The impact of the EU emissions trading scheme on the wholesale electricity pricing formulation

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ
ΤΜΗΜΑ ΔΙΕΘΝΩΝ ΚΑΙ
ΕΥΡΩΠΑΪΚΩΝ ΣΠΟΥΔΩΝ

MSc Energy: Strategy, Law and Economics

University of Piraeus

Konstantinos Menyktas, July 2022

MEN20022

Disclaimer: Το έργο που εκπονήθηκε και παρουσιάζεται στην υποβαλλόμενη διπλωματική εργασία είναι αποκλειστικά ατομικό δικό μου. Όποιες πληροφορίες και υλικό που περιέχονται έχουν αντληθεί από άλλες πηγές, έχουν καταλλήλως αναφερθεί στην παρούσα διπλωματική εργασία. Επιπλέον τελώ εν γνώσει ότι σε περίπτωση διαπίστωσης ότι δεν συντρέχουν όσα βεβαιώνονται από μέρους μου, μου αφαιρείται ανά πάσα στιγμή αμέσως ο τίτλος. / the intellectual work fulfilled and submitted based on the delivered master thesis is exclusive property of mine personally. Appropriate credit has been given in this diploma thesis regarding any information and material included in it that have been derived from other sources. I am also fully aware that any misrepresentation in connection with this declaration may at any time result in immediate revocation of the degree title.

Κωνσταντίνος Μενύκτας

Table of Contents

Table of Figures and Tables

Abstract

In this thesis, we are going to examine the impact of the European Union Emissions Trading Scheme (EU ETS) on wholesale electricity prices. To do so, we will look into 1. the factors that affect the EUA prices and 2. the passthrough rate of the European Union Allowance (EUA) prices to the wholesale electricity prices. This way, it will be easier to quantify the impact of the EUA prices on the electricity prices in the past but also, we will be able to make an educated prediction for the future (mainly in the medium-long term). The main problem is that the EUA prices are affected by a wide variety of factors, and due to the significance of the EUA prices to the wholesale prices, many energy market players are having trouble planning their strategies, because of the extreme fluctuations of the Wholesale electricity prices. This research will be a step toward understanding and quantifying the fluctuations of the power prices that are caused by the fluctuations in the EUA prices. We are going to examine the EU ETS history and draw some conclusions regarding the changes in its structure and its scope and the impact on the EUA prices. Moreover, we are going to use some statistical analysis to conclude the case of the post-Target model Greek Day-Ahead Market (DAM) and illustrate the bidding patterns of the Greek power producers following various factors and their marginal cost. Last, we are going to implement an OLS to the Greek DAM and provide robust evidence that the passthrough rate of the EUA price to the Greek DAM is 94% and then we will combine all of the above in an attempt to quantify the impact of the EU ETS to the wholesale electricity prices in Europe as the conclusion.

Chapter 1: Introduction

The European Union Emission Trading Scheme (EU ETS), is the natural evolution of the Kyoto Protocol for the European Union area. The main purpose of the EU ETS is rationing and limiting the Greenhouse Gas emissions from the economic activities within the EU, with the ultimate target of achieving a carbon-neutral economy by 2050 (European Commission,2021). This is done through the imposed obligation (which is enforced by the EU) of the polluters (from specific industries) to buy one EUA (European Union Allowance) for each ton of Green House Gas equivalent emission that they emit. One of the industries that are affected significantly by the ETS is electricity production, since some production technologies are responsible for the majority of the CO2 emissions in Europe (as we are going to see in the next chapter more analytically). The EUA cost is added to the production cost of the polluting power production technologies, which might lead to more expensive electricity. In this thesis, we are going to examine what is the impact of the EU ETS on wholesale electricity prices.

More specifically, to shed some light on that problem, we are going to look into 1. the factors that affect the EUA prices and 2. the passthrough rates of the EUA cost from the power producers to the wholesale markets as two separate issues. This thesis is an effort to establish some scenarios regarding the EUA price levels up to the year 2030 and assess how these EUA price levels are going to increase the current wholesale prices in the Greek DAM. This research can be of great importance to several stakeholders, like the European governments, the governments of other countries that are considering launching their Emission Trading System (e.g. China), policy makers, Energy traders/suppliers, and of course the academia, as it can assist with the identification of the ideal EUA price which will balance the contribution towards the achievement of the EU environmental targets, without compromising the competitiveness of the European industries or the standard of living of the European citizens.

The methods that are going to be used are: statistical analysis for the explanation of the impact of the changes of the ETS rules throughout the 4 phases to the ETS price, techno-economic analysis on the impact of the EUA price on the marginal cost of the Greek power producers and on the way that the EU can motivate the power producers to substitute the polluting technologies, like coal and lignite, to more environmentally friendly ones, through marginal cost controlling. Moreover, we will demonstrate some statistical analysis regarding the EUA passthrough rates of the natural gas producers to the Greek DAM and we will implement an Ordinary Least Square (OLS) regression to examine the significance and the correlation of the EUA price to the Greek wholesale prices for the period after the beginning of the EU Target Model in Greece (from November 2020 to December 2021).

The most important result of this research is the quantification of the impact of the EUA price on the electricity prices for the next few years, along with a method of adjusting the quantification in accordance with the changes in the most important factors that affect 1. the EUA price and 2. the passthrough rates of the power producers to the wholesale electricity prices.

The main contribution of this thesis is that it sheds light on all the aspects of the relation between the EUA prices (and the ETS) and the wholesale spot power prices, as we examine the factors that affect the EUA prices, the endgame (goals) of the relevant EU policies and the passthrough rates of the EUA cost to the power prices as an interconnected system. On top of that, we examine the Greek DAM after the beginning of the Target Model, while at the same time we take into consideration the Greek power production stack that is mentioned in the Greek national plan regarding the energy and the environment (which, probably, has not been done before). The results that we get appear to be robust, as they confirm both the results of the previous literature and our regression analysis regarding the passthrough rates of the EUA cost. Moreover, the main gap in the related existing literature that this thesis is set out to fill, is that our analysis can be considered as a framework that can be applied and provide conclusions about the impact of the EU policies on the EUA prices and about the passthrough rates of the EUA prices to the power prices in the long term, rather than a static prediction model whose robustness would be compromised in case that some aspects of the ETS or the Greek DAM would change significantly.

Going forward, in the next chapters, the history of the EU ETS is going to be analyzed, with consideration of the changes in its scope, the limitation of each period of the ETS, and the macroeconomic factors that affected the EUA prices (e.g., the 2008 financial crisis or the countries' power production stack). After that, we are going to summarize the previous literature review that is related to the two main topics of this thesis: 1. What are the factors that affect the EUA prices, and 2. what is the passthrough rate of the EUA cost to the wholesale power prices from the power producers. To do so, we are going to see how the electricity spot market (Target Model) works, argue about the importance of the EU policies that are aimed at the achievement of the EU's environmental targets, and how they can overtake the various other factors that have been spotted in the literature review in the long run. That section will be followed by an illustration of the marginal cost of the Greek lignite and natural gas producers to conclude that we can estimate the EUA price levels that the EU will impose in the long term (by affecting the EUA supply), to phase out coal and lignite usage by the year 2030 (which is a benchmark target). Then, with the use of the statistical analysis, we are going to combine data from various sources and illustrate the importance of the natural gas power production units in setting the Greek DAM price (also known as the Marginal Clearing Price, MCP) and show the bidding patterns of the natural gas units concerning various factors like the residual demand for electricity, the fuel price and the EUA price. This way, the readers can understand in better way the logic behind the ETS and how the EU uses the marginal cost of the power producers as a tool for the reduction of pollutive technologies. Lastly, we are going to present an OLS regression, which will help us estimate the overall passthrough rate of the EUA price to the Greek DAM prices and make all of the concluding remarks in the last chapter.

Chapter 2: The History of ETS

2.1 The Kyoto Protocol

The EUA scheme is the European means towards the achievement of the targets that were set in the Kyoto Protocol, in 1997. The Kyoto Protocol (initially) burdened mainly 37 industrialized countries and the EU Member States, to reduce Greenhouse Gas emissions, proportionately, to achieve specific targets in various timeframes (United Nations Framework Convention on Climate Change (website), 2021). This means that each country has undertaken specific targets to collectively manage to reduce drastically the CO2 emissions from human activities with a longer-term target to achieve the nullification of the net emissions during the next decades.

Moreover, according to (United Nations Framework Convention on Climate Change (website), 2021), several mechanisms were created to secure that the Kyoto Protocol targets will be achieved. The "Clean Development Mechanism" allows countries that assist with the development of CO2 cutting technologies in developing countries, to earn an equivalent number of tradable emission reduction credits. Similarly, the "Joint implementation" awards emission reduction units for the same reasons as the Clean Development Mechanism. Most importantly, the "Emission Trading" mechanism allows for countries that have excess (unused) emission allowances, to sell them to other countries that have a deficit of allowances.

All of the transactions between countries are registered in an international transaction log and they are linked to the regional emission trading schemes (such as the EU emission trading scheme). Last, the various countries submit their emissions every year, following the compliance regulations.

According to (United Nations Framework Convention on Climate Change (website), 2021), Annex B includes the countries' target for emission reductions, for the period 2008 - 2012 (first period), in a way that, as an average, the emissions would decrease to that of the 95% of the emissions of the base year 1990. Nevertheless, some individual countries chose different base years (e.g. 1995). Similarly, in the second Period (2013 – 2020) the participants committed to an average reduction of 18% from their base year.

It is important to mention that 2 of the biggest Western economies, namely the United States of America and Canada, withdrew from the Kyoto Protocol commitments. This fact can jeopardize the global collective effort of the participant countries.

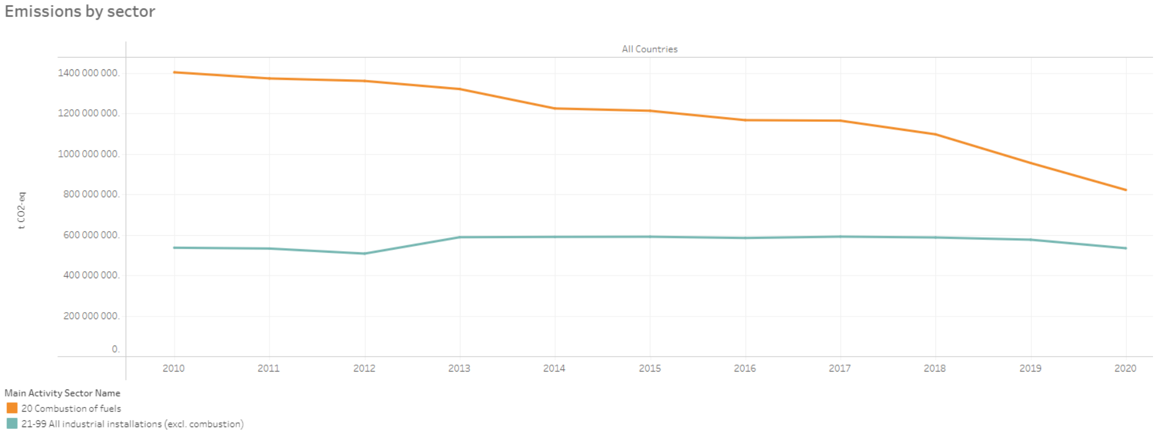
2.2 EUAs and the ETS

Following the official website of the European Commission (2021), the European Trading Scheme (ETS) was decided (and agreed upon) in 2003 and commenced in 2005, which made it “the first international Emission Trading Scheme in the world”. Similarly, with the Kyoto Protocol, the EU ETS is divided into distinctive Periods, with different targets or even further changes from the previous periods (e.g. industries/countries included).

The concept is that countries commit to a limit of emissions (“Cap”) that they will produce for certain periods, as the emissions allowances were distributed to different countries and industries with the use of the “national allocation plans”. The participant countries are the EU-27 plus the U.K., Iceland, and Norway. Each country gets allocated free allowances, which in turn are allocated to various industries (and companies), or the liable entities will have to buy the allowances from the European Trading System (cap and trade). The utility of this system is twofold. First of all, there is a cap on the maximum CO2 (or equivalent) emissions the EU-regulated industries can release. At the same time, the EUAs are a “marginal cost” tool, which guides the pollutant industries toward more sustainable practices in an indirect way. As the demand for EUAs becomes higher than the supply, the prices of the EUAs also increase, which makes the pollutant technologies more expensive than the sustainable ones, and thus the industries choose to invest in the latter, as it makes economic sense. In other words, the “polluters” get “taxed” for each ton of CO2 emissions (or equivalent gases) that they release, which makes their products more expensive and less competitive compared to the production of more sustainable companies.

The vast majority of the verified emissions comes from the “Combustion of Fuels”, while the other most polluting industries are the refineries, cement production, and metal production. In figure 1 (taken from the European Environmental Agency (2021)), it is illustrated that the verified emissions from combustion are higher than the sum of the verified emissions from all the other industries that are liable to the EU ETS together. Nevertheless, it can be observed that the EU ETS has been more focused on reducing the emissions for energy production, as there is an ongoing decline year by year, in contrast to the rest of the industries whose emissions are slightly higher in 2019 compared to 2010. This is because after Phase 1, every sector, except for heating and electricity, was awarded free allowances which have been reduced gradually. The free allocations were 80% in 2013 and went down to 30% by 2020. Moreover, ten developing European countries were eligible for free allowances, but not all of those countries chose to get them (because there were alternative options for these countries to benefit from the European funds in different manners).

Figure 1: Emissions by sector

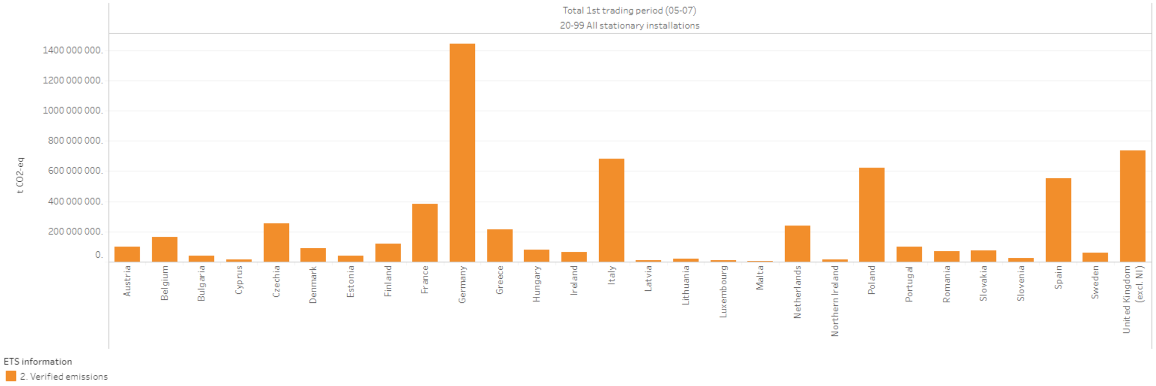


Source: (European Environmental Agency, 2021)

2.2.1 Phase 1 (2005 – 2007)

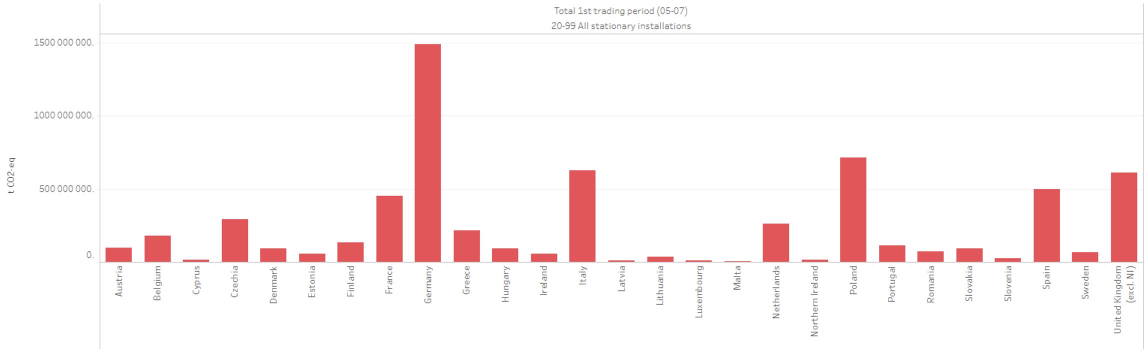
The first period, which is called Phase 1 (2005-2007), was the 3-year test period that was used as a bridge to the next phases that had stricter rules and punishments for deviations. According to the official website of the European Commission (2021), the power generation industry was mainly liable to buy EUAs, although the majority of the EUAs were distributed for free and a symbolic price was established for deviations from the rules (40 euros per ton). The main result from the first phase was the infrastructure testing that would set the basis for the success of the European Trading Scheme. It is important to mention that phase 1 allowances could not be stored and transferred to the next phases.

Figure 2: Emissions by country Phase 1 (2005-2007)



Source: (European Environmental Agency, 2021)

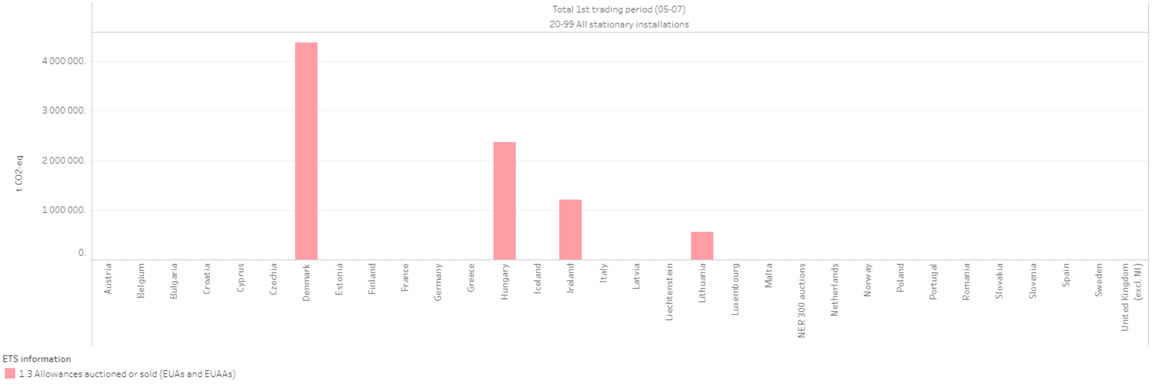
Figure 3: Freely allocated Allowances by country Phase 1 (2005-2007)



Source: (European Environmental Agency, 2021)

From figure 2, figure 3, and figure 5, it is obvious that the vast majority of the allowances had been allocated freely, as only 8.5 million tons of CO2 equivalent emissions were sold or auctioned, out of a total of 6,321 million. All the figures are excluding Aviation emissions and they were taken from the European Environmental Agency website.

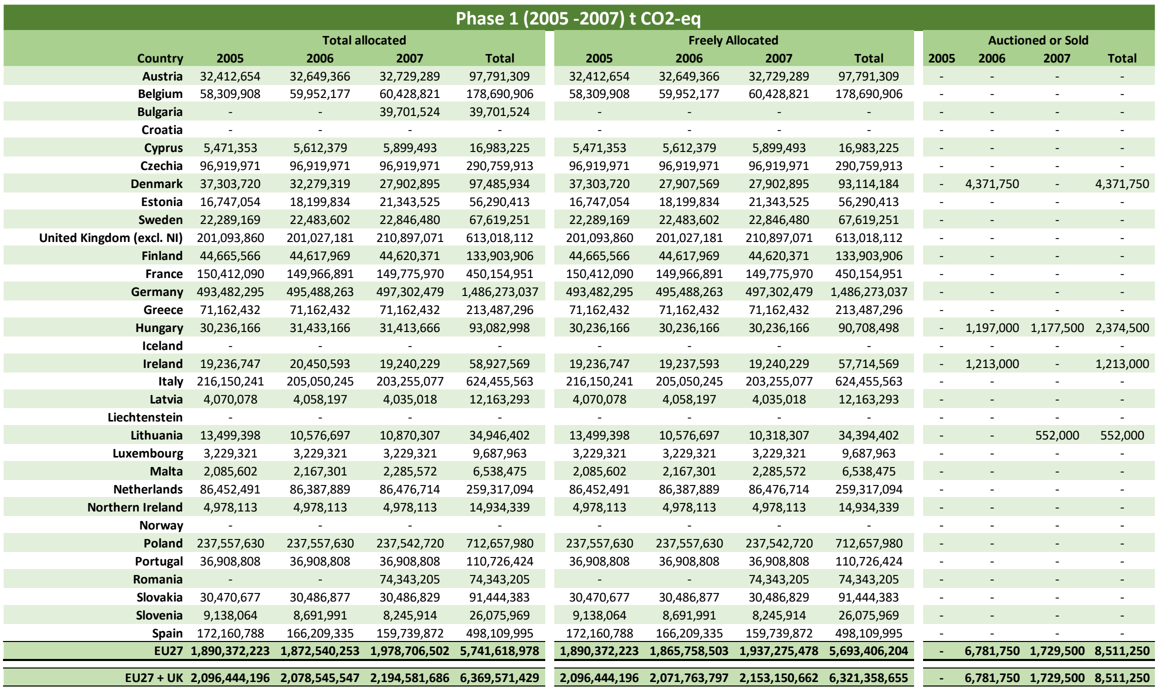
Figure 4: Allowances auctioned or sold by country Phase 1 (2005-2007)



Source: (European Environmental Agency, 2021)

Following Aleluia (2018), in April 2006, there was evidence of an oversupply of emissions, which caused the price to drop from approximately 30 euros to lower than 15 euros within one week (from 24/04/2006 to 28/04/2006). In Figure 6 (data from the European Environmental Agency), we can see the magnitude of the EUA 2007 fall, after the realization of the oversupply. The price of the EUAs is very closely related to their scarcity. Due to the oversupply of EUAs, the price was close to zero by the end of 2007, as the liable entities had already covered the need for emission allowances.

Figure 5: Phase 1 Summary (2005-2007)

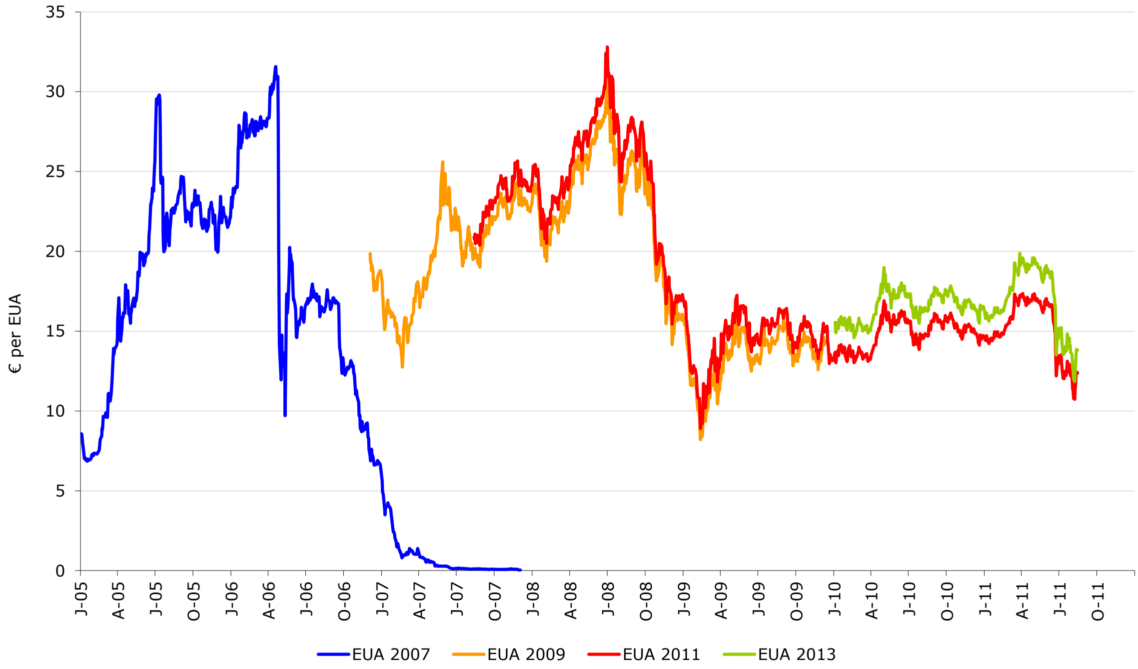


Phase 1 (2005 -2007) t CO2-eq

	Total allocated				Freely Allocated				Auctioned or Sold			
Country	**2005**	**2006**	**2007**	**Total**	**2005**	**2006**	**2007**	**Total**	**2005**	**2006**	**2007**	**Total**
Austria	32,412,654	32,649,366	32,729,289	97,791,309	32,412,654	32,649,366	32,729,289	97,791,309	-	-	-	-
Belgium	58,309,908	59,952,177	60,428,821	178,690,906	58,309,908	59,952,177	60,428,821	178,690,906	-	-	-	-
Bulgaria	-	-	39,701,524	39,701,524	-	-	-	-	-	-	-	-
Croatia	-	-	-	-	-	-	-	-	-	-	-	-
Cyprus	5,471,353	5,612,379	5,899,493	16,983,225	5,471,353	5,612,379	5,899,493	16,983,225	-	-	-	-
Czechia	96,919,971	96,919,971	96,919,971	290,759,913	96,919,971	96,919,971	96,919,971	290,759,913	-	-	-	-
Denmark	37,303,720	32,279,319	27,902,895	97,485,934	37,303,720	27,907,569	27,902,895	93,114,184	-	4,371,750	-	4,371,750
Estonia	16,747,054	18,199,834	21,343,525	56,290,413	16,747,054	18,199,834	21,343,525	56,290,413	-	-	-	-
Sweden	22,289,169	22,483,602	22,846,480	67,619,251	22,289,169	22,483,602	22,846,480	67,619,251	-	-	-	-
United Kingdom (excl. NI)	201,093,860	201,027,181	210,897,071	613,018,112	201,093,860	201,027,181	210,897,071	613,018,112	-	-	-	-
Finland	44,665,566	44,617,969	44,620,371	133,903,906	44,665,566	44,617,969	44,620,371	133,903,906	-	-	-	-
France	150,412,090	149,966,891	149,775,970	450,154,951	150,412,090	149,966,891	149,775,970	450,154,951	-	-	-	-
Germany	493,482,295	495,488,263	497,302,479	1,486,273,037	493,482,295	495,488,263	497,302,479	1,486,273,037	-	-	-	-
Greece	71,162,432	71,162,432	71,162,432	213,487,296	71,162,432	71,162,432	71,162,432	213,487,296	-	-	-	-
Hungary	30,236,166	31,433,166	31,413,666	93,082,998	30,236,166	30,236,166	30,236,166	90,708,498	-	1,197,000	1,177,500	2,374,500
Iceland	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	19,236,747	20,450,593	19,240,229	58,927,569	19,236,747	19,237,593	19,240,229	57,714,569	-	1,213,000	-	1,213,000
Italy	216,150,241	205,050,245	203,255,077	624,455,563	216,150,241	205,050,245	203,255,077	624,455,563	-	-	-	-
Latvia	4,070,078	4,058,197	4,035,018	12,163,293	4,070,078	4,058,197	4,035,018	12,163,293	-	-	-	-
Liechtenstein	-	-	-	-	-	-	-	-	-	-	-	-
Lithuania	13,499,398	10,576,697	10,870,307	34,946,402	13,499,398	10,576,697	10,318,307	34,394,402	-	-	552,000	552,000
Luxembourg	3,229,321	3,229,321	3,229,321	9,687,963	3,229,321	3,229,321	3,229,321	9,687,963	-	-	-	-
Malta	2,085,602	2,167,301	2,285,572	6,538,475	2,085,602	2,167,301	2,285,572	6,538,475	-	-	-	-
Netherlands	86,452,491	86,387,889	86,476,714	259,317,094	86,452,491	86,387,889	86,476,714	259,317,094	-	-	-	-
Northern Ireland	4,978,113	4,978,113	4,978,113	14,934,339	4,978,113	4,978,113	4,978,113	14,934,339	-	-	-	-
Norway	-	-	-	-	-	-	-	-	-	-	-	-
Poland	237,557,630	237,557,630	237,542,720	712,657,980	237,557,630	237,557,630	237,542,720	712,657,980	-	-	-	-
Portugal	36,908,808	36,908,808	36,908,808	110,726,424	36,908,808	36,908,808	36,908,808	110,726,424	-	-	-	-
Romania	-	-	74,343,205	74,343,205	-	-	74,343,205	74,343,205	-	-	-	-
Slovakia	30,470,677	30,486,877	30,486,829	91,444,383	30,470,677	30,486,877	30,486,829	91,444,383	-	-	-	-
Slovenia	9,138,064	8,691,991	8,245,914	26,075,969	9,138,064	8,691,991	8,245,914	26,075,969	-	-	-	-
Spain	172,160,788	166,209,335	159,739,872	498,109,995	172,160,788	166,209,335	159,739,872	498,109,995	-	-	-	-
EU27	**1,890,372,223**	**1,872,540,253**	**1,978,706,502**	**5,741,618,978**	**1,890,372,223**	**1,865,758,503**	**1,937,275,478**	**5,693,406,204**	**-**	**6,781,750**	**1,729,500**	**8,511,250**
EU27 + UK	**2,096,444,196**	**2,078,545,547**	**2,194,581,686**	**6,369,571,429**	**2,096,444,196**	**2,071,763,797**	**2,153,150,662**	**6,321,358,655**	**-**	**6,781,750**	**1,729,500**	**8,511,250**

Source: (European Environmental Agency, 2021)

Figure 6: EUA 2007 price drop

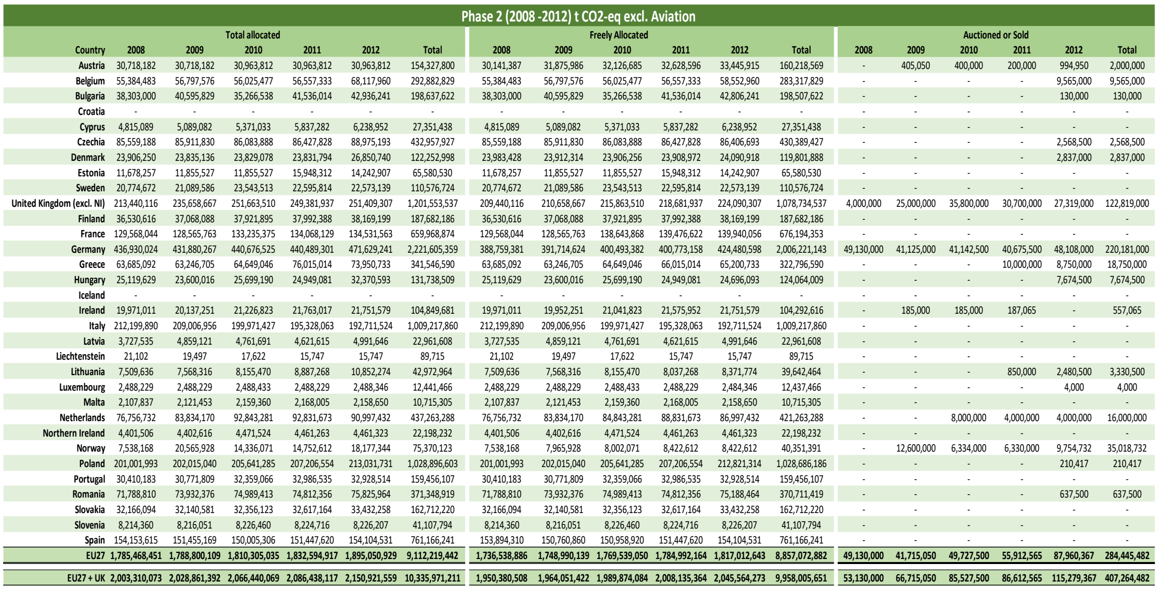


Source: (European Environmental Agency, 2021)

2.2.2 Phase 2 (2008 – 2012)

Following the official website of the European Commission (2021), during the second phase of the ETS, each party member had individual targets related to their emissions. The cap was even lower compared to phase 1, "Nitrous Oxide" emissions were included as Greenhouse Gas emissions and 3 additional non-EU members joined the scheme (namely: "Iceland, Liechtenstein, and Norway"). At the same time, the non-compliance fee increased from €40/ton (in Phase 1) to €100/ton. One union-wide registry was formed and it replaced the individual country ones and the liable companies started buying EUAs (1.4 billion tons worth of "international credits").

Figure 7: Phase 2 Summary (2008-2012)



Phase 2 (2008 -2012) t CO2-eq excl. Aviation																		
	Total allocated						Freely Allocated						Auctioned or Sold					
Country	2008	2009	2010	2011	2012	Total	2008	2009	2010	2011	2012	Total	2008	2009	2010	2011	2012	Total
Austria	30,718,182	30,718,182	30,963,812	30,963,812	30,963,812	154,327,800	30,141,387	31,875,986	32,126,685	32,628,596	33,445,915	160,218,569	-	405,050	400,000	200,000	994,950	2,000,000
Belgium	55,384,483	56,797,576	56,025,477	56,557,333	68,117,960	292,882,829	55,384,483	56,797,576	56,025,477	56,557,333	58,552,960	283,317,829	-	-	-	-	9,565,000	9,565,000
Bulgaria	38,303,000	40,595,829	35,266,538	41,536,014	42,936,241	198,637,622	38,303,000	40,595,829	35,266,538	41,536,014	42,806,241	198,507,622	-	-	-	-	130,000	130,000
Croatia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyprus	4,815,089	5,089,082	5,371,033	5,837,282	6,238,952	27,351,438	4,815,089	5,089,082	5,371,033	5,837,282	6,238,952	27,351,438	-	-	-	-	-	-
Czechia	85,559,188	85,911,830	86,083,888	86,427,828	88,975,193	432,957,927	85,559,188	85,911,830	86,083,888	86,427,828	86,406,693	430,389,427	-	-	-	-	2,568,500	2,568,500
Denmark	23,906,250	23,835,136	23,829,078	23,831,794	26,850,740	122,252,998	23,983,428	23,912,314	23,906,256	23,908,972	24,090,918	119,801,888	-	-	-	-	2,837,000	2,837,000
Estonia	11,678,257	11,855,527	11,855,527	15,948,312	14,242,907	65,580,530	11,678,257	11,855,527	11,855,527	15,948,312	14,242,907	65,580,530	-	-	-	-	-	-
Sweden	20,774,672	21,089,586	23,543,513	22,595,814	22,573,139	110,576,724	20,774,672	21,089,586	23,543,513	22,595,814	22,573,139	110,576,724	-	-	-	-	-	-
United Kingdom (excl. NI)	213,440,116	235,658,667	251,663,510	249,381,937	251,409,307	1,201,553,537	209,440,116	210,658,667	215,863,510	218,681,937	224,090,307	1,078,734,537	4,000,000	25,000,000	35,800,000	30,700,000	27,319,000	122,819,000
Finland	36,530,616	37,068,088	37,921,895	37,992,388	38,169,199	187,682,186	36,530,616	37,068,088	37,921,895	37,992,388	38,169,199	187,682,186	-	-	-	-	-	-
France	129,568,044	128,565,763	133,235,375	134,068,129	134,531,563	659,968,874	129,568,044	128,565,763	138,643,868	139,476,622	139,940,056	676,194,353	-	-	-	-	-	-
Germany	436,930,024	431,880,267	440,676,525	440,489,301	471,629,241	2,221,605,359	388,759,381	391,714,624	400,493,382	400,773,158	424,480,598	2,006,221,143	49,130,000	41,125,000	41,142,500	40,675,500	48,108,000	220,181,000
Greece	63,685,092	63,246,705	64,649,046	76,015,014	73,950,733	341,546,590	63,685,092	63,246,705	64,649,046	66,015,014	65,200,733	322,796,590	-	-	-	10,000,000	8,750,000	18,750,000
Hungary	25,119,629	23,600,016	25,699,190	24,949,081	32,370,593	131,738,509	25,119,629	23,600,016	25,699,190	24,949,081	24,696,093	124,064,009	-	-	-	-	7,674,500	7,674,500
Iceland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	19,971,011	20,137,251	21,226,823	21,763,017	21,751,579	104,849,681	19,971,011	19,952,251	21,041,823	21,575,952	21,751,579	104,292,616	-	185,000	185,000	187,065	-	557,065
Italy	212,199,890	209,006,956	199,971,427	195,328,063	192,711,524	1,009,217,860	212,199,890	209,006,956	199,971,427	195,328,063	192,711,524	1,009,217,860	-	-	-	-	-	-
Latvia	3,727,535	4,859,121	4,761,691	4,621,615	4,991,646	22,961,608	3,727,535	4,859,121	4,761,691	4,621,615	4,991,646	22,961,608	-	-	-	-	-	-
Liechtenstein	21,102	19,497	17,622	15,747	15,747	89,715	21,102	19,497	17,622	15,747	15,747	89,715	-	-	-	-	-	-
Lithuania	7,509,636	7,568,316	8,155,470	8,887,268	10,852,274	42,972,964	7,509,636	7,568,316	8,155,470	8,037,268	8,371,774	39,642,464	-	-	-	850,000	2,480,500	3,330,500
Luxembourg	2,488,229	2,488,229	2,488,433	2,488,229	2,488,346	12,441,466	2,488,229	2,488,229	2,488,433	2,488,229	2,484,346	12,437,466	-	-	-	-	4,000	4,000
Malta	2,107,837	2,121,453	2,159,360	2,168,005	2,158,650	10,715,305	2,107,837	2,121,453	2,159,360	2,168,005	2,158,650	10,715,305	-	-	-	-	-	-
Netherlands	76,756,732	83,834,170	92,843,281	92,831,673	90,997,432	437,263,288	76,756,732	83,834,170	84,843,281	88,831,673	86,997,432	421,263,288	-	-	8,000,000	4,000,000	4,000,000	16,000,000
Northern Ireland	4,401,506	4,402,616	4,471,524	4,461,263	4,461,323	22,198,232	4,401,506	4,402,616	4,471,524	4,461,263	4,461,323	22,198,232	-	-	-	-	-	-
Norway	7,538,168	20,565,928	14,336,071	14,752,612	18,177,344	75,370,123	7,538,168	7,965,928	8,002,071	8,422,612	8,422,612	40,351,391	-	12,600,000	6,334,000	6,330,000	9,754,732	35,018,732
Poland	201,001,993	202,015,040	205,641,285	207,206,554	213,031,731	1,028,896,603	201,001,993	202,015,040	205,641,285	207,206,554	212,821,314	1,028,686,186	-	-	-	-	210,417	210,417
Portugal	30,410,183	30,771,809	32,359,066	32,986,535	32,928,514	159,456,107	30,410,183	30,771,809	32,359,066	32,986,535	32,928,514	159,456,107	-	-	-	-	-	-
Romania	71,788,810	73,932,376	74,989,413	74,812,356	75,825,964	371,348,919	71,788,810	73,932,376	74,989,413	74,812,356	75,188,464	370,711,419	-	-	-	-	637,500	637,500
Slovakia	32,166,094	32,140,581	32,356,123	32,617,164	33,432,258	162,712,220	32,166,094	32,140,581	32,356,123	32,617,164	33,432,258	162,712,220	-	-	-	-	-	-
Slovenia	8,214,360	8,216,051	8,226,460	8,224,716	8,226,207	41,107,794	8,214,360	8,216,051	8,226,460	8,224,716	8,226,207	41,107,794	-	-	-	-	-	-
Spain	154,153,615	151,455,169	150,005,306	151,447,620	154,104,531	761,166,241	153,894,310	150,760,860	150,958,920	151,447,620	154,104,531	761,166,241	-	-	-	-	-	-
EU27	**1,785,468,451**	**1,788,800,109**	**1,810,305,035**	**1,832,594,917**	**1,895,050,929**	**9,112,219,442**	**1,736,538,886**	**1,748,990,139**	**1,769,539,050**	**1,784,992,164**	**1,817,012,643**	**8,857,072,882**	**49,130,000**	**41,715,050**	**49,727,500**	**55,912,565**	**87,960,367**	**284,445,482**
EU27 + UK	**2,003,310,073**	**2,028,861,392**	**2,066,440,069**	**2,086,438,117**	**2,150,921,559**	**10,335,971,211**	**1,950,380,508**	**1,964,051,422**	**1,989,874,084**	**2,008,135,364**	**2,045,564,273**	**9,958,005,651**	**53,130,000**	**66,715,050**	**85,527,500**	**86,612,565**	**115,279,367**	**407,264,482**

Source: (European Environmental Agency, 2021)

Figure 8: EUA Dec Future prices Phase 2 (2008-2012)

Source: (European Environmental Agency, 2021)

During the Second Phase, the Cap was decided following the first Phase's actual emissions. Nevertheless, after the financial crisis in 2008, the demand for EUAs was severely reduced, due to the slowdown of the economy. This fact, lead to an oversupply of EUAs in the period between 2008-2012, as is evident in Figure 8. It should be noted that in Phase 1 only 0.13% of the total allowances, that were allocated, had been sold or auctioned. In Phase 2, this percentage increased significantly to 3.94%, but still, due to the big recession in 2008, the EUA price was fluctuating to very low levels. Moreover, in 2012, when the European Commission decided to not reduce the allowances that would be released during the next year, the EUA price fell even further (below €7).

2.2.3 Phase 3 (2013-2020)

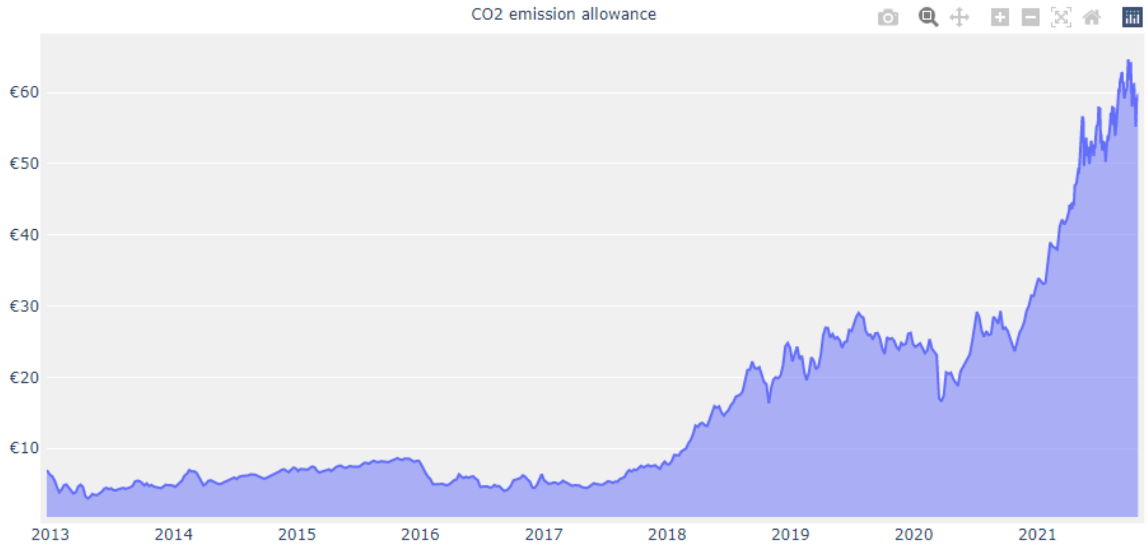
Once again, following the official website of the European Commission (2021), significant changes were implemented in the European Trading Scheme for Phase 3. First of all, instead of having individual country Caps for carbon emissions, one single Cap was established for the whole of the European Union (and the countries that participated in the ETS). Moreover, auctioning replaced the free allocations on a big scale and the scope of the EU ETS became wider (including more types of emissions and sectors). During phase 3, there was no free allocation for the power sector and the EU Cap was 2,080 million tonnes of emissions for 2013, which was reduced by 1.74% each year (International Carbon Action Partnership, 2021). 57% of the EUAs were auctioned, including the Aviation allowances (49% excluding the Aviation allowances). Since Phase 1 and Phase 2 were experimental periods, the results of Phase 3, regarding the prices of the EUAs, are the most useful ones for future EUA price predictions. Also, there have not been significant changes to the scope of the EU ETS between Phases 3 and 4, apart from the fact that from Phase 4 onwards (starting from January 2021), the aviation allowances can be used for meeting both the aviation and the stationary installation obligations (Emissions-euets.com, 2021).

Figure 9: Phase 3 Summary (2013-2020)

	Phase 3 (2013 -2020) t CO2-eq excl. Aviation		
Country	**Total allocated**	**Freely allocated**	**Auctioned or Sold**
Austria	248,519,168	162,189,168	86,330,000
Belgium	429,718,897	270,550,397	159,168,500
Bulgaria	254,619,341	118,521,341	136,098,000
Croatia	67,829,325	37,538,325	30,291,000
Cyprus	26,184,561	20,571,061	5,613,500
Czechia	470,981,530	278,595,530	192,386,000
Denmark	149,139,900	71,463,900	77,676,000
Estonia	84,175,475	44,028,975	40,146,500
Sweden	247,238,582	191,357,582	55,881,000
United Kingdom (excl. NI)	1,096,654,888	449,824,388	646,830,500
Finland	253,598,275	149,898,775	103,699,500
France	924,214,236	584,656,236	339,558,000
Germany	2,463,658,756	1,221,741,256	1,241,917,500
Greece	333,219,109	113,800,109	219,419,000
Hungary	175,800,344	87,240,344	88,560,000
Iceland	14,120,418	11,699,918	2,420,500
Ireland	98,337,260	40,286,260	58,051,000
Italy	1,166,577,707	567,431,207	599,146,500
Latvia	32,431,219	15,193,719	17,237,500
Liechtenstein	64,855	10,855	54,000
Lithuania	79,967,714	46,803,214	33,164,500
Luxembourg	17,616,628	10,061,628	7,555,000
Malta	6,482,000	-	6,482,000
Netherlands	568,286,649	360,431,149	207,855,500
Northern Ireland	25,880	25,880	-
Norway	181,295,398	133,088,398	48,207,000
Poland	1,189,261,708	684,116,208	505,145,500
Portugal	201,301,774	90,280,274	111,021,500
Romania	485,062,500	217,480,500	267,582,000
Slovakia	214,832,245	115,902,245	98,930,000
Slovenia	43,567,870	15,509,870	28,058,000
Spain	1,023,450,174	479,682,674	543,767,500
EU27	**11,556,072,947**	**5,995,331,947**	**5,560,741,000**
EU27 + UK	**12,652,753,715**	**6,445,182,215**	**6,207,571,500**

Source: (European Environmental Agency, 2021)

Figure 10: Phase 3 EUA Dec Future Price (2013-2021)



Source: (Sandbag.de, 2021)

In figure 10 (from Sandbag.de (2021)), we can see the price of the December EUA future for each year. We can observe that from early 2013 up to 2016 (before the Brexit announcement) the price had an increasing trend, due to the reforms of the scope of the ETS. Nevertheless, the price of the EUAs was not significant enough to affect the technological generation mix for electricity production effectively, as coal and lignite were still significantly cheaper than natural gas. The reason that the EUA prices were constantly below €10 is that there was an oversupply of EUAs, because of the low economic activity in Europe, after the global economic crisis in 2008. The level of EUA prices decreased even further, after the Brexit announcement in 2016 (Fjellheim, 2018). In 2017, the prices started rising steadily, as the oversupply of the EUAs started vanishing through the use of the Market Stability Reserve, which means that the aggregated excess EUAs from the previous years got absorbed by the Market Stability Reserve (or even canceled). The EUAs, that are planned to be released, can be reduced by 24% when the oversupply exceeds the 833,000 thousand EUAs (Rack, 2020). This is the reason that during the period of the Covid Pandemic, between 2020 and 2021, the prices did not sink, similarly to the previous decade. This means that to calculate the price, we should not take the Supply as a given variable, but rather we should consider it as a variable that is dependent on the demand, and manipulated in a way that forms the desirable EUA prices which will help the targets of the EU be achieved. We should also keep in mind that the Market Stability Reserve can be used to release additional EUAs in the economy, in the case that the EUA prices get to be so high that would have a severe adverse impact on the EU economy.

2.2.4 Aviation EUAs:

According to the European Commission (2021), the Aviation sector is responsible for 3.8% of the European CO2 emissions. The yearly Cap for Aviation emissions for Phase 3 was 210,349,264, out of which only 15% would be sold and auctioned. Due to the commitment of the International Civil Aviation Organization (ICAO) initiative in 2016, “to offset around 80% of the emissions above 2020 levels**”**, from 2016 onwards, the only flights that are liable to the EU ETS are those that happen within the EEU, although this decision will be revisited in 2024. Approximately, 55 million EUAs have been sold and Auctioned in Phase 3. During phase 4, the CAP for aviation EUAs will be reduced by 2.2% (similarly to the stationary installations CAP).

Figure 11: Phase 3 (2013-2020) Aviation EUAs

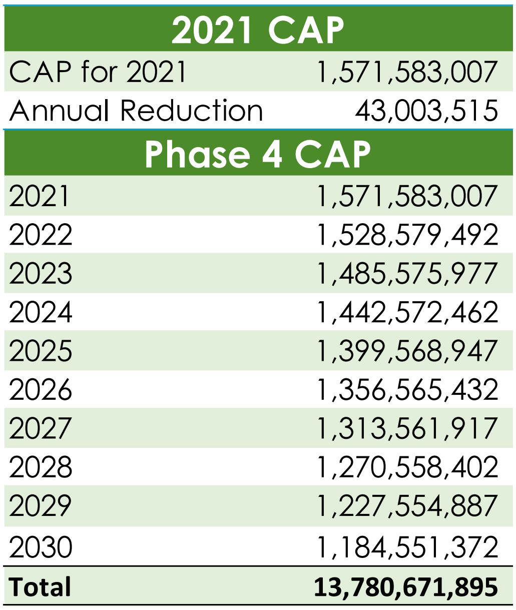
					Aviation Allowances				
	2013	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total allocated**
Total allocated	32,133,585	41,360,778	48,104,174	37,584,901	37,389,280	36,195,655	35,692,124	37,671,798	**306,132,295**
Freely Allocated	32,133,585	32,082,778	31,713,674	31,587,401	32,658,780	30,594,155	30,189,624	30,166,798	**251,126,795**
Auctioned or Sold	-	9,278,000	16,390,500	5,997,500	4,730,500	5,601,500	5,502,500	7,505,000	**55,005,500**

Source: (European Environmental Agency, 2021)

2.2.5 Phase 4 (2021 – 2030):

First of all, the UK launched its own Emissions Trading Scheme from the beginning of 2021, and thus, the UK’s share of allowances was removed from Phase 4’s Cap. A cap of 1,571,583,007 allowances was set for the whole of the EU, for the year 2021 and a Cap reduction of 2.2% per year (approximately 43 million EUAs) was established (which might become 4.2% per year as was mentioned before). This reduction can be assumed for the rest of the trading scheme’s life. For Aviation, the cap for 2021 is 38 million EUAs and it will be reduced by 2.2% each year, similarly to the installation Cap (International Carbon Action Partnership, 2021). 3 countries will get free allocations for the power sector (namely Bulgaria, Romania, and Hungary), whereas another seven will benefit from the monetization fund.

Figure 12: Phase 4 (2021-2030) EU Allowances Cap



2021 CAP	
CAP for 2021	1,571,583,007
Annual Reduction	43,003,515
Phase 4 CAP	
2021	1,571,583,007
2022	1,528,579,492
2023	1,485,575,977
2024	1,442,572,462
2025	1,399,568,947
2026	1,356,565,432
2027	1,313,561,917
2028	1,270,558,402
2029	1,227,554,887
2030	1,184,551,372
Total	**13,780,671,895**

Source: (European Environmental Agency, 2021)

Some further changes have been announced for Phase 4 (Fit for 55), but they have not passed through all the necessary legislative procedures, like the commitment to decreasing the CO2 emissions by 55% from 1990 levels, reduction to the Cap for phase 4 and almost doubling the annual reduction of the Cap from 2.2% to 4.2%, faster elimination of the freely allocated EUAs, “Carbon Border Adjustment Mechanism” and more (International Carbon Action Partnership, 2021).

Chapter 3: Analysis of the EU ETS statistics and trends

First of all, it is important to understand the impact that each country has on the ETS. Some countries’ economic activities affect the Demand (and thus the Price) of the EUAs more significantly than others.

Figure 13: 2020 EUAs per country %

	Total Allocated		Freely Allocated		Auctioned or Sold	
Country	**2020**	**%**	2020	%	**2020**	**%**
Austria	25,640,825	1.90%	18,172,825	2.79%	7,468,000	1.07%
Belgium	45,693,934	3.39%	31,172,434	4.79%	14,521,500	2.08%
Bulgaria	26,437,645	1.96%	8,006,145	1.23%	18,431,500	2.64%
Croatia	7,206,324	0.53%	4,265,324	0.66%	2,941,000	0.42%
Cyprus	2,863,276	0.21%	1,285,776	0.20%	1,577,500	0.23%
Czechia	47,559,024	3.53%	17,989,524	2.76%	29,569,500	4.24%
Denmark	13,169,096	0.98%	6,449,596	0.99%	6,719,500	0.96%
Estonia	8,846,844	0.66%	2,982,844	0.46%	5,864,000	0.84%
Sweden	24,287,269	1.80%	19,189,269	2.95%	5,098,000	0.73%
United Kingdom (excl. NI)	159,083,753	11.80%	48,058,253	7.38%	111,025,500	15.92%
Finland	24,222,107	1.80%	15,251,607	2.34%	8,970,500	1.29%
France	93,522,167	6.94%	64,148,167	9.86%	29,374,000	4.21%
Germany	243,808,779	18.09%	136,375,779	20.95%	107,433,000	15.41%
Greece	33,979,992	2.52%	13,351,992	2.05%	20,628,000	2.96%
Hungary	18,513,335	1.37%	9,243,335	1.42%	9,270,000	1.33%
Iceland	2,896,047	0.21%	1,405,547	0.22%	1,490,500	0.21%
Ireland	9,751,305	0.72%	4,729,305	0.73%	5,022,000	0.72%
Italy	110,366,123	8.19%	57,962,123	8.91%	52,404,000	7.52%
Latvia	3,012,052	0.22%	1,301,552	0.20%	1,710,500	0.25%
Liechtenstein	34,181	0.00%	681	0.00%	33,500	0.00%
Lithuania	8,153,903	0.60%	4,600,903	0.71%	3,553,000	0.51%
Luxembourg	1,842,064	0.14%	1,152,564	0.18%	689,500	0.10%
Malta	623,000	0.05%	-	0.00%	623,000	0.09%
Netherlands	58,874,946	4.37%	40,894,446	6.28%	17,980,500	2.58%
Northern Ireland	1,630	0.00%	1,630	0.00%	-	0.00%
Norway	45,208,763	3.35%	15,526,763	2.39%	29,682,000	4.26%
Poland	173,381,976	12.86%	43,277,976	6.65%	130,104,000	18.66%
Portugal	20,885,565	1.55%	10,489,565	1.61%	10,396,000	1.49%
Romania	51,694,785	3.83%	18,686,285	2.87%	33,008,500	4.73%
Slovakia	23,011,720	1.71%	13,048,220	2.00%	9,963,500	1.43%
Slovenia	4,279,625	0.32%	1,611,625	0.25%	2,668,000	0.38%
Spain	107,410,772	7.97%	57,125,772	8.78%	50,285,000	7.21%
EU27	**1,189,038,453**	**88.20%**	**602,764,953**	**92.62%**	**586,273,500**	**84.08%**
EU27 + UK	**1,348,123,836**	**100.00%**	**650,824,836**	**100.00%**	**697,299,000**	**100.00%**

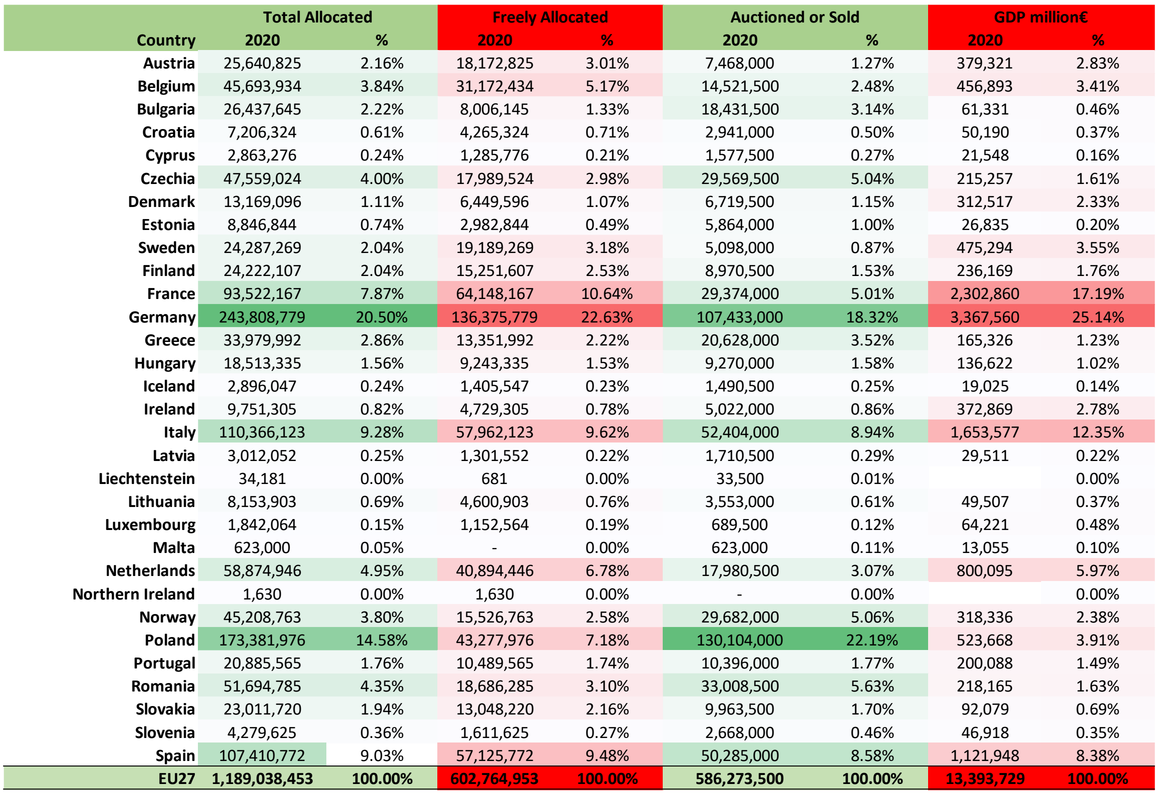
Source: (European Environmental Agency, 2021)

It can be easily inferred that Germany is the most significant country in every aspect, as it got 18% of the total allocated EUAs, 21% of the freely allocated EUAs, and 15.4% of the Auctioned/sold EUAs (excluding Aviation). The fact that Germany has so many freely allocated EUAs derives from its big industrial activity (there are no free EUAs for the power sector since 2012, except in the 3 countries that were mentioned earlier). Poland is the second most important country, in terms of total allocations, but the first most important country in terms of Auctioned/Sold EUAs (18.66% of the EUAs). Poland also has big manufacturing industries, but the most important factor is that its heating and electricity generation industries are based on coal and lignite. It is no coincidence that Poland is one of the countries that object to the EU ETS very strongly. The UK accounted for almost 12% of the total allocation and nearly 16% of the auctioned/sold allocation. It is evident that the removal of the UK from the EU ETS will affect the prices significantly. As expected, Italy, France, Spain, and the

Netherlands are also very important participants in the ETS, and the changes in their industries that are liable to the EU ETS should be monitored carefully.

It is interesting to see the same table after we take the UK out and include the GDP per country (Eurostat, 2021).

Figure 14: 2020 EUAs and GDP per country %



	Total Allocated		Freely Allocated		Auctioned or Sold		GDP million€	
Country	**2020**	**%**	**2020**	**%**	**2020**	**%**	**2020**	**%**
Austria	25,640,825	2.16%	18,172,825	3.01%	7,468,000	1.27%	379,321	2.83%
Belgium	45,693,934	3.84%	31,172,434	5.17%	14,521,500	2.48%	456,893	3.41%
Bulgaria	26,437,645	2.22%	8,006,145	1.33%	18,431,500	3.14%	61,331	0.46%
Croatia	7,206,324	0.61%	4,265,324	0.71%	2,941,000	0.50%	50,190	0.37%
Cyprus	2,863,276	0.24%	1,285,776	0.21%	1,577,500	0.27%	21,548	0.16%
Czechia	47,559,024	4.00%	17,989,524	2.98%	29,569,500	5.04%	215,257	1.61%
Denmark	13,169,096	1.11%	6,449,596	1.07%	6,719,500	1.15%	312,517	2.33%
Estonia	8,846,844	0.74%	2,982,844	0.49%	5,864,000	1.00%	26,835	0.20%
Sweden	24,287,269	2.04%	19,189,269	3.18%	5,098,000	0.87%	475,294	3.55%
Finland	24,222,107	2.04%	15,251,607	2.53%	8,970,500	1.53%	236,169	1.76%
France	93,522,167	7.87%	64,148,167	10.64%	29,374,000	5.01%	2,302,860	17.19%
Germany	243,808,779	20.50%	136,375,779	22.63%	107,433,000	18.32%	3,367,560	25.14%
Greece	33,979,992	2.86%	13,351,992	2.22%	20,628,000	3.52%	165,326	1.23%
Hungary	18,513,335	1.56%	9,243,335	1.53%	9,270,000	1.58%	136,622	1.02%
Iceland	2,896,047	0.24%	1,405,547	0.23%	1,490,500	0.25%	19,025	0.14%
Ireland	9,751,305	0.82%	4,729,305	0.78%	5,022,000	0.86%	372,869	2.78%
Italy	110,366,123	9.28%	57,962,123	9.62%	52,404,000	8.94%	1,653,577	12.35%
Latvia	3,012,052	0.25%	1,301,552	0.22%	1,710,500	0.29%	29,511	0.22%
Liechtenstein	34,181	0.00%	681	0.00%	33,500	0.01%		0.00%
Lithuania	8,153,903	0.69%	4,600,903	0.76%	3,553,000	0.61%	49,507	0.37%
Luxembourg	1,842,064	0.15%	1,152,564	0.19%	689,500	0.12%	64,221	0.48%
Malta	623,000	0.05%	-	0.00%	623,000	0.11%	13,055	0.10%
Netherlands	58,874,946	4.95%	40,894,446	6.78%	17,980,500	3.07%	800,095	5.97%
Northern Ireland	1,630	0.00%	1,630	0.00%	-	0.00%		0.00%
Norway	45,208,763	3.80%	15,526,763	2.58%	29,682,000	5.06%	318,336	2.38%
Poland	173,381,976	14.58%	43,277,976	7.18%	130,104,000	22.19%	523,668	3.91%
Portugal	20,885,565	1.76%	10,489,565	1.74%	10,396,000	1.77%	200,088	1.49%
Romania	51,694,785	4.35%	18,686,285	3.10%	33,008,500	5.63%	218,165	1.63%
Slovakia	23,011,720	1.94%	13,048,220	2.16%	9,963,500	1.70%	92,079	0.69%
Slovenia	4,279,625	0.36%	1,611,625	0.27%	2,668,000	0.46%	46,918	0.35%
Spain	107,410,772	9.03%	57,125,772	9.48%	50,285,000	8.58%	1,121,948	8.38%
EU27	**1,189,038,453**	**100.00%**	**602,764,953**	**100.00%**	**586,273,500**	**100.00%**	**13,393,729**	**100.00%**

Sources: (European Environmental Agency, 2021) and (Eurostat, 2021)

Generally, it is common knowledge that higher GDP means higher economic activity and higher needs for energy. The fact that countries with very high GDP, like France which accounts for 17% of the European GDP, only get 7.9% of the total EUA allocations derives from France's big nuclear fleet for power generation (more than 70%), which is not liable to the ETS.

Moreover, as was mentioned before, after looking at the verified emissions per industry, the combustion fuels industry (power and heat generation) is by far the most polluting and it accounts for 60% of the verified emissions in Europe. The refining of oil, the production of iron and steel, and the production of cement account for slightly below 10% of the total verified emissions in the EU for 2020. This information can help us understand the impact of changes in these industries on the Demand and the Price of the EUAs.

Figure 15: 2020 verified emissions by Industry %

Industry	**2020**	**%**
20 Combustion of fuels	737,607,359	60%
21 Refining of mineral oil	104,288,156	9%
24 Production of pig iron or steel	98,734,250	8%
25 Production or processing of ferrous metals	7,588,786	1%
27 Production of secondary aluminium	1,062,240	0%
29 Production of cement clinker	107,298,248	9%
30 Production of lime, or calcination of dolomite/magnesite	24,705,788	2%
31 Manufacture of glass	16,073,184	1%
34 Production or processing of gypsum or plasterboard	1,044,274	0%
35 Production of pulp	4,522,114	0%
38 Production of nitric acid	3,694,471	0%
41 Production of ammonia	19,312,272	2%
99 Other activity opted-in under Art. 24	683,094	0%
33 Manufacture of mineral wool	1,748,705	0%
28 Production or processing of non-ferrous metals	5,989,764	0%
32 Manufacture of ceramics	13,074,103	1%
36 Production of paper or cardboard	19,476,618	2%
23 Metal ore roasting or sintering	2,100,316	0%
42 Production of bulk chemicals	31,967,546	3%
26 Production of primary aluminium	4,573,509	0%
44 Production of soda ash and sodium bicarbonate	3,955,764	0%
43 Production of hydrogen and synthesis gas	8,192,243	1%
22 Production of coke	4,982,517	0%
37 Production of carbon black	1,441,395	0%
39 Production of adipic acid	110,945	0%
40 Production of glyoxal and glyoxylic acid	11,818	0%
45 Capture of greenhouse gases under Directive 2009/31/EC	5,376	0%
Total	**1,224,244,855**	**100%**

Source: (European Environmental Agency, 2021)

Figure 16: 2020 verified emissions by Industry & country

2020 verified emissions	**Combustion of fuels**	**Refining of mineral oil**	**Production of pig iron or steel**	**Production of cement clinker**	**Rest**
Austria	5,920,008	2,731,772	10,975,189	2,740,245	4,666,931
Belgium	14,834,065	5,792,283	3,924,794	3,904,538	13,055,897
Bulgaria	16,737,564	1,773,167	91,676	1,555,217	3,687,671
Croatia	2,891,303	806,029	10,389	1,946,533	1,667,493
Cyprus	3,003,729	-	-	1,249,819	41,340
Czechia	41,963,345	804,323	5,360,473	2,748,134	3,799,440
Denmark	7,244,765	931,660	-	2,339,867	316,138
Estonia	3,873,952	1,608,677	-	36,815	97,973
Finland	8,205,827	3,056,496	4,039,810	850,921	3,424,575
France	37,873,532	7,836,632	12,754,474	9,352,025	14,195,708
Germany	207,787,959	21,479,849	25,065,607	20,133,284	45,808,288
Greece	20,263,137	5,247,998	103,844	4,708,677	1,404,648
Hungary	12,654,752	-	756,094	1,396,691	4,100,344
Iceland	419	-	-	-	1,779,645
Ireland	10,051,972	300,762	-	2,683,970	241,104
Italy	74,696,293	15,386,069	7,705,607	11,063,050	17,161,724
Latvia	1,131,326	-	2	778,966	111,696
Liechtenstein	600	-	-	-	-
Lithuania	1,143,703	1,478,463	-	875,536	2,639,960
Luxembourg	206,538	-	326,864	628,887	214,211
Malta	810,207	-	-	-	-
Netherlands	46,627,396	10,335,409	5,803,651	-	11,347,797
Northern Ireland	2,812,224	-	-	-	-
Norway	13,041,192	1,998,595	76,191	1,076,112	7,536,842
Poland	134,940,506	4,324,966	2,720,871	11,153,180	55,378,809
Portugal	9,154,407	3,067,805	158,081	4,056,643	2,296,841
Romania	19,072,939	1,599,302	3,996,097	6,017,679	1,981,167
Slovakia	7,156,023	1,014,614	4,478,181	2,182,459	3,338,720
Slovenia	4,567,263	-	210,124	708,513	609,693
Spain	40,169,606	12,539,845	5,120,418	12,285,788	18,923,027
Sweden	4,625,242	2,172,035	5,132,004	1,900,811	2,594,560
EU27	**737,607,359**	**104,288,156**	**98,734,250**	**107,298,248**	**176,316,842**

Source: (European Environmental Agency, 2021)

Chapter 4: Literature Review

To understand the impact of the EU trading scheme to wholesale electricity prices, we need to understand two things: 1. The factors that affect the EUA prices and 2. The passthrough rate of the EUA prices to the DAM market. Thus, in this chapter, we are going to summarize the previous literature that is related to the two issues mentioned above and after that, we are going to present relevant analysis and discuss the differences between our findings and the papers in this section and we will try to draw some conclusions that are helpful for the academia and the policy makers.

4.1 EUA Price Determinants

First of all, following Chung et al. (2018), the EUA price levels can make the difference between moving to more sustainable technologies and practices, or not (this is going to be further analyzed in the next chapter when the marginal cost of the production units is going to be illustrated along with the way that the EU is manipulating the marginal cost of the various power production units to make the cleaner technologies more competitive). If the EUA price is set too low, then the more environmentally friendly technologies will not be preferred by companies, which need a financial incentive to replace the old polluting technologies with the new cleaner ones. Thus, understanding the factors that influence EUA prices is very important. The paper also provides evidence that various factors that affect the demand for EUAs (given that the Supply is fixed) affect their prices too, like the economic sentiment (growth prospects), the level of industrial activity and the price of oil and coal. The logic behind the effect of the oil and coal prices is that, when the prices of oil and coal are high, it usually means that their demand is high, and thus more EUAs will be needed in order to cover their emissions. Nevertheless, in the Regression analysis section that is going to be presented later on, we can see that the oil and coal prices have a negative (but not very strong) correlation with the Greek DAM prices. If the prices of coal and oil boost the EUA prices, then we would expect that there would be a positive correlation with the Greek MCP too.

On the very same subject, Andriiko and Sushchenko (2015) used multivariable linear regressions to verify the correlation and the causality between various factors and the prices of the EUAs. They used both the spot EUA and the December futures EUA (the most liquid EUA product in ICE) prices as dependent variables and they claim that the results do not change significantly. They start by examining the impact of the economic growth on the prices of the EUA, but since the GDP indicators are usually calculated on an annual basis, they use the energy produced and the carbon emissions as proxies instead, to get more observations. Even though the energy produced and the carbon emitted tend to increase along with the increase of the economic activity, these are not precise proxies of the economic activity, as they fail to take into consideration many factors like the energy efficiency of the economy, the type of fuel that is used for the energy generation, etc. For instance, as was mentioned in the previous chapter, France's GDP is second only to Germany's GDP, but at the same time, the verified emissions of France's economy were rather low, compared to other EU countries (Poland had a much lower GDP and the much higher sum of emissions) (figure 14). If Andriiko and Sushchenko (2015) measured the economic activity of Poland and France, using the proxy of the total emissions, they would get misleading independent variables that would show that Poland's economy is bigger than France's. Thus, the results of this analysis are not very robust. Also, some economies have high growth, without being very energy dependent, due to the nature of their economic activities. This fact is also not being taken into consideration in this analysis. The second factor that they examine is the issuing of Green Bords (Bonds to fund environmentally friendly initiatives). If the price of the Green bond is high (low-interest rates) then the participants in the polluting industries will be more inclined to borrow and invest in green initiatives, which will make the various economic activities of Europe less polluting (and vice versa). The third factor is the price of fuel. The logic is that if the prices of the non-environmentally friendly fuels increase, then the substitution cost for more environmentally friendly fuels will decrease and more power generators will be using the less polluting fuels to generate electricity (and the price of the EUAs will decrease). An example of that is when coal gets more expensive, while the price of natural gas remains stable, the power producers have the financial incentive to use a higher percentage of natural gas in their generation mix. Nevertheless, there are instances where the price of fuel increases and the demand for that fuel does not decrease. In those instances, the price of the EUAs will increase. Last, they support that when the temperature is significantly different from the seasonal average, then the EUA prices are affected. In conclusion, the authors prove that the EUA prices have a statistically important inverse relation with the Oil prices (Fuel Prices), the Green Bond yields, and the percentage of Renewable Energy produced. The negative correlation with the Oil prices is in accordance with the regression of this thesis, which is going to be presented in the next chapter, as we will show that the Oil prices and the power prices have a negative correlation, which can be explained by the lower EUA price levels. The same applies to the Renewable energy percentage, as in my regression I take into consideration the Residual Demand, which is the electricity Demand in the Day Ahead Market minus the Renewable energy that is produced.

Lovcha et al. (2022), support that the demand for EUAs has to be strong enough to set high prices that will support the adoption of more environmentally friendly technologies. They claim that structural changes (shocks), the percentage of fossil fuel technologies in the power generation mix, the economic activity (which leads to higher energy demand or even directly to higher emissions), and the oil price are all positively related to higher EUA prices. The latter has a twofold reason because the oil prices usually have the same fluctuations as the Natural Gas prices in Europe (although there is a tendency for the Natural Gas prices to be indexed on the TTF market in Europe instead of the oil price indexation, during the past few years) and also because the Oil Prices are usually correlated with the economic activity (high economic activity is usually followed by higher oil prices). The most significant impact on the EUAs prices comes from the price of Natural Gas. The main reason is that, when the Natural Gas price is high, then the thermal producers are inclined to use other more polluting technologies like coal, lignite, or oil, which emit more GHG to the environment, and thus, the demand for EUAs increases. In contrast, higher coal prices, lead to lower EUA prices, since the thermal producers will be more likely to use cheaper natural gas. Last, they conclude that Carbon prices affect electricity prices directly, but the opposite causal effect is not substantial. This means that higher EUA prices will lead to higher electricity prices (as expected), but higher electricity prices will not necessarily lead to higher carbon prices.

Koch et al. (2014) try to explain the reason why the EUA price fell from €30 in 2008 to €5 in 2013. In contrast to the findings of Lovcha et al. (2022), their model provided statistically insignificant results (but with the expected sign) for both the switching cost between coal and natural gas and for the price of coal and the Price of EUAs. Nevertheless, this inconsistency between the two studies can be explained by the fact that the EUA market was quite immature up to 2013 (as phase 1 and phase 2 were more like introductory periods) and the economic crisis had dominated the markets, and their prices., Also, consistent with the previous papers, the prices of natural gas and the expectations of economic growth appear to be statistically significant factors for the EUA price movements. Last, the effect of the renewable energy sources penetration appears to be statistically significant, but the relevant coefficients are rather low (thus they do not appear to affect the EUA prices very much). Overall, the model does not appear to be very good, as it exhibits an adjusted R squared of just below 10%.

Friedrich et al. (2019) examine if the sudden rise of the EUA prices in 2018 was driven by the fundamental factors (decreased supply of EUAs) or by an overreaction of the market participants. Even though they find that the most significant variables of the EUA prices are the coal and natural gas prices (following the previous literature) they claim that the sharp price increase can be mainly explained by the participants' speculation, rather than factors like the clean spreads. If this is true, then the policy makers will find it difficult to implement changes, as the markets will overreact negatively or positively to the market signals and the ultimate scope of the policies' changes will be missed.

The table below summarizes all of the above:

Figure 17: EUA price prediction literature review summary

Study	**Period**	**Dependent Variable**	**Independent Variable(s)**	**Model(s)**	**Results**
Chung et al. (2018)	2013-2017	EUA price	Australian Thermal Coal Price, Brent Futures Index, European Nature Gas Future Index, UK Power Future Index, European Industrial Production Index, European Economic Sentiment Index, Euro area Bank Lending Index, European Average Temperature Maximum Index, European Average Temperature Minimum Index, European Average Precipitation Index, CER Futures Price	Impulse Response Function	Positive correlation with all of the variables except the min. temperature
Andriiko and Suschenko (2015)	2010-2014	EUA price	Oil price, green bonds Index, green energy production	Linear Regression	Negative correlation with all of the factors

Lovcha et al. (2022)	2008-2018	EUA price	Share of fossil fuels in electricity production, Gas, Oil, Coal, Electricity prices, and CO2 tons emitted	SVAR	Positive correlation with the percentage of the fossil fuel, the higher CO2 emissions, the oil prices and the natural gas price, Negative Correlation with Coal price
Koch et al. (2014)	2008-2013	EUA Price	Switching Fuel Price, Coal price and Natural Gas price, STOXX EUROPE 600 index, Economic Sentiment Indicator, Renewable Energy Deployment	OLS	Positive correlation with the price of Natural Gas, and the expectation for economic growth
Friedrich et al. (2019)	2008-2018	EUA Price	Coal, Natural Gas, and Oil prices, Temperature averages, STOXX Europe 600 index, and STOXX Europe 50 index	OLS, Time-varying coefficient regression, Formal bubble detection, and Time stamping and crash odds prediction	Positive Correlation with the Natural Gas, Oil and Coal prices and the economic growth speculations

From the table above, it is evident that the significance of the factors that determine the EUA price levels may vary significantly, depending on the explanatory model that is used or even the period under examination. Furthermore, the prediction of future EUA prices is hard to be done accurately since the policy makers will adjust either the supply of the EUAs to the market (through the Market Stability Reserve) or they will change the scope of the EU ETS to achieve the targets of having a carbon neutral economy by the middle of this century. This means that if the Natural Gas price is very high during this decade, the policy makers will try to manipulate the EUA market in a way that coal and oil become so expensive (by increasing the allowances price) in order to get the desirable technologies to be more competitive. The problem is that the prices of coal, oil, and natural gas are hard to predict accurately in the long term. Also, drawing generalized conclusions from factors like economic sentiment may not be safe, as the EUA demand will be affected differently if the downturn of the economy happens mainly in countries with a greener production stack or not. If the European economy does great, but for some reason, Poland’s economy is experiencing a downturn, the demand for EUAs is going to be affected significantly.

To conclude, the scope of the EUAs will be changing and it will be adapting constantly throughout the years. For instance, new economic activities might become liable to the EU ETS in the future. Also, there is a peril that is constantly being overlooked that the green transition of the European Economy is too sudden in a way that makes it not sustainable in the long term. During the past few months, the transition from coal and lignite to natural gas as the main fuel in Europe (and globally) has increased the demand for the commodity significantly, which in turn increased the natural gas prices in an unexpected and unprecedented manner. The natural outcome of the high commodity prices is the high electricity prices which lead to less competitive manufacturing industries in the EU and to households that struggle to afford to cover their basic energy needs (energy poverty). If this crisis persists, there is a good chance that the Commission will relax the scope of the EUAs and that it will realign its policies in a way that will not jeopardize the wellbeing of the EU citizens. In the next chapter, we are going to discuss the effectiveness of the various factors that were mentioned above, for explaining the EUA price fluctuations in the long term and the short term and we are going to demonstrate an alternative way of estimating the EUA price in the long term.

4.2 How EUAs affect the Wholesale Electricity Prices

According to Chung et al. (2018), the price of the EUAs affects European electricity prices. This makes sense, as the coal, the lignite, and the natural gas that is used to produce electricity get more expensive or cheaper after accounting for the EUA price, and thus, more expensive EUAs usually lead to more expensive electricity production for economies that have a high percentage of polluting technologies in their energy generation mix. Also, as it was mentioned before, Chung et al. (2018) provide evidence that if the cost of the EUAs is not high enough to make the energy generation from the less polluting fuels cheaper, the companies (since they are profit driven) will keep using the polluting energy generation technologies to maximize their wealth. This means that the price of the EUAs can incentivize the electricity producers to move from cheap sources like coal and lignite to more expensive ones, like natural gas. Thus, higher EUA prices are likely to increase the Natural Gas prices, due to the higher demand for the latter (because the demand for the more expensive coal and lignite will be reduced). Moreover, the paper provides proof that the EUA prices affect the electricity prices (with the use of a "Granger Causality test"). Lovcha et al. (2022) also support that the EUA price affects directly the electricity prices, but the opposite relation does not necessarily hold (one-way causation). In the next chapter (and more specifically in the section "The marginal cost of the natural gas units, the lignite units, and the EUA price that is needed to equate them", we are going to demonstrate the way the EUA expense is incorporated in the marginal cost of the power producers and thus, how their bids are affected by the EUA price (which supports the one-way causality assumption).

Jouvet and Solier (2013) mention that since the EUAs can be sold in various markets, their value is considered to be marginal cost, irrespectively whether the EUAs had been allocated for free, or if they had been bought (cost of opportunity). It is important to mention, that this paper examines the effect of the EUAs on the electricity prices for periods 1 and 2. Since 2013, there had been no more EUAs directly allocated to the power producers in any of the developed EU nations. Moreover, the paper supports that the success of the EU ETS is based on the fact that the producers will pass through their

EUA costs on the spot prices. They also claim that the markets that are closer to the model of perfect competition, are more likely to have participants (power producers) that pass 100% of the EUA cost to the spot prices. Their observations include that the cost of the EUAs is passed on a higher percentage during peak hours when the demand for electricity that has to be covered by the thermal producers is higher (this is also proven in the next chapter in the "Statistical Analysis of the Passthrough rates of the Greek Natural Gas units to the DAM price section" of this thesis). At the same time, it is observed that after the 2008 financial crisis, the percentage of the CO2 allowance cost that was passed on to the price was lower (or even nil in 2009). This is mainly because lower demand for fuel and electricity made it harder for power producers to increase their prices and because there was a surplus of EUAs (the supply of the auctioned EUAs being higher than the demand) in most countries, as their energy-intensive industries were experiencing an economic decline. This fact highlights the difficulty of setting a policy regarding the EU ETS that will lead to the required results with certainty, as many factors affect the demand for the EUAs in both the long term and the short term.

Similarly, Guo and Gissei (2021) analyzed the power market of Great Britain for the period 2015 – 2018 and concluded that the EUA cost and the Gas cost are passed on to the power spot prices. As expected, when the demand that needs to be covered by thermal producers is high, the coal producers have the opportunity to pass through the EUA costs more easily. Also, due to the substantial shutdown costs, the coal producers are more likely to bid lower than the marginal cost (so they cannot recover their EUA cost) during off-peak hours to avoid having to shut down and restart at a later time their production units. Hintermann (2014) examined the German power market and provided robust evidence that the EUA cost is passed through on the electricity prices almost completely (100%), whereas the fuel price increases pass through only partially. The author also points out that the power producers buy fuels from different suppliers with different contracts, thus the case might be that some producers have lower fuel costs, instead of passing through their marginal cost partially.

Dagoumas and Polemis (2020) analyzed the passthrough rates in the Greek power market for the period 2014 to 2017. This specific period was chosen, as there were no major changes in the Greek power market (Mandatory Pool) or the EU ETS phase 3 regulations. After taking into consideration the variable costs and the technical characteristics of the 24 power generation units, combined with the market rules on bidding below the marginal cost, they used some linear (OLS) models and a non-linear "instrumental variable approach" model and they proved that one Euro increase of the EUA leads to an increase of the wholesale Greek prices of more than one euro (approximately, depending on the model). Moreover, these findings are also a big part of the previous literature and they are following the regression model that is going to be presented in the next chapter of this thesis

Fabra and Reguant (2014), studied the Spanish market between the periods “January 2004 to February 2006” to understand the impact of the EUA prices of the first period of the EU ETS on the electricity prices. They provided evidence that there is an “almost complete” pass-through rate of the EUA cost, which is very similar to both our findings and the literature that was discussed in this section’s findings.

Figure 18: EUA price passthrough rate literature review summary

Study	**Period**	**Dependent Variable**	**Independent Variable(s)**	**Model(s)**	**Results**
Chung et al. (2018)	2013-2017	Electricity Price	EUA price	Granger Causality test	Positive correlation between EUA and Electricity prices
Jouvet and Solier (2013)	2005-2012	Spread between the Electricity Price and the Fuel Cost	Fuel costs and EUA price	Linear Regression for different areas and timeframes	More competitive markets and tighter periods lead to higher passthrough rates
Guo and Gissei (2021)	2015 – 2018	Electricity Price (GB)	Coal, Gas and EUA price, Residual Demand, Renewable Generation and Nuclear Generation	Vector Error Correction	Positive relation between the EUA cost and the electricity price which is enhanced during more tight hours (75% pass-through rate)
Hintermann (2014)	2010-2014	Electricity Price (DE)	Fuel cost, EUA price, Seasonal dummies	OLS	Approximately 100% pass-through of the EUA to the Electricity prices, depending on the model
Dagoumas and Polemis (2020)	2014-2017	Electricity Price (GR)	EUA, Coal, Gas, Oil prices, Temperature, Wind speed, Humidity, and Solar radiation	OLS and non-linear model (instrumental variable model)	Passthrough rate of approximately 100% (depending on the model)

Previous literature provides significant evidence that EUA prices have a positive correlation with wholesale electricity prices, even when the period or the countries that are examined are different. Moreover, the most recent literature supports that the power producers passthrough approximately 100% of the EUA expenses to the wholesale prices (but the percentage may vary depending on variables like the tightness of the market). In the next chapter, we are going to implement an OLS regression similar to Dagoumas and Polemis (2020), which provides very similar results (94% passthrough rate of the EUA expense) even after the change of the Greek wholesales market from the

Mandatory Pool to the Target Model. This means that the EU ETS has the same effect on most European markets, even on the ones that might have a different structure. Moreover, in the next chapter, we are going to analyze the bidding patterns of the Greek power producers and illustrate similar results to the previous literature regarding the timing of the passthrough rates of the EUA (and the fuel cost) to the wholesale markets. Last, we are going to discuss the importance of these results to the European governments and the policy makers.

Chapter 5: Calculation of the Impact of the EU ETS on the Electricity Day Ahead Price

First of all, as it was mentioned before, there are two separate aspects regarding the impact of the EU ETS on wholesale market prices. The first is how the price of the EUAs gets affected by various factors and the second is the passthrough rate of the EUA cost to the wholesale electricity prices. Going forward, in this chapter, we are going to give a brief description of the way that the Greek DAM works (Target Model) and how the market price is formed. After that, we are going to illustrate the reasoning behind why the EU ETS is manipulated by the EU Commission (through the Market Stability Reserve and the supply of the EUAs), in a way that the EU targets and policies affect the formulation of the EUA prices more significantly in the long term, compared to the factors that were mentioned in the literature review before. Nevertheless, those factors still play a vital role in the formulation of the EU policy regarding the ETS, the short-term price fluctuations, and the structure of the EUA market. Then, we are going to discuss the marginal cost of the lignite and the natural gas units in Greece and calculate the appropriate EUA prices that equate to the marginal production cost of the two technologies. This is important because one of the benchmark targets of the EU is to eliminate coal and lignite by the year 2030 (2028 for Greece), through the use of ETS (marginal cost controlling). To tackle the second aspect of the way that the EUAs affect the wholesale prices, which is the passthrough rates of the producers’ costs to the Greek DAM price (aka Marginal Clearing Price or MCP), we are going to focus on the case of Greece by demonstrating evidence related to the importance of the natural gas units for the formation of the Greek DAM price during 2021 and up to 2030. Due to the importance of this production technology, we are going to focus on the bidding patterns and strategies of the natural gas units, with statistical analysis in Excel, demonstrate the conclusions, and discuss their significance. Last, in the next section, we are going to conduct a regression analysis to examine the passthrough rates of various components (including the EUA price), that were highlighted in the literature review, from the power producers to the Greek DAM price, and discuss the results.

5.1 How DAM works

In this section, the setup and the way that the Day Ahead Market (Target Model) is operated are going to be discussed. First of all, Greece adopted the European Target Model in November 2020. In the HEnEX Spot Trading Rulebook, from the Hellenic Energy Exchanges S.A. (2021), it is mentioned that the power producers and the off-takers must submit their bids (and asks) for day D, until 12 PM CET in D-1 (Day Ahead Market). The producers bid their power production, for every hour for Day D, in pairs of MWh per hour and prices in ascending order (more MWh for higher prices) and the off-takers do so (for their Load portfolio) in descending order. The price for all of the MWh that are sold or bought is going to be the price of the last order that made the Demand (MWh) and the Supply (MWh) equate. This market order is going to be partially accepted, which means that only a part of the quantity (MWh) of that order will be bought or sold and the price of that order is going to be the marginal price of the system (MCP or DAM price). All of the MWh that have been sold (bids) for a price higher than the marginal price are going to be rejected (and not executed). In this way, the most expensive power production unit (or border for imports or exports), that had its bid accepted by the market operator, is going to set the price for the Greek DAM. When the Demand is low, then only the cheaper production units will manage to sell their power production for a small profit margin or even for a negative margin, whereas when the Demand is high, the more expensive production units will be setting the price, and thus a higher profit margin will be achieved from the power producers.

5.2 How the EUA prices are affected by the EU policies

Previous literature provides support and numerous ways to predict the EUA prices and to understand how the future EUA prices will affect the electricity prices. The problem is that to forecast the future EUA prices, previous literature would require factors like the future price of oil, Europe’s economic growth, the price of coal and natural gas, the probable changes in the EU ETS scope and regulations, and other factors that are hard to predict, especially in the long term. As it was mentioned before, the EU created the EU ETS to achieve specific and measurable targets, like a carbon-neutral economy by the year 2050. Obviously, during the transitional period, the economy must move from polluting technologies and fuels to more sustainable ones, in a gradual manner. This means that for the first step, during the next decade, the benchmark target of the EU is to eliminate coal and lignite, by the year 2030 (and replace it with renewable energy sources and natural gas). We can assume that even if the factors that enhance the price of the EUAs do not favor a high price of the EUA, the EU will revisit and change the regulations (or just withdraw EUAs), to achieve a EUA price that will be at least high enough to force the transition from coal and lignite to natural gas. On the other hand, if the EUA price is too high, the EU will release EUAs from the Market Stability Reserve to relieve the economy from the excess cost and make sure that the competitiveness of the European industry (and even the European targets of a sustainable economy) will not be jeopardized. After understanding the scope of the EU ETS for the next decade, we can make various assumptions on the level of the prices of coal, lignite, and natural gas, to speculate what the level of the EUA prices will be.

5.3 The marginal cost of the natural gas units, the lignite units, and the EUA price that is needed to equate them

As was mentioned before, the main target of the EU is to eliminate the use of coal and lignite from the European electricity production stack, through ETS. The more polluting technologies will have to buy more EUA, in accordance with the CO2 equivalent that they emit and their marginal price will make them less competitive against the greener production technologies. In this section, we are going to demonstrate the marginal cost of the natural gas and the Greek lignite units, to find the appropriate EUA price that would make the production of electricity from natural gas units cheaper.

To calculate the level of the EUA price that would make the marginal cost of the Lignite unit and the Natural Gas unit equal, we first have to define how the marginal costs are calculated. In Greece, we have 2 natural gas units with an efficiency of 63% and the rest of the Greek natural gas fleet has an estimated efficiency of 50%. In accordance to www.volker-quaschning.de (2021), the CO2 tons that are emitted by a natural gas power plant with an efficiency of 63% is 0.33 CO2 tons/MWh of electricity, thus a natural gas power plant with an efficiency of 50% emits approximately 0.4 CO2 tons/MWh of electricity. This means that if the cost of 1 MWh of natural gas is €60, then a natural gas unit with 50% efficiency will need 2 MWh of natural gas to produce 1 MWh of electricity, thus the cost is €120. Moreover, if the cost of the EUAs is €50, then the gas production unit will have an additional cost of 0.4 tons x €50 = €20, so its marginal cost for every additional MWh produced (given that the unit is not in a ramping up or synchronizing phase) will be €140.

For a Greek lignite unit, the fuel cost is approximately €35/MWh of electricity and the emissions are around 1.54 tco2/MWh of electricity, in accordance to Maniatis and Moustakas (2020, p39). Moreover, most of the Greek Lignite units have an efficiency of 36%, which means that their marginal cost (to produce one additional MWh of electricity) is approximately €112, accounting for the same EUA cost as the previous example (€50). It is important to mention that the EUAs will be used to phase out coal and lignite production from Europe, but this thesis will focus on the lignite versus natural gas costs, as we are going to focus on the case of Greece and because coal is a more liquid product in the commodity markets, whose price fluctuates significantly.

Figure 19: Marginal cost for Natural Gas (CCGT) and Lignite power production units

Technology	Efficiency	Fuel Price	FuelCost/MWhel	EUA Price/t	Tons CO2	EUA Cost/Mwhel	Total Cost	EUA Price for Parity with Lignite
CCGT (NG)	50%	€60.00	€120.00	€74.56	0.2	€29.82	**€149.82**	€74.56
CCGT (NG)	63%	€60.00	€95.24	€74.56	0.2	€23.67	**€118.91**	€49.27
Lignite	36%	€12.60	€35.00	€74.56	1.54	€114.82	**€149.82**	-

In table 18 we can see that a Natural Gas unit with 50% efficiency and a fuel price of €60//MWh of natural gas (or €120/MWh of electricity), has the same marginal cost as a lignite unit with 36% efficiency and a fuel price of €12.6 (which is equivalent to €35/ MWh of electricity) when the EUA price is €74.56. A natural gas unit with higher efficiency of 63% has the same marginal cost as a lignite unit when the EUA price is €49.27. If we ignored the EUA cost, the lignite unit would have a marginal cost of just €35, while the marginal cost of the natural gas unit would be as high as €120. Since for the same price as EUA the lignite unit is only penalized by almost €30, whereas the lignite unit is penalized by €115, the two units become equally cost efficient for their capacity to produce one additional MWh of electricity.

Figure 20: EUA prices that make the marginal cost between a CCGT (50% efficiency) unit equal to the marginal cost of a lignite unit

	€/MW Natural Gas												
€ MWh electricity from Lignite	**€20.00**	**€30.00**	**€40.00**	**€50.00**	**€60.00**	**€70.00**	**€80.00**	**€90.00**	**€100.00**	**€110.00**	**€120.00**	**€130.00**	**€140.00**
€20.00	€17.54	€35.09	€52.63	€70.18	€87.72	€105.26	€122.81	€140.35	€157.89	€175.44	€192.98	€210.53	€228.07
€25.00	€13.16	€30.70	€48.25	€65.79	€83.33	€100.88	€118.42	€135.96	€153.51	€171.05	€188.60	€206.14	€223.68
€30.00	€8.77	€26.32	€43.86	€61.40	€78.95	€96.49	€114.04	€131.58	€149.12	€166.67	€184.21	€201.75	€219.30
€35.00	€4.39	€21.93	€39.47	€57.02	€74.56	€92.11	€109.65	€127.19	€144.74	€162.28	€179.82	€197.37	€214.91
€40.00	-	€17.54	€35.09	€52.63	€70.18	€87.72	€105.26	€122.81	€140.35	€157.89	€175.44	€192.98	€210.53
€45.00	(€4.39)	€13.16	€30.70	€48.25	€65.79	€83.33	€100.88	€118.42	€135.96	€153.51	€171.05	€188.60	€206.14

From table 19 we can see the EUA prices that can make the marginal cost between a natural gas unit (with 50% efficiency) equal to the marginal cost of a lignite unit, following their various possible prices. Horizontally we have the prices of natural gas as €/MWh of natural gas and vertically we have the lignite price as €/MWh of electricity. Given the fact that in the year ahead TTF natural gas products for 2022, have a price between €70-€80/MWh and that the lignite cost usually lies between €30 - €35 it would be fair to believe that the Commission will "manipulate" the EUA supply (or scope) so that its price for 2022 or 2023 will rise to the level of €90 - €100. If this does not happen, and if the natural gas price does not fall lower than €70, the current EUA prices will not be high enough to incentivize companies and governments to use the more sustainable technologies, as the lignite units will have priority in the stack model of each country.

The EU has set the target of massively reducing the coal and lignite production by 2030, and of eliminating it in the following decade. This means that by the year 2030, even the more efficient and less polluting lignite and coal units will have to have higher marginal costs than the average natural gas units.

Figure 21: EUA prices that make the marginal cost between a CCGT (50% efficiency) unit equal to the marginal cost of an efficient (43%) lignite unit

	€/MWh natural gas												
€/MWh electricity from Lignite	**€30.00**	**€40.00**	**€50.00**	**€60.00**	**€70.00**	**€80.00**	**€90.00**	**€100.00**	**€110.00**	**€120.00**	**€130.00**	**€140.00**	**€150.00**
€20.00	€70.67	€106.01	€141.34	€176.68	€212.01	€247.35	€282.69	€318.02	€353.36	€388.69	€424.03	€459.36	€494.70
€25.00	€61.84	€97.17	€132.51	€167.84	€203.18	€238.52	€273.85	€309.19	€344.52	€379.86	€415.19	€450.53	€485.87
€30.00	€53.00	€88.34	€123.67	€159.01	€194.35	€229.68	€265.02	€300.35	€335.69	€371.02	€406.36	€441.70	€477.03
€35.00	€44.17	€79.51	€114.84	€150.18	€185.51	€220.85	€256.18	€291.52	€326.86	€362.19	€397.53	€432.86	€468.20
€40.00	€35.34	€70.67	€106.01	€141.34	€176.68	€212.01	€247.35	€282.69	€318.02	€353.36	€388.69	€424.03	€459.36
€45.00	€26.50	€61.84	€97.17	€132.51	€167.84	€203.18	€238.52	€273.85	€309.19	€344.52	€379.86	€415.19	€450.53
€50.00	€17.67	€53.00	€88.34	€123.67	€159.01	€194.35	€229.68	€265.02	€300.35	€335.69	€371.02	€406.36	€441.70

In figure 21 we can see that to have an average (by today's standards) natural gas unit to be more cost-efficient than a lignite unit which has an efficiency of 43%, with fuel costs of €60 per natural gas MWh for the natural gas production unit and €35 per electricity MWh for the lignite unit, the EUA price would have to be higher than €150. This means that the EU will ensure that the EUA price gradually increases to these levels by 2030, to push the coal and the lignite units out of competition and to enhance the use of renewable energy resources and natural gas. If the price of European natural gas reduces significantly from the levels of €60-€70, the EU will not have to push the level of the EUA prices that high. The €60 - €70 per MWh of natural gas is an assumption based on current TTF future prices for 2022, and I assume that the European natural gas price will fall during the next years, but it will not go below €60, as an average until 2030, due to the increased global demand for that fuel in Europe and Asia. The reason that I am not going to further lengths to make more sophisticated predictions of the future natural gas prices, is that this would be outside of the scope of this thesis, which examines the EU ETS and its impact on electricity prices. This analysis is important for policymakers because it can guide their marginal cost policies towards a cleaner power production stack in Europe. Also, the power traders that expect high prices of natural gas in the long term, can easily predict that the Commission will manipulate the EUA price in a way that will make coal and lignite usage for power production more expensive and thus, the EUA price will rise and the European energy markets will rise even further. This can contradict the shorter-term patterns of the market.

5.4 The importance of Natural Gas in the Greek Market

In this section, we are going to demonstrate the importance of natural gas for the Greek Market to highlight the significance of the natural gas pass-through rates for the price formation of the Greek DAM.

Lignite used to be the main fuel until 2019, after which it was partially substituted by natural gas. In 2021 natural gas steadily became the dominant fuel. After pulling the hourly "Load" and "Generation per Production Type" from Entsoe Transparency Platform (2021) for the Greek DAM, for the year

2021, I created the monthly averages in hourly MWh that were produced per technology and divided each one of them by the monthly average load of each month, in Excel. Thus, in figure 22 we can see that natural gas had a higher percentage in the generation mix for almost every month of 2021, whereas Lignite production was constantly lower than 20%.

Figure 22: 2021 Greece Generation mix per month

Year	Month	Wind	Solar	Hydro	Gas	Lignite	Coal	Nuclear	Other
2021	**1**	25%	5%	17%	40%	14%	0%	0%	0%
2021	**2**	23%	8%	26%	28%	16%	0%	0%	0%
2021	**3**	21%	10%	8%	42%	19%	0%	0%	0%
2021	**4**	18%	12%	6%	51%	12%	0%	0%	0%
2021	**5**	18%	17%	11%	42%	12%	0%	0%	0%
2021	**6**	8%	15%	11%	59%	7%	0%	0%	0%
2021	**7**	15%	12%	11%	53%	10%	0%	0%	0%
2021	**8**	13%	12%	10%	51%	14%	0%	0%	0%
2021	**9**	19%	11%	6%	54%	9%	0%	0%	0%
2021	**10**	25%	8%	6%	51%	10%	0%	0%	0%
2021	**11**	24%	7%	7%	54%	8%	0%	0%	0%
2021	**12**	24%	5%	17%	43%	10%	0%	0%	0%

Source: (Transparency Entsoe, 2021)

Moreover, according to the Greek Ministry of Environment and Energy (2019), in the National Plan for Climate and Energy, Greece's natural gas generation units are going to have an increasingly important role, as the lignite units are going to be phased out gradually, until 2028. Also, there are targets for an increase in the production of electricity from renewable energy sources (mainly wind and solar). After taking the capacity per technology that is mentioned in the National Plan for Climate and Energy and adjusting it for the part that belongs to the interconnected system (as the non-interconnected system does not affect the wholesale prices), we can calculate the expected electricity production in average MWh per hour for each year between 2022 and 2030.

Figure 23: Historical and National Plan targets (avg MWh/hour) for the Greek Power Market

	Year	Wind	Solar	Hydro	Gas	Lignite	Coal	Nuclear	Other	Total	Demand
Historical	**2018**	555	390	576	1,740	1,737				4,998	5,848
	2019	663	412	384	1,976	1,219				4,653	5,900
	2020	829	456	330	2,160	623	-	-	-	4,426	5,550
	2021	1,028	524	601	2,509	622	-	-	-	5,284	5,844
Forecast	**2022**	1,017	616	408	2,107	467	-	-	-	4,614	5,622
	2023	1,111	695	446	2,080	390	-	-	-	4,723	5,659
	2024	1,206	775	485	2,053	312	-	-	-	4,831	5,695
	2025	1,300	855	524	2,027	234	-	-	-	4,939	5,731
	2026	1,394	935	563	2,000	156	-	-	-	5,047	5,768
	2027	1,488	1,015	601	1,973	78	-	-	-	5,155	5,804
	2028	1,582	1,094	640	1,947	-	-	-	-	5,263	5,841
	2029	1,676	1,174	679	1,920	-	-	-	-	5,449	5,877
ESEK Targets	**2030**	**1,770**	**1,254**	**718**	**1,894**	**-**	**-**	**-**	**-**	**5,636**	**5,913**

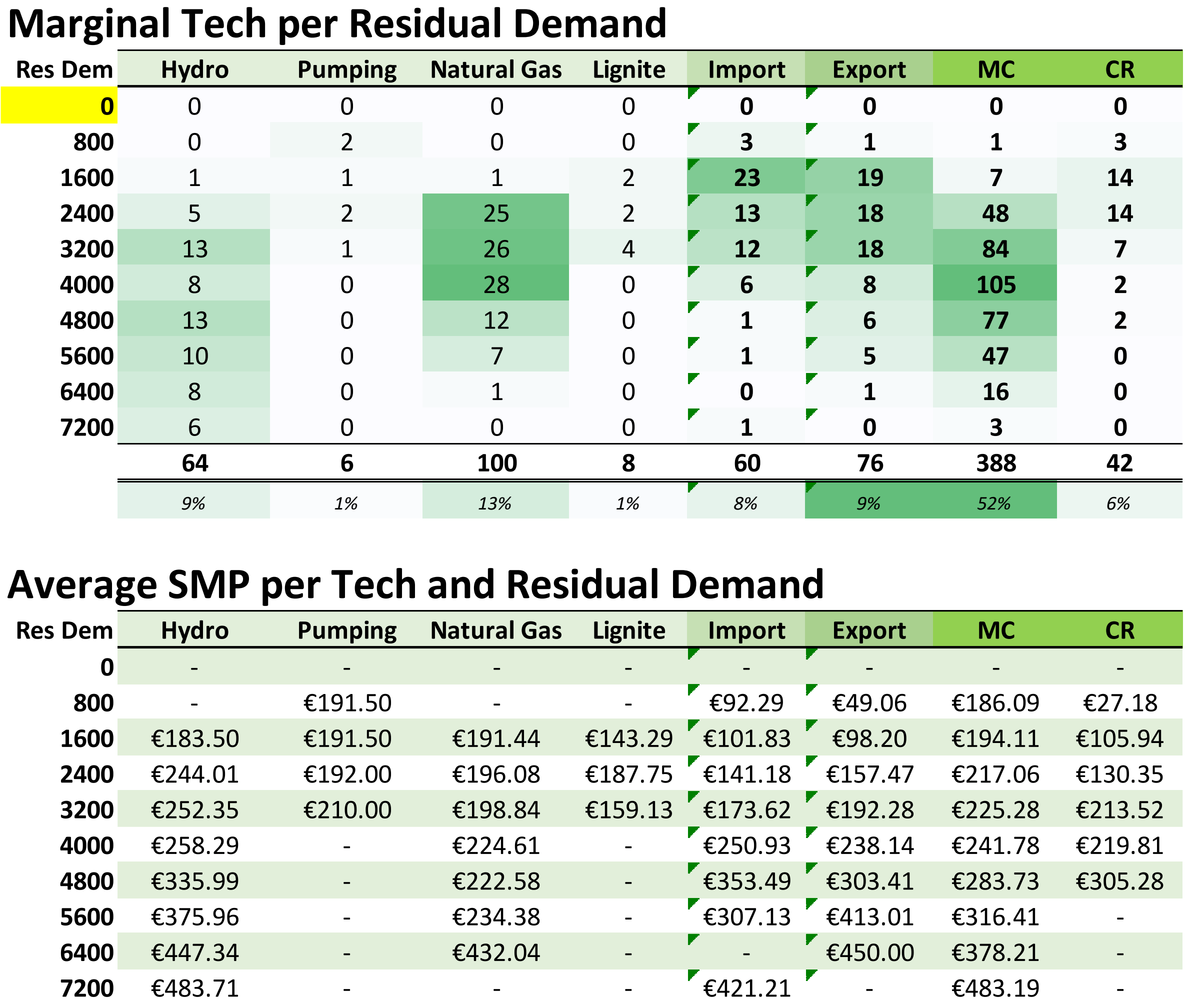
Sources: (Transparency Entsoe, 2021) and (the Greek Ministry of Environment and Energy (2019))

As Lignite will be phased out and renewable energy sources will be increasing, natural gas will be becoming the dominant fuel for setting the price of the Greek Day Ahead Market (DAM). As we mentioned before, the prices are set by marginal technology (or technologies). This means that the various power production units bid (in ascending order) combinations of quantities and prices (MWh / hour and Euros/MWh). The off-takers do the same in descending order and the producer that has placed the bid for the last MWh needed to cover the demand (at the point where the supply and demand meet) sets the system price for the Day Ahead Market, which is the price that all of the producers will be compensated with (Hellenic Energy Exchange, 2021). Furthermore, as it was mentioned in the literature review, it has been observed that when the demand for electricity that needs to be covered by the thermal producers is high, the producers pass through their full cost, plus a margin for profit, on the spot prices. When the demand is lower, the producers absorb a part of the marginal cost, as they are trying to avoid switching their units on and off, or because they have committed to participate in the balancing market (which might be profitable for them). It can also be assumed that the Renewable units (Solar, Wind, and Hydro Run of River) bid the full production with a price of zero or lower, because their marginal cost is 0, and if they do not sell their products in the Greek Day Ahead Market, they undertake the risk of losing their produced energy (when it cannot be stored). This means that when the coal is phased out, the system price will be set mainly by the natural gas units. We can further illustrate this pattern with the use of Statistical Analysis, by examining the power production technologies that set the price in December 2021 and comparing the price that was set between different thresholds of residual demand of the Greek Day Ahead Market. After drawing all of the "Day Ahead Market Report" excel files from the Energy Exchange Group for December 2021, I calculated the Residual Demand for each hour as Residual Demand = Demand – Renewable Production (wind and solar). After that, I created a formula to estimate the production technology that sets the price for each hour. Knowing that the ETSS trader system (the system which is used in the Greek DAM energy trading), does not allow decimals for imports or exports of energy, every time that the value of the hourly MWh for the borders (imports of export) has decimal points, it means that the order was partially accepted and that it was the marginal order, so it set the price. Similarly, we assumed that if the value of the MWh/ hour of the hydro production (or the pumping consumption), the lignite production, or the Crete conventional production had decimals, then the relevant technology was partially accepted from Euphemia and thus it set the Greek DAM price. Last, if the natural gas production had decimals, then the assumption would be that natural gas set the price (alone) and if the natural gas value and the import or export value had decimals, then I set the indicator as MC, which means that the price was set simultaneously from natural gas and a border. It is important to mention that for the sake of this exercise, if a hydro or lignite unit had decimals, then

I would count that hour to be set by that technology, even if the natural gas value had decimals for the same hour.

Furthermore, I assembled all of the “Day Ahead Market Report” excel files from the Energy Exchange Group (including the workings that were mentioned before) and I created a table that calculates (counts) the marginal technology (the production technology which sets the price), for every hour of December 2021, concerning the residual demand (total demand of the system minus the wind and solar production).

Figure 24: December 2021 Marginal Technologies/Residual Demand in Greek DAM



Marginal Tech per Residual Demand

Res Dem	Hydro	Pumping	Natural Gas	Lignite	Import	Export	MC	CR
0	0	0	0	0	0	0	0	0
800	0	2	0	0	3	1	1	3
1600	1	1	1	2	23	19	7	14
2400	5	2	25	2	13	18	48	14
3200	13	1	26	4	12	18	84	7
4000	8	0	28	0	6	8	105	2
4800	13	0	12	0	1	6	77	2
5600	10	0	7	0	1	5	47	0
6400	8	0	1	0	0	1	16	0
7200	6	0	0	0	1	0	3	0
	64	6	100	8	60	76	388	42
	9%	1%	13%	1%	8%	9%	52%	6%

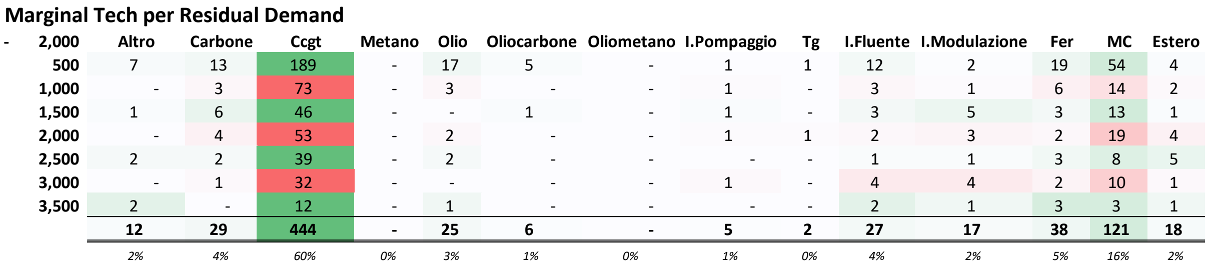
Average SMP per Tech and Residual Demand

Res Dem	Hydro	Pumping	Natural Gas	Lignite	Import	Export	MC	CR
0	-	-	-	-	-	-	-	-
800	-	€191.50	-	-	€92.29	€49.06	€186.09	€27.18
1600	€183.50	€191.50	€191.44	€143.29	€101.83	€98.20	€194.11	€105.94
2400	€244.01	€192.00	€196.08	€187.75	€141.18	€157.47	€217.06	€130.35
3200	€252.35	€210.00	€198.84	€159.13	€173.62	€192.28	€225.28	€213.52
4000	€258.29	-	€224.61	-	€250.93	€238.14	€241.78	€219.81
4800	€335.99	-	€222.58	-	€353.49	€303.41	€283.73	€305.28
5600	€375.96	-	€234.38	-	€307.13	€413.01	€316.41	-
6400	€447.34	-	€432.04	-	-	€450.00	€378.21	-
7200	€483.71	-	-	-	€421.21	-	€483.19	-

source: (Energy Exchange Group: Day-Ahead Market Report, 2021)

December 2021 has 31 days x 24 hours/ day = 744 hours in total. In the first table, we can see how many times each production technology has set the Day Ahead Market’s price (for Greece) for specific thresholds of residual demand. Hydro and Pumping are the hydro units that belong to PPC (all of the Lignite units also belong to PPC). The “Import” represents the times that an import from one of the 5 Greek Borders (Turkey, Bulgaria, North Macedonia, Albania, and Italy) has set the price and Export represents the times that export from Greece to one of the aforementioned borders sets the price. The “CR” counts the occasions where the interconnection of mainland Greece with Crete sets the price (either flow) and last the “MC” illustrates the times that a border and natural gas have set the price, along with, or not, another technology. It is evident that 10% of the time the Hydro units set the price, the Lignite units set the price only 1% of the time, and the borders (imports and exports together) set the price 17% of the time on their own. Natural gas on its own has set the price 13% of the time and after we take into consideration the times that the price was set by natural gas and the borders together, we can see that natural gas set the Greek Day Ahead Price 65% of the times in December 2021. Moreover, in the second table, we can see the average price that was set, per technology and residual demand in the Greek market (using the same work that was described before). It is obvious that the higher the residual demand, the higher the prices. For instance, on the occasions that the natural gas set the price and the residual demand threshold was between 1600 and 2400 MWh/ hour, the average price was €191, whereas the average price for the same technology and the 5600- 6400 is €234. It is important to mention that even when the borders set the price for Greece, natural gas prices are still very relevant since natural gas sets the prices for some of those countries directly or indirectly. A very straightforward example of this is the case of Italy. After combining the data from the report “ historical data day ahead market” from the Gestore Mercati Energetici (2022) that provides info related to the Marginal Technology of the Italian Day Ahead Market, for every hour with the “Load" data from Transparency Entsoe related to the Italian bidding zone “Italy – Sud” (or Italy South in English), I created a similar table with the number of times that each technology sets the price in Italy South (which is the part of Italy that is interconnected with Greece). In this case, all of the technologies that are mentioned in the table below are given (on an hourly basis for each hour of the month) directly from GME. After that, I used the info from Transparency Entsoe to get the Load and the Wind and Solar production for every hour of December 2021 for Italy Sud, I created some thresholds of residual demand (from -2,000 to 3,500) in Excel and I counted how many times each technology set the price.

Figure 25: December 2021 Marginal Technologies/Residual Demand in Italian DAM



Marginal Tech per Residual Demand

- 2,000	Altro	Carbone	Ccgt	Metano	Olio	Oliocarbone	Oliometano	I.Pompaggio	Tg	I.Fluente	I.Modulazione	Fer	MC	Estero
500	7	13	189	-	17	5	-	1	1	12	2	19	54	4
1,000	-	3	73	-	3	-	-	1	-	3	1	6	14	2
1,500	1	6	46	-	-	1	-	1	-	3	5	3	13	1
2,000	-	4	53	-	2	-	-	1	1	2	3	2	19	4
2,500	2	2	39	-	2	-	-	-	-	1	1	3	8	5
3,000	-	1	32	-	-	-	-	1	-	4	4	2	10	1
3,500	2	-	12	-	1	-	-	-	-	2	1	3	3	1
	12	**29**	**444**	**-**	**25**	**6**	**-**	**5**	**2**	**27**	**17**	**38**	**121**	**18**
	2%	*4%*	*60%*	*0%*	*3%*	*1%*	*0%*	*1%*	*0%*	*4%*	*2%*	*5%*	*16%*	*2%*

Sources: (Gestore Mercati Energetici, 2022) and (Transparency Entsoe, 2021)

The most important part of the table above is that 61% of the time, Ccgt (which stands for "Combined Cycle Gas Turbines") sets the price and MC sets the price for 16% of the time. Thus, the "Italy – Sud" Day Ahead market price is set 77% by the natural gas prices, which in turn affect significantly the Greek Day Ahead Market prices (imports and exports).

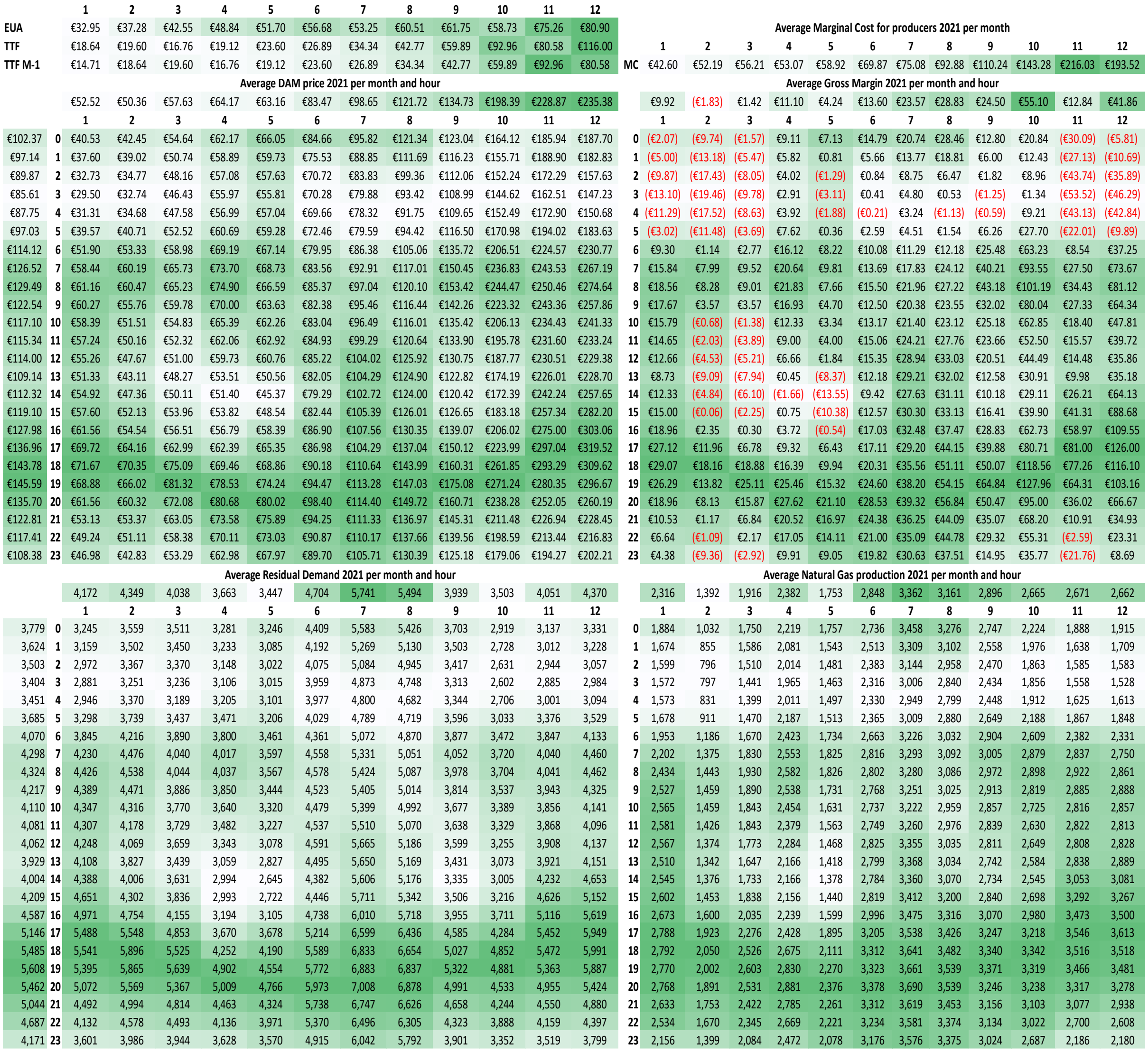
All of the above highlight the significance that the natural gas units have for the setting of the Greek DAM price. If we can calculate the natural gas passthrough rates correctly, we can draw very safe conclusions for the formulation of the Greek DAM. This finding is very important, for the policymakers and the traders as they can focus more on the natural gas unit costs to estimate the future DAM prices, instead of having to analyze all of the available technologies. In other words, if the Greek Government wanted to reduce the prices of the Greek DAM, by using a cap on the fuel prices, then the policy would be much more efficient if the cap was focused on the natural gas fuel price, rather than lignite.

5.5 Statistical Analysis of the Passthrough rates of the Greek Natural Gas units to the DAM price

All of the above lead to the conclusion that we can get an accurate estimation of the effect of the EUAs on the Greek spot prices if we analyze the pass-through patterns of the natural gas units. In this section, we are going to use some statistical analysis to examine the pass-through rates of the natural gas units to the Greek DAM prices and discover the natural gas producers' bidding patterns and strategies. To do so, I have assembled the hourly data for the Greek Load, the production per technology, and the DAM prices in Excel for the year 2021, from Transparency Entsoe. Also, I have accumulated the daily future prices of the EUA (Euros/ton CO2 equivalent) and TTF (Euros/MWh) the marginal cost components for the natural gas units) from Investing.com (2021 and 2022) for the year 2021. I summarized this info as the average per month for the futures (EUA and TTF) and as the average per month and hour for the residual demand (demand – wind production – solar production), the DAM price. After that, I calculated the monthly average marginal cost for the natural gas units (in the same way as it was described in the "The marginal cost of the natural gas units, the lignite units, and the EUA price that is needed to equate them" section above, and last I calculated the average gross revenue (or cost), which is the DAM price (MCP) minus the marginal cost, per month and hour. All of the workings and the tables were created in Excel.

Some of the conclusions that can be inferred from this statistical analysis (illustrated in the table below) are that the natural gas producers try to maximize their profits by bidding high (over their total cost) when there is high residual demand and by bidding low when the residual demand is low. Also, there can be observed some seasonality patterns for the Greek Day Ahead Market prices. For instance, during months with the highest/lowest temperatures, the prices tend to be higher, because the electricity demand is higher. Also, during weekends and bank holidays, the residual demand tends to be lower, thus the power producers do not have the opportunity to bid high. There are patterns in the hourly bidding of the producers, as the residual demand statistically will be much higher during some hours (e.g. at 21 00 compared with 03:00), so the producers tend to systematically bid lower in certain hours, even if the actual residual demand ends up being higher in reality. Last, when the natural gas producers bid under their marginal cost for some hours to keep their units in the market (and avoid the shut-off and costs), then they tend to bid much higher in the hours that the residual demand is high to recover their losses and ensure a positive overall gross margin. The higher the losses during the "tighter hours" the higher their profit margin will be when they will have the opportunity to bid higher.

Figure 26: Average Data for the Greek DAM for 2021



	1	2	3	4	5	6	7	8	9	10	11	12
EUA	€32.95	€37.28	€42.55	€48.84	€51.70	€56.68	€53.25	€60.51	€61.75	€58.73	€75.26	€80.90
TTF	€18.64	€19.60	€16.76	€19.12	€23.60	€26.89	€34.34	€42.77	€59.89	€92.96	€80.58	€116.00
TTF M-1	€14.71	€18.64	€19.60	€16.76	€19.12	€23.60	€26.89	€34.34	€42.77	€59.89	€92.96	€80.58

Average Marginal Cost for producers 2021 per month

	1	2	3	4	5	6	7	8	9	10	11	12
MC	€42.60	€52.19	€56.21	€53.07	€58.92	€69.87	€75.08	€92.88	€110.24	€143.28	€216.03	€193.52

Average DAM price 2021 per month and hour

		1	2	3	4	5	6	7	8	9	10	11	12
		€52.52	€50.36	€57.63	€64.17	€63.16	€83.47	€98.65	€121.72	€134.73	€198.39	€228.87	€235.38
€102.37	0	€40.53	€42.45	€54.64	€62.17	€66.05	€84.66	€95.82	€121.34	€123.04	€164.12	€185.94	€187.70
€97.14	1	€37.60	€39.02	€50.74	€58.89	€59.73	€75.53	€88.85	€111.69	€116.23	€155.71	€188.90	€182.83
€89.87	2	€32.73	€34.77	€48.16	€57.08	€57.63	€70.72	€83.83	€99.36	€112.06	€152.24	€172.29	€157.63
€85.61	3	€29.50	€32.74	€46.43	€55.97	€55.81	€70.28	€79.88	€93.42	€108.99	€144.62	€162.51	€147.23
€87.75	4	€31.31	€34.68	€47.58	€56.99	€57.04	€69.66	€78.32	€91.75	€109.65	€152.49	€172.90	€150.68
€97.03	5	€39.57	€40.71	€52.52	€60.69	€59.28	€72.46	€79.59	€94.42	€116.50	€170.98	€194.02	€183.63
€114.12	6	€51.90	€53.33	€58.98	€69.19	€67.14	€79.95	€86.38	€105.06	€135.72	€206.51	€224.57	€230.77
€126.52	7	€58.44	€60.19	€65.73	€73.70	€68.73	€83.56	€92.91	€117.01	€150.45	€236.83	€243.53	€267.19
€129.49	8	€61.16	€60.47	€65.23	€74.90	€66.59	€85.37	€97.04	€120.10	€153.42	€244.47	€250.46	€274.64
€122.54	9	€60.27	€55.76	€59.78	€70.00	€63.63	€82.38	€95.46	€116.44	€142.26	€223.32	€243.36	€257.86
€117.10	10	€58.39	€51.51	€54.83	€65.39	€62.26	€83.04	€96.49	€116.01	€135.42	€206.13	€234.43	€241.33
€115.34	11	€57.24	€50.16	€52.32	€62.06	€62.92	€84.93	€99.29	€120.64	€133.90	€195.78	€231.60	€233.24
€114.00	12	€55.26	€47.67	€51.00	€59.73	€60.76	€85.22	€104.02	€125.92	€130.75	€187.77	€230.51	€229.38
€109.14	13	€51.33	€43.11	€48.27	€53.51	€50.56	€82.05	€104.29	€124.90	€122.82	€174.19	€226.01	€228.70
€112.32	14	€54.92	€47.36	€50.11	€51.40	€45.37	€79.29	€102.72	€124.00	€120.42	€172.39	€242.24	€257.65
€119.10	15	€57.60	€52.13	€53.96	€53.82	€48.54	€82.44	€105.39	€126.01	€126.65	€183.18	€257.34	€282.20
€127.98	16	€61.56	€54.54	€56.51	€56.79	€58.39	€86.90	€107.56	€130.35	€139.07	€206.02	€275.00	€303.06
€136.96	17	€69.72	€64.16	€62.99	€62.39	€65.35	€86.98	€104.29	€137.04	€150.12	€223.99	€297.04	€319.52
€143.78	18	€71.67	€70.35	€75.09	€69.46	€68.86	€90.18	€110.64	€143.99	€160.31	€261.85	€293.29	€309.62
€145.59	19	€68.88	€66.02	€81.32	€78.53	€74.24	€94.47	€113.28	€147.03	€175.08	€271.24	€280.35	€296.67
€135.70	20	€61.56	€60.32	€72.08	€80.68	€80.02	€98.40	€114.40	€149.72	€160.71	€238.28	€252.05	€260.19
€122.81	21	€53.13	€53.37	€63.05	€73.58	€75.89	€94.25	€111.33	€136.97	€145.31	€211.48	€226.94	€228.45
€117.41	22	€49.24	€51.11	€58.38	€70.11	€73.03	€90.87	€110.17	€137.66	€139.56	€198.59	€213.44	€216.83
€108.38	23	€46.98	€42.83	€53.29	€62.98	€67.97	€89.70	€105.71	€130.39	€125.18	€179.06	€194.27	€202.21

Average Gross Margin 2021 per month and hour

	1	2	3	4	5	6	7	8	9	10	11	12
	€9.92	(€1.83)	€1.42	€11.10	€4.24	€13.60	€23.57	€28.83	€24.50	€55.10	€12.84	€41.86
0	(€2.07)	(€9.74)	(€1.57)	€9.11	€7.13	€14.79	€20.74	€28.46	€12.80	€20.84	(€30.09)	(€5.81)
1	(€5.00)	(€13.18)	(€5.47)	€5.82	€0.81	€5.66	€13.77	€18.81	€6.00	€12.43	(€27.13)	(€10.69)
2	(€9.87)	(€17.43)	(€8.05)	€4.02	(€1.29)	€0.84	€8.75	€6.47	€1.82	€8.96	(€43.74)	(€35.89)
3	(€13.10)	(€19.46)	(€9.78)	€2.91	(€3.11)	€0.41	€4.80	€0.53	(€1.25)	€1.34	(€53.52)	(€46.29)
4	(€11.29)	(€17.52)	(€8.63)	€3.92	(€1.88)	(€0.21)	€3.24	(€1.13)	(€0.59)	€9.21	(€43.13)	(€42.84)
5	(€3.02)	(€11.48)	(€3.69)	€7.62	€0.36	€2.59	€4.51	€1.54	€6.26	€27.70	(€22.01)	(€9.89)
6	€9.30	€1.14	€2.77	€16.12	€8.22	€10.08	€11.29	€12.18	€25.48	€63.23	€8.54	€37.25
7	€15.84	€7.99	€9.52	€20.64	€9.81	€13.69	€17.83	€24.12	€40.21	€93.55	€27.50	€73.67
8	€18.56	€8.28	€9.01	€21.83	€7.66	€15.50	€21.96	€27.22	€43.18	€101.19	€34.43	€81.12
9	€17.67	€3.57	€3.57	€16.93	€4.70	€12.50	€20.38	€23.55	€32.02	€80.04	€27.33	€64.34
10	€15.79	(€0.68)	(€1.38)	€12.33	€3.34	€13.17	€21.40	€23.12	€25.18	€62.85	€18.40	€47.81
11	€14.65	(€2.03)	(€3.89)	€9.00	€4.00	€15.06	€24.21	€27.76	€23.66	€52.50	€15.57	€39.72
12	€12.66	(€4.53)	(€5.21)	€6.66	€1.84	€15.35	€28.94	€33.03	€20.51	€44.49	€14.48	€35.86
13	€8.73	(€9.09)	(€7.94)	€0.45	(€8.37)	€12.18	€29.21	€32.02	€12.58	€30.91	€9.98	€35.18
14	€12.33	(€4.84)	(€6.10)	(€1.66)	(€13.55)	€9.42	€27.63	€31.11	€10.18	€29.11	€26.21	€64.13
15	€15.00	(€0.06)	(€2.25)	€0.75	(€10.38)	€12.57	€30.30	€33.13	€16.41	€39.90	€41.31	€88.68
16	€18.96	€2.35	€0.30	€3.72	(€0.54)	€17.03	€32.48	€37.47	€28.83	€62.73	€58.97	€109.55
17	€27.12	€11.96	€6.78	€9.32	€6.43	€17.11	€29.20	€44.15	€39.88	€80.71	€81.00	€126.00
18	€29.07	€18.16	€18.88	€16.39	€9.94	€20.31	€35.56	€51.11	€50.07	€118.56	€77.26	€116.10
19	€26.29	€13.82	€25.11	€25.46	€15.32	€24.60	€38.20	€54.15	€64.84	€127.96	€64.31	€103.16
20	€18.96	€8.13	€15.87	€27.62	€21.10	€28.53	€39.32	€56.84	€50.47	€95.00	€36.02	€66.67
21	€10.53	€1.17	€6.84	€20.52	€16.97	€24.38	€36.25	€44.09	€35.07	€68.20	€10.91	€34.93
22	€6.64	(€1.09)	€2.17	€17.05	€14.11	€21.00	€35.09	€44.78	€29.32	€55.31	(€2.59)	€23.31
23	€4.38	(€9.36)	(€2.92)	€9.91	€9.05	€19.82	€30.63	€37.51	€14.95	€35.77	(€21.76)	€8.69

Average Residual Demand 2021 per month and hour

		1	2	3	4	5	6	7	8	9	10	11	12
		4,172	4,349	4,038	3,663	3,447	4,704	5,741	5,494	3,939	3,503	4,051	4,370
3,779	0	3,245	3,559	3,511	3,281	3,246	4,409	5,583	5,426	3,703	2,919	3,137	3,331
3,624	1	3,159	3,502	3,450	3,233	3,085	4,192	5,269	5,130	3,503	2,728	3,012	3,228
3,503	2	2,972	3,367	3,370	3,148	3,022	4,075	5,084	4,945	3,417	2,631	2,944	3,057
3,404	3	2,881	3,251	3,236	3,106	3,015	3,959	4,873	4,748	3,313	2,602	2,885	2,984
3,451	4	2,946	3,370	3,189	3,205	3,101	3,977	4,800	4,682	3,344	2,706	3,001	3,094
3,685	5	3,298	3,739	3,437	3,471	3,206	4,029	4,789	4,719	3,596	3,033	3,376	3,529
4,070	6	3,845	4,216	3,890	3,800	3,461	4,361	5,072	4,870	3,877	3,472	3,847	4,133
4,298	7	4,230	4,476	4,040	4,017	3,597	4,558	5,331	5,051	4,052	3,720	4,040	4,460
4,324	8	4,426	4,538	4,044	4,037	3,567	4,578	5,424	5,087	3,978	3,704	4,041	4,462
4,217	9	4,389	4,471	3,886	3,850	3,444	4,523	5,405	5,014	3,814	3,537	3,943	4,325
4,110	10	4,347	4,316	3,770	3,640	3,320	4,479	5,399	4,992	3,677	3,389	3,856	4,141
4,081	11	4,307	4,178	3,729	3,482	3,227	4,537	5,510	5,070	3,638	3,329	3,868	4,096
4,062	12	4,248	4,069	3,659	3,343	3,078	4,591	5,665	5,186	3,599	3,255	3,908	4,137
3,929	13	4,108	3,827	3,439	3,059	2,827	4,495	5,650	5,169	3,431	3,073	3,921	4,151
4,004	14	4,388	4,006	3,631	2,994	2,645	4,382	5,606	5,176	3,335	3,005	4,232	4,653
4,209	15	4,651	4,302	3,836	2,993	2,722	4,446	5,711	5,342	3,506	3,216	4,626	5,152
4,587	16	4,971	4,754	4,155	3,194	3,105	4,738	6,010	5,718	3,955	3,711	5,116	5,619
5,146	17	5,488	5,548	4,853	3,670	3,678	5,214	6,599	6,436	4,585	4,284	5,452	5,949
5,485	18	5,541	5,896	5,525	4,252	4,190	5,589	6,833	6,654	5,027	4,852	5,472	5,991
5,608	19	5,395	5,865	5,639	4,902	4,554	5,772	6,883	6,837	5,322	4,881	5,363	5,887
5,462	20	5,072	5,569	5,367	5,009	4,766	5,973	7,008	6,878	4,991	4,533	4,955	5,424
5,044	21	4,492	4,994	4,814	4,463	4,324	5,738	6,747	6,626	4,658	4,244	4,550	4,880
4,687	22	4,132	4,578	4,493	4,136	3,971	5,370	6,496	6,305	4,323	3,888	4,159	4,397
4,171	23	3,601	3,986	3,944	3,628	3,570	4,915	6,042	5,792	3,901	3,352	3,519	3,799

Average Natural Gas production 2021 per month and hour

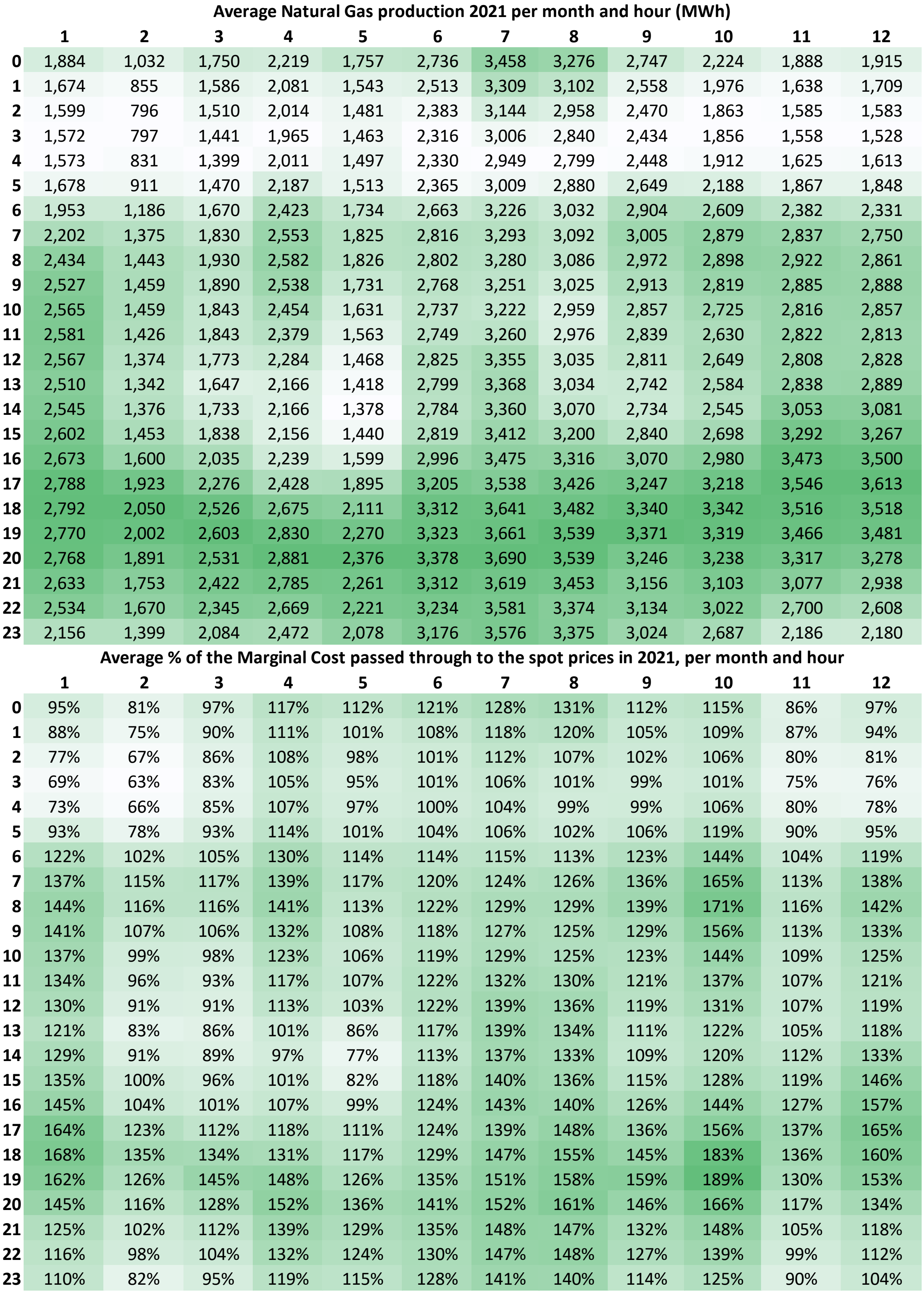
	1	2	3	4	5	6	7	8	9	10	11	12
	2,316	1,392	1,916	2,382	1,753	2,848	3,362	3,161	2,896	2,665	2,671	2,662
0	1,884	1,032	1,750	2,219	1,757	2,736	3,458	3,276	2,747	2,224	1,888	1,915
1	1,674	855	1,586	2,081	1,543	2,513	3,309	3,102	2,558	1,976	1,638	1,709
2	1,599	796	1,510	2,014	1,481	2,383	3,144	2,958	2,470	1,863	1,585	1,583
3	1,572	797	1,441	1,965	1,463	2,316	3,006	2,840	2,434	1,856	1,558	1,528
4	1,573	831	1,399	2,011	1,497	2,330	2,949	2,799	2,448	1,912	1,625	1,613
5	1,678	911	1,470	2,187	1,513	2,365	3,009	2,880	2,649	2,188	1,867	1,848
6	1,953	1,186	1,670	2,423	1,734	2,663	3,226	3,032	2,904	2,609	2,382	2,331
7	2,202	1,375	1,830	2,553	1,825	2,816	3,293	3,092	3,005	2,879	2,837	2,750
8	2,434	1,443	1,930	2,582	1,826	2,802	3,280	3,086	2,972	2,898	2,922	2,861
9	2,527	1,459	1,890	2,538	1,731	2,768	3,251	3,025	2,913	2,819	2,885	2,888
10	2,565	1,459	1,843	2,454	1,631	2,737	3,222	2,959	2,857	2,725	2,816	2,857
11	2,581	1,426	1,843	2,379	1,563	2,749	3,260	2,976	2,839	2,630	2,822	2,813
12	2,567	1,374	1,773	2,284	1,468	2,825	3,355	3,035	2,811	2,649	2,808	2,828
13	2,510	1,342	1,647	2,166	1,418	2,799	3,368	3,034	2,742	2,584	2,838	2,889
14	2,545	1,376	1,733	2,166	1,378	2,784	3,360	3,070	2,734	2,545	3,053	3,081
15	2,602	1,453	1,838	2,156	1,440	2,819	3,412	3,200	2,840	2,698	3,292	3,267
16	2,673	1,600	2,035	2,239	1,599	2,996	3,475	3,316	3,070	2,980	3,473	3,500
17	2,788	1,923	2,276	2,428	1,895	3,205	3,538	3,426	3,247	3,218	3,546	3,613
18	2,792	2,050	2,526	2,675	2,111	3,312	3,641	3,482	3,340	3,342	3,516	3,518
19	2,770	2,002	2,603	2,830	2,270	3,323	3,661	3,539	3,371	3,319	3,466	3,481
20	2,768	1,891	2,531	2,881	2,376	3,378	3,690	3,539	3,246	3,238	3,317	3,278
21	2,633	1,753	2,422	2,785	2,261	3,312	3,619	3,453	3,156	3,103	3,077	2,938
22	2,534	1,670	2,345	2,669	2,221	3,234	3,581	3,374	3,134	3,022	2,700	2,608
23	2,156	1,399	2,084	2,472	2,078	3,176	3,576	3,375	3,024	2,687	2,186	2,180

source: (Transparency Entsoe, 2021) and (Investing.com, 2021)

To analyze table 24 further and shed some light on the percentage of the EUA cost that the natural gas producer passes through to the spot prices, some things should be highlighted. First of all, according to Stefanou (2021), the Greek Gas market mainly supports Month Ahead products (due to capacity issues) and there is no efficient spot market, which should reflect the current prices. This means that the natural gas units have to book their gas inputs with the month ahead prices and that the spot prices (e.g. TTF) do not affect the market significantly. An electricity producer will have the marginal cost of last month's gas price per MWh of gas and not this month's spot price. In table 24, various statistics and trends are illustrated. As it was mentioned before, at the top left corner, there are the average prices of the Month Ahead futures for TTF (daily closing prices), their one-month lag values, and the Dec-22 EUA futures (daily closing prices), per month (Investing.com, 2021). Also, on the top right, the marginal cost per month for a Greek natural gas unit with 50% efficiency can be seen, per month, based on the aforementioned costs (with one month lag for the TTF prices). We can also see the average DAM prices, the average residual demand, the average per hour and month, the average gross margin (as DAM price – Marginal cost), and the average MWh of electricity produced from the Greek natural gas units in 2021, per hour and month. All of the data was taken from Transparency Entsoe.

The second set of important observations and patterns can be drawn from the tables above. For instance, the level of the average DAM prices tends to have similar patterns to the level of the residual demand (high residual demand usually leads to higher prices). July is the month with the highest residual demand, but all of the months after July exhibit higher DAM prices. This happens since the TTF and the EUA prices increased significantly, which can also be seen by the monthly increase of the Marginal Cost per month (MC). It can be observed that when the residual demand is low, then the gross margin for the gas units is low (or even negative), but also, if the marginal cost is negative, then for the same levels of residual demand (per hour) the electricity producers produce fewer quantities (MWh of electricity). At the same time, during the months that the electricity producers lose money to keep their units operating, they tend to bid much higher when they have the opportunity, to both reclaim their expenses and achieve a profit. For instance, the residual demand of the hour 0 (midnight) in October 2021 is lower than the same hour in November. Nevertheless, a higher quantity of MWh is produced in October (for the very hour), as an average, because of the higher gross profit opportunity. The tables have some simplifications for the scope of this exercise like, the mandatory hydro production and the prices of the Greek borders (which can increase or decrease the opportunity of the natural gas units to bid higher) have been omitted. For example, in October, the prices of Italy and Bulgaria were very high, which allowed the Greek natural gas units to bid higher than normal.

Figure 27: Average % of the Marginal Cost passed through to the spot prices and average natural gas production in 2021, per month and hour



Average Natural Gas production 2021 per month and hour (MWh)

	1	2	3	4	5	6	7	8	9	10	11	12
0	1,884	1,032	1,750	2,219	1,757	2,736	3,458	3,276	2,747	2,224	1,888	1,915
1	1,674	855	1,586	2,081	1,543	2,513	3,309	3,102	2,558	1,976	1,638	1,709
2	1,599	796	1,510	2,014	1,481	2,383	3,144	2,958	2,470	1,863	1,585	1,583
3	1,572	797	1,441	1,965	1,463	2,316	3,006	2,840	2,434	1,856	1,558	1,528
4	1,573	831	1,399	2,011	1,497	2,330	2,949	2,799	2,448	1,912	1,625	1,613
5	1,678	911	1,470	2,187	1,513	2,365	3,009	2,880	2,649	2,188	1,867	1,848
6	1,953	1,186	1,670	2,423	1,734	2,663	3,226	3,032	2,904	2,609	2,382	2,331
7	2,202	1,375	1,830	2,553	1,825	2,816	3,293	3,092	3,005	2,879	2,837	2,750
8	2,434	1,443	1,930	2,582	1,826	2,802	3,280	3,086	2,972	2,898	2,922	2,861
9	2,527	1,459	1,890	2,538	1,731	2,768	3,251	3,025	2,913	2,819	2,885	2,888
10	2,565	1,459	1,843	2,454	1,631	2,737	3,222	2,959	2,857	2,725	2,816	2,857
11	2,581	1,426	1,843	2,379	1,563	2,749	3,260	2,976	2,839	2,630	2,822	2,813
12	2,567	1,374	1,773	2,284	1,468	2,825	3,355	3,035	2,811	2,649	2,808	2,828
13	2,510	1,342	1,647	2,166	1,418	2,799	3,368	3,034	2,742	2,584	2,838	2,889
14	2,545	1,376	1,733	2,166	1,378	2,784	3,360	3,070	2,734	2,545	3,053	3,081
15	2,602	1,453	1,838	2,156	1,440	2,819	3,412	3,200	2,840	2,698	3,292	3,267
16	2,673	1,600	2,035	2,239	1,599	2,996	3,475	3,316	3,070	2,980	3,473	3,500
17	2,788	1,923	2,276	2,428	1,895	3,205	3,538	3,426	3,247	3,218	3,546	3,613
18	2,792	2,050	2,526	2,675	2,111	3,312	3,641	3,482	3,340	3,342	3,516	3,518
19	2,770	2,002	2,603	2,830	2,270	3,323	3,661	3,539	3,371	3,319	3,466	3,481
20	2,768	1,891	2,531	2,881	2,376	3,378	3,690	3,539	3,246	3,238	3,317	3,278
21	2,633	1,753	2,422	2,785	2,261	3,312	3,619	3,453	3,156	3,103	3,077	2,938
22	2,534	1,670	2,345	2,669	2,221	3,234	3,581	3,374	3,134	3,022	2,700	2,608
23	2,156	1,399	2,084	2,472	2,078	3,176	3,576	3,375	3,024	2,687	2,186	2,180

Average % of the Marginal Cost passed through to the spot prices in 2021, per month and hour

	1	2	3	4	5	6	7	8	9	10	11	12
0	95%	81%	97%	117%	112%	121%	128%	131%	112%	115%	86%	97%
1	88%	75%	90%	111%	101%	108%	118%	120%	105%	109%	87%	94%
2	77%	67%	86%	108%	98%	101%	112%	107%	102%	106%	80%	81%
3	69%	63%	83%	105%	95%	101%	106%	101%	99%	101%	75%	76%
4	73%	66%	85%	107%	97%	100%	104%	99%	99%	106%	80%	78%
5	93%	78%	93%	114%	101%	104%	106%	102%	106%	119%	90%	95%
6	122%	102%	105%	130%	114%	114%	115%	113%	123%	144%	104%	119%
7	137%	115%	117%	139%	117%	120%	124%	126%	136%	165%	113%	138%
8	144%	116%	116%	141%	113%	122%	129%	129%	139%	171%	116%	142%
9	141%	107%	106%	132%	108%	118%	127%	125%	129%	156%	113%	133%
10	137%	99%	98%	123%	106%	119%	129%	125%	123%	144%	109%	125%
11	134%	96%	93%	117%	107%	122%	132%	130%	121%	137%	107%	121%
12	130%	91%	91%	113%	103%	122%	139%	136%	119%	131%	107%	119%
13	121%	83%	86%	101%	86%	117%	139%	134%	111%	122%	105%	118%
14	129%	91%	89%	97%	77%	113%	137%	133%	109%	120%	112%	133%
15	135%	100%	96%	101%	82%	118%	140%	136%	115%	128%	119%	146%
16	145%	104%	101%	107%	99%	124%	143%	140%	126%	144%	127%	157%
17	164%	123%	112%	118%	111%	124%	139%	148%	136%	156%	137%	165%
18	168%	135%	134%	131%	117%	129%	147%	155%	145%	183%	136%	160%
19	162%	126%	145%	148%	126%	135%	151%	158%	159%	189%	130%	153%
20	145%	116%	128%	152%	136%	141%	152%	161%	146%	166%	117%	134%
21	125%	102%	112%	139%	129%	135%	148%	147%	132%	148%	105%	118%
22	116%	98%	104%	132%	124%	130%	147%	148%	127%	139%	99%	112%
23	110%	82%	95%	119%	115%	128%	141%	140%	114%	125%	90%	104%

source:(Transparency Entsoe, 2021)

In the table above, it can be inferred that the natural gas units will produce more natural gas when they have the opportunity to bid high and achieve higher revenue (pass through a high percentage of their marginal cost). Also, the higher the losses (negative marginal cost) the natural gas units have, the higher they will bid (and achieve a higher % of their marginal cost to pass through) during the hours that they will have the opportunity. This means that for the same quantity of electricity produced, they will expect a higher return per MWh of electricity, to make up for their losses.

These findings bear great significance for various stakeholders. First of all, policymakers and energy suppliers should take into consideration that if the cost of the EUA is very high, the hourly fluctuations of the DAM price are going to be significant. This happens because the natural gas units will be inclined to bid low when the market is tight (maybe even lower than their marginal cost) for their baseload quantity, and they will bid very high, when they will get the opportunity, to recover their losses. This means that energy suppliers can reduce their costs by creating special contracts (and offering special prices) with their customers, regarding the timing of the consumption and policymakers must have this trend into consideration during the designing of new laws regarding energy storage from batteries or the bidding patterns of the Hydro units. This pattern also reveals the significance of the levels of renewable production and demand.

Also, if the producers' marginal costs are very high, the natural gas producers tend to offer less quantity (MWh) when the market is tight, which might enhance the production of energy from less green production technologies (like lignite) or higher energy imports from countries that have different rules for the allocation of EUAs (like Bulgaria). Thus, the EU policymakers must identify the ideal EUA price which will lead to the long-term extinction of the polluting power-producing technologies, while at the same time the annual CO2 reduction targets are not compromised. Last, the policymakers can estimate the financial viability of the units. If the EUA gets too high and the natural gas units have to sell their baseload under the cost for many hours, the various companies will stop investing in this technology and there is a chance that there will be occasions of energy deficit when the power demand will be very high or even a regression towards the usage of more polluting technologies (to cover the deficits).

Moreover, we are going to illustrate in the next chapter that the pass-through rate of the cost of gas (fuel) is almost 200% and that the pass-through rate of the EUA is almost 100%. But the policymakers need to understand the patterns of the bidding of the natural gas producers so that they can estimate the appropriate timing of the EUA withdrawal/release or changes in the scope of the EU ETS and the potential impact and its impact on the wholesale markets and to society as a whole.

5.6 Regression Analysis

Similarly, to Dagoumas and Polemis (2020), we are going to examine the pass-through rate of the EUA price to the Greek DAM price (MCP), using regression analysis. We are going to use a linear OLS (Ordinary Least Square) regression, in Python, with the daily average Day Ahead Market prices, known as the Market Clearing Price or MCP of the Greek system as the dependent variable (Price, Euros/MWh), and the daily average of the Residual Demand of the Greek Day Ahead Market (Res_Demand, MWh/h), the daily average of the Priority Power Purchases for the Hydro production (Hydro_PPT, MWh/h), the EUA December futures' daily closing prices (EUA_Price, Euros/Ton CO2), the next month TTF futures' daily closing prices (TTF, Euros/MWh), the Brent futures' daily closing prices (Brent, USD/bbl) and the Rotterdam Coal futures' daily closing prices (Coal, Euros/MWh) as the independent variables, from the beginning of the Target Model in Greece (1/11/2020) until 21/02/2020 (478 daily observation). The Day Ahead Market Prices and the Residual Demand came from the Energy Exchange Group Day Ahead Market Report, the Priority Power Purchase MWh for the Hydro units came from the ISP Requirements of ADMIE (2022), and the rest of the data came from Investing.com.

The equation for the regression is:

(1) MCP(i) = a0 + b1 ResDemand(i) + b2 PPT_Hydro(i) + b3 EUA_Price + b4 TTF(i) + b5 Coal(i) + b6 Brent(i) + ε(i)

In the table below, we can see the descriptive statistics (number of observations, Mean, Standard Deviation, Minimum, Maximum, etc) of all of the variables that are used in the regression. The MCP Price (Price) has a very high STD of €74.8, with a minimum value of €27.44 and a maximum value of €415.94, which can be explained by the high STD and big gap between the minimum and the maximum value of the TTF and the EUA_Price. This is under the fact that the most important coefficients of the regressions are the ones of the TTF and the EUA_Price, as we are going to illustrate in the next paragraphs of this section.

Figure 28: Descriptive Statistics

	Price €/MWh	Res_Demand MWh/h	PPT_Hydro MWh/h	EUA_Price €/Ton CO2	TTF €/MWh	Coal €/MWh	Brent $/bbl
Observations	478	478	478	478	478	478	478
Mean	120.18	4,283.32	402.60	53.97	46.74	116.79	69.67
Standard deviation	74.80	1,027.20	378.02	18.14	33.34	52.10	12.52
Min	27.44	1,619.73	72.79	23.84	12.89	50.80	38.97
Percentile 25%	58.93	3,561.06	121.66	39.02	18.99	67.85	63.28
Percentile 50% (median)	91.03	4,192.04	268.29	53.13	32.38	110.55	71.06
Percentile 75%	190.68	4,899.32	493.01	61.73	75.68	148.80	77.65
Max	415.94	7,559.56	2,048.67	96.43	180.27	274.50	96.48

Moreover, OLS is a linear way to find the optimal coefficients for the independent variables, so that the square of the values of the errors between the real values of the dependent variable and the forecasted values of the dependent variable is minimized (Gulve, 2020). The outcome of the regression can be summarized in the figure below.

Figure 29: OLS regression outcome

```
                    OLS Regression Results

=======================================================================
Dep. Variable: Price           R-squared (uncentered):           0.973
Model: OLS                     Adj. R-squared (uncentered):      0.973
Method: Least Squares          F-statistic:                      2888.
Date:   Sun, 29 May 2022       Prob (F-statistic):                0.00
Time:    18:38:01              Log-Likelihood                  -2177.9
No. Observations: 478          AIC:                              4368.
Df Residuals: 472              BIC:                              4393.
Df Model: 6
Covariance Type: nonrobust
=======================================================================
              coef    std err     t          P>|t|      0.025       0.975
-----------------------------------------------------------------------
Res_Demand     0.0085   0.001      8.333      0.000       0.006       0.010
PPT_Hydro     -0.0251   0.003     -8.011      0.000      -0.031      -0.019
EUA_Price      0.9369   0.155      6.064      0.000       0.633       1.240
TTF            1.9045   0.075     25.338      0.000       1.757       2.052
Coal          -0.1360   0.044     -3.110      0.002      -0.222      -0.050
Brent         -0.4127   0.143     -2.894      0.004      -0.693      -0.132
=======================================================================
=======
Omnibus:                 21.666   Durbin-Watson:                    0.538
Prob(Omnibus):           0.000    Jarque-Bera (JB):                56.518
Skew:                    -0.096   Prob(JB):                      5.34e-13
Kurtosis:                4.674    Cond. No.                          862.
```

```
==============================================================================
```

It is evident that the values of the t-tests illustrate that all of the independent variables are statistically significant (different from zero), as all of the t-stat absolute values are much higher than 1.96. Especially the EUA price and the TTF coefficients' t stats are 6.064 and 25.338, which means that the coefficients appear to be very solid (and nowhere near to being insignificantly different from zero), while at the same time the F-Statistical is much higher than the F critical value. Moreover, the adjusted R square has a value of 97.3%, which means that these variables explain a very big part (almost 100%) of the fluctuations of the dependent variable (Day Ahead Market price or MCP), but the Durbin-Watson test shows signs of autocorrelation, which might compromise (partly) the validity of the outcome. The signs of the coefficients agree with the majority of previous literature, as the Residual demand, the EUA_Price, and the TTF price are all positively correlated with the Day Ahead Market price. It is important to mention that an increase of 1 euro in the TTF price has an impact of approximately 1.9 euro increase in the electricity prices. This is in line with the fact that the majority of the Greek natural gas units (which set the prices very often) have an average efficiency of 50%, which means that they need 2 MWh of natural gas to produce 1 MWh of electricity (Figure 19). Very close to the outcome of Dagoumas and Polemis (2020) and of Fabra and Reguant (2014), we can see that a 1 euro increase in the EUA prices, leads to an increase of 0.94 euros in the electricity prices (almost 1:1). Last, the coefficients of coal and brent have a negative correlation with the Greek DAM prices, since 1. in the Greek interconnected system, there is no coal (apart from lignite whose cost is considerably different from coal, and is dependent of PPC's extraction costs) units and the oil units are only used in rare and extreme cases and 2. when coal and oil are more expensive, their demand decreases (while the demand for natural gas increases), and thus the demand for EUAs decreases, along with the EUA prices, and electricity becomes cheaper. Nevertheless, this explanation contradicts Chung et al. (2018) existing literature, which claimed that the oil and coal prices are positively correlated to the EUA prices (which in turn would make the MCP prices higher).

The result of this regression is the very essence of this thesis. It is proven that after the beginning of the target model in Greece, the pass-through rate of the EUA cost from the production units to the Greek MCP is almost 94%. The result seems to agree with previous literature and it can be used by the policymakers to coordinate any changes in the scope of the EU ETS in a way that the EU can achieve its environmental targets, while at the same time the social welfare and the economic activity of the Union are not severely compromised. Moreover, the natural gas price has a great effect on the Greek Market price. The main target of the EU is to eliminate coal and lignite and replace them with Renewable Energy Sources and Natural Gas (during the transitionary period until 2030). But, in periods when the natural gas price is very high, there is a chance that the price of the EUA would make the marginal cost of the coal/lignite units' (as we saw in the previous chapter) higher than the one of the natural gas production units', will be so high that it is going to lead to unsustainable MCP in the long run. If this happens, all of the EU's green initiatives might be hindered and the policymakers might have to either "decompress" the inflated EUA prices, or resolve to different tools and solutions for the achievement of our green targets.

The fact that the results of our regression for the period after the beginning of the target model are so similar to the regression of Dagoumas and Polemis (2020) proves that changes in the power spot market rules do not affect the effectiveness of the ETS to the wholesale market prices. It would be interesting to see in future research if other factors would change the EUA passthrough rate, like the elimination of lignite and the increase of the RES market share in power production.

Furthermore, the findings of this chapter can be combined with the statistical analysis of the previous section. As we saw, the pass-through rate of the EUA is 0.94 on average, for the period that was under examination. Nevertheless, this number is not fixed through time. For instance, we proved that when the Residual Demand for the Greek DAM is low, the producers tend to bid below their marginal cost, so that they do not have to switch their units off and on. If the Greek system has constantly a very high output of Renewables (with zero marginal cost), then the natural gas units might not be financially viable (if they are not able to pass through their marginal cost) before we are ready to phase them out completely, without having energy deficit issues. This must be taken into account by the policymakers and the governments that will want to replace the natural gas units 100% with RES, so that they can adjust their policies, or the EUA prices in a way that the European power supply safety will not be compromised. Also, we have seen that if the power producers undersell their production during certain periods, they bid much higher than their marginal cost when they have the opportunity (high Residual Demand). This can be taken into consideration for creating appropriate policies for power storage and cross-border trading. For instance, if we know the marginal cost of a battery, we should aim to set the marginal cost of the natural gas units, through the EUA price, at levels that will allow the batteries to take priority in the production stack during high residual demand hours, and deter the natural gas units from achieving excessive profit margins, while at the same time, the natural gas units do not get to be financially unsustainable until the European power systems are ready to phase them out without any issues.

Last, the EU Commission and the policymakers should take into consideration the levels of the EUA price that is needed for the substitution of coal and lignite by natural gas, which is dependent on the levels of the natural gas and lignite prices. For instance, if the natural gas fuel costs €90/MWh (of natural gas) then the EUA price should be around €127/ton CO2 to make the marginal cost of a Greek lignite unit comparatively higher (as we saw in the previous section of this chapter). The policymakers should take into consideration the future power production stack (which was shown for each year up to 2030, for the case of Greece, in this chapter), and estimate the future passthrough rate of the EUA price to the wholesale price (as lignite will be phased out, the natural gas units will be emitting fewer GHG and thus the passthrough rate might be reduced overall) and find the optimal solution between achieving the European environmental targets and not jeopardizing the European economy. If the EUA price is too high, the EU might provide subsidies or a price cap for the natural gas prices, in a way that even lower EUA prices will make the natural gas units more competitive against coal and lignite units.

Chapter 6: Conclusions and policy implications

To sum up, to estimate the impact of the EU ETS on wholesale electricity prices, we need to consider the factors that affect the EUA price levels and the pass-through rates of the EUA price to the wholesale prices. The result of the OLS regression that we demonstrated before was very similar to what we expected to find and following previous literature, which supports the case that approximately 100% of the EUA price (94% to be precise) is currently passed through to the wholesale electricity prices. Moreover, there are no foreseeable changes to the fundamental factors that affect the EUA price pass-through rate for the next few years. This fact, combined with the long-term targets of the EU, related to phasing out coal and lignite by the year 2030, through the use of marginal cost affecting policies, and the current natural gas and lignite prices (approximately €90/MWh and €35/MWh accordingly) can help us estimate that the EUA price levels are going to increase to €127/ton of GHG equivalent and thus the wholesale DAM price (MCP) of Greece is going to be burdened by that amount (in average). If the prices of natural gas do not change significantly, this estimation will hold, and even if the natural gas prices do change, we have provided a formula for new estimations.

We also provided statistical analysis of the bidding patterns of the Greek natural gas units, related to their marginal cost (and other factors like the tightness of the market) and an analysis of the Greek national plan regarding the energy and the environment, where it is evident that lignite is going to be phased out from the Greek power production fleet (by 2028) and it will be replaced by natural gas and RES units. This means that the current passthrough rate of the EUA price to the wholesale prices is going to change in the long term (gradually by 2030) for three reasons: 1. There will not be lignite units, which need to buy approximately 1.5 EUA for each MWh of electricity produced and 2. the production share from renewable energy sources is going to increase greatly, which is going to force the natural gas producers to sell their produced energy with lower prices (even lower than their marginal cost) as the residual demand is going to decrease significantly 3. the natural gas units (with the efficiency of 50%) only need to buy 0.4 EUAs per MWh of electricity.

Some additional results of this thesis are 1. the different impacts that different countries have on the EUA prices (both in the short and in the long term). For instance, changes in the power production fleet or the economy of Poland, will have a greater effect on the EUA price (and demand) even compared to countries with higher GDP (like France) 2. in previous literature some of the factors that affect the EUA price seem to have contradicting roles, in different researches (e.g. the price of oil and coal), which is a signal that there might be additional major factors related to the EUA prices that are overlooked 3. for the next decade, the natural gas production units are going to have a major role in setting the prices for most of the European countries, whose power production stack will be similar to Greece's and Italy's.

The results of this thesis are quite important for numerous reasons. First of all, we managed to not only provide another confirmation regarding the pass-through rate of the EUA price to the wholesale price of electricity, but additionally, we provide a robust method of calculating the fundamentally necessary price levels of the EUA in the medium/longer term (so that the EU environmental targets can be achieved), the impact on the Greek DAM prices, a techno-economic analysis behind the results and a solid foundation for future research regarding the impact of the EUA price to the wholesale prices in the very long term.

This can be useful for policymakers and governments, as the importance of the factors that affect the EUA price levels in the short term and the long term is revealed, along with the impact on the wholesale prices. This is also interesting for the power producers/suppliers and traders, as they can recognize the short-term market price deviation from their fundamental value and they can act to profit from it. For instance, if there is a consistent downturn in the European economy, while the natural gas prices are very high, it can be expected that the EU Commission will push for a reduction of the available EUAs to enhance their prices up to the point that coal and lignite get to be more expensive to use for power production. Given the fact that the power producers in Greece currently pass through 100% of the EUA price to the wholesale prices, the energy traders can expect that the DAM prices in Greece will rise in accordance with the EUA price expected to increase, and thus take long positions.

Unfortunately, the impact of the ETS on the Greek MCP, in the long run, is still unclear. Apart from the fact that it is hard to predict the fuel prices in the long term, we cannot be sure about the effect that the future production stack will have on the pass-through rates. Future research could shed light on issues like what will the impact of using batteries for power storage will be, the future natural gas units' efficiencies, the scaling up the Hydrogen technology for power production, the need for safety of the power system against power deficits, changes to the scope of the EU ETS, the target year for the elimination of the usage of natural gas units and other similar factors. Moreover, future research could combine a similar analysis for all of the European countries, taking into consideration all of the country-specific factors, and calculate the historical EUA passthrough rates for each country. Last, researchers could use more sophisticated econometric methods and explain any possible deviations in the results from previous literature, using only data from the fourth phase of the ETS.

References

ADMIE (2022), ISP Requirements, Available at: https://www.admie.gr/agora/statistika-agoras/dedomena?data_type%5B%5D=10342&since=&until=&op=%CE%A5%CF%80%CE%BF%CE%B2%CE%BF%CE%BB%CE%AE

Aleluia, J. (2018), *The European Union Emissions Trading System (EU ETS): design elements and reporting framework,* Regional Collaboration Centre for Asia and the Pacific, Bangkok, https://unfccc.int/sites/default/files/resource/6.Case%20study1%20Development%20of%20ETS%20in%20EU%20and%20the%20key%20design%20elements%20and%20lesson%20learned.pdf (Accessed: 17 October 2021)

Andriiko O., Sushchenko O. (2015), *Carbon price formation: Choosing factors and developing EUA price model,* Kyiv National Economic University, Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2586822

Chung C.Y., Jeong M., Young J. (2018), *The Price Determinants of the EU Allowance in the EU Emissions Trading Scheme,* Sustainability *2018,* 10 *(11),* 4009, Available at: https://www.mdpi.com/2071-1050/10/11/4009/htm

Dagoumas A., Polemis M. (2020), *Carbon pass-through in the electricity sector: An econometric analysis,* Energy Economics, Volume 86, 2020, 104621, ISSN 0140-9883, Available at: https://www.sciencedirect.com/science/article/pii/S0140988319304189

*Emissions-euets.com (*2021), *Aviation in the EU ETS,* Available at: https://www.emissions-euets.com/carbon-market-glossary/965-aviation-in-the-eu-ets, (Accessed: 20 October 2021)

Energy Exchange Group (2021), *Day-Ahead Market Report,* Available at: https://www.enexgroup.gr/web/guest/markets-publications-el-day-ahead-market, (Accessed: 28 Feb 2022)

Entsoe Transparency Platform (2021), Available at: https://transparency.entsoe.eu/dashboard/show

European Commission (2021), *Development of EU ETS (2005-2020)*. Available at: https://ec.europa.eu/clima/policies/ets/pre2013_en (Accessed: 01 September 2021)

European Environmental Agency (2021), *Emissions by Sector,* eea.europa.eu, published: August 2021. Available at : https://www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1

(Accessed 10 October 2021), https://www.eea.europa.eu/data-and-maps/figures/eua-future-prices-200520132011/eua-future-prices-200520132011-excel-file, https://www.eea.europa.eu/data-and-maps/figures/eua-future-prices-200820132012

Eurostat (2021), *GDP and main components (output, expenditure and income*), Available at: https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Fabra N., Reguant M. (2014), *Pass-through of emissions costs in electricity markets*, American Economic Review, 104 (9): 2872-99, Available at: https://www.aeaweb.org/articles?id=10.1257/aer.104.9.2872

Fjellheim, H., (2018), *Will high European carbon prices last?,* Refinitv, https://www.refinitiv.com/perspectives/market-insights/will-high-european-carbon-prices-last/, (Accessed: 20 October 2021)

Friedrich M., Fries S., Pahle M., Edenhofer O. (2019), "*Understanding the explosive trend in EU ETS prices -- fundamentals or speculation?*" Papers 1906.10572, arXiv.org, revised Mar 2020, Available at: https://ideas.repec.org/p/arx/papers/1906.10572.html

Gestore Mercati Energetici (2022), *historical data day ahead market year 2021*, Available at: https://www.mercatoelettrico.org/En/Download/DatiStorici.aspx

Greek Ministry of Environment and Energy (2019), *National Plan for climate and Energy*, Available at: https://ec.europa.eu/energy/sites/ener/files/documents/el_final_necp_main_el.pdf (Accessed: 15 December 2021)

Gulve, A., (2020), *Ordinary Least Square (OLS) Method for Linear Regression*, Analytics Vidhya, Available at: https://medium.com/analytics-vidhya/ordinary-least-square-ols-method-for-linear-regression-ef8ca10aadfc (Accessed :31 May 2022)

Guo B., Gissey G.C. (2021), *Cost pass-through in the British wholesale electricity market*, Energy Economics, Volume 102, 2021, 105497, ISSN 0140-9883, Available at: https://www.sciencedirect.com/science/article/pii/S0140988321003820

Hellenic Energy Exchanges S.A. (2021), *HEnEX Spot Trading Rulebook (version 1.4)*, Available at: https://www.enexgroup.gr/documents/20126/144557/Spot_Trading_Rulebook_v1.4_en.pdf (Accessed: 15 December 2021)

Hintermann B. (2014), *Pass-through of CO2 Emission Costs to Hourly Electricity Prices in Germany*, CESifo Working Paper, No. 4964, Center for Economic Studies and ifo Institute (CESifo), Munich. Available at: https://www.econstor.eu/bitstream/10419/103124/1/cesifo_wp4964.pdf

International Carbon Action Partnership (2021), *EU Emissions Trading System (EU ETS),* published: 9 August 2021, Available at: https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems%5B%5D=43 (Accessed: 20 October 2021)

Investing.com (2021) and (2022), *Dutch TTF Natural Gas Futures*, Available at: https://www.investing.com/commodities/dutch-ttf-gas-c1-futures-historical-data

Investing.com (2021) and (2022), Carbon Emissions Futures, Available at: https://www.investing.com/commodities/carbon-emissions-historical-data

Investing.com (2022), Rotterdam coal futures, Available at: https://www.investing.com/commodities/rotterdam-coal-futures-historical-data

Investing.com (2022), Brent Oil Futures, Available at: https://www.investing.com/commodities/brent-oil-historical-data

Jouvet P. A., Solier B. (2013), *An overview of CO2 cost pass-through to electricity prices in Europe*, Energy Policy, Volume 61, 2013, Pages 1370-1376, ISSN 0301-4215, Available at: https://www.sciencedirect.com/science/article/pii/S030142151300445X

Koch N., Fuss S, Grosjean G, Edenhofer O. (2014), *Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence*, Energy Policy, Volume 73, 2014, Pages 676-685, ISSN 0301-4215, Available at: https://www.sciencedirect.com/science/article/pii/S0301421514003966

Lovcha Y., Perez-Laborda A., Sikora I. (2022), *The determinants of CO2 prices in the EU emission trading system*, Applied Energy, Volume 305, 2022, ISSN 0306-2619, Available at: https://www.sciencedirect.com/science/article/pii/S0306261921012162

Maniatis G., Moustakas A. (2020), *Delignification of the power production: Socioeconomic effects and hedging actions*, IOBE, Available at: https://www.sdam.gr/sites/default/files/consultation/%CE%A3%CF%87%CE%AD%CE%B4%CE%B9%CE%BF_%CE%B4%CE%AF%CE%BA%CE%B1%CE%B9%CE%B7%CF%82_%CE%BA%CE%B1%CE%B9_%CE%B1%CE%BD%CE%B1%CF%80%CF%84%CF%85%CE%BE%CE%B9%CE%B1%CE%BA%CE%AE%CF%82_%CE%BC%CE%B5%CF%84%CE%AC%CE%B2%CE%B1%CF%83%CE%B7%CF%82_%CE%BB%CE%B9%CE%B3%CE%BD%CE%B9%CF%84%CE%B9%CE%BA%CF%8E%CE%BD_%CF%80%CE%B5%CF%81%CE%B9%CE%BF%CF%87%CF%8E%CE%BD__%CE%95%CF%80%CE%B9%CF%80%CF%84%CF%8E%CF%83%CE%B5%CE%B9%CF%82_%CE%BA%CE%B1%CE%B9_%CE%B1%CE%BD%CF%84%CE%B9%CF%83%CF%

84%CE%B1%CE%B8%CE%BC%CE%B9%CF%83%CF%84%CE%B9%CE%BA%CE%AD%CF%82_%CE%B4%CF%81%CE%AC%CF%83%CE%B5%CE%B9%CF%82.pdf

Rack, Y. (2020), *Why the next recession will not break the world's largest carbon market*, S&P Global, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/why-the-next-recession-will-not-break-the-world-s-largest-carbon-market-58024554 (Accessed: 20 October 2020)

Sandbag (2021), *CO2 emission Allowances*, Available at: https://sandbag.be/index.php/carbon-price-viewer/ , (Accessed: 20 October 2021)

Stefanou H. (2021), *Producers to RAE, Why the wholesale electricity prices in Greece remain high – The critical peculiarity of the Greek Gas market*, EnergyPress.gr, Available at: https://energypress.gr/news/paragogoi-pros-rae-giati-oi-times-hondrikis-reymatos-stin-ellada-paramenoyn-ypsiles-i-krisimi (Accessed 15/01/2022)

United Nations Framework Convention on Climate Change (2021), *What is the Kyoto Protocol*. Available at: https://unfccc.int/kyoto_protocol (Accessed: 01 September 2021)

www.volker-quaschning.de (2021), *Specific Carbon Dioxide Emissions of Various Fuels,* volker-quaschning, Available at: https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php (Accessed: 03 January 2022)