Determining the Economic Value of Nuclear Power in Spain

By

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ABSTRACT

The nature of deregulated energy markets in the United States has forced several nuclear reactors into early retirement over the next few years subjecting the energy market and economy as a whole to uncalculated risk. The unforeseen implications of early retirements of nuclear assets has inspired a cause for concern in Spain where nuclear power faces similar problems. In order to assess the danger that Spain's current market structure incentivizes a premature retirement of nuclear assets and suggest possible implications for carbon emissions, this thesis research project analyzed the economic performance of nuclear power generators in Spain and identified the underlying factors driving it. This was done by calculating the short run profitability of each nuclear reactor. Historical data on the generation, operating costs, and marginal price from the Spanish electricity market was gathered to develop a net profit model. The model was then applied looking forward into the future and revealed an average profitability of +32.24523 €/MWh for the nuclear reactors in Spain. These results point to a positive future for nuclear power in Spain and an incentive to extend the licenses of soon-to-be-retired reactors.

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Chapter 1

Introduction

The struggle of commercial nuclear reactors in the United States to compete in deregulated energy markets under significant financial pressure has resulted in several units being subjected to early retirement over the past few years [1]. These early retirements have inspired a cause for concern in international markets where nuclear power faces similar problems with competing forms of energy production such as low-cost natural gas and subsidized renewables. Spain, whose nuclear industry currently generates a fifth of the country's electricity, is one such place where there exists great concern over the future of nuclear power [2].

Spain currently has seven nuclear reactors with the construction of the first commercial nuclear power plant beginning in 1964 and its operation beginning in 1968 [2]. Over the past two decades, the commitment of the Spanish government to nuclear power has been questionable due to the allure of renewables. However, there has been an indication of more support of nuclear energy in Spain due to the increasing cost of subsidizing renewables since Spain's economic recession in 2012. The proposal of a new uranium mining project has also inspired hope in the nuclear industry, but nuclear reactors are still vulnerable to competition in the Spanish energy market [3].

Previous work in this area has been focused on nuclear power in US energy markets [1]. These studies have resulted in the development of economic models that predict the likelihood of early retirement of different nuclear power generators as well as their effects on carbon emissions. This thesis research project will analyze the economic performance of nuclear power generators in Spain and identify the underlying factors driving it. A key objective will be to assess the danger that the current market structure incentivizes a premature retirement of these assets.

Chapter 2
Background

2.1 The Spanish Electricity Market

There are three fundamental parts of every electricity industry which are generation, transmission, and distribution. Generation refers to the various power plants that produce the electricity, and which are connected to the high voltage lines of the transmission network. Transmission includes the high voltage lines and associated equipment that connect generators to the distribution networks serving load centers. Distribution is the low voltage lines and associated equipment that bring the electricity from the transmission network to the final retail customer [3]. The analysis in this paper will focus on the generation side of the electricity market.

The Spanish electricity market is part of the overall Iberian electricity market (MIBEL) together with the Portuguese electricity system. MIBEL is a product of the Santiago International Agreement between Spain and Portugal which established the governance structure for an integrated Iberian energy market, including (1) a spot electricity market, MIBEL, encompassing the daily and intraday markets, and (2) a futures market for electricity (including forwards and derivatives). The agreement created a Spanish-Portuguese business group, the Operador del Mercado Ibérico. Its Spanish division, OMIE or OMI-Polo Espanol, manages the spot electricity market, MIBEL, while its Portuguese division, OMIP, manages the futures market. Each market manager is 50% owned by a Spanish company, OMEL, and 50% by a Portuguese company, OMIP SGPS [4].

Another critical component of the Spanish electricity industry is the company Red Eléctrica de España, S.A. (REE), the Spanish Transmission and System Operator (TSO) [5]. REE's main function is the technical management of the Spanish electricity system which requires the continuous surveillance and coordination of the generation and transmission systems. The national regulator in Spain is the Comisión Nacional de la Energía (CNE). Its main purpose is to regulate the energy systems, maintain free competition and transparency of the performance, benefit all the organizations working in the system and the consumers [5].

There are five large electricity producers in Spain: Endesa, Iberdrola, Gas Natural SDG (traded as Gas Natural Fenosa), EDP HC Energía, and Visego. Spain has the luxury of a diverse energy portfolio which can be seen in Figure 2.1 below. Wind energy, hydropower, and nuclear energy contribute to the majority of the electricity production and the number of units of each generation type greater than ten megawatt hours can be seen in Figure 2.2 below.

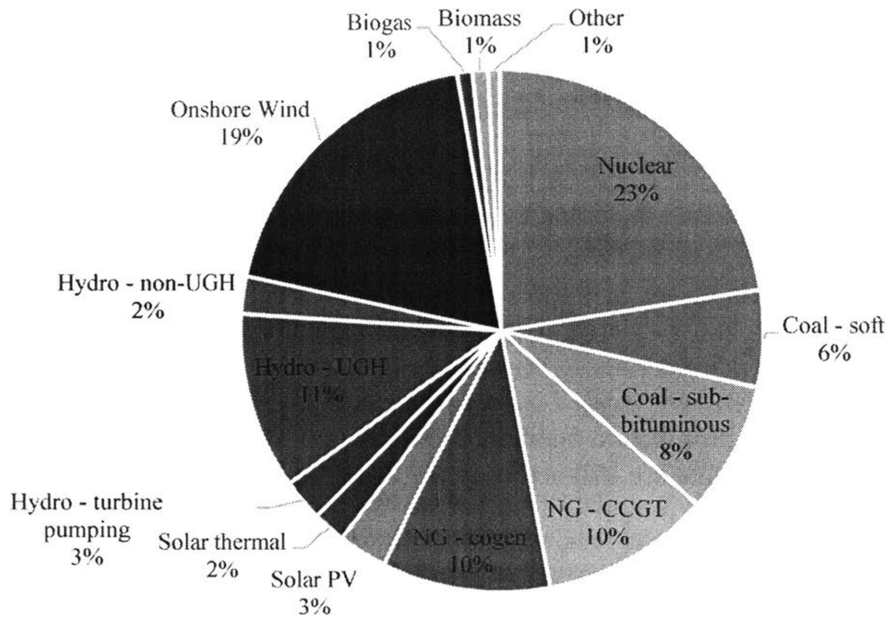

Figure 2.1. A pie chart showing the percentage each electricity production type contributes to the total generation of electricity in Spain.

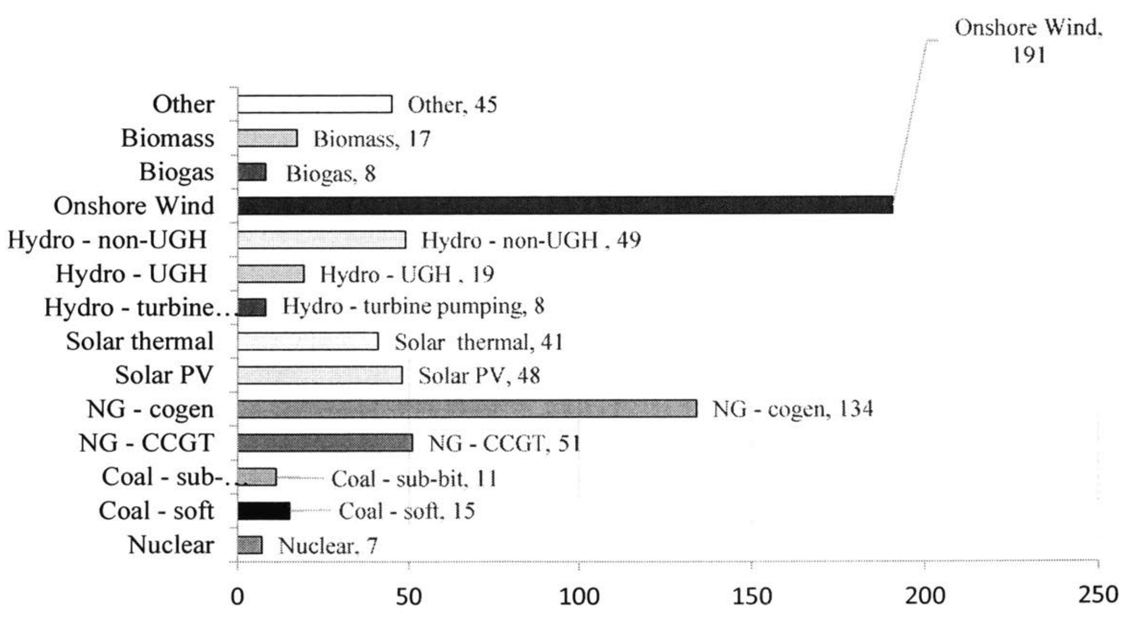

Figure 2.2. The number of units of each electricity production type that is greater 10 MWh.

2.2 Nuclear Power in Spain

2.2.1 History of Nuclear Governance

The first development of nuclear energy in Spain began in the early 1950's. During this time, the presiding organization over all nuclear matters was the Junta de Energía Nuclear (Nuclear Energy Board or JEN), an organization within the former Ministry of Industry and Energy of Spain [4]. The JEN had full control over raw materials procurement, basic scientific research and technology development, and personnel training. Due to the growth in popularity of nuclear power and a need for more regulations, the Spanish government passed the Nuclear Energy Act on April 29th, 1964.

The Nuclear Energy Act prompted a need for the transfer of responsibilities from the JEN to new organizations and entities that are still active today. These include the Consejo de Seguridad Nuclear (Nuclear Safety Council or CSN), the Empresa Nacional de Uranio, S.A (currently, ENUSA Industrias Avanzadas, S.A.), and the Empresa Nacional de Residuos Radiactivos, S.A. (ENRESA) [4]. ENUSA, a state owned company, was established in 1972 with the purpose of taking charge of all the nuclear fuel cycle front-end activities. The Nuclear Safety Council was created in 1980 in order to put more of an emphasis on nuclear safety and radiological protection matters. ENRESA was established in 1984 to manage nuclear waste and handle the dismantling of nuclear installations. In 1986, the Nuclear Energy Board was completely replaced by the Centre for Energy-Related, Environmental and Technological Research (CIEMAT). The current relationship between all of these organizations can be seen in Figure 2.3 below.

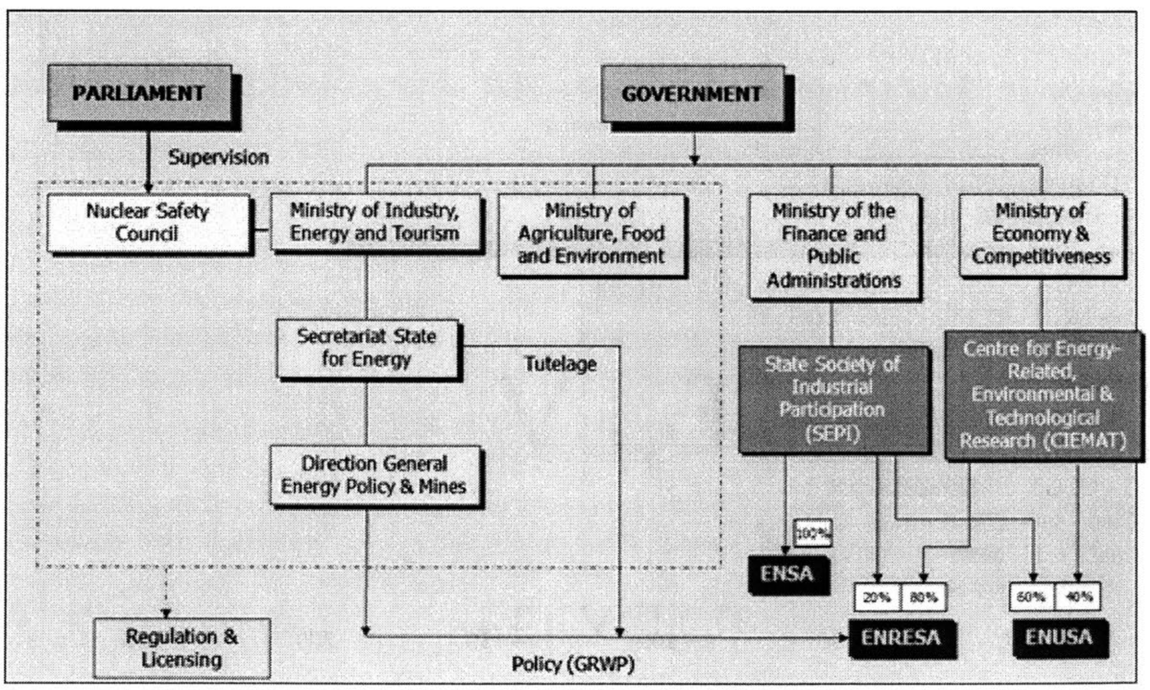

Figure 2.3. The current institutional framework of nuclear energy in Spain.

2.2.2 Nuclear Power Plants

In the late 1960's, the construction of the first generation nuclear power plants (NPPs) José Cabrera, Santa María de Garońa, and Vandellós I started. The construction of the second generation NPPs Almaraz I and II, Lemóniz I and II, Ascó I and II, and Cofrentes began in the early 1970's, but Lemóniz I and II were never completed. A third generation of NPPs consisting of five units started construction in the early 1980's, but only Vandellós II and Trillo I were completed due to a 1984 moratorium, or construction pause, which was confirmed indefinitely ten years later [2].

As of today, only seven nuclear reactors remain in operation in the Spanish electricity market. A summary of their timelines can be seen in Table 1 below and it should be noted that all but one of the NPPs are approaching the end of their current licensing in the next two to three years and the end of their 40-year lifespans shortly thereafter.

Table 1. Current capacities, licensing, and end-of-life dates of nuclear reactors in Spain. [5]

Nuclear Power Plant	Type	Gross Capacity (MW)	Net Capacity (MW)	Comission-ed	Current license until	To be closed (after 40 years)
Almaraz I	PWR	1035.3	1011	May, 1981	2020	2021
Almaraz II	PWR	1045	1006	Oct, 1983	2020	2023
Ascó I	PWR	1032.5	996	Aug, 1983	2021	2023
Ascó II	PWR	1027.21	992	Oct, 1985	2021	2025
Cofrentes	BWR	1092.02	1064	Oct, 1984	2021	2024
Vandellós II	PWR	1087.14	1045	Dec, 1987	2020	2027
Trillo I	PWR	1066	1003	May, 1988	2024	2028

Chapter 3
Approach and Methods

In order to determine the economic performance of nuclear power generators in Spain, the short-run profitability of each nuclear power generator must be evaluated. This is done by subtracting the short-run operating cost from the revenue from electricity sales in order to give an indication of each generator's economic performance. Installed capacity, the maximum amount of power a power plant can output, was taken as given, and did not take into account major capital investments for refurbishment, uprates or other important changes to capacity. The key input was the annual operating cost of the units. Historical data from 2014 to 2017 was used to calculate the short-run profitability of each reactor. The model was then applied to the years from 2018 to 2021 to determine whether the current market structure provides incentives to continue operating these units or whether it incentivizes premature shutdown.

The net profit per megawatt hour (MWh) of each nuclear generating unit can be calculated directly according to,

$$Net\ Profit\ per\ MWh = AMP - MC, \qquad (3.1)$$

where *AMP* is the average marginal price of the day ahead market associated with MIBEL in Spain and *MC* is the total marginal cost associated with each power plant. The annual *AMP* from 2007 to 2017 was gathered from the OMIE database and can be seen in Figure 3.1 below. The total marginal cost of a nuclear plant consists of its fuel costs and fixed operation and maintenance costs. The average annual marginal cost was determined using information from REE's System Information Operation System (eSIOS) and REE's National Statistical Series (REE) [6]. The marginal costs for each plant can be seen in Table 2 below.

The total net profit over the period of one year can then be calculated using,

$$Net\ Profit = (AMP - MC) * Generation, \qquad (3.2)$$

where *Generation* refers to the total amount of megawatt hours produced by a unit in the course of a year. Using equations 3.1 and 3.2, one can reveal and compare the economic viability of each reactor.

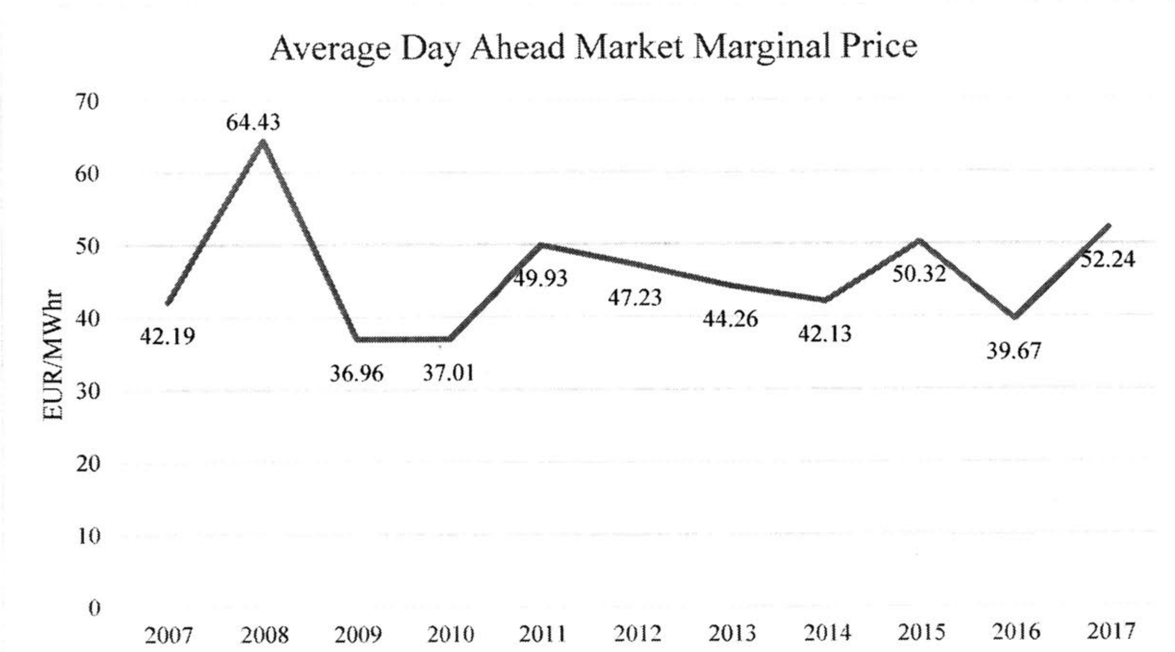

Figure 3.1. The annual average marginal price in EUR/MWh for the day ahead MIBEL market in Spain from 2007-2017.

Table 2. Marginal cost of each plant in **€/MWh** based on estimates found in REE database. Historical data was used from 2014 to 2017 and the marginal cost from 2017 was used for the years 2019 to 2021 [6].

	2014	2015	2016	2017	2018	2019	2020	2021
Almaraz I	11.02	11.02	14.4450214	13.5676428	13.5676428	13.5676428	13.5676428	13.5676428
Almaraz II	11.03	11.03	14.4450321	13.5680387	13.5680387	13.5680387	13.5680387	13.5680387
Ascó I	11.05	11.05	14.4450535	13.5680601	13.5680601	13.5680601	13.5680601	13.5680601
Ascó II	11.06	11.06	14.4450642	13.5680708	13.5680708	13.5680708	13.5680708	13.5680708
Cofrentes	11	11	14.445	13.5680066	13.5680066	13.5680066	13.5680066	13.5680066
Vandellós II	11.01	11.01	14.4450428	13.5680173	13.5680173	13.5680173	13.5680173	13.5680173
Trillo I	11.04	11.04	14.4450749	13.5680494	13.5680494	13.5680494	13.5680494	13.5680494

Table 3. Annual net generation in **MWh** of each nuclear reactor from 2012 to 2021. Historical data was obtained from the PRIS database for 2012-2017 and the average over that period was used as the generation for the future (2018-2021) [5].

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Almaraz I	7346070	7695840	7252450	8438610	7447790	7753930	7655782	7655782	7655782	7655782
Almaraz II	7698780	7412900	7949000	7635930	7726480	8593490	7836097	7836097	7836097	7836097
Ascó I	7388220	8687390	7096390	7397930	8349800	7522940	7740445	7740445	7740445	7740445
Ascó II	7831530	7274220	6837370	8442110	7646240	7716070	7624590	7624590	7624590	7624590
Cofrentes	9064140	8012790	9114790	7438670	9187250	7060250	8312982	8312982	8312982	8312982
Vandellós II	7718560	7742950	8824890	7478530	7650330	8997980	8068873	8068873	8068873	8068873
Trillo I	7948780	7487110	7785490	7926990	8004550	7983090	7856002	7856002	7856002	7856002

Chapter 4.

Results and Discussion

The results of the short run profitability calculations yielded positive values for all of the nuclear reactors which indicates that each unit will remain substantially profitable for the duration of their license. In order to estimate an annual *AMP* for every year from 2018 to 2021, a second degree polynomial was fitted to the plot above in Figure 4.1. The individual plant analysis shows profitability in the range of +32.2452 €/MWh to +32.2456 €/MWh as seen in Figure 4.1 below. This is an extremely narrow range which can be attributed to the homogenous nature of the nuclear reactors in Spain. Each unit has a similar installed capacity, a low marginal cost with respect to other energy generators, and a high capacity factor. The short run profitability of each nuclear reactor is expected to decrease over the next four years as indicated in Figure 4.2 below. This is due to the overall declining electricity price in the Spanish market which is common amongst most electricity markets around the world.

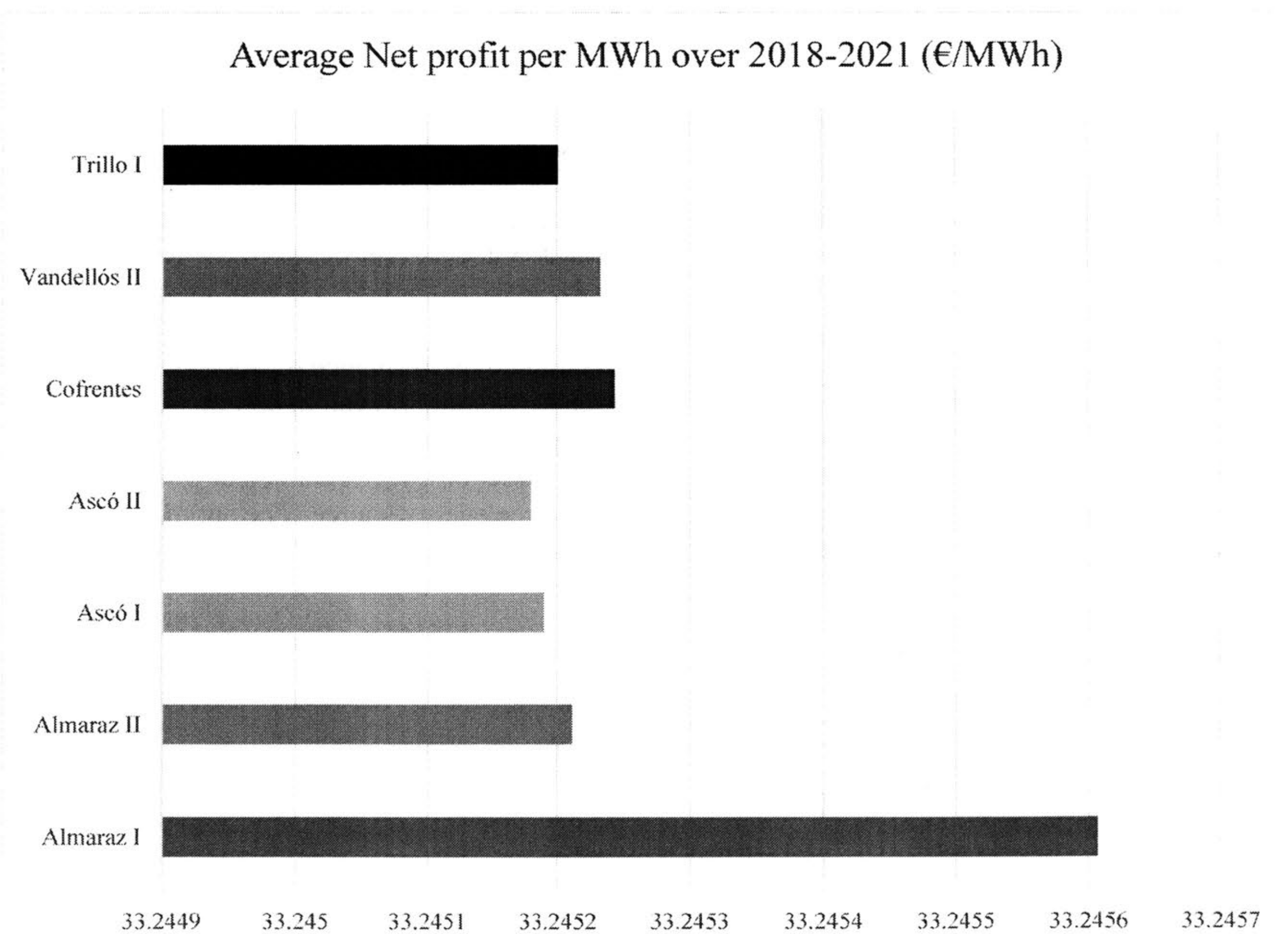

Figure 4.1. The profitability of the seven Spanish nuclear reactors occupied a narrow range of +32.2452 €/MWh to +32.2456 €/MWh.

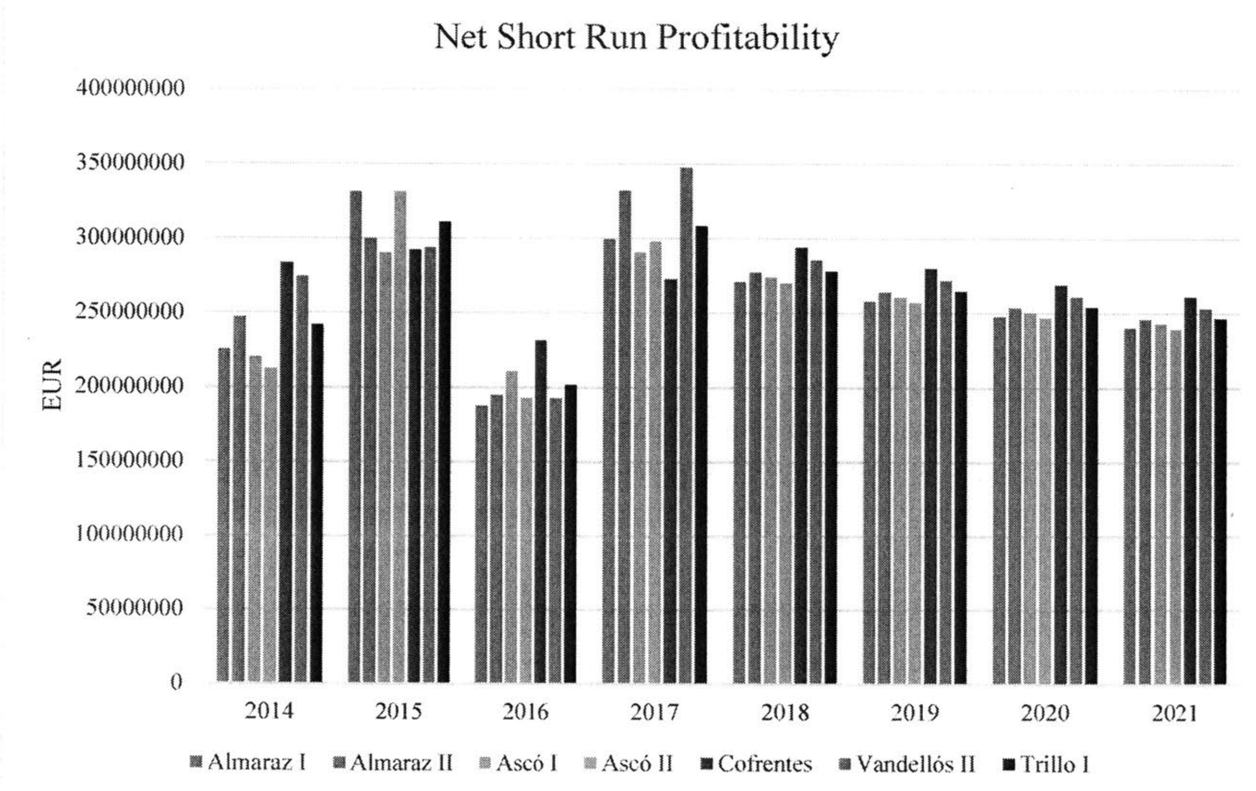

Figure 4.2. The net short run profitability of each nuclear reactor from 2014 to 2021 in euro. This shows the overall large profit nuclear power brings in due to its low marginal cost and lack of carbon emissions.

Some potential market indicators of the good economic performance of nuclear power are a stable or slightly increasing wholesale electricity price and a more prevalent and increasing cost of European Emission Allowance (EUA). The European Union adds a cost per ton of carbon dioxide emitted during electricity generation to overall production costs and nuclear power fortunately evades this extra cost due to it being a carbon free energy source. The sporadic behavior of the EUA over the last four years can be seen in Figure 4.3 below.

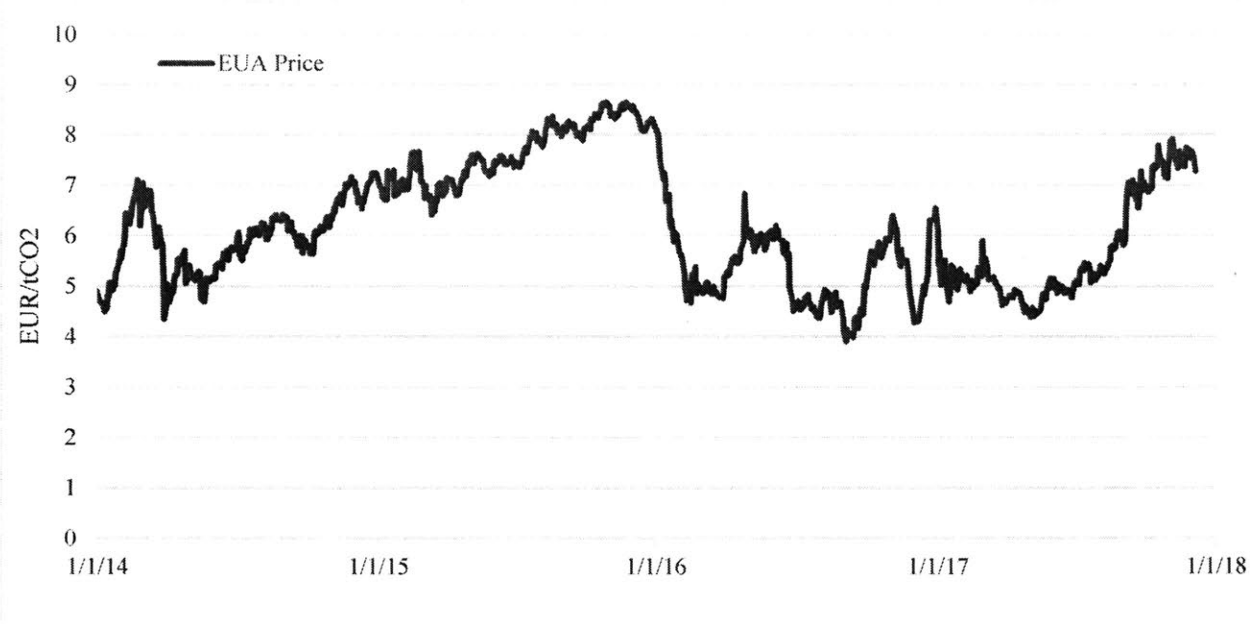

Figure 4.3. The European Emission Allowance (EUA) price in euro per ton CO_2 from 2014 to 2018. This was retrieved from the EEX Spot Market [7].

Chapter 5.
Conclusion

The findings of this thesis point to a positive future economic performance for nuclear power in Spain. However, this is not necessarily true since all of the nuclear reactors in Spain are approaching the end of their licensed periods of operation within the next decade. There are currently no plans to extend the life of the existing nuclear power plants in Spain which sparks great concern for the implications of what would be the removal of over twenty percent of the current grid. Replacing the units with combined cycle gas turbines or other fossil fuels generators would seriously impact Spain's ability to meet the environmental goals set forth by itself and the European Union. On the other hand, replacing the nuclear reactors with renewables will require a significant amount of more generating units than what would be removed. This is taxing on the grid and already existing infrastructure within the electricity market.

In order to fully explore the possibilities and implications of nuclear retirements in Spain, the wholesale electricity market needs to be heavily scrutinized and modeled to account for the variability in factors that affect price such as medium to long term market conditions and the uncertainty associated with all future cash flows. Once a wholesale electricity model is conceived, the price can be better manipulated to account for scenarios such as premature reactor shutdown or a need to meet environmental constraints. In the future, the work done on the short run profitability of nuclear reactors in Spain can be used in conjunction with a wholesale electricity model to better analyze alternative scenarios for mitigating carbon emissions and the costs associated with them.

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