University of Piraeus-Department of International & European Studies

Master in Energy: Strategy, Law, and Economics

Thesis' Subject: Wholesale electricity market analysis and price forecasting

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Athens, 18.5.2021

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Acknowledgements: I would like to thank and express my gratitude to my supervisor Associate Professor Michael-Polemis for his valuable support and guidance during the writing of this thesis. I would also like to thank my family for their support during the period of this master’s program.

ABSTRACT

This thesis aims to implement a forecasting technique, to predict the 24 market-clearing prices of the day-ahead electric energy market of Hungary, Italy, Greece, and Bulgaria. The analysis is based on a dynamic regression model implemented in Conejo et al (2005) for the Italian wholesale market. This thesis attempts to conduct a similar approach, to evaluate if a dynamic regression model, using the Ordinary Least Squared and the Fully-Modified Ordinary Least Squared methodology, is optimal for the implementation in different countries, with different energy characteristics. To conduct the forecast analysis, the forecasted values of demand and renewable energy production are used from the European Network of Transmission System Operators for electricity website. The relevant approach leads to significant results for Hungary, Italy, and Greece, while for Bulgaria the results for the sample period are not presented, since the deviation from the actual prices does not lead to a good forecast approach. The sample period is 2019, including one week for every season of the year. The proposed technique can be used or to be upgraded by electric energy market participants, since this analysis is based on only two variables, by using additional variables in the analysis, which affect the final price, or by using better-forecasted values.

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2 Introduction

While the European energy market becomes more complex and liberalized, with many players being engaged, since the state monopolies are not any more vertically integrated into all the segments of the market, in line with the EU directives imposed the last decades, the electricity price forecasting has become crucial for all the participants. This thesis mainly focuses on the analysis of the electricity markets of Hungary, Bulgaria, Italy, and Greece, while it aims to conduct an electricity price forecasting for the countries on an hourly-day ahead level. This thesis proposes a dynamic regression technique used in the bibliography, for the four countries mentioned above, by using the Ordinary Least Squared and the Fully-Modified Ordinary Least Squared methodology. The final analysis leads to acceptable results only for Hungary, Italy, and Greece, since due to the high price volatility in Bulgaria during the examined period, the forecasted values resulted in big deviations from the actual prices. The main contribution of this thesis is that it presents a technique, which under certain conditions, can be used and provide a good electricity price forecast, in countries with different power system structures and characteristics. The two methodologies followed in this analysis, provide similar results, with the daily errors ranging from 3%-18%, while the weekly error ranges from 8%-18%. The restriction of the approach used is that the dynamic regression can be optimal for periods without extreme volatility. An attempt to conduct the same analysis for one week of each season during 2020 was made, but due to Covid-19, the price volatility was intense, leading to bad forecasted estimates. Although, the proposed methodology, can be considered a good price forecasting approach, since it takes into consideration only two variables, price, and demand or residual, and it can be upgraded, by using additional variables affecting the final electricity prices. The structure of this thesis is as follows: Chapter 2 presents the basic EU energy policies implemented in the last decades, while it analyses the market coupling theory and explains basic mechanisms of the domestic power exchanges of the countries concerning market coupling theory. Chapter 3 introduces the electricity market analysis of the four countries examined in this thesis, by pointing out the energy and electricity mix, the power system structure, and basic characteristics of the power markets and power exchanges of each country. Chapter 4 presents the impact of COVID-19 on the energy markets and focuses on the electricity market of the aforementioned countries during 2020. The fifth chapter makes a short reference to various techniques used in the bibliography for electricity price forecasting and the sixth chapter presents the forecasting approach followed in this thesis and the parameters taken into account. Finally, the last chapter presents the results of the analysis conducted.

3 EU energy policy

The EU Commission has been introduced directives towards the liberalization of the retail electricity markets in the last decades. The main target of these directives is the achievement of greater integration among EU energy markets to enhance energy security and to increase social welfare. Traditionally, the structure of most energy systems was based on natural monopolies, being vertically integrated into all the segments of the market (production, distribution, and trading). The liberalization process introduced the decomposition of those segments, promoting the operation of the market under free-market rules on specific domains, such as trading and production, while the transmission and distribution remained under the responsibility of the monopoly. The EU Commission introduced the first legislative package in 1996-

1998 (Directives 96/92, 98/30)[1], the second in 2003 (Directives 2003/54, 2003/55)[2], and the third legislative package in 2009[3]. The first package introduced a plan for better control and monitoring of the energy markets, by imposing the establishment of the regulatory authorities, a timetable for the gradual opening of the markets. Furthermore, a crucial step towards the separation of accounting and functional operation between generation, transmission, and supply activities with regulated access of third parties in the networks. The second legislative package gave the right to consumers of choosing their provider. Moreover, it included the legal separation of networks' operation from supply activities and gave more responsibilities to National Regulatory Authorities (European Commission). The European energy markets used to operate under different electricity regulatory frameworks, with legal differentiations, resulting in low cross-border competition. Therefore, the establishment of the National Regulatory Authorities would impose common rules in the energy markets, promoting competition and investment. As it concerns the third legislative package, the EU Target Model was presented, as the single market model applicable to all Member States, which included the facilitation of the cross-border trading and market coupling of regions and the creation of the Authority for the Cooperation of Energy Regulators (ACER)[4]. Most of the EU countries have been operating under free and better-regulated energy market rules since 2008, enhancing the competition and leading to price convergence. The energy packages also specify a strategic plan for carbon emissions reduction by emphasizing the promotion of renewable energy sources. The target for 2020 was a reduction by 20% in greenhouse gas emissions compared to 1990, at least 20% share of renewable energy consumption, 20% increase in energy efficiency, and 10% in the electricity interconnection. For 2030 the ongoing goal is a 40% reduction in greenhouse gas emissions compared to 1990 levels, at least 27% share of renewable energy consumption, and a 30% increase in energy efficiency. The long-term goal is to reduce by 80-95% the greenhouse gas emissions compared to 1990 levels[5].

3.1 Energy and the internal market

In February 2015, the EU Commission presented the plan for the Energy Union, which had as a basic pillar the energy flows across borders while emphasizing the security of supply among EU countries, through the diversification of energy sources, the connection of networks, the reduction of both energy use and energy imports. This plan has five basic dimensions:

[1] European Parliament (1996). *DIRECTIVE 96/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 December 1 996 concerning common rules for the internal market in electricity*. [Online]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31996L0092&from=EN

[2] European Parliament (2003). *DIRECTIVE 2003/54/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC.* [Online]. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:caeb5f68-61fd-4ea8-b3b5-00e692b1013c.0004.02/DOC_1&format=PDF

[3] European Parliament (2009). *REGULATION (EC) No 714/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003.* [Online]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0714&from=EN

[4] European Parliament (2009). *REGULATION (EC) No 713/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators.* [Online]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32009R0713&from=EN

[5] Hellenic Association for Energy Economics (2019), Greek Energy Market Report (In Greek). [Online]. Available at: https://segm.gr/wp-content/uploads/2019/05/haees-greek-energy-market-report-2019-upload-version.pdf

1. Security of supply-solidarity
2. Energy efficiency
3. Climate action decarbonizing the economy
4. Research, innovation, and competitiveness
5. A fully integrated internal market

The approval of the Third Energy Package (Regulation (EC) No 714/2009) specifies the implementation of the market coupling among EU members, for the cross-border trading of electricity and gas, under common Network Codes. EU published the Commission Regulation (EU) 2015/1222[6] of 24 July 2015 establishing a guideline on capacity allocation and congestion management (CACM). The target model for the electricity markets is described in Article 3 of CACM. This is the establishment of the price coupling based on implicit capacity allocation with a single algorithm (European Commission). These are:

• The adoption of the Price Coupling of Regions (PCR) solution as the basis for pan-European single day-ahead coupling

• The adoption of the Cross-Border Intraday (XBID) solution as the basis for pan-European single intraday coupling; and

• The role of the NEMO Committee as the body representing all NEMOs and responsible to oversee the future establishment, development, and operation of the MCO functions

3.1.1 The EU Target Model

The main characteristic of the EU Target Model is the integration of the wholesale electricity market by operating under common rules. The EU Target Model at the first stage describes the forward market, where long-term agreements can take place among EU energy markets. Moreover, it includes the integration at the day-ahead stage by imposing implicit auctions for the physical transmission rights on interconnections between markets. On intraday and balancing markets, a progressive integration follows, by focusing on renewable generation, allowing for production adjustment close to real-time, after the closure of the day-ahead market. Before the implementation of the EU Target Model, the forecast of a renewable generation took place just once during the day, for the next day. The renewable generation forecast is a stochastic process that causes imbalances in the system, leading to overproduction or underestimation of the total production. Thus, in line with the EU Target Model all market participants, including renewable producers, retailers, and aggregators can predict and correct their position close to real-time, making the system more balanced, therefore, optimizing the energy sources, promoting energy security and the social welfare.

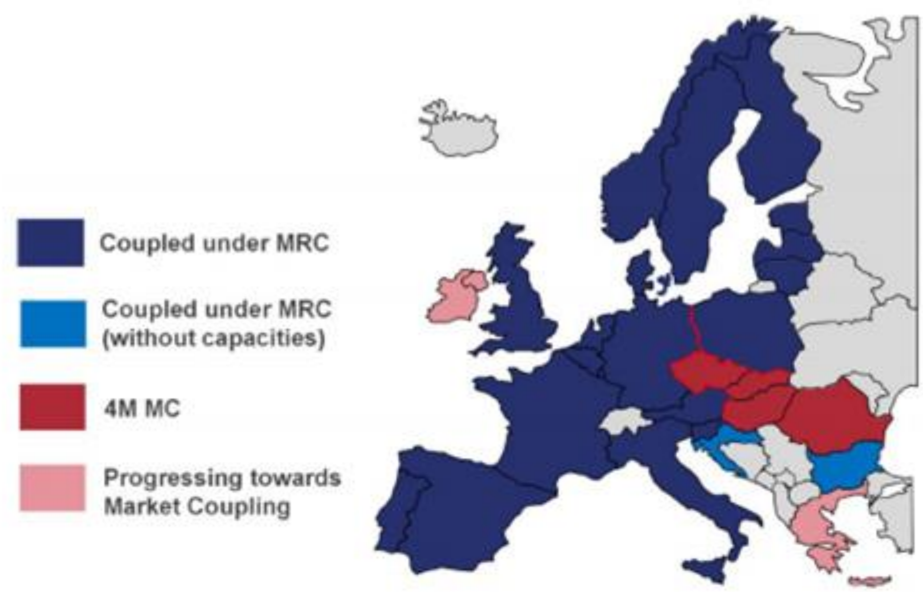
3.2 Market Coupling Theory

The EU Target Model is the reference model for developing the Internal Electricity Market, which introduces the Forward, the Day-ahead, the Intra-day, and the balancing market. The main target of the model focuses on capacity calculation, capacity allocation, congestion management, and the balancing of the system. This model intends to establish a stronger Pan-European dimension, by promoting the cross-

[6] European Commission (2015). *COMMISSION REGULATION (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management.* [Online]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R1222&from=EN

regional roadmaps as the main reference to the market integration process. The integration of the markets bases on market coupling theory, which aims at maximizing the energy flow, from the low price area to the high price area, taking into account the cross-border capacity. The highest the cross-border capacity the more the prices will converge among EU members. The implementation of the market coupling started by implementing the integration to the group of neighboring countries and the fully integrated market will follow next years.[7] The countries under study in this thesis are Hungary, Italy, Greece, and Bulgaria. Hungary is coupled with Slovakia, Czech Republic, and Romania, while Italy is coupled with Slovenia. In December 2020, Greece was coupled with Italy and operate under market coupling rules. Bulgaria is expected to operate under fully market coupling rules with Greece in May of 2021.

Figure 2. 1 Pan-European Single Day-Ahead Coupling (2017)



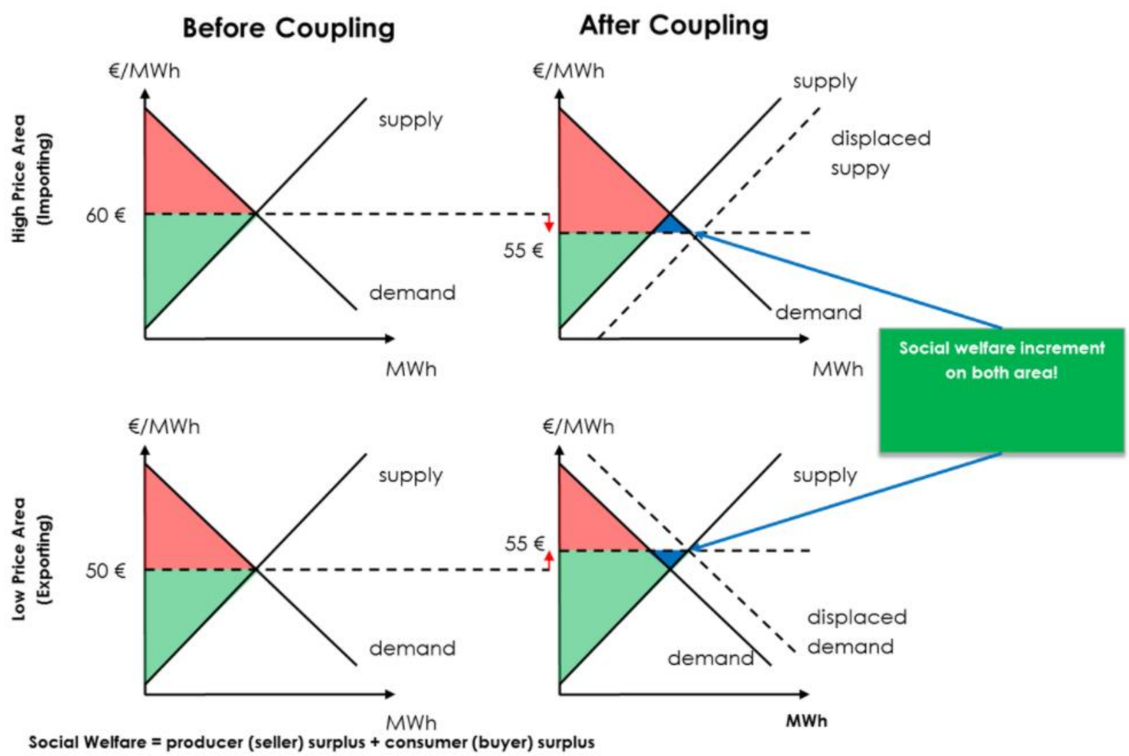
(Source: ENTSOE)

TSOs, power markets, and National regulators constitute important players of this regional grouping, by controlling the transmission rights auction process, the smooth operation of the power exchanges, and the compliance to the states' and EU laws. Therefore, the primary target of the market coupling theory is to assure the deeper integration of the regional power market, by serving national and international interests, while maximizing social welfare. Figure 2.2 presents a simple illustration of the market coupling theory. On the left side of this figure, where the before coupling theory is presented, it is clear that the final price of a country is calculated by a simple matching of the supply and demand curve. The country that needs imported volumes to balance the system, from a country being able to provide a surplus of power production, results in lower prices for the importing country since the additional volumes contribute to balance the system, avoiding the cost of production from expensive technologies or the speculation strategies from domestic market participants. However, the price of the exporting country

[7] European Commission (2014). EU Energy Markets in 2014. [Online]. Available at: [2014_energy_market_en.pdf (europa.eu)]

will increase, since additional power resources are used. On the after coupling side of Figure 2.2, it is clear that the exporting country serves the energy demands of the importing country, but at the same time results in a higher price. Figure 2.2 depicts that the after coupling theory favors the country that needs more energy and disfavors the country that balances the system of the region. Although, the final stage of the market coupling theory will result in lower prices for the majority of the EU members, favoring the total social welfare. Moreover, another benefit of the market coupling theory is the improvement of the market liquidity and the optimization of the cross-border trading process, since the transmission rights auctions will turn from explicit auctions to implicit. That means that the market players will no longer need to acquire the transmission rights capacity separately, but the result of the market coupling price solution will incorporate these costs. The big drawback of the explicit auctions is that energy players may transfer electricity from country A to country B, where the average price may be e.g. 50 €/MWh and 60 €/MWh respectively, and the average price of the PTRs auction can be more than the spread (10 €/MWh). These results in irrational trading, concerning price converging.

Figure 2. 2 Market Coupling Theory



(Source: HUPX)

3.2.1 Day-ahead Coupling

For the implementation of the pan-European single day-ahead coupling, the "Price Coupling of Regions" (PCR) solution is used in most EU countries, representing almost 85% of the European electricity consumption. PCR uses a governance structure based on a co-ownership agreement and a co-operation agreement among power exchanges. Moreover, PCR uses a common price-coupling algorithm known as EUPHEMIA (an acronym for Pan-European Hybrid Electricity Market Integration Algorithm) to estimate the electricity prices and to implicitly allocate cross-border capacity. EUPHEMIA[8] has been developed to match energy demand and supply for all the periods of a trading day by considering the social welfare maximization and the networks' capacity constraints. EUPHEMIA's first development started in 2011, known as the COSMOS algorithm, and took its final version in 2012. Technically the way that EUPHEMIA works starts with the market participants' order submissions to their respective power Exchanges. These orders include buy and sell orders, depending on the position that each market participant has in the market. Suppliers submit buy orders while producers sell orders. The algorithm handles a variety of order types at the same time, such as Aggregated Hourly Orders (including Linear, Stepwise and Hybrid Curves), Complex Orders (specifying income and operational conditions), and Block Orders (defining supply or demand levels, price limits, number of periods, minimum acceptance ratio). All these orders are grouped into successful and rejected orders, concerning social welfare and the capacity of the relevant network capacity, resulting in hourly prices. Some of the European Power Exchanges that use the EUPHEMIA algorithm and are analyzed in this thesis are GME (Italian Power Exchange), ENEX (Greek Power Exchange), IBEX (Bulgarian Power Exchange) the 4m MC coupling power exchanges, which are HUPX (Hungarian Power Exchange), OKTE (Slovakian Power Exchange), OTE (Czech Republic's Power Exchange) and OPCOM (Romanian Power Exchange)[9].

3.2.2 Intraday Coupling

After the introduction of the Third Energy Package, which imposed higher shares of renewable energy sources in the market, the Intraday Market coupling became more urgent. The European Commission has established intraday trading (continuous trading) where cross-zonal transmission capacities are allocated through implicit continuous allocation. This model has been laid down in the Framework Guidelines for Capacity Allocation and Congestion Management (CACM). The main objective of the Intraday market is the continuation of trading after the day-ahead market ends. The Cross-Border Intraday (XBID)[10] involved or aspiring to participate in the project, include Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Hungary, Germany, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. The XBID project includes intraday markets, enabling continuous trading, by matching the available bids and orders from EU market participants, operating in different zones, as long as the transmission capacity is available. The main target of the XBID algorithm is to provide extra liquidity to the markets, making the system more balanced in real-time, by correcting the declared positions of the market players in the day-ahead market, especially for the renewable electricity generators since the production forecast on day-1 leads to big deviations compared to the actual. The main advantage of the XBID project is that it matches orders from different areas, contributing to the transmission of energy in areas that are in a power deficit, provided, that there is enough transmission capacity. This project depends on the development of a common IT system with three basic elements: The Shared Order Book (SOB), the Single Capacity Management Module (CCM), and a Shipping Module (SM). The XBID goal is to create one integrated European Intraday market. An intraday market is an important tool for completing the European Internal Energy Market, by connecting intraday markets leading to balanced systems and

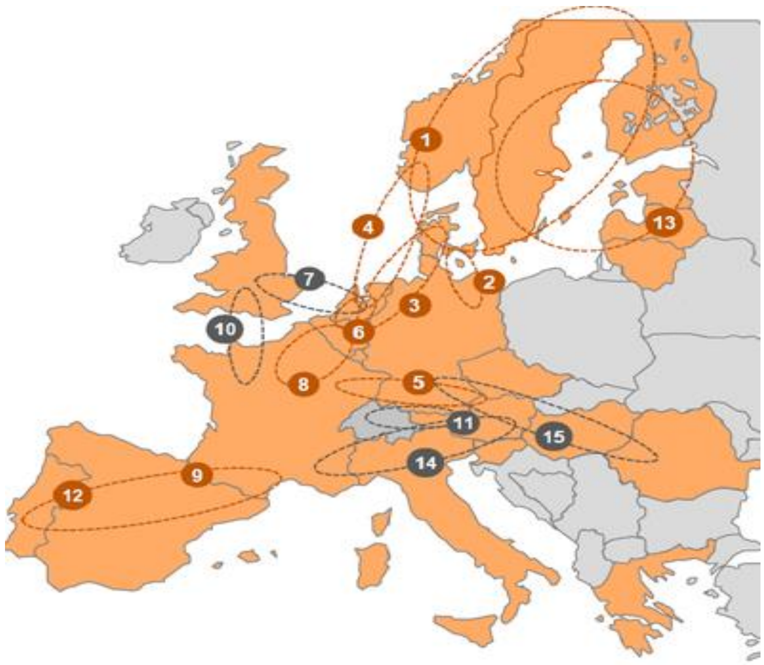
[8] HUPX. [Online] Available at: Euphemia Public Description.pdf (hupx.hu)

[9] REN, Sistema de Informacao de Mercados de Energia. Available at: https://www.mercado.ren.pt/EN/ELECTR/INTERPROJ/REGINITSWE/DAYAHEAD/Pages/default.aspx

[10] European Commission (2018). XBID Cross-Border Intraday Market Project. [Online]. Available at: 180306 MESC meeting XBID Update v2.0 (europa.eu)

the maximization of social welfare. XBI is a project that was initiated to establish intraday market coupling, which was originally cooperation between six power exchanges (APX, BELPEX, EPEX SPOT, GME, Nord Pool, and OMIE).

Figure 2. 3 Xbid solution implementation on different countries



(Source: European Commission, 2018)

4 Electricity market analysis

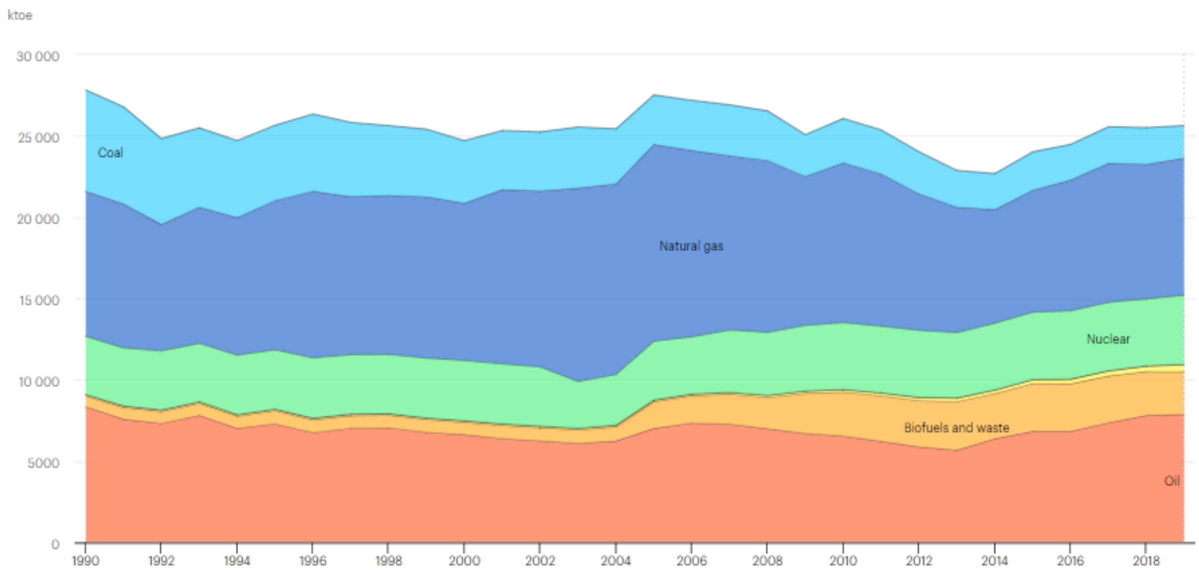
4.1 Hungary

4.1.1 Hungarian Energy dependency

Hungary is highly dependent on imported energy volumes (62.57%, 2017 rate) since the limited fossil-fuel domestic resources are insufficient to cover the energy demand of the country. Hungary has a high-energy dependency rate, reaching 90% to oil and gas imports that mainly come from Russia. The oil production was 16.000 bbl while the imported oil volumes were 121.000 bbl in 2016. The gas production in the same period was 1.81 bn m^3 and the imported gas volumes reached 13.37 bn m^3. In 2018 oil and gas represented 63% (30% and 33% respectively) of the Total Primary Energy Supply and Nuclear represent 16%. As it concerns the energy mix of Hungary Figure 3.1 depicts that the energy production is based on natural gas and oil products. Furthermore, nuclear and coal contribute to the energy mix of the country, while renewable energy sources account for a small percentage of the energy mix[11].

[11] IAEA (2019). Country Nuclear Power Profiles. [Online]. Available at: https://www-pub.iaea.org/MTCD/publications/PDF/cnpp2019/countryprofiles/Hungary/Hungary.htm

Figure 3. 1 Total energy supply (TES) by source, Hungary 1990-2019



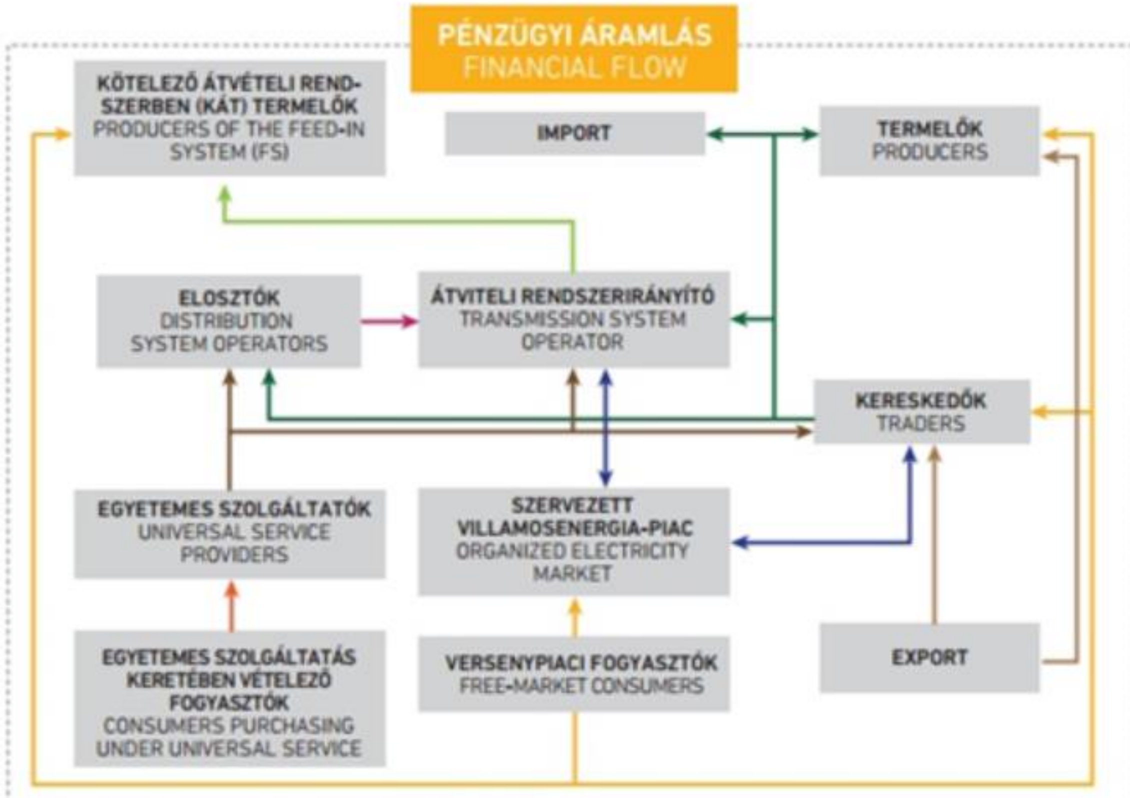
(Source: IEA)

Energy intensity interprets the correlation of energy to GDP production. A high-energy intensity index shows that inefficient methods and technology are used for to conversion of energy to GDP. According to Eurostat's report, Hungary's energy intensity has been slightly decreased by 15% from 2007 to 2017. The index is almost double the average of EU-28 countries, which shows that the economic stability and growth of the country is dependent on energy more than the average, so there is enough room for Hungary to improve the optimization of energy consumption.

4.1.2 Hungarian electricity market liberalization

Following the new EU energy policy, both gas and electricity markets should be liberalized under certain conditions. In line with the EU directives, customers can choose their suppliers from the first of July 2007, to enhance the economic competitiveness and provide sustainable security of supply. During the same year, the Hungarian Parliament adopted those reforms and the Hungarian electricity was fully liberalized. The first year of the implementation of this scheme was considered a transition period for the market players to adapt to the new rules. The liberalization process introduced the establishment of the Hungarian Power Exchange, which is the operator of the organized Hungarian spot power market with a leading position in Central and Eastern Europe. The establishment of the power exchange promotes the liquidity of the Hungarian energy market and supports the domestic working capital in the sector. Furthermore, the National Regulatory Authority of Hungary (MEKH) licenses HUPX as Nominated Electricity Market Operator (NEMO). Other actions to the liberalization of the market took place in February 2008, when the Hungarian Parliament adopted the National Climate Change Strategy (2008-2025). In April 2008, a resolution on a new energy policy concept for 2008-2020 was adopted, emphasizing the energy policy, with the basic pillar the balance between the security of supply, cost-effectiveness, energy efficiency, and protection of the environment. As it concerns the distribution and transmission system in Hungary, the operator is MAVIR, which ensures the operation of the Hungarian electricity system. MAVIR operates as an independent member of the state-owned MVM group following the independent transmission operator (ITO) model, under the unbundling rules of the Third Energy Package. Figure 3.2 below presents the Hungarian electricity industry as it is presented in IAEA's report 2019.

Figure 3. 2 The illustration of the Hungarian electricity industry

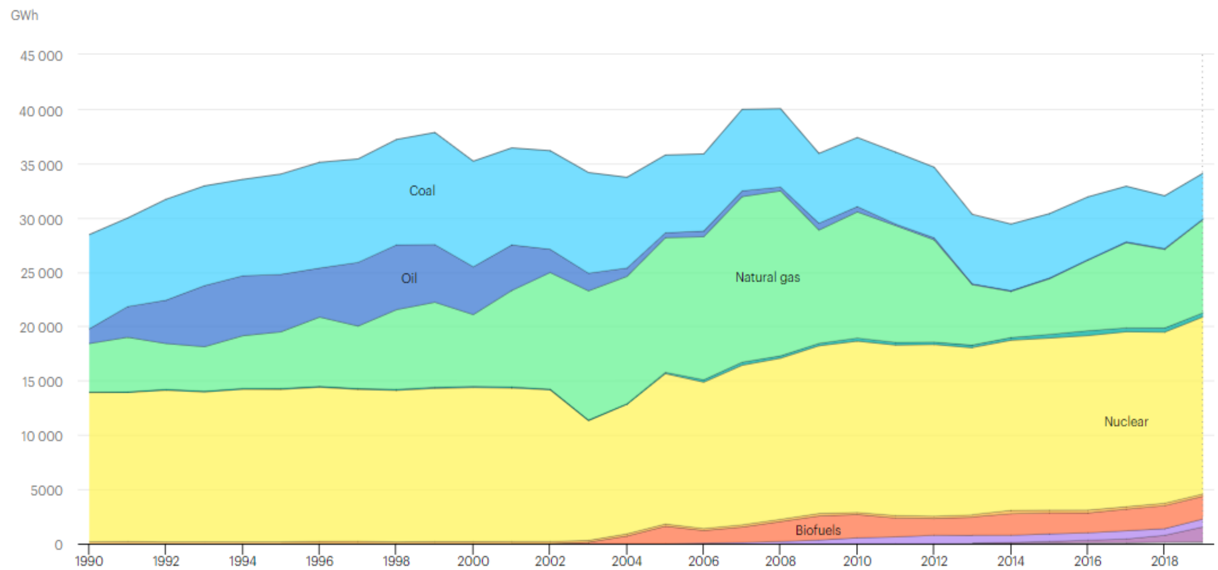


(Source: IAEA)

4.1.3 Hungarian Electricity generation

Hungarian electricity generation mostly depends on nuclear power and gas (Figure 3.3). The installed capacity of nuclear power produced 50% of the total electricity generated in 2017, while gas & oil accounted for 25.22%. Lignite units produced 14.85% of the total production, and the RES technology share was only 9.91%. The majority of the RES production comes from Biomass with 48.45% and wind, which accounts for 23.12%. Other technologies in the RES portfolio are solar (2.87%), waste (12.51%), and biogas (6.33%). Although, Hungary is not able to fully provide itself with self-produced electricity since it can cover only 77% of the overall electricity demand. Therefore, the rest of the electricity demand is being imported from neighboring countries, and specifically, most of the imported electricity comes from Slovakia. In 2003, 30 electricity generating companies were active in the Hungarian electricity market. This number increased to 68 companies in 2010, following the full liberalization of the electricity market, but the competition was very intense since there were many companies to serve the needs of the Hungarian market and this number dropped to 30 companies in 2017[12].

Figure 3. 3 Electricity generation by source, Hungary 1990-2018



(Source: IEA)

4.1.4 Hungarian Electricity Prices

In this paragraph, the Hungarian wholesale electricity prices are presented, for the period 2011-2020. This period includes the pre-decoupling period (2011-2014) and the period after the coupling of Hungary-Slovakia-Czech-Romania.

[12] Eurostat (2019). Energy, transport, and environment statistics. [Online]. Available at: https://ec.europa.eu/eurostat/documents/3217494/10165279/KS-DK-19-001-EN-N.pdf/76651a29-b817-eed4-f9f2-92bf692e1ed9

Table 3. 1 4M MC wholesale electricity prices, 2011-2020

Year	Average Prices (€/MWh)			
	HU	SK	CZ	RO
2011	55.80	-	-	-
2012	51.49	-	-	-
2013	42.37	-	-	-
2014	40.50	33.64	32.96	40.98
2015	40.60	33.57	32.32	36.42
2016	35.43	31.62	31.18	33.37
2017	50.36	40.94	36.46	48.19
2018	51.00	48.47	46.03	46.45
2019	50.36	41.51	40.21	50.38
2020	39.00	34.01	33.56	38.88

The average prices are the outcome of the total trades in every country, including the flows from each border, the total cost of the production, the electricity mix, the consumption, etc. The wholesale price in Hungary during 2016, 2017, 2018 was equal to 35,43 €/MWh, 50,35 €/MWh and 51,00 €/MWh respectively, while the retail electricity prices, for the years mentioned above, were 112,5 €/MWh, 113,5 €/MWh and 118 €/MWh (respectively). Hungary has one of the lowest retail electricity prices among EU-28 members since the average retail electricity prices in EU-28 (during 2018) was 211,3 €/MWh. It is worth mentioning that the average wholesale electricity prices seem to be inelastic to the retail prices since it is observed that in 2016 the suppliers could purchase electricity at the price of 35,43 €/MWh and sell to their clients at the price of 112,5 €/MWh, while in 2017 the purchasing price (wholesale) was 50,36 €/MWh and the selling (retail) price was 113,5 €/MWh. There is a 42% increase in the wholesale price, while the retail price was increased by less than 1% (Eurostat, 2019)

4.1.5 Hungarian Power exchange

HUPX is a private company owned 100% by MAVIR Hungarian Independent Transmission Operator Company. HUPX is licensed by the Hungarian Regulatory Authority to operate an organized electricity market in Hungary and to develop an electricity trading platform and facilities, where electricity trading and other related transactions are conducted. At the first stage, HUPX conducted the day-ahead closed auction trading platform for the Market Area of Hungary. The development of a trading platform of physical future products and Over The Counter (OTC) clearing facility followed as the next step, and finally the establishment of the market coupling (4M MC), including HUPX (Hungary), OKTE (Slovenia), OTE (Czech Republic) and OPCOM (Romania). HUPX is an organized market offering electricity trading on the day-ahead level and intraday level, which enables intraday trading on OTC clearing facilities for the delivery of electricity domestically and to the members of the 4M, MC mentioned above. Under the liberalization theory, energy exchanges play a significant role in the efficiency of the total domestic production and the moderation of the electricity prices for consumers. HUPX serves the security of domestic supply, enhancing the cost-effectiveness of trading, contributing to the developments and investment in the energy sector[13].

4.1.5.1 Market Coupling (CZ-SK-HU-RO)

As was mentioned in a previous paragraph, the approval of the Third Energy Package includes the implementation of the market coupling. Hungary operates under a coupled market rules, with Slovakia, the Czech Republic, and Romania, which was completed in 2013 by implementing the Price Coupling of Regions (PCR) solution. The power exchanges HUPX, OKTE, OTE, and OPCOM, in line with the Transmission System Operators of each country (MAVIR, CEPS, SEPS, and Transelectrica) and with the support of the National Regulatory Authorities (MEKH, ERU, URSO, and ANRE) jointly cooperated on the 4M MC project. Before the implementation of the 4M MC, only CS-SK-HU were coupled, with Hungary becoming a member in 2012. The main goal of this project is to develop and implement the necessary solutions to ensure technical and procedural compatibility with the EU Target Model, for further integration of the markets.

4.1.5.2 Day-Ahead Market

The day-ahead market of HUPX is taking part in the market coupling (4M MC) between Czech, Slovak, Hungarian and Romanian markets using the implicit allocation method based on ATC (Available Transfer Capacity). On HUPX DAM (day-ahead market) standard hourly and block day-ahead electricity products can be traded. Some technical characteristics of the day-ahead market on HUPX are the following:

- Trading procedure: Daily Auction
- Underlying: Electrical power transiting over the Hungarian Transmission System managed by MAVIR Ltd. (the Hungarian TSO)
- Order Book Opening: 24 hrs per day starting forty-five days preceding the Delivery Day
- Order Book closes: Daily at 11:00 am
- Publication time: As soon as possible from 11:40 am
- Clearing and Settlement: Trade information transmitted by HUPX to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- Delivery procedure: Nomination by HUPX (together with ECC) and by the Balance Group Responsible of the HUPX Member to the TSO (MAVIR Ltd.) based on the regulations of the Commercial Code of the Hungarian Electricity System
- Minimum and maximum prices: -500.0 €/MWh / 3000.0 €/MWh

4.1.5.3 Intraday market

In line with the EU energy directives, HUPX joined the XBID project in November 2019 which resulted in a significant increase in the market's intraday. Some of the technical characteristics of the intraday market on HUPX are the following:

- Trading procedure: Continuous
- Underlying: Electrical power transiting over the Hungarian Transmission System managed by MAVIR Ltd. (the Hungarian TSO)
- Trading opens (GOT=gate opening time): Contracts for the next day open at 3:00 pm
- Trading closes (GCT=gate closure time): 60 minutes before delivery

[13] HUPX. [Online]. Available at: https://hupx.hu/en/

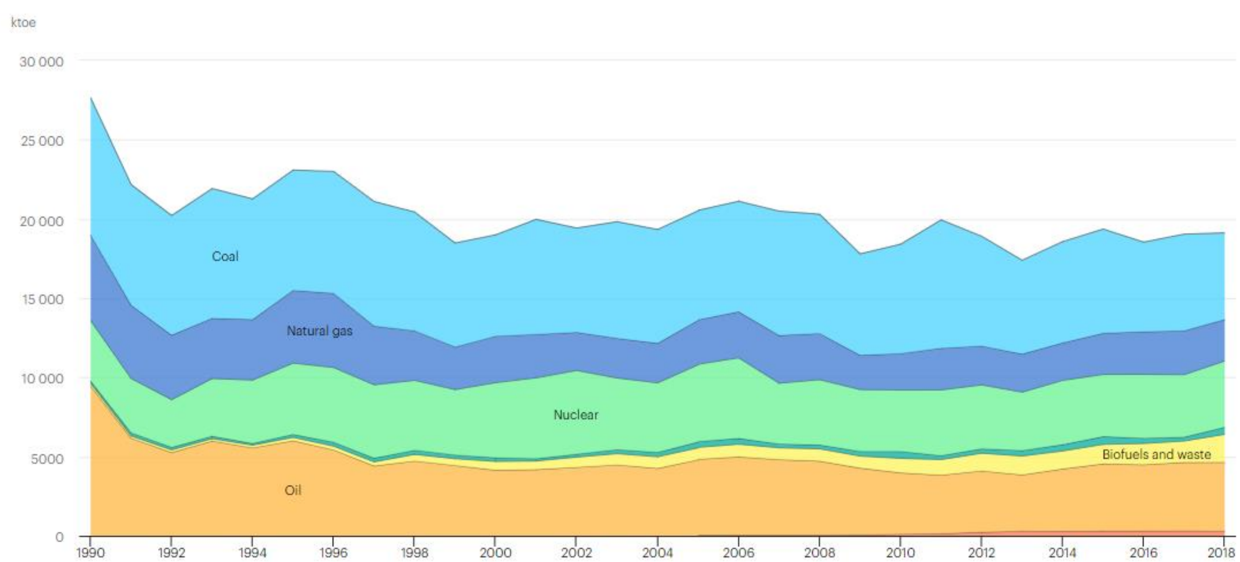
- Clearing and Settlement: Trade information transmitted by HUPX to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- Delivery procedure: Nomination by ECC on behalf of HUPX and by the Balance Group Responsible of the HUPX Member to MAVIR Ltd. based on the regulations of the Commercial Code of the Hungarian Electricity System
- Delivery: Delivery at any injection or withdrawal point on the Hungarian Transmission System.
- Minimum and maximum prices: -9999.00 €/MWh / 9999.00 €/MWh

4.2 Bulgaria

4.2.1 Bulgarian Energy dependency

Bulgaria has a well-structured and diverse power structure since it produces energy from different sources, such as nuclear power, lignite units, and renewable sources with a high percentage in hydro power. Bulgaria is a crucial energy hub, with an important strategic geographical location, for the energy balance of the Balkans and the whole of South-Eastern Europe, since massive amounts of oil and gas are transported and distributed from Russia through Bulgaria. According to Eurostat, Bulgaria is in the top five of the most energy-independent countries for 2018. From 2007 to 2017, the net energy imports have been decreased by 30%, while domestic production increased. The energy mix is composed mainly of coal (33%), nuclear energy (22%), and natural (14%) in 2017[14]. As Figure 3.4 depicts, Bulgaria does not use a specific energy source as a primary source, although it uses different energy sources to cover the energy demand. However, in the last two decades nuclear and coal production, account for the biggest share.

Figure 3. 4 Total energy supply (TES) by source, Bulgaria 1990-2019



(Source: IEA)

Coal and nuclear capacity account for more than 45% of the total installed capacity, while during 2017 nuclear energy produced more than 33% of the total energy produced. Bulgaria's energy intensity has

[14] IAEA (2019). Country Nuclear Power Profiles. [Online]. Available at: https://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2019/countryprofiles/Bulgaria/Bulgaria.htm

decreased from 2007 to 2017 by 30%. Although, the index is one of the highest among EU-28 countries, which shows that the economic stability and growth of the country is extremely dependent on energy. Table 3.2 depicts that Bulgaria is a good energy balanced country, being able to cover 100% of the domestic electricity demand. Concerning oil demand, Bulgaria has inefficient domestic resources, thus the volumes are imported, while the total natural gas demands are equal to the domestic production.

Table 3. 2 Energy Balance, Bulgaria

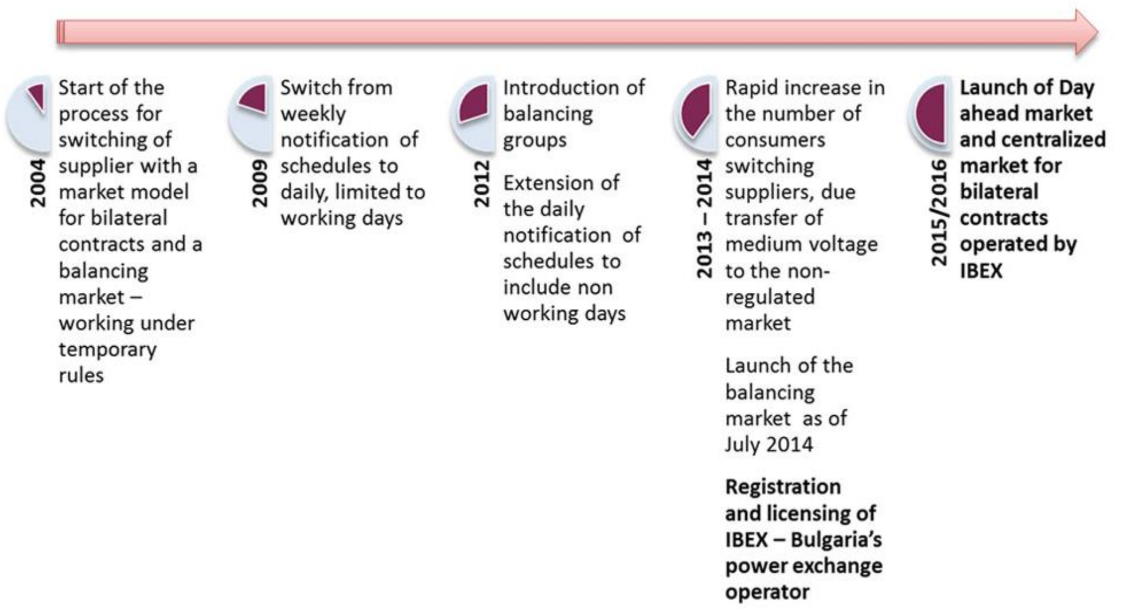
Electricity	total	Bulgaria per capita	Compared to Europe per capita
Own consumption	32.34 bn kWh	4,636.05 kWh	5,511.05 kWh
Production	42.29 bn kWh	6,062.42 kWh	5,925.27 kWh
Import	4.57 bn kWh	654.84 kWh	729.94 kWh
Export	9.19 bn kWh	1,316.99 kWh	707.85 kWh
Crude Oil	**Barrel**	**Bulgaria per capita**	**Compared to Europe per capita**
Production	1,000.00 bbl	0.000 bbl	0.005 bbl
Import	133,900.00 bbl	0.019 bbl	0.020 bbl
Natural Gas	**Cubic meters**	**Bulgaria per capita**	**Compared to Europe per capita**
Own consumption	3.31 bn m³	474.93 m³	903.40 m³
Production	79.28 m m³	11.37 m³	456.61 m³
Import	3.26 bn m³	466.76 m³	854.09 m³
Export	31.15 m m³	4.47 m³	398.75 m³

(Source: WorldData)

4.2.2 Bulgarian electricity market liberalization

In line with the EU directives for the liberalization process, Bulgaria introduced the first steps in 2004, when the high voltage power consumers could freely choose their electricity provider at freely negotiated market prices. The next step took place some years later, in 2013 when the medium voltage consumers had the right to freely choose their electricity supplier. The establishment of the organized power exchange, Independent Bulgarian Electricity Exchange (IBEX) followed, starting its operation in early 2016. The share of the Bulgarian power market is concentrated in three state-owned companies (approx. 85%), taking the advantage of their position. According to the latest amendments to the energy law (EU directive 2019/944), the non-household consumer in Bulgaria, from the 1st of October 2020 are obliged to choose their supplier, otherwise, after the 1st of July 2021, they will be represented by the last resort supplier. The last resort supplier is an entity that serves the needs of their clients as an electricity supplier, although it provides economic disincentives to its clients, so they prefer to join the free market and make the competition more intense. About 250.000 companies in Bulgaria will be affected and will have to choose their supplier, while household consumers remain on the regulated market. Figure 3.5 shows the most important steps to the liberalization of the Bulgarian power market as is presented on IBEX's website. Concerning the distribution and transmission operation in Bulgaria, the Electricity System Operator EAD (ESO) was established in 2007 as a subsidiary of the National Electricity Company (NEK). The main objectives of ESO are the operational planning and the management of the Bulgarian electricity system, by ensuring the operation, maintenance, and reliability of the grid. One of the final steps in line with the Directive 2009/72/EC took place in 2015, where the ESO was unbundling from NEK.

Figure 3. 5 Steps of the Bulgarian power market liberalization



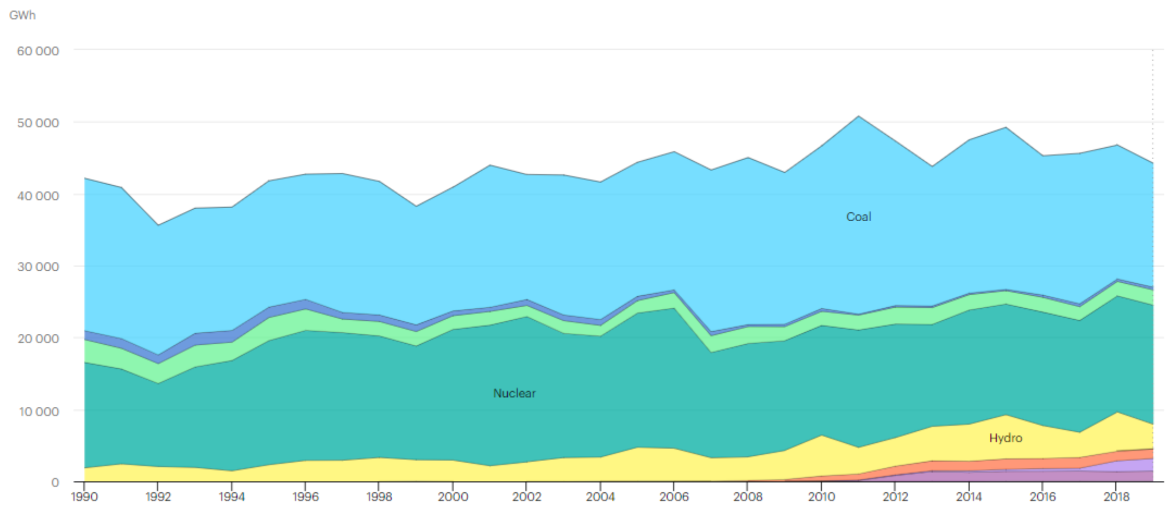
(Source: IBEX)

4.2.3 Bulgarian electricity generation

The electricity generation in Bulgaria is dominated by state-owned companies including nuclear and thermal power plants. The market is still highly regulated, although the implementation of several reforms, improved the open market rules. Bulgaria's first nuclear power plant started its operation in 1974 (Kozloduy). More nuclear plants were installed the next years, reaching a capacity equal to 3.760 MW, although during 2004 and 2007 four reactors were taken off-line. The electricity generation depends on local coal and nuclear power [15].

[15] Eurostat (2019). Energy, transport, and environment statistics. [Online].Available at: https://ec.europa.eu/eurostat/documents/3217494/10165279/KS-DK-19-001-EN-N.pdf/76651a29-b817-eed4-f9f2-92bf692e1ed9

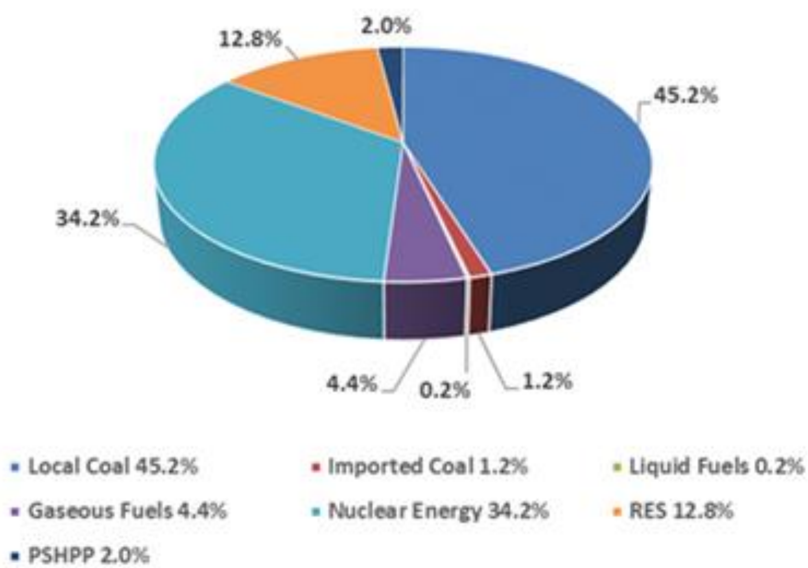
Figure 3. 6 Electricity generation by source, Bulgaria 1990-2019



(Source: IEA)

Figure 3.7 below presents the composition of the electricity generation percentages during 2017. Nuclear power produces 34.2% of the total electricity, while local coal the 45.2%.

Figure 3. 7 Structure of gross electricity generation by fuel, Bulgaria 2017



(Source: IAEA)

In Table 3.2 presented above, it is obvious that Bulgaria can cover the domestic electricity demand and is capable to produce additional volumes, being exported to neighboring countries. Bulgaria is an exporting electricity country and the majority of the exporting volumes flow to Romania, Greece, North Macedonia, Serbia, and Albania. The electricity prices of each country are extremely sensitive to the market conditions of their neighboring countries. The final electricity prices of Bulgaria are highly affected by the daily conditions (demand, wind, temperature, etc.) of Romania and Greece.

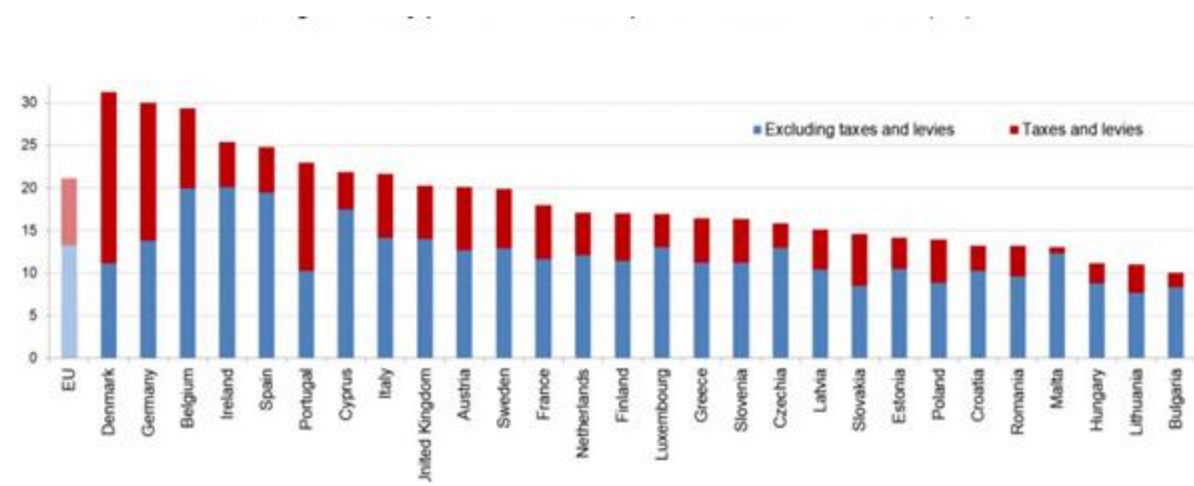
4.2.4 Bulgarian Electricity Prices

Table 3.3 shows the average wholesale electricity prices of Bulgaria for the period 2017-2020. During 2017 the annual average price was 39.32 €/MWh and the next year the price remains almost stable. A sharp increase by 19% is noticed from 2018 to 2019 and during 2020 it was decreased at 39,24 €/MWh. According to Eurostat the average retail electricity prices in the second half of the year in Bulgaria during 2016, 2017, and 2018 was 93,8 €/MWh, 98,3 €/MWh, 100,5 €/MWh respectively. Bulgarian retail electricity prices are one of the lowest between EU-28, and for comparison reasons, Figure 3.8 is presented. The taxes and levies in Bulgaria seem to be one of the lowest rates in the EU, while the highest rate is observed in Denmark and Germany, leading to the highest EU retail electricity prices for 2018.

Table 3. 3 Bulgarian wholesale electricity prices, 2017-2020

Year	Average Prices (€/MWh)
2017	39,32
2018	39,89
2019	47,46
2020	39,24

Figure 3. 8 Average electricity price for households per 100 KWh in 2nd half of 2018 (in €)



(Source: Eurostat)

4.2.5 Bulgarian Power exchange

The Independent Bulgarian Energy Exchange (IBEX) was established in January 2014, as a fully owned subsidiary of the Bulgarian Energy Holding EAD. The State Energy and Water Regulatory Commission have granted IBEX a 10-year license for organizing a Power Exchange for electricity in Bulgaria, under transparent and non-discriminatory principles. IBEX is a full member of the Multi-Regional Coupling (MRC), as well as an associated member of the Price Coupling of Regions (PCR). Furthermore, IBEX is a member of the European energy exchange EUROPEX. On Wednesday 22 April 2015, IBEX and Nord Pool Spot agreed to implement the first competitive Bulgarian day-ahead power market. Today, IBEX offers organized market segments for both short-term and long-term products while it has also introduced the intraday market. IBEX ensures and further enables the upcoming full liberalization of the electricity market and provides possibilities for market integration into the single European intraday electricity market, which is aimed at removing the barriers to cross-border electricity trading[16]

4.2.5.1 Market Coupling

During 2021-2022 Bulgaria is expected to be coupled with Romania on the day-ahead market. Romania is already coupled with Hungary, Czech Republic, and Slovakia. Furthermore, the coupling of Bulgaria with Greece is expected to be on the last stage during May 2021. The next phase includes coupling projects with Serbia and North Macedonia.

4.2.5.2 Day-Ahead Market

The day-ahead market segment offer products that are in accordance with the Single Day-ahead Coupling and Single Intraday Coupling regarding their nature and conditions. Some technical characteristics of the day-ahead market on IBEX are the following:

- Trading procedure: Daily Auction
- Underlying: Electrical power transiting over the Bulgarian Transmission System managed by ESO (Electricity System Operator of Bulgaria)
- Order Book Opening: 24 hrs per day starting forty-five days preceding the Delivery Day
- Order Book closes: Daily at 11:00 am
- Publication time: As soon as possible from 12:40 am
- Clearing and Settlement: Trade information transmitted by IBEX to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- Delivery procedure: Nomination by IBEX (together with ECC) and by the Balance Group Responsible of the IBEX Member to the TSO based on the regulations of the Commercial Code of the Bulgarian Electricity System
- Minimum and maximum prices: -500.0 €/MWh / 3000.0 €/MWh

4.2.5.3 Intra-day market

In line with the EU energy directives, the Independent Bulgarian Energy Exchange (IBEX) EAD, successfully started the Intraday market segment in Bulgaria under market coupling conditions, in November of 2019. Some of the technical characteristics of the intraday market are the following

- Trading procedure: Continuous

[16] IBEX. [Online]: Available at: http://www.ibex.bg/en/

- Underlying: Electrical power transiting over the Bulgarian Transmission System managed by ESO (Electricity System Operator of Bulgaria)
- Trading opens (GOT=gate opening time): Contracts for the next day open at 3:00 pm
- Trading closes (GCT=gate closure time): 60 minutes before delivery
- Clearing and Settlement: Trade information transmitted by IBEX to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- Delivery procedure: Nomination by ECC on behalf of IBEX and by the Balance Group Responsible, based on the regulations of the Commercial Code of the Bulgarian Electricity System
- Delivery: Delivery at any injection or withdrawal point on the Bulgarian Transmission System.
- Minimum and maximum prices: -9999.00 €/MWh / 9999.00 €/MWh
- The minimum amount of electricity that can be traded: 100 KWh

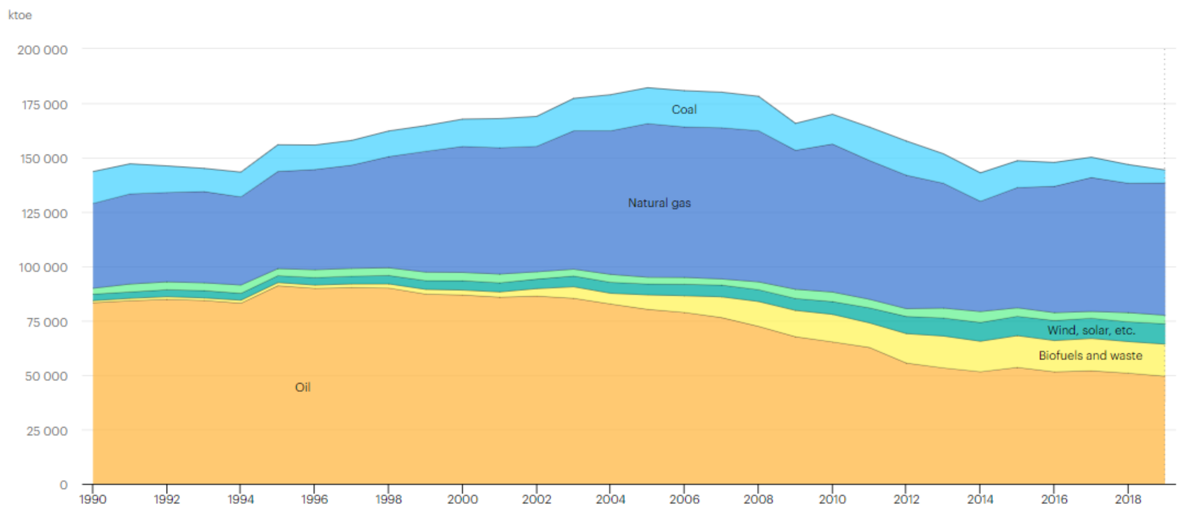
4.3 Italy

4.3.1 Italian Energy dependency

Italy is one of the largest energy consumers in Europe, after Germany, France, and the United Kingdom while its energy strategic position is of high importance, since it constitutes a transit of refined products, ranking the country on the second place among EU members in crude oil refining capacity (Germany is in the first place), according to Oil & Gas Journal. The energy consumption in Italy is mostly driven by petroleum and natural gas. The net imports of petroleum and other liquids were approx. 1.2 million barrels per day in 2016. Moreover, it is the second-largest natural gas importer in Europe after Germany, since the annual imports of natural gas were 2.3 trillion cubics (TcF) in 2016, accounting for 92% of the total natural supply in the country. Italy is highly dependent on Russian natural gas imports accounted for 42% of the total imports for the same period. The second larger provider of natural gas is Libya and Algeria accounting for almost 37% of the total imports. Natural gas is imported through pipelines that connect Italy with Algeria and Libya across the Mediterranean Sea. Liquefied natural gas (LNG) imports accounted for about 9% of Italy's total natural gas supply in 2016, most of which came from Qatar. Other energy sources that contribute to the Italian energy mix are coal, hydroelectricity, and other renewable sources, which show a significant increase over the last decade[17]. According to Figure 3.9 that presents the energy mix of Italy in 2018, natural gas accounts for 45% of the total production, hydroelectric for 16,3%, and the rest of renewable energy sources account for almost 24%.

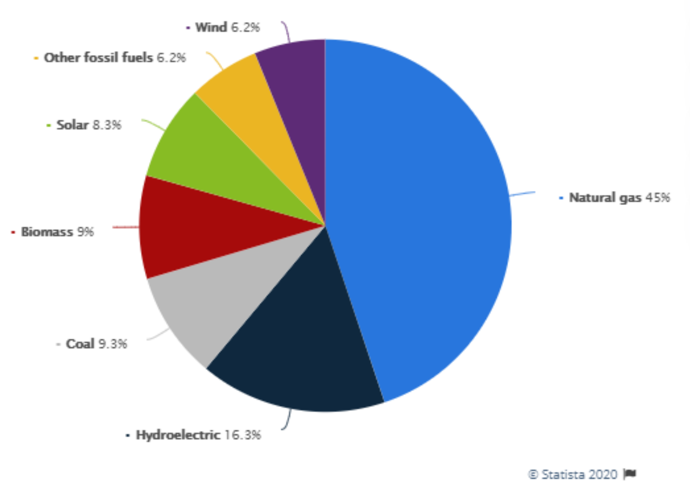
[17] EIA. (2017). [Online]. Available at: https://www.eia.gov/international/analysis/country/ITA

Figure 3. 9 Total energy supply (TES) by source, Italy 1990-2019



(Source: IEA)

Figure 3. 10 Energy Mix, Italy 2018

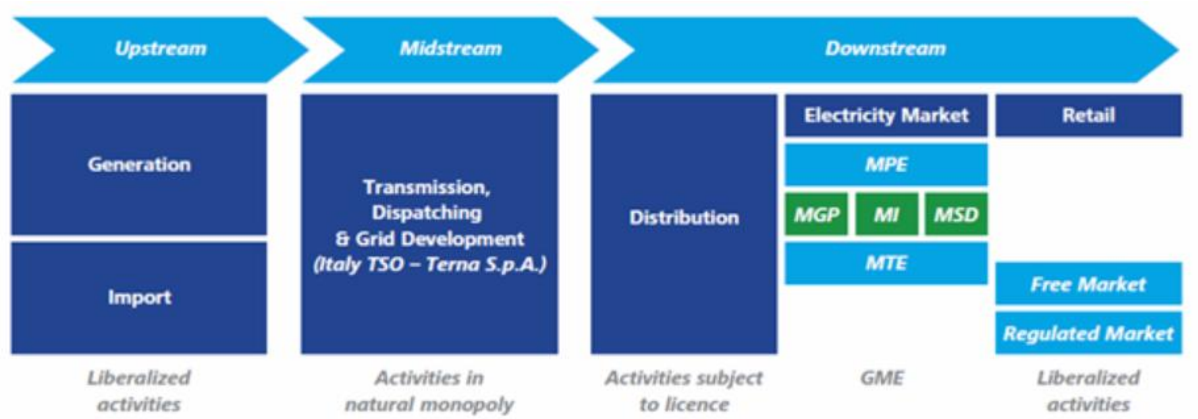


(Source: Statista)

4.3.2 Italian electricity market liberalization

The energy sector in most of the countries globally started its operation as a natural monopoly governed by the state. In most cases that was a necessary action since the cost was enormous for the private companies to be engaged in energy projects. Furthermore, the operation of the energy system would be easier to be governed and closely regulated by one entity instead of many companies engaged. That was the case also in Italy where the electricity system was organized following monopoly principles, in terms of production, transmission, and distribution. The structure was based on the state governed company, ENEL. The Italian energy market has been implemented reforms on the market since 1999, when the first actions to the liberalization process started, by introducing the right to other entities to operate in the energy sector, by ending the natural monopolies. Some of the big reforms of the Italian market include the sale of 25% of the power generation capacity of ENEL (vertically integrated monopolist). Furthermore, the operation of the Independent Transmission System Operator since 1999, guarantees transparent and non-discriminatory access to all power generation companies. *As part of the electricity liberalization process the Gestore dei Mercati Energetici S.p.A (GME), was initially vested with the organization and economic management of the wholesale power market under principles of neutrality, transparency, objectivity, and competition. Concerning the high voltage electricity transmission and Terna was established as a result of the liberalization of the electricity market in 1999 (Europex).* On later steps that were introduced in 2007 by the EU, the retail markets should operate under free choices and unregulated markets. *Under the current regulatory scheme, a majority of Italy's electricity customers are supplied by the local incumbents at a regulated price. This is the case for 53.5% of residential customers and 40.9% of the small and medium enterprises. While all customers are formally free to switch to an alternative supplier, the flow of consumers towards the free price regime has been disappointingly slow in the past 12 years – not least because the name of the regulated tariff, "greater protection", creates a false perception of safety as opposed to the "jungle" of the market. To make things even worse, the largest operator – the former monopolist, Enel, which is still state-controlled – has a market share of about 70% among small customers. Of these, about two-thirds are due to the regulated tariff. Hence, Italy's electricity retail market is strongly concentrated by design[18].* The last step of the electricity market liberalization process took place in the summer of 2020 when Italy decided to phase out electricity retail price regulation. Until the summer of 2020, the local distributor supplied residential customers and small businesses that preferred to be under a regulated scheme tariff called "maggior tutela" which means greater protection. Figure 3.11 presents the electricity system in Italy as it is presented in IAEA's report.

Figure 3. 11 Italian electricity system structure



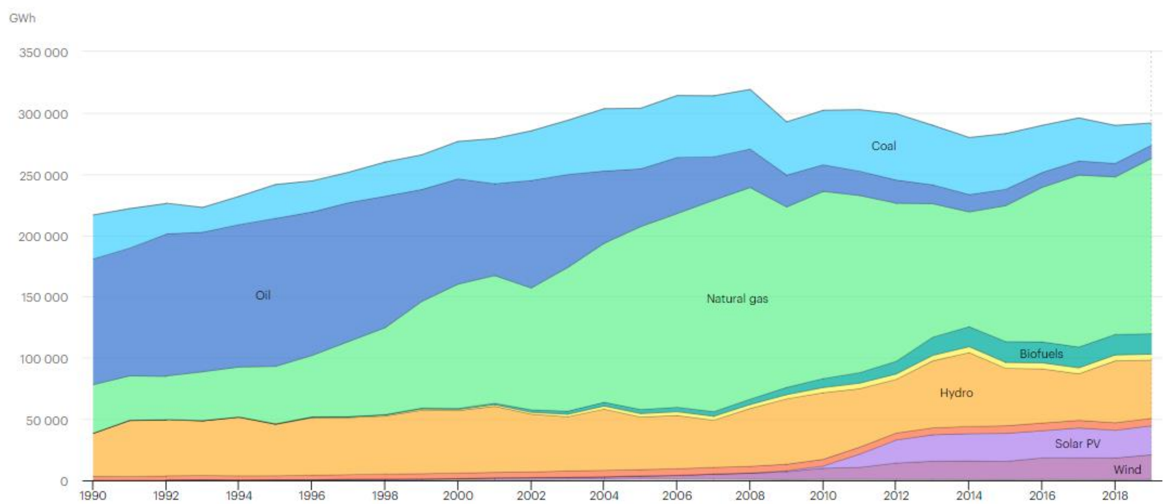
(Source: IAEA)

[18] A, Mingardi. (2020). The library of Economics and Liberty. [Online]. Available at: https://www.econlib.org/electricty-liberalization-in-italy/

4.3.3 Italian electricity generation

The Italian electricity production market is based on fossil fuels (67%), mainly natural gas, while renewable energy production plays a crucial role in accounting for 33% of the total electricity production. Natural gas production showed the highest percentage in 2010, while its share has been declined in the last decade, mainly because RES technology has gained additional market share. Figure 3.12 shows the annual gross production of electricity by source in Italy in the last two decades.

Figure 3. 12 Electricity generation by source, Italy 1990-2019



(Source: IEA)

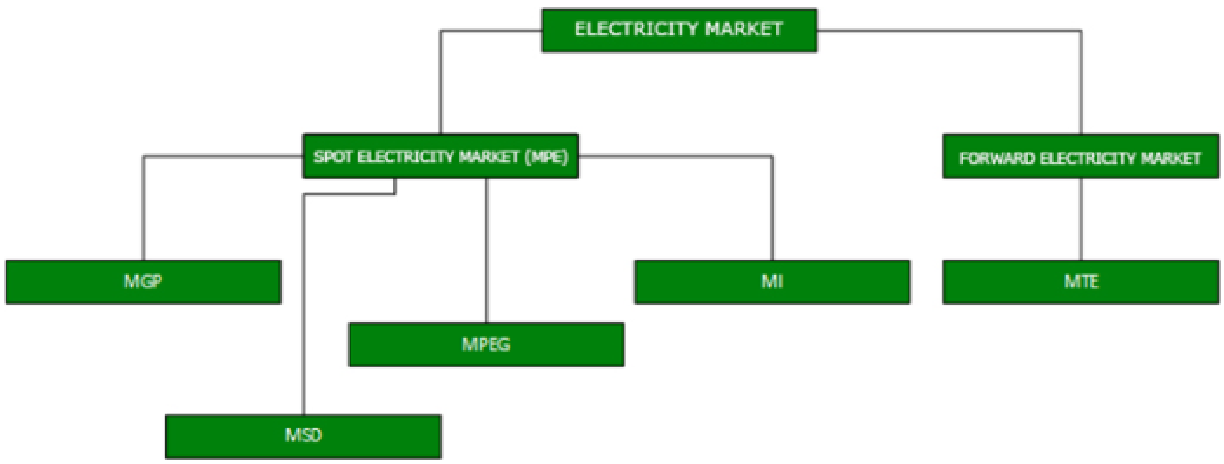
As it concerns electricity production, the Italian market is characterized by monopoly, since ENEL, the state-owned company, is the largest producer by far. In the last two decades, the Italian government gave great emphasis on increasing the market share of renewable energy (wind and solar) by subsidizing renewable projects, resulting in an 18% market share in 2016 from 1% in 2000. This RES growth plan is following the EU policy that promotes the energy security of the country and therefore the EU's energy dependence. To meet the needs of the electricity demand Italy imports energy from other countries, contributing with 16% of the total electricity consumption demand. France plays a crucial and supportive role in the power sector of the Italian market since it constitutes a power source by exporting energy to Italy, accounting for almost 50% of the total imports in Italy.

4.3.4 Italian Power exchange

GME is responsible for the power, gas, and environmental markets in Italy. As it concerns the power market, GME manages the power market platform IPEX (Italian Power Exchange). IPEX platform is used for setting the purchase and buy orders for wholesale electricity. The available products that can be traded on the IPEX platform, include products for the forward physical market (MTE), a market for the trading of daily products (MPEG) with continuous trading mode (MPEG), a day-ahead auction market (MGP), and an intraday auction market (MI) which is composed by 7 different sessions. GME is a founding member of the Price Coupling of Regions (PCR) project providing a technical solution for the coupling of the day-ahead EU markets. GME is also a party of the XBID project for the delivery of an intraday continuous trading implicit auction compliant with CACM (GME).

Figure 3. 13 Italian electricity market structure

The Electricity Market consists of the Spot Electricity Market (MPE) and of the Forward Electricity Market (MTE).



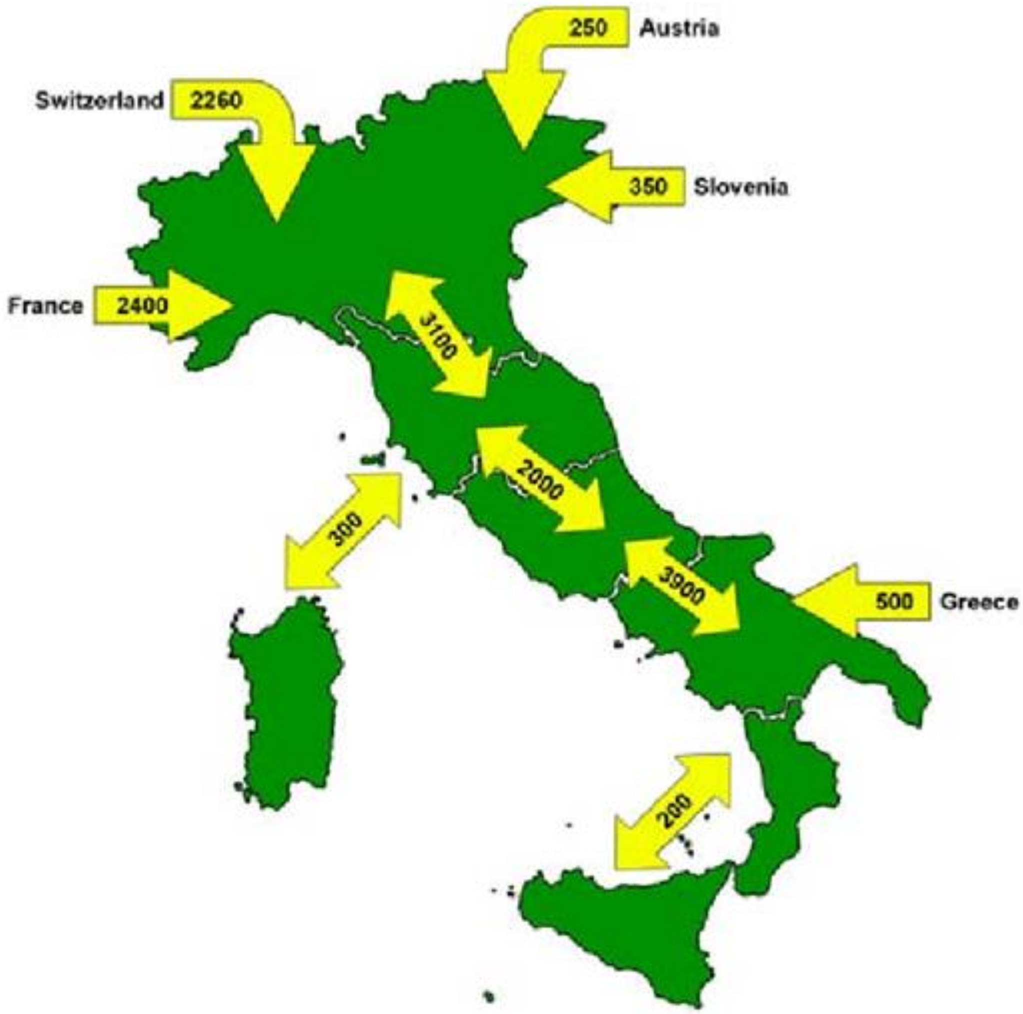
(Source:GME)

4.3.4.1 Market Coupling

One of the basic interpretations of market coupling is the implicit auctions for the interconnection capacity rights between countries. Italy uses implicit allocation with Slovenia, France, Greece and Austria. The mechanism simultaneously performs the implicit auctions for the daily physical rights transmission and the clearing of the buy and sell energy orders. The Italian power market operates under the coupling model developed since GME is a full member of the Price Coupling of Regions (PCR). That means that for the daily market price solution the Euphemia algorithm is used in the region. The Italian electricity market is decomposed in power zones. Each power zone has its market price for every single day. The prices may deviate from region to region, but the main concept, in this case, is that every region contributes to the energy needs of each region. The difference in the price is an outcome of the capacity that connects each area. In case that the energy needs of a zone are high and the imported volumes from other areas are not able to cover the energy demand, the final price will deviate. Geographical zone: representing a portion of the national grid. Geographical zones are northern Italy (NORD), central-northern Italy (CNOR), central-southern Italy (CSUD), southern Italy (SUD), Sicilia (SICI), Sardegna (SARD). Foreign virtual zone: point of interconnection with neighboring countries. It includes France (FRAN), Switzerland (SVIZ), Austria (AUST), Slovenia (SLOV), Slovenia coupling representing the interconnection dedicated to the market coupling between Italy and Slovenia (BSP); Corsica (CORS), Corsica AC (COAC), Greece (GREC), France coupling (XFRA), Austria coupling (XAUS), Malta (MALT), Switzerland coupling (XSVI) and Montenegro (MONT). The procedure described above is the PCR decentralization price coupling mechanism. The Figure presents all the zones that operate on the Italian market coupling and the capacity of their interconnections. At the end of the trading day, the Italian geographical zones are valued at the “Prezzo Unico Nazionale” (PUN –

national single price); this price is equal to the average of the prices of geographical zones, weighted for the quantities purchased in these zones.[19]

Figure 3. 14 Italian market coupling and interconnection capacities



(Source: Pfuger, T.B, Sensfuß, F., & Wietschel M. (2009). Agent-based simulation of the effects of an import of electricity from renewable sources in Northern Africa into the Italian power market. *Internationale Energiewirtschaftstagung an der TU Wien.* [Online]. Available at https://www.econstor.eu/bitstream/10419/28520/1/570113083.pdf)

4.3.4.2 Day-Ahead Market

The day-ahead market of Italy is taking part in the market coupling between France, Slovenia, Austria and Greece by using the implicit allocation method based on ATC (Available Transfer Capacity). On GME DAM

[19] GME. [Online]. Available at: https://www.mercatoelettrico.org/En/Default.aspx

(day-ahead market) standard hourly and block day-ahead electricity products can be traded. Some technical characteristics of the day-ahead market on GME are the following:

- Trading procedure: Daily Auction
- Underlying: Electrical power transiting over the Italian Transmission System managed by TERNA. (the Hungarian TSO)
- Order Book Opening: The MGP gate opens at 8 a.m. on the ninth day before the day of delivery.
- Order Book closes Daily at 12:00 a.m.
- Publication time: As soon as possible from 12:55 a.m.
- Clearing and Settlement: Trade information transmitted by GME to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- Delivery procedure: Nomination by GME (together with ECC) and by the Balance Group Responsible of the GME Member to the TSO (TERNA) based on the regulations of the Commercial Code of the Italian Electricity System
- Minimum and maximum prices: -500.0 €/MWh / 3000.0 €/MWh
- The accepted demand bids pertaining to consuming units belonging to Italian geographical zones are valued at the “Prezzo Unico Nazionale” (PUN – national single price); this price is equal to the average of the prices of geographical zones, weighted for the quantities purchased in these zones.

4.3.4.3 Intra-day market

Intraday Market (MI) allows Market Participants to modify the schedules defined in the MGP by submitting additional supply offers or demand bids. The MI takes place in seven sessions: MI1, MI2, MI3, MI4, MI5, MI6, and MI7. Some of the technical characteristics of the intraday market are the following:

- Trading procedure: Continuous
- Underlying: Electrical power transiting over the Italian Transmission System managed by Terna (the Italian TSO)
- Trading opens (GOT=gate opening time): Contracts for the next day open at 3:00 pm
- Trading closes (GCT=gate closure time): 60 minutes before delivery
- Clearing and Settlement: Trade information transmitted by GME to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- In the Italian intraday market there seven MI markets. Each MI opens after the MI-1 has closed and results are published for each MI.
- Minimum and maximum prices: -9999.00 €/MWh / 9999.00 €/MWh
- *Unlike in the MGP, accepted demand bids are valued at the zonal price.*

4.4 Greece

4.4.1 Greek Energy dependency

The dependence of Greece is extremely high on natural gas and oil products. Greece does not produce domestic gas and oil products (the production is limited to few barrels of oil), thus it is almost 100% dependent on imported volumes. Greece is one of the most energy-dependent countries among EU states. The respective indicator that depicts the energy dependence of a country in 2016 was equal to 73.6% for Greece, leading the country to the 7th place of the most dependent EU members. In terms of natural gas, Greece is highly dependent on Russia, since the imported natural gas accounts almost for 60%

of the total imports. As it concerns oil imports, 45% of the total imports come from Iraq[20]. One of the factors that lead Greece to the top seven of the energy dependence list is the non-interconnected Greek islands, which cover the energy demand by using almost 100% imported oil as a primary source to cover the electricity demand. Oil products covered 49% of the energy demand of the country in 2017. Moreover, Greece's domestic energy sources include lignite, which reserves are one of the highest in the EU. Although, according to EU directives Greece and other European countries should reduce the CO2 emissions, thus lignite share has already decreased. Figure 3.15 shows that Greece traditionally has been depended on coal to cover its energy demand. Additionally, oil and gas products play a significant role in the energy mix, while the increase of natural gas share has been observed from 2004 and onwards. The explanation for this tense is that in 2004, the first liberalization rules started to be implemented, with private companies engaged in power production by using natural gas, leading to reduction of oil and coal share. The RES technology intensively increased its market share, since the rise during the last decade contributed to the reduction of coal and oil consumption.[21] The Greek governments have been implementing the EU plan for the RES technology, achieving the first goal for 2020 (20% share), while the next target for 2030 according to the National Energy and Climate Plan (NECP) includes:

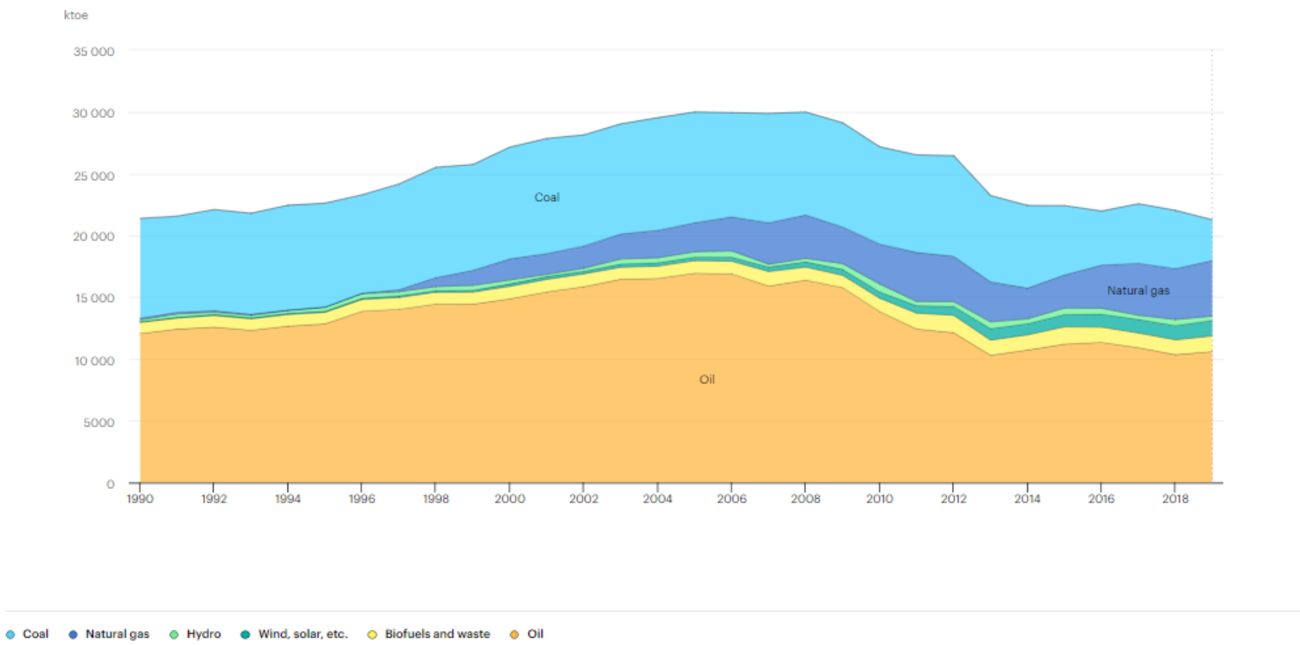
- 35% share of RES in gross final energy consumption
- 60% share of RES in gross final electricity consumption
- 40% share of RES in final energy for heating and cooling
- More than 14% share of RES in final energy for transport
- Reduction of final energy consumption by 38% compared to the respective forecasts of 2007
- Reduction of total greenhouse gas emissions by at least 40% compared to 1990

Greece has a significant strategic geographical location for the energy balance of Balkans and Europe and will become a crucial energy hub since there are projects of major importance under implementation or at their very first steps, having as a main target the diversification of resources of the EU members, especially from Russia. These projects will inject natural gas into the EU, from Cyprus and Israel through Greece (East Med Pipeline), and will connect Greece with Turkey, transporting natural gas from Azerbaijan (TAP). The imported natural gas will be transported from Greece to Italy and then it will flow to other European countries. Lastly, Greece will become an LNG hub, since the terminal in Revithoussa will increase its capacity and the construction of an LNG terminal in the Northern area of Greece will provide additional capacity, enhancing the trading optionality in the region and promoting energy security & diversification.

[20] IENE. (2018). Energy Security of Greece. [Online]. Available at: https://www.iene.gr/articlefiles/energgeiki-asfaleia_elladas.pdf

[21] Hellenic Association for Energy Economics. (2019). Greek Market Report 2019. [Online]. Available at: https://www.haee.gr/media/4858/haees-greek-energy-market-report-2019-upload-version.pdf

Figure 3. 15 Total energy supply (TES) by source, Greece 1990-2019



(Source: IEA)

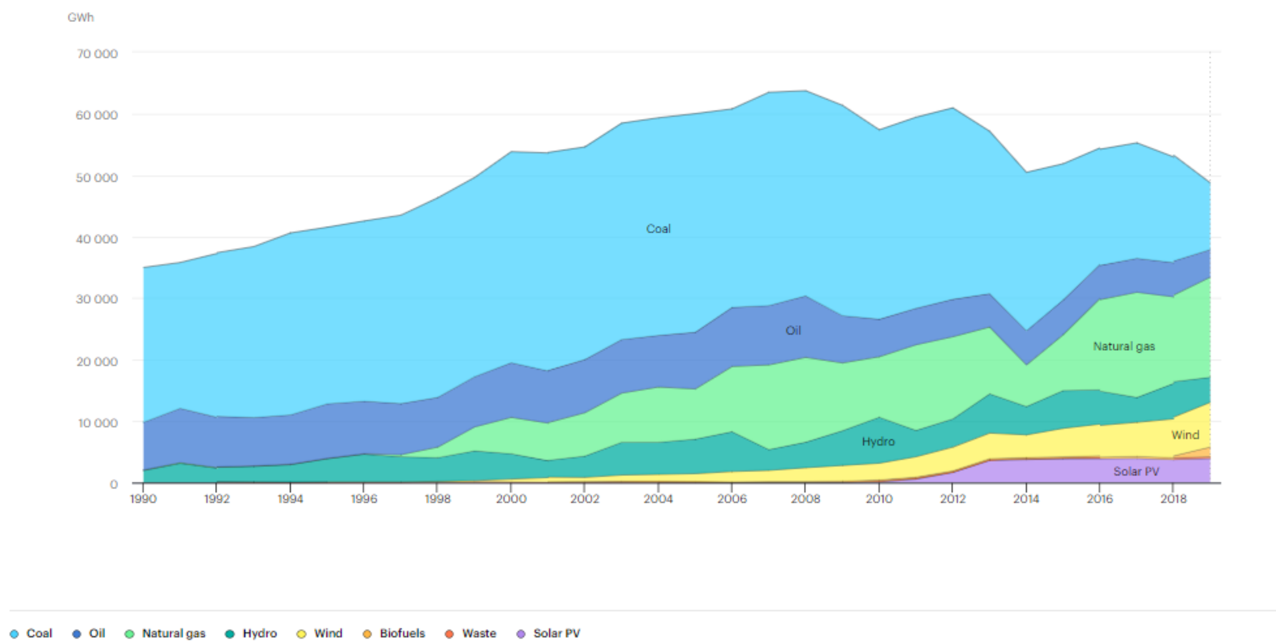
4.4.2 Greek electricity market liberalization

The Greek electricity market has implemented the last steps towards liberalization in 2020. Even if the first steps started in 2001, continuous delays led the market liberalization to be under full operation after 19 years. The Greek electricity system started power production with the establishment of the state-owned company (PPC) DEH in 1950, which was vertically integrated into all the segments of the electricity market, acting as a state monopoly. The first step to market liberalization was implemented in 2001 when the monopolist firm PPC was initially split into two entities, the Public Power Corporation (PPC) and the Hellenic Transmission System Operator (HTSO). The PPC would be only responsible for the electricity generation and supply, as well as for the electricity distribution. The HTSO would control and operate the electricity transmission system and help the daily electricity auctions, while it would be also responsible for the operation of the wholesale electricity market. The second step was introduced in 2004, where independent generators began commercial operation. Furthermore, electricity suppliers entered the retail electricity market in 2009. According to the EU directives, the structure of PPC and HTSO should move to the next level during 2011, which includes their decomposition in more entities. Thus, PPC and HTSO were split into four entities, the Power Public Corporation (PPC-DEH), the Hellenic Electricity Distribution Network Operator (HEDNO-DEDDIE), the Operator of Electricity Market (OOEM-LAGIE) and the Independent Power Transmission Operator (IPTO-ADMIE). One of the factors that caused delays in the liberalization of the electricity market was that some electricity suppliers that managed to gain almost 8% of the retail electricity market in 2012, were finally suspended from the market. This event, made all the private companies engaged in the retail market seem non-transparent to the clients, leading the liberalization process to step backward. The next years, the tariffs were opened to free-market rules, starting with the medium voltage retail tariffs in 2012 and then with the households tariffs. Private companies were active in the retail market, although they could not gain market share, since PPC had the advantage of the economies of scale. The PPC had the exclusive rights for the exploitation of lignite in Greece, which led to low generation cost, giving the advantage of offering law retail tariffs, that was for many years regulated and private companies couldn't afford to compete. PPC's monopoly has been discouraging private companies to compete the state company in other fields than power production. Another factor that delayed the liberalization process in Greece was that the government, was the actual manager of the biggest corporation of the country (PPC), constituting the company leverage for votes and political influence. After many years of asymmetric competition, the implementation of NOME Auctions (Nouvelle Organization du Marché de l'Electricité) in Greece took place. Electricity generation from PPC's lignite plants was auctioned with all market participants having access to claim volumes, to become more competitive and increase their market share. The target was that the market share of PPC should be decreased to 50% in 2019, from 90% in 2016. This target failed, since the actual market share of PPC in 2019 was still high (75%). Although, private companies managed to increase their market share until 2020, PPC still has the edge accounting for approx. 67%. Following the liberalization process, *HEnEx S.A. was founded on 18.6.2018, following a spin-off of the Electricity Market branch of LAGIE S.A. and currently DAPEEP.S.A.* The Greek Regulator (Regulatory Authority for Energy-RAE) has designated building upon the accrued experience of more than a decade, operating continuously and consistently the Day-Ahead Scheduling Energy Transactions System, HEnEx S.A. as Nominated Electricity Market Operator (NEMO) for the operation of the Day-Ahead and Intraday Electricity Markets. Additionally, HEnEx's Derivatives market started operation in March of 2020. The last steps took place in November and December of 2020 when the Greek electricity systems operate under the Euphemia market algorithm and the market coupling of Greece with the Italian market has been implemented. The Greek-Bulgarian market coupling has been announced to be under full operation in May 2021.

4.4.3 Greek Electricity generation

In electricity generation, Greece uses coal, gas, oil, RES technology as power sources. Coal has been for many years the primary source for electricity production in Greece. Although, lignite production started to decrease after the liberalization of the energy market in line with the EU directives for cleaner energy production. However, the contribution of coal is still high, accounting for almost 30% of the total electricity production and RES electricity production market share reached 26% in 2018. Figure 3.16 illustrates that wind and solar technology presented a sharp increase from 2012 and onwards, reaching almost 20% in 2020. The next target is to increase the market share of RES to 30% until 2030, according to the EU directive 2009/29/EC. Concerning natural gas market share in the Greek electricity production mix, an increase is expected, replacing lignite and oil production. Additionally, the non-interconnected Greek islands will soon join the interconnected system, leading to diversification of their energy sources supply, which is mostly driven by oil products for electricity production. Imported electricity volumes play a major role in the Greek electricity mix, since Bulgaria, Italy, North Macedonia, Albania and Turkey daily contribute to the electricity demand of the country, accounting for 19% of the total electricity mix. The majority of the imported volumes comes from Bulgaria 35%, Italy 23% and North Macedonia 23%.

Figure 3. 16 Electricity generation by source, Greece 1990-2019



(Source: IEA)

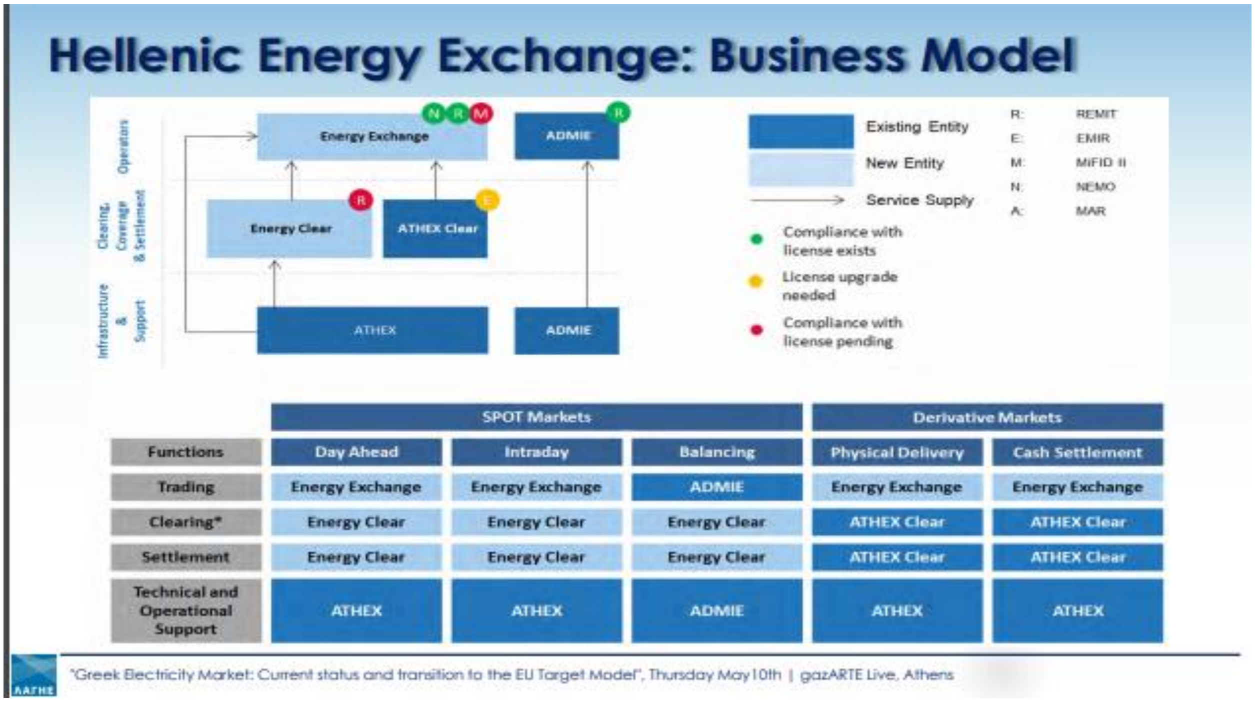
4.4.4 Greek Power exchange

Before the establishment of the Hellenic Energy Exchange in 2018, responsible for the operation of the day-ahead electricity market was the public company LAGIE. LAGIE had the responsibility of clearing, settlement, and reporting services to the Regulatory Authority for Energy (RAE) and the Agency for the Cooperation of Energy Regulators (ACER). In line with the EU Target Model implementation, LAGIE and the Athens Stock Exchange (ATHEX) signed a memorandum of cooperation, establishing the Hellenic Energy Exchange, which belongs to EnExGroup. EnExGroup consists of Hellenic Energy Exchange S.A.[22] (HEnEx S.A.) and EnEx Clearing House S.A. (EnExClear S.A.). The HEnEx is responsible for the Day-Ahead, Intraday electricity market, and energy derivatives market. EnExClear S.A., a subsidiary of HEnEx founded in November 2018, is responsible for the clearing and settlement of transactions concluded in the Day-Ahead and Intraday Markets, as well as the clearing and settlement of positions in the Balancing Market. Since November 2020, the Greek electricity system operates under new rules following the EU Target Model. The Intraday market was for the first time introduced by HEnEx to the market, while the new algorithm EUPHEMIA was for the first time used to provide the market clearing price. In December 2020, the market coupling with Italy started its operation for the first time. Therefore, instead of explicit auction auctions between Italy and Greece, implicit auctions are used. Furthermore, responsible for the market coupling operation is now the TSOs of the two countries by transferring electricity from the country with

[22] EnEx. [Online].Available at: https://www.enexgroup.gr/el/home

lower wholesale electricity prices to the higher-cost country – to the extent permitted by grid interconnection capacities – until price discrepancies have evened out.

Figure 3. 17 Hellenic Energy Exchange



4.4.5 Market Coupling

The Greek day-ahead market in December 2020 was finally coupled with the Italian electricity market following the Pan-European day-ahead market. The existing grid interconnection between Greece-Italy is a 163km subsea cable with a 500-MW capacity in operation since 2002, which is used to facilitate the target model coupling to harmonize the energy markets of the two countries. The day-ahead market capacity is now using implicit allocation auction, by using the Euphemia algorithm. Under the price coupling the electricity prices and cross-border flows, of the two countries are calculated simultaneously, making the system more efficient and maximizing social welfare. The next step is the implementation of the Greek-Bulgarian Market Coupling project that is scheduled to be implemented in May of 2021.

4.4.5.1 Day-Ahead Market

The day-ahead market of Greece is taking part in the market coupling with Italy, by using the implicit allocation method based on ATC (Available Transfer Capacity). On HEnEX day-ahead market standard hourly and block day-ahead electricity products can be traded. Some technical characteristics of the day-ahead market on HEnEX are the following:

- Trading procedure: Daily Auction
- Underlying: Electrical power transiting over the Greek Transmission System managed by ADMIE. (the Greek TSO)
- Order Book Opening: The day-ahead gate opens at 8 a.m
- Order Book closes Daily at 12:00 a.m.

- Publication time: As soon as possible from 13:00 a.m.
- Clearing and Settlement: Trade information transmitted by HEnEX to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- Delivery procedure: Nomination by HEnEX (together with ECC) and by the Balance Group Responsible of the HEnEX Member to the TSO (ADMIE) based on the regulations of the Commercial Code of the Greek Electricity System
- Minimum and maximum prices: -500.0 €/MWh / 3000.0 €/MWh

4.4.5.2 Intraday market

Intra-Day Market (MI) allows Market Participants to modify the schedules defined in the day-ahead market by submitting additional supply offers or demand bids. The intraday sessions are composed of three intraday markets, LIDA 1, LIDA 2 and LIDA 3. Some of the technical characteristics of the intraday market are the following:

- Trading procedure: Continuous
- Underlying: Electrical power transiting over the Italian Transmission System managed by Terna (the Italian TSO)
- Trading opens (GOT=gate opening time): Contracts for the next day open at 3:00 pm
- Trading closes (GCT=gate closure time): 60 minutes before delivery
- Clearing and Settlement: Trade information transmitted by HEnEX to the Central Counterparty, ECC AG for Settlement and Delivery of the Contracts
- In the Greek intraday market, there are three available markets (LIDA). Each LIDA opens after the LIDA-1 has closed and results are published for each session
- Minimum and maximum prices: -9999.00 €/MWh / 9999.00 €/MWh

5 The impact of Covid-19

5.1 Covid-19

The first case of Covid-19 patient was recorded in a city in Eastern China, Wuhan, in December of 2019. The Covid-19 was an unknown virus, on this form, that causes severe pneumonia. In the beginning, Covid-19 was treated as a common virus, although the rate of spread around the word was extremely fast and finally many countries had to deal with the new global pandemic. Until the end of 2020, more than 200 countries and territories have been affected by the new pandemic, with more than 77.4 million recorded cases and more than 1.7 million deaths worldwide. The countries facing the most cases and deaths are the United States of America (18 million cases- 320k deaths), India (10.1 million cases-146k deaths), Brazil (7.3 million cases-187k deaths), Russia (2.85 million cases-50k deaths) and France (2.48 million cases-61k deaths). The European countries that were most affected by the new pandemic are France, Italy, UK and Spain. Most of the EU countries have announced a lockdown in March 2019, with a few weeks delays on some cases. The measures that the lockdown imposed affected the economic activities, with almost all the businesses being forced to stop their operation, such as theaters, gyms, bars, restaurants and most of the companies imposed a limit on the employees that would work with a physical presence. The demand for the majority of the products was limited, leading industrial and commercial companies to decrease their production. Therefore, the lockdowns had a direct effect on the energy demand, leading to a tremendous decline in energy prices. However, the fall of the energy prices was not driven only by the low demand since temperature and RES generation contributed to this drop[23].

5.2 The effect of Covid-19 on energy demand

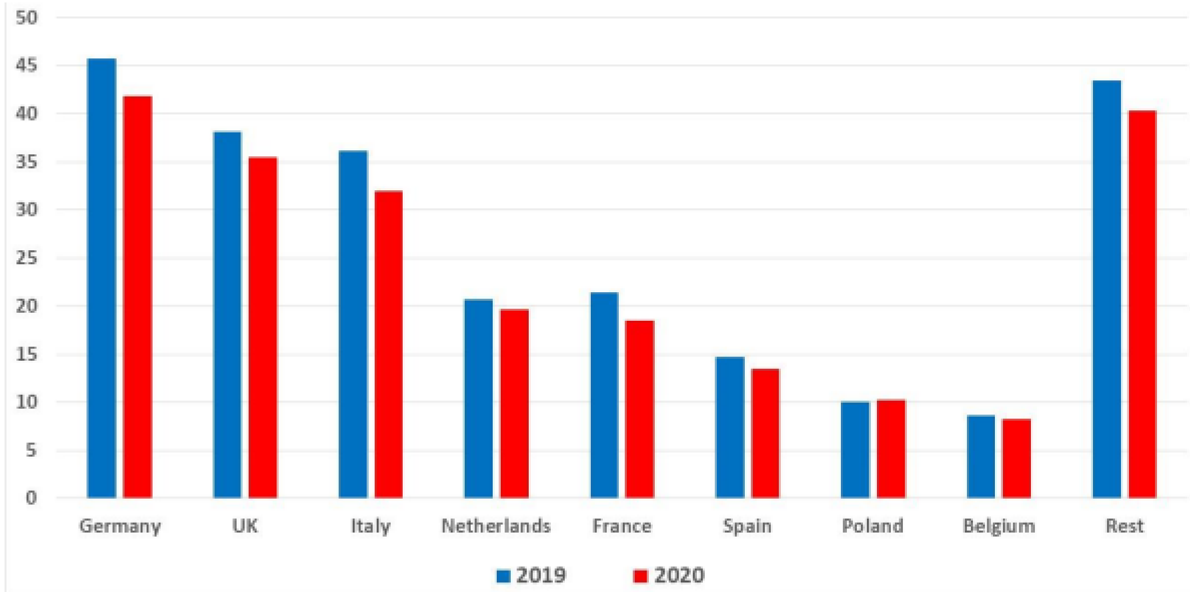
5.2.1 Natural gas demand

Natural gas had the tense from 2014 and onwards to increase its share in the energy mix of the countries, since other sources of energy like oil and coal have been replaced as primary sources for heating and power generation. The first drop in natural gas demand was recorded during 2020 due to the impact of Covid-19. The effect of the lockdowns that most governments imposed had a direct negative effect on the economic activity, leading to the decline of natural gas demand. Focusing on EU countries, Figure 4.1 presents the gas demand decline from 2019 to 2020 for the period January-May, for 8 EU countries and the rest are included on the last bar chart. The decline is about 10% in Germany, 8 % in the UK and 11.5% in Italy. Natural gas demand in Europe has approximately declined by 8%, which is equal to 19 billion cubic meters (bcm). The lockdown effect was not the only factor contributing to this drop, since other factors were leading to the natural gas decline, such as temperature and high renewable sources generation. In March 2020 temperatures were the sixth warmest in Europe since 1979 limiting the natural gas demand for heating, and the renewable energy capacity has been more increased compared to the previous year, with high power generation due to windy and sunny days, led to an increase by 16% compared to 2019 [24].

[23] Ghiani, E., Galici, M., Mureddu M., & Pilo, F. (2020). Impact on Electricity Consumption and Market Pricing of Energy and Ancillary Services during Pandemic of COVID-19 in Italy. *Energies.* [Online]. Available at: https://www.mdpi.com/1996-1073/13/13/3357/pdf

[24] Honoré, A. (2020). *Natural gas demand in Europe: The impact of COVID-19 and other influences in 2020.* The Oxford Institute for Energy Studies. [Online]. Available at: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2020/06/Natural-gas-demand-in-Europe-the-impacts-of-COVID-19-and-other-influences-in-2020.pdf

Figure 4. 1 Monthly natural gas demand (bcm) in Europe, January to May 2019 and 2020



(Source: The Oxford Institute for energy studies)

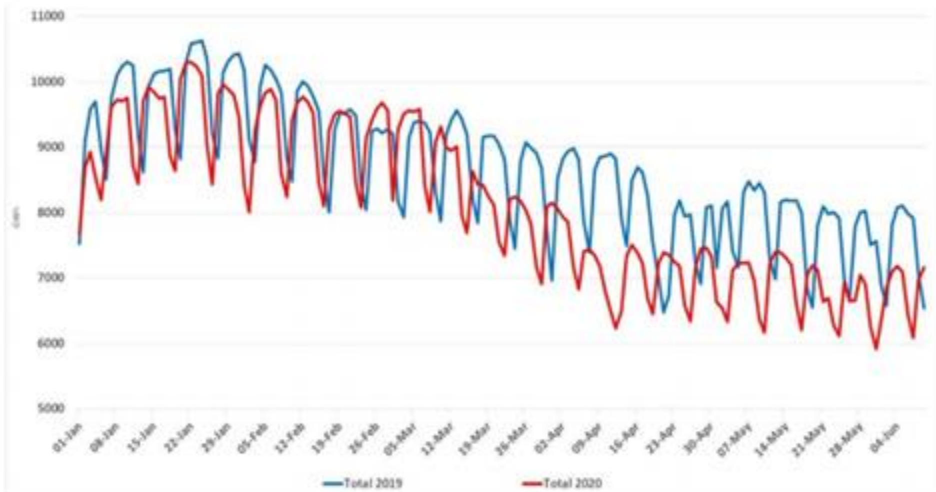
5.2.2 Electricity demand

The electricity demand is positively correlated with the natural gas demand since in most countries natural gas is one of the primary energy sources for electricity generation. Therefore, the factors that affected the fall of electricity demand are almost the same as referred to in the previous paragraph, including the lockdown that negatively affected the economic activity, the high temperature in the majority of the EU countries, which led to low electricity consumption for heating and the high RES generation share in the energy mix. Italy was the first EU country that announced a full lockdown. The effect on the demand was direct, leading to a drop of around 6-10% on the peak load demand and during the weekend, this drop was more intense reaching an 18-22% decline. To be more specific, the figures below present the rise of the RES production and the electricity demand decline, from January to April for 2019 and 2020, for Italy, Greece, Bulgaria, and Hungary. The goal of these graphs is to examine the change in-demand and RES production specifically to the four countries examined in this thesis, while it is known from the bibliography that the demand and RES production as an average in Europe, were decreased and increased respectively[25]. Figures 4.3 shows that the Italian load at the beginning of 2020 was at lower levels compared to 2019. Although the sharp decline is noticed during the mid of March until the end of April due to the lockdown effect and the seasonality of the demand. Greece imposed a lockdown on 23 of March, leading to a sharp decrease of the load during April, is also affected by higher temperatures compared to previous months. According to Figure 4.7, the RES production in Italy did not contribute to the price reduction, since during March 2020 the average RES production was 23% lower compared to 2019 and 17% less than February 2020 production. The RES production was more intense during April 2020 being 6% higher than March 2020 and 7% higher than the previous year. The RES production in

[25] Honoré A., (2020), The Oxford Institute for Energy Studies. Natural gas demand in Europe: The impact of COVID-19 and other influences in 2020. Available at: https://www.oxfordenergy.org/publications/natural-gas-demand-in-europe-the-impacts-of-covid-19-and-other-influences-in-2020/

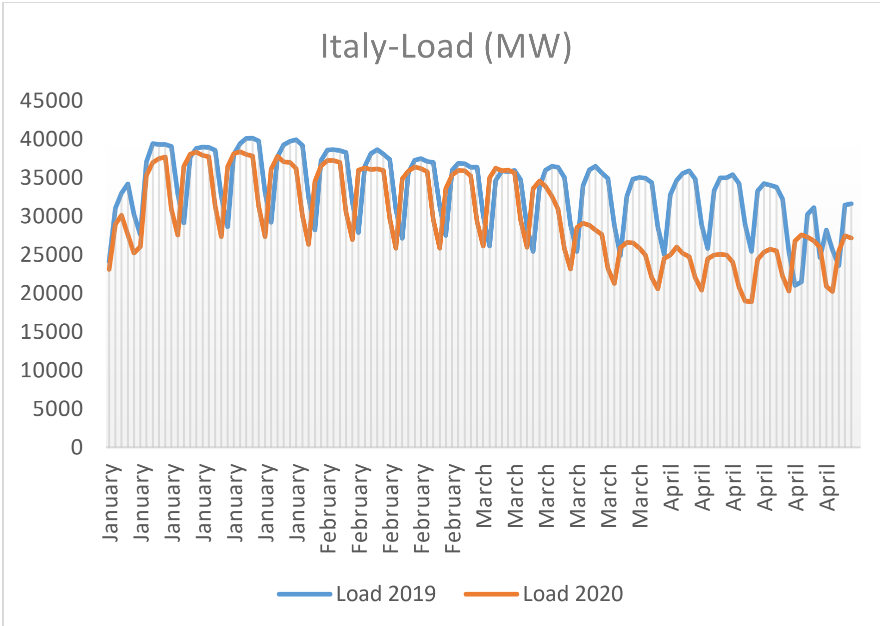
Greece showed an upward trend during April 2020 compared to April 2019 (+36%), contributing to the decrease of the wholesale electricity prices. Bulgaria's electricity demand was in lower levels from the beginning of 2020 compared to 2019, due to lower temperatures, but it was also affected from COVID-19 in April where the load showed an unusual drop, compared to 2019. The RES production in Bulgaria and Hungary claims a small market share in the electricity production, so it may be considered as an insignificant factor, since the average RES production during April 2020 was only 381 MWh and 334 MWh respectively. Hungary was affected from COVID-19 at the end of March, where the first decline in the demand is observed, compared to 2019.

Figure 4. 2 Daily power generation in Europe, 1 January-10 June 2020 vs 2019 (GWh)



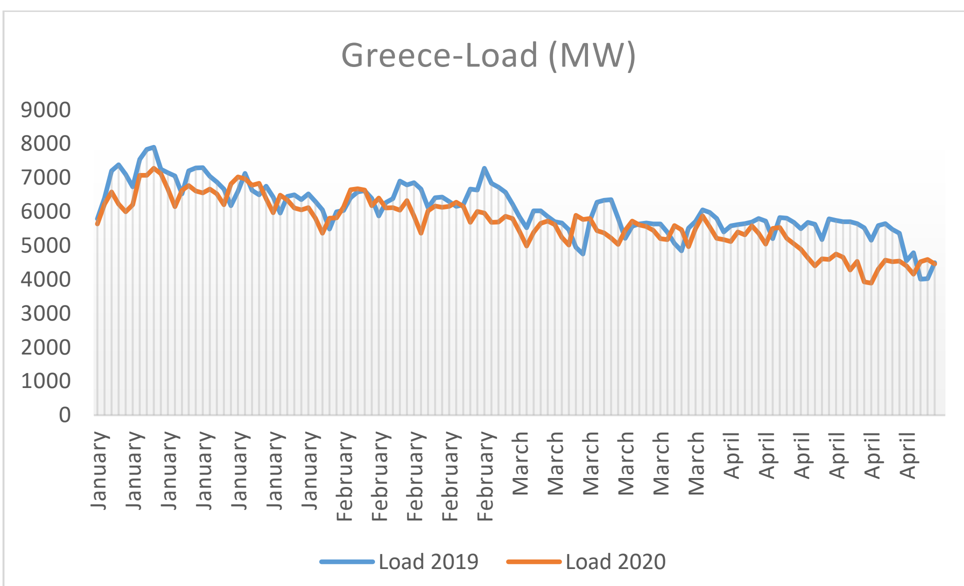
(Source: The Oxford Institute for energy studies)

Figure 4. 3 Italian Load, January to April 2019 and 2020



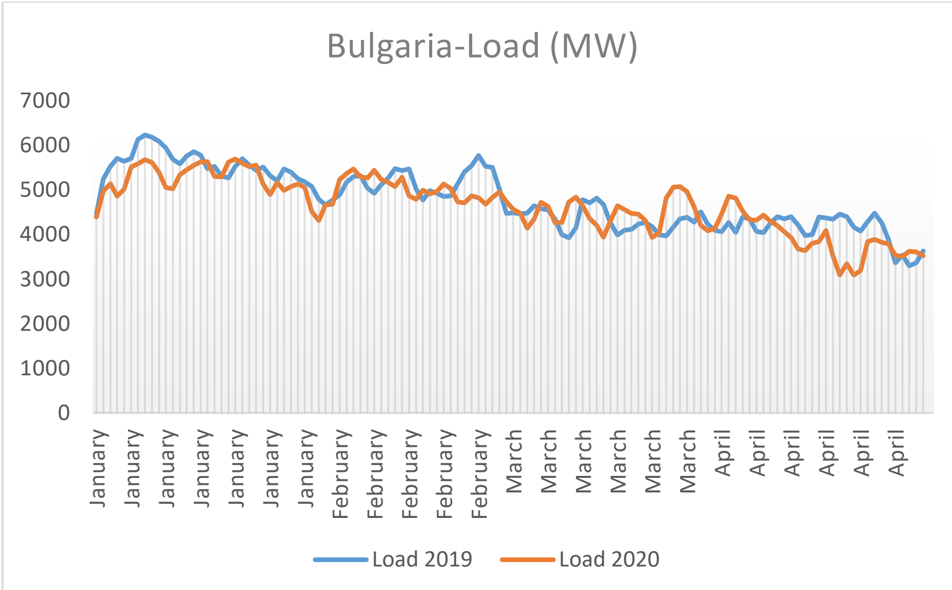
(Source: Data from ENTSOE, Author's calculations)

Figure 4. 4 Greek Load, January to April 2019 and 2020



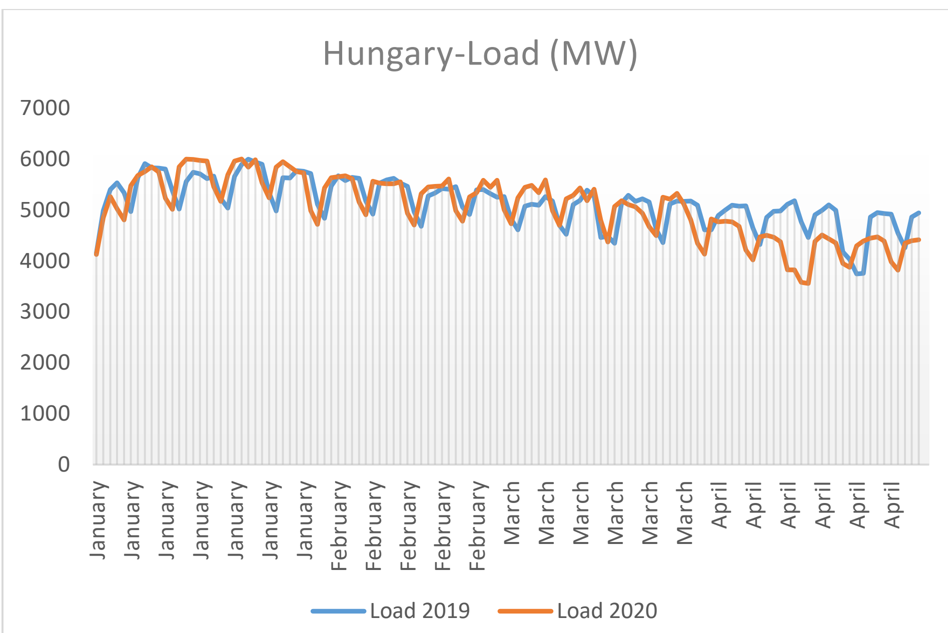
(Source: Data from ENTSOE, Author's calculations)

Figure 4. 5 Bulgarian Load, January to April 2019 and 2020



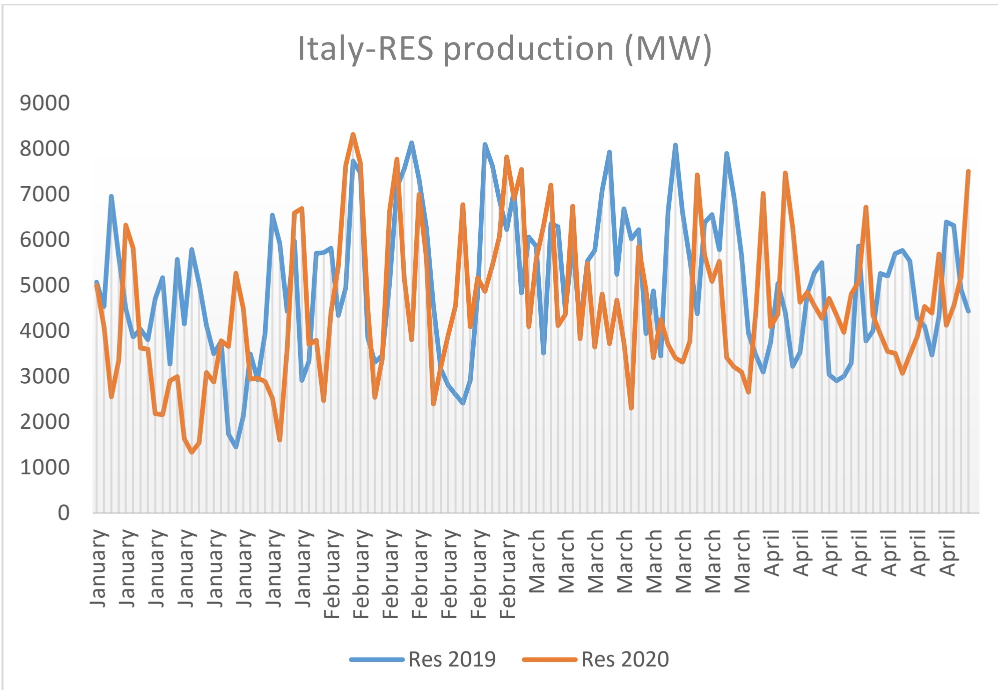
(Source: Data from ENTSOE, Author's calculations)

Figure 4. 6 Hungarian Load, January to April 2019 and 2020



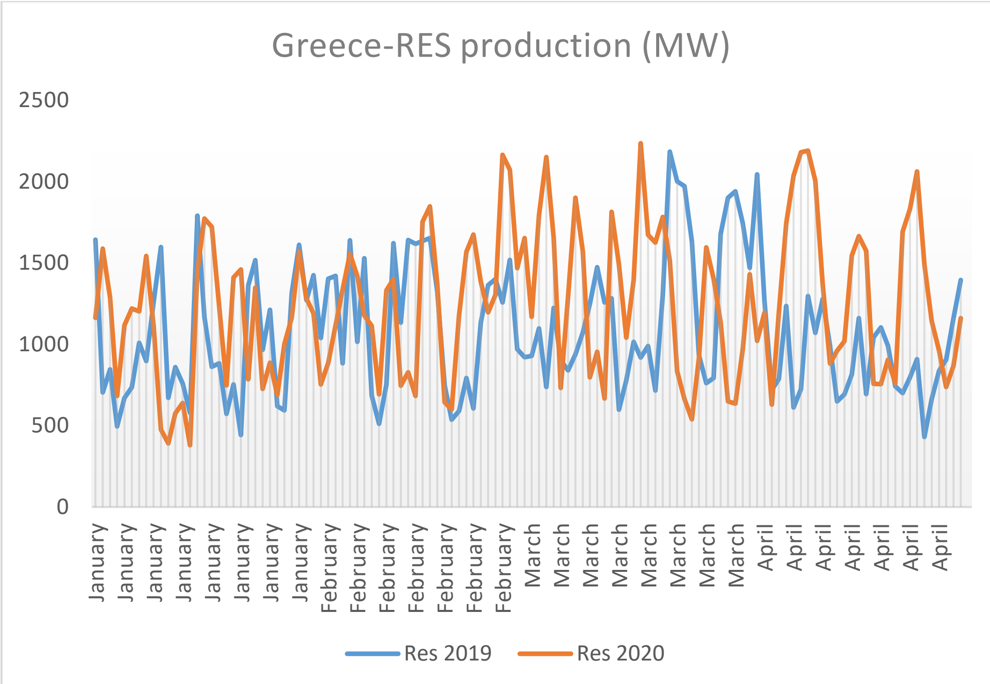
(Source: Data from ENTSOE, Author’s calculations)

Figure 4. 7 Italian RES production, January to April 2019 and 2020



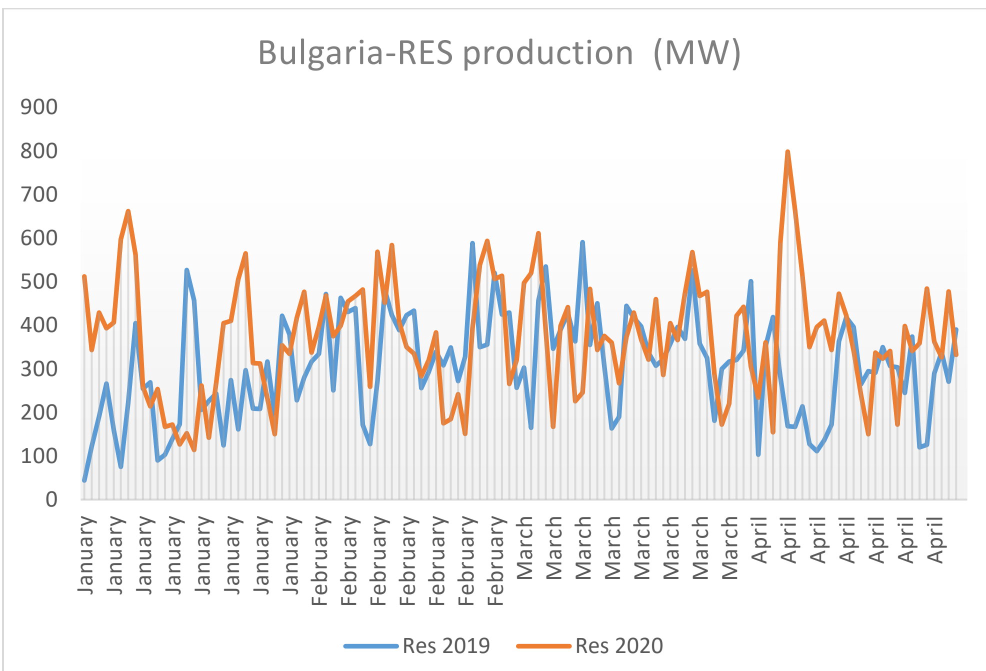
(Source: Data from ENTSOE, Author’s calculations)

Figure 4. 8 Greek RES production, January to April 2019 and 2020



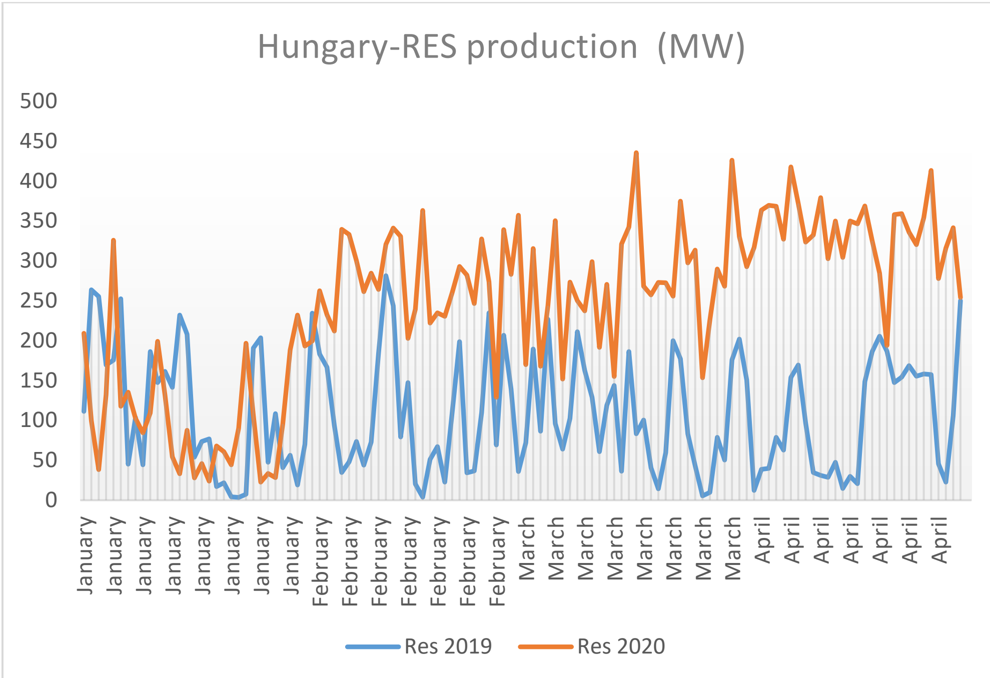
(Source: Data from ENTSOE, Author's calculations)

Figure 4. 9 Bulgarian RES production, January to April 2019 and 2020



(Source: Data from ENTSOE, Author's calculations)

Figure 4. 10 Hungarian RES production, January to April 2019 and 2020



(Source: Data from ENTSOE, Author's calculations)

5.3 The effect of Covid-19 on energy prices

5.3.1 Natural gas and oil prices

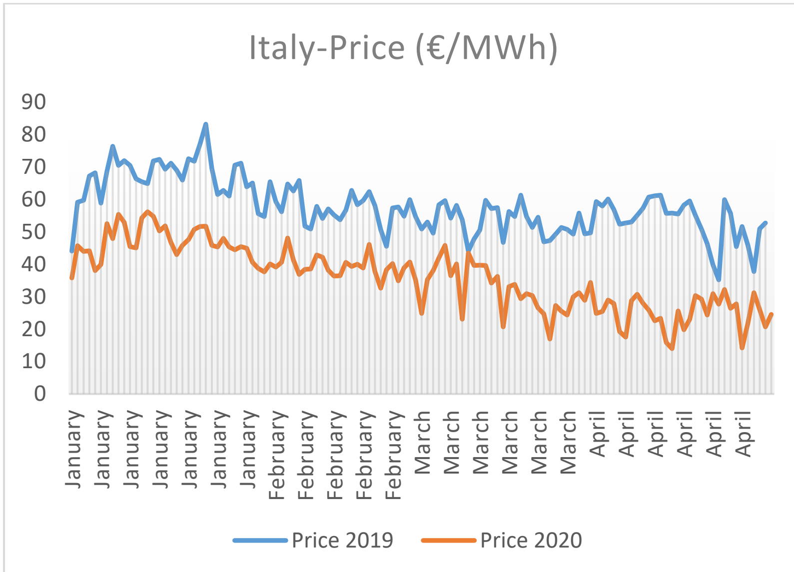
Regarding the COVID-19 pandemic outbreak, the subsequent measures adopted as a means to prevent the spread resulted in the creation of a negative economic and social climate, both at the international and domestic level. The consequent significant impact on the demand for oil products, being obvious that the whole sector internationally, was notably impacted by the world economic slowdown because of the spread of the coronavirus. Specifically, during the period March – June 2020, the imposed transportation ban worldwide and the subsequent unprecedented demand drop for liquid fuels, led to the lowering of the demand for crude oil and petroleum products. Also, the oversupply of crude oil at a greater scale than the available storage capacity caused a sharp and deep drop in crude prices to which the petroleum product prices did not adjust immediately. In a few words, the oil demand was falling while the supply of oil was increasing, so the oil and natural gas prices should fall. The cost of Brent crude fell to below $23 a barrel, which was the lowest price since 2002 when the US and UK were preparing an invasion of Iraq. Natural gas prices fell to USD 1.63 per mmBtu, showing a relative decrease of 38% from the November 2019 peak, reaching its minimum since November 1995. As explained above, the Covid-19 led to a drop in demand, which is easy to be interpreted since lots of businesses and economic activities stopped/decreased their operation. The big question is why the oil production did not react rationally and the production was not decreased to stabilize the prices. The reason is the chicken game (according to game theory) was played among Saudi Arabia, the US, and Russia. Saudi Arabia decided to maintain the production at the same levels to put pressure on other big oil producers and make their economy suffer from low oil prices. Therefore, none of the above countries did reduce the production, as a response to

Saudi's Arabia pressure. The crude prices started to rebound within May – June 2020 following the reduction of the production from OPEC and Russia, combined with the increase of demand after the restart of the international economy. Furthermore, it is safe to say that the impact of Covid-19 has mainly affected the entities that are included in oil trading, mostly in the first quarter of 2020. The majority of the world's most powerful energy groups tried to sustain positive margins, as the drop of the demand as long as the oversupply by OPEC, had a negative impact on gross margins. As we know from the connection of crude oil with its sub-products, natural gas had a drop in its price too. In conclusion, we can fairly believe that as longs as the coronavirus spread will be restricted, the worlds' production will begin again (China and East Asia have already begun) increasing again demand for energy – with oil prices having a positive inclination again in 2021 (The Organization for World Peace).

5.3.2 Wholesale electricity prices

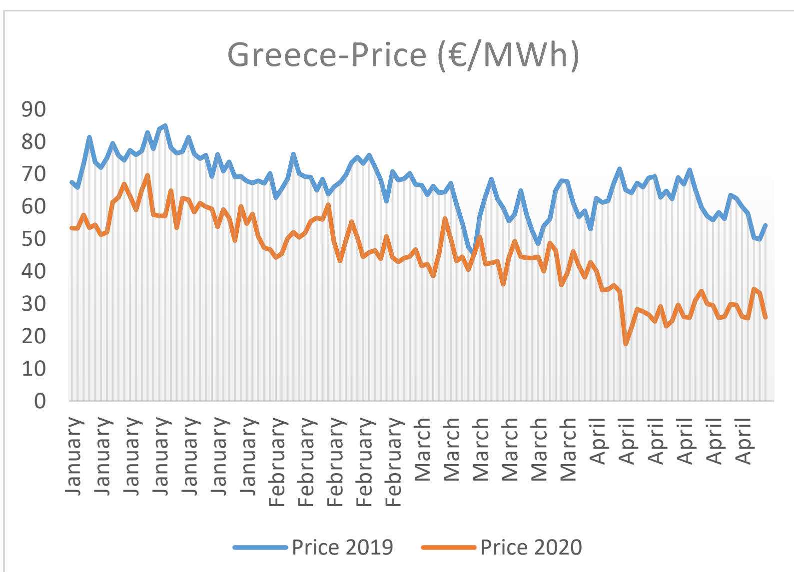
The wholesale electricity prices were also affected in all EU countries, since there a positive correlation with the electricity demand. The lockdowns were announced with a few weeks delay between some EU countries. As it was mentioned before, Italy was the first country to announce full lockdown. Although, Greece was affected a few weeks later, being fully productive during the period that Italy decreased the domestic production. This led to unusual spreads of the prices, leading to high profits for power traders. On the contrary, the future products that were in force during the lockdown period, led to massive losses, since the drop in demand-energy prices were unexpected. As an example, we could refer to the annual future products indexed in the Greek system marginal price. The future contracts during 2019 for 2020 were negotiating close to 60-63 €/MWh (wholesale price), while the average of March to April in 2020 was equal to 36,45 €/MWh and for the same period in 2019 the average price was 61,10 €/MWh (-40%). At the same time, this period was a big opportunity for the electricity suppliers who bought electricity volumes at lower prices compared to previous market levels, being able to provide competitive prices to the costumers and claim bigger market share and profit. On the figures below the evolution of the wholesale electricity prices in Italy, Greece, Bulgaria, and Hungary are presented for the period January-April for the 2019 and 2020. On the first figure, it is clear the Italian wholesale electricity prices (PUN) have been ranging to lower levels from the beginning of 2020 compared to 2019. The same tense was followed in Greece, Bulgaria, and Hungary as it can been seen on the next figures. During the second week of March 2020, a sharp decline in prices is being observed in Italy, followed by the drop of demand. The fall from February 2020 to March 2020 was equal to 18% and then a drop approx. 23%. The average price of Italy during April 2020 was equal to 24,81 €/MWh, while during April 2019 was 53,35 €/MWh (-53%). In Greece, the first big decline of the price started the first days of April, following the drop in demand. The average price of Greece in April 2020 dropped to 29 €/MWh from 44 €/MWh of the previous month. Compared to the April of 2019 the price was lower by 54%. Bulgaria's price during April 2020 was equal to 25 €/MWh, which is 40% less than April 2019 and 13% lower than March 2020. In Hungary, from April 2019 to April 2020 (26 €/MWh) the drop was 45% while decrease from March 2019 was 15%. The prices referred above for the four countries, it is easy to say that were unsustainable prices for power generators, but was a big opportunity for suppliers.

Figure 4. 11 Italian wholesale electricity price, January to April 2019 and 2020



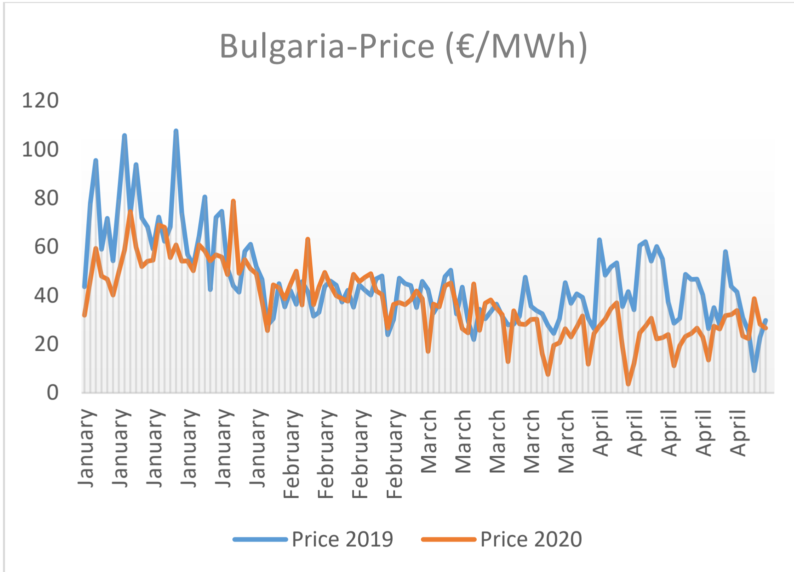
(Source: Data from ENTSOE, Author's calculations)

Figure 4. 12 Greek wholesale electricity price, January to April 2019 and 2020



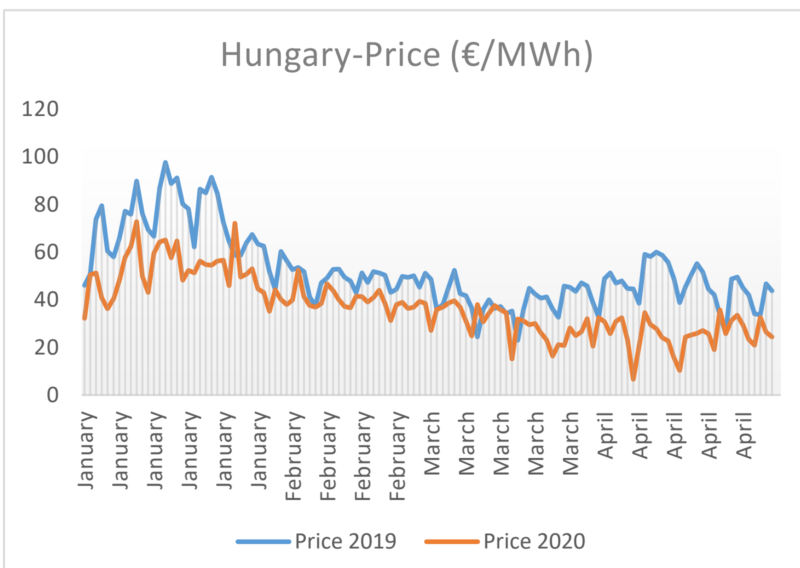
(Source: Data from ENTSOE, Author's calculations)

Figure 4. 13 Bulgarian wholesale electricity price, January to April 2019 and 2020



(Source: Data from ENTSOE, Author's calculations)

Figure 4. 14 Hungarian wholesale electricity price, January to April 2019 and 2020



(Source: Data from ENTSOE, Author's calculations)

6 Models used for wholesale electricity price forecasting

6.1 The need for wholesale electricity price forecasting

During the last three decades, the electric power industry has been under significant restructures, according to the market liberalization process. In the past, public monopolies were vertically integrated in all the segments of the electricity markets, the production, distribution, transportation, and supply. This period the crucial variable that needed to be forecasted was the demand, in order the production units to offer equivalent volumes for the balancing of the system. The need for wholesale electricity price forecasting has been the key tool for energy groups, since the market was liberalized and became competitive with new players entering the market to make profit. Electricity price forecasting is a very difficult task since it the volatility is very high. As an example, the volatility of the wholesale electricity prices of the four countries examined in this thesis, Bulgaria, Greece, Hungary and Italy for the period 2017-2020, is 19,76 €/MWh, 16,15 €/MWh, 20,67 €/MWh, and 16,8 €/MWh, respectively. Price forecasting is a key tool for energy players to hedge their position, to minimize their cost or to speculate on the prices. The time horizon forecast diverse, since it can be break down to short term, including hourly, peak, off peak, daily, weekly forecasts medium term, such as, month(s) ahead, quarters and long term for year(s) ahead forecast. Producers, retailers, and large consumers must have optimal forecast models to engage in bilateral contracts. Traders use price forecast for hedging and speculation purposes.

6.2 Forecast techniques

As it concerns wholesale electricity price forecasting, there are various models used, such as time series techniques, including autoregressive models such as ARX, ARMAX, ARIMAX, dynamic regression and transfer function. The main concept of these models is that they use an auto regression technique for the historical prices, since *electricity prices are also influenced by the present and past values of various exogenous factors, most notably the generation capacity, load profiles and ambient weather conditions. To capture the relationship between prices and these fundamental variables, time series models with eXogenous or input variables can be used*. Other models fund in the bibliography are K-Nearest Neighbors (KNN), Regression Tree (M5P), Random Forest (RFR), and Support Vector Machine (SVM)[26]. Furthermore, a more modern approach for price forecasting are the Artificial Neural Networks (ANNs) which are mathematical models that resemble the functioning of the human brain, by using data sets to produce specified outputs. The advantage of the ANNs is that the models *can approximate any nonlinear function. Feedforward backpropagation neural networks are specially suited to forecasting electricity prices because they can process nonlinearities using sigmoid functions for the inputs and linear functions for the outputs (*Antonio J. Conejo, Javier Contreras, Rosa Espinola, Miguel A. Plazas, "Forecasting electricity prices for a day-ahead pool-based electric energy market, International Journal of Forecasting 21 (2005) 435-462).

6.3 Basic Parameters in price forecasting

The basic parameters that most of the forecasting models use, are the historical and forecast values for the demand, the production by source, the residual (Load-Wind-Solar production), temperature, outages of unit production, the available transfer capacity between border and the historical market clearing prices. In most electricity markets the series of prices presents some standard features, such as high

[26]Haluzan, M., Verbic, M., & Zoric, J. (2020). Performance of alternative electricity price forecasting methods: Findings from the Greek and Hungarian power exchanges, *Applied Energy,* 277. [Online]. Available at: https://doi.org/10.1016/j.apenergy.2020.115599

frequency, non-constant mean, and variance, daily and weekly seasonality, calendar effect on weekends and holidays, high volatility and presence of outliers.

7 Analysis of the forecasting models and data sets

The main goal of this thesis is to implement a technique used in the bibliography, to forecast the day-ahead prices on hourly bases, for Bulgaria, Italy, Greece and Hungary. Many papers refer to electricity price forecasting techniques, although the main driver for the analysis contacted in this thesis a dynamic regression model (Conejo, 2005). The authors use different price forecasting techniques and make the comparison of the results. Time series models are used: ARIMA, Dynamic Regression and Transfer Function and other techniques such as Neural Networks and Wavelet prediction. The Dynamic Regression model was concluded as one of the most effective techniques among the other used in their analysis. The considered historical data used are load and price, spanning 53 days, while they used forecasted values for load. In order to examine the effectiveness of the models the authors use four different weeks (Winter, Spring, Summer and Fall). The general Dynamic Regression model has the form

$$p_h = c + u(B)p_h + v(B)d_h + \varepsilon_h \tag{1}$$

where the p_h is the price in hour h, d_h is the demand in hour h, c is a constant and ε_h is the error term. The Polynomial functions of the back-shift operator B, $u(B)$ and $v(B)$ have the form

$$u(B) = \sum_{k=1}^{nU} u_k B^k \tag{2}$$

$$v(B) = \sum_{k=1}^{nV} v_k B^k \tag{3}$$

The constants u_k and v_k are the selected polynomial coefficients

The equation (3) relates the price at hour h to the past values of price and demand.

After the appropriate selection of the coefficients, they conclude that the final dynamic regression model is:

$$\log(p_h) = c + (u_1B^1 + u_2B^2 + u_3B^3 + u_{24}B^{24} + u_{25}B^{25} + u_{48}B^{48} + u_{49}B^{49} + u_{72}B^{72} + u_{73}B^{73} + u_{96}B^{96} + u_{97}B^{97} + u_{120}B^{120} + u_{121}B^{121} + u_{144}B^{144} + u_{145}B^{145} + u_{168}B^{168} + u_{169}B^{169} + u_{192}B^{192} + u_{193}B^{193}) * \log(p_h) + (v_1B^1 + v_2B^2 + v_3B^3 + v_{24}B^{24} + v_{25}B^{25} + v_{48}B^{48} + v_{49}B^{49} + v_{72}B^{72} + v_{73}B^{73} + v_{96}B^{96} + v_{97}B^{97} + v_{120}B^{120} + v_{121}B^{121} + v_{144}B^{144} + v_{145}B^{145} + v_{168}B^{168} + v_{169}B^{169} + v_{192}B^{192} + v_{193}B^{193}) * \log(d_h) + \varepsilon^h \tag{4}$$

7.1 Data sets of the analysis

7.1.1 Historical data

The historical data used for the day-ahead electricity price forecasting for Hungary, Bulgaria and Italy are the load and prices of the last 53 days. The historical data used for forecasting the day-ahead price in Greece is the residual load.

Residual Load= Load-Wind-Photovoltaics (5)

The residual load was preferred to be included in the analysis for Greece than using the load as in the other three countries since it was observed that the errors were smaller, and all the data were available on ENTSOE's website. For Italy, missing data for the forecasted values of RES production on ENTSOE's website, made the comparison not possible, while in Hungary and Bulgaria the RES capacity is limited, so the results would not deviate.

7.1.2 Source of the data

All data sets were retrieved from the transparency market platform of ENTSOE (https://transparency.entsoe.eu/). As it concerns the load or residual used in the analysis for the next day, the forecasted values on day-ahead level available on ENTSOE were used in order to make the prediction procedure more realistic, rather than using the actual values.

7.1.3 Period

The selected weeks for forecasting are same weeks used in the aforementioned paper for the 2019 in order to avoid biased results (18-24 of February, 20-26 of May, 19-25 of August and 18-24 of November). The year 2019 is selected rather than the 2020, since as it was described on Chapter 4 the Covid-19 led to unexpected sharp decrease of the prices, making price forecasting a very difficult task for time series techniques.

7.1.4 Forecasting Technique

The forecasting technique chosen in this thesis is the autoregressive dynamic regression (ARDL) that uses different lags for every country and every period, since the coefficients leading to better and acceptable results, according to several criteria, are chosen. In order to compare different methods, the Ordinary Least Squares (OLS) and the Fully-Modified OLS method are used. Additionally, the equation (4) is used as a standard coefficient selection, by implementing the OLS approach for every country and every period. In order to forecast from hour 1 to 24 of day d, historical data are used, and for every next hour the forecasted values of price are also used, including the demand (or residual) predictions. The analysis was conducted on EVIEWS statistical package, which supports the above techniques and offers a familiar environment for non-programmers. At this point, it has to be mentioned that for the examined periods, the results for Bulgarian day-ahead price forecasting did not lead to results that can be considered a good forecast approach, due to the intense price volatility of the selected periods. For that reason, no results are presented for Bulgaria.

8 Results of the analysis

8.1 Model Testing

Some diagnostic tests that have been considered to choose the best model are the following:

- The adjusted R^2
- The standard error
- The Akaike Information Criteria (AIC)
- The p-value of the coefficients

Furthermore, for every dynamic regression model the criteria considered and should not be violated are:

- Unit Root Test: All data used for the three countries (price, load, residual) are either I(0) or I(1), meaning that an ARDL model can be conducted.
- Serial Correlation LM Test: Every final model satisfies the hypothesis that there is no serial correlation.

- CUSUM Test: Every final model seems to be within the resulted limits of the CUSUM test, making the models stable.

8.2 Performance of the final models

To assess the prediction capacity of all the proposed models for every period and country the statistical measures used are:

1. The weekly-hourly error: $e_{wh} = \frac{1}{7}\frac{(\sum_{hd=1}^{7} p_h^{true} - \sum_{hd=1}^{7} p_h^{est})}{\sum_{hd=1}^{7} p_h^{true}}$ (6)

   This error estimator may not be the best to assess the predictive ability of the models since it doesn't take into account the absolute values, but the weekly average of each hour, comparing the forecasted hourly (e.g hour=1 or 2 etc.) values with the actual values.

   Where, $\bar{p}_h^{true,24} = \frac{1}{24}\sum_{h=1}^{24} p_h^{true}$ (7)

2. The daily error: $e_{day} = \frac{1}{24}\sum_{h=1}^{24} \frac{|p_h^{true} - p_h^{est}|}{\bar{p}_h^{true,24}}$, (8)

   Where, $\bar{p}_h^{true,24} = \frac{1}{24}\sum_{h=1}^{24} p_h^{true}$

   (8)

3. The week error: $e_{week} = \frac{1}{168}\sum_{h=1}^{168} \frac{|p_h^{true} - p_h^{est}|}{\bar{p}_h^{true,168}}$, (9)

   Where, $\bar{p}_h^{true,168} = \frac{1}{168}\sum_{h=1}^{168} p_h^{true}$ (10)

8.3 Italy

8.3.1 Winter week

The final dynamic regression model used for the winter week in Italy (18-24 February 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_3B_3 + u_4B_4 + u_5B_5 + u_{24}B_{24} + u_{25}B_{25} + u_{72}B_{72} + u_{73}B_{73} + u_{120}B_{120}) * \log(p_{h)} + (v_0B_0 + v_1B_1 + v_3B_3) * \log(d_h) \quad (11)$$

Table 7. 1 Italy: Average price forecasting results for the winter week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	52.59	51.41	2%	51.41	2%	50.94	3%
2	50.51	49.75	2%	49.72	2%	49.42	2%
3	47.97	48.56	1%	48.53	1%	47.92	0%
4	46.82	48.02	3%	48.03	3%	47.07	1%
5	47.34	48.34	2%	48.41	2%	47.97	1%
6	50.80	51.04	0%	51.20	1%	51.58	2%
7	59.13	58.71	1%	59.01	0%	61.23	4%
8	62.49	64.67	3%	65.08	4%	66.87	7%
9	65.55	68.30	4%	68.77	5%	69.46	6%
10	61.86	66.32	7%	66.76	8%	65.98	7%
11	55.97	61.32	10%	61.69	10%	58.88	5%
12	51.74	57.51	11%	57.83	12%	54.01	4%
13	47.79	53.63	12%	53.81	13%	49.54	4%
14	46.23	52.01	12%	52.08	13%	47.70	3%
15	49.01	54.16	11%	54.09	10%	50.18	2%
16	51.88	56.95	10%	56.60	9%	54.14	4%
17	57.97	61.18	6%	60.52	4%	59.75	3%
18	66.07	66.43	1%	65.38	1%	67.34	2%
19	75.15	73.82	2%	72.27	4%	76.63	2%
20	74.97	75.56	1%	73.75	2%	77.21	3%
21	68.07	70.65	4%	68.91	1%	70.90	4%
22	63.60	65.54	3%	63.98	1%	65.09	2%
23	57.52	58.87	2%	57.52	0%	57.99	1%
24	52.02	53.58	3%	52.39	1%	53.02	2%

Table 7. 2 Italy: Daily errors for the winter week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
18/2/2019	62.80	8%	8%	8%
19/2/2019	58.38	9%	9%	12%
20/2/2019	59.64	4%	4%	5%
21/2/2019	62.37	7%	7%	7%
22/2/2019	58.12	7%	7%	8%
23/2/2019	50.66	11%	11%	8%
24/2/2019	45.58	14%	14%	13%

Table 7. 3 Italy: Weekly error for the winter week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
56.79	8%	8%	9%

8.3.2 Spring

The final dynamic regression model used for the spring week in Italy (20-26 May 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_3B_3 + u_{24}B_{24} + u_{25}B_{25} + u_{48}B_{48} + u_{49}B_{49} + u_{72}B_{72} + u_{73}B_{73} + \\ + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169} + u_{192}B_{192} + u_{193}B_{193}) * \log{(p_{h)}} + \\ (v_0B_0 + v_1B_1 + v_{24}B_{24} + v_{25}B_{25} + v_{120}B_{120} + v_{144}B_{144}) * \log{(d_h)} \qquad (12)$$

Table 7. 4 Italy: Average price forecasting results for the spring week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	42.38	43.96	4%	43.73	3%	43.63	3%
2	39.71	42.94	8%	42.39	7%	42.62	7%
3	38.93	43.10	11%	42.38	9%	42.85	10%
4	39.05	43.73	12%	42.92	10%	43.63	12%
5	41.31	45.20	9%	44.36	7%	45.24	10%
6	45.01	48.63	8%	47.78	6%	48.72	8%
7	50.22	52.72	5%	51.92	3%	52.73	5%
8	54.48	57.24	5%	56.58	4%	56.80	4%
9	53.52	55.90	4%	55.33	3%	56.18	5%
10	51.76	53.86	4%	53.39	3%	54.55	5%
11	48.81	51.35	5%	51.00	4%	52.12	7%
12	45.55	48.80	7%	48.53	7%	49.17	8%
13	43.03	46.02	7%	45.79	6%	46.37	8%
14	44.62	47.46	6%	47.30	6%	47.24	6%
15	46.43	49.78	7%	49.70	7%	48.71	5%
16	47.27	51.07	8%	50.93	8%	49.67	5%
17	47.41	52.50	11%	52.33	10%	51.20	8%
18	49.95	53.87	8%	53.74	8%	52.94	6%
19	54.62	57.33	5%	57.32	5%	56.74	4%
20	59.53	61.82	4%	62.04	4%	61.28	3%
21	57.41	59.88	4%	60.14	5%	60.01	5%
22	51.19	55.66	9%	56.06	10%	55.30	8%
23	45.07	49.07	9%	49.54	10%	48.95	9%
24	43.61	47.57	9%	48.22	11%	47.42	9%

Table 7. 5 Italy: Daily errors for the spring week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
20/5/2019	49.24	9%	9%	7%
21/5/2019	58.38	10%	9%	10%
22/5/2019	59.64	4%	5%	7%
23/5/2019	62.37	6%	7%	5%
24/5/2019	58.12	9%	8%	6%
25/5/2019	50.66	7%	7%	7%
26/5/2019	45.58	11%	11%	13%

Table 7. 6 Italy: Weekly error for the spring week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
54.86	8%	8%	8%

8.3.3 Summer

The final dynamic regression model used for the summer week in Italy (19-25 May 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_{24}B_{24} + u_{25}B_{25} + u_{48}B_{48} + u_{49}B_{49} + u_{72}B_{72} + u_{73}B_{73} + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169}) * \log(p_{h)} + (v_0B_0 + v_1B_1 + v_{72}B_{72} + v_{73}B_{73} + v_{192}B_{192} + v_{193}B_{193}) * \log(d_h) \quad (13)$$

Table 7. 7 Italy: Average price forecasting results for the summer week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	43.13	42.54	1%	42.43	2%	42.93	0%
2	41.51	40.94	1%	40.74	2%	41.12	1%
3	40.49	39.48	2%	39.23	3%	39.69	2%
4	40.26	38.68	4%	38.38	5%	38.89	3%
5	40.85	39.74	3%	39.39	4%	40.08	2%
6	41.90	40.56	3%	40.15	4%	40.84	3%
7	41.75	41.88	0%	41.37	1%	41.70	0%
8	43.71	42.47	3%	41.92	4%	42.30	3%
9	43.30	42.34	2%	41.77	4%	41.85	3%
10	42.03	41.50	1%	40.96	3%	40.84	3%
11	40.35	40.90	1%	40.41	0%	39.91	1%
12	39.38	40.29	2%	39.90	1%	39.30	0%
13	38.97	39.13	0%	38.85	0%	38.14	2%
14	39.41	39.72	1%	39.51	0%	38.74	2%
15	42.18	42.41	1%	42.27	0%	41.65	1%
16	44.37	44.24	0%	44.16	0%	43.96	1%
17	47.31	46.94	1%	46.89	1%	46.65	1%
18	57.34	53.35	7%	53.28	7%	53.12	7%
19	63.84	61.96	3%	61.73	3%	62.76	2%
20	65.95	65.53	1%	65.14	1%	67.14	2%
21	60.88	62.00	2%	61.50	1%	63.68	5%
22	51.40	53.75	5%	53.27	4%	54.64	6%
23	46.53	48.27	4%	47.83	3%	48.76	5%
24	45.61	46.54	2%	46.13	1%	46.97	3%

Table 7. 8 Italy: Daily errors for the summer week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
19/8/2019	46.65	6%	6%	5%
20/8/2019	46.58	4%	4%	5%
21/8/2019	46.01	5%	5%	5%
22/8/2019	45.82	7%	7%	13%
23/8/2019	47.24	4%	3%	5%
24/8/2019	44.90	5%	5%	6%
25/8/2019	44.34	7%	7%	10%

Table 7. 9 Italy: Weekly error for the summer week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
45.94	5%	5%	7%

8.3.4 Fall

The final dynamic regression model used for the fall week in Italy (18-24 November 2019) is:

$$\log(p_h) = c + (u_1 B_1 + u_2 B_2 + u_3 B_3 + u_4 B_4 + u_5 B_5 + u_{24} B_{24} + u_{72} B_{72} + u_{73} B_{73} + u_{120} B_{120}) * \log(p_h) + (v_0 B_0 + v_1 B_1 + v_3 B_3) * \log(d_h) \quad (14)$$

Table 7. 10 Italy: Average price forecasting results for the fall week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	46.51	45.23	3%	45.32	3%	44.67	4%
2	42.75	42.75	0%	42.86	0%	42.21	1%
3	40.63	40.38	1%	40.57	0%	39.88	2%
4	39.37	38.81	1%	39.06	1%	38.40	2%
5	38.07	38.11	0%	38.40	1%	37.92	0%
6	40.51	40.21	1%	40.59	0%	40.24	1%
7	48.80	47.35	3%	47.86	2%	47.43	3%
8	55.84	54.03	3%	54.45	2%	53.76	4%
9	60.68	58.32	4%	58.58	3%	58.34	4%
10	58.48	58.24	0%	58.32	0%	58.59	0%
11	55.93	56.56	1%	56.61	1%	56.80	2%
12	54.94	55.43	1%	55.49	1%	55.56	1%
13	53.73	53.82	0%	53.81	0%	53.78	0%
14	53.43	53.21	0%	53.21	0%	53.21	0%
15	54.14	53.83	1%	53.88	0%	53.44	1%
16	56.47	55.47	2%	55.51	2%	54.74	3%
17	60.75	58.76	3%	58.81	3%	58.38	4%
18	67.33	65.13	3%	65.22	3%	64.56	4%
19	67.38	66.81	1%	66.80	1%	66.93	1%
20	65.50	65.38	0%	65.46	0%	64.99	1%
21	59.44	60.06	1%	60.22	1%	59.14	1%
22	53.97	54.93	2%	55.22	2%	53.68	1%
23	50.04	51.10	2%	51.49	3%	50.03	0%
24	46.09	47.29	3%	47.72	4%	46.60	1%

Table 7. 11 Italy: Daily errors for the fall week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
18/11/2019	56.52	8%	7%	9%
19/11/2019	60.95	9%	8%	9%
20/11/2019	57.92	6%	6%	5%
21/11/2019	55.97	3%	3%	3%
22/11/2019	52.18	11%	11%	10%
23/11/2019	44.91	5%	4%	5%
24/11/2019	42.20	6%	6%	5%

Table 7. 12 Italy: Weekly error for the fall week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
52.95	7%	7%	7%

8.4 Hungary

8.4.1 Winter

The final dynamic regression model used for the winter week in Hungary (18-24 February 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_{24}B_{24} + u_{25}B_{25} + +u_{72}B_{72} + u_{73}B_{73} + u_{120}B_{120} + u_{121}B_{121} + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169} + u_{192}B_{192} + u_{193}B_{193}) * \log(p_{h)} + (v_0B_0 + v_1B_1 + v_2B_2 + v_3B_3 + v_{168}B_{168} + v_{169}B_{169} + v_{192}B_{192} + v_{193}B_{193}) * \log(d_h) \quad (15)$$

Table 7. 13 Hungary: Average price forecasting results for the winter week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	38.69	36.21	6%	36.08	7%	37.94	2%
2	37.55	33.67	10%	33.39	11%	35.27	6%
3	36.43	33.01	9%	32.59	11%	34.74	5%
4	35.95	32.43	10%	31.88	11%	34.36	4%
5	36.57	33.38	9%	32.73	10%	35.54	3%
6	40.22	37.35	7%	36.62	9%	39.83	1%
7	49.22	47.29	4%	46.46	6%	49.83	1%
8	55.34	55.36	0%	54.44	2%	58.27	5%
9	57.20	56.28	2%	55.38	3%	58.99	3%
10	54.34	54.22	0%	53.44	2%	56.51	4%
11	50.83	51.65	2%	51.02	0%	53.50	5%
12	49.59	50.04	1%	49.55	0%	51.57	4%
13	47.36	48.61	3%	48.24	2%	49.78	5%
14	45.67	46.93	3%	46.66	2%	47.82	5%
15	44.96	46.47	3%	46.27	3%	47.05	5%
16	46.26	47.84	3%	47.68	3%	48.36	5%
17	48.74	49.88	2%	49.71	2%	50.43	3%
18	60.61	57.23	6%	57.00	6%	57.60	5%
19	67.94	62.92	7%	62.49	8%	63.69	6%
20	66.29	60.88	8%	60.33	9%	61.91	7%
21	57.13	54.57	4%	54.06	5%	55.32	3%
22	48.49	48.58	0%	48.20	1%	49.16	1%
23	47.27	45.03	5%	44.71	5%	45.70	3%
24	41.04	40.37	2%	40.05	2%	41.04	0%

Table 7. 14 Hungary: Daily errors for the winter week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
18/2/2019	51.31	9%	11%	9%
19/2/2019	47.18	7%	8%	15%
20/2/2019	51.83	10%	11%	8%
21/2/2019	51.27	9%	11%	5%
22/2/2019	50.35	12%	12%	10%
23/2/2019	43.09	8%	7%	8%
24/2/2019	44.38	13%	13%	14%

Table 7. 15 Hungary: Weekly error for the winter week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
48.49	10%	11%	10%

8.4.2 Spring

The final dynamic regression model used for the spring week in Hungary (20-26 May 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_{24}B_{24} + u_{25}B_{25} + +u_{72}B_{72} + u_{73}B_{73} + u_{120}B_{120} + u_{121}B_{121} + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169} + u_{192}B_{192} + u_{193}B_{193}) * \log(p_{h)} + (v_0B_0 + v_1B_1 + v_2B_2 + v_3B_3 + v_{168}B_{168} + v_{169}B_{169} + v_{192}B_{192} + v_{193}B_{193}) * \log(d_h) \quad (16)$$

Table 7. 16 Hungary: Average price forecasting results for the spring week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	38.81	34.86	10%	35.08	10%	37.51	3%
2	35.25	29.39	17%	29.85	15%	31.61	10%
3	33.33	26.18	21%	26.73	20%	28.40	15%
4	32.31	24.21	25%	24.67	24%	25.95	20%
5	32.41	24.49	24%	24.92	23%	26.02	20%
6	33.82	26.78	21%	27.21	20%	28.21	17%
7	39.49	35.72	10%	36.45	8%	35.89	9%
8	45.81	45.48	1%	46.41	1%	44.91	2%
9	48.04	46.92	2%	47.65	1%	46.71	3%
10	45.26	45.49	1%	46.31	2%	46.18	2%
11	43.06	44.72	4%	45.85	6%	45.74	6%
12	41.22	44.19	7%	45.55	11%	44.42	8%
13	40.14	43.88	9%	45.40	13%	42.87	7%
14	37.55	42.06	12%	43.52	16%	40.36	7%
15	37.20	40.78	10%	42.17	13%	38.82	4%
16	37.18	41.02	10%	42.42	14%	38.83	4%
17	38.75	41.58	7%	42.92	11%	39.29	1%
18	40.47	41.50	3%	42.71	6%	39.39	3%
19	44.25	42.08	5%	43.26	2%	40.35	9%
20	49.02	44.00	10%	45.26	8%	42.36	14%
21	54.90	47.23	14%	48.62	11%	45.26	18%
22	49.12	45.31	8%	46.42	6%	43.43	12%
23	47.08	39.20	17%	39.94	15%	38.79	18%
24	42.36	34.42	19%	35.01	17%	34.77	18%

Table 7. 17 Hungary: Daily errors for the spring week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
20/5/2019	46.67	11%	11%	11%
21/5/2019	47.80	12%	11%	17%
22/5/2019	42.35	10%	11%	11%
23/5/2019	42.94	12%	13%	16%
24/5/2019	43.33	9%	10%	5%
25/5/2019	37.16	12%	11%	8%
26/5/2019	27.57	28%	27%	23%

Table 7. 18 Hungary: Daily errors for the spring week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
41.12	13%	13%	13%

8.4.3 Summer

The final dynamic regression model used for the summer week in Hungary (19-25 May 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_3B_3 + u_{24}B_{24} + u_{25}B_{25} + +u_{48}B_{48} + u_{49}B_{49} + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169}) * \log(p_{h)} + (v_0B_0 + v_1B_1 + v_2B_2 + v_3B_3 + v_{24}B_{24} + v_{25}B_{25} + v_{72}B_{72} + v_{73}B_{73} + v_{192}B_{192} + v_{193}B_{193}) * \log(d_h) \quad (17)$$

Table 7. 19 Hungary: Average price forecasting results for the summer week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	44.82	40.57	9%	41.32	8%	42.41	5%
2	38.28	34.65	9%	35.06	8%	34.90	9%
3	31.51	31.85	1%	31.97	1%	31.55	0%
4	30.05	29.96	0%	30.02	0%	30.09	0%
5	30.73	29.94	3%	29.73	3%	30.37	1%
6	35.25	32.53	8%	31.68	10%	33.48	5%
7	41.80	39.68	5%	37.80	10%	39.79	5%
8	50.67	50.74	0%	47.41	6%	50.24	1%
9	49.57	51.80	4%	48.52	2%	51.39	4%
10	50.84	52.93	4%	49.72	2%	52.65	4%
11	51.79	54.67	6%	51.62	0%	54.22	5%
12	55.03	56.04	2%	52.65	4%	55.52	1%
13	58.40	59.17	1%	55.17	6%	58.47	0%
14	57.19	58.63	3%	54.62	4%	58.23	2%
15	57.47	57.71	0%	53.94	6%	57.34	0%
16	59.99	58.66	2%	55.19	8%	58.40	3%
17	64.51	60.92	6%	57.50	11%	60.44	6%
18	66.21	61.98	6%	58.56	12%	61.65	7%
19	63.99	59.84	6%	56.29	12%	58.75	8%
20	66.08	62.90	5%	59.36	10%	61.60	7%
21	77.43	68.90	11%	67.29	13%	68.59	11%
22	64.16	59.72	7%	58.05	10%	59.52	7%
23	58.99	52.47	11%	50.62	14%	52.57	11%
24	44.92	44.31	1%	42.49	5%	44.33	1%

Table 7. 20 Hungary: Daily errors for the summer week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
19/8/2019	50.32	11%	10%	21%
20/8/2019	53.14	19%	20%	19%
21/8/2019	56.89	15%	13%	12%
22/8/2019	53.48	9%	8%	9%
23/8/2019	55.19	17%	21%	12%
24/8/2019	51.97	18%	19%	13%
25/8/2019	43.50	14%	14%	15%

Table 7. 21 Hungary: Daily errors for the summer week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
52.07	15%	15%	14%

8.4.4 Fall

The final dynamic regression model used for the fall week in Hungary (18-24 November 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_{24}B_{24} + u_{25}B_{25} + +u_{72}B_{72} + u_{73}B_{73} + u_{120}B_{120} + u_{121}B_{121} + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169} + u_{192}B_{192} + u_{193}B_{193}) * \log(p_{h)} + (v_0B_0 + v_1B_1 + v_2B_2 + v_3B_3 + v_{168}B_{168} + v_{169}B_{169} + v_{192}B_{192} + v_{193}B_{193}) * \log(d_h) \quad (18)$$

Table 7. 22 Hungary: Average price forecasting results for the fall week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	31.91	29.86	6%	29.50	8%	31.65	1%
2	30.38	28.03	8%	27.37	10%	29.39	3%
3	29.34	27.31	7%	26.35	10%	28.67	2%
4	28.95	26.74	8%	25.52	12%	28.27	2%
5	30.19	28.36	6%	26.90	11%	29.86	1%
6	33.78	32.51	4%	30.77	9%	33.74	0%
7	39.92	40.34	1%	38.27	4%	40.45	1%
8	49.37	48.85	1%	46.35	6%	49.29	0%
9	52.01	51.42	1%	48.72	6%	51.59	1%
10	51.20	51.94	1%	49.39	4%	51.44	0%
11	49.94	51.64	3%	49.34	1%	50.64	1%
12	49.78	51.77	4%	49.73	0%	50.50	1%
13	49.02	51.21	4%	49.40	1%	49.86	2%
14	49.15	50.15	2%	48.53	1%	49.06	0%
15	49.63	49.59	0%	48.10	3%	48.67	2%
16	51.25	50.71	1%	49.27	4%	49.78	3%
17	57.58	55.47	4%	53.96	6%	54.28	6%
18	62.52	58.91	6%	57.20	9%	58.84	6%
19	57.78	55.69	4%	53.98	7%	55.73	4%
20	54.09	52.53	3%	51.00	6%	51.96	4%
21	47.92	48.08	0%	46.68	3%	47.67	1%
22	42.33	42.21	0%	40.97	3%	41.84	1%
23	39.52	38.40	3%	37.25	6%	38.35	3%
24	35.35	34.15	3%	33.04	7%	34.22	3%

Table 7. 23 Hungary: Daily errors for the fall week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
18/11/2019	48.79	8%	12%	12%
19/11/2019	47.54	9%	8%	9%
20/11/2019	56.10	13%	12%	16%
21/11/2019	49.61	6%	6%	6%
22/11/2019	43.59	11%	10%	18%
23/11/2019	32.35	14%	8%	17%
24/11/2019	34.97	9%	17%	9%

Table 7. 24 Hungary: Daily errors for the fall week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
44.71	10%	10%	12%

8.5 Greece

8.5.1 Winter

The final dynamic regression model used for the winter week in Greece (18-24 February 2019) is:

$$\log(p_h) = c + (u_1 B_1 + u_2 B_2 + u_{24} B_{24} + u_{48} B_{48} + +u_{49} B_{49} + u_{121} B_{121} + u_{144} B_{144} + u_{145} B_{145} + u_{168} B_{168}) * \log\,(p_{h)} + (v_0 B_0 + v_1 B_1 + v_2 B_2) * \log\,(d_h) \quad (19)$$

Table 7. 25 Greece: Average price forecasting results for the winter week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	68.08	64.92	5%	65.53	4%	64.01	6%
2	67.41	64.72	4%	65.65	3%	64.23	5%
3	66.94	59.50	11%	60.56	10%	59.28	11%
4	65.44	58.18	11%	59.25	9%	58.64	10%
5	65.85	62.43	5%	63.03	4%	64.44	2%
6	67.64	70.61	4%	70.64	4%	74.11	10%
7	69.87	72.19	3%	72.29	3%	74.82	7%
8	70.58	71.83	2%	72.12	2%	73.82	5%
9	70.49	71.87	2%	72.15	2%	73.29	4%
10	69.76	71.58	3%	71.70	3%	72.57	4%
11	69.22	70.76	2%	70.81	2%	71.26	3%
12	68.73	70.40	2%	70.44	2%	70.92	3%
13	68.78	70.40	2%	70.42	2%	70.67	3%
14	68.52	69.60	2%	69.59	2%	70.01	2%
15	70.94	71.56	1%	71.66	1%	71.64	1%
16	72.58	73.06	1%	73.12	1%	73.43	1%
17	73.90	75.24	2%	75.29	2%	75.10	2%
18	78.13	81.83	5%	81.88	5%	81.43	4%
19	78.27	82.26	5%	82.28	5%	81.92	5%
20	78.56	81.87	4%	81.96	4%	81.20	3%
21	78.84	80.71	2%	80.79	2%	79.85	1%
22	77.43	76.98	1%	77.14	0%	75.93	2%
23	75.88	74.96	1%	75.24	1%	74.08	2%
24	72.64	71.41	2%	71.67	1%	70.72	3%

Table 7. 26 Greece: Daily errors for the winter week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
20/5/2019	73.54	8%	8%	8%
21/5/2019	75.30	7%	6%	6%
22/5/2019	73.30	5%	5%	7%
23/5/2019	75.88	8%	7%	8%
24/5/2019	72.16	4%	3%	5%
25/5/2019	68.21	11%	11%	10%
26/5/2019	61.67	13%	13%	13%

Table 7. 27 Greece: Daily errors for the winter week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
71.44	8%	8%	8%

8.5.2 Spring

The final dynamic regression model used for the spring week in Greece (20-26 May 2019) is:

$$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_3B_3 + u_{24}B_{24} + +u_{72}B_{72} + u_{120}B_{120} + u_{121}B_{121} + u_{144}B_{144} + u_{145}B_{145} + u_{168}B_{168} + u_{169}B_{169}) * \log\,(p_{h)} + (v_0B_0 + v_1B_1 + v_2B_2 + v_3B_3 + v_{24}B_{24} + v_{192}B_{192} + v_{193}B_{193}) * \log\,(d_h) \quad (20)$$

Table 7. 28 Greece: Average price forecasting results for the spring week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	63.04	63.90	1%	64.25	2%	62.73	0%
2	60.66	61.85	2%	62.61	3%	61.77	2%
3	54.69	59.63	9%	60.85	11%	59.10	8%
4	54.55	59.07	8%	60.60	11%	59.18	8%
5	60.45	61.77	2%	63.58	5%	62.08	3%
6	63.87	65.50	3%	67.35	5%	65.94	3%
7	63.85	67.05	5%	68.91	8%	65.46	3%
8	64.31	69.11	7%	71.05	10%	69.88	9%
9	66.64	67.33	1%	69.06	4%	68.68	3%
10	65.32	65.87	1%	67.13	3%	67.54	3%
11	66.78	65.82	1%	66.74	0%	65.98	1%
12	67.85	66.32	2%	66.90	1%	66.65	2%
13	66.83	64.58	3%	64.85	3%	65.75	2%
14	56.05	56.35	1%	56.51	1%	57.73	3%
15	52.70	50.88	3%	51.14	3%	50.60	4%
16	54.44	53.81	1%	54.37	0%	52.39	4%
17	64.40	61.94	4%	62.49	3%	59.66	7%
18	70.44	70.51	0%	70.77	0%	68.41	3%
19	71.63	76.02	6%	76.29	7%	74.34	4%
20	71.45	75.55	6%	75.93	6%	72.89	2%
21	69.31	74.40	7%	74.96	8%	71.79	4%
22	71.90	70.44	2%	70.67	2%	72.60	1%
23	73.13	67.67	7%	67.26	8%	67.83	7%
24	67.26	65.60	2%	64.52	4%	67.72	1%

Table 7. 29 Greece: Daily errors for the spring week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
20/5/2019	63.50	14%	17%	15%
21/5/2019	57.91	13%	14%	10%
22/5/2019	66.31	8%	8%	8%
23/5/2019	73.00	12%	12%	11%
24/5/2019	68.53	5%	5%	5%
25/5/2019	62.17	11%	11%	11%
26/5/2019	58.20	15%	15%	15%

Table 7. 30 Greece: Daily errors for the spring week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
64.23	11%	12%	11%

8.5.3 Summer

The final dynamic regression model used for the summer week in Greece (19-25 May 2019) is:

$$\log(p_h) = c + (u_1 B_1 + u_2 B_2 + u_3 B_3 + u_{24} B_{24} + +u_{72} B_{72} + u_{120} B_{120} + u_{121} B_{121} + u_{144} B_{144} + u_{145} B_{145} + u_{168} B_{168} + u_{169} B_{169}) * \log(p_{h)} + (v_0 B_0 + v_1 B_1 + v_2 B_2 + v_3 B_3 + v_{24} B_{24} + v_{192} B_{192} + v_{193} B_{193}) * \log(d_h) \quad (21)$$

Table 7. 31 Greece: Average price forecasting results for the summer week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	61.16	58.55	4%	58.42	4%	59.16	3%
2	54.60	57.79	6%	57.63	6%	57.96	6%
3	52.83	56.82	8%	56.61	7%	56.77	7%
4	49.26	55.74	13%	55.66	13%	55.45	13%
5	48.24	55.06	14%	55.03	14%	54.83	14%
6	49.38	55.14	12%	55.12	12%	54.78	11%
7	54.96	55.94	2%	55.72	1%	56.16	2%
8	57.40	57.41	0%	57.01	1%	57.74	1%
9	60.86	58.05	5%	57.51	6%	58.95	3%
10	60.62	58.47	4%	57.79	5%	59.67	2%
11	60.51	58.62	3%	57.86	4%	59.60	1%
12	62.04	59.28	4%	58.45	6%	60.20	3%
13	61.88	59.72	3%	58.90	5%	60.47	2%
14	59.46	58.33	2%	57.81	3%	58.88	1%
15	58.10	57.07	2%	56.85	2%	57.72	1%
16	57.55	57.23	1%	57.10	1%	57.74	0%
17	59.69	59.09	1%	58.83	1%	59.47	0%
18	60.60	60.61	0%	60.25	1%	60.75	0%
19	63.56	62.01	2%	61.58	3%	61.98	2%
20	67.15	63.89	5%	63.35	6%	63.67	5%
21	71.94	64.53	10%	63.81	11%	65.45	9%
22	66.17	63.51	4%	62.90	5%	64.45	3%
23	63.05	62.32	1%	61.76	2%	62.89	0%
24	60.77	60.71	0%	60.34	1%	61.07	1%

Table 7. 32 Greece: Daily errors for the summer week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
19/8/2019	60.22	3%	2%	3%
20/8/2019	57.43	7%	7%	7%
21/8/2019	61.72	18%	18%	16%
22/8/2019	63.38	8%	9%	9%
23/8/2019	56.31	9%	9%	8%
24/8/2019	57.62	4%	5%	4%
25/8/2019	58.03	7%	7%	7%

Table 7. 33 Greece: Daily errors for the summer week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
59.24	8%	8%	8%

8.5.4 Fall

The final dynamic regression model used for the fall week in Greece (18-24 November 2019) is:

$\log(p_h) = c + (u_1B_1 + u_2B_2 + u_{48}B_{48} + u_{49}B_{49}) * \log\,(p_{h)} + (v_0B_0 + v_1B_1 + v_2B_2) * \log(d_h)$ (22)

Table 7. 34 Average price forecasting results for the fall week and hourly errors

Hour	Actual	OLS	Error OLS	Fully-Modified OLS	Error Fully-Modified OLS	OLS standard model	Error OLS standard model
1	45.67	48.86	7%	48.75	7%	47.25	3%
2	40.42	49.12	22%	48.96	21%	45.41	12%
3	36.86	49.17	33%	49.08	33%	43.75	19%
4	36.72	50.37	37%	50.48	37%	43.18	18%
5	41.49	52.55	27%	52.96	28%	46.22	11%
6	45.92	56.73	24%	57.36	25%	50.26	9%
7	54.94	60.64	10%	61.44	12%	56.46	3%
8	59.73	60.56	1%	61.38	3%	60.22	1%
9	59.81	59.51	0%	60.12	1%	61.32	3%
10	59.24	57.78	2%	58.13	2%	61.60	4%
11	57.29	57.06	0%	57.12	0%	61.02	7%
12	56.55	56.99	1%	56.77	0%	61.01	8%
13	56.38	56.84	1%	56.36	0%	61.23	9%
14	54.36	55.98	3%	55.27	2%	60.81	12%
15	57.30	58.18	2%	57.18	0%	61.80	8%
16	59.14	59.95	1%	58.72	1%	64.08	8%
17	62.67	63.44	1%	61.90	1%	66.62	6%
18	64.47	65.20	1%	63.39	2%	69.90	8%
19	63.86	63.31	1%	61.30	4%	70.07	10%
20	62.94	61.65	2%	59.41	6%	68.72	9%
21	58.82	58.42	1%	56.08	5%	66.29	13%
22	55.78	54.26	3%	51.93	7%	62.35	12%
23	52.39	52.11	1%	49.73	5%	58.85	12%
24	44.32	48.73	10%	46.44	5%	55.51	25%

Table 7. 35 Greece: Daily errors for the fall week

Date	Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
18/11/2019	54.28	7%	7%	11%
19/11/2019	56.23	13%	13%	10%
20/11/2019	54.73	11%	14%	6%
21/11/2019	54.73	6%	6%	5%
22/11/2019	52.81	10%	14%	13%
23/11/2019	51.95	14%	16%	21%
24/11/2019	50.68	10%	11%	13%

Table 7. 36 Greece: Daily errors for the fall week

Actual Value	Error OLS	Error Fully-Modified OLS	Error OLS standard model
53.63	10%	12%	11%

9 Conclusions

The main purpose of this thesis is to examine whether a forecasting technique (Dynamic Autoregressive Technique) used in the bibliography is capable to provide adequate results for the four electricity markets presented, having as the main target to implement the same technique, to forecast the wholesale electricity prices in countries with different energy characteristics. The basic limitation of this analysis is that the examined period should not be characterized by extreme volatility since the analysis was also conducted for 2020, but due to Covid-19, which led to a sharp drop in the prices, the final results presented big deviations from the actual prices. Although, the technique followed, constitutes a good forecast approach, taking into consideration that it can be used in different countries. Furthermore, it has to be mentioned that this analysis considers only two variables (price, demand, or residual), therefore, it can be upgraded by adding more variables affecting the final price, such as natural gas and oil price, EUA's price, temperature, demand and res production of neighboring countries, etc., or by providing into the model better-forecasted values of demand or residual. The analysis showed that for the examined periods, the chosen technique can only be used for Italy, Hungary, and Greece, while for Bulgaria the results are not presented since a big deviation between the forecasted and the actual values of price was observed, probably due to the high volatility of the prices the examined periods. Three approaches were used to compare the results and conclude if there is a better technique outperforming the others. The Ordinary Least Squares method was chosen as the first method, while the second was the Fully Modified Ordinary Lease Squares, offered on Eviews statistical package. For every country and every period examined, the optimal lag length is specified by taking into account several criteria, such as the adjusted $R^{2,}$ the standard error, the Akaike Information Criteria (AIC), the p-value of the coefficients, the serial Correlation LM Test, the CUSUM Test. The third approach used, implements the Ordinary Least Squared method by using standard lags as it is used in the bibliography (4). The data are retrieved from ENTSOE's

website and the analysis for every period includes historical data spanning 53 days and the forecast values available on the website. At this point, it has to be mentioned that the more accurate the forecast of the load and wind, the best the results will be from the methods used. To validate the performance of the results there are three error tests used on a daily and weekly level. The conclusions for the day-ahead forecast approach by assessing the results using the average weekly-hourly table show that the average hourly prices of the week result in a small deviation for the four periods examined for the three countries that forecasted values are presented. Although, as it was already mentioned in a previous paragraph this error term is not the best to assess the results, since no absolute values are used. For that reason, it is better to focus on the next two error tests used on a daily and weekly level. The main
For the winter week, the daily error in Italy ranges between 4% and 14%, while the weekly error is 8% both for OLS and Fully-Modified OLS methods. For the spring week, the daily error ranges between 3% and 11%, while the weekly error is 7% for all the three approaches used. For the summer week, the daily error ranges between 4% and 7%, while the weekly error is 5% for OLS and Fully-Modified OLS, while the standard approach used 7%. For the fall week, the daily error ranges between 3% and 11%, while the weekly error is 5% for OLS and Fully-Modified OLS, while the standard approach used 7%. For the winter week, the daily error in Hungary ranges between 7% and 14%, while the weekly error is 10% for OLS and 11% for the Fully-Modified OLS method. For the spring week, the daily error ranges between 9% and 28%, while the weekly error is 13% using both OLS and Fully-Modified OLS methods. For the summer week, the daily error ranges between 9% and 19%, while the weekly error is 15% for the OLS and Fully-Modified OLS methods. For the fall week, the daily error ranges between 8% and 14%, while the weekly error is 10% for OLS, 12% for Fully-Modified OLS, and 11% for the standard approach used. For the winter week, the daily error in Greece ranges between 7% and 13%, while the weekly error is 8% both for OLS and Fully-Modified OLS methods. For the spring week, the daily error ranges between 5% and 15%, while the weekly error is 11% using the OLS method and 12% the Fully-Modified OLS method. For the summer week, the daily error ranges between 2% and 18%, while the weekly error is 8% for both OLS and Fully-Modified OLS methods. For the fall week, the daily error ranges between 6% and 14%, while the weekly error is 10% for OLS, 12% for Fully-Modified OLS and 11% for the standard approach used. The market coupling has urged the price forecasting to a very challenging task, since the price solution for each country is highly driven from the interconnected markets, as well as the market conditions of each country, such as wind, temperature, demand, renewable energy production etc. The market algorithm ''Euphemia'' used for the estimation of the market coupling price for each region, is characterised as very complex and the majority of the energy market participants cannot approach this technique. Based on the final results of the methodology used in this thesis, it is proposed that the latest can be used and also be upgraded at a further extent, from the side of energy market participants, such as power traders, aggregators, producers, to estimate the day-ahead prices. For power traders, this methodology can be very useful since they can speculate on financial contracts being available on energy exchanges, or to gain profit from physical delivery products. The aggregators are responsible for renewable energy portfolios, since they represent their day-ahead production on the energy exchanges and can benefit from the price spikes based on their forecast. Furthermore, for power producers a good forecast technique is the basic key towards the maximization of their profit, since their production schedule is based on their price forecast. Last but not least, battery producers can use this methodology, since the price forecasting consists the basic pillar of their operation. The forecast of price spikes, for battery discharge (sale), and price drops, for battery charge (buy), can optimize the business operation of battery producers.

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APPENDIX:

Italy Winter Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 18:47
Sample (adjusted): 121 1272
Included observations: 1152 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.437236	0.083303	-5.248713	0.0000
LOGP(-1)	1.098864	0.027146	40.48034	0.0000
LOGP(-2)	-0.154841	0.041390	-3.741018	0.0002
LOGP(-3)	-0.044270	0.041280	-1.072425	0.2838
LOGP(-4)	-0.073934	0.040000	-1.848330	0.0648
LOGP(-5)	0.072057	0.024283	2.967422	0.0031
LOGP(-24)	0.229467	0.025714	8.923883	0.0000
LOGP(-25)	-0.213807	0.025889	-8.258459	0.0000
LOGP(-72)	0.132596	0.024962	5.311973	0.0000
LOGP(-73)	-0.111701	0.025154	-4.440606	0.0000
LOGP(-120)	0.028858	0.009386	3.074691	0.0022
LOGL	0.585635	0.048359	12.11019	0.0000
LOGL(-1)	-0.689564	0.066544	-10.36258	0.0000
LOGL(-3)	0.160274	0.026875	5.963597	0.0000

R-squared	0.947405	Mean dependent var	4.140821
Adjusted R-squared	0.946804	S.D. dependent var	0.218472
S.E. of regression	0.050389	Akaike info criterion	-3.126017
Sum squared resid	2.889417	Schwarz criterion	-3.064655
Log likelihood	1814.586	Hannan-Quinn criter.	-3.102856
F-statistic	1576.848	Durbin-Watson stat	1.962051
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:07
Sample (adjusted): 122 1272
Included observations: 1151 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	1.143989	0.018784	60.90233	0.0000
LOGP(-2)	-0.158401	0.028640	-5.530678	0.0000
LOGP(-3)	-0.029857	0.028589	-1.044328	0.2966
LOGP(-4)	-0.077200	0.027712	-2.785804	0.0054
LOGP(-5)	0.076690	0.016801	4.564573	0.0000

LOGP(-24)	0.234612	0.017788	13.18915	0.0000
LOGP(-25)	-0.222948	0.017910	-12.44836	0.0000
LOGP(-72)	0.138100	0.017268	7.997297	0.0000
LOGP(-73)	-0.125241	0.017402	-7.196788	0.0000
LOGP(-120)	0.014162	0.006493	2.180976	0.0294
LOGL	0.592937	0.033454	17.72392	0.0000
LOGL(-1)	-0.712346	0.046035	-15.47394	0.0000
LOGL(-3)	0.151502	0.018597	8.146530	0.0000
C	-0.310478	0.057654	-5.385237	0.0000

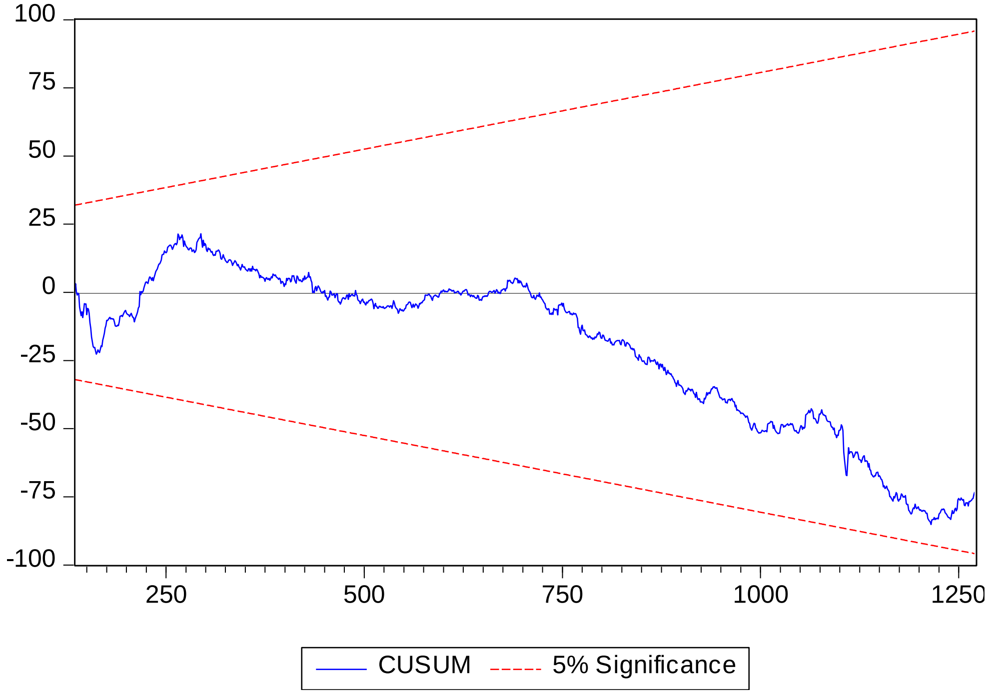
R-squared	0.946323	Mean dependent var	4.141003
Adjusted R-squared	0.945709	S.D. dependent var	0.218480
S.E. of regression	0.050906	Sum squared resid	2.946500
Long-run variance	0.001215		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.177170	Prob. F(120,1018)	0.1046
Obs*R-squared	140.3757	Prob. Chi-Square(120)	0.0985

4. CUSUM test



Italy Spring Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:12
Sample (adjusted): 194 1272
Included observations: 1079 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.117582	0.164803	-0.713472	0.4757
LOGP(-1)	0.968543	0.030726	31.52160	0.0000
LOGP(-2)	-0.092372	0.042769	-2.159816	0.0310
LOGP(-3)	-0.072468	0.027890	-2.598352	0.0095
LOGP(-24)	0.385776	0.030275	12.74234	0.0000
LOGP(-25)	-0.336867	0.031264	-10.77489	0.0000
LOGP(-48)	-0.092824	0.031155	-2.979446	0.0030
LOGP(-49)	0.095084	0.031097	3.057633	0.0023
LOGP(-72)	0.129367	0.027962	4.626534	0.0000
LOGP(-73)	-0.130580	0.027907	-4.679105	0.0000
LOGP(-144)	0.138589	0.027470	5.045168	0.0000
LOGP(-145)	-0.091499	0.028478	-3.212998	0.0014
LOGP(-168)	0.132248	0.030601	4.321650	0.0000
LOGP(-169)	-0.121736	0.030715	-3.963441	0.0001
LOGP(-192)	-0.035929	0.028249	-1.271893	0.2037
LOGP(-193)	0.036520	0.028236	1.293398	0.1962
LOGL	0.628052	0.104931	5.985385	0.0000
LOGL(-1)	-0.804288	0.161819	-4.970288	0.0000
LOGL(-2)	0.322962	0.080382	4.017825	0.0001
LOGL(-24)	-0.269576	0.079075	-3.409131	0.0007
LOGL(-25)	0.222240	0.075179	2.956135	0.0032
LOGL(-120)	0.010314	0.016247	0.634814	0.5257
LOGL(-144)	-0.064514	0.022018	-2.930101	0.0035

R-squared	0.899427	Mean dependent var	3.943797
Adjusted R-squared	0.897332	S.D. dependent var	0.244129
S.E. of regression	0.078223	Akaike info criterion	-2.237410
Sum squared resid	6.461563	Schwarz criterion	-2.131175
Log likelihood	1230.083	Hannan-Quinn criter.	-2.197182
F-statistic	429.2649	Durbin-Watson stat	1.937746
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:07
Sample (adjusted): 122 1272
Included observations: 1151 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	1.143989	0.018784	60.90233	0.0000
LOGP(-2)	-0.158401	0.028640	-5.530678	0.0000
LOGP(-3)	-0.029857	0.028589	-1.044328	0.2966
LOGP(-4)	-0.077200	0.027712	-2.785804	0.0054
LOGP(-5)	0.076690	0.016801	4.564573	0.0000
LOGP(-24)	0.234612	0.017788	13.18915	0.0000
LOGP(-25)	-0.222948	0.017910	-12.44836	0.0000
LOGP(-72)	0.138100	0.017268	7.997297	0.0000
LOGP(-73)	-0.125241	0.017402	-7.196788	0.0000
LOGP(-120)	0.014162	0.006493	2.180976	0.0294
LOGL	0.592937	0.033454	17.72392	0.0000
LOGL(-1)	-0.712346	0.046035	-15.47394	0.0000
LOGL(-3)	0.151502	0.018597	8.146530	0.0000
C	-0.310478	0.057654	-5.385237	0.0000

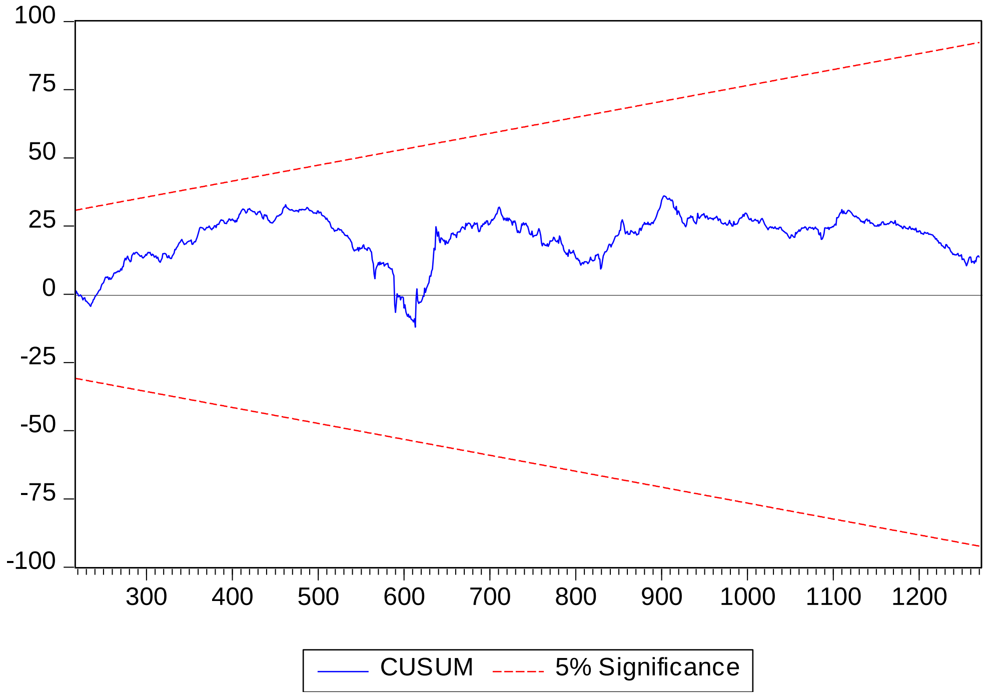
R-squared	0.946323	Mean dependent var	4.141003
Adjusted R-squared	0.945709	S.D. dependent var	0.218480
S.E. of regression	0.050906	Sum squared resid	2.946500
Long-run variance	0.001215		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.988275	Prob. F(144,912)	0.5247
Obs*R-squared	145.6441	Prob. Chi-Square(144)	0.4460

4. CUSUM test



Italy Summer Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:18
Sample (adjusted): 194 1272
Included observations: 1079 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.091189	0.091469	-0.996943	0.3190
LOGP(-1)	0.868661	0.015519	55.97342	0.0000
LOGP(-24)	0.239549	0.028890	8.291681	0.0000
LOGP(-25)	-0.194546	0.028948	-6.720594	0.0000
LOGP(-48)	0.121492	0.028809	4.217093	0.0000
LOGP(-49)	-0.113190	0.028768	-3.934640	0.0001
LOGP(-72)	0.159213	0.029858	5.332302	0.0000
LOGP(-73)	-0.136024	0.029928	-4.545071	0.0000
LOGP(-144)	0.101070	0.028333	3.567244	0.0004
LOGP(-145)	-0.101145	0.028432	-3.557417	0.0004
LOGP(-168)	0.259255	0.029634	8.748548	0.0000
LOGP(-169)	-0.232269	0.029916	-7.764121	0.0000
LOGL	0.703735	0.075615	9.306800	0.0000
LOGL(-1)	-0.631101	0.074042	-8.523591	0.0000
LOGL(-72)	-0.308295	0.066824	-4.613565	0.0000
LOGL(-73)	0.287156	0.065176	4.405832	0.0000
LOGL(-192)	-0.339363	0.070291	-4.828000	0.0000
LOGL(-193)	0.307005	0.069102	4.442753	0.0000

R-squared	0.936454	Mean dependent var	3.884878
Adjusted R-squared	0.935435	S.D. dependent var	0.190354
S.E. of regression	0.048368	Akaike info criterion	-3.203410
Sum squared resid	2.482183	Schwarz criterion	-3.120270
Log likelihood	1746.240	Hannan-Quinn criter.	-3.171928
F-statistic	919.7335	Durbin-Watson stat	2.063984
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:22
Sample (adjusted): 195 1272
Included observations: 1078 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	0.945561	0.010761	87.87093	0.0000
LOGP(-24)	0.232331	0.020043	11.59174	0.0000
LOGP(-25)	-0.217987	0.020081	-10.85524	0.0000
LOGP(-48)	0.122240	0.019993	6.114139	0.0000

LOGP(-49)	-0.121793	0.019966	-6.100029	0.0000
LOGP(-72)	0.156794	0.020703	7.573465	0.0000
LOGP(-73)	-0.151069	0.020747	-7.281549	0.0000
LOGP(-144)	0.104216	0.019670	5.298140	0.0000
LOGP(-145)	-0.108130	0.019734	-5.479428	0.0000
LOGP(-168)	0.257127	0.020543	12.51626	0.0000
LOGP(-169)	-0.249595	0.020739	-12.03505	0.0000
LOGL	0.686814	0.052428	13.10025	0.0000
LOGL(-1)	-0.655933	0.051332	-12.77836	0.0000
LOGL(-72)	-0.297104	0.046327	-6.413240	0.0000
LOGL(-73)	0.292563	0.045182	6.475194	0.0000
LOGL(-192)	-0.327529	0.048737	-6.720314	0.0000
LOGL(-193)	0.320743	0.047913	6.694331	0.0000
C	-0.086587	0.063417	-1.365345	0.1724

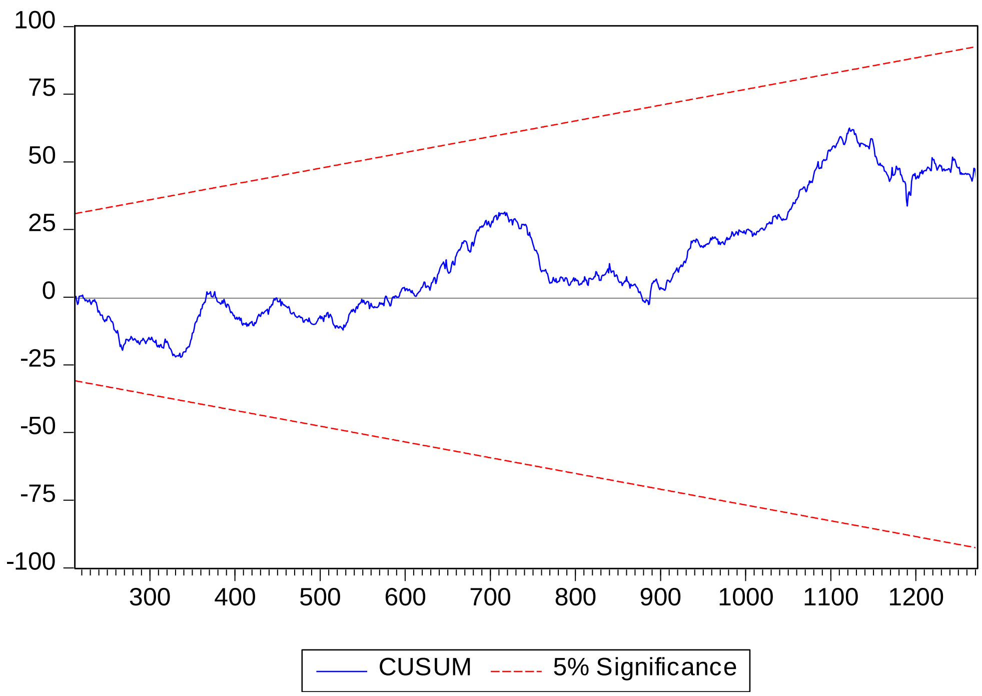
R-squared	0.934838	Mean dependent var	3.884870
Adjusted R-squared	0.933793	S.D. dependent var	0.190442
S.E. of regression	0.049002	Sum squared resid	2.545278
Long-run variance	0.001124		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.051128	Prob. F(193,868)	0.3195
Obs*R-squared	204.4083	Prob. Chi-Square(193)	0.2731

4. CUSUM test



Italy Fall Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:26
Sample (adjusted): 170 1272
Included observations: 1103 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.308450	0.144753	-2.130863	0.0333
LOGP(-1)	1.000639	0.027531	36.34565	0.0000
LOGP(-2)	-0.158373	0.026114	-6.064718	0.0000
LOGP(-24)	0.344233	0.027239	12.63771	0.0000
LOGP(-25)	-0.250039	0.029109	-8.589650	0.0000
LOGP(-49)	-0.026247	0.016821	-1.560429	0.1190
LOGP(-72)	0.118892	0.027707	4.291038	0.0000
LOGP(-73)	-0.106296	0.028098	-3.783036	0.0002
LOGP(-96)	0.033186	0.013133	2.526861	0.0117
LOGP(-120)	0.070860	0.025843	2.741928	0.0062
LOGP(-121)	-0.093975	0.024938	-3.768400	0.0002
LOGP(-168)	0.150365	0.025654	5.861214	0.0000
LOGP(-169)	-0.134833	0.025761	-5.234028	0.0000
LOGL	0.885490	0.096257	9.199181	0.0000
LOGL(-1)	-0.973491	0.134657	-7.229390	0.0000
LOGL(-2)	0.199709	0.061800	3.231535	0.0013
LOGL(-24)	-0.441639	0.084773	-5.209677	0.0000
LOGL(-25)	0.364982	0.081732	4.465599	0.0000
LOGL(-48)	0.051878	0.025448	2.038573	0.0417
LOGL(-72)	-0.216874	0.070907	-3.058579	0.0023
LOGL(-73)	0.179044	0.067045	2.670507	0.0077

R-squared	0.945503	Mean dependent var	3.873005
Adjusted R-squared	0.944495	S.D. dependent var	0.271605
S.E. of regression	0.063989	Akaike info criterion	-2.641364
Sum squared resid	4.430310	Schwarz criterion	-2.546059
Log likelihood	1477.713	Hannan-Quinn criter.	-2.605315
F-statistic	938.6080	Durbin-Watson stat	1.988699
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:27
Sample (adjusted): 171 1272
Included observations: 1102 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	1.051660	0.020745	50.69545	0.0000
LOGP(-2)	-0.126863	0.019679	-6.446559	0.0000
LOGP(-24)	0.348060	0.020528	16.95550	0.0000
LOGP(-25)	-0.290547	0.021938	-13.24396	0.0000
LOGP(-49)	-0.020204	0.012677	-1.593717	0.1113
LOGP(-72)	0.125370	0.020890	6.001538	0.0000
LOGP(-73)	-0.117704	0.021174	-5.558992	0.0000
LOGP(-96)	0.020397	0.009894	2.061410	0.0395
LOGP(-120)	0.080030	0.019476	4.109179	0.0000
LOGP(-121)	-0.097673	0.018806	-5.193700	0.0000
LOGP(-168)	0.155108	0.019329	8.024761	0.0000
LOGP(-169)	-0.149825	0.019411	-7.718596	0.0000
LOGL	0.893613	0.072520	12.32225	0.0000
LOGL(-1)	-1.047620	0.101462	-10.32529	0.0000
LOGL(-2)	0.215118	0.046581	4.618119	0.0000
LOGL(-24)	-0.427076	0.063867	-6.686916	0.0000
LOGL(-25)	0.380501	0.061576	6.179322	0.0000
LOGL(-48)	0.033954	0.019172	1.770995	0.0768
LOGL(-72)	-0.199863	0.053422	-3.741241	0.0002
LOGL(-73)	0.178708	0.050514	3.537826	0.0004
C	-0.197003	0.109061	-1.806367	0.0711

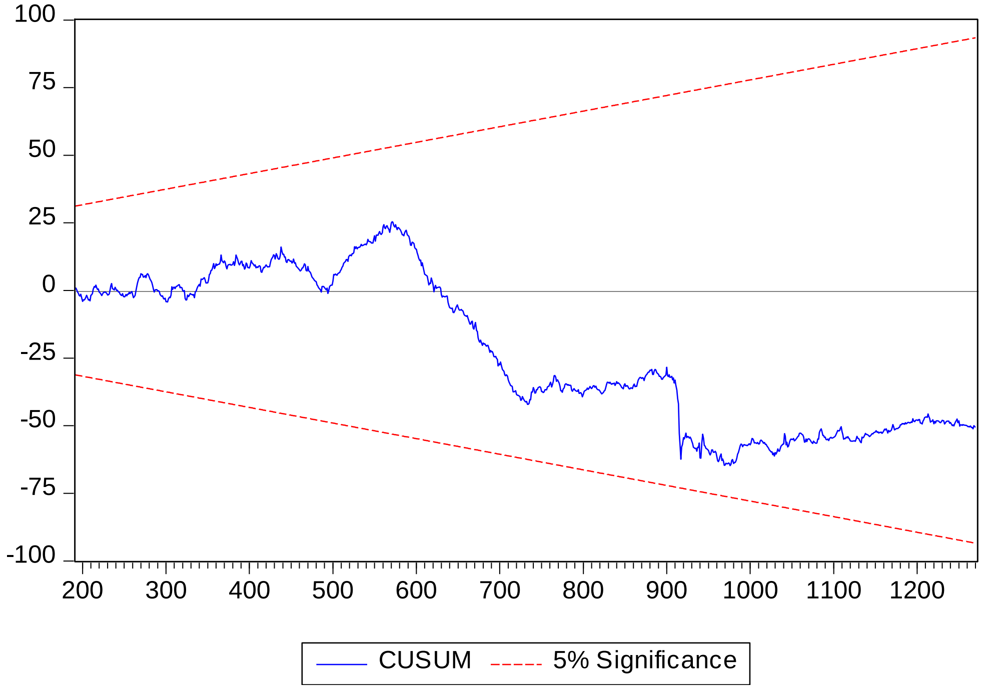
R-squared	0.943902	Mean dependent var	3.873172
Adjusted R-squared	0.942864	S.D. dependent var	0.271672
S.E. of regression	0.064938	Sum squared resid	4.558493
Long-run variance	0.002324		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.981056	Prob. F(169,913)	0.5533
Obs*R-squared	169.5180	Prob. Chi-Square(169)	0.4743

4. CUSUM test



Hungary Winter Week

1. Results of the OLS

C	-0.360850	0.281164	-1.283414	0.1996
LOGP(-1)	0.976518	0.029666	32.91656	0.0000
LOGP(-2)	-0.102197	0.028929	-3.532623	0.0004
LOGP(-24)	0.175916	0.028320	6.211769	0.0000
LOGP(-25)	-0.108352	0.028925	-3.745978	0.0002
LOGP(-72)	0.089348	0.024218	3.689336	0.0002
LOGP(-73)	-0.076533	0.024173	-3.166029	0.0016
LOGP(-120)	0.071437	0.023626	3.023685	0.0026
LOGP(-121)	-0.060701	0.023794	-2.551059	0.0109
LOGP(-144)	0.052423	0.024123	2.173181	0.0300
LOGP(-145)	-0.059291	0.024141	-2.456062	0.0142
LOGP(-168)	0.055171	0.025867	2.132876	0.0332
LOGP(-169)	-0.047944	0.025965	-1.846476	0.0651
LOGP(-192)	0.061345	0.026381	2.325391	0.0202
LOGP(-193)	-0.055778	0.026551	-2.100754	0.0359
LOGL	0.933382	0.229262	4.071246	0.0001
LOGL(-1)	-0.481027	0.292799	-1.642855	0.1007
LOGL(-2)	-0.644305	0.206966	-3.113098	0.0019
LOGL(-3)	0.289428	0.099639	2.904763	0.0038
LOGL(-168)	0.536881	0.231523	2.318908	0.0206
LOGL(-169)	-0.412126	0.231731	-1.778466	0.0756
LOGL(-192)	-0.803220	0.150866	-5.324074	0.0000
LOGL(-193)	0.636379	0.152572	4.171008	0.0000

R-squared	0.956836	Mean dependent var	4.123035
Adjusted R-squared	0.955937	S.D. dependent var	0.354084

S.E. of regression	0.074326	Akaike info criterion	-2.339621
Sum squared resid	5.833749	Schwarz criterion	-2.233386
Log likelihood	1285.226	Hannan-Quinn criter.	-2.299394
F-statistic	1064.048	Durbin-Watson stat	2.002772
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:45
Sample (adjusted): 195 1272
Included observations: 1078 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	1.022365	0.019771	51.71107	0.0000
LOGP(-2)	-0.084499	0.019294	-4.379625	0.0000
LOGP(-24)	0.170843	0.018873	9.052337	0.0000
LOGP(-25)	-0.126096	0.019278	-6.540940	0.0000
LOGP(-72)	0.089225	0.016133	5.530526	0.0000
LOGP(-73)	-0.085723	0.016105	-5.322741	0.0000
LOGP(-120)	0.075598	0.015770	4.793765	0.0000
LOGP(-121)	-0.064938	0.015864	-4.093485	0.0000
LOGP(-144)	0.051725	0.016076	3.217591	0.0013
LOGP(-145)	-0.060362	0.016084	-3.752901	0.0002
LOGP(-168)	0.054247	0.017240	3.146596	0.0017
LOGP(-169)	-0.048455	0.017298	-2.801134	0.0052
LOGP(-192)	0.059222	0.017574	3.369870	0.0008
LOGP(-193)	-0.061281	0.017688	-3.464539	0.0006
LOGL	0.957846	0.152821	6.267771	0.0000
LOGL(-1)	-0.535973	0.195204	-2.745711	0.0061
LOGL(-2)	-0.685994	0.137919	-4.973878	0.0000
LOGL(-3)	0.294614	0.066379	4.438397	0.0000
LOGL(-168)	0.563081	0.154492	3.644717	0.0003
LOGL(-169)	-0.492448	0.154594	-3.185428	0.0015
LOGL(-192)	-0.828707	0.100569	-8.240227	0.0000
LOGL(-193)	0.748629	0.101753	7.357341	0.0000
C	-0.148518	0.187500	-0.792101	0.4285

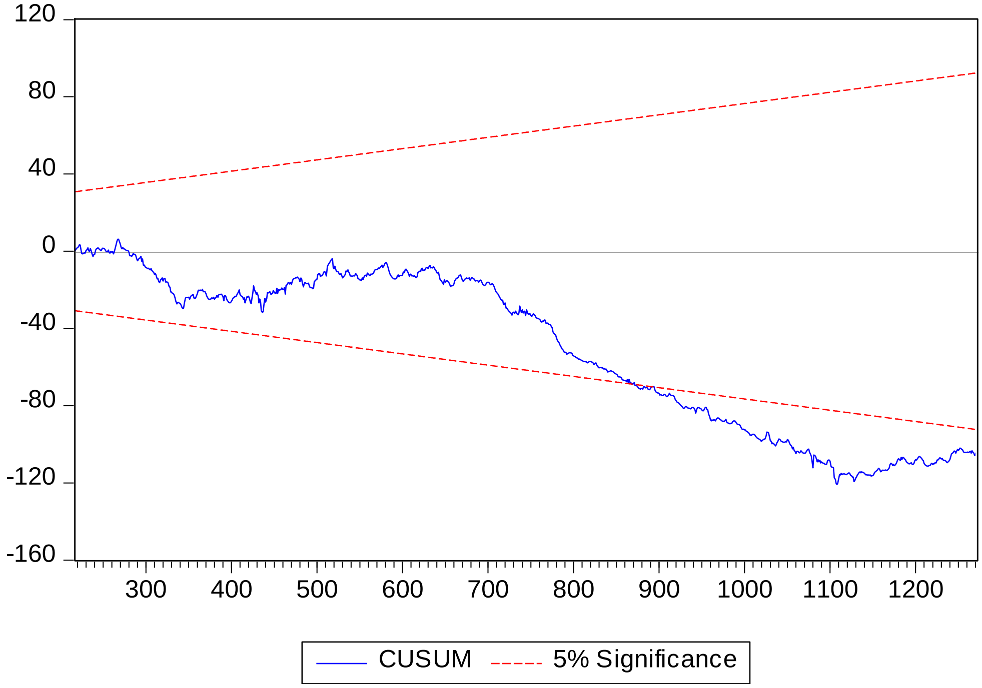
R-squared	0.956026	Mean dependent var	4.123241
Adjusted R-squared	0.955110	S.D. dependent var	0.354183
S.E. of regression	0.075042	Sum squared resid	5.941035
Long-run variance	0.002452		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.054343	Prob. F(193,863)	0.3099
Obs*R-squared	205.8755	Prob. Chi-Square(193)	0.2498

4. CUSUM test



Hungary Spring Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:38
Sample (adjusted): 194 1272
Included observations: 1079 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-3.221977	0.869319	-3.706322	0.0002
LOGP(-1)	0.967581	0.030256	31.97956	0.0000
LOGP(-2)	-0.182099	0.030302	-6.009519	0.0000
LOGP(-24)	0.106671	0.029711	3.590224	0.0003
LOGP(-25)	-0.087077	0.029710	-2.930874	0.0035
LOGP(-72)	0.018923	0.028999	0.652553	0.5142
LOGP(-73)	-0.018529	0.028960	-0.639809	0.5224
LOGP(-120)	0.007120	0.029087	0.244796	0.8067
LOGP(-121)	-0.008804	0.029089	-0.302668	0.7622
LOGP(-144)	0.004870	0.029743	0.163731	0.8700
LOGP(-145)	-0.018098	0.029843	-0.606431	0.5444
LOGP(-168)	-0.003198	0.030408	-0.105187	0.9162
LOGP(-169)	0.016933	0.030514	0.554923	0.5791
LOGP(-192)	0.003438	0.031043	0.110752	0.9118
LOGP(-193)	-0.006956	0.031524	-0.220664	0.8254
LOGL	1.093253	0.586403	1.864337	0.0626
LOGL(-1)	-0.240237	0.832189	-0.288681	0.7729
LOGL(-2)	-0.697598	0.647514	-1.077348	0.2816
LOGL(-3)	0.361887	0.315959	1.145362	0.2523

LOGL(-168)	0.768806	0.528427	1.454896	0.1460
LOGL(-169)	-0.878028	0.528728	-1.660643	0.0971
LOGL(-192)	0.024923	0.435618	0.057214	0.9544
LOGL(-193)	0.035844	0.438445	0.081752	0.9349

R-squared	0.790367	Mean dependent var	3.722680
Adjusted R-squared	0.785999	S.D. dependent var	0.580817
S.E. of regression	0.268687	Akaike info criterion	0.230548
Sum squared resid	76.23560	Schwarz criterion	0.336782
Log likelihood	-101.3805	Hannan-Quinn criter.	0.270775
F-statistic	180.9712	Durbin-Watson stat	2.067452
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:40
Sample (adjusted): 195 1272
Included observations: 1078 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	1.010075	0.020344	49.64943	0.0000
LOGP(-2)	-0.145977	0.020376	-7.164136	0.0000
LOGP(-24)	0.110204	0.019977	5.516540	0.0000
LOGP(-25)	-0.099558	0.019976	-4.983884	0.0000
LOGP(-72)	0.020361	0.019498	1.044274	0.2966
LOGP(-73)	-0.018984	0.019473	-0.974933	0.3298
LOGP(-120)	0.009934	0.019557	0.507969	0.6116
LOGP(-121)	-0.011068	0.019559	-0.565874	0.5716
LOGP(-144)	0.006791	0.019999	0.339548	0.7343
LOGP(-145)	-0.022936	0.020068	-1.142922	0.2533
LOGP(-168)	-0.004751	0.020445	-0.232382	0.8163
LOGP(-169)	0.015597	0.020516	0.760230	0.4473
LOGP(-192)	0.003446	0.020873	0.165089	0.8689
LOGP(-193)	-0.002567	0.021197	-0.121104	0.9036
LOGL	1.087904	0.394277	2.759240	0.0059
LOGL(-1)	-0.388494	0.559629	-0.694200	0.4877
LOGL(-2)	-0.799105	0.435535	-1.834768	0.0668
LOGL(-3)	0.418588	0.212466	1.970142	0.0491
LOGL(-168)	0.852427	0.355300	2.399172	0.0166
LOGL(-169)	-0.888828	0.355500	-2.500221	0.0126
LOGL(-192)	0.018555	0.292914	0.063348	0.9495
LOGL(-193)	0.033355	0.294815	0.113140	0.9099
C	-2.345447	0.584497	-4.012763	0.0001

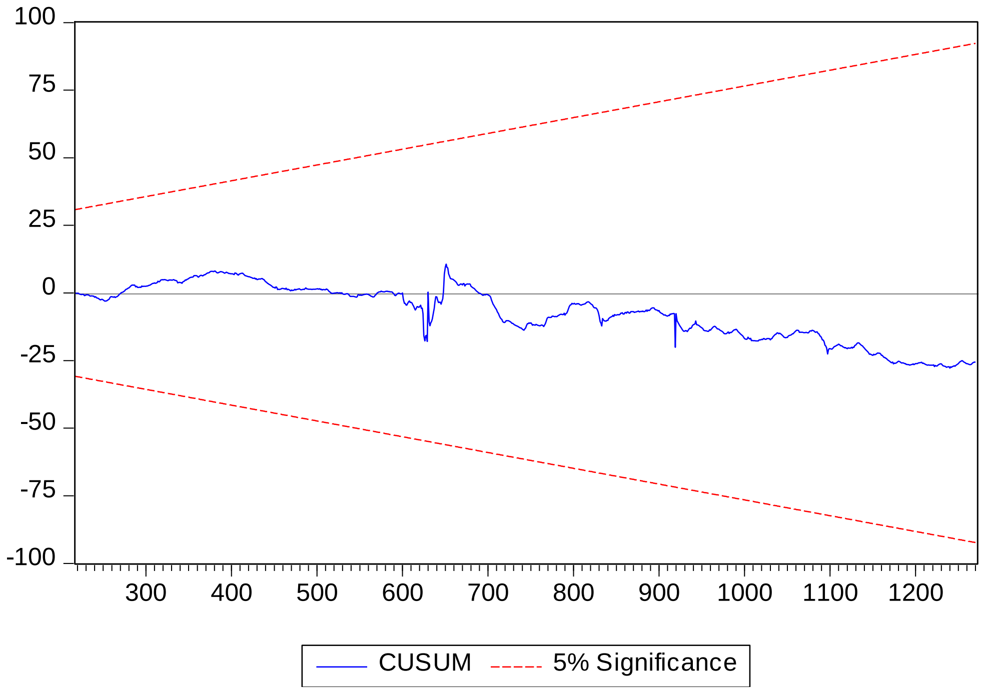
R-squared	0.786525	Mean dependent var	3.722828
Adjusted R-squared	0.782074	S.D. dependent var	0.581066
S.E. of regression	0.271257	Sum squared resid	77.62711
Long-run variance	0.032636		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.526980	Prob. F(193,863)	1.0000
Obs*R-squared	113.7568	Prob. Chi-Square(193)	1.0000

4. CUSUM test



Hungary Summer Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:48
Sample (adjusted): 194 1272
Included observations: 1079 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.007535	0.321663	-3.132267	0.0018
LOGP(-1)	0.777845	0.022849	34.04297	0.0000
LOGP(-3)	0.072688	0.021929	3.314756	0.0009
LOGP(-24)	0.248327	0.030098	8.250580	0.0000
LOGP(-25)	-0.190401	0.030543	-6.233939	0.0000
LOGP(-48)	0.117452	0.028725	4.088871	0.0000
LOGP(-49)	-0.116717	0.028790	-4.054089	0.0001
LOGP(-144)	0.065011	0.026905	2.416288	0.0158
LOGP(-145)	-0.078987	0.027183	-2.905740	0.0037
LOGP(-168)	0.193506	0.029355	6.591932	0.0000
LOGP(-169)	-0.147089	0.029596	-4.969950	0.0000

LOGL	1.292439	0.191091	6.763488	0.0000
LOGL(-1)	-0.486869	0.269297	-1.807925	0.0709
LOGL(-2)	-0.801970	0.220167	-3.642543	0.0003
LOGL(-3)	0.217067	0.119203	1.820981	0.0689
LOGL(-24)	0.510207	0.282485	1.806137	0.0712
LOGL(-25)	-0.583168	0.281258	-2.073430	0.0384
LOGL(-72)	-0.320217	0.149160	-2.146803	0.0320
LOGL(-73)	0.363582	0.146779	2.477077	0.0134
LOGL(-192)	-0.856591	0.267883	-3.197636	0.0014
LOGL(-193)	0.812118	0.266922	3.042528	0.0024

R-squared	0.927529	Mean dependent var	3.953003
Adjusted R-squared	0.926159	S.D. dependent var	0.279473
S.E. of regression	0.075943	Akaike info criterion	-2.298391
Sum squared resid	6.101880	Schwarz criterion	-2.201394
Log likelihood	1260.982	Hannan-Quinn criter.	-2.261662
F-statistic	677.0464	Durbin-Watson stat	1.999095
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:49
Sample (adjusted): 195 1272
Included observations: 1078 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	0.830719	0.015330	54.18948	0.0000
LOGP(-3)	0.102705	0.014713	6.980448	0.0000
LOGP(-24)	0.241622	0.020214	11.95297	0.0000
LOGP(-25)	-0.209719	0.020506	-10.22713	0.0000
LOGP(-48)	0.118906	0.019272	6.169880	0.0000
LOGP(-49)	-0.121767	0.019315	-6.304162	0.0000
LOGP(-144)	0.069046	0.018052	3.824868	0.0001
LOGP(-145)	-0.073727	0.018237	-4.042666	0.0001
LOGP(-168)	0.187931	0.019700	9.539858	0.0000
LOGP(-169)	-0.164460	0.019885	-8.270679	0.0000
LOGL	1.311136	0.128209	10.22655	0.0000
LOGL(-1)	-0.565055	0.180711	-3.126845	0.0018
LOGL(-2)	-0.820145	0.147787	-5.549506	0.0000
LOGL(-3)	0.168029	0.079991	2.100615	0.0359
LOGL(-24)	0.519958	0.189522	2.743516	0.0062
LOGL(-25)	-0.550601	0.188696	-2.917921	0.0036
LOGL(-72)	-0.337266	0.100078	-3.370015	0.0008
LOGL(-73)	0.365918	0.098484	3.715521	0.0002
LOGL(-192)	-0.836158	0.179739	-4.652070	0.0000
LOGL(-193)	0.816297	0.179082	4.558230	0.0000
C	-0.535266	0.215973	-2.478388	0.0134

R-squared	0.926188	Mean dependent var	3.953059

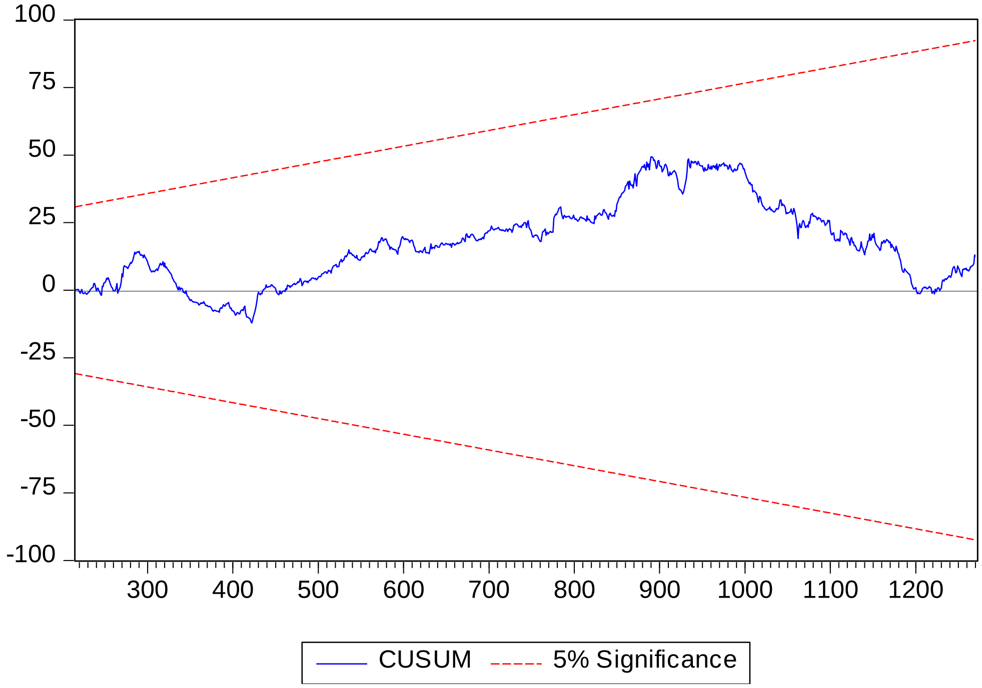
Adjusted R-squared	0.924791	S.D. dependent var	0.279597
S.E. of regression	0.076677	Sum squared resid	6.214522
Long-run variance	0.002596		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.743528	Prob. F(193,865)	0.9942
Obs*R-squared	153.5324	Prob. Chi-Square(193)	0.9834

4. CUSUM test



Hungary Fall Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:51
Sample (adjusted): 194 1272
Included observations: 1079 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.244551	0.277485	-0.881311	0.3783
LOGP(-1)	0.891087	0.029017	30.70918	0.0000
LOGP(-2)	-0.043468	0.027706	-1.568872	0.1170
LOGP(-24)	0.280527	0.029061	9.652885	0.0000
LOGP(-25)	-0.216309	0.029635	-7.299187	0.0000
LOGP(-72)	0.075998	0.027799	2.733870	0.0064

LOGP(-73)	-0.076294	0.027696	-2.754671	0.0060
LOGP(-120)	0.080652	0.026812	3.008086	0.0027
LOGP(-121)	-0.090868	0.027069	-3.356955	0.0008
LOGP(-144)	0.031878	0.027622	1.154061	0.2487
LOGP(-145)	-0.012761	0.027548	-0.463219	0.6433
LOGP(-168)	0.129738	0.029316	4.425446	0.0000
LOGP(-169)	-0.078423	0.029658	-2.644266	0.0083
LOGP(-192)	0.001993	0.028999	0.068711	0.9452
LOGP(-193)	-0.009289	0.028977	-0.320571	0.7486
LOGL	1.367114	0.162909	8.391863	0.0000
LOGL(-1)	-0.999127	0.227721	-4.387501	0.0000
LOGL(-2)	-0.383595	0.202563	-1.893707	0.0585
LOGL(-3)	0.124503	0.099185	1.255263	0.2097
LOGL(-168)	-0.240466	0.174004	-1.381952	0.1673
LOGL(-169)	0.278685	0.173633	1.605023	0.1088
LOGL(-192)	-0.463735	0.139815	-3.316781	0.0009
LOGL(-193)	0.361247	0.137331	2.630483	0.0087

R-squared	0.940887	Mean dependent var	3.883573
Adjusted R-squared	0.939656	S.D. dependent var	0.342447
S.E. of regression	0.084122	Akaike info criterion	-2.092008
Sum squared resid	7.472823	Schwarz criterion	-1.985773
Log likelihood	1151.638	Hannan-Quinn criter.	-2.051781
F-statistic	764.0096	Durbin-Watson stat	2.022985
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:53
Sample (adjusted): 195 1272
Included observations: 1078 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth
= 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	0.949194	0.020920	45.37248	0.0000
LOGP(-2)	-0.016419	0.019964	-0.822467	0.4110
LOGP(-24)	0.280180	0.020879	13.41941	0.0000
LOGP(-25)	-0.243727	0.021294	-11.44603	0.0000
LOGP(-72)	0.075631	0.019985	3.784316	0.0002
LOGP(-73)	-0.076625	0.019901	-3.850243	0.0001
LOGP(-120)	0.084280	0.019486	4.325100	0.0000
LOGP(-121)	-0.094036	0.019596	-4.798693	0.0000
LOGP(-144)	0.030195	0.019860	1.520409	0.1287
LOGP(-145)	-0.018900	0.019794	-0.954835	0.3399
LOGP(-168)	0.125885	0.021065	5.975987	0.0000
LOGP(-169)	-0.099757	0.021316	-4.679837	0.0000
LOGP(-192)	0.001317	0.020835	0.063201	0.9496
LOGP(-193)	-0.002228	0.020818	-0.107002	0.9148
LOGL	1.415109	0.117046	12.09021	0.0000
LOGL(-1)	-1.090145	0.163613	-6.662930	0.0000

LOGL(-2)	-0.425404	0.145568	-2.922375	0.0035
LOGL(-3)	0.140077	0.071258	1.965766	0.0496
LOGL(-168)	-0.256682	0.125026	-2.053033	0.0403
LOGL(-169)	0.279457	0.124747	2.240196	0.0253
LOGL(-192)	-0.442732	0.100485	-4.405940	0.0000
LOGL(-193)	0.380449	0.098688	3.855059	0.0001
C	0.016461	0.199429	0.082541	0.9342

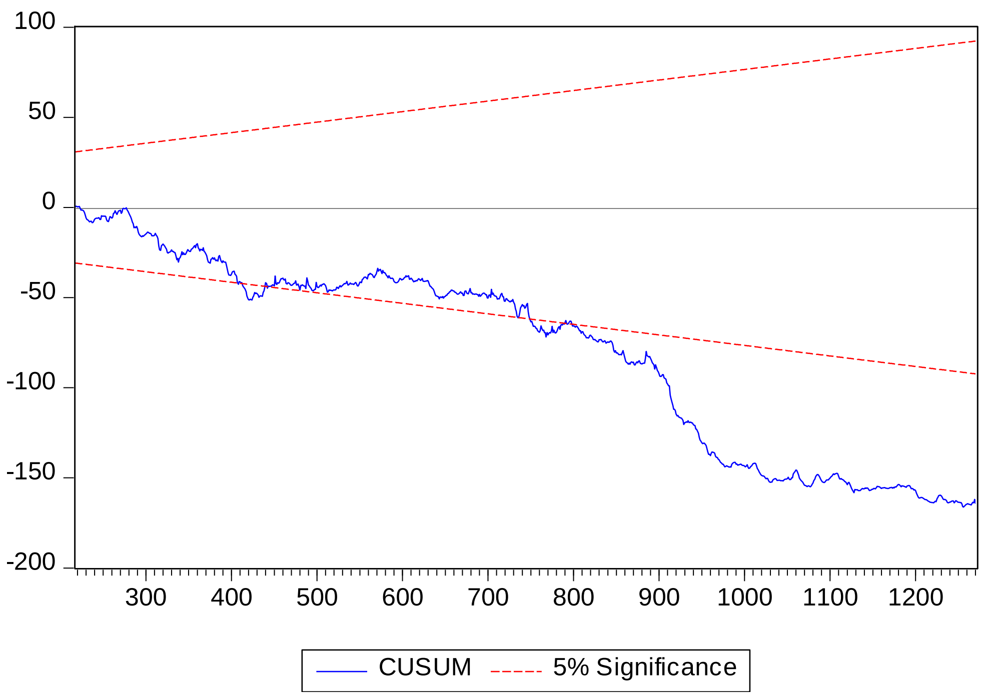
R-squared	0.939238	Mean dependent var	3.883793
Adjusted R-squared	0.937971	S.D. dependent var	0.342529
S.E. of regression	0.085309	Sum squared resid	7.677862
Long-run variance	0.003653		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.146168	Prob. F(193,863)	0.1053
Obs*R-squared	220.1474	Prob. Chi-Square(193)	0.0876

4. CUSUM test



Greece Winter Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:55
Sample (adjusted): 169 1272
Included observations: 1084 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.268741	0.097346	-2.760671	0.0059
LOGP(-1)	0.700434	0.029418	23.80950	0.0000
LOGP(-2)	-0.083915	0.028374	-2.957426	0.0032
LOGP(-24)	0.075627	0.019264	3.925793	0.0001
LOGP(-48)	0.139360	0.026190	5.321071	0.0000
LOGP(-49)	-0.103419	0.026235	-3.941991	0.0001
LOGP(-121)	-0.052944	0.018631	-2.841744	0.0046
LOGP(-144)	0.250941	0.033058	7.591007	0.0000
LOGP(-145)	-0.189528	0.033228	-5.703894	0.0000
LOGP(-168)	0.073769	0.021531	3.426209	0.0006
LOGR	0.342292	0.044766	7.646319	0.0000
LOGR(-1)	-0.341879	0.075663	-4.518440	0.0000
LOGR(-2)	0.125098	0.042401	2.950350	0.0032

R-squared	0.801401	Mean dependent var	4.282902
Adjusted R-squared	0.799176	S.D. dependent var	0.142545
S.E. of regression	0.063879	Akaike info criterion	-2.651717
Sum squared resid	4.370309	Schwarz criterion	-2.591893
Log likelihood	1450.231	Hannan-Quinn criter.	-2.629069
F-statistic	360.1475	Durbin-Watson stat	1.967643
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 19:56
Sample (adjusted): 170 1272
Included observations: 1071 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth
= 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	0.775504	0.025478	30.43785	0.0000
LOGP(-2)	-0.036825	0.024583	-1.497985	0.1344
LOGP(-24)	0.069060	0.016680	4.140295	0.0000
LOGP(-48)	0.146978	0.022430	6.552653	0.0000
LOGP(-49)	-0.124413	0.022494	-5.530873	0.0000
LOGP(-121)	-0.032300	0.016031	-2.014815	0.0442
LOGP(-144)	0.250415	0.028380	8.823737	0.0000
LOGP(-145)	-0.212945	0.028528	-7.464353	0.0000

LOGP(-168)	0.048282	0.018615	2.593666	0.0096
LOGR	0.360958	0.038455	9.386574	0.0000
LOGR(-1)	-0.395644	0.065224	-6.065928	0.0000
LOGR(-2)	0.119562	0.036635	3.263634	0.0011
C	-0.232533	0.083979	-2.768955	0.0057

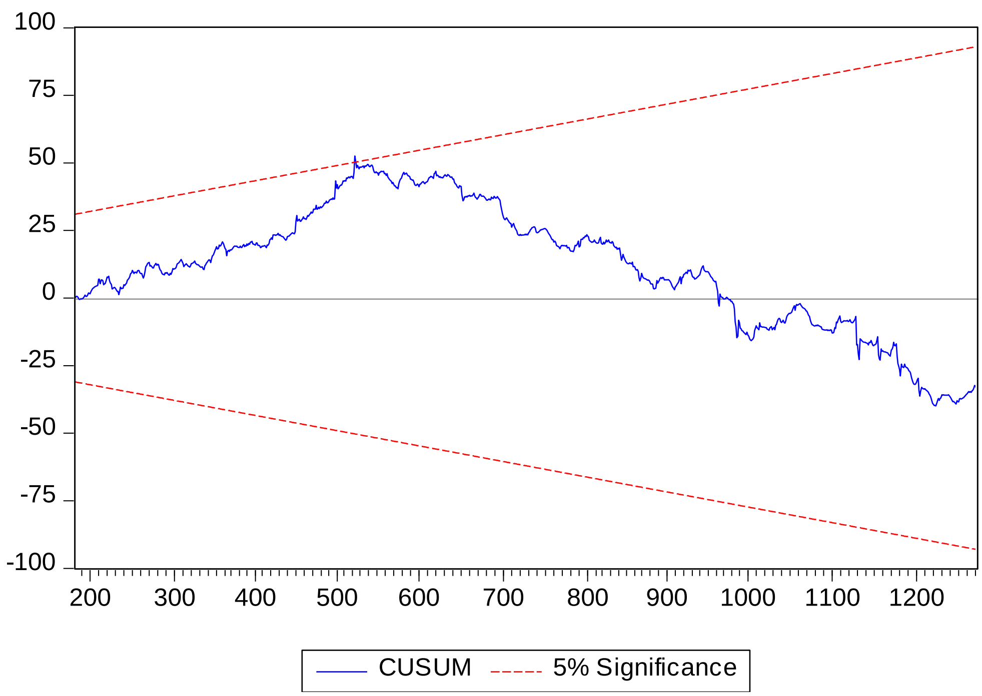
R-squared	0.796497	Mean dependent var	4.284667
Adjusted R-squared	0.794189	S.D. dependent var	0.141481
S.E. of regression	0.064185	Sum squared resid	4.358621
Long-run variance	0.002989		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.073041	Prob. F(168,903)	1.0000
Obs*R-squared	14.53304	Prob. Chi-Square(168)	1.0000

4. CUSUM test



Greece Spring Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 19:59
Sample (adjusted): 194 1272
Included observations: 1020 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.045377	0.373965	-0.121341	0.9034
LOGP(-1)	0.679332	0.030698	22.12975	0.0000
LOGP(-2)	-0.038850	0.035910	-1.081885	0.2796
LOGP(-3)	-0.066225	0.028600	-2.315587	0.0208
LOGP(-24)	0.091453	0.021214	4.311025	0.0000
LOGP(-72)	0.040253	0.018819	2.138967	0.0327
LOGP(-120)	0.042319	0.026808	1.578619	0.1147
LOGP(-121)	-0.045217	0.026643	-1.697162	0.0900
LOGP(-144)	0.054214	0.027305	1.985467	0.0474
LOGP(-145)	-0.085368	0.027305	-3.126431	0.0018
LOGP(-168)	0.362131	0.027891	12.98389	0.0000
LOGP(-169)	-0.194980	0.029510	-6.607266	0.0000
LOGR	1.000315	0.196722	5.084907	0.0000
LOGR(-1)	-0.473055	0.359177	-1.317054	0.1881
LOGR(-2)	-0.470932	0.338800	-1.390002	0.1648
LOGR(-3)	0.257746	0.158791	1.623179	0.1049
LOGR(-24)	-0.096198	0.049389	-1.947770	0.0517
LOGR(-192)	-0.665240	0.136558	-4.871486	0.0000
LOGR(-193)	0.532222	0.135723	3.921373	0.0001

R-squared	0.718827	Mean dependent var	4.110936
Adjusted R-squared	0.713771	S.D. dependent var	0.356646
S.E. of regression	0.190807	Akaike info criterion	-0.456655
Sum squared resid	36.44378	Schwarz criterion	-0.364867
Log likelihood	251.8941	Hannan-Quinn criter.	-0.421803
F-statistic	142.1714	Durbin-Watson stat	2.032855
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 20:00
Sample (adjusted): 195 1272
Included observations: 1011 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth
= 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	0.754188	0.026721	28.22437	0.0000
LOGP(-2)	-0.030117	0.031214	-0.964851	0.3349

LOGP(-3)	-0.014449	0.024877	-0.580806	0.5615
LOGP(-24)	0.081110	0.018457	4.394566	0.0000
LOGP(-72)	0.032088	0.016354	1.962136	0.0500
LOGP(-120)	0.045240	0.023398	1.933496	0.0535
LOGP(-121)	-0.054125	0.023195	-2.333415	0.0198
LOGP(-144)	0.056003	0.023725	2.360548	0.0184
LOGP(-145)	-0.087903	0.023724	-3.705141	0.0002
LOGP(-168)	0.371791	0.024241	15.33737	0.0000
LOGP(-169)	-0.249327	0.025650	-9.720443	0.0000
LOGR	1.067762	0.171618	6.221724	0.0000
LOGR(-1)	-0.593917	0.313474	-1.894628	0.0584
LOGR(-2)	-0.498824	0.295964	-1.685423	0.0922
LOGR(-3)	0.225080	0.138466	1.625530	0.1044
LOGR(-24)	-0.093892	0.043233	-2.171791	0.0301
LOGR(-192)	-0.717265	0.119302	-6.012206	0.0000
LOGR(-193)	0.625465	0.118425	5.281549	0.0000
C	0.273624	0.325741	0.840006	0.4011

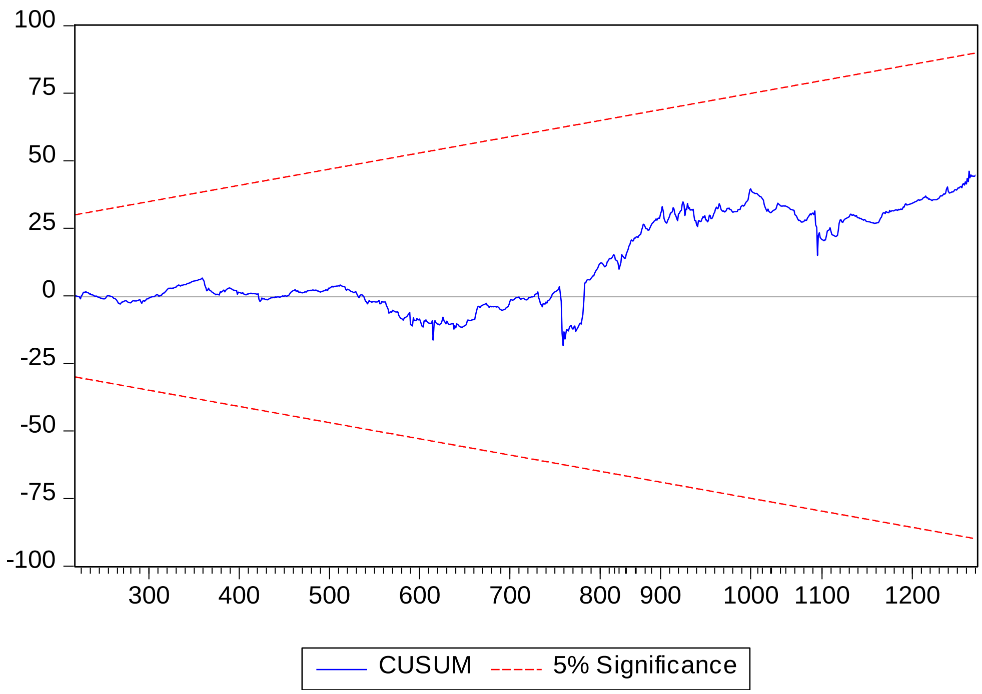
R-squared	0.712135	Mean dependent var	4.109956
Adjusted R-squared	0.706911	S.D. dependent var	0.357980
S.E. of regression	0.193802	Sum squared resid	37.25865
Long-run variance	0.027462		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.209750	Prob. F(168,833)	1.0000
Obs*R-squared	41.39740	Prob. Chi-Square(168)	1.0000

4. CUSUM test



Greece Summer Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 20:02
Sample (adjusted): 194 1272
Included observations: 1079 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.024605	0.125261	0.196429	0.8443
LOGP(-1)	0.750160	0.030671	24.45808	0.0000
LOGP(-2)	-0.039380	0.037829	-1.040996	0.2981
LOGP(-3)	0.045446	0.030316	1.499057	0.1342
LOGP(-24)	0.087580	0.020710	4.228879	0.0000
LOGP(-72)	0.020135	0.015628	1.288432	0.1979
LOGP(-120)	0.058759	0.029319	2.004145	0.0453
LOGP(-121)	-0.056487	0.029253	-1.930984	0.0538
LOGP(-144)	0.014886	0.029218	0.509459	0.6105
LOGP(-145)	-0.002190	0.029265	-0.074818	0.9404
LOGP(-168)	0.109337	0.029512	3.704894	0.0002
LOGP(-169)	-0.059198	0.029566	-2.002233	0.0455
LOGR	0.359205	0.075617	4.750344	0.0000
LOGR(-1)	-0.233920	0.140489	-1.665034	0.0962
LOGR(-2)	-0.056959	0.134087	-0.424793	0.6711
LOGR(-3)	0.026385	0.063577	0.415011	0.6782
LOGR(-24)	-0.047739	0.015420	-3.095787	0.0020
LOGR(-192)	-0.143387	0.056691	-2.529276	0.0116
LOGR(-193)	0.127638	0.056333	2.265769	0.0237

R-squared	0.773021	Mean dependent var	4.135709
Adjusted R-squared	0.769167	S.D. dependent var	0.109344
S.E. of regression	0.052535	Akaike info criterion	-3.037241
Sum squared resid	2.925467	Schwarz criterion	-2.949482
Log likelihood	1657.592	Hannan-Quinn criter.	-3.004010
F-statistic	200.5578	Durbin-Watson stat	1.981687
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 20:03
Sample (adjusted): 195 1272
Included observations: 1078 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	0.812948	0.023225	35.00311	0.0000
LOGP(-2)	-0.021171	0.028642	-0.739175	0.4600

LOGP(-3)	0.083666	0.022945	3.646373	0.0003
LOGP(-24)	0.068309	0.015674	4.358203	0.0000
LOGP(-72)	0.003689	0.011832	0.311760	0.7553
LOGP(-120)	0.065935	0.022198	2.970280	0.0030
LOGP(-121)	-0.058969	0.022145	-2.662854	0.0079
LOGP(-144)	0.009458	0.022173	0.426575	0.6698
LOGP(-145)	-0.004088	0.022221	-0.183962	0.8541
LOGP(-168)	0.100809	0.022348	4.510968	0.0000
LOGP(-169)	-0.073906	0.022378	-3.302629	0.0010
LOGR	0.355179	0.057231	6.206086	0.0000
LOGR(-1)	-0.239853	0.106334	-2.255652	0.0243
LOGR(-2)	-0.069254	0.101505	-0.682271	0.4952
LOGR(-3)	0.005915	0.048132	0.122885	0.9022
LOGR(-24)	-0.036312	0.011672	-3.111019	0.0019
LOGR(-192)	-0.164726	0.042938	-3.836407	0.0001
LOGR(-193)	0.159577	0.042650	3.741543	0.0002
C	-0.035666	0.094800	-0.376221	0.7068

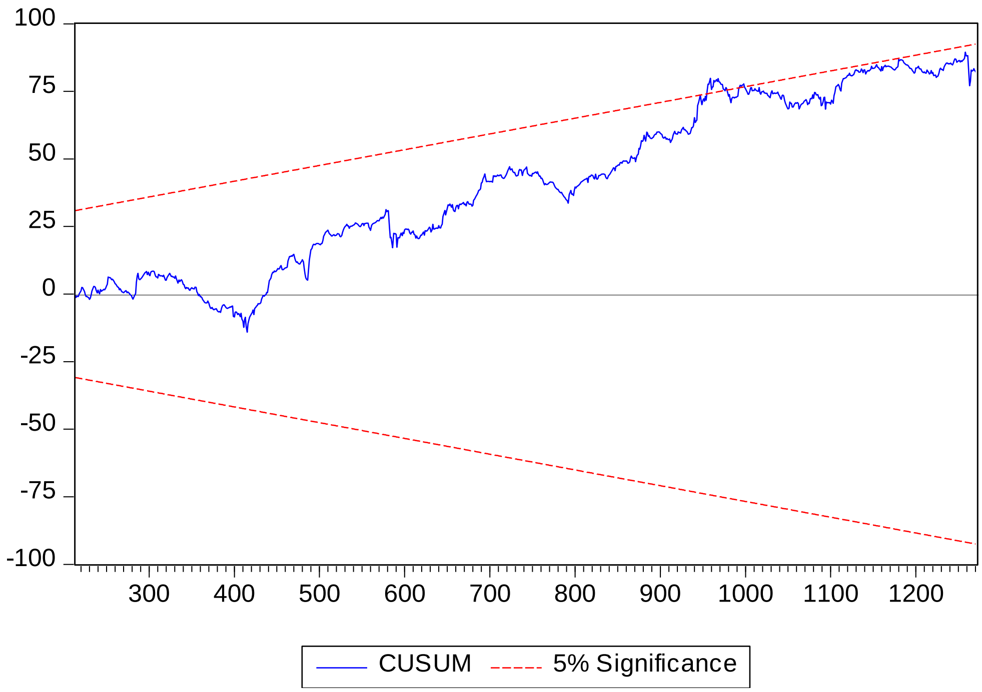
R-squared	0.766727	Mean dependent var	4.135612
Adjusted R-squared	0.762762	S.D. dependent var	0.109349
S.E. of regression	0.053261	Sum squared resid	3.004061
Long-run variance	0.001581		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.997249	Prob. F(193,867)	0.5002
Obs*R-squared	196.0172	Prob. Chi-Square(193)	0.4260

4. CUSUM test



Greece Fall Week

1. Results of the OLS

Dependent Variable: LOGP
Method: Least Squares
Date: 03/30/21 Time: 20:05
Sample (adjusted): 50 1272
Included observations: 1208 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.272205	0.169229	-1.608503	0.1080
LOGP(-1)	0.916473	0.029793	30.76136	0.0000
LOGP(-2)	-0.104402	0.026252	-3.976846	0.0001
LOGP(-48)	0.084236	0.024549	3.431409	0.0006
LOGP(-49)	-0.048247	0.024585	-1.962404	0.0499
LOGR	0.860878	0.097881	8.795145	0.0000
LOGR(-1)	-1.036483	0.176462	-5.873691	0.0000
LOGR(-2)	0.282888	0.096611	2.928111	0.0035

R-squared	0.720162	Mean dependent var	4.090036
Adjusted R-squared	0.718530	S.D. dependent var	0.244345
S.E. of regression	0.129634	Akaike info criterion	-1.241599
Sum squared resid	20.16605	Schwarz criterion	-1.207846
Log likelihood	757.9256	Hannan-Quinn criter.	-1.228888
F-statistic	441.1713	Durbin-Watson stat	1.673898
Prob(F-statistic)	0.000000		

2. Results of the Fully-Modified OLS

Dependent Variable: LOGP
Method: Fully Modified Least Squares (FMOLS)
Date: 03/30/21 Time: 20:07
Sample (adjusted): 51 1272
Included observations: 1201 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 7.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOGP(-1)	1.059050	0.025596	41.37609	0.0000
LOGP(-2)	-0.161604	0.025815	-6.259960	0.0000
LOGP(-48)	0.074620	0.021029	3.548520	0.0004
LOGP(-49)	-0.064279	0.023705	-2.711583	0.0068
LOGR	0.853309	0.073337	11.63552	0.0000
LOGR(-1)	-1.130144	0.131666	-8.583426	0.0000
LOGR(-2)	0.346193	0.071850	4.818274	0.0000
C	-0.199976	0.125840	-1.589132	0.1123

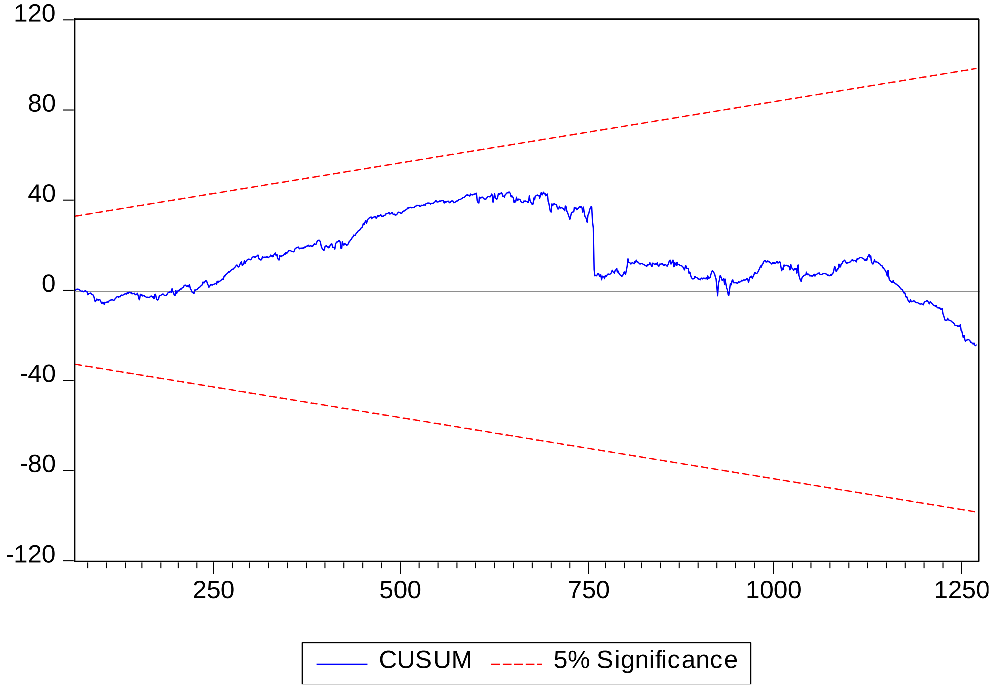
R-squared	0.716470	Mean dependent var	4.090546
Adjusted R-squared	0.714807	S.D. dependent var	0.244142
S.E. of regression	0.130380	Sum squared resid	20.27983
Long-run variance	0.009269		

3. Serial Correlation Test

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.442973	Prob. F(49,1151)	0.9997
Obs*R-squared	22.35895	Prob. Chi-Square(49)	0.9996

4. CUSUM test



120
80
40
0
-40
-80
-120
250
500
750
1000
1250
CUSUM
5% Significance