Louvain School of Management

Evaluation of the impact of the war in Ukraine and of the measures taken to mitigate it on European and Belgian electricity prices

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During the preparation of this master’s thesis, Louis Ceyssens utilized ChatGPT4.0 for the following purpose:

1. Bibliographical research: This artificial intelligence was used as a search tool for obtaining scientific sources and specific European Union reports.

2. Mathematical review: In addition to the calculations performed on Excel, it was interesting to ask the artificial intelligence to perform its own calculations following the same model. This ensured their accuracy.

After using ChatGPT4.0, Louis Ceyssens diligently reviewed and edited the content produced by the tool. We take full responsibility for the final content presented in this thesis.

By signing this declaration, we affirm that the content of this master’s thesis reflects our original work, augmented by the responsible use of AI.

Abstract:

The large-scale invasion of Ukraine in February 2022 has caused major disruption to the European energy sector, and particularly to the European electricity market. The aim of this thesis is to evaluate the impact of the war and of the measures taken to mitigate it on European and Belgian electricity prices. The study employs a dual quantitative research approach, combining explanatory and evaluative methods. The investigation begins by examining the mechanism and variable through which these events have had an impact on power prices. Subsequently, the extent to which electricity prices have been influenced by the occurrence of the war and the implementation of mitigation measures is evaluated.

The explanatory research reveals a strong linear relationship between gas and electricity prices, with the former being a significant driver of the latter due to the Merit Order principle. The link is evident for both the EU27 and Belgium, given the importance of the primary energy resource in their respective electricity production mixes. It is therefore clear that this relationship represents the primary mechanism through which electricity prices have been influenced these last years.

The evaluative research highlights the sharp increase in gas prices and electricity prices in 2021 and 2022. This initial rise was triggered by the post-Covid economic recovery, but the situation was then significantly worsened by the war in Ukraine. Since reaching a zenith in August 2022, European mitigation measures managed to have a considerable influence on gas prices, which subsequently resulted in a reduction in electricity prices for both zones. However, prices remain slightly above pre-crisis levels, indicating the need for continued efforts and long-term measures to achieve stability.

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Foreword

It is with excitement that I present the results of this Master's thesis about the "Evaluation of the impact of the war in Ukraine and of the measures taken to mitigate it on European and Belgian electricity prices". The motivation behind this research was to ascertain the manner and extent to which this geopolitical event and the European response have impacted electricity prices, and more broadly, the functioning of the European electricity market, with a particular emphasis on Belgium.

I would like to express my sincere gratitude to the UCLouvain, and specifically the Louvain School of Management, for guaranteeing access to valuable resources on scientific writing techniques and its internal libraries. I would also like to thank my relatives for their unfailing support throughout this project. At last, but not least, I would like to thank my thesis supervisor Ina Aust-Gronarz, professor in Human Resource Management and academic director of the International Business program. It has been a pleasure to receive her precious advice, especially in the areas of scientific methodology and scientific writing.

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1. Introduction

1.1 Practical problem statement

The large-scale invasion of Ukraine in February 2022 has resulted in significant disruptions to the European electricity market. Indeed, the EU's unequivocal condemnation of the act as a "flagrant violation of international law", has deepened the political and economic rift with Russia and pushed the communist power to use its energy resources, and primarily its gas, as a political weapon. At the beginning of 2022, Russia took the unilateral decision to drastically cut off its exports to several European Union member states. Concurrently, Europe opted for a further reduction of these energy imports, thereby preventing the financing of a potential conflict on its doorstep (European Commission, 2022a).

Given the importance of natural gas in electricity production, the entire European electricity market suffered the consequences. It can even be said that, in a broader economic context, the entire European economy has been affected. Indeed, given the central role played by energy, and electricity particularly, in the development of modern economies, the energy crisis led to a meteoric rise in inflation in 2022 across the EU member countries.

Since then, the European institutions have been trying to restore stability to the domestic electricity market by implementing various measures aimed at restoring reasonable prices and facilitating the transition away from dependence on Russian resources.

1.2 Research gap, question and nature

This research aims to contribute to the existing literature by filling a gap regarding the specific impact of the Ukrainian war on the European electricity market. As a matter of fact, the current state of knowledge regarding the functioning of this market and the mechanisms through which electricity prices are determined is relatively advanced. Studies have been conducted on the impacts of natural resources and energy policies for electricity generation. However, most of the existing research focuses on explaining how the market functions in general, without focusing on a particular period or geographical area.

Nevertheless, the market has been facing unprecedent changes following the Russian invasion. As a result, several components influencing electricity prices, such as gas prices, have deviate from their usual course. The analyzed geopolitical event has therefore had a significant economic impact and prompted European institutions to implement temporary solutions to cope with this energy crisis.

Thereby, this study focuses on analyzing the complexity of the situation, particularly the impact of the war in Ukraine on electricity prices in Europe, with a specific focus on Belgium. To carry out the study in the best possible way, a dual quantitative research approach has been used, namely explanatory and evaluative. These are clearly underlined in the research question:

"What impact had the war in Ukraine on the pricing of electricity in the European Union, in particular Belgium, and how effective were the measures put in place to mitigate the price increase?"

First, we note the explanatory nature of this research question. The objective here is to understand and assess the variables and mechanism through which the war in Ukraine had an impact on electricity pricing in Europe, and particularly in Belgium. Similarly, it is important to understand this price formation mechanism in order to understand on which variables mitigating measures have acted to counter the impact of the war on electricity prices.

As for the evaluative nature, the objective is to quantify the impact of the war on the European electricity market, and specifically on Belgium. Similarly, the intention is to conduct a quantitative assessment of the efficacy of the measures implemented to address the rising cost of electricity.

1.3 Structure of the research

To conduct this research, it is essential to divide it into different sections. This enables the complexity of the subject to be fully incorporated, prior to addressing the problem and the research question. To this end, the thesis follows an overall deductive framework divided into sub-sections.

The first part of the study synthesizes the previous theory established regarding the functioning of the electricity market at both European and Belgian levels. In addition, it highlights how European institutions have considered recent disruptions in their decision-making processes.

Subsequently, the methodology employed to conduct the research is highlighted. It outlines which statistical models are used, which variables are important for carrying out the research, and which data are collected.

Afterwards, incorporating this data into the statistical models defined in the methodology provides the quantitative results. These findings permit the formulation of several elements to answer the research question.

It is then essential to interconnect the findings of the quantitative study with the theory of the literature review, in order to identify both the similarities and the differences between the two.

This work will finally be concluded by summarizing the main points and the answers provided to the research question in the study.

2. Literature review

In order to build a consistent literature review, it was important to gather the right information to understand the subtleties of the situation in which the European electricity market finds itself.

To this end, many scientific articles were consulted via online libraries (Google scholar & Science Direct). In addition, numerous documents from the European Commission and its Council were useful (Commission Regulations, reports, guidelines and statistics). Lastly, it was very useful to read numerous reports from the supranational and national entities who make up the European electricity market (EPEX Spot, Elia, CREG, Baringa, etc.).

This literature review is divided in three main parts. The first part is dedicated to the description of the European electricity market and its functioning. Next, there is a description of Belgium's place in the European network and its mode of operation. Finally, we conclude this literature review with a description of the management of the recent energy crisis caused by the war in Ukraine, with a focus on the mitigation measures that have been implemented since February 2022.

2.1 The European electricity market

The liberalization of the markets resulting from the Single European Act in 1986 laid the foundations for a single European electricity market. Conventionally, energy was managed through national monopolies, but the need for a greater security of supply and more transparency led to additional directives aiming at the liberalization of this sector in 1996 through the 96/92/EC directive (Nguyen, 2022). For more than three decades now, the European Union has set itself the goal of creating and managing an integrated electricity market to guarantee its citizens secure, sustainable and affordable supply (European Commission, 2024).

To achieve those past but also present and future objectives, the EU had to ensure that several crucial points such as management systems, good planning and reliable infrastructures were in place. First**, electricity supply and generation** must be sufficient to meet the needs of European industry and more than 500 million citizens[1]. Additionally, to **enable trade** and retain confidence in the functionality of the market, this one must work efficiently by ensuring that supply meets demand. Therefore, the system must offer consistent prices that correspond to the demand and to the costs of production. To achieve this, several European trade platforms have been established (Gomez et al., 2019). Finally, the **transmission capacity** needed for a vast and unique network must be able to withstand the market's electricity movements. Lastly, market rules must take each stakeholder into account, as these should create incentives for market participants that improve reliability and adequacy of the energy system (Honkapuro et al., 2023).

Nevertheless, despite the implementation of these various elements and the considerable length of time that has elapsed since the inception of the European electricity market, its operating mode has not yet stabilised into a fixed form. Recent changes in the energy sector, such as the increasing share of renewable energy, decentralized production, geopolitical tensions, and the growing need for demand response, challenge the functionality of the current model and lead to uncertainty toward it (Honkapuro et al., 2023).

2.1.1 Electricity generation and supply

Electricity generation and the energy sources on which it depends is central to the development of the European market. It is a pivotal subject that has evolved considerably in recent years.

However, net electricity consumption in Europe does not appear to have changed much since 2000. In fact, it remains very stable, hovering around 2750TWh per year. Moreover, recent events in Ukraine, triggering a rise in gas prices, have even caused demand to fall to its lowest level since 2001 (Brown & Jones, 2024). We might therefore assume that, given steady consumption, electricity generation in Europe would have changed little. In term of numbers,

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[1] The European electricity market comprises the EU member states (448 million). In addition, the UK, Norway and Switzerland are included in many of the network's regulations and transactions (European Commission, 2020).

this assertion is indeed accurate, as the generation has remained relatively close to the consumption values, with minimal fluctuations in recent years (Eurostat, 2024c).

But in spite of these stable data, major changes have been observed in recent years in the electricity generation. The energy mix needed to generate electricity in Europe, as well as the principles governing its process, and the geopolitical relations to obtain certain energy resources, were marked by numerous decisions and events. Indeed, the European Union has set itself the goal of increasing the proportion of electricity generated from green energy sources to achieve carbon neutrality. Furthermore, the objective is to enhance the Union's autonomy in electricity production resources, thereby mitigating the risk of future price shocks (European Council, 2023). These modifications have thus had a profound effect on the electricity generation model over the past few years.

2.1.1.1 European electricity mix

Historically, Europe has mainly relied on fossil fuels. Abundant coal reserves guaranteed the necessary energy supply for many countries before falling drastically due to its environmental impact. Subsequently, oil and nuclear power became the main sources of energy. It can therefore be said that these three energy sources have played an essential role in Europe's power generation landscape (Eurostat, 2024c).

Despite the historic dependence on fossil fuels, a notable shift in the electricity mix of European countries happens since the nineties. The share of electricity from solid fuels and oil products has decreased significantly, while low-carbon sources like wind, solar, biomass, and biogas have increased. This shift reflects a broader trend toward cleaner energy sources across Europe (Scarlat et al., 2022).

This change was further supported by the implementation of the third legislative package in the energy sector by the European Commission, where the organization set clear expectations for its electricity production sector. Since 2009, there has thus been a progressive reduction in the use of fossil fuels combined with a less pronounced decline in nuclear energy. Nevertheless, electricity generation from natural gas has shown a clear increasing trend due to its lower emissions compared to other fossil fuels and its high efficiency (see Appendix 1). For these reasons, this energy source had been designated as transitional fuel, to make the transition from grey energy to green energy in electricity generation.

Unfortunately, given the new geopolitical reality with the war in Ukraine, the EU has reconsidered this option, accelerating the decline of natural gas-based electricity production. According to the European Council, this decision will be supported by increased investments in green power generation. Although strongly pushed by the exceptional situation, the shift towards a greener grid is facilitated by the significant rise in electricity production from renewable energy, highlighting Europe's commitment to reducing its carbon footprint and transitioning towards sustainable energy sources (Scarlat et al., 2022). Additionally, to offset the reduction in gas-fired electricity production, some existing coal capacities might be used longer than initially expected, with nuclear power playing a role as well (European Commission, 2022b).

Nowadays, the EU generation still hovers around the same numbers with a production of 2,641 terawatt-hours in 2022. A substantial portion of this came from renewable sources, forming the biggest part of the energy mix. Fossil fuels also played a significant role, with natural gas still being the primary nonrenewable resource used, followed by coal. On its side, nuclear power contributed a notable share to the electricity production, highlighting its continuous importance in the European energy landscape (see Appendix 2) (European Council, 2024).

2.1.1.2 The Merit Order principle

The Third Energy Package, which was adopted in 2009, established the Merit Order principle as a decision-making method for the electricity production within the member states. In fact, everyday, the nominated electricity market operators (NEMOs)[2] have the responsibility of allocating their different geographical zones'[3] production capacity to the various power generators following this principle, as electricity storage remains complex (European Union, 2015).

The aforementioned principle ranks power plants based on their marginal production costs. The marginal cost represents the expense incurred by a power plant to produce one additional megawatt-hour (MWh) of electricity on the next day (EPEX Spot, 2024). This ranking

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[2] 'Nominated electricity market operator (NEMO)' means an entity designated by the competent authority to perform tasks related to single day-ahead or single intraday coupling (European Union, 2015).

[3] The European electricity market is divided in bidding zones (most of the time a country). Each bidding zone has one (or sometimes several) designated NEMO(s).

determines the sequence in which power plants are called upon to generate electricity daily to meet demand.

The Merit Order is a system of electricity pricing based on the submission of supply bids by generators indicating the quantity of electricity they are willing to produce for the next day. The market operator (NEMO) orders these bids from the lowest marginal cost to the highest marginal cost. Electricity demand is then met by sequentially activating the plants in this ordered list until total demand is met. The price of all electricity traded on this market is determined by the marginal cost of the last power station activated, which is known as the marginal power station (see Appendix 3) (EPEX Spot, 2024).

Power plants with the lowest marginal costs, such as renewables, are thus dispatched first. These plants have very low operating costs once constructed due to their reliance on free energy sources. As demand increases, plants with higher marginal costs, such as nuclear, gas, and coal, are finally invited to produce in ascending order of their marginal costs (European Council, 2024b).

Therefore, electricity prices in European markets are often set by coal or gas plants which are the marginal power stations. Consequently, fuel prices and carbon costs are significant drivers of electricity prices. However, the magnitude of these impacts mainly depends on a country’s production portfolio and the frequency with which different plants are marginal (Kosch & Blech, 2022).

Finally, the utilization of low-emission energies is clearly encouraged by this principle, since green electricity producers are the first to be called by NEMO. Additionally, renewable power plants have the opportunity to achieve greater profitability through the marginal cost definition (see Appendix 3).

2.1.1.3 International trade and cooperation for energy resources

While Europe is self-sufficient in the production of its own electricity, the continent still relies on partners for the import of energy sources behind its generation. Thanks to highly developed infrastructures such as numerous power plants and smart grids, the transformation of primary energy into electricity requires no external intervention. Nevertheless, Europe's dependence on external resources is a point that creates uncertainty towards electricity supply in the European market.

The fragility of this point was first seen in the aftermath of Covid in 2021, when demand for natural gas exploded as a result of the economic recovery, throwing supply and demand off balance, therefore driving up prices (European Council, 2023). Subsequently, this rise in prices was exacerbated by geopolitical tensions. Indeed, the Russian unilateral decision to suspend gas deliveries to some EU members via pipelines unbalanced the supply-demand equilibrium, thereby precipitating an energy crisis that pushed up gas prices to records levels in 2022. This, in turn, had a massive indirect impact on electricity prices (European Council, 2023).

As described, the existing situation is risky, although the EU is putting measures in place to reduce its dependence on fossil fuels, and therefore on imports. Nowadays, a considerable proportion of the fossil fuels utilized in Europe still originates from abroad, including both coal and natural gas. In 2022, these two resources accounted together for more than 35% of the energy mix required for power generation (European Council, 2024). With regard to coal, it can be observed that for approximately fifteen years, more than 50% of the resource utilized in Europe has been imported from its principal trading partners: Russia[4], the United States and Australia (Eurostat, 2024b). For what concerns gas, historically, the EU has relied on imports for over 80% of its consumption, whether via pipelines or tankers (liquified natural gas, LNG). Historically, the main trading partner was Russia until its large-scale invasion of Ukraine. In 2021, its exports still accounted for 45 percent of the total gas imports into Europe. But, trade of pipeline gas coming from Russia has drastically diminished, while volumes of LNG imports from more reliable partners are on the increase. These combined effects relegated Russian gas (pipeline and LNG) to only 15 percent of the imports in 2023 (European Council, 2024a).

Following these energy crises faced by the European market for electricity, the EU has decided to implement and accelerate certain measures to reduce the impact these uncertainties could have. First, a diversification of partners is at the heart of the energy supply reorganization (European Council, 2023). Secondly, the transition to more renewable electricity has accelerated in the wake of the conflict in Ukraine, responding to the desire for European independence. Even though the European strategy recognizes that a proportion of other energy sources (fossil or nuclear) will always be needed to compensate for the variability of the elements in green energy production (European Council, 2023).

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[4] Since 2022 and the large-scale invasion of Ukraine the EU has decided on several sanctions concerning coals imports from Russia making them drop from 51 million metric tons in 2021 to only 12 in 2023 (Statista, 2024).

2.1.2 Domestic electricity trade and cooperation

Within the framework of the unified electricity market, a strong internal marketplace is also essential to achieve the objectives of security, affordability and sustainability and to facilitate the integration of member states. To ensure the electricity market efficiency, emphasis must be placed on basic market principles, effective governance, and advanced planning (Honkapuro et al., 2023).

First and foremost, in a freely competitive electricity market, the main objective is to improve market efficiency. To achieve this, it must maintain confidence in the functioning of the market, prices must therefore match demand and supply, and cover electricity production costs. Moreover, the market must be transparent and transmission capacity must be sufficient to support cross-border electricity trading (Honkapuro et al., 2023).

2.1.2.1 Electricity pricing

2.1.2.1.1 Pricing actors

Matching demand and supply by allocating corresponding prices is the role of nominated electricity market operators (NEMOs). This role is referred to as the market coupling operator (MCO) function. NEMOs provide a marketplace, a trading platform, where wholesale buyers and sellers can exchange electricity in an organized way, with a set of rules, at public prices (Gomez et al., 2019). Those market operators are thus required to match orders for each of the different bidding zones by determining a market clearing price. They collect buy and sell orders from market participants, and then ensure that supply meets demand (European Union, 2015).

Additionally, a close connection between NEMOs and transmitting system operators (TSOs)[5] is required for the allocation of interconnection and production capacities. In fact, each region or bidding zone in the electricity market has a certain capacity for transmitting electricity within its borders but also across it, to neighboring zones. This capacity can vary due to physical infrastructure limits. Every day, TSOs verify the coupling results[6] of the NEMOs to ensure that

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[5] The European Commission defines a transmission system operator (TSO) as follow: “An organisation which is responsible for the transport of energy at national or regional level using fixed infrastructure”.

[6] Everyday TSOs are responsible for validating the NEMOs production plan and coupling results, ensuring they respect transmission capacities. Should this not be the case, the TSO is required to rebalance the plan through redispatching measures after the initial NEMOs’ market clearing (European Union, 2015).

they adhere to the established transmission capacities. It is thus TSOs responsibility to manage electricity flows, address potential issues, and ensure the reliability of the interconnected European grid. (Gomez et al., 2019).

The bidding zones are usually delimited by state borders, but some countries can be divided in several zones to reflect internal congestions. The market participants of each zone submit bids and receive market coupling results through their assigned NEMOs. Nowadays, the main ones are OMIE (Spain and Portugal), EPEX Spot (Austria, Belgium, France, Germany, The Netherlands, UK & Switzerland), Nord Pool (Denmark, Estonia, Finland, Latvia, Lithuania, Norway & Sweden), and several other single-country zones NEMOs. All those entities are required to agree on a plan setting out how to jointly perform the market coupling operator function (Gomez et al., 2019).

Historically, it was typical for a single NEMO to oversee operations within a single bidding zone. However, the implementation of the European Union's energy market regulations, particularly the CACM Regulation (Capacity Allocation and Congestion Management) in 2015, has resulted in a shift in the regulatory landscape, allowing for the operation of multiple NEMOs within the same bidding zone. This process is referred to as "collaborative market coupling," whereby several NEMOs, in collaboration with the local TSO, ensure the market coupling process. Nevertheless, a designated national legal monopoly for day-ahead and intraday trading services in a member state remains a common practice (European Union, 2015).

2.1.2.1.2 Zonal pricing

In order for the same price for electricity to be achieved throughout the entire European market area, it is necessary to ensure that transmission and production capacity is practically unlimited and that no losses occur. Given the impossibility of this approach, several alternative pricing strategies for electricity have been developed. On the European market, uniform pricing within bidding zones is therefore currently utilized (Honkapuro et al., 2023).

A bidding zone is the largest geographical area in which bids and offers from market participants can be matched without the need to attribute cross-zonal capacity. Currently, bidding zones in Europe are mostly defined by national borders (see Appendix 4) (European Union Agency for the Cooperation of Energy Regulators, 2022).

This uniform pricing implies that the power system is free of network constraints within each bidding zone and that the hourly day-ahead power price is the same for all grid users within it (Eicke & Schittekatte, 2022). Transmission capacity is thus assumed to be unlimited within the zone resulting in a uniform electricity price. This pricing system is underlined by the Commission Regulation (EU) 2015/1222 which focuses on Capacity Allocation and Congestion Management (CACM) in the European electricity market. It emphasizes the importance of defining those zones in a way that promotes the efficient management of congestion and the overall efficiency of the market.

Unfortunately, this model can reach its limits and, today, some zones may be confronted with power flows creating structural congestion. This problem mainly appears due to a lack of transmission capacity. It requires thus TSOs to use redispatch measures. This involves ordering certain market participants to change their planned generation or consumption after the initial NEMO's market clearing[7]. This ensures that the physical flows of electricity match the capacity of the transmission system (Eicke & Schittekatte, 2022). These TSOs interventions were supposed to be infrequent but have intensified as generation capacity has grown faster than the transmission capacity.

Consequently, the ENTSO-E[8] suggests that alternative bidding zone configurations should be studied for the year 2025, as internal congestions can have an impact on the cross-zonal trade and can therefore result in the loss of efficiency for the whole grid.

2.1.2.1.3 The Merit Order's impact on prices

Electricity bills for European consumers are composed of multiple elements, which can differ between countries such as taxes or levies. One component across all bills is the marginal cost to produce one additional megawatt-hour (MWh) of electricity on the next day (EPEX Spot, 2024). This marginal cost has a particular impact on the European electricity market, as it enables NEMOs, in collaboration with TSOs, to determine the quantity of electricity to be

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[7] The process by which supply, and demand are matched to set the price and quantity of electricity for each zone.

[8] Organization thar coordinates and integrates national electricity grids across Europe. The ENTSO-E is responsible for coordinating the TSOs for the future organization of the European network

produced by each power plant daily, based on the Merit Order principle (see section 1.1.2) (European Union, 2015).

In order to meet the demand for the following day, the local NEMO accepts supply bids from producers sequentially, starting with the one with the lowest marginal cost. Electricity demand is then met by sequentially activating the plants in the aforementioned list until the total demand is reached (European Council, 2024b). The price of all electricity traded on this market is determined by the marginal cost of the last power station activated, which is known as the marginal power station (see Appendix 3).

It is evident that this system enhances market efficiency through its transparency and efficacy in maintaining equilibrium between supply and demand. Indeed, it encourages generators to offer their production at a price that does not exceed their real operating costs. If generators were to offer electricity at a price higher than their true marginal cost, they would be at risk of not selling any of their output (EPEX Spot, 2024). Furthermore, this system incentivizes generators to offer their electricity at competitive prices, thereby ensuring that supply is met in an efficient manner while guaranteeing that demand is consistently met at the lowest possible cost (EPEX Spot, 2024).

In addition to the marginal cost included in the price of electricity for European citizens, it is necessary to consider other components. The prices also greatly depend on the geopolitical situation, the different national energy mixes, imports diversification, network costs, environmental protection costs, local infrastructures developments, or levels of excise and taxation (Eurostat, 2024a). Different national policies can therefore have a major influence on electricity prices. For example, in 2023, Luxembourg offered its citizens numerous subsidies (negative taxes 49%), bringing down the price of its electricity, while Denmark raised its taxes by 48%, almost doubling the price of its electricity over the same period (Eurostat, 2024a).

2.1.2.2 Trading platforms

Given the role entrusted to them, market operators must provide a marketplace where wholesale buyers and sellers can exchange electricity in an organized way, with a set of rules, at public prices. Their market coupling operator (MCO) function obliges them to match orders for the day-ahead and intraday markets for the different bidding zones and simultaneously allocate cross-zonal capacities (Gomez et al., 2019).

2.1.2.2.1 Day-ahead market

In day-ahead markets, the NEMOs allow trading of hourly power contracts for the next day through a blind auction that takes place once a day. Hourly contracts are submitted by supplier and buyers in terms of multiple volume-price pairs. It reflects their willingness to buy or sell, in volume, for all price ticks between the minimum and maximum prices of the auction[9] (Shah & Chatterjee, 2020).

Once the submissions have been gathered, the market operator establishes a demand curve based on the buy-orders and it also establishes a supply curve based on the sell-orders, for each hour of the following day. The market clearing price (MCP), which reflects supply and demand, lies at the intersection of both curves (EPEX Spot, 2024).

To determine this intersection and thus the MCP, NEMOs use a precise algorithm called EUPHEMIA[10] (Pan-European Hybrid Electricity Market Integration Algorithm). Euphemia has been designed to achieve several key objectives. First, it aims to maximize economic surplus for the single day-ahead market operations across all interconnected bidding zones for the upcoming day. Secondly, it employs the marginal pricing principle (Merit Order), ensuring that all accepted bids within a bidding zone have the same price per market time unit. Additionally, the algorithm facilitates efficient price formation, respects cross-zonal capacity and allocation constraints, and is designed to be both repeatable and scalable (European Union, 2015).

In the auction, buyers and sellers are not matched one-to-one. Instead, there is an overall executed buy volume that is equal to an overall executed sell volume for each delivery period. An auction has the advantage of gathering liquidity at one point in time while offering full transparency. Exchange members use the auction to sell and buy the largest part of the produced and needed electricity (EPEX Spot, 2024).

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[9] Since the application of the EU Commission Regulation 2015/1222, NEMOs must develop a proposal on harmonized maximum and minimum prices to be applied in all bidding zones which participate in single day-ahead coupling in cooperation with the relevant TSOs.

[10] EUPHEMIA was born thanks to Price Coupling of Regions (PCR) initiative. European Power Exchanges have collaboratively created a single price coupling solution to be used to calculate electricity prices across Europe, respecting the capacity of the relevant network elements on a Day-Ahead basis (Gomez et al., 2019).

2.1.2.2.2 Intraday market

Single Intraday Coupling (SIDC) is an initiative led by NEMOs and TSOs since 2018 which enables continuous cross-border trading across Europe. This initiative is in line with the Capacity Allocation and Congestion Management (CACM) EU Target model for an integrated intraday market. The purpose of the SIDC initiative is to increase the overall efficiency of electricity trading.

The intraday market is based on a common IT system with one single order book, one single capacity management module and one shipping module. Therefore, when market participants of each NEMO submit orders, they are put together in the common shared order book. This enables market participants to submit orders for continuous matching in one country, which are then linked to supply submissions from market participants in any other country within the project's reach, as long as transmission capacity is available (Gomez et al., 2019). All TSOs shall therefore verify that the results of the continuous trading matching algorithm are consistent with cross-zonal capacity (European Union, 2015). According to the most recent data, 25 European countries now benefit from the SIDC (see Appendix 5).

As the production of electricity coming from renewable energy sources increases, market participants are becoming more interested in trading in the intraday market. This is due to the fact that maintaining balance in the market has become increasingly challenging for participants (i.e., to supply the correct amount of energy) following the closure time of the day-ahead market (ENTSO-E, 2024). As a result, requests for trades that have occurred through SIDC have risen from 24 million in 2019 to over 88 million in 2022.

2.1.3 Transmission capacity

To ensure that European citizens and businesses can be supplied with electricity at all times, it is essential that the infrastructure on which the market relies is fully operational. It is therefore needed to ensure that the grid, at high voltage level, can support the transport of electrical power, allowing European Network members to exchange electricity

2.1.3.1 TSOs' roles

A few decades ago, this transmission capacity was developed locally, purely for national requirements through local Transmission System Operators (TSOs). Today, this grid of individual operators has evolved into a deeply interconnected network across Europe to create the largest electricity transmission system on our planet (ACER-EU, 2024).

Nowadays, those interconnected organisations are still responsible at national or sometimes sub-national level for the bulk transmission of electric power on the main high voltage electric networks and for validating the NEMOs production plan and coupling results, ensuring they respect transmission capacities (European Union, 2015). Additionally, they are in charge of providing grid access to the main market players (i.e. generating companies, traders, suppliers and distributors) according to non-discriminatory and transparent rules. Finally, in order to ensure the security of supply, they also guarantee the safe operation and maintenance of the system (ENTSO-E, 2024).

2.1.3.2 TSOs cooperation

To control operators' participation in this system, the European Commission has issued regulations setting out the requirements for EU-wide TSOs (Verseille & Staschus, 2015). In 2009, the third legislative package in the energy sector was launched and led to the creation of the ENTSO-E (European Network of Transmission System Operators for Electricity). Moreover, in 2017, additional guidelines on electricity transmission system operation, Commission Regulation (EU) 2017/1485, were brought in to supplement the previous ones by focusing on operational details (European Union, 2017).

The main role of ENTSO-E today is to dictate access, coordinate, and integrate national electricity grids across Europe. To this end, ENTSO-E helps balancing supply and demand to improve reliability and develops and implements rules for capacity allocation and congestion management, ensuring efficient use of transmission capacity and managing network bottlenecks (Verseille & Staschus, 2015)(ACER-EU, 2024).

2.1.3.3 Current overview of TSOs participating in the EU network for electricity

Today, ENTSO-E has a membership of 40 companies from 36 different countries (see Appendix 6). The European power system is divided in five synchronous zones of varying sizes (see Appendix 7) (see Appendix 8): Continental Europe with 24 countries, Northern Europe, the Baltic States, the United Kingdom, and Ireland, all interconnected by high-voltage direct current (HDVC)[11] lines (Hofmann, 2020).

Since the Brexit, the UK zone and its 3 TSOs are not able to participate in EU bodies anymore such as the Agency for the Cooperation of Energy Regulators (ACER) and the ENTSO-E. Nevertheless, in view of the many economic connections, electricity exchanges are continuing under the EU-UK Trade and Cooperation Agreement (European Commission, 2021).

Within these five synchronous zones, power is distributed through alternating current[12] lines, balancing load within the subnetwork under normal conditions. When line loading approaches capacity limits, TSOs must manage and reduce critical power flows through re-dispatching (Hofmann, 2020).

2.2 Belgium in the European electricity market

Since the end of the nineties and the first directives for the liberalization of the European electricity market (EU Directive 96/92/EC), Belgium has been part of the change leading to a harmonized market for all members of the European Union[13]. Indeed, this country was part of the EMELIE project, the first project to observe the economic and environmental impact of the liberalization process of the electricity market (Lise & Linderhof, 2004). This project, the first in a long line leading to the European electric market, involved 8 countries, namely Belgium, Denmark, Finland, France, Germany, The Netherlands, Norway and Sweden, which we refer to as EU8. Since its participation in this project, Belgium has been an integral part of building a single European electricity market and network.

2.2.1 Belgian electricity market's main actors

Nowadays, following the liberalization of the sector, the generation capacity and the management of the Belgian power flows have evolved considerably towards a liberalized model interconnected to the European network.

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[11] A high-voltage direct current (HVDC) electric power transmission system uses direct current (DC). HVDC lines are commonly used for long-distance power transmission, since they require fewer conductors and incur less power loss than equivalent AC lines.

[12] Alternating Current (AC) is a type of electrical current, in which the direction of the flow of electrons switches back and forth at regular intervals or cycles. Current flowing in power lines and normal household electricity that comes from a wall outlet is alternating current (European Commission, n.d.)

[13] Some other countries, like Norway and the UK are part of the European electricity market through economic and diplomatic agreements such as the European Economic Area (EEA).

As part of the management of the European electricity market, Belgium represents one single bidding zone. Nevertheless, this single zone is managed through a collaborative market coupling process. This means that two NEMOs provide their platforms for electricity trading, fostering competition and providing market participants with more choices. Those two entities use the same market coupling infrastructure collaborating with the local TSO to harmonize the day-ahead and intraday markets prices and facilitate cross-border trading (European Union, 2015). Today, the main market operator is EPEX SPOT (21.2 TWh traded day-ahead in 2022) and the second one is Nord Pool (9.2 TWh traded day-ahead in 2022)(Baringa Partners LLP, 2023).

Concerning the transmission capacity, it is operated by one TSO, Elia Transmission Belgium. Elia manages high-voltage network up to the distribution plants. From there, the Distribution System Operators (DSOs) take charge of distribution to residential customers (CREG, 2018). In Belgium, we count four main DSOs: Fluvius (Flanders), Sibelga (Brussels), ORES (Wallonia except Liege), and RESA (Wallonia, mainly around Liege). Those are responsible for managing the network that distributes electricity from the high voltage grid to consumers. This involves maintaining and upgrading the medium and low voltage infrastructure (Baringa Partners LLP, 2023). DSOs ensure that part of the market functions smoothly, without any commercial purpose. They are public structures that are partly financed by transmission and distribution costs, which are charged directly to the consumer (CREG, 2018).

2.2.2 Belgium's electricity mix

2.2.2.1 Electricity producers

In Belgium, the term "producer" is applied to any entity that generates electricity. This encompasses both private individuals (e.g., a household with solar panels) and corporate entities (grey or green power plants). No supply license is needed for the supply of green power through a direct line, for example. However, the generation market remains concentrated between the big historical producers. The 27GW of installed generation capacity[14] is dominated by Engie Electrabel (11GW) and EDF Luminus (approx. 2.3GW), accounting for approximately 50 percent of the total installed capacity (Baringa Partners LLP, 2023).

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[14] Capacity is a measure of the maximum amount of electricity the country's system can supply at any given time.

2.2.2.2 Capacity mix

This capacity mix is still dominated by natural gas and nuclear capacities, respectively accounting for 25 and 22 percent of the mix in 2022. However, following its denuclearization program, the Belgian government decided on the definitive closure of the Doel 3 reactor in late September 2022 and Tihange 2 in February 2023. Therefore, there was a drop in the nuclear generation capacity supposed to be offset by natural gas power plants. Under the same program, two other reactors are scheduled for shutdown by 2025 (Baringa Partners LLP, 2023).

On its side, generation capacity from green energies has leapt in recent years to reach 50 percent of the mix in 2022 (Baringa Partners LLP, 2023).

2.2.2.3 Electricity generation mix and pricing

Concerning the effective generation mix, we can see that it is historically dominated by nuclear and natural gas power generation. In fact, the geographical constraints are impeding the capacity of renewable energy sources to assume a more prominent role in the production process (Baringa Partners LLP, 2023). For example, in 2022 and 2023, we see that the generation mix was dominated by 74 and 66 percent by the two above-mentioned sources (see Appendix 9) (Elia, 2024). Nevertheless, if we look at the available data, the renewable energy systems have seen a steady growth. Wind energy, in particular, has seen a drastic increase in its use with offshore farms playing a prominent role (CREG, 2023).

It is therefore logical, by the Merit Order principle and its marginal power stations, that gas prices usually have a significant impact on electricity prices in Belgium. In fact, gas power plants are often the last to be called upon by the NEMOs to generate electricity. This makes the country one of the most sensitive to gas price variations in Europe (Kosch & Blech, 2022).

2.3 Recent changes following the Russian invasion

As previously outlined in section 1.1.3 (International trade and cooperation for energy resources), Europe and its electricity market have historically relied on foreign energy resources. Until February 2022, Russia constituted its primary energy supplier. However, Russia's invasion of Ukraine has led to a notable deterioration in the bilateral economic relations with the EU. As the exchanges in the energy sector came to a halt, a historic rise in prices, and particularly gas prices, was observed. In order to mitigate the effects of the crisis on its electricity market and to reduce the potential impact of future uncertainties, the European

Union implemented a series of measures concerning its electricity mix and its international trade relationships for energy resources. (European Council, 2023).

During an informal meeting called "The Versailles Declaration" on March 11, 2022, the EU leaders agreed on the necessity for measures to be adopted in the energy sector. These political figures concurred on the need of a gradual reduction in the European reliance on imports of Russian gas, oil, and coal. Following this meeting, the European Commission was invited to propose, by the end of May 2022, a REPowerEU plan to make the EU members independent from Russian fossil fuels (European Council, 2022).

After elaboration, the plan presented on 18 May 2022, focused on three main areas.

The first set of measures concerns energy savings through the reduction of consumption. Those measures aim at reducing energy consumption by 13% by 2030 through behaviour changes and smart investments. To supplement the REPowerEU plan in the short term, in July 2022 the Commission proposed a gas reduction plan. This one, more focused on the short term and urgency of the situation, set a target for all member states to reduce gas demand by 15% between 1 August 2022 and 31 March 2023 substituting it with other energy resources (European Commission, 2022d). This gas reduction plan, among other things, supported another measure, the one on gas storage published a month earlier. Indeed, the adoption of the new storage rules required member countries to reach 80% gas storage capacity by November 2022, in order to ensure supply to the European network during the winter of 2022-2023. Therefore, the reduction in gas consumption between August and March of those same years enabled Europe to reach these safety levels to avoid shortages (European Commission, 2022b).

The second point of focus concerns the diversification of energy imports. This is achieved mainly by strengthening partnerships with international reliable suppliers and increasing the use of LNG terminals. In that sense, between 2022 and 2024, new or consolidated gas import agreements were concluded with the USA, Norway, Azerbaijan, Israel and Egypt (European Commission, 2022c). To supplement these partnerships, the European Commission has decided to launch the EU energy platform in May 2023, called AggregateEU. The platform facilitates the sharing of demand bids coming from European members and enables international partners to respond via supply bids, thereby fostering increased market competition and transparency (European Commission, 2022c).

The final focus of the REPowerEU plan concerns renewable energies. Indeed, the disastrous situation with Russia has prompted the EU to move away from fossil fuels and turn as quickly as possible to locally-produced renewable energies. These measures include an increase in the renewable energy target to 45% by 2030.

In addition to the measures included in the plan described above, two other major European policies were implemented.

First, a market mechanism to limit excessive gas and electricity prices spikes was implemented in October 2022. In fact, if natural gas price on the TTF[15] market exceeds 180€/MWh for three working days, member countries can apply a price ceiling on it and suspend transactions above the limit. The agreement responds to the call for the creation of a price mechanism to limit extreme gas price peaks while ensuring security of supply and market stability in the EU (European Council, 2022). In Europe, the common price cap is therefore 180€/MWh, but some countries like Belgium are more stringent, imposing a price cap of 130€/MWh (Baringa Partners LLP, 2023).

Secondly, the European Council requested that its members reduce their electricity consumption by 5% during peak hours. This contributes to a reduction in the necessity for gas-fired power plants and a stabilization of electricity prices. Member States have been encouraged to implement a variety of demand reduction measures, including national awareness campaigns, regulatory measures to limit non-essential consumption, and incentives for consumers to reduce their electricity use (European Council , 2022).

In conclusion, as described, the European electricity market, and more broadly the European energy market, has been particularly prone to turbulences as a result of this exceptional situation. It is evident that future work and measures are still required before its operating mode stabilizes into a fixed form. However, here again through this unusual situation, a clear indication for a transition to a more eco-responsible energy mix is observed. Additionally, this transition would have a beneficial effect on the second European objective of achieving greater autonomy on the energy market, consequently facilitating the development of a more independent European electricity market.

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[15] This index reflects the monthly average prices of natural gas traded at the Title Transfer Facility (TTF), a major European gas trading hub. The TTF index serves as a benchmark for market prices in Europe.

3. Methodology

The methodology section consists of a thorough explanation of the methodology used to conduct the quantitative analysis.

3.1 Data collection

In order to answer the research question and its various subsections as fully as possible, the selection of representative data required rigorous selection and analysis. To achieve this, it was first necessary to gain a comprehensive understanding of the functioning of the European electricity market and of the forces that influence the electricity prices, through the literature review. Following this, we were able to better determine the variables to be analyzed in order to assess the direct and indirect impact of the war in Ukraine on electricity prices, and the effectiveness of the measures implemented.

The quantitative data related to these variables were collected via supranational databases such as Eurostat and Ember, but also via local databases in the specific case of Belgium, such as CREG (Commission de Régulation de l'Electricité et du Gaz). The sample used covers the period from 2015 to 2024 on a monthly basis for each variable. This allows us to observe those during a period of economic stability when they seemed to be following their normal course, before being disrupted by various events.

3.2 Variables identification

3.2.1 Electricity prices

It seemed obvious that the first variable to focus on would be the price of electricity, in order to observe its variations. Indeed, it is important to have these figures to be able to measure the impact of different events over time, whether it be the start of the war and its effects, or the implementation of European solutions to mitigate them.

Two observation poles were selected. First, the focus is on the electricity price for the EU27, based on a monthly average of prices across member countries. Secondly, the other point of attention is Belgium’s monthly electricity price, given the focus of the research question. The data collected for these two entities range from January 2015 to June 2024.

The electricity prices selected are those of the day-ahead market in euros per megawatt-hour, as they best reflect the dynamics of the European market and its main players. In fact, they are based on the market coupling of supply and demand on the wholesale market, and are determined by the EUPHEMIA algorithm through the entire European electricity market (ENTSO-E, 2024). Therefore, these data offer the most accurate representation of market dynamics, supply-demand balance fluctuations, and geopolitical events impacts.

3.2.2 Gas prices

The second variable selected, in view of its influence on electricity prices in Europe and more specifically in Belgium, is the mensuel gas prices. Indeed, the effect of the latter through the Merit Order principle is not negligible. Belgium is one of the European countries where the marginal cost of electricity is most often defined by a natural gas power plant. The EU27 are also greatly dependent on it, although there are notable variations between members. Indeed, some European countries seem to be slighlty less affected by the situation, given their electricity mixes, which depend on other energy resources. European data should therefore be treated with a high degree of caution. Finally, the gas trade was one of the flows most affected by the war in Ukraine. Indeed, we have seen a sharp drop in pipeline imports from Russia in recent years. Consequently, the majority of resolutions pertaining to the electricity market were, in fact, direct actions concerning gas, encompassing aspects such as gas supply, the reduction of gas consumption, and the imposition of a price ceiling on gas.

For data selection, we used the TTF101 index price. This index reflects the monthly average prices of natural gas traded at the Title Transfer Facility (TTF), a major European gas trading hub. The TTF101 index serves as a benchmark for market prices in Europe, making it appropriate for analyzing electricity price formation through the Merit Order principle (European Commission, 2024b). Monthly prices in euros per megawatt hour were collected for Belgium and the EU27 between January 2015 and March 2024.

3.3 Data analysis

"What impact had the war in Ukraine on the pricing of electricity in the European Union, in particular Belgium, and how effective were the measures put in place to mitigate the price increase?"

This research question will be answered through a quantitative study in two steps.

3.3.1 Explanatory research

First, as described in the "Research gap, question and nature " section (1.2), it is important to tackle the explanatory part of the research. Given the influence that primary energy resources have on the formation process of electricity prices, it seemed primordial to define the relationship between natural gas and electricity prices. The aim here is to understand and assess the mechanism through which the war in Ukraine impacts the pricing of electricity in Europe, and particularly in Belgium. Additionally, assessing the degree of influence of gas prices on electricity prices, will also help to understand the mechanism through which mitigation measures are intended to have an impact.

In view of the importance of the Merit Order principle in the electricity price formation process, we will carry out a causal bivariate analysis using the "Simple Linear Regression" model for those two variables at European and Belgian level. To this end, we use the following equation:

$$Y= \beta 0 + \beta 1X + \epsilon$$

Where Y is the dependent variable, the electricity price. X is the independent variable, the gas price. $\beta 0$ is the intercept, $\beta 1$ is the slope, and ϵ is the error term, the difference between the observed and predicted values of Y[16].

A relationship of dependence exists between the two variables, as supported by many researchers in the literature review. Our aim here is to assess the significance of this correlation at both European and Belgian level, and to analyze the degree of correlation between 2015 and 2024. It will be done through the computation of the coefficient of determination (R^2), for each of the two geographical zones[17]. This will enable us to confirm the degree of impact of a variation in gas prices on electricity pricing at these two geographical levels.

3.3.2 Evaluative research

The second section of the research question pertains to the evaluative aspect. The first objective of this part is to evaluate the impact of the war on electricity prices. The second one is to assess

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[16] The mathematical model for obtaining the various parameters is described in greater detail in the Appendix 10.

[17] The mathematical model for obtaining the coefficient of determination is described in greater detail in the Appendix 10.

the effectiveness and impact of European policies and interventions[18] aimed at mitigating the increase in electricity prices at the EU27 and Belgian levels.

To assess the impact of the war on electricity prices, we begin with a univariate descriptive analysis of the evolution of its annual average price[19] and volatility (standard deviation) with a particular focus on periods of high variation (2021-2022) for the two geographic zones. As explained, given the influence of gas prices on electricity pricing, the same analysis will be carried out for this variable, separately. This will enable us to measure the impact of the war in Ukraine on those two different prices over time.

Then, in order to ascertain the efficacy of the measures implemented by the EU to counterbalance the war's impact, it is essential to establish a set of criteria for evaluation. Here again, the effectiveness of mitigation measures will be reflected in the EU27 and Belgian gas and electricity prices. Therefore, to assess the impact of the REPower EU plan and the two other major European policies, we will continue our univariate descriptive analysis of the evolution of their annual average prices[20] and volatilities (standard deviations) for the two geographic zones. However, for this evaluative part, the emphasis will be on the period of implementation of these solutions up to the present day.

4. Findings and Analysis

4.1 Explanatory research

The aim of this section is to explain the main mechanism by which the war has had an impact on electricity prices. In the same way, it will help us to understand where mitigation measures have sought to have an impact to counter rising prices.

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[18] The list of measures implemented by the EU is not exhaustive in this work. Indeed, the main measures concerning the European electricity market are included, but some countries, depending on their electricity mix, may have implemented additional measures.

[19] For the EU27 data, the monthly average prices of both electricity and gas are computed through a mean of the members' monthly prices. Afterwards, the annual average price is computed with these average monthly members' prices.

[20] For the EU27 data, the monthly average prices of both electricity and gas are computed through a mean of the members' monthly prices. Afterwards, the annual average price is computed with these average monthly members' prices.

4.1.1 *Correlation between gas and electricity*

Given the importance of gas prices in electricity pricing and the direct impact of the war on this variable, it is important to assess the degree of dependence between gas and electricity prices using simple linear regressions for our two geographic areas. In the same way, most of the mitigation measures implemented in Europe focus directly on gas to have an impact on electricity, which increases the interest in assessing the relationship between the two variables. As a reminder, we use the following equation for the linear regression line: $Y= \beta 0 + \beta 1X + \epsilon$.

Using gas and electricity price data for the EU27 between 2015 and 2024, we obtain the following equation: $Y = 16.6 + 1.68X$. The gas price coefficient indicates the anticipated change in electricity prices for each unit change in gas prices. In this case, for every 1 €/MWh increase or decrease in gas prices, the electricity price is projected to vary by approximately 1.68 €/MWh. The y-intercept (16.6) represents the value of the electricity price when the gas price is zero. Although a scenario in which gas price is equal to zero is not realistic, the intercept provides a baseline level of electricity prices, assuming that gas prices have no influence on the results (see graph, Appendix 12).

After calculating the linear regression, it seemed important to obtain the coefficient of determination. This coefficient, called R-squared, indicates the proportion of the variance in the dependent variable that is predictable from the independent variable. For the EU27, the R-squared value is 0.962, indicating that 96.2% of the variability in electricity prices can be attributed to the variability in gas prices. This high value indicates the presence of a robust linear relationship between the two variables. This indicates that fluctuations in gas prices exert a considerable influence on those of electricity, with changes in the former largely responsible for subsequent changes in the latter.

On its side, a review of the data for Belgium between 2015 and 2024 reveals the following equation: $Y=15.29+1.76X$. This equation suggests that for each 1 €/MWh variation in gas price, electricity price is expected to rise or fall by approximately 1.76 €/MWh. Here, the y-intercept is 15.29, representing the value of the electricity price in Belgium if the gas price was zero (see graph, Appendix 13).

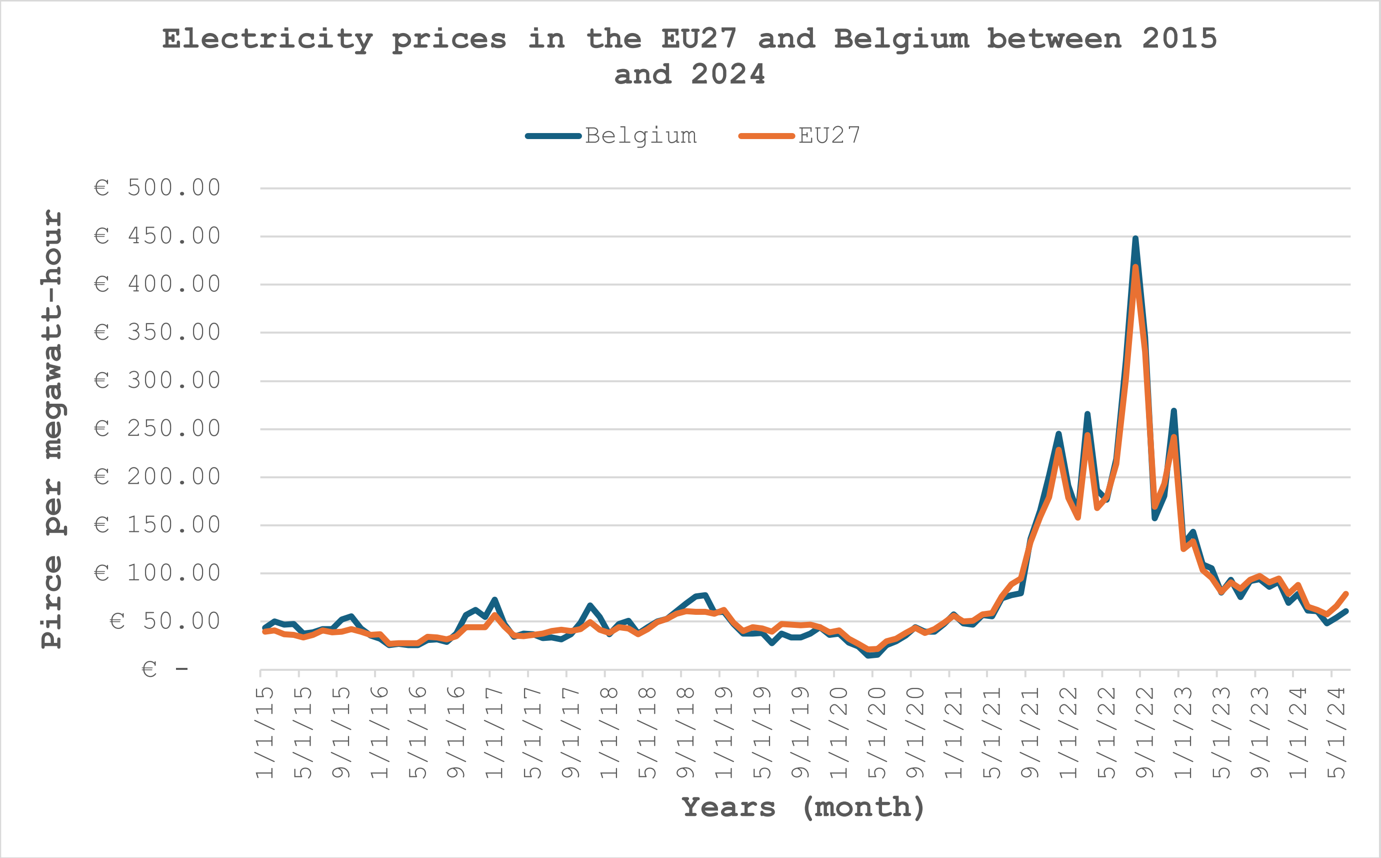
The value of the coefficient of determination is 0.954 meaning that 95.4 percent of the variability in electricity prices can be explained by the variability in gas prices in this country. Once again, the high R-squared value indicates a strong linear relationship between gas and electricity price.

4.2 Evaluative research

This section presents a review of the evolution of electricity and gas prices between 2015 and 2024 for the EU27 and Belgium. The first objective is to assess the impact of the war on electricity prices. In the same way, the second objective is to evaluate the effectiveness of the mitigation measures quantitatively, by observing the evolution of the prices of our two variables.

4.2.1 Electricity prices evolution

In this section we review the evolution of electricity prices between January 2015 and June 2024 for the EU27 and Belgium.



Data source: (Ember, 2024)

The analysis of this first variable reveals very clear trends over the years. For both the EU and Belgium, electricity prices appear to be relatively stable between 2015 and 2020, with annual means fluctuating between 30 and 55€/MWh. The standard deviations of these annual prices, based on monthly average prices, were between 2 and 9 for the EU and between 6 and 14 for Belgium, indicating a great stability on the market.

Then, 2021 marks a clear break with the stable trend in electricity prices. Here we see an increase of 195.6% (EU) and 225.9% (Belgium) compared to the 2020 average price. Prices will then continue to rise, more than doubling over the year to reach record average rates in 2022. That year, the average electricity price was €233.11/MWh for the EU27 and €243.77/MWh for Belgium.

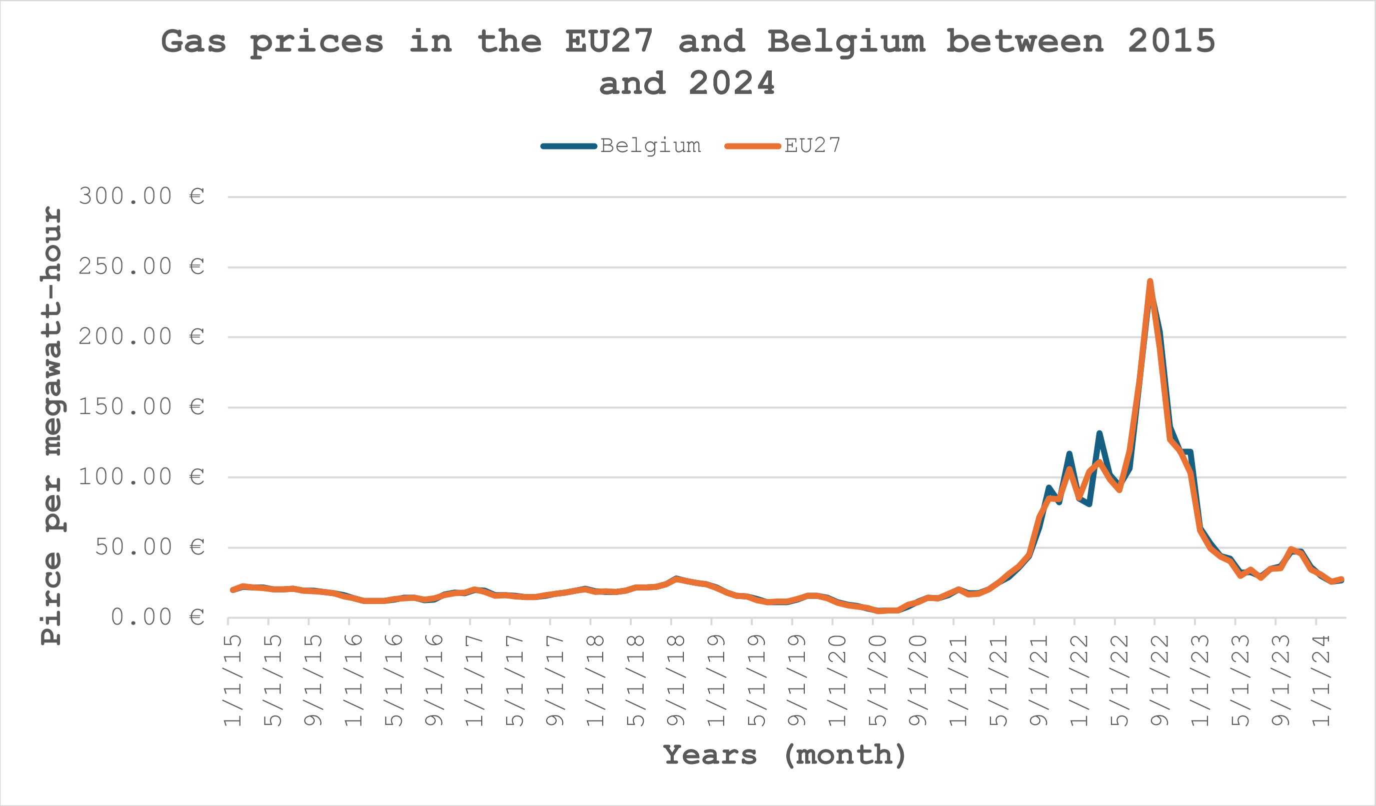
These two years were also marked by significant fluctuations, making electricity prices particularly volatile for 24 months (see Appendix 14). In 2022, for the EU27, the standard deviation was more than 12 times its usual median value, giving rise to a price dispersion as unique as it is frightening. August was the most expensive month, with an average value of €418.5/MWh, while October, although still very high, only reached €158.2/MWh. For Belgium, the standard deviation reached 89.6€/MWh, which is more than 7 times the median value of this statistic between 2015 and 2020. This variability resulted in a spread of 448.1 €/MWh in August and 157.5 €/MWh in February of the same year.

After that period electricity prices for the EU27 gradually fell back, to finally reach levels just above those of the stable period at the start of 2024. There has only been, a slight upturn in December 2022, when prices rose again to 242€/MWh, before resuming their downward trend. In 2024, the EU27 electricity prices remain around 1.5 time higher than between 2015 and 2020, but we continue to observe an overall decline over the first semester. In terms of stability, electricity prices have fallen from a standard deviation of 80.1 in 2022 to just 16.5 in 2023, which is quite impressive. In the first half of 2024, they continued to stabilize to finally reach a standard deviation of 11.6.

In Belgium, prices followed the same trend as for the EU27. A similar upturn has even been seen in December 2022, with prices rising to 268.9€/MWh. Since then, there has been a steady decline. Prices in 2024 remain slightly high but we continue to observe a decline over the months. For what concerns volatility, standard deviation followed the same course but eventually returned to a perfectly normal rate in 2024.

4.2.2 Gas prices evolution

In this section we review the evolution of gas prices between January 2015 and March 2024 for the EU27 and Belgium.



Data source: (CREG, 2024)

Regarding the fluctuations in natural gas prices, a similar trend can be observed between 2015 and 2020 for both geographical zones. The period in question can be characterized as one of relative stability, with prices remaining at a consistent level of approximately 20€/MWh, although there was a brief decline in the first few months of 2020, which brought the average annual price for this period down to around 10€. The annual volatility of gas prices, based on monthly data, is minimal, with standard deviations ranging between 1 and 4€/MWh over the same period for the two entities.

Subsequently, in a manner comparable to the trajectory of electricity prices, costs escalated in 2021, to finally reach historic peaks of 240.16 (EU27) and 235.78 (Belgium) euros per megawatt-hour in August 2022. In view of this important increase, the average price of gas in 2022 for the EU27 reached 130.27€/MWh, reflecting an increase of 179% between 2021 and the following year. It should also be noted that the average price had already risen from 9.61 to 46.61€/MWh between 2020 and 2021, representing an increase of 384%. In Belgium, the average annual price rose to €131.99/MWh in 2022, an increase of 179.8% compared to 2021. The previous year, this price had already risen by 393.7%.

Additionally, as for electricity prices, a wide variance was observed that year, making the standard deviation rise from around 4 in 2020 to over 45 for our two zones in 2022.

However, as from August 2022, gas prices have gradually fallen back, similarly to the other variable. In fact, there has been a general fall in gas prices since then, with a slight upturn in December 2022 for both zones.

The EU27 average annual price has therefore fallen from 130.27€/MWh in 2022 to 28.06€/MWh at the start of 2024. Nevertheless, prices remained slightly higher in 2024 than between 2015 and 2020. Volatility also remained higher than usual, at 9.76 in 2023. However, there was a clear improvement when compared with the 2022 value of 46.87.

Belgium on its side is no exception. Between 2022 and 2024, it has seen a decline in gas prices on its territory. Average annual prices have fallen from 131.99€/MWh to 27.34€/MWh at the start of this year. This remains above the average price of 16.26€/MWh between 2015 and 2020, despite a clear improvement over the last two years. Volatility also fell, from 48.3 to 10.12 between 2022 and 2023. Despite an improvement, it remained slightly high, although it seems to be stabilizing at the start of 2024.

5. Discussion and Interpretation

5.1 Interpretation of the results

5.1.1 Impact of the war and mitigation measures on electricity prices through the pricing mechanism

By examining the results and the evolution of our two variables, we have been able to assess the interdependent relationship between gas and electricity at the EU27 and Belgian levels. This has enabled us to gain a deeper knowledge of the impact of the war in Ukraine on the European electricity market, as well as of the impact of the policies put in place to counter its effect. Indeed, we understand that these events had strong marked direct effects on the price of primary resources, particularly gas. Through the linear regression model, we now understand the extent of their indirect impacts on electricity prices and on their formation processes in the two zones.

The results for the European Union demonstrate a statistically significant linear relationship between gas and electricity prices. It can thus be observed that the increase or decrease in gas price on the European market directly induces a proportionally greater increase or decrease in electricity price (times 1.68). Moreover, it can be demonstrated that 96.2 percent of the variability observed in electricity price can be attributed to fluctuations in the price of gas, which represents a significant factor.

Similar results can be observed for Belgium. In fact, the linear relationship shows a significant influence of the gas price on the electricity price. Here again, an increase in the price of the first variable induces a proportionally higher increase in the second (times 1.76), and the same for a decrease. Additionally, for the Belgian market too, the variability of electricity prices can be significantly explained by the variability of natural gas prices, at 95.4 percent.

Therefore, if we compare the two linear regressions, we notice very similar patterns. Nevertheless, the price of electricity in Belgium is more sensitive to changes in gas prices than the price for the EU27 as a whole. This can be explained by the different electricity mixes used by the member countries. Indeed, countries that produce a large part of their electricity from natural gas, such as Belgium, have seen their electricity prices rise drastically with the increase in gas prices in recent years. Similarly, the reduction in gas prices led to a proportionally greater fall in electricity prices for Belgium than for the EU27 average electricity price. Other EU27 member countries, such as Sweden, prioritize other energy sources in their electricity mix, and have therefore seen their electricity prices vary to a lesser extent. Average European electricity prices were therefore slightly less sensitive to an increase or decrease in gas prices than Belgian prices alone.

5.1.2 Impact of the war on gas and electricity prices

In terms of numbers, the observations underline the significant impact of the war on gas and electricity prices in 2022. Although the price of the primary energy resource was already high in 2021 due to the economic recovery in the aftermath of Covid, the war clearly prolonged and fortified this extreme inflation. As a matter of fact, the lack of natural gas supply in Europe due to the war created additional disruptions.

Indeed, for the EU27, we see that the average annual gas price had never been as high and volatile as it was in 2022. It reached 130.27€/MWh, an increase of 179% compared to the same statistic for 2021, which had already risen by 384% compared to the previous year.

Consequently, the average annual electricity price was more than doubled between 2021 and 2022, rising from 102.66 to 233.11€/MWh, reflecting an increase of 127% and following the 196% increase of previous year.

In Belgium, prices have also followed the upward curve from 2021 to 2022. The average annual gas price reached 131.99€/MWh following exactly the same increase as the EU27 that year. Between 2020 and 2021, the country saw its gas price rise by 393.7%. Concerning the dependent variable, the electricity price rose by 134.8% in 2022 and by 225.9% between 2021 and 2020.

Here we can observe the slight difference between our two regions and how they have been affected by the war. Indeed, electricity prices in Belgium seem more affected by variations in gas prices than the EU27, given its electricity mix. Once again, this can be explained by the fact that some other members counterbalance the linear relationship through electricity mixes that rely on other energy resources. Nevertheless, the general trend remains the same for both entities. As gas prices rose sharply in 2022, so did electricity prices. What's more, the war has made these prices highly volatile for the two geographic zones.

5.1.3 Impact of the mitigation measures on gas and electricity prices

If we now look at the impact of the mitigation measures, it reveals a markedly different curve from that observed in the first part of 2022. Once the initial effects of the first implemented measures were felt, a downward trend in gas and electricity prices began. This trend has persisted to the present day.

Indeed, the price hike of 2022 had brought average annual gas price to 130.27€/MWh and electricity price to 233.11€/MWh for the EU27. Between 2022 and 2023, the policies implemented have succeeded in reducing these rates by 68.84% and 58.2% respectively. In 2024, these measures have continued to lower rates, although the price of gas remains 1.73 times higher than during the stable period from 2015 to 2020. On its side, the price of electricity remains 1.7 times higher for the EU27.

Belgium logically followed similar curves. It registered its highest annual rates in 2022, 131.99€/MWh and 243.74€/MWh, for gas and electricity respectively. Then, by following European directives, this country succeeded in lowering the annual average price of gas by 68.5% and the annual average price of electricity by 60% between 2022 and 2023. Nevertheless, in 2024, as for the EU27, its annual prices remain above the rates seen between

2015 and 2020. The price of gas remains 1.68 times higher, while the price of electricity remains 1.44 times higher.

From these results, we understand that the mitigation measures have been particularly effective in tackling the energy crisis on the European electricity market. Since August 2022, the European Union has been able to reverse the trend and force prices down. Nevertheless, in view of the rates observed at the start of 2024, it is vital to continue these efforts to return to more reasonable rates, as they remain abnormally high, even when annual inflation is considered.

5.2 Relation to literature review

5.2.1 Relationship between the pricing mechanism and the results of the study

The literature review provided insight into the operating model of the European electricity market, and particularly on the electricity pricing mechanism. While there are some variations between member states, one of the pillars of this system, which applies to all, is the Merit Order principle. Indeed, the definition of prices on the day-ahead market depends very much on the marginal cost of the bidding zone. This marginal cost represents the expense incurred by a power plant to produce one additional megawatt-hour of electricity on the next day (EPEX Spot, 2024). The zonal marginal cost is set by the marginal power station which is the last entity to be called upon to produce electricity for the next day following the Merit Order principle. According to the literature review, this role is mainly attributed to gas or coal power stations in Europe. As a result, fossil energies are significant drivers of electricity prices.

The quantitative results of this study clearly point in this direction. Indeed, the linear regressions show a high degree of dependence of electricity prices on gas prices for the two geographical zones observed. More than 95% of the variability in the electricity prices can be attributed to gas prices for the EU27 and Belgium, following the calculation of coefficients of determination.

We can therefore see that the theory underlying the functioning of the European electricity market, and its pricing mechanism, is well supported by the data collected and the statistics presented.

5.2.2 Relationship between the mitigation measures and the results of the study

As evaluated through the quantitative study, the price of electricity is highly dependent on variations in the price of primary energy resources, especially gas. Furthermore, as explained in the literature review, one of the points leading to uncertainty towards the European electricity market is its dependence on external partners for its supply. In order to reverse the prevailing trend of 2022 and bring prices down, the European Commission has introduced measures to stabilize the gas market and reduce uncertainty towards its supply.

Indeed, the price reduction was first made possible by regulating the supply-demand equilibrium[21]. Demand for natural gas fell from August 2022 thanks to three main measures. First, the EU has called for an effective 15% reduction in gas consumption by its member countries. Then, through the REPowerEU plan, other energy sources such as green energies have been prioritized for various sectors, including the production of electricity. Finally, the European Council has asked its members to reduce their electricity consumption to rely less on gas-fired power plants and stabilize electricity prices. Taken together, these measures have clearly led to a fall in demand, which in turn has driven down supply prices.

Moreover, it was necessary to restore market confidence by reassuring gas supply. To this end, Europe has established and strengthened five direct gas supply partnerships between 2022 and 2024 with more reliable partners. It has also implemented the EU energy platform, giving access to supply bids from other international partners. These measures have greatly diversified the EU gas supply, giving it greater stability and lowering its unprecedented 2022 volatility.

Another measure had a direct impact on the gas prices. Indeed, the market cap introduced by the EU in October 2022 and reinforced by certain countries such as Belgium has blocked supply bids that did not meet the desired criteria, forcing them to lower their prices to access the European market. Since then, the data collected has not exceeded it, testifying to its efficiency.

The REPowerEU plan, on its side, calls for a gradual shift away from natural gas for power generation towards other energy resources. Over the long term, we should therefore see a diminishing impact of gas prices on electricity prices.

Finally, through its different measures, the European Union managed to have a considerable influence on the gas prices, which subsequently resulted in a reduction in electricity prices. Nevertheless, as demonstrated by the outcomes, prices in 2024 remain above the norm,

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[21] Russian gas supplies to Europe have fallen sharply as a result of the conflict in Ukraine.

underscoring the necessity for the continued implementation of these measures. Furthermore, it is apparent that some of these measures necessitate a lengthy implementation period and are intended to yield long-term outcomes.

5.3 Limitations and future work

In the course of researching and writing this work, we came across several limitations. It was important to point them out to maintain the objectivity and credibility of this work. What's more, we see that these limitations open possibilities for future research of interest.

First of all, although the analysis of data for the EU27 gives us a good representation of the general trend in the European electricity market, this may differ from the local situation of the different members. In fact, some countries have an electricity mix composed mainly of other energy sources. Sweden, for example, has an electricity mix consisting mainly of hydropower and nuclear power. Therefore, we know that this country has been much less affected by the situation. Therefore, if we want to analyze the exact situation of a country concerning the impact of the war on its electricity sector, we need to refer to the general European trend given the various links in the network, but it is also important to analyze the country's own data in depth.

Secondly, regarding the analysis of gas and electricity prices, it is difficult to make a real distinction between the impact of the economic recovery after the Covid and the direct impact of the war in Ukraine. In fact, we can see that prices were already rising in 2021 and that the war intensified and prolonged this increase from February 2022. If we wanted to isolate the effects of each of these two events, we would have to build multivariate linear regression models, which would require much more technical and in-depth research. It would be interesting to conduct such research to assess the impact of each of these events separately on the European electricity market.

Finally, given the recent nature of the phenomenon studied, it is difficult to assess the total impact of these mitigation measures. Indeed, we were able to observe their effects between their implementation and the present[22]. It would therefore also be interesting to measure their effectiveness over the long term. The evolution of the European electricity mix towards more eco-responsible resources and the use of the energy trading platform are two good examples.

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[22] We were able to assess their effect until June 2024 for the electricity prices and until March 2024 for the gas prices.

What's more, at the start of 2024, we observed that the two variables remained relatively high. Hence, it would be interesting to track these in the years to come to see if the measures have been able to bring them further down to lower levels, like those experienced between 2015 and 2020.

6. Conclusions of the study

Through this work, we were able to gather and master the necessary quantitative tools and link them to pre-existing knowledge in order to answer the research question underpinned by the problematic.

This problematic focused on the impact of the war in Ukraine and on the mitigation measures implemented to limit its effects on the European electricity market, with a particular focus on Belgium, in light of the exceptional disruptions observed in recent years. The aim was first to understand the mechanism and variables by which external events have impacted electricity prices. Subsequently, the objective was to evaluate the magnitude of their influence on electricity prices.

The primary finding of this research is the significant correlation between variations in gas and electricity prices. Already described as a determining variable in the literature review through the Merit Order principle, we were able to evaluate its influence statistically. To this end, simple linear regressions have been established for the EU27 and Belgium. For both zones, the equations obtained reveal robust explanatory relationships between the two variables. It is now clear that the Russian cutoff in gas supply and Europe's subsequent measures to mitigate the impact, particularly focused on natural gas too, have had a significant impact on electricity prices due to the dependence of the latter variable on the primary energy resource.

For the evaluative part of this work, we were able to observe variations in electricity and gas prices through univariate descriptive analyses. This enabled us to measure the impact of the war on electricity prices, as well as the effectiveness of the mitigation policies put in place. For both study regions, the observed curves are quite similar, although electricity prices in Belgium are slightly more sensitive to changes in gas prices induced by external events. Generally speaking, we see prices remaining stable between 2015 and 2020 for both variables. However, in 2021, prices rose as a result of the post-Covid economic recovery. In 2022, the war in Ukraine massively reinforced the prices rise by throwing the supply-demand equilibrium out of balance, reaching a peak in August. Subsequently, the initial impact of mitigating measures was observed, resulting in a decline in prices to lower and, notably, more stable levels. Nevertheless, current prices remain somewhat elevated in comparison to the standards.

Moreover, given the recent nature of the data and the need for observation time to measure the effects of mitigation measures, it would be interesting to continue this research in the future.

Finally, considering the problematic, we were able to develop elements of answer to address the research question. Our findings lent statistical support to the pre-existing theory regarding the explanatory part of the study. Those enabled us to identify the main parameters determining electricity pricing that were affected by the war and by the implementation of mitigation measures for the two geographical areas studied. Additionally, as underlined for the evaluative aspect of the study, we were able to furnish statistical data that quantify the impact of the two events in question on electricity prices for the studied period and for the regions in question.

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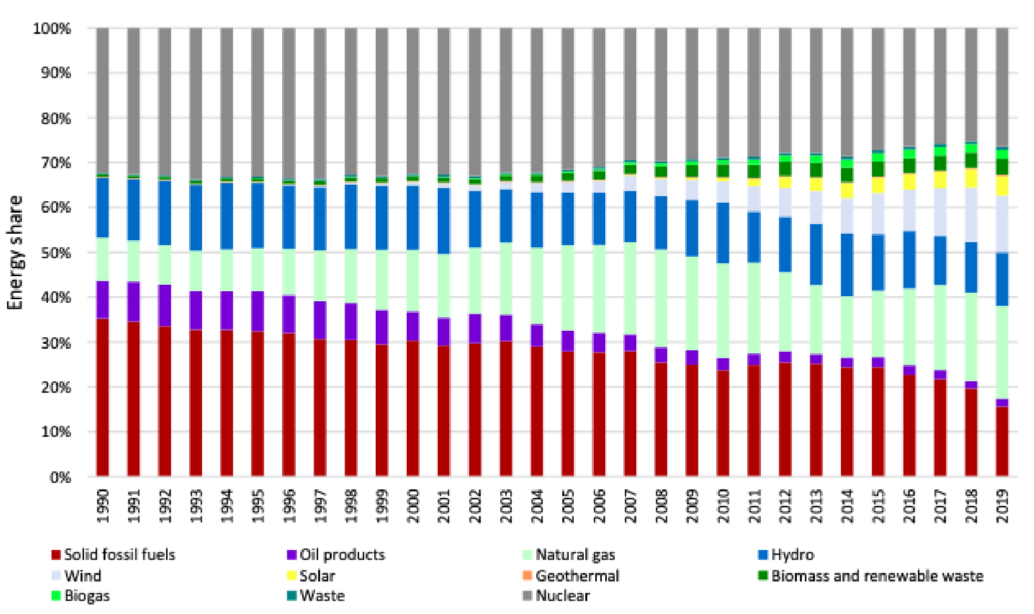
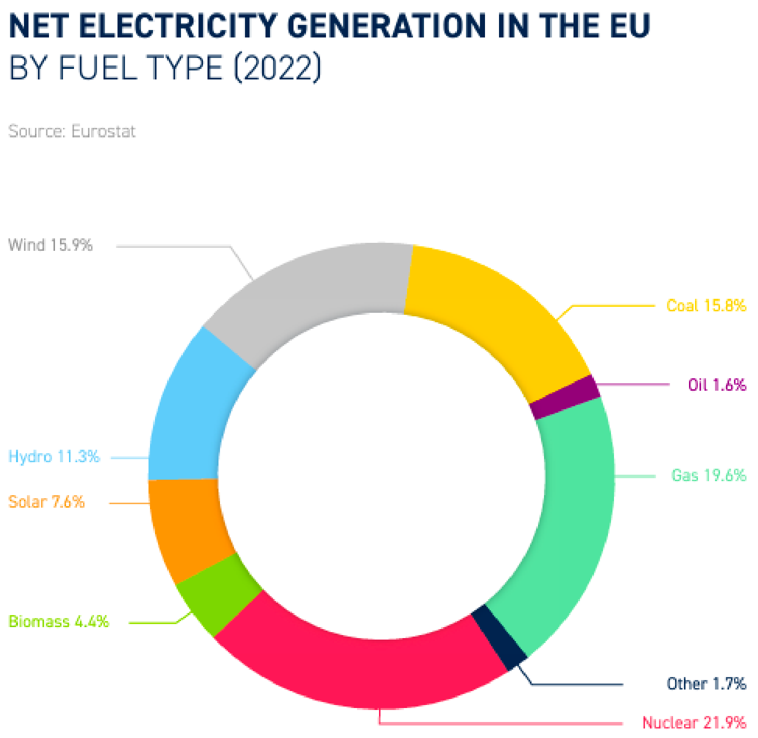
8. Appendices

8.1 Appendices, Literature Review

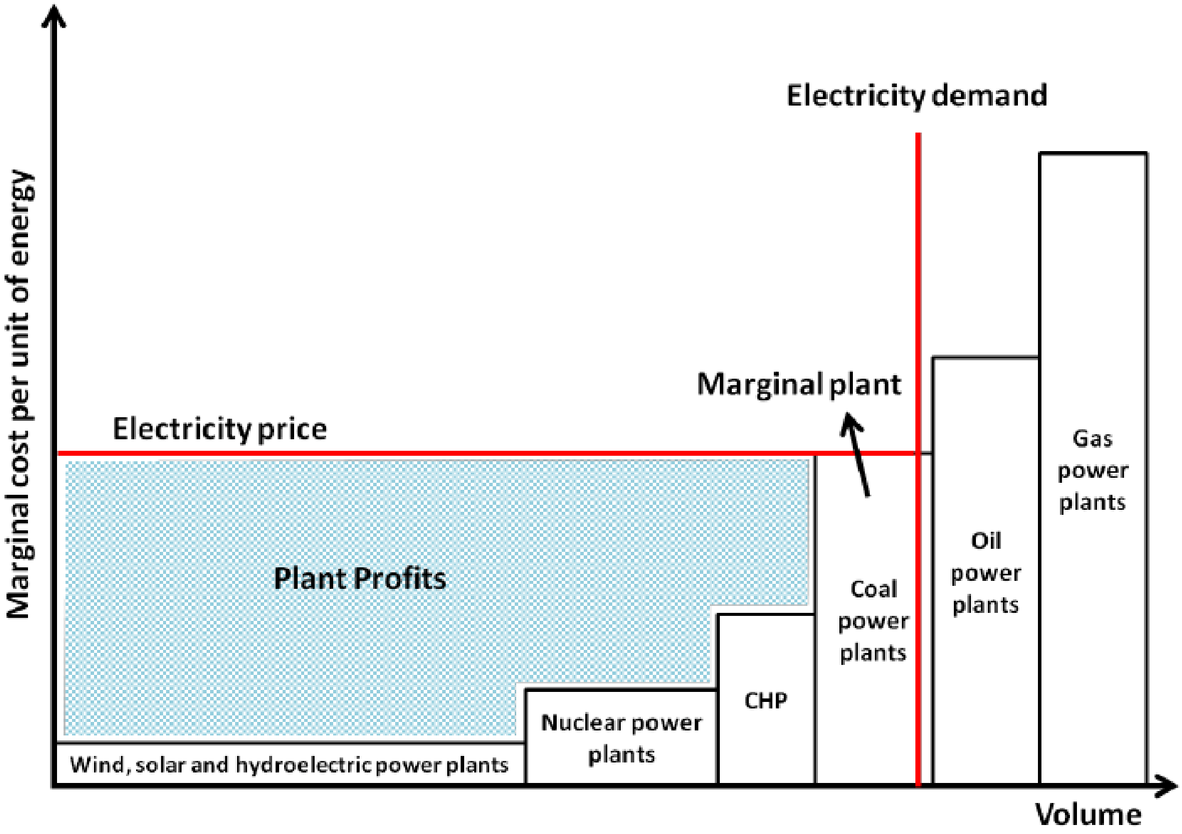
Appendix 1: Electricity production per source of energy, Europe (1990 – 2019)



Appendix 2: Electricity generation per source of energy, Europe 2022



Appendix 3: Merit-Order Principle



Appendix 4: Bidding Zones

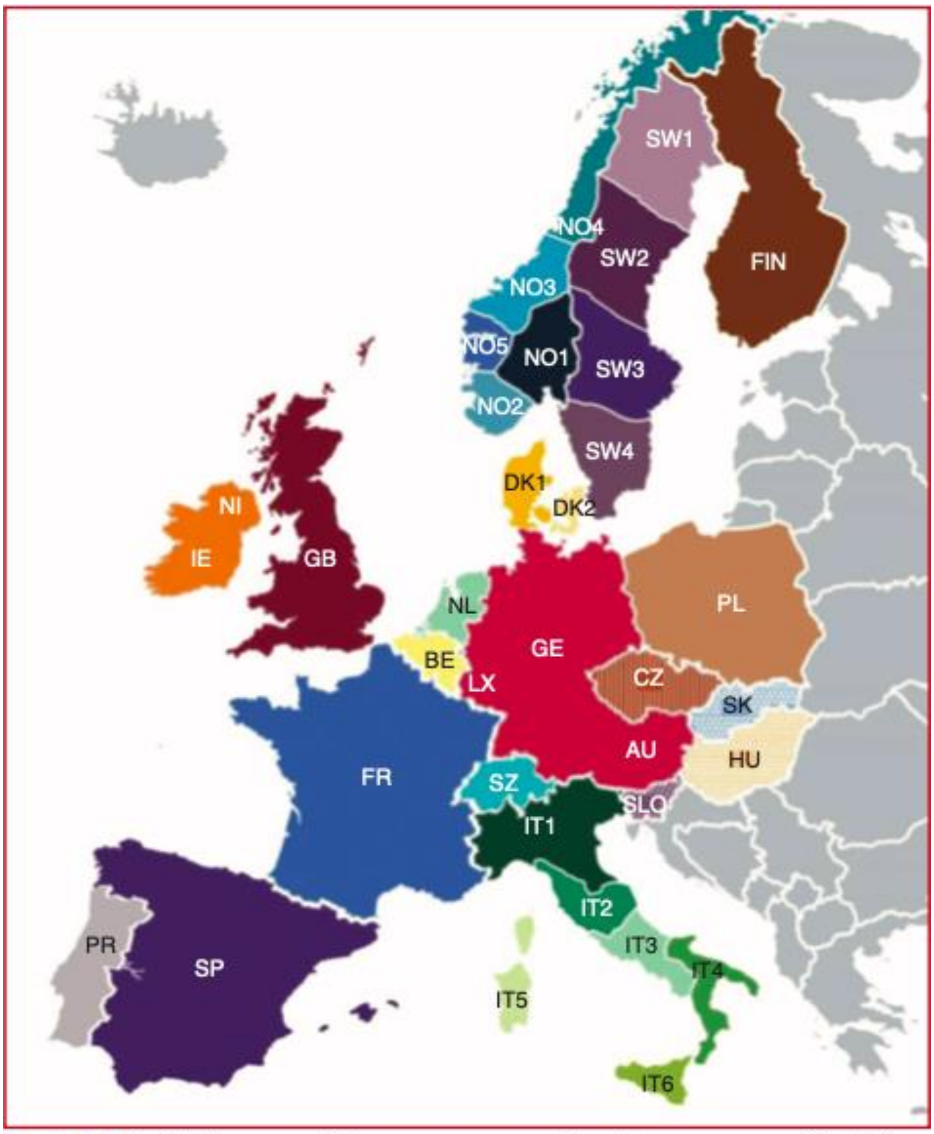
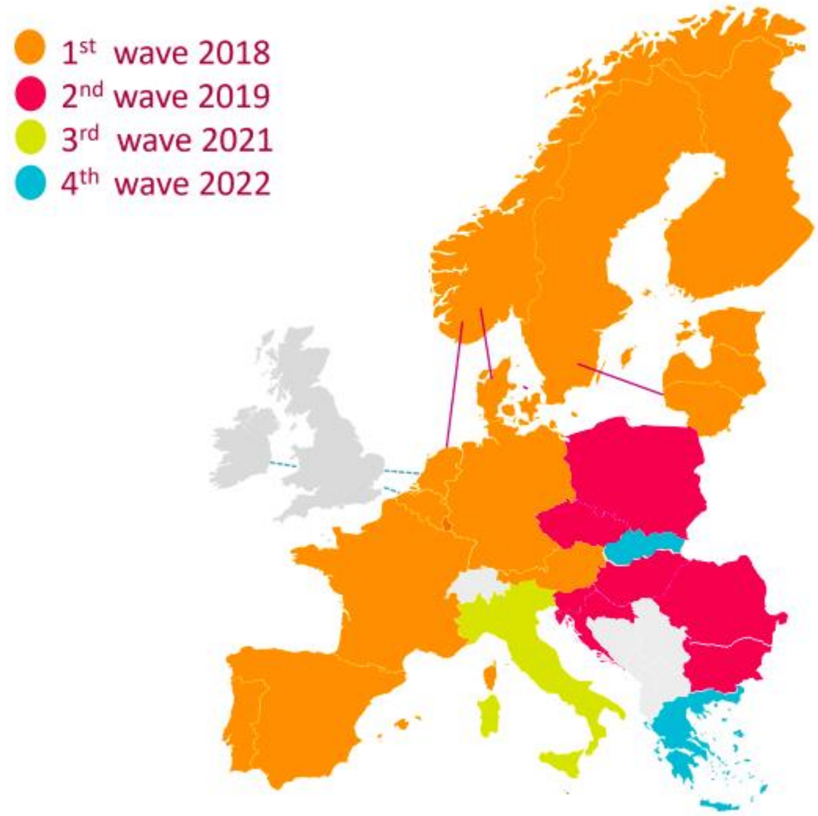


figure 1. The bidding zones in European power markets. (Image courtesy of the Office of Gas and Electricity Markets, "Bidding Zones Literature Review." London, United Kingdom, 2014.)

Appendix 5: Intraday market participants



Appendix 6: List of TSOs participating in the ENTSO-E

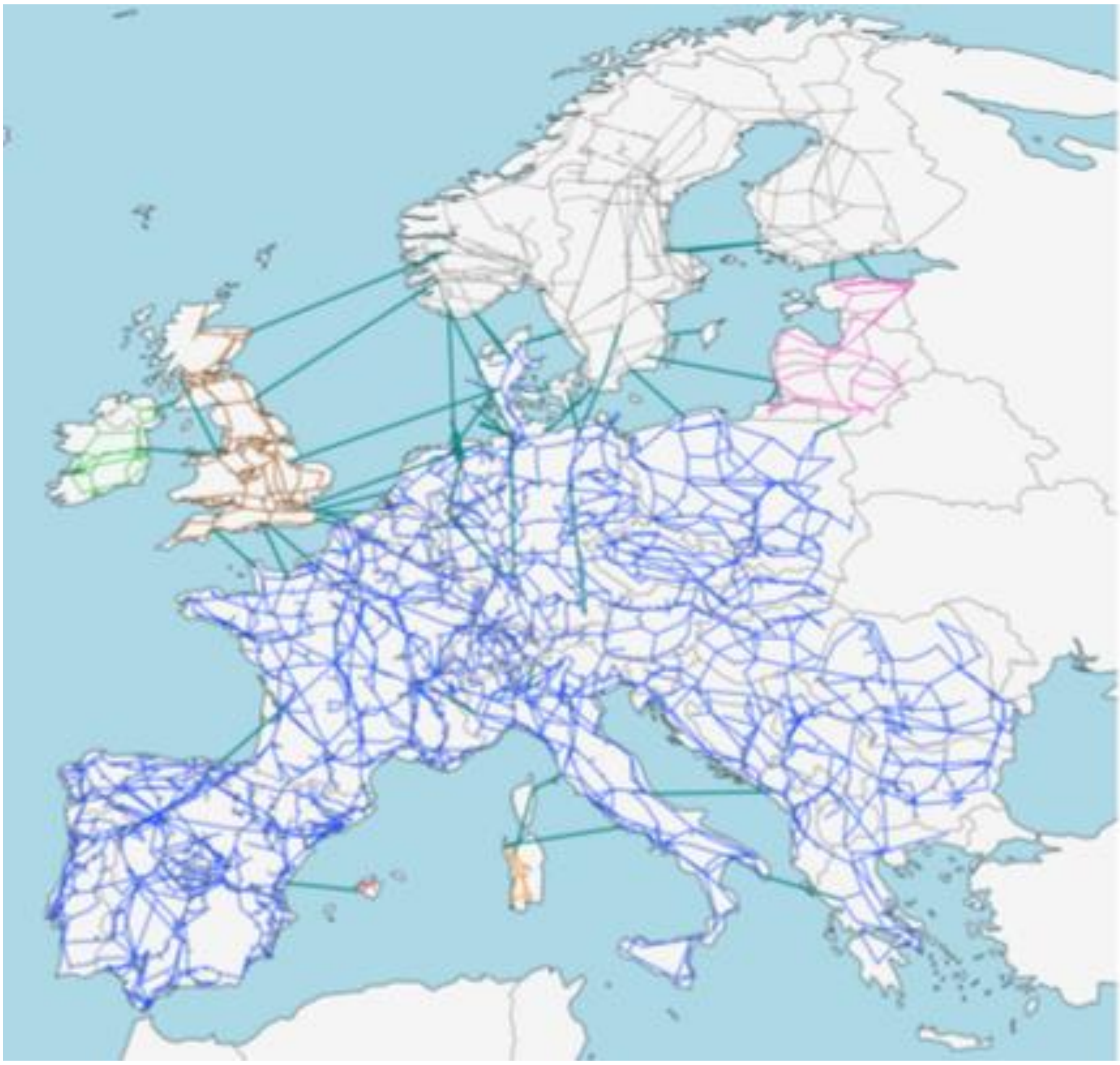
Country		**Company**	**A**
AT	Austria	Austrian Power Grid AG Vorarlberger Übertragungsnetz GmbH	
AL	Albania	OST sh.a – Albanian Transmission System Operator	
BA	Bosnia and Herzegovina	Nezavisni operator sustava u Bosni i Hercegovini	
BE	Belgium	Elia System Operator SA	
BG	Bulgaria	Electroenergien Sistemen Operator EAD (Електроенергиен системен оператор)	
CH	Switzerland	Swissgrid ag	
CY	Cyprus	Cyprus Transmission System Operator	
CZ	Czech Republic	ČEPS a.s.	
DE	Germany	TransnetBW GmbH TenneT TSO GmbH Amprion GmbH 50Hertz Transmission GmbH	
DK	Denmark	Energinet	
EE	Estonia	Elering AS	
ES	Spain	Red Eléctrica de España S.A.	

FI	Finland	Fingrid Oyj
FR	France	Réseau de Transport d'Electricité
GR	Greece	Independent Power Transmission Operator S.A.
HR	Croatia	HOPS d.d.
HU	Hungary	MAVIR Magyar Villamosenergia-ipari Átviteli Rendszerirányító Zártkörűen Működő Részvénytársaság
IE	Ireland	EirGrid plc
IS	Iceland	Landsnet hf
IT	Italy	Terna - Rete Elettrica Nazionale SpA
LT	Lithuania	Litgrid AB
LU	Luxembourg	Creos Luxembourg S.A.
LV	Latvia	AS Augstsprieguma tīkls
ME	Montenegro	Crnogorski elektroprenosni sistem AD
NI	Northern Ireland [1]	System Operator for Northern Ireland Ltd
NL	Netherlands	TenneT TSO B.V.
NO	Norway	Statnett SF
MK	Republic of North Macedonia	Transmission System Operator of the Republic of North
PL	Poland	Polskie Sieci Elektroenergetyczne S.A.
PT	Portugal	Rede Eléctrica Nacional, S.A.
RO	Romania	C.N. Transelectrica S.A.
RS	Serbia	Akcionarsko društvo Elektromreža Srbije
SE	Sweden	Svenska Kraftnät
SI	Slovenia	ELES, d.o.o.
SK	Slovak Republic	Slovenská elektrizačná prenosová sústava, a.s.
UA	Ukraine	National Power Company Ukrenergo

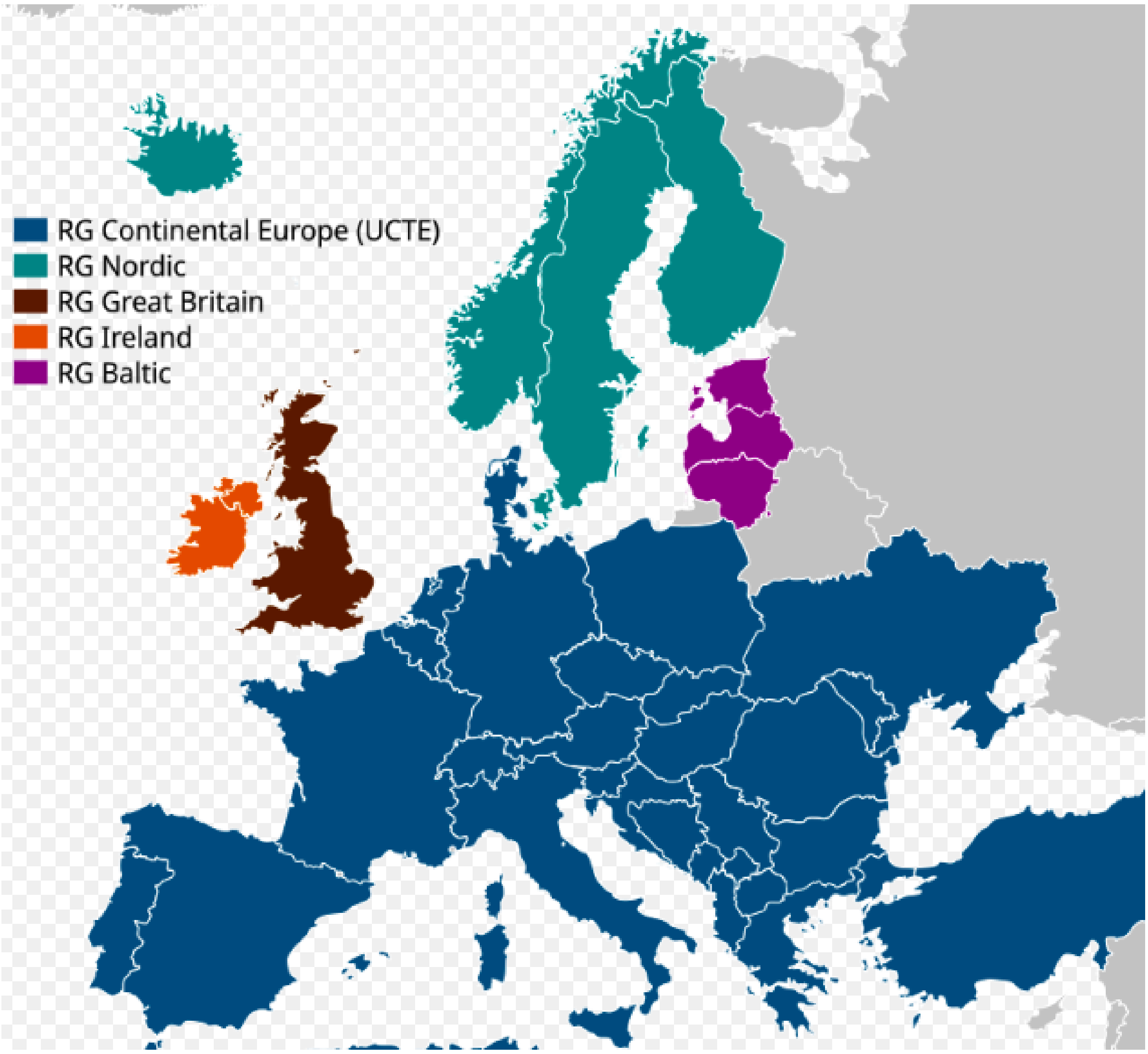
Observer Members

MD	Moldova	Moldelectrica
TR	Türkiye	Turkish Electricity Transmission Corporation

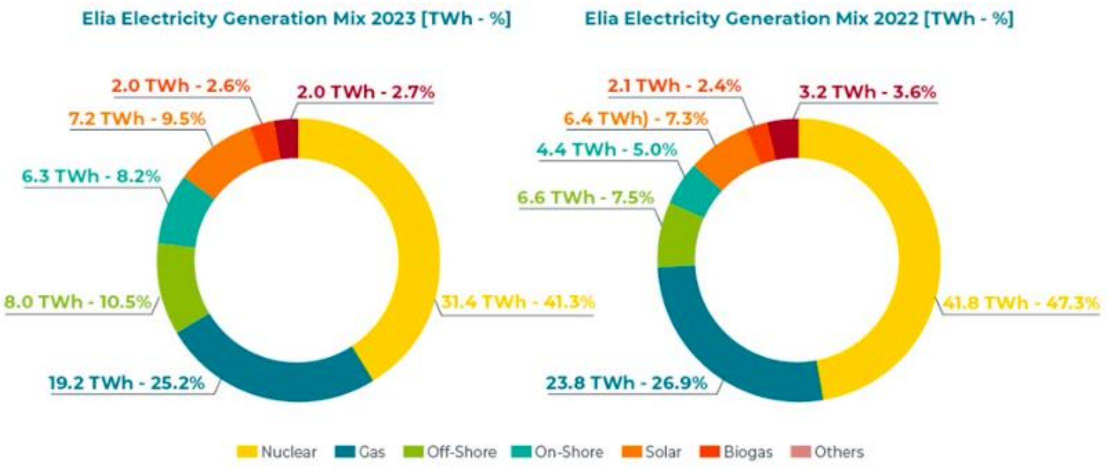
Appendix 7: TSO connections – European Network



Appendix 8: ENTSO-E, five European synchronous zones



Appendix 9 : Electricity Generation Mixes, Belgium



8.2 Appendices, Results

Appendix 10 : Mathematical Model

$$Y = \beta 0 + \beta 1x + \epsilon$$

Y is the dependent variable, the values of the electricity price.

x is the independent variable, the values of the gas price.

$\beta 0$ is the y-intercept.

$\beta 1$ is the slope of the line.

ϵ is the error term (the difference between the actual and predicted values).

To obtain the different parameters:

a. Calculate the means:

$$\bar{x} = (1/n) * \Sigma(xi)$$

$$\bar{y} = (1/n) * \Sigma(yi)$$

b. Calculate the slope ($\beta 1$):

$$\beta 1 = \Sigma[(xi - \bar{x}) * (yi - \bar{y})] / \Sigma[(xi - \bar{x})^2]$$

c. Calculate the intercept ($\beta 0$):

$$\beta 0 = \bar{y} - \beta 1 * \bar{x}$$

To obtain the coefficient of determination (R-squared):

a. Calculate the Total Sum of Squares (SST):

$$SST = \Sigma(yi - \bar{y})^2$$

b. Calculate the Residual Sum of Squares (SSE):

$$SSE = \Sigma(yi - \hat{y}i)^2$$

Where $\hat{y}i$ is the predicted value of y for the “ith” observation.

c. Calculate the R^2 (R-squared):

$$R^2 = 1 - (SSE / SST)$$

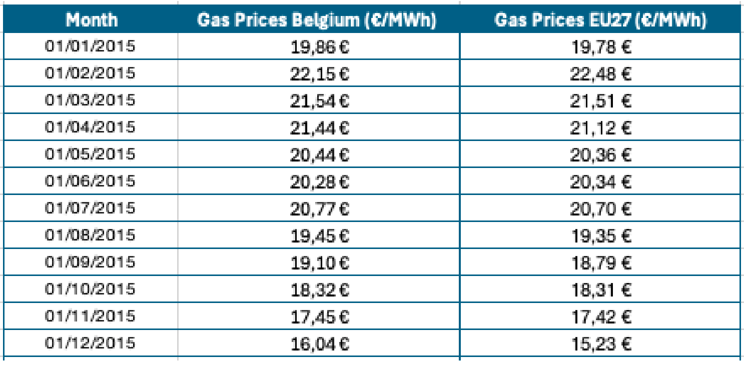
R^2 values range from 0 to 1, where:

$R^2 = 0$, the independent variable does not explain any of the variance in the dependent variable.

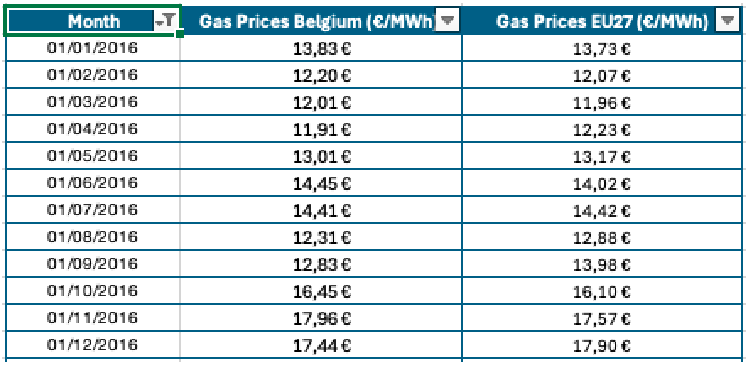
$R^2 = 1$, the independent variable explains all the variance in the dependent variable.

Appendix 11: Data for quantitative research

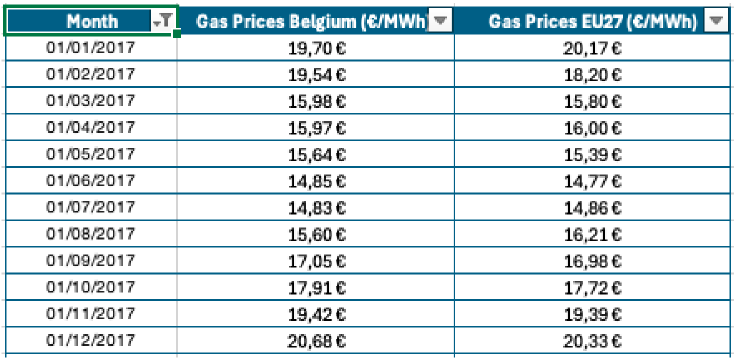
1. Gas prices, independent variable (X)



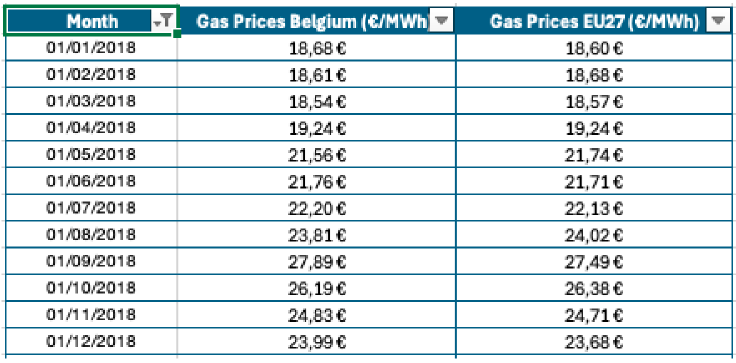
Month	Gas Prices Belgium (€/MWh)	Gas Prices EU27 (€/MWh)
01/01/2015	19,86 €	19,78 €
01/02/2015	22,15 €	22,48 €
01/03/2015	21,54 €	21,51 €
01/04/2015	21,44 €	21,12 €
01/05/2015	20,44 €	20,36 €
01/06/2015	20,28 €	20,34 €
01/07/2015	20,77 €	20,70 €
01/08/2015	19,45 €	19,35 €
01/09/2015	19,10 €	18,79 €
01/10/2015	18,32 €	18,31 €
01/11/2015	17,45 €	17,42 €
01/12/2015	16,04 €	15,23 €



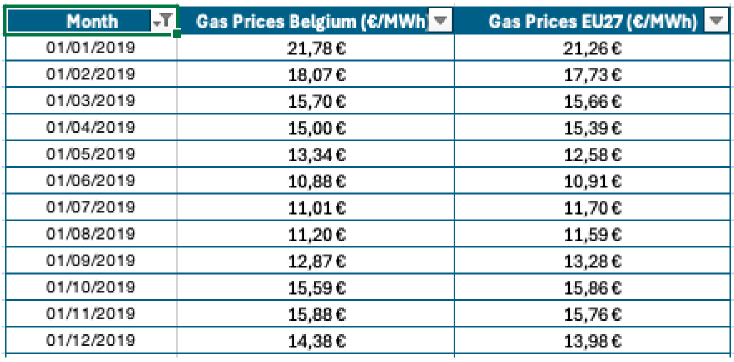
Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2016	13,83 €	13,73 €
01/02/2016	12,20 €	12,07 €
01/03/2016	12,01 €	11,96 €
01/04/2016	11,91 €	12,23 €
01/05/2016	13,01 €	13,17 €
01/06/2016	14,45 €	14,02 €
01/07/2016	14,41 €	14,42 €
01/08/2016	12,31 €	12,88 €
01/09/2016	12,83 €	13,98 €
01/10/2016	16,45 €	16,10 €
01/11/2016	17,96 €	17,57 €
01/12/2016	17,44 €	17,90 €



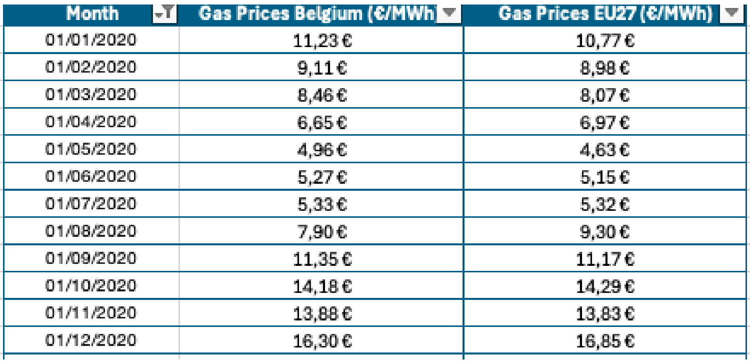
Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2017	19,70 €	20,17 €
01/02/2017	19,54 €	18,20 €
01/03/2017	15,98 €	15,80 €
01/04/2017	15,97 €	16,00 €
01/05/2017	15,64 €	15,39 €
01/06/2017	14,85 €	14,77 €
01/07/2017	14,83 €	14,86 €
01/08/2017	15,60 €	16,21 €
01/09/2017	17,05 €	16,98 €
01/10/2017	17,91 €	17,72 €
01/11/2017	19,42 €	19,39 €
01/12/2017	20,68 €	20,33 €



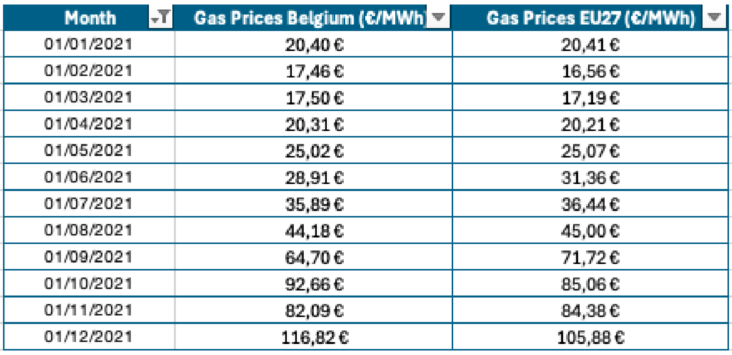
Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2018	18,68 €	18,60 €
01/02/2018	18,61 €	18,68 €
01/03/2018	18,54 €	18,57 €
01/04/2018	19,24 €	19,24 €
01/05/2018	21,56 €	21,74 €
01/06/2018	21,76 €	21,71 €
01/07/2018	22,20 €	22,13 €
01/08/2018	23,81 €	24,02 €
01/09/2018	27,89 €	27,49 €
01/10/2018	26,19 €	26,38 €
01/11/2018	24,83 €	24,71 €
01/12/2018	23,99 €	23,68 €



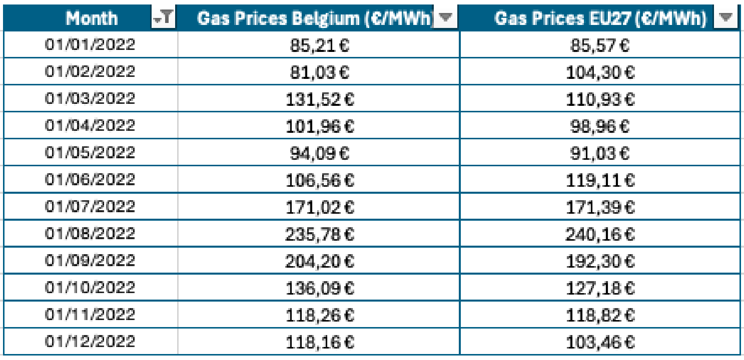
Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2019	21,78 €	21,26 €
01/02/2019	18,07 €	17,73 €
01/03/2019	15,70 €	15,66 €
01/04/2019	15,00 €	15,39 €
01/05/2019	13,34 €	12,58 €
01/06/2019	10,88 €	10,91 €
01/07/2019	11,01 €	11,70 €
01/08/2019	11,20 €	11,59 €
01/09/2019	12,87 €	13,28 €
01/10/2019	15,59 €	15,86 €
01/11/2019	15,88 €	15,76 €
01/12/2019	14,38 €	13,98 €



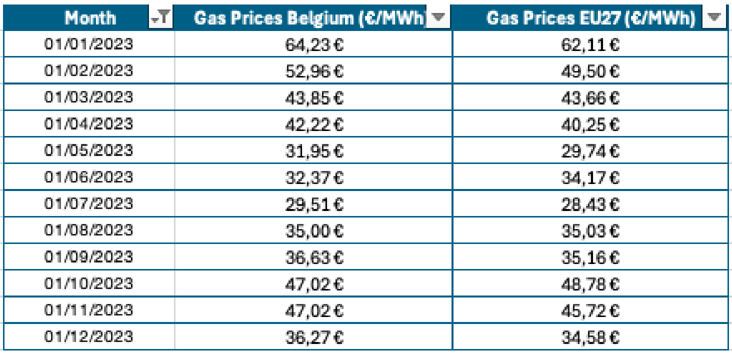
Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2020	11,23 €	10,77 €
01/02/2020	9,11 €	8,98 €
01/03/2020	8,46 €	8,07 €
01/04/2020	6,65 €	6,97 €
01/05/2020	4,96 €	4,63 €
01/06/2020	5,27 €	5,15 €
01/07/2020	5,33 €	5,32 €
01/08/2020	7,90 €	9,30 €
01/09/2020	11,35 €	11,17 €
01/10/2020	14,18 €	14,29 €
01/11/2020	13,88 €	13,83 €
01/12/2020	16,30 €	16,85 €



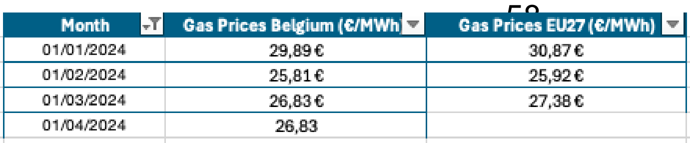
Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2021	20,40 €	20,41 €
01/02/2021	17,46 €	16,56 €
01/03/2021	17,50 €	17,19 €
01/04/2021	20,31 €	20,21 €
01/05/2021	25,02 €	25,07 €
01/06/2021	28,91 €	31,36 €
01/07/2021	35,89 €	36,44 €
01/08/2021	44,18 €	45,00 €
01/09/2021	64,70 €	71,72 €
01/10/2021	92,66 €	85,06 €
01/11/2021	82,09 €	84,38 €
01/12/2021	116,82 €	105,88 €



Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2022	85,21 €	85,57 €
01/02/2022	81,03 €	104,30 €
01/03/2022	131,52 €	110,93 €
01/04/2022	101,96 €	98,96 €
01/05/2022	94,09 €	91,03 €
01/06/2022	106,56 €	119,11 €
01/07/2022	171,02 €	171,39 €
01/08/2022	235,78 €	240,16 €
01/09/2022	204,20 €	192,30 €
01/10/2022	136,09 €	127,18 €
01/11/2022	118,26 €	118,82 €
01/12/2022	118,16 €	103,46 €

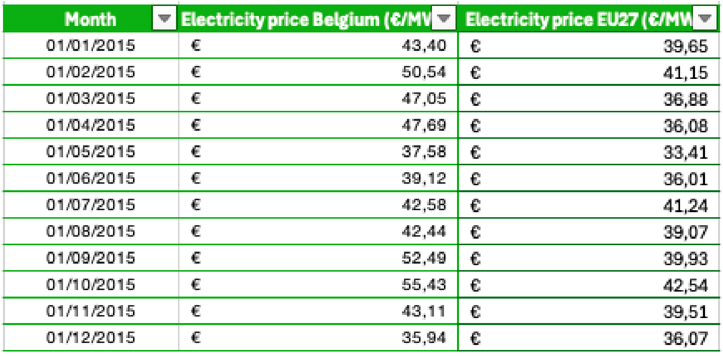


Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2023	64,23 €	62,11 €
01/02/2023	52,96 €	49,50 €
01/03/2023	43,85 €	43,66 €
01/04/2023	42,22 €	40,25 €
01/05/2023	31,95 €	29,74 €
01/06/2023	32,37 €	34,17 €
01/07/2023	29,51 €	28,43 €
01/08/2023	35,00 €	35,03 €
01/09/2023	36,63 €	35,16 €
01/10/2023	47,02 €	48,78 €
01/11/2023	47,02 €	45,72 €
01/12/2023	36,27 €	34,58 €

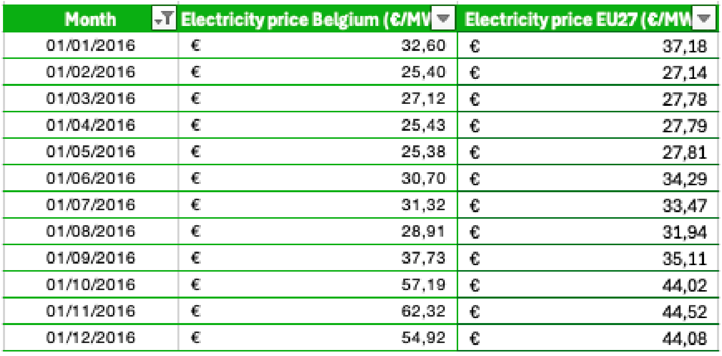


Month	Gas Prices Belgium (€/MWh	Gas Prices EU27 (€/MWh)
01/01/2024	29,89 €	30,87 €
01/02/2024	25,81 €	25,92 €
01/03/2024	26,83 €	27,38 €
01/04/2024	26,83	

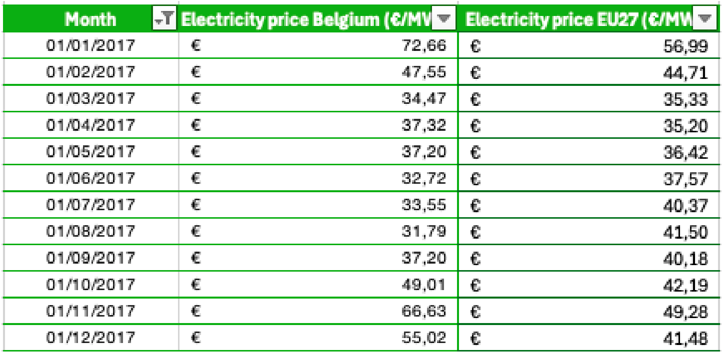
2. Electricity prices, dependent variable (Y)



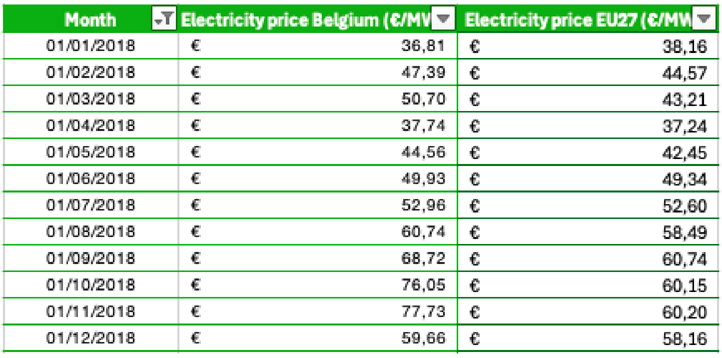
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2015	€ 43,40	€ 39,65
01/02/2015	€ 50,54	€ 41,15
01/03/2015	€ 47,05	€ 36,88
01/04/2015	€ 47,69	€ 36,08
01/05/2015	€ 37,58	€ 33,41
01/06/2015	€ 39,12	€ 36,01
01/07/2015	€ 42,58	€ 41,24
01/08/2015	€ 42,44	€ 39,07
01/09/2015	€ 52,49	€ 39,93
01/10/2015	€ 55,43	€ 42,54
01/11/2015	€ 43,11	€ 39,51
01/12/2015	€ 35,94	€ 36,07



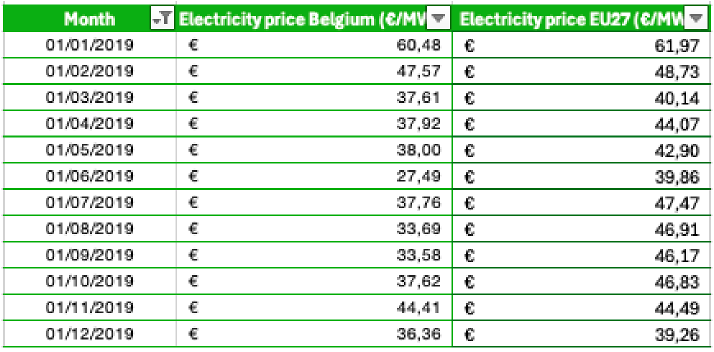
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2016	€ 32,60	€ 37,18
01/02/2016	€ 25,40	€ 27,14
01/03/2016	€ 27,12	€ 27,78
01/04/2016	€ 25,43	€ 27,79
01/05/2016	€ 25,38	€ 27,81
01/06/2016	€ 30,70	€ 34,29
01/07/2016	€ 31,32	€ 33,47
01/08/2016	€ 28,91	€ 31,94
01/09/2016	€ 37,73	€ 35,11
01/10/2016	€ 57,19	€ 44,02
01/11/2016	€ 62,32	€ 44,52
01/12/2016	€ 54,92	€ 44,08



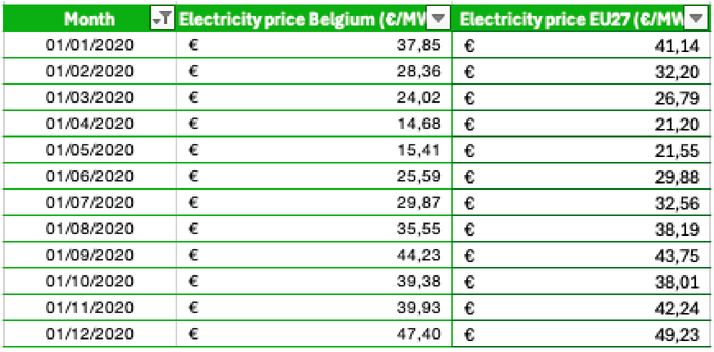
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2017	€ 72,66	€ 56,99
01/02/2017	€ 47,55	€ 44,71
01/03/2017	€ 34,47	€ 35,33
01/04/2017	€ 37,32	€ 35,20
01/05/2017	€ 37,20	€ 36,42
01/06/2017	€ 32,72	€ 37,57
01/07/2017	€ 33,55	€ 40,37
01/08/2017	€ 31,79	€ 41,50
01/09/2017	€ 37,20	€ 40,18
01/10/2017	€ 49,01	€ 42,19
01/11/2017	€ 66,63	€ 49,28
01/12/2017	€ 55,02	€ 41,48



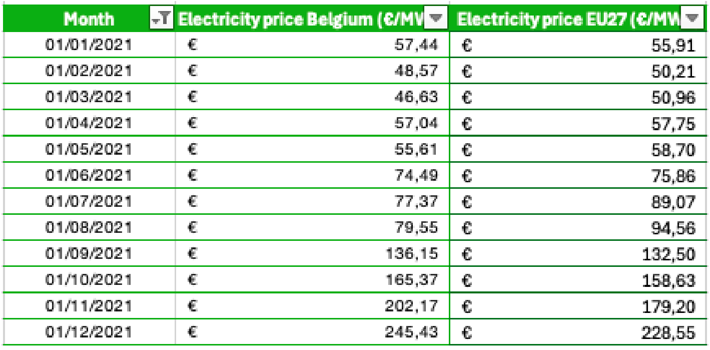
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2018	€ 36,81	€ 38,16
01/02/2018	€ 47,39	€ 44,57
01/03/2018	€ 50,70	€ 43,21
01/04/2018	€ 37,74	€ 37,24
01/05/2018	€ 44,56	€ 42,45
01/06/2018	€ 49,93	€ 49,34
01/07/2018	€ 52,96	€ 52,60
01/08/2018	€ 60,74	€ 58,49
01/09/2018	€ 68,72	€ 60,74
01/10/2018	€ 76,05	€ 60,15
01/11/2018	€ 77,73	€ 60,20
01/12/2018	€ 59,66	€ 58,16



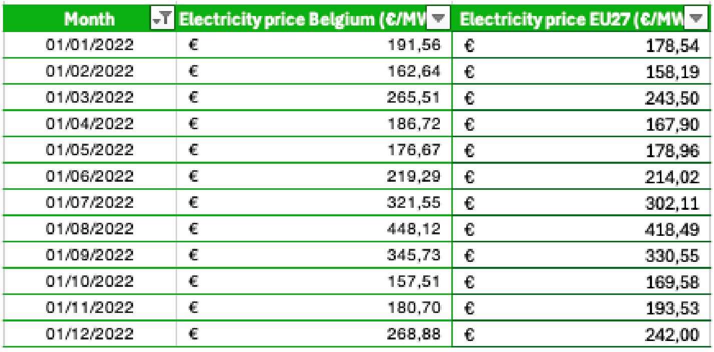
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2019	€ 60,48	€ 61,97
01/02/2019	€ 47,57	€ 48,73
01/03/2019	€ 37,61	€ 40,14
01/04/2019	€ 37,92	€ 44,07
01/05/2019	€ 38,00	€ 42,90
01/06/2019	€ 27,49	€ 39,86
01/07/2019	€ 37,76	€ 47,47
01/08/2019	€ 33,69	€ 46,91
01/09/2019	€ 33,58	€ 46,17
01/10/2019	€ 37,62	€ 46,83
01/11/2019	€ 44,41	€ 44,49
01/12/2019	€ 36,36	€ 39,26



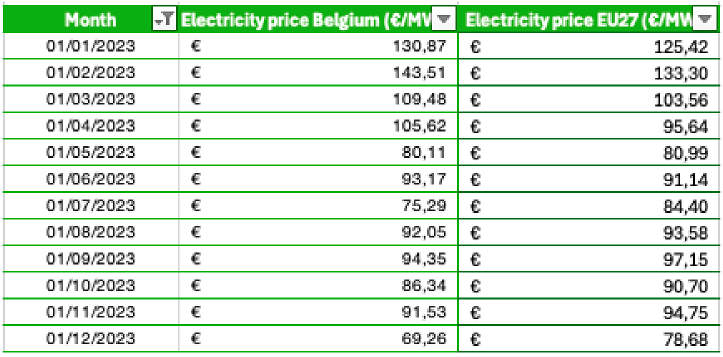
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2020	€ 37,85	€ 41,14
01/02/2020	€ 28,36	€ 32,20
01/03/2020	€ 24,02	€ 26,79
01/04/2020	€ 14,68	€ 21,20
01/05/2020	€ 15,41	€ 21,55
01/06/2020	€ 25,59	€ 29,88
01/07/2020	€ 29,87	€ 32,56
01/08/2020	€ 35,55	€ 38,19
01/09/2020	€ 44,23	€ 43,75
01/10/2020	€ 39,38	€ 38,01
01/11/2020	€ 39,93	€ 42,24
01/12/2020	€ 47,40	€ 49,23



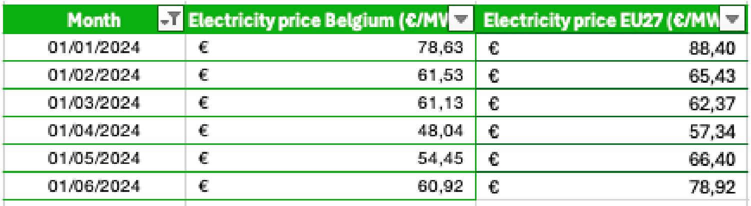
Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2021	€ 57,44	€ 55,91
01/02/2021	€ 48,57	€ 50,21
01/03/2021	€ 46,63	€ 50,96
01/04/2021	€ 57,04	€ 57,75
01/05/2021	€ 55,61	€ 58,70
01/06/2021	€ 74,49	€ 75,86
01/07/2021	€ 77,37	€ 89,07
01/08/2021	€ 79,55	€ 94,56
01/09/2021	€ 136,15	€ 132,50
01/10/2021	€ 165,37	€ 158,63
01/11/2021	€ 202,17	€ 179,20
01/12/2021	€ 245,43	€ 228,55



Month	Electricity price Belgium (€/MW	Electricity price EU27 (€/MW
01/01/2022	€ 191,56	€ 178,54
01/02/2022	€ 162,64	€ 158,19
01/03/2022	€ 265,51	€ 243,50
01/04/2022	€ 186,72	€ 167,90
01/05/2022	€ 176,67	€ 178,96
01/06/2022	€ 219,29	€ 214,02
01/07/2022	€ 321,55	€ 302,11
01/08/2022	€ 448,12	€ 418,49
01/09/2022	€ 345,73	€ 330,55
01/10/2022	€ 157,51	€ 169,58
01/11/2022	€ 180,70	€ 193,53
01/12/2022	€ 268,88	€ 242,00

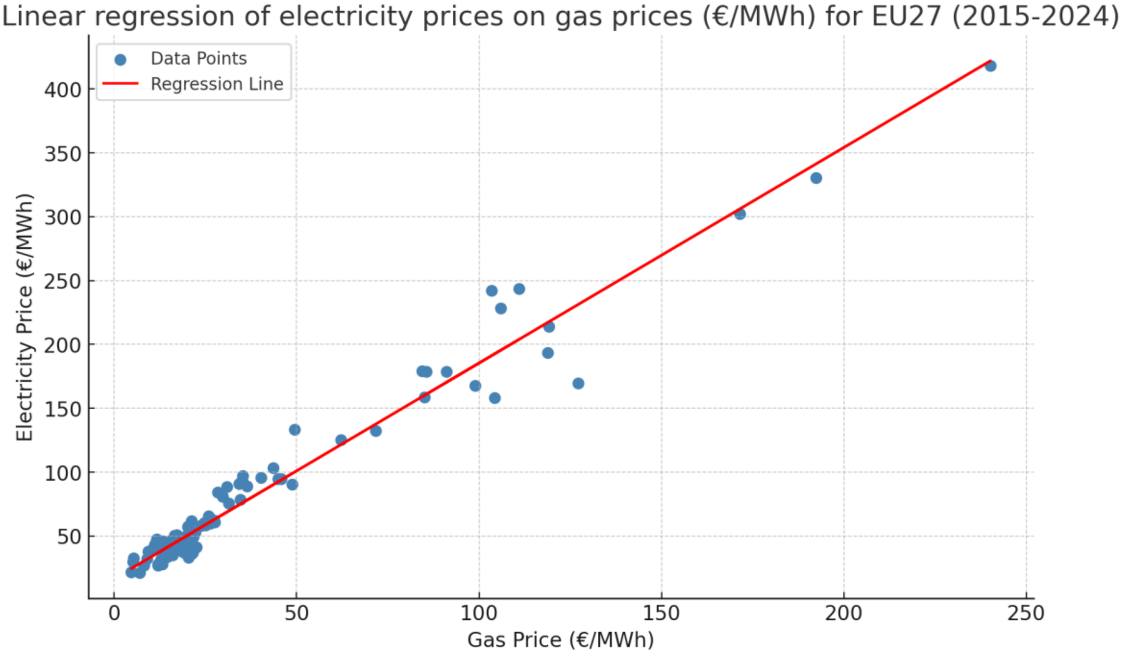


Month	Electricity price Belgium (€/MV	Electricity price EU27 (€/MW
01/01/2023	€ 130,87	€ 125,42
01/02/2023	€ 143,51	€ 133,30
01/03/2023	€ 109,48	€ 103,56
01/04/2023	€ 105,62	€ 95,64
01/05/2023	€ 80,11	€ 80,99
01/06/2023	€ 93,17	€ 91,14
01/07/2023	€ 75,29	€ 84,40
01/08/2023	€ 92,05	€ 93,58
01/09/2023	€ 94,35	€ 97,15
01/10/2023	€ 86,34	€ 90,70
01/11/2023	€ 91,53	€ 94,75
01/12/2023	€ 69,26	€ 78,68

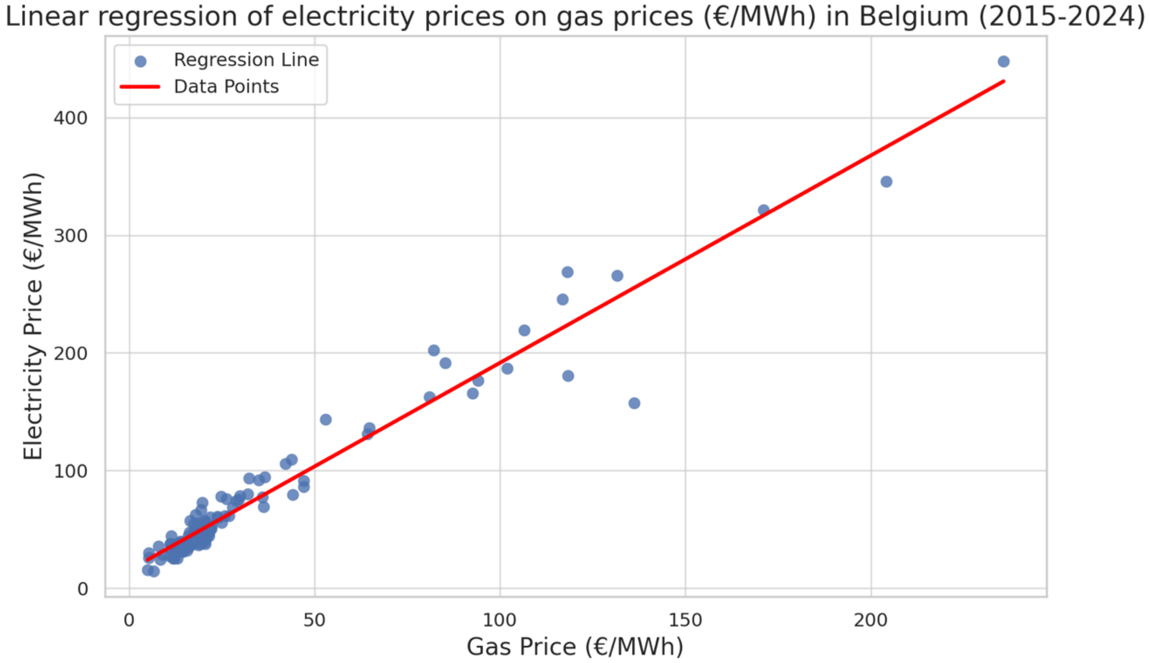


Month	Electricity price Belgium (€/MV	Electricity price EU27 (€/MW
01/01/2024	€ 78,63	€ 88,40
01/02/2024	€ 61,53	€ 65,43
01/03/2024	€ 61,13	€ 62,37
01/04/2024	€ 48,04	€ 57,34
01/05/2024	€ 54,45	€ 66,40
01/06/2024	€ 60,92	€ 78,92

<u>Appendix 12 :</u> Linear Regression, EU27



<u>Appendix 13:</u> Linear Regression, Belgium



Appendix 14: Annual Data, per resource, per zone

EU27 Electricity Prices										
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Average Price (€/MWh)	38,46	34,59	41,77	50,44	45,73	34,73	102,66	233,11	97,44	69,81
St. Deviation	2,73	6,65	6,27	9,05	6,02	8,87	58,97	80,09	16,54	11,58

Belgium Electricity Prices										
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Average Price (€/MWh)	44,78	36,59	44,59	55,25	39,37	31,86	103,82	243,74	97,63	60,78
St. Deviation	6,01	13,57	13,82	13,64	8,35	10,65	67,21	89,64	21,85	10,21

EU27 Gas Prices										
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Average Price (€/MWh)	19,61	14,17	17,15	22,25	14,64	9,61	46,61	130,27	40,59	28,06
St. Deviation	1,97	2,03	1,99	3,09	2,96	3,92	31,63	46,87	9,76	1,03

Belgium Gas Prices										
Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Average Price (€/MWh)	19,74	14,07	17,26	22,28	14,64	9,55	47,16	131,99	41,59	27,34
St. Deviation	1,79	2,15	2,10	3,15	3,17	3,83	33,86	48,31	10,12	0,59