THE IMPACT OF THE WAR ON UKRAINE'S WHOLESALE ELECTRICITY MARKET: AN EVALUATION OF PRICE, SUPPLY, AND DEMAND CHANGES

by

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LIST OF ABBREVIATIONS

BCM Bilateral Contracts Market

DAM Day Ahead Market

HPP Hydro power plant

NPP Nuclear power plant

SPP Solar power plant

TPP Thermal power plant

TSO Transmission system operator

WPP Wind power plant

CHAPTER 1. INTRODUCTION

Russia's war against Ukraine started on 24 February 2022, has caused widespread destruction of public infrastructure, heavy industry, housing as well as critical infrastructure such as power plants, transmission lines and industrial facilities, resulting in supply and demand shocks in the wholesale electricity market but also led to some price changes on it.

One year after the invasion, the total damage to Ukraine's energy infrastructure was estimated at $8.1 billion (KSE Institute, 2023). In particular, the majority of TPPs, HPPs, solar and wind power plants were significantly damaged, captured or even destroyed. Ukraine's largest nuclear power plant, the 6,000 MW Zaporizhzhia NPP, was seized on March 4, 2022. Later in September-October 2022, the aggressor's repeated deliberate shelling of key thermal power plants and substations that distribute electricity from these plants were partially or completely destroyed. All this has led to a gradual reduction in the supply of electricity to the market, resulting in a 2-3 times reduction in supply on the spot market during a period of active attacks on the Ukrainian energy sector.

Similarly, the largest electricity consumers in Ukraine were severely damaged or even completely destroyed and shut down. In particular, the Azovstal and Illich Iron and Steel Works were completely seized and subsequently destroyed. All of them participated in the electricity market on the demand side, which is why we can observe a sharp reduction in demand of up to 75% on the spot market in March 2022. The most significant changes in volumes and prices are observed on the spot market, where electricity is traded at short notice (from 1 day before delivery to 2 hours before the delivery).

The wholesale electricity market in Ukraine was reformed in July 2019 and consists of several segments that facilitate the trading and supply of electricity.

Domestic wholesale electricity market is also interconnected with neighbouring countries and relies on imports and exports of electricity during periods of surplus or deficit in the energy system. The market is also affected by various factors such as weather, demand, supply, commodity prices, regulations and policies which also fundamentally affect prices and trading volumes in a particular market segment.

In the wholesale electricity market, the market segments are organized in such a way that the largest trading volumes take place exactly in the first two market segments: Bilateral Contracts Market (BCM) and Day Ahead Market (DAM), together they usually account for approximately 80-90% of all electricity volumes, and the Ukrainian market is no exception.

This paper aims to investigate the impact of the war on the Ukrainian wholesale electricity market, which has experienced significant changes due to destruction of energy infrastructure and industrial facilities. The paper will analyze how the war has affected the electricity prices, supply and demand shocks in different segments of the market, such as the DAM and the BCM, through a variety of assessment techniques and tools.

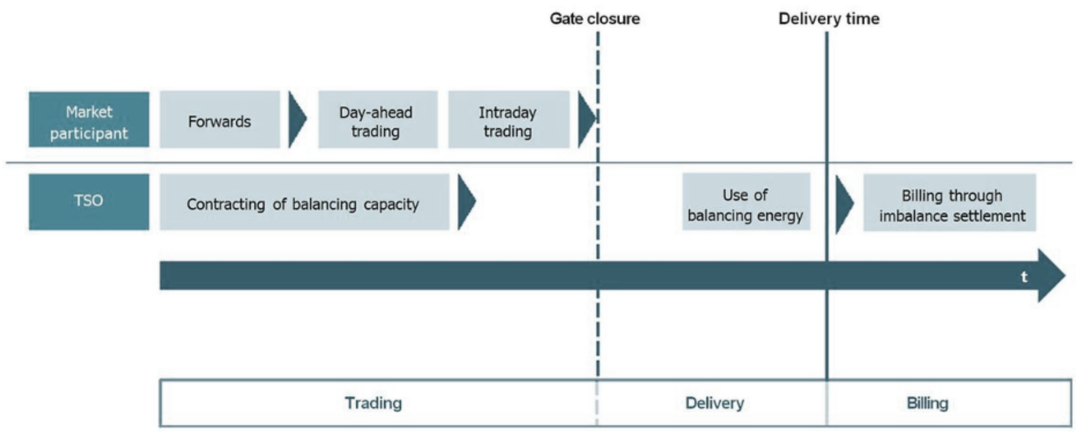
In particular, by using different statistical methods to analyze data on electricity prices, supply and demand from the electricity exchanges before and after the beginning of the invasion. The paper also aims to compare the changes in the main segments of the electricity market.

CHAPTER 2. INDUSTRY OVERVIEW AND RELATED STUDIES

Wholesale electricity market design

The wholesale electricity market design is arranged in such a way that market segments follow each other, it is possible to represent these segments from left to right on the x-axis, which represents the time to physical delivery of electricity.

Figure 1: Power Market Design



Source: The Bundesnetzagentur's electricity market information platform SMARD. 2018

Initially, market participants trade long-term contracts in forward and futures format. This allows them to hedge their risk and to have certainty of purchasing electricity at the agreed price for a certain period. This is beneficial to both producers and consumers of electricity. In Ukraine it is usually a week to a few months.

It is followed by the spot market segment – «day-ahead market» (DAM), where participants trade the day before delivery. This wholesale power market in Ukraine operates on a marginal pricing system, also known as a pay-as-clear market.

That is, sellers offer electricity volumes that they could not or did not want to sell in the previous segment under bilateral contracts, and buyers enter this segment to purchase additional volumes for their consumption schedule that they could not or did not want to buy under forward contracts. In Ukraine, bids must be submitted in this segment by 12 noon, the day preceding the day of electricity delivery.

Next comes a market called the intraday market. This is often used for volumes that are not sold or bought in the day-ahead market, and therefore participants can buy or sell additional volumes of electricity as they require. Such trading takes place in this segment for up to 2 hours before physical delivery.

If supply-side volumes are not sold on these three segments, they move to the Balancing Market segment, which is automatically controlled by the transmission system operator. This is a so-called penalty market. For both sellers and buyers, as the Transmission System Operator (TSO) has to command the power plants to reduce or increase capacity to compensate for these un-traded volumes for grid stability.

It is worth mentioning that as the market moves through the segments, the wholesale price of electricity should increase with the normal operation of the market and the absence of market manipulation. This increases the risk of participants falling into a balancing market, where their volumes will be sold at a large discount or, conversely, for consumers sold to them at a much higher price.

Overall, the Ukrainian electricity market is a complex and dynamic system consisting of five different segments: Day Ahead Market, Bilateral Agreements Market, Intraday Market, Balancing Market and Ancillary Services Market. These segments are designed to ensure efficient operation, competition, and transparency in the market. The main segments of the wholesale electricity market in Ukraine include:

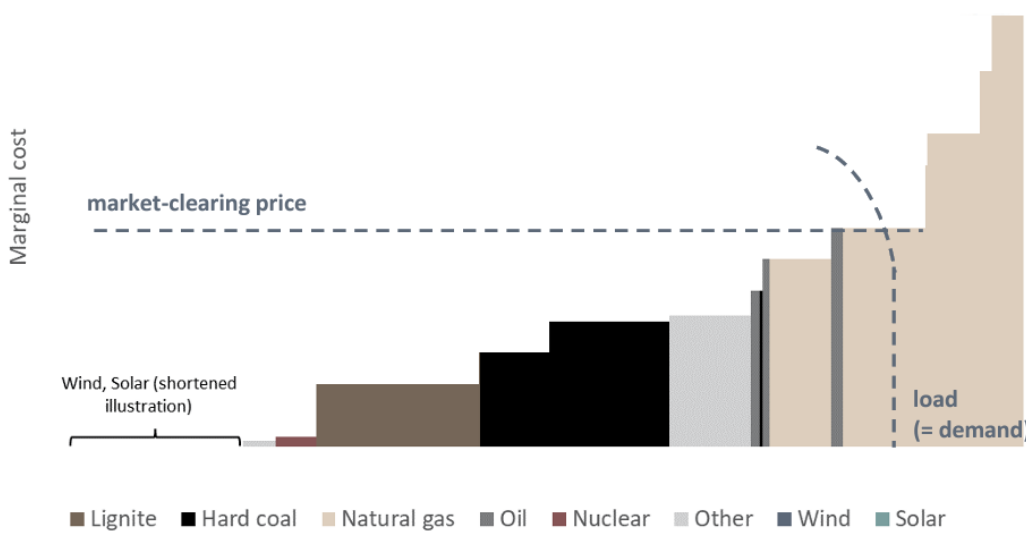
Day-Ahead Market

The Day-Ahead Market is the spot market segment where market participants, including generators, traders, and retailers, submit their bids and asks to sell or purchase electricity for the next day. The DAM allows participants to plan their electricity procurement or sales in advance based on forecasted demand and supply conditions.

Under this system, all electricity generators receive the same price for the power they sell at a given moment. Producers, ranging from national public companies to individual private companies who generate renewable energy and sell it to the grid, participate in the market by setting their prices based on their production costs.

Bidding starts with the cheapest energy sources and moves to the more expensive ones, with the cheapest electricity being purchased first. Once the total demand is met, all participants receive the price of the last producer from whom electricity was bought.

Figure 2: DAM market-clearing



Source: Anna Weiss, Overview of EU electricity market design. 2022

This model promotes efficiency, transparency, and encourages keeping costs as low as possible.

In general, the day-ahead market serves two primary purposes:

Firstly, it facilitates spot trading for the following day, which is inherently uncertain. In this market, consumers who anticipate potential imbalances in their consumption seek out alternatives by estimating average prices and placing purchase orders. On the other hand, producers assess their available capacity, unrealized volumes, and anticipated expenses for resources like gas or coal. Since the spot component of the market is unpredictable, it is designed to be as transparent as possible. With a central counterparty overseeing transactions, any possibility of engaging in unfair agreements or arrangements is eliminated.

The second function of the day-ahead market is to allow participants to adjust their own volumes. Despite the existence of a minimum price limit and the fact that prices tend to be higher compared to the bilateral contracts market, companies still choose to engage in buying and selling activities within this market.

The DAM in Ukraine is organized and operated by the Market Operator as a state enterprise, that was established on June 18, 2019 in accordance with the Law of Ukraine «On the Electricity Market". The company is responsible for organization of selling and buying of electricity on the Day-Ahead Market and the Intraday Market, helps to balance demand and supply at the electricity market.

As this state exchange is responsible for organizing the purchase and sale of electricity on the day-ahead and intraday markets and helps to ensure a balance between supply and demand in the electricity market.

On the day-ahead market, electricity is bought and sold on the day following the day of trading, thus market participants shall submit their bids by 12 noon on the day preceding the physical delivery day of electricity. The price on this market segment is determined on the basis of marginal pricing to minimize the price and maximize trade volumes. No participant sees the declared prices and volumes of purchase/sale of electricity by other participants. This technology of trading on the DAM promotes competition.

Trading volumes on this market segment in the pre-war period averaged about 100 000 MWh per day.

Bilateral Contracts Market

Bilateral Contracts Market is a forward electricity market that refer to agreements or contracts between two parties for the purchase or sale of electricity. These agreements are typically contracts with state or private companies and can involve various market participants, including generators, suppliers, traders, large consumers, and other market intermediaries. Bilateral agreements play a crucial role in facilitating the trading and supply of electricity.

They allow market participants to negotiate and customize the terms of their electricity transactions, including the volume, price, delivery period, and other contractual conditions. These agreements provide flexibility and enable participants to meet their specific electricity needs and manage their risks.

This market segment is also fulfils the function of price stability: Bilateral contracts provide a degree of price stability for market participants. By negotiating fixed prices or price mechanisms within the contracts, buyers and sellers can mitigate the risks associated with fluctuating electricity prices in the broader market.

The next function of this market is risk management, as bilateral contracts offer a means for managing risks associated with electricity supply and demand. Participants can secure a reliable source of electricity by establishing long-term contracts, ensuring a consistent supply of power even during periods of market volatility or unforeseen circumstances.

A bilateral agreement is an electricity purchase and sale agreement concluded between two market participants usually outside of organized market segments (OTC), except for an agreement for the supply of electricity to a consumer.

Bilateral agreements among private companies are concluded in an arbitrary form and on terms and conditions determined by agreement of the parties. While bilateral agreements with state generating companies organized and conducted through auctions on Ukrainian Energy Exchange (UEEX), where the prices are determined through a competitive bidding process. However, private companies are also allowed to participate in the BCM market outside the stock exchange and enter into transactions with both public and other private companies. This sub-type of market segment is called over-the-counter (OTC)

Bilateral contracts are usually long-term, ranging from a week to up to a year, and are concluded by market participants both on the platform of another private electricity exchange called the Ukrainian Energy Exchange and also in a contractual format between private companies over the phone and emails, usually most of these volumes are concluded by electricity trading companies or electricity suppliers.

However, bilateral market participants are obliged to register their transactions with counterparties every day before 10 am, before the day of physical delivery of electricity. Then, these volumes are recorded by the Ukrainian energy system operator NEC Ukrenergo on its MMS (Market Management System) platform. Trading volumes on this market segment in the pre-war period averaged about 610 000 MWh per day.

Market supply

According to the International Energy Agency (IEA) as of mid- September 2022, 30% of thermal and solar generation and 90% of wind generation capacity in Ukraine had been destroyed or was under russian occupation. The supply on the electricity market comes either from power plants (private, state-owned) or as imports from foreign countries. In 2021, domestic electricity producers accounted for approximately 98.9% of consumption, while imported electricity accounted for 1.1% of the country's total consumption (Ukrenergo, 2022). Considering the Ukrainian energy system or integrated power system (IPS) is a set of power plants, electricity and heat networks operating in the modes of generation, transmission and distribution of electricity and heat infrastructure. Currently, the largest volumes of electricity are produced in Ukraine at nuclear, thermal and hydroelectric power plants which in total make up about 91% of the country's generation. Electricity is also generated at power stations operating on alternative sources (solar power plants, wind farms, biofuel power plants.).

In accordance with the Ministry of Energy, in 2021, the generation in integrated power system of Ukraine generated 156 575 GWh of electricity, which is 5.2% more than in 2020 (148 856 GWh). As for the overall structure of electricity generation in Ukraine, in 2021 is presented in Table 1

Table 1. Structure of electricity generation in 2021.

Power plant type	% of total	GWh
Nuclear power plants	55.1	86205
Thermal power plants	23.8	37225
Renewables	8.0	12520
Hydro power plants	5.8	9155
Combined heat and power plants	5.5	8609
Pumped storage plants	0.8	1290
Other	1.0	1570

In the years before the war, the number of industrial solar and wind power plants had increased significantly. Most of them are located in the southern regions of Ukraine.

Market Supply Disruption: An Analysis

Nuclear Power Sector

In 2021, nuclear energy was pivotal to Ukraine's power grid, supplying 55.5% of its electricity from its four operational Nuclear Power Plants (NPPs) with a cumulative capacity of 13,835 MW. Notably, of these, the Zaporizka NPP (ZNPP), which is recognized as the largest in Europe and ranks fifth globally according to a 2019 report by Power Technology, holds significant importance with its 6,000 MW capacity, making up 43% of Ukraine's nuclear capacity. Prior to Russia's extensive military campaign in 2022, ZNPP contributed to approximately 25% of Ukraine's electricity. However, since early March 2022, the facility has been under Russian control and its operations ceased from September 11, 2022. Moreover, the Pivdennoukrainska NPP endured artillery fire, while both the Khmelnytska and Rivnenska NPPs faced repercussions due to assaults on their power transmission infrastructures.

Thermal Power Sector

As of early 2022, Ukraine hosted 12 Thermal Power Plants (TPPs) with a collective capacity of 21.5 GW according to Energy Charter Secretariat (2023). A considerable portion of these relied on coal for power generation and constituted 23.8% of the country's electricity in 2021. Since 2014, the occupied Donbas region has housed two of these TPPs with a combined capacity of 3.3 GW. Post the events of February 24, 2022, three additional TPPs (Zaporizka, Luhanska, and Vyglehirska TPPs) with a total capacity of 7.7 GW came under Russian control. Tragically, by April 2023, Ukraine witnessed the loss or damage of approximately 78% of its thermal capacity. Notably, DTEK Energy, the leading TPP operator in Ukraine, estimated damages from these assaults at around $160 million. The state-owned enterprise "Centrenergo" wasn't spared either, facing missile attacks frequently during the 2022/2023 heating period.

Large Hydropower Sector

The 2022/2023 heating season saw hydropower infrastructures being heavily targeted, with over 30 missile strikes reported. Ukrhydroenergo PJSC declared a loss of 2,000 MW in generation capacity due to wartime activities. While there have been efforts to restore power, as of April 2023, only 500 MW has been reinstated. Furthermore, transmission lines connecting these plants operated below their potential, managing only 50-70% of the original capacity due to extensive damage. A notable incident was the demolition of the Kakhovska HPP on June 6, 2023, with preliminary assessments quoting losses upwards of $1.5 billion and a loss of 340 MW in generation according to Ukrhydroenergo CEO Ihor Syrota (2023).

Wind Power

In 2022, Ukraine boasted an onshore wind power capacity of 1.6 GW. A significant portion of these facilities was strategically positioned in southern regions close to the Azov and Black seas, areas that currently lie under Russian occupation. It's estimated that around 80% of Ukraine's wind power capacity is compromised due to this occupation. Recent reports also highlight damages to at least 10 wind turbines, which roughly equates to a 1% loss in total wind energy capacity in accoradance with Energy Charter Secretariat (2023).

Solar Power

The report of Energy Charter Secretariat (2023) also provides information that presently, approximately 13% of Ukraine's Photovoltaic (PV) assets are under occupation. Perturbingly, close to 8% of the entire solar capacity has been reported as damaged or completely destroyed, which includes a significant number of prosumer installations.

Market demand

According to the International Energy Agency, Ukraine's electricity demand has fallen by about 40% since Russia's invasion with no sign of recovery. Overall, net electricity consumption in 2021 varies from 10 GW/hour in summer to 24 GW/hour in winter, while after the invasion it drops to an average of 10 GW/hour.

However, gross domestic electricity consumption in 2021 was 154 826 GWh, which is 8 391 GWh or 5.7% more than in 2020 (146 435 GWh). While the net consumption of electricity by different types of consumers was 125 483 GWh, which is 7 576 GWh or 6.4% more than in 2020 (117 907 GWh). As for the overall structure of electricity consumption in Ukraine by consumer type in 2021 is presented in Table 2.

Table 2. Ukrainian electricity consumption structure in 2021.

Consumer type	% of total	GWh
Households	30.8	38659
Metallurgical industry	23.0	28873
Residential consumers	12.0	15023
Other non-industrial consumers	6.9	8599
Transport	4.9	6171
Other	4.1	5193
Chemicals and petrochemicals industry	3.5	4349
Food-manufacturing industry	3.5	4405
Agricultural consumers	2.9	3722
Machine industry	2.8	3522
Petroleum industry	2.6	3261
Construction materials	2.1	2670
Construction	1.0	1064

Market Demand Disruption: Overview

At the beginning of 2022, there were 17.7 mln electricity consumers in Ukraine, including 17.2 mln households and 0.5 mln commercial customers. As a result of hostilities, electricity demand decreased by 30-35% compared to 2021. The consumption pattern also changed due to the shutdown of industrial enterprises and the massive displacement of consumers from Eastern to Western Ukraine according to Energy Charter Secretariat (2023)

According to estimates based on TSO Ukrenergo data, the average Ukrainian household had to endure five cumulative weeks without electricity from October 10 to December 31, 2022. While, the consumption volume of electricity by the industrial sector in 2022, following the onset of the war, automatically became confidential information. According to data from GMK Center (2022), considering a decline of over 65% in metallurgy production, the drop in consumption can also be estimated at 60-70%. Specifically, ArcelorMittal Ukraine halted metal product production at its enterprises and the consumption of electricity, which before the war was 500 MW per hour according to the CEO ArcelorMittal Ukraine Mauro Longobardo (2022).

Import and export

Before the events of 24 February 2022, Ukraine's historic electricity trade landscape was marked by a mix of dependencies and strategic shifts. In the post-Soviet era, Ukraine and Russia maintained strong energy ties, especially in the realms of natural gas and nuclear energy. For electricity specifically, Ukraine had been historically an exporter to its western neighbors like Hungary, Poland, and Slovakia. With the annexation of Crimea by Russia in 2014 and the subsequent conflict in Eastern Ukraine, the energy relationship between Ukraine and Russia became increasingly strained. This led to Ukraine making concerted efforts to diversify its energy sources and reduce its dependency on Russia. As part of its broader energy strategy, Ukraine began integrating its electricity system with the European Union, targeting synchronization with the Continental European power grid. This transition also aimed to open new avenues for electricity trade with EU countries. Over the years leading up to 2022, these efforts, in tandem with domestic reforms in the energy sector, defined Ukraine's approach to electricity import and export, wherein the nation aimed to be more self-reliant and pivot westward.

Related studies

The relevant literature on this topic can be divided into two categories: studies that analyze the impact of war or natural disasters on energy markets in general, and papers that focus on the Ukrainian and European electricity market specifically.

Some examples of the former are: (Feveile, Adolfsen et al. 2022), who provide an overview of the impact of the war in Ukraine on euro area energy markets; (Thomson, 2022), who discusses six ways that Russia's invasion of Ukraine has reshaped the energy world, and specialized in energy consulting agency (Wood Mackenzie 2022), who examine the implications of the war for energy policy and corporate strategies.

Some examples of the latter are (Ferriani and Gazzani, 2022), who analyze the impact of the war on energy prices and firms' financial performance in Ukraine and Pollitt (2022), who explores the state of the Ukrainian electricity market in time of war.

While there are also many articles related to the price spikes on other energy commodities, which confirms that the war in Ukraine has caused a dramatic increase in energy prices, especially in Europe, where Russia is a major supplier of gas and oil. In particular, the difference in prices the day before - 23 February the war and several months later 31 July European gas and electricity wholesale prices increased by 115% and 237%, respectively. (Gazzani, Ferriani et al. 2022). On top of that authors assume, that the energy shock has negatively affected the financial performance of European firms that are more energy intensive and emit more carbon, as measured by lower equity returns and higher CDS spreads.

A paper by Michael G. Pollitt Professor of Business Economics at the University of Cambridge (2022) discusses the challenges and opportunities for the energy market in time of war, focusing on the case of the war in Ukraine and its impact on European gas and electricity prices. In particular, he argues that wholesale electricity prices in EU are now around double (in real terms) the level they have been since 1999. The author argues that war can disrupt energy supply and demand, increase price volatility and uncertainty, and affect investment decisions and regulatory frameworks. Thus, author suggests some policy responses to mitigate the negative effects of war on the energy market, such as, demand reduction, import substitution, home electricity production, fair pricing schemes which encourage energy saving, and profiteering ex-post assessment and taxation. He also draws on historical examples of energy interventions during wartime and stresses the need for pragmatic and democratic solutions.

Some articles from Japanese researches (Kimura and Nishio, 2022) examines how households and firms in Japan saved electricity after the Great East Japan Earthquake in March 2011 and the subsequent shutdown of nuclear power plants, which caused a severe electricity shortfall. The authors conducted surveys of energy users each fall from 2011 to 2014 and analyzed the major electricity-saving measures, the motivations and perceptions of energy users, and the trends over time. The main findings of this paper are:

Electricity demand in Japan decreased by more than 15% compared with the 2010 level in summer 2011, mainly due to mandatory rationing for large customers and voluntary conservation by households and small customers Most of the electricity savings achieved in 2011 persisted for almost four years, despite the relaxation of mandatory rationing and the decline in the implementation rates of various electricity-saving measures.

The main motivations for saving electricity were social norms, environmental awareness, and economic incentives. The perception of electricity shortage risk also affected the behavior of energy users, especially in 2011 and 2012. The Japanese experience of saving electricity after Fukushima provides valuable lessons for coping with temporary electricity shortfalls and promoting long-term energy efficiency.

CHAPTER 3. METHODOLOGY

This chapter outlines the approaches employed in this research, discusses the objective, variables, and provides details about the model specification. Among the methodologies employed for assessing the impact of war on energy markets, with a specific focus on the power market, Ordinary Least Squares (OLS) stands out as the most widely used. Another commonly adopted approach is the instrumental variable method, specifically the Two-Stage Least Squares (2SLS) technique, which can be regarded as an extension of the OLS method. This method proves valuable in situations where the error term of the dependent variable exhibits correlation with the independent variable.

The objective is to investigate the extent to which such events influence electricity prices and to provide insights into the market dynamics.

Below is a detailed description of what each variable means which are further used in regression analysis:

Traded - stands fo agregatad daily contracted volume on the DAM;
Supply – stands for agregated daily volume declared by supply side on the DAM;
Demand – stands for agregated daily volume declared by demand side on the DAM;
Price – stands for daily weighted average price on the DAM;
BCM – stands for agregated daily contracted volume on the bilateral contracts market;

This paper uses quantitative methods to estimate changes in trading volumes as well as electricity prices in the two main segments of the Ukrainian electricity market: the day-ahead market and the bilateral contract market, as well as their aggregate value as a proxy for the entire Ukrainian wholesale electricity market.

These segments have historically accounted for 80-95% of the traded electricity on each day in terms of primary sales based on data from NEC Ukrenergo, the Market Operator, and NERC.

Due to the fact that these two segments of the market occupy the predominant part of electricity trading in Ukraine, the sample for this study can be considered objective and representative for the analysis of the entire wholesale electricity market of Ukraine.

For the main comparative analysis, the dataset was divided into 8 periods of 30, 90, 180, 360 days before and after the start of the Russian invasion.

The first period analyses the mentioned data for each variable for 30 days before and 30 days after the start of the invasion (26.01.2022 - 26.03.2022), the second period data for 90 days before and after the start of the invasion (27.11.2021 - 25.05.2022), the third period data for 180 days before and after the start of the invasion (29.08.2021 - 23.08.2022), the fourth period data for 360 days before and after the start of the invasion (02.03.2021 - 19.02.2023).

February 24, 2022 is included in the pre-invasion period, as the traded volumes on that day in the two market segments were submitted, offered, traded and paid as early as February 23 before 12:00 noon, thus market participants did not know what would happen the next day. That said, February 25, 2022 is included in the post-invasion analysis period, as volumes and trades for that day were submitted by participants as early as February 24 before 12:00 noon.

For the regression analysis we used the dummy variable «War» which takes values of 0 from 1 January 2021 to 23 February 2022, and 1 from 24 February 2022 until the end of April 2023.

In this research paper, we aim to investigate the relationships and dependencies among several variables in the context of changes on wholesale electricity market. Our analysis focuses on the variables: Price, Traded, Supply, Demand, BCM and War.

The first equation explores the relationship between Price and the War variable. We model Price as a function of War and an error term ε.

$$Price \sim \beta 0 \ + \ \beta 1 \ * \ War \ + \ \varepsilon$$

The coefficients β0, β1 and represent the intersection and the impact of War variable on the Day Ahead Market Price. The main point of interest is β1 coefficient, as it is estimate the effect of russian invasion on DAM market price.

The second equation investigates the relationship between Traded and the other variables.

$$Traded \sim \beta 0 \ + \ \beta 1 * \ War \ + \ \varepsilon$$

Traded is modeled as a function of War, and an error term ε. The coefficients β0, β1, represent the impact War variable on traded day-ahead market volumes.

In particular, for the basic analysis of quantitative changes caused by the war by means of descriptive statistics, the calculation of the arithmetic mean, as well as the sum of the traded volumes for a certain period of time.

Similarly, the second equation examines the relationship between Supply and the War variable. Supply is modeled as a function of War and an error term ε.

$$Supply \sim \beta 0 \ + \ \beta 1 \ * \ War \ + \ \varepsilon$$

The coefficients β0, β1 represent the intersection and the impact of the War variable on agregated market supply.

The fourth equation analyzes the relationship between Demand and the the impact of the war on agregated market demand.

$$Demand \sim \beta 0 + \beta 1 * War + \varepsilon$$

In this linear regression equation DAM market demand is modeled as a function of war effect and an error term ε. The coefficients β0, β1 represent the intersection and the impact of War variable on Demand.

Finally, the fifth equation explores the relationship between BCM and the impact of War variable on it.

$$BCM \sim \beta 0 + \beta 1 * War + \varepsilon$$

BCM or bilateral contracts market is modeled as a function of War and an error term ε. The coefficients β0, β1 represent the intersection and impact of War variable on BCM.

The Chow Test

Another instrument to prove that Russian invasion has influensed wholesale power market and caused structural changes on it is the Chow test, that was used in this research.

The Chow Test is a statistical test used to determine whether there are significant differences in the intercepts and slopes of two or more groups in a regression model. In the context of examining the impact of an event, like the Russian war, on the wholesale power market, the Chow Test can help establish whether this event led to structural changes in market behavior, price levels, supply-demand dynamics.

The Chow Test formula is generally given as:

$$F = \frac{\left(RSS0 - (RSS1 + RSS2)\right)/_{P}}{\frac{(RSS1 + RSS2)}{(N1 + N2 - 2p)}}$$

Where:

RSS_0: residual sum of squares of the pooled model (without considering the break).
RSS_1 and **RSS_2**: residual sum of squares of the models in each of the two segments divided by the breakpoint.
P: number of parameters in the regression model.
N_1 and **N_2**: number of observations in each segment.

Thus, the basic form of the Chow Test compares the sum of squared residuals from the separate models (pre-war and post-war) against the sum of squared residuals from a combined model (encompassing the entire period).

Test Statistic: Compute the Chow Test statistic. It typically follows an F-distribution under the null hypothesis that there is no structural break.

Therefore, this test can be helpful in detecting breakpoints thst the war might have caused significant disruptions in the energy sector, influencing prices, supply chains, or demand patterns. The Chow Test can help identify whether these changes are statistically significant, distinguishing them from normal market fluctuations.

CHAPTER 4. DATA

DATA COLLECTION

To analyze the impact of the war on the Ukrainian wholesale electricity market in this paper we have used the website of the State Spot Exchange for Electricity Trading SE Market Operator to collect data on daily trading volumes and daily weighted average price per 1 MWh on that day.

In particular, by manual scrapping the trading data on DAM for each trading day was collected from 1 January 2021 until 30 April 2023 on the following variables: total traded volume in MWh, declared sales volume in MWh, declared purchase volume in MWh, weighted average price, UAH/MWh.

The data with on traded bilateral contracts for purchase and sale of electricity for each day in MWh has also been added, as BCM. This data is subsequently published on the platform of the energy market regulator NCREPU. This data was also collected for analysis for 850 days over the same period as the data from the Market Operator.

Thus, a complete dataset was formed to analyze the market data, which consisted of 850 observations and 5 variables named as follows: Traded, Supply, Demand, Price, BCM.

DATA DESCRIPTION

Based on the analysis of historical price trends in the day-ahead market presented in the Table 3, the electricity price on this market segment dropped significantly in the first six months after the war. Overall, a year after the invasion, the price has even increased significantly.

Table 3. Mean of weighted average electricity price on day ahead market segment, UAH/MWh

Days	Before agression	After agression	Difference, levels	Difference, %
30	2,219.13	2,244.85	25.72	1.2%
90	2,760.37	2,280.68	- 479.69	-17.4%
180	2,746.60	2,414.24	- 332.36	-12.1%
360	2,093.08	2,916.49	823.41	39.3%

The analysis is based on historical data, measuring electricity prices in Ukrainian hryvnia (UAH) per megawatt-hour (MWh). For the 30-day period, the mean electricity price before aggression was 2,219 UAH/MWh, while after aggression it increased to 2,245 UAH/MWh, representing a 1.2% increase.

Looking at the 90-day period, the mean electricity price before aggression was 2,760 UAH/MWh, but after aggression, it decreased to 2,281 UAH/MWh. The difference in price levels is -479.69 UAH/MWh, indicating a 17.4% decrease.

While for the 180-day period, the mean electricity price before aggression stood at 2,747 UAH/MWh, but after aggression, it declined to 2,414 UAH/MWh. The difference in price levels is -332.36 UAH/MWh, signifying a 12.1% decrease.

Finally, considering the 360-day period, the mean electricity price before aggression was 2,093 UAH/MWh, and after aggression, it rose to 2,916 UAH/MWh, reflecting a significant increase of 39.3%

The observed variations in electricity prices can be attributed to the effects of the aggression event on the supply-demand balance, but it should also be mentioned that the price in this market segment was effectively regulated by the regulator NERC.

Namely, the regulator's actions to set the lower price at not less than UAH 1,378.97/MWh during night time hours (00:00 - 07:00) and UAH 2,646.25/MWh during day time hours (07:00 - 23:00), shortly after the aggression started on February 28, did not allow the average daily price to drop below UAH 2226 /MWh. The historical evolution of the weighted average price of electricity in the day-ahead market, broken down by periods (30, 90, 180, 360) days, can be observed in the charts below.

Figure 3 shows a huge drop in the first days of the war on 26 and 27 February, with the price dropping from 2,635 UAH/MWh to 990 UAH/MWh. The price then hovered at the minimum level set by the power market regulator since 28 February for 2646 UAH/MWh from 8:00 am to 22:00 pm and 1378 UAH/MWh – from 23:00 pm to 7:00 am.

Figure 3. Weighted average price on DAM segment, 30 days before / 30 days after invasion, UAH/MWh

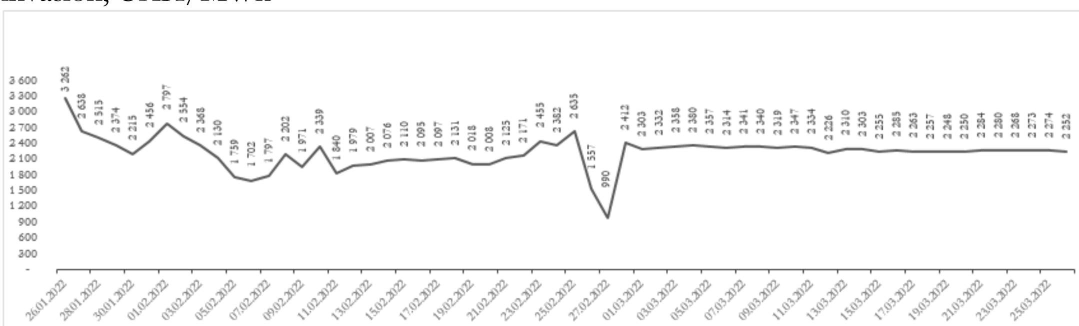
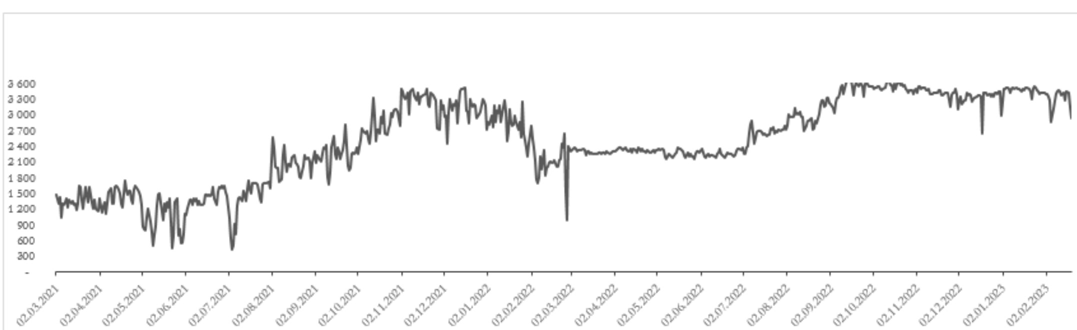


Figure 4 stands for weighted average price on DAM segment for 360 days before and after invasion, shows an increase in the weighted average price in the market, as the heating season approaches and attacks on energy infrastructure begin in the autumn of 2022.

Figure 4. Weighted average price on DAM segment, 360 days before / 360 days after invasion, UAH/MWh



The Table 4 below provides a comprehensive view of traded market volumes before and after the start of a war. It details changes in the daily traded volumes at specific timeframes relative to the start of the war (30 days, 90 days, 180 days, and 360 days).

Table 4. Descriptive statistics of daily Traded volumes on DAM, MWh

	Before 30	After 30	%	Before 90	After 90	%	Before 180	After 180	%	Before 360	After 360	%
Min	88 405	22 390	-75%	75 495	6 550	-91%	64 116	6 550	-90%	43 186	6 550	-85%
Max	161 916	89 969	-44%	169 739	89 969	-47%	169 739	89 969	-47%	169 739	89 969	-47%
Mean	121 596	38 802	-68%	131 665	28 857	-78%	110 038	24 080	-78%	93 070	36 109	-61%
Median	119 066	34 912	-71%	134 231	28 019	-79%	108 370	21 162	-80%	83 898	35 040	-58%
St. Dev	19 535	14 626	-25%	21 604	14 358	-34%	28 885	12 452	-57%	27 835	18 311	-34%
St. Error	3 567	2 670	-25%	2 277	1 513	-34%	2 153	928	-57%	1 467	965	-34%

As can be seen based on the table. There was a significant reduction in the traded volume for all indicators except for standard deviation and standard error. These, in turn, increased as the measurement horizon increased. Thus, over 360 days: max value of daily traded volumes decreased by 47% to 89 969 MWh, while the minimal value for this indicator decreased by 85% to 6 550 MWh, mean of traded volumes on day-ahead market dropped by 61% to 36 109 MWh, standard deviation decreased by 34% from 27 835 to 18 311 MWh.

The Table 5 provides an analysis of aggregated supply market volumes before and after the beginning of a war. The time periods remain the same.

Table 5. Descriptive statistics of agregated Supply volumes on DAM, MWh

	Before 30	After 30	%	Before 90	After 90	%	Before 180	After 180	%	Before 360	After 360	%
Min	152 651	120 842	-21%	97 935	70 925	-28%	78 053	31 319	-60%	78 053	18 129	-77%
Max	260 212	257 077	-1%	260 212	281 098	8%	260 212	281 098	8%	260 212	281 098	8%
Mean	207 616	167 999	-19%	186 960	160 010	-14%	148 520	115 991	-22%	142 522	90 467	-37%
Median	202 468	165 423	-18%	190 106	159 916	-16%	145 033	87 680	-40%	140 002	74 317	-47%
St. Dev	30 562	29 241	-4%	31 463	59 866	90%	46 164	62 456	35%	37 552	52 522	40%
St. Error	5 580	5 339	-4%	3 316	6 310	90%	3 441	4 655	35%	1 979	2 768	40%

From the table, it's evident that the supply market volumes consistently decreased following the war's commencement across all specified timeframes. In particular, the median supply volume was reduced by 47%, from 140,002 to 74,317 MWh. However, metrics like the standard deviation and standard error have witnessed significant increases in specific intervals, indicating higher variability and uncertainty in the supply market volumes post-war.

Regarding agregated demand in the spot market, Table 6 depicts an analysis of aggregated demand market volumes both before and after the onset of a war.

Table 6. Descriptive statistics of agregated Demand volumes on DAM, MWh

	Before 30	After 30	%	Before 90	After 90	%	Before 180	After 180	%	Before 360	After 360	%
Min	101 147	22 428	-78%	76 078	6 550	-91%	68 850	6 550	-90%	43 193	6 550	-85%
Max	172 158	90 101	-48%	172 158	90 101	-48%	172 158	90 101	-48%	172 158	90 101	-48%
Mean	138 564	38 808	-72%	138 752	28 859	-79%	116 887	24 244	-79%	97 355	37 246	-62%
Median	137 095	34 912	-75%	138 494	28 019	-80%	115 846	21 397	-82%	86 942	36 247	-58%
St. Dev	19 921	14 641	-27%	20 753	14 364	-31%	29 008	12 463	-57%	29 665	19 054	-36%
St. Error	3 637	2 673	-27%	2 188	1 514	-31%	2 162	929	-57%	1 563	1 004	-36%

On this table it can be observed how the volumes on the aggregate demand side have significantly decreased on each time interval. So over a 30-day interval on average, volumes declined from 138 564 to 38 808 MWh, a decrease of 72%, while on 360-day interval it declines by 62% to 37 246 MWh. At the same time standard deviation decreased by 36% to 1004 MWh as well as standard error decreased by 36%.

If we shift to analyze the market of bilateral contracts, in terms of aggregate daily trades in this segment, we will see a similar trend in all indicators. The data are presented in the Table 7 below.

Table 7. Descriptive statistics of Traded volumes on BCM, MWh

	Before 30	After 30	%	Before 90	After 90	%	Before 180	After 180	%	Before 360	After 360	%
Min	549 460	314 875	-43%	485 604	301 534	-38%	485 604	299 476	-38%	485 604	278 805	-43%
Max	672 785	661 814	-2%	672 785	661 814	-2%	672 785	661 814	-2%	730 333	661 814	-9%
Mean	580 205	383 549	-34%	573 571	357 105	-38%	559 776	351 175	-37%	586 283	349 665	-40%
Median	573 995	366 332	-36%	574 788	347 181	-40%	564 028	346 266	-39%	575 757	345 433	-40%
St. Dev	24 530	80 560	228%	28 117	55 276	97%	28 869	41 124	42%	48 330	34 306	-29%
St. Error	4 478	14 708	228%	2 964	5 827	97%	2 152	3 065	42%	2 547	1 808	-29%

As the table shows, traded volumes in the largest market segment fell by an average of 40% 360 days after the invasion began, to a level of 349 665. The standard deviation also fell by

29% to 34,306 MWh. All of this suggests a substantial overall decline in the total BCM traded volumes after the aggression.

There were substantial decreases in the traded volumes on both market segments, as well as in the total aggregates traded volumes. The supply and demand volumes on DAM were also significantly affected, with notable declines observed in both categories. These results emphasize the substantial impact of the invasion on energy trading .

CHAPTER 5. RESULTS

5.1. The results of the regression model used in the study, that aims to estimate effect of the war on the Day-Ahead Market price called «Price» variable based on «War» variable are follows:

Price

Based on the data we can observe that despite the war, the price did not decrease, but even increased significantly over the 360 day period. In general, this can be explained to a large extent by the regulator setting a lower price level.

Table 8. Regression results of the impact of the war on price on DAM for a period 30 days before and after the invasion.

30 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	2219.13	56.11	39.55	<2e-16
War	25.72	79.36	0.32	0.75
Multiple R-squared:		0.001808		
Adjusted R-squared:		-0.0154		

The regression analysis shows that the intercept is 2219.13 with a standard error of 56.11, which is statistically significant with a t-value of 39.55 and a p-value of less than 2e-16. With

60 number of observations and 58 degrees of freedom. Regarding the «War» variable, the estimate coefficient is 25.72 with a standard error of 79.36, resulting in a t-value of 0.32. This corresponds to a insignificant p-value of 0.75, indicating that the «War» variable, within the context of this model and data, does not have a statistically significant impact on the dependent variable on 30 days time horizon.

However, over a period of 360 days before and after the war began, the regression results indicate that the war significantly increased the spot market price, the results are presented in Table 9.

Table 9. Regression results of the impact of the war on price on DAM for a period 360 days before and after the invasion.

360 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	2093.08	35.86	58.36	<2e-16
War	823.41	50.72	16.23	<2e-16
Multiple R-squared:		0.2685		
Adjusted R-squared:		0.2675		

The estimated intercept is 2093.08 with a standard error of 35.86. This intercept is statistically highly significant, with a t-value of 58.36 and a p-value of less than 2e-16. This significance suggests that in the absence of the war (when «War» = 0), the baseline level of the dependent variable (price) is predicted to be around 2093.08 UAH/MWh. The estimated coefficient for the «War» variable is 823.41, with a standard error of 50.72. The t-value for this estimate is 16.23, which is considerably high, and the corresponding p-value is less than 2e-16, indicating that this result is statistically significant. This significant positive coefficient suggests that the presence of war is associated with an increase in the price by approximately 823.41 UAH/MWh. With 720 number of observations and 718 degrees of freedom.

5.2. The linear regression models that analyzes the relationship between the Day-Ahead Market demand, supply, traded volumes and explanatory variable «War» demonstrated the next results:

Demand

The summary of the results from the linear regression analysis estimating the relationship between the Day-Ahead Market demand and the explanatory variable «War» over a 30-day period is presented in Table 10.

The estimated intercept is 138 564 with a standard error of 3,192. This yields a t-value of 43.41, which is highly significant as indicated by a p-value of less than 2e-16. The interpretation of this result is that when the variable «War» is at 0, the average expected Day-Ahead Market demand is around 138,564 MWh. While the estimated coefficient for «War» is -99 756 with a standard error of 4,514. The t-value for this coefficient is -22.10, indicating a highly significant negative relationship with a p-value of less than 2e-16. This negative coefficient means that the presence of war is associated with a decrease in the demand by approximately 99 756 MWh. With 60 number of observations and 58 degrees of freedom.

Table 10. Regression results of the impact of the war on agregated demand on DAM for a period 360 days before and after the invasion.

30 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	138564	3192	43.41	<2e-16
War	-99756	4514	-22.10	<2e-16
Multiple R-squared:		0.8939		
Adjusted R-squared:		0.892		

However, for the period of 360 days before and after the war began, the regression results indicate that demand gradually began to recover to pre-war levels. The results are presented in Table 11

Table 11. Regression results of the impact of the war on agregated demand on DAM for a period 360 days before and after the invasion.

360 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	97355	1314	74.09	<2e-16
War	-60109	1858	-32.35	<2e-16
Multiple R-squared:		0.593		
Adjusted R-squared:		0.592		

The estimated intercept is 97 355 with a standard error of 1,314, yielding a t-value of 74.09. The p-value is less than 2e-16, indicating that the intercept is statistically highly significant. This result suggests that in the absence of war, the average expected aggregated demand on DAM is predicted to be approximately 97 355 MWh. The coefficient for the «War» variable is -60 109, with a standard error of 1 858. This results in a t-value of -32.35, indicating a statistically significant negative relationship with a p-value of less than 2e-16. The negative coefficient implies that the occurrence of war is associated with a decrease in the aggregated demand on DAM by about 60 109 MWh. With 720 number of observations and 718 degrees of freedom.

Supply

The regression analysis summarized below investigates the relationship between the Day-Ahead Market supply and the explanatory variable «War» over a period of 30 days. The key findings from this analysis presented in Table 12 and Table 13.

Table 12. Regression results of the impact of the war on agregated supply on DAM for a period 30 days before and after the invasion.

30 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	207616	5461	38.02	<2e-16
War	-39617	7722	-5.13	3.5e-06
Multiple R-squared:		0.3121		
Adjusted R-squared:		0.3003		

The estimated intercept is 207 616 with a standard error of 5 461. This results in a t-value of 38.02, indicating a statistically significant intercept with a p-value of less than 2e-16. The interpretation is that in the absence of war, the average expected Day-Ahead Market agregated supply is approximately 207 616 MWh. The coefficient for «War» is -39 617, with a standard error of 7 722, resulting in a t-value of -5.13. The corresponding p-value is 3.5e-06, which indicates that this result is statistically significant. The negative coefficient for «War» suggests that the occurrence of war is associated with a decrease in the Day-Ahead Market agregated supply by about 39 617 MWh. With 60 number of observations and 58 degrees of freedom.

However, on a 360-day horizon, the supply in the market has only decreased.

Table 13. Regression results of the impact of the war on agregated supply on DAM for a period 360 days before and after the invasion.

360 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	142522	2406	59.23	<2e-16
War	-52054	3403	-15.30	<2e-16
Multiple R-squared:		0.2458		
Adjusted R-squared:		0.2447		

The estimated intercept is 142 522, with a standard error of 2 406. This leads to a t-value of 59.23, suggesting that the intercept is statistically highly significant (p-value < 2e-16). This means that if the variable «War» is 0 (before the war), the average predicted aggregated supply is about 142 522 MWh. The coefficient for «War» is -52 054, with a standard error of 3 403, resulting in a t-value of -15.30. The p-value for this coefficient is less than 2e-16, indicating a highly significant negative relationship. Thus, the occurrence of war is associated with a decrease in aggregated supply by approximately 52 054 MWh. With 720 number of observations and 718 degrees of freedom.

Traded volumes

The linear regression model that analyzes the relationship between the Day-Ahead Market daily traded volumes named «Traded», and dummy explanatory variable «War» demonstrated the two key points of ineterest is the coefficient for:

Table 14. Regression results of the impact of the war on daily traded volumes on DAM for a period 30 days before and after the invasion.

30 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	121596	3151	38.59	<2e-16
War	-82795	4456	-18.58	<2e-16
Multiple R-squared:		0.8562		
Adjusted R-squared:		0.8537		

The estimated value of the intercept is 121 596, with a standard error of 3 151. This gives a t-value of 38.59, which is highly significant statistically (p-value < 2e-16). The interpretation here is that in the absence of war, the average expected daily traded volume is approximately 121 596 MWh. With 60 number of observations and 58 degrees of freedom. The coefficient for «War» is -82 795, with a standard error of 4 456, resulting in a t-value of -18.58. The p-value for this coefficient is less than 2e-16, indicating a statistically significant negative relationship. This finding means that the occurrence of war is associated with a substantial decrease in daily traded volumes by about 82 795 MWh.

However, as can be seen in the Table 15 below, in the 365-day period following the war, pro-traded volumes decreased excluding the war (intercept), but the estimate for the War variable decreased, which may also signal a gradual decrease in the impact of the war over time.

Table 15. Regression results of the impact of the war on daily traded volumes on DAM for a period 360 days before and after the invasion.

360 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	93070	1242	74.95	<2e-16
War	-56961	1756	-32.44	<2e-16
Multiple R-squared:		0.5944		
Adjusted R-squared:		0.5938		

The estimated value of the intercept is 93 070, with a standard error of 1 242, provides a t-value of 74.95. This result is statistically highly significant p-value < 2e-16. It implies that, in the absence, the average baseline daily traded volume is estimated to be around 93 070 MWh. The coefficient for «War» is -56 961 MWh, with a standard error of 1 756, leading to a t-value of -32.44. The corresponding p-value is less than 2e-16, indicating a statistically significant negative effect. This means that the presence of war is associated with a decrease in daily traded volumes by approximately 56 961 MWh. With 720 number of observations and 718 degrees of freedom.

Bilateral contract market

The trading volume in the bilateral contracts market also suffered a significant decrease after the war started, which is reflected in the results of regressions for both 30-day and 360-day periods.

Table 16. Regression results of the impact of the war on daily traded volumes on BCM for a period 30 days before and after the invasion.

30 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	580205	10872	53.37	<2e-16
War	-196656	15375	-12.79	<2e-16
Multiple R-squared:		0.7383		
Adjusted R-squared:		0.7338		

The intercept represents the average daily traded volumes on the BCM 30 days before the war when all other variables are set to zero. The estimated value is 580 205 MWh. With a standard error of 10 872, the t-value is 53.37, and the p-value is less than 2e-16. This suggests that the average daily traded volume 30 days before the war is significantly different from zero. The «War» variable indicates the change in the daily traded volumes on the BCM due to the onset of the war. The estimated impact of the war is a decrease of 196 656 MWh in daily traded volumes. The st. error for this estimate is 15 375, and the t-value is -12.79. The p-value is less than 2e-16, prove that the war had a statistically significant negative impact on the daily traded volumes on the BCM. With 60 number of observations and 58 degrees of freedom.

Table 17. Regression results of the impact of the war on daily traded volumes on BCM for a period 360 days before and after the invasion.

360 Days Period				
Variable	**Estimate**	**Std.Error**	**t-value**	**P-value**
(Intercept)	586283	2209	265.43	<2e-16
War	-236618	3124	-75.75	<2e-16
Multiple R-squared:		0.8888		
Adjusted R-squared:		0.8886		

The intercept represents the average daily traded volumes on the BCM 360 days before the war when all other variables are set to zero. The estimated value is 586 283. With a standard error of 2 209, the t-value is an extremely high 265.43, and the p-value is less than 2e-16. This indicates that the average daily traded volume 360 days before the war is significantly different from zero. With 720 number of observations and 718 degrees of freedom.

The «War» variable signifies the change in the daily traded volumes on the BCM due to the onset of the war. The estimated impact of the war is a decrease of 236 618 in daily traded volumes. The standard error for this estimate is 3,124, leading to a t-value of -75.75. The p-value is less than 2e-16, which suggests that the war had a statistically significant negative impact on the daily traded volumes on the BCM.

5.3. The results of the the Chow Test

The results of the of the Chow test conducted on all variables with break point designated February 24, 2022, the test showed that each time series demonstrated a structural break caused by war.

Table 18. The results of the the Chow Test on each all variables with a break point designated February 24, 2022

The Chow Test results		
Variable	F stat.	p-value
Price	91.357	< 2.2e-16
Traded	854.16	< 2.2e-16
Demand	980.56	< 2.2e-16
Supply	102.71	< 2.2e-16
BCM	674.46	< 2.2e-16

Timeseries with Price variable

The F-statistic is 91.357 with a p-value that's virtually zero (p-value < 2.2e-16). Relatively high F-statistic suggests a significant difference in the regression models between the two groups (data samples before and after 24 february 2022), related to the Russian war in your analysis).The p-value is extremely small (less than 2.2e-16), which is far below any standard significance level 0.05 or 0.01. This means the probability of observing such a large F-statistic under the null hypothesis (which states that there is no structural break at the specified date) is almost zero.

The same situation with all other variables such as: Traded, Demand, Supply, BCM with p-value of less than 2.2e-16 signals a significant evidence of structural break. Moreover, for visual detection, structural breaks can be seen on Figures №5 - №9 (which are located in the Appendix).

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

In this study, we analyzed historical data on electricity prices on two biggest market segments Bilateral Contracts Market (BCM) and Day Ahead Market (DAM) to investigate the impact of russian aggression.

We examined price changes before and after the aggression event across different time periods (30-day, 90-day, 180-day, and 360-day).

Our findings reveal interesting patterns in electricity prices. In the 30-day period, there was a 1.1% increase in the mean electricity price after aggression. However, the 90-day, 180-day, and 360-day periods showed significant price decreases of 17.4%, 12.1%, and 39.3%, respectively.

The observed variations in electricity prices can be attributed to the effects of the aggression event on the supply-demand balance. However, it is important to note that the electricity price in this market segment was effectively regulated by the National Energy and Utilities Regulatory Commission (NERC). The regulator implemented measures to set minimum prices during specific time periods, which prevented the average daily price from dropping below certain thresholds.

Additionally, several regression models were conducted to estimate the impact of the War dummy variable on «Price», «Traded,» «Supply,» «Demand,» «BCM». The inclusion of the «War» dummy variable allowed us to examine its impact on market price, agregated demand, agregated supply, daily traded volumes in the two largest market segments. The regression analysis showed that for one unit increase in the «War» dummy variable (from the 25 of February 2022), the predicted value of «Price» increased by 823.1 UAH/MWh on 360 days after Russian invasion horizon.

The research paper findings reveal a significant decrease in traded volumes across both DAM and BCM over a 30-day period after beginning of the agression. On DAM, there was a substantial decrease of 68.1% in the mean traded volumes, dropping from 121 596 MWh to 38 802 MWh. Similarly, the mean traded volumes on BCM experienced a decline of 33.9%, going from 580 205 MWh to 383 549 MWh.

Our findings demonstrate a significant decline in trading activity and energy volumes in all categories on 360-day period after the outbreak of war. Thus, the mean traded volumes on DAM decreased by 61.2%, indicating a substantial decrease from 93 070 MWh to 36 109 MWh. Similarly, the average traded volumes on BCM decreased by 40.4%, from 586 283 MWh to 349 665 MWh.

Moving to the analysis of submitted supply and demand volumes on DAM , it was found out that 360 day period after the beginning of the war daily supply was reduced by market participants on the Day-Ahead Market by about 37% or 52 054 MWh in average, while daily demand was diminished by around 62% or 60 109 MWh in average.

In addition, the structural break Chow Test conducted confirmed that each time series under study underwent a structural change.

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APPENDIX

Figure 5. Day-Ahead Market Price Trends with Suspected Structural Break on 24.02.2022

Figure 6. Day-Ahead Market Daily Traded Volumes with Suspected Structural Break on 24.02.2022

Figure 7. Day-Ahead Market Daily Demand Volumes with Suspected Structural Break on 24.02.2022

Figure 8. Day-Ahead Market Daily Supply Volumes with Suspected Structural Break on 24.02.2022

Figure 9. Day-Ahead Market Daily Traded Volumes with Suspected Structural Break on 24.02.2022