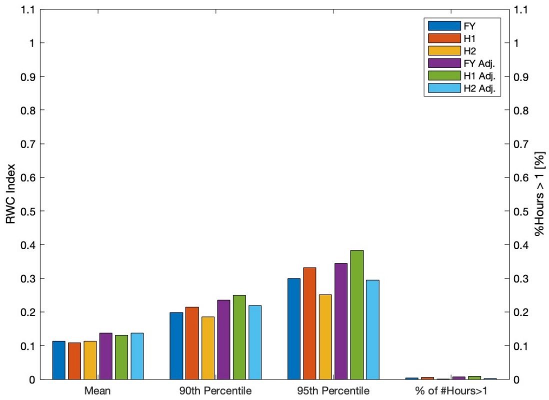


(c) RWC Results H2

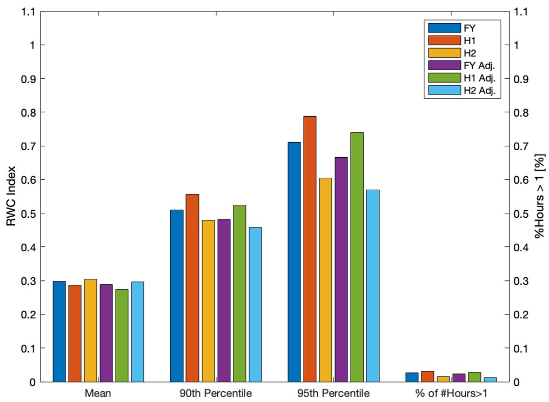
Figure 5.11: Comparison Between Company Results FY, H1, and H2 (20€)



(a) RWC Results Iberdrola & Iberdrola Adj.

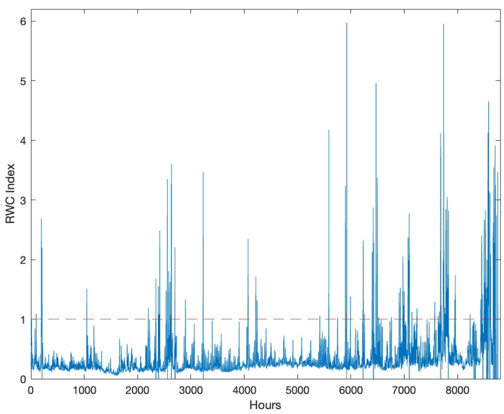


(b) RWC Results EDP & EDP Adj.

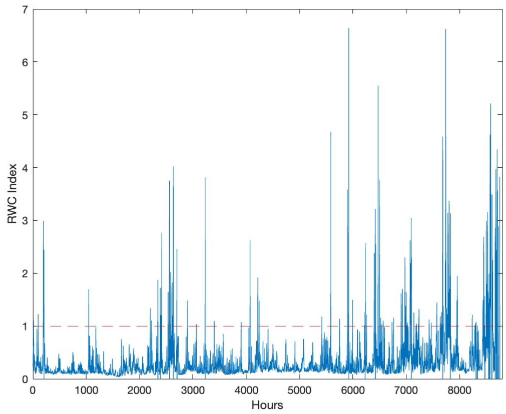


(c) Endesa & Endesa Adj.

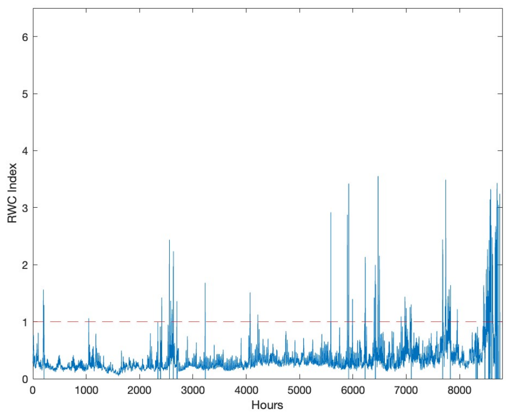
Figure 5.12: Comparison Between FY, H1, and H2 (20€) for each Company



(a) Iberdrola FY



(b) Iberdrola H1



(c) Iberdrola H2

Figure 5.13: Comparison Iberdrola RWC Values (2022) FY, H1, and H2 Results

Chapter 6

Conclusions

The objective of liberalizing the wholesale electricty markets was to avoid monopolies, introduce competition amongst market players, and hence reduce market power. The liberalization is ongoing and more competition has been established into modern energy markets. However, in many countries pivotal dominant markets players are still present which makes the exertion of market power more likely. This creates an important role for authorities to implement policies to reduce market power potential and to monitor existing players to prevent them from illegal practices. This study attempts to assess the potential for market power practices by dominant generators in the Iberian wholesale electricity market. For this porpuse, the RWC Index was utilized. The RWC Index was developed by [31] and has the crucial advantage that it can be calculated with publicly available data. Another advantage is its simplicity and standardized form. This makes the RWC Index particularly interesting as it can be applied in different markets with ease and it allows for intertemporal and intercompany comparison [31]. A supplementary advantage is that it takes the power plant portfolios of the generators as well as demand elasticity into account, which both have an effect on market power potential. This is unlike other indexes or methods. Especially taking the generator's portfolio into account is crucial, as [31] point out that a more diversified power plant portfolio increases the incentives for exercising market power.

Due to its several advantages, the RWC Index was calculated to assess the incentives to exercise market power experienced by the dominant market players in the Iberian wholesale market, being Iberdrola, Endesa and EDP. Together, they generate more than 50% of the electricity generation in the Iberian wholesale electricity market. Only the dominant market players were investigated as market power potential is most likely to be experienced by dominant large electricity players. The RWC Indexes clearly show that Iberdrola experienced the largest incentives during 2022, with almost 366 (or 4.18% of the time) hours where there was undoubtedly an incentive to withhold capacity. Next, Endesa also had a significant amount of hours (229 or 2.61% of the time) where incentives to withhold capacity were definitely present. This is less the case for EDP which could be expected as EDP has a total installed capacity that is significantly smaller than Iberdrola and Endesa. This is a proof that larger generators in general encounter higher incentives to manipulate the market. The fact that Iberdrola and Endesa both have a significant larger installed base load capacity (being nuclear for Iberdrola and nuclear and hard coal for Endesa) could also increase their incentives. As baseload capacity is characterized by low marginal costs, an increase in market prices by withholding capacity from other more flexible technologies could lead to much higher profit margins on the baseload generation. This could easily compensate for the lost profit margins on the generation technology that was utilized to withhold capacity (which typically has higher marginal costs and thus lower profit margins).

Another interesting insight from the results is that the RWC Indexes for the different companies show that there are clearly periods in the year where capacity withholding was more likely compared to other periods. Higher incentives were clearly observed for all companies between hours 2,000 and 3,000 (between March and April) and towards the end of the year. This clearly shows that market power potential varies over time. This shows how important the period of investigation is to examine adequately whether companies have the potential to execute market power or not. If there is a perception of potential market power abuse but indexes show that incentives to execute market power were very low during that period, it provides evidence that the company was most likely not manipulating the market, or at least not on purpose, as market power abuse should be a profitable strategy. Another important conclusion here is that the fact that all companies experience similar higher incentives to withhold capacity during certain periods can create an acute situation. As all generators benefit from one generator withholding capacity, it could create a self-reinforcing cycle in which other generators respond to a certain generator withholding capacity by withholding part of their capacity as well, and so forth. This kind of strategic behaviour is typically examined by simulation models, rather than by structural indexes, as discussed in Chapter 2.

The RWC Index shows that market authorities in the Iberian market should most likely focus more on Iberdrola and Endesa upon monitoring for market power. However, it must be mentioned that the amount of hours in which both companies have clear incentives to withhold capacity is rather limited. Hence, authorities should also prevent that further regulation and liberalization attempts reduce market efficiencies. Furthermore, as the proportion of power purchasing agreements (PPAs) in the generator's portfolio is not considered by the RWC Index[1], the actual incentives to withhold capacity could actually be even lower. This deserves further investigation. It can therefore be concluded that the RWC Index seems to support the hypothesis that the amount of market power potential, and the incentives to exercise it, seem to be rather limited in the Iberian market. This applies even to the large dominant market players. This does, however, not imply that authorities should not push to increase the level of competition in the Iberian wholesale electricity market.

Next, in the last years renewable energies have been massively penetrating the electricity markets. As renewable sources such as solar and wind are less flexible, they typically limit market power potential. This is taken into account by the RWC as the residual demand is utilized to forecast day-ahead prices and estimate price jumps. The higher the amount of renewables being dispatched, the lower the residual load which typically coincides with lower day-ahead prices. However, it must be noted that renewables do not eliminate market power abuse either, hence the need for authorities to monitor markets remains.

The RWC Index is a very useful tool to perform initial market power screenings to assess whether there are incentives for certain market players to manipulate the market. It is helpful as the RWC Index can point towards certain market players and certain periods in time, where market power

[1]This limitation will be further discussed in Chapter 9 which discusses limitations of the RWC Index and further steps for market monitoring.

abuse is most likely to occur. After this step, a more in-depth analysis can be performed on the suspected company by investigating planned or unplanned maintenance of units, unexpected outages of units, ramp-rate manipulation, or any other peculiar strategic behaviour. In such an analysis, transmission related factors could also be included, which is not taken into account by the RWC Index. The transmission network has the potential to increase (transmission constraints can create local or regional markets) or decrease (in case of cross-border transmission lines with other region or countries) market power potential.

Chapter 7

Environmental, Social, and Gender Impact

Market power abuse might have severe environmental and social consequences. These effects might manifest in different ways. This section attempts to address the most likely consequences of market power abuse practices from an environmental, social and gender equality perspective, and it highlights once again the importance of careful monitoring market power to prevent any abusive practices.

The most obvious consequence of market power abuse has already been depicted in Chapter 2.4. Market power abuse shifts market prices above competitive levels which leads to distorted price signals [12] which results in operational and investment inefficiencies. The presence of inefficiencies is caused by these upward price shifts as they imply the replacement of more efficient (i.e. baseload) units (due to strategic purposes) for a more expensive marginal technology [8]. Depending on the technology used for baseload and the marginal generator, it might imply an adverse environomical impact if the marginal generator is less efficient or uses a more polluting technology (i.e. fuel). Furthermore, as the distorted price signals result in operational and investment inefficiencies, these also imply a negative environmental impact as generation will become less efficient, which implies an inefficient use of resources. These resources are typically (fossil) fuels and financial resources and could have been employed in a better way. In turn, higher returns on the use of these resources could have been used to lower environmental impacts by for instance investing in clean technologies or carbon capture and storage (CCS) technologies.

Furthermore, as market manipulation is most likely done by using flexible and dispatchable generation assets, it could discourage the adoption of renewable energy assets as they often do not provide this flexibility. Market power abuse typically occurs during peak demand hours where peaks are typically met by more expensive and flexible gas or even oil-fueled power plants [8]. As it makes these kind of technologies financially attractive, it might hinder further renewable projects to attract necessary investments and secure long-term contracts, impeding their further deployment. Note that also renewable energy sources such as hydropower and batteries often have this flexibility. These technologies could therefore be used as well to manipulate generation.

Last but not least, unfair market practices (or the exposure of it) might undermine investor confidence in the overall sector. Investors might be hesitant to invest in projects that face the potential of market abuse as it creates uncertainty and an additional financial risk. This lack of investor confidence might hinder or slow down the further penetration of renewable energy projects.

The energy sector is a strongly regulated market. If policymakers deem it necessary or are compelled by political pressure to impose more regulation to prevent market power practices, it might have unfavorable effects. Too much regulation might hinder innovation, increase compliance costs, reduce competition, reduce efficiency, decrease investments, and distort the overall market. This in turn, can slow down the energy transition.

In addition, market manipulation distorts competition which can prevent new entrants to enter the market. These new entrants could be active in renewable energy. The lack of competition would also suppress innovation.

The effects of strategic bidding on the clearing price and their associated shifts in social welfare were well illustrated in Fig. 2.1. These artificial prices shift trading surplus from costumers to suppliers and this wealth transfer creates overall social welfare losses [6]. Note that customers not only include residential customers, but also commercial, industrial, and transportation customers. All of these being worse off because of market power abuse. This in turn will have an impact on the general costs of goods[1], as companies are tempted to raise prices to sustain their profit margins when their input prices augment. To summarize, market power abuse leaves everyone worse off, except for the generation companies.

However, special attention should be given to those who are most vulnerable to these effects, being typically low-income individuals and families, as they typically spend a larger portion of their income on commodities such as gas, water, and electricity. Fig. 7.1 displays the evolution of the percentage of the population that is unable to keep their home adequately warm. The number of inhabitants of Spain that are unable to maintain their home sufficiently warm amounted to 10.9% in 2020, significantly higher than the 7.5% in 2019 [60]. Spain is ranked sixth in the EU for energy poverty, while Portugal is fourth with 17.5% [60].

Last but not least, while the social implications of market power abuse are very straightforward, the gender impact is less evident. As already mentioned, low-income individuals and families typically spend a larger portion of their income on commodities. These vulnerable groups, that often include women and young mothers, should be protected from any of the unfavorable consequences of market power abuse. Higher energy prices due to abusive practices could lead to challenges to meet energy needs, and they could prevent vulnerable groups to access essential services, engage in productive activities, and prevent economic empowerment.

[1]Especially on goods and services that are energy-intensive.

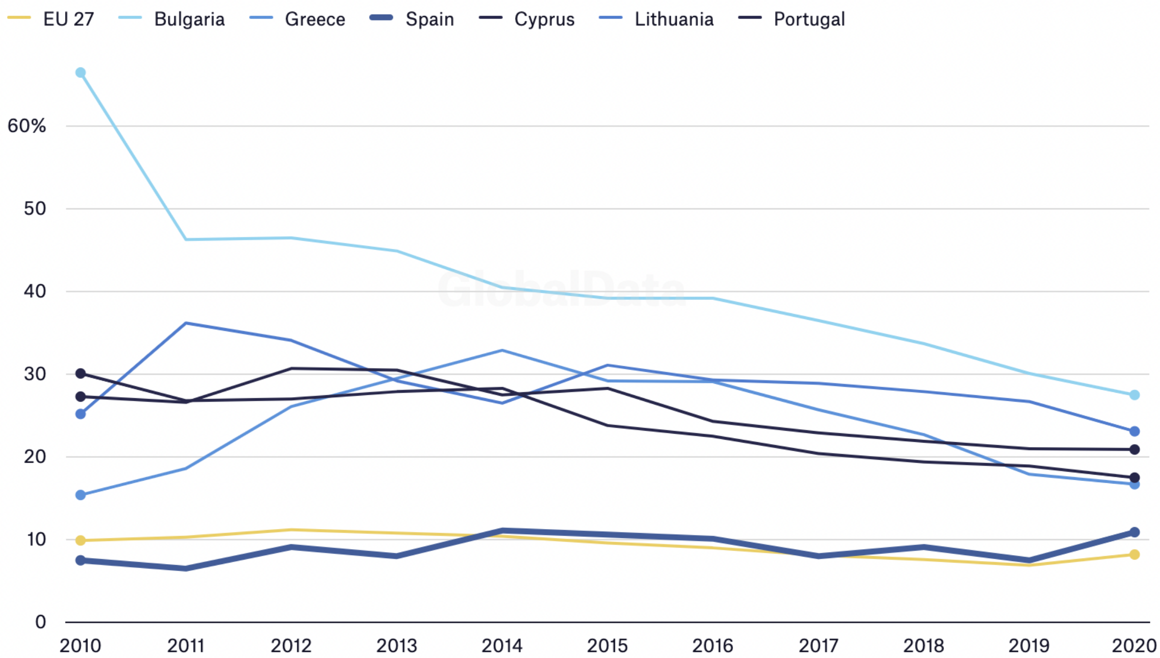


Figure 7.1: Population unable to keep home adequately warm by poverty status, 2010–20. Source: Eurostat and [60].

Chapter 8

Project Cost and Planning

This chapter covers the cost and planning of this master's dissertation.

8.1 Project Cost

As in any project, monitoring the costs associated to achieve a successful project outcome is essential. The costs for this project are fully originating from the labor expenses performed by the student Clarysse Henri. The software used during this project was either freely available or a licence was provided by Universitat Politècnica de Catalunya. For this reason, no costs for software use were included. The workload for the student was in line with the workload of 30 ECTS university credits, as was assigned to this master's thesis. This corresponds to 750 hours of labor work. Assuming a labor cost of 8€/hour, a total sum of 6,000 € is obtained. This sum is the taxable base of this project. Applying a VAT (Value Added Tax) of 21%, a total budget of 7,260 € is obtained. These results are summarized in Table 8.1 below.

Table 8.1: Project Costs

Cost	**Hours [hour]**	**Cost/hour [€/hour]**	**Total [€]**
Taxable Basis Project Cost	750	8.0	6,000
VAT (21%)			1,260
Total			7,260

8.2 Project Planning

This master's dissertation was initiated in February 2023, and will run up to July 2023. Figure 8.1 depicts the timeline that was utilized throughout the project with the different tasks and time dedicated to each of them. As can be observed, the project was initiated by an initial project proposal in coordination with the supervisors being Maria Elena Martin Cañadas and Jordi de la Hoz. Next, a literature review was initiated to gain in depth knowledge on state-of-the-art developments within this field. After obtaining a better understanding on recent developments within the field of market power detection, this project could proceed with the appropriate steps from the RWC Index methodology. Each task and the required time to execute it can be found in the figure below. Last but not least, this master's dissertation will be completed by presenting and defending the work during an oral presentation in July 2023.

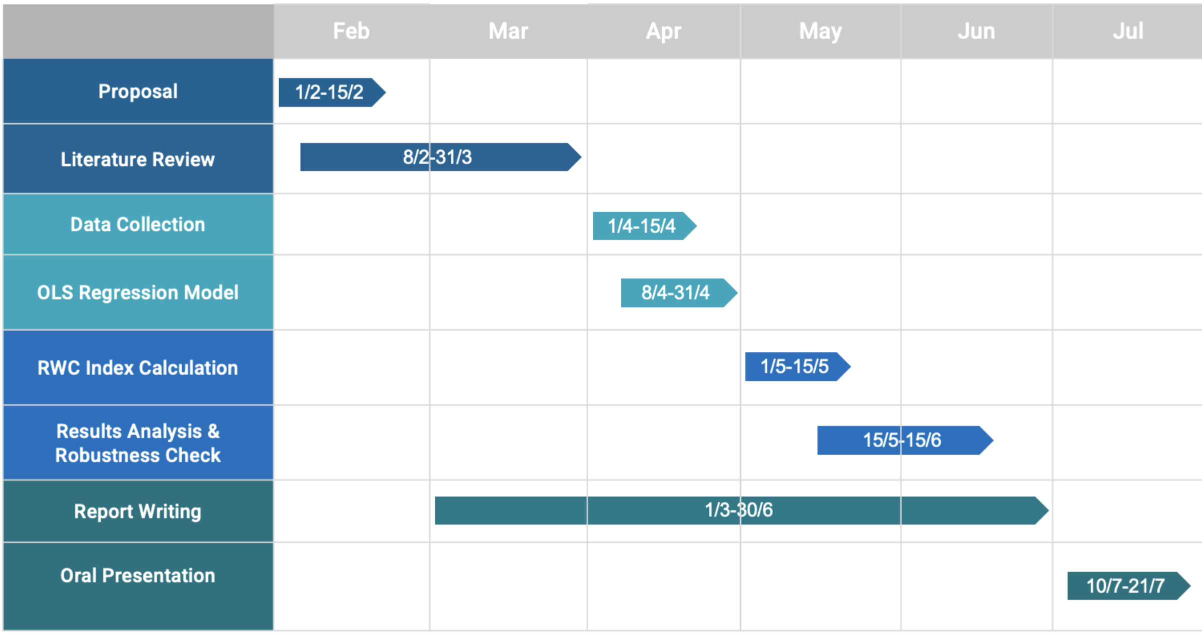


Figure 8.1: Project Planning

Chapter 9

Limitations and Further Work

As already discussed, the RWC Index is a very useful tool to monitor markets and to assess where and when market power might be executed. However, it should only be used as a tool to perform an initial market screening after which more in depth tools and analyses should be employed. The RWC Index, for instance, does not consider transmission related market power practices nor does it take into account ramp-rate manipulation. As discussed in Chapter 2, these are two under-investigated sources of market power abuse. Nonetheless, the RWC Index is very useful for narrowing the scope to a limited group of companies that might exercise their dominant market position. After narrowing down the scope of the investigation, more specific tools and in-depth analyses could be considered as a next step to include the aforementioned topics such as transmission related and ramp-rate market manipulation.

Despite its benefits, the RWC Index has some drawbacks that should be taken into account. First of all, the OLS model assumes the independent variables[1] (being the residual load and the control variables) are strictly exogenous. This implies that the assumption goes that the independent variables have an impact on the dependent variable (being the day-ahead price) and not vice versa. However, it could be argued that the day-ahead price also impacts residual load, in case demand management is widely deployed. In case there is a reverse causality between prices and residual load, endogeneity exists in the model. This in turn, can lead to biased and inconsistent parameter estimates [61]. As demand management in the Iberian electricity market is not widely deployed yet, this master's thesis did not consider this endogeneity problem as a severe issue. This is in line with [31] as they highlight that demand in wholesale markets is very price inelastic because the abundance of electricity customers are unaware of real-time wholesale prices [62, 63]. However, over time, as demand management becomes more prevalent because of the introduction of flexible technologies such as vehicle to grid and smart meters, endogeneity might become a complication to consider. An approach to solve endogeneity problems is to wield an instrumental variables (IV) approach. The Two Stage Least Squares (TSLS) estimator is the most widely used IV estimator utilized in statistics [61]. This approach was also performed by [31] in which lagged residual load, wind, solar, and run-of-the-river generation are used as instrumental variables. Hence, this approach could be employed rather than the OLS regression model when endogeneity concerns are present. For this master's dissertation, the IV approach was not applied as it was not considered a large concern. This reasoning can be supported by [31] who find similar results for both the OLS and TSLS approach upon applying their newly developed RWC Index.

Another factor that should be taken into account is that electricity generators often sell a large portion of their electricity through power purchasing agreements (PPAs). As discussed in Chapter 2, long-term PPAs reduce the market power potential as they will not benefit from temporary price jumps in the day-

[1] Also called explanatory variables.

ahead electricity market for this part of the generation. In the RWC calculation, as can be observed in Equation 4.5, the entire running capacity of each generator is taken into account. However, if generators already have sold a large portion of their capacity, it significantly reduces the potential to exercise market power. The share of PPAs in the electricity generator's portfolio should be taken into account after an initial screening with the RWC Index.

As mentioned before, the investigation period is an extremely important decision to make upon applying the RWC methodology. On the one hand, at least a period of some months should be considered as it reflects seasonal changes [31]. Longer sample periods on the other hand could improve the statistical inference which would make the RWC Index more precise. Furthermore, selecting a too long period might reduce the validity of the RWC Index as structural changes might be disregarded [31]. For this reason, it is advised to perform the RWC calculations for different periods in time during an investigation. This work does this by considering 2022 as a full period as well as by splitting that sample in H1 and H2 of 2022. It shows that results do not differ significantly depending on the period. However, due to the Russian invasion of Ukraine, 2022 was a very turbulent year on the European wholesale electricity markets, hence it could be helpful to perform the same analysis for different periods before 2022. Nonetheless, it has to be mentioned that control variables can control for these structural changes. The fact that the results do not significantly change upon adding the control variables in the regression model, shows that selecting 2022 as a sample was an appropriate decision.

Furthermore, the RWC Index calculation fails to properly consider cross-border transmission capacity and its effects on market power. Cross-border transmission capacity can either alleviate or increase market power potential. As depicted in Chapter 4, the residual demand is utilized as the variable explaining prices in the day-ahead electricity market. To calculate this residual load, the total load is utilized, after which non-flexible energy generation sources such as wind and solar are subtracted. The value used for the total load can, however, include electricity trading from bordering bidding zones [31]. In this case, there is cross-border transmission capacity with France and Morocco. However, it is not straightforward to make adjustments for the non-flexible energy generation sources in those neighbouring bidding zones [31]. Nonetheless, the impact of cross-border transmission can be significant if smaller electricity markets with high reliability on supply from bordering bidding zones are considered [31]. In [31], it is pointed out that in this case, it might be advisable to rather estimate the demand instead of using the total load which can be done by summing up the bids from the price-setting firms in the specific bidding zone investigated. Fortunately, the Iberian market is a large market and cross-border transmission only presents a small fraction of the total energy generation. For France, the cross-border transmission capacity represents less than 3% of the total Iberian generation installed capacity, while for Morocco this is far below 1% [64]. For this reason, only a marginal impact can be expected from the cross-border capacity on potential market power potential in the Iberian market. However, caution is still recommended to monitor cross-border electricity flows. A potential impact could be that if transmission capacity reaches its limits, market power of local firms might increase.

At last, the RWC Index looks at the expected price jump if one MW is withheld. However, in reality, generators could be shutting down an entire plant of several hundreds of MWs if that is deemed profitable. The RWC Index fails to take this strategy into account. Hence, further research should focus on the expected impact of such strategies and find methods to quantify this type of strategic behaviour to identify potential market power abuse.

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