IMPACT OF ELECTRICITY PRICES IN EUROPE ON PRODUCTION COSTS FOR TISSUE PAPER: A CASE STUDY OF ZEWA BRAND

by

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LIST OF ABBREVIATIONS

CEPI Confederation of European Paper industries

PwC PricewaterhouseCoopers

LLC Limited Liability Company

PPI Producer Price Index

MWh Megawatt-hour

kWh Kilowatt-hour

EP Processing Energy Cost

ES Setup Energy Cost

ET Transportation Energy Cost

TOU Time to Use

CHAPTER 1. INTRODUCTION

It is widely known for the European market to have a great variety of sectors. The Pulp and Paper Sector sector is not last on the list, especially in the field of hygiene. The tissue paper industry accounts for 10.2% of the entire sector. Despite economics shocks and Covid pandemic, tissue paper manufacturers' output increased by about 3.5% in 2024 compared to 2023.

The production process of tissue paper demands a lot of efforts, but what is more important, energy. Each stage of manufacturing is accompanied by the use of a large amount of electricity. Starting with the preparation of raw materials like wood pulp, bleaching, drying, and ending with winding. Such a high dependence of the industry on energy resources makes it vulnerable to price fluctuations in the electricity market.

The energy crisis of 2021-2022 has significantly changed European energy market, and introduced irreversible shifts, such as replacement of russian pipeline gas. The highest price was recorded in August 2022 (around 400 EUR/MWh). Even though there was a decrease in energy prices in 2023, the impact on bills, particularly for the most unprotected sectors, is still substantial.

In this research I investigate the impact of Electricity Price fluctuations in Europe, and in Germany particularly, on the Production Costs of tissue paper for Zewa Brand. My objective is to examine how changes in Electricity Prices affect the overall cost structure, including raw materials, manufacturing processes, and labor. Furthermore, I look at the way these fluctuations affect Zewa's market competitiveness for future pricing startegies.

This topic is relevant not only to me because I work as a Financial Specialist for Zewa Brand, which is my professional domain, but also to the whole industry as it highly relies on electricity and gas for pulping, drying, and converting processes. I am interested in examining the relationship between Electricity Prices and Production Costs of tissue paper as it is a significant and valuable aspect of the business. Moreover, it is crucial to comprehend the impact of the European energy market, as the production of this product is carried out in Germany, while its sale to the final consumer is done in Ukraine. The investigation provides insights into the influence of these factors not only on the company as a whole but also consumers as well. It is naturaly, as every corporate company prioritizes its profitability and end customers.

The tissue paper manufacturing is experiencing significant challenges due to fluctuating Electricity Prices in Europe, as the main portion of the mills is located in Mannheim, Germany. Besides, particularly in Mannheim, there was built a unique 8,000 square meter facility to produce high quality pulp of straw. Essity (owner of Zewa Brand) is known to be the first and only company that integrated an alternative fiber as a complement to current raw materials in the production process. Considering all this, the issue of the impact of the cost of electricity on the production process is one of the most critical.

The direction of the European Union towards green energy, particularly starting in 2022, the reduction and abandonment of nuclear energy, and the restructuring of the energy sector significantly affect large industrial production. Understanding these dynamics is essential for companies like Essity to perform accurate forecasts and compete in pricing strategies to manage with consumer affordability.

It is highly important topic to examine as tissue paper is an essential commodity in everyday life of each person and any changes in production proccess affect consumer behavior and household budgets. It is used for a variety of purposes, from personal hygiene to household cleaning. Moreover, tissue paper plays a crucial role in the sphere of healthcare and sanitation. It uses in hospitals for varoius purposes like cleaning and disinfecting surfaces or during medical procedures and operations.

The structure of the paper is organized as follows. In Chapter 2 I present detailed industry overview, which is divided into two sections: Pulp and Paper Sector and Energy Sector.

This part also includes related studies. In Chapter 3 you can find step by step methodology, that I used to conduct my research. Chapter 4 describes collected data for the models. Chapter 5 is the most important part of this thesis as it shows the results of my modelling and forecasting. Chapter 6 is a closure part that summarizes all conclusions and recommendations.

CHAPTER 2. INDUSTRY OVERVIEW AND RELATED STUDIES

2.1 Pulp and Paper Sector

The tissue paper industry is a big part of Pulp and Paper sector in Europe, which is contributing substantially to the economy. From the economic perspective the industry has high capital cost and long investment cycles, but at the same time it is efficient in usage of limited natural resources. According to the information from European Commission the annual turnover from the production of pulp, as well as hygienic, packaging and specialized paper products is around EUR 180 billion[1]. Even so, current and future tariff barriers, including taxes for wood industry, can create an unfair playground which leads to decrease in exports.

Even though global economy is still recovering from various shocks and Covid pandemic, Europe's Pulp and Paper sector had a positive year in 2024. Tissue paper manufacturers' output increased by about 3.5%[2] compared to 2023 and accounted for 10.2% of total paper production. However, Paper for Recycling field is remaining lower its peak level in 2021. There is active European debate around the optimization of high production costs, including energy and natural gas, since all EU manufacturing sectors are struggling from this problem, with no exception for Pulp and Paper industry.

The graph below represents the transformation of the European Pulp and Paper industry from 1991 to 2024 (Figure 1). It shows both number of Paper and Board mills in Europe and paper production in million tons. We can see that the line which represents number of mills has downward trend, suggesting decreasing in number of mills in line with increasing efficiency and optimization in manufacturing process. With the time, mills were becoming

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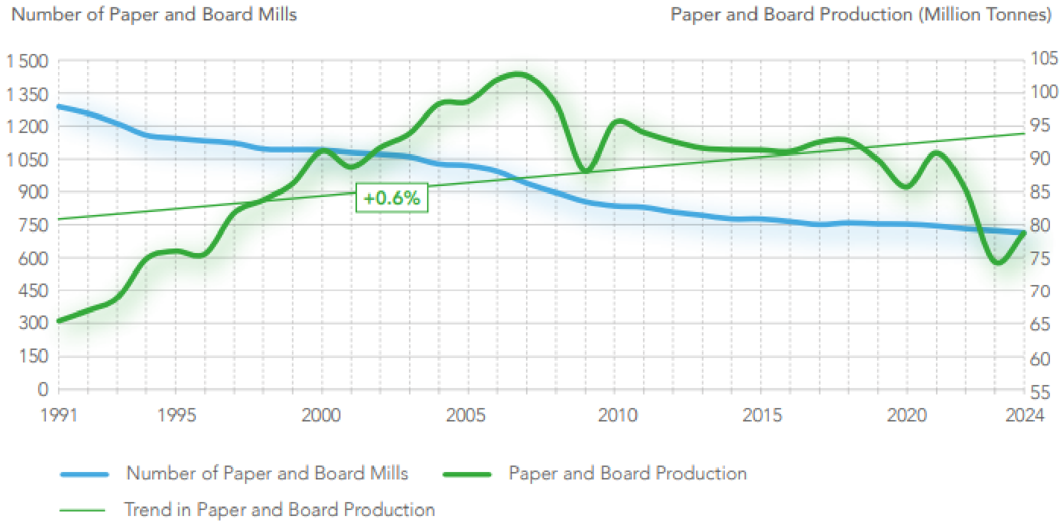
[1] European Commission (2025). Pulp and Paper industry https://single-market-economy.ec.europa.eu/sectors/raw-materials/related-industries/forest-based-industries/pulp-and-paper-industry_en

[2] Cepi (2024). Preliminary Statistics 2024 FINAL-Cepi-Preliminary-Statistics-2024.pdf

larger and more technologically efficient due to availability of quick adaptation to new trends. Industry started to produce higher amount of paper, or just stay at previous level, but with much less facilities. On the other hand, production line has fluctuating character, but, at the same time, stable trend over the long period. It proves that paper industry overall is growing and with right focus on high-growth segments, the industry will be cost-effective and energy-saving.

Figure 1. Number of Paper and Board Mills and Paper and Board Production

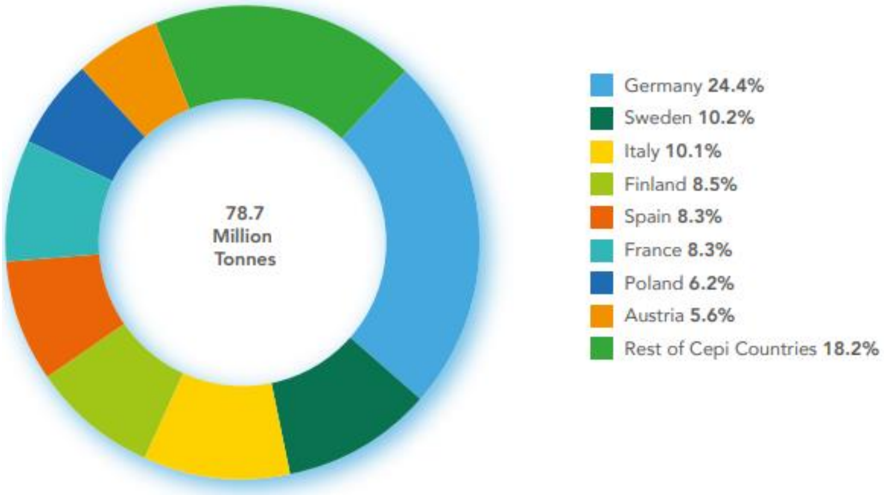


Source: Cepi Key Statistics 2024

For better understanding, it is important to figure out key stages in the production process of tissue paper. There are different types of tissue paper: toilet paper, facial tissues, paper towels, and napkins, but the manufacturing process for all of them is similar. The first step is preparation of raw material that is usually either wood pulp or recycled paper pulp. Wood logs are being chopped into small chips, after what this material is being mixed with water and different chemicals, which helps to leave only cellulose fibers. After pulping, it is necessary to make the tissue paper white and clean. This process is called bleaching. The next step is to form a wet sheet of paper by thinning out the pulp and spreading onto a forming fabric. Then, this wet sheet is going through press rollers that compact fibers for a more rigid structure. The importance of electricity in this process is especially clear on the stage when wet paper is moving through drying cylinders. It removes water by using heated rollers or steam. Further steps include creping, calendering, rolling and converting. Creping makes tissue paper soft and flexible. After that special calendering rollers smooth the sheet's surface and adjust thickness. Next, the finished paper is wound onto large reels. Finally, it is being cut and converted into various consumer products like toilet rolls, towels or napkins. Hence, the question of the production optimization is crucial in particular industry.

Germany is the biggest paper market in Europe (Figure 2). There are a lot of manufacturers and processors located inside country. According to Confederation of European Paper industries, Germany produced around 20 million tons of paper in 2024.

Figure 2. Paper and Board Production by country in 2024



Source: Cepi Key Statistics 2024

Brand Zewa is one of the leaders in the hygiene tissue paper segment with a strong market presence in Germany with competitors like Tempo and Kleenex. These are two big global brands, but the main difference is that Tempo is also owned by Essity, whereas Kleenex is owed by another company, Kimberly-Clark. They are both focusing on facial tissue and hygiene paper market. Overall, Essity is recognized to be the key player, covering all major product categories.

What is more important is that Zewa is well-known to be focusing on sustainability topic which is highly discussed worldwide nowadays. Essity, as a global company in hygiene and health, is trying to reduce harmful environmental impact from production and become absolute eco-friendly. There is a commitment to achieve net-zero emissions of greenhouse gases by 2050. Also, company's target is that at least 50% of its innovations are to give in social and environmental improvements.

Being a global buyer of both fresh and recycled wood-based fiber materials, company is responsible for impact on forest biodiversity and its reasonable usage. They are integrating alternative fiber as a complement to current raw materials in the production process. For now, Essity is the first and only company in Europe that produces high quality pulp of straw. To make it possible, there was built a unique 8,000 square meter facility in Mannheim, Germany. It is totally new soft and highly absorbent cellulose which is being recycled into high-quality hygiene products from brand Zewa. As a result, it will enable to reduce a usage of natural resources like energy and water.

All the above goals of sustainable development correspond to the general tendency of the industry and the future trend all around the world. New technologies and AI improvements can substantially reduce harmful impact on the environment and optimize all resources. There already exists the 2050 Roadmap[3] towards a low-carbon bio-economy. The main message is to build reliable synergies and partnership in value chain. This applies to both producers and consumers where the top priority should be an improved usage of resources. The future of the industry highly depends on the current economic crisis. Already, there

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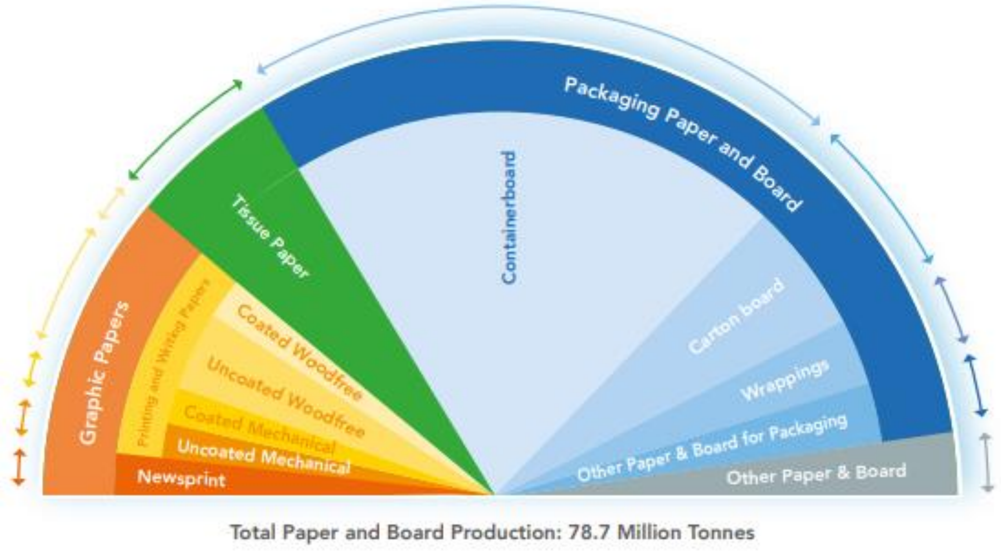
[3] Cepi (2013). Industry Forum – CEPI 2050 Roadmap: the strategic role of the value chain https://www.cepi.org/industry-forum-cepi-2050-roadmap-the-strategic-role-of-the-value-chain/

should be a reduction in excessive regulation and unpredictability of legislation in European politics to support and successfully develop the Pulp and Paper sector.

In additional to that, the industry is expecting continuous changes and shifts in usual structure. Due to digitalization and technological era, there has already been a decline in printing and graphic paper. In contrast, the demand for tissue paper is continuing to grow thanks to tendency of being more focused on personal hygiene and health in general. Even though, tissue paper is not the biggest part of the industry overall, it is a huge segment which signalizes about prospects and growth (Figure 3).

Figure 3. Paper and Board - A Whole Range of Products for Everyday Life



Source: Cepi Key Statistics 2024

2.2 Energy Sector

The history of German nuclear power began in 1960s with research reactors. By 1990, around 25% of Germany's electricity came from nuclear. In 2021, atomic power accounted for 13.3% of the country's electricity, produced by six plants. First three of them were closed at the end of 2021, and the other three stopped working by April 2023. It was not a spontaneous decision, on the contrary, the movements against nuclear power became more intensive after Chernobyl disaster in 1986. Moreover, after Fukushima disaster in 2011, the government announced that all its nuclear power plants would be switched off by 2022. However, the Russia-Ukraine war led Germany to reconsider its plan to stop its remaining three reactors by the end of 2022. The government decided to keep them until April 2023.

At the same time, to remain as productive as before, Germany used 7% more fossil fuels between 2002 and 2022 alongside with increase in usage of natural gas and small reductions in coal and oil. By some estimations, Germany could save around €696 billion[4] on its energy shift if it continued to use nuclear power during that time. Interesting fact that Germany has some of the lowest wholesale electricity prices in Europe, yet its retail prices are among the highest. It caused by energy policies and taxes.

The analysis by PricewaterhouseCoopers (PwC) stated that in a scenario where Germany had maintained its nuclear power plants, the emission-free generation would have reached 94%[5] by 2024. Also, it would almost completely displace fossil generation.

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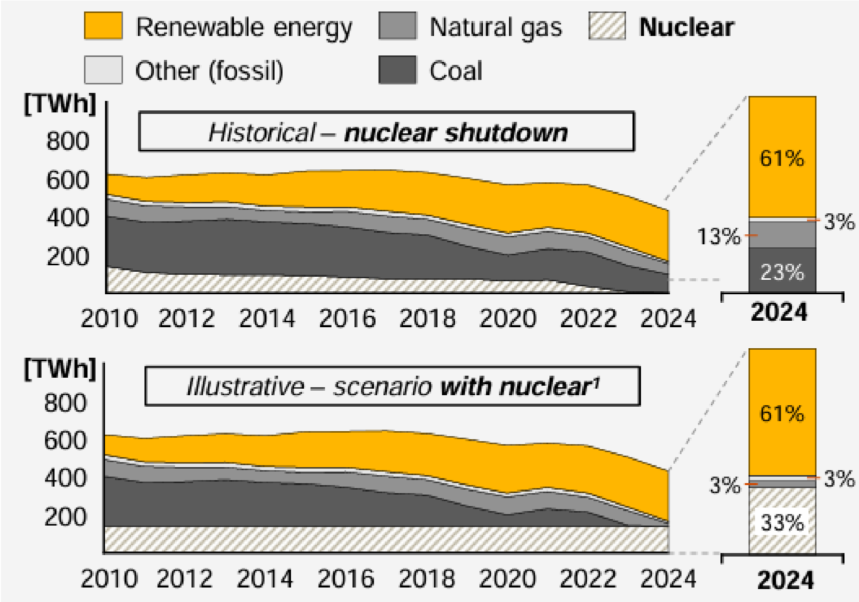
[4] Nuclear power in Germany https://en.wikipedia.org/wiki/Nuclear_power_in_Germany#History

[5] PwC (2025).Germany and nuclear energy: What have been the consequences of the closure of the nuclear power plants? https://www.foronuclear.org/wp-content/uploads/2025/03/Ficha-nuclear-Caso-Alemania_vingles.pdf?x44548

Figure 4. Scenarios of electricity generation with and without closure of nuclear power plants



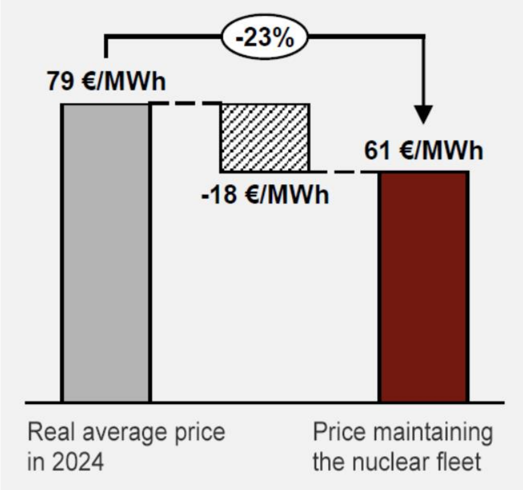
Source: PwC

The picture above shows two scenarios of electricity generation. One with closure of nuclear power plants and other without. The top chart represents the real historical situation without nuclear power where total electricity generation is fluctuating around 600-650 TWh. We can see that nuclear contribution was substantial at the beginning alongside with coal and natural gas, comparing single sources. The alternative type of energy or renewable energy is increasing over this period. As the nuclear power loses its part, the renewable energy is becoming share significantly bigger part, starting from 2018. Overall, the total electricity generation is declining substantially to roughly 400 TWh (Figure 4).

The bottom chart is a representation of theoretical scenario when nuclear power plants still work and assume that it will replace fossil generation. The situation from 2010 to 2018 looks similarly to the historical scenario. However, it this case, the nuclear power contribution remains at the same level. Looking at the renewable energy, it is also increasing as on the top chart. The biggest difference is that the contributions from coal and natural gas show a decrease to almost zero level. Overall, the total electricity generation is also decreasing, but not so dramatically, to 500 TWh (Figure 4).

The following figure illustrates impact of nuclear power stations closure on prices for electricity. It is shown that if Germany had kept its nuclear power stations in operation since 2010, the price for electricity would be lower by €18/MWh[6] in average (Figure 5).

Figure 5. How nuclear generation influences the price of electricity



Source: PwC

Obviously, this situation relates not only to one sector or industry, but also it contributes to the economic recession inside the country. It affects players from both sides, industrial companies and manufactures, and consumers. As a result, households have lower purchasing power, whereas industrials lose its competitiveness, leading to reduction in production power.

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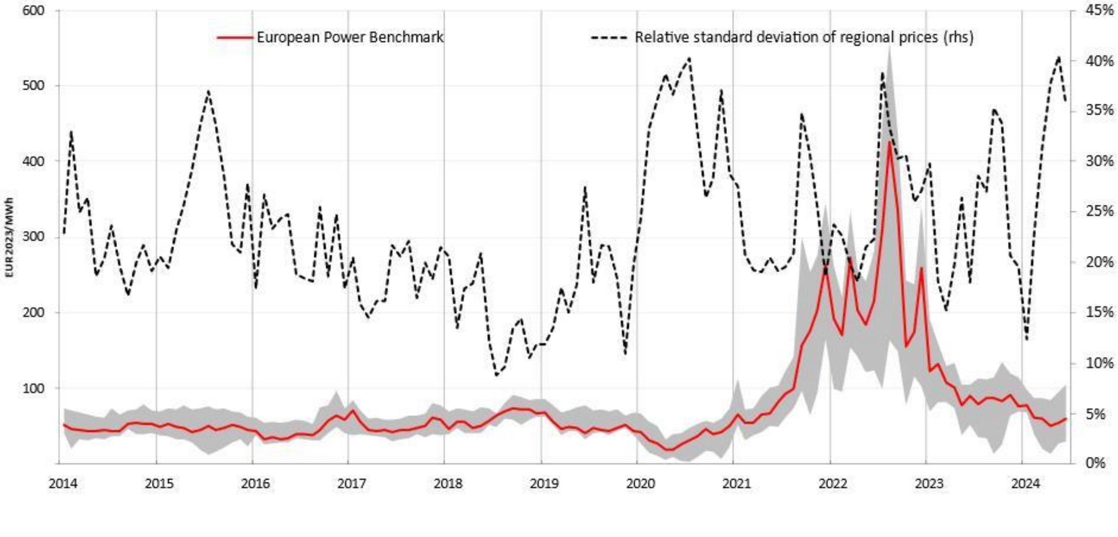
[6] PwC (2025). Germany and nuclear energy: What have been the consequences of the closure of the nuclear power plants? https://www.foronuclear.org/wp-content/uploads/2025/03/Ficha-nuclear-Caso-Alemania_vingles.pdf?x44548

In 2020, global pandemic COVID-19 has caused a significant decrease in spot prices for electricity due to weak demand and rising interest to renewable generation. The following years were the complete opposite, the energy crisis of 2021-2022 has changed not only European energy markets but also global distribution. There were record highs during 2022-2023, reaching 400 EUR/MWh[7] in August 2022. Only in the second part of 2023 prices have stabilized above their historical average. In the graph below you can see the fluctuation of monthly average wholesale electricity prices in Europe in EUR/MWh (Figure 6). It shows the evolution of the European Power Benchmark.

Figure 6. Evolution of monthly average wholesale day-ahead baseload electricity prices in Europe in EUR/MWh



Source: Trinomics et al. (2024), based on data from S&P Platts, ENTSO-E

Despite the decrease in 2023, industrial electricity costs in EU were significantly higher comparing to pre-crisis levels. In average, such costs are between 1-3% of total production costs for different sectors. For energy-intensive industry such as Pulp and Paper the range reaches 5-10%. In the graph below it is noticeable that Paper sector is situated in the middle,

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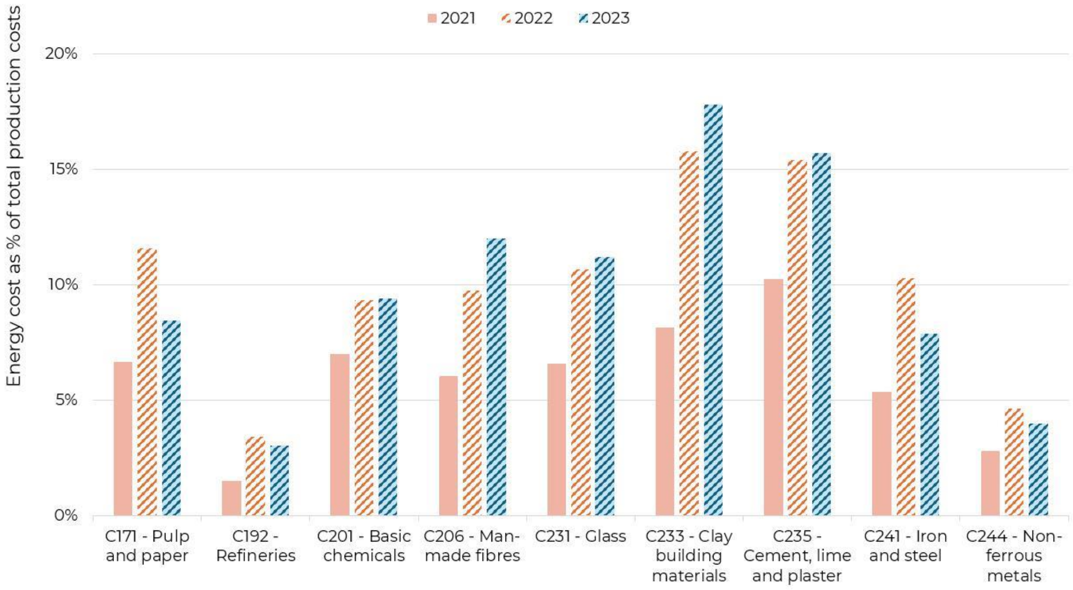
[7] European Commission (2025). Report on energy prices and costs in Europe EUR-Lex - 52025DC0072 - EN - EUR-Lex

showing not the highest energy cost shares of total production costs, but it is still huge (approximately 8%) (Figure 7). In all sectors it has increased in 2022 and 2023.

Figure 7. Estimated energy costs (as shares of production costs) for manufacturing sectors in 2021–2023, EU average



Source: Trinomics et al. (2024), based on data from industrial plant operators

Europe is a major paper producing region in the world with 25% of the global production. In turn, Germany is the top paper producer in Europe with around 19 million tons[8] produced each year (before the pandemic COVID-19 it was 23 million tons[9] per year).

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[8] News within the industry of pulp and paper (2025). German paper industry faces sharp decline: A halt in post-pandemic recovery https://www.pulpapernews.com/20240305/15419/german-paper-industry-faces-sharp-decline-halt-post-pandemic-recovery

[9] World Paper Mill (2019). Top 10 Pulp & Paper Producing Countries in World https://worldpapermill.com/top-pulp-paper-producing-countries/

2.3 Related Studies

My research is not something absolutely new or totally innovative. It rather focuses on contribution to the entire field of paper industry based on tendencies of modern markets and changeable history of nowadays. I am basing on already existed methods and knowledge.

It is known for paper industry to be highly energy intensive with high power consumption. Julianna Torvelainen (2023) examined the question of how different energy concepts affect the paper manufacturing costs. Researcher also described all steps in paper production process and the necessary amount of energy for each step.

Author presented AFRY cost competitiveness modelling tool which simulated four different energy production concepts. It is highly relevant to my study as the research was conducted during the European energy crisis of 2022-2023, which is also my topic. There are four key concepts: natural gas, renewable energy, alternative energy and integrated pulp. All of them has different impact on manufacturing costs, and Julianna Torvelainen (2023) models how Total Manufacturing Cost per ton was affected by Net Energy Cost.

The total cost formula is represented like this:

$$CMC = C_{FIBER} + C_{CHEMICALS} + C_{LABOR} + C_{FIXED} + C_{NET\ ENERGY}, \tag{2.1}$$

where $C_{NET\ ENERGY}$ is the sum of fuel costs, purchased electricity costs, CO_2, subtracting revenue from electricity surplus.

Natural gas has the highest cost, and due to extremely high and volatile prices, mills in Europe met difficulties in 2022. Renewable and alternative energy are similar, as they are both more stable and cost-competitive, comparing to fossil fuels. The last concept is believed to be the most cost-effective since it uses internal fuels, making its external cost almost zero. Overall, thesis highlights the big impact of energy costs on total production costs of tissue paper and concludes the importance of switching to low-emission energy concepts.

Another author, Jobien Laurijssen (2013), states that a share of energy expenses in total costs for some mills in Europe is over 30%. It suggests that energy has become a major cost component in the manufacturing process in this industry, proving the sector's vulnerability to increasing prices. In comparison, in 2001 it was just 15%.

Jobien Laurijssen (2013) emphasizes on the importance of heat-to-power ratio of a mill. It particularly depends on the paper type which is produced. The following table shows power demand in kWh/ton, heat demand in MJ/ton and the ratio between them.

Table 1. Heat-to-power ratio

Type of Paper	*Power Demand (kWh/ton)*	*Heat Demand (MJ/ton)*	*Heat-to-power ratio*
Corrugated Board	350	4500	3.6
Printing Paper	600	5000	2.3
Tissue	1300	5500	1.2

Source: Jobien Laurijssen (2013)

The power demand for tissue paper is extremely high, comparing to heat-to-power ration with value of 1.2. It shows that tissue production is extremely electricity – intensive and strategies of energy transformation should be optimized (Table 1).

Zhiqiang Zeng, Xiaobin Chen, Kaiyao Wang (2021) represented the idea of using Time-of-Use (TOU) electricity pricing scheme to significantly decrease energy costs. It is a specific electricity pricing structure with tariffs which are different, depending on part of the day, week, or even season. The idea behind this process is to stabilize the load at power stations and reduce mill's payments for the energy sources. There are three main periods:

- On – peak,

- Mid – peak,
- Off – peak.

The period with the highest electricity demand and price is On - peak, it is usually evenings during weekday. Of course, price varies regarding the country and region, for instance, in Guangdong, China it is 1.0348 CNY/kWh, comparing to 0.3351 CNY/kWh during Off – peak period. So, TOU approach has a big impact on industrial Production Costs.

Zhiqiang Zeng, Xiaobin Chen, Kaiyao Wang (2021) breaks down the total energy cost for production process into three components. The first one is Processing Energy Cost (EP) that consists of costs of running the papermaking and conversion lines. The formula for calculations considers the start time, duration, and power consumption of each job, multiplying by the price of electricity during the periods.

$$EP = \sum_{j=1}^{m}\sum_{i=1}^{n}(EP1 + EP2 + EP3 + EP4)O_{i,j}, \tag{2.2}$$

The second component is Setup Energy Cost (ES) which includes cost of machine changeovers. It is also both time and energy consuming process.

$$ES = \sum_{j=1}^{m}\sum_{i=1}^{n}(ES1 + ES2 + ES3 + ES4)O_{i,j}, \tag{2.3}$$

where ES1, ES2, ES3, ES4 – costs for different segments.

By shifting hours of these operational processes to the period of the least load on the energy system, the cost can be significantly reduced.

The third one is Transportation Energy Cost (ET) when produced rolls of tissue paper are being transported. Usually, the much smaller cost is needed for this part of manufacturing. The model considers the amount of energy consumed and applies the TOU tariffs based on the time of day.

$$ET = \sum_{j=1}^{m2}\sum_{i=1}^{n}((TP1 * P1 + TP2 * P2 + TP3 * P3) * W_i * TC(\sum_{h=1}^{m1}O_{i,h}, l), \tag{2.4}$$

where TP1, TP2, TP3 – the proportions of processing time in three periods.

These models demonstrate the direct link between electricity consumption and production costs. The logic behind this approach is that electricity cost is directly proportional to price. As any production costs is a sum of all costs, including energy, total cost has a linear relationship with the electricity price.

CHAPTER 3. METHODOLOGY

In this research I examine a hypothesis which is related to both electricity prices and production costs. Since I want to analyze how changing electricity prices affect the cost of production in the paper industry, I must first inquire into these two parts independently.

Hypothesis states that higher electricity prices in Europe lead to increased production costs for Zewa tissue paper in Germany, affecting its market competitiveness. In order to confirm or reject this, I took a few preliminary steps.

Firstly, I have collected historical and current prices of electricity from two sources: Eurostat and EMBER (a global energy think tank). The main difference is that Eurostat collects data bi-annually, while EMBER accumulates monthly figures. The important thing is that I diversified the data on electricity for households and non-households, and as a result, in my research I use information only for industrial sectors. The data is measured in EUR per MWh (a megawatt hour equals 1,000 kilowatts of electricity generated per hour).

By the second step I have obtained aggregate production costs data for Zewa tissue paper produced in Mannheim, Germany. I received this information from the internal SAP system of Essity LLC. The dataset includes various cost components from raw materials and warehousing to utility costs, but in my research, I use total cost of production. I also analyze the change in production cost for separate product groups of the brand, since such analysis gives an opportunity to explain the impact of fluctuations of electricity prices on the brand more preciously. In this case, I use the monthly data for analysis and further modeling to have the same base with electricity prices. The information is presented in the Euro currency unit per ton and has a real value rather than a nominal value. All datasets contain information from 2015 to early 2025.

3.1 Time Series Analysis

Another component of this research is to conduct a comprehensive Time Series Analysis. I examine the relationship between energy prices and the production costs of tissue paper. I develop a regression model for each specific group of brand products. These models also account for seasonal patterns and trend cycles. Such segmented analysis is needed to better understand how each type of products reacts to electricity price changes.

Each model demonstrates how fluctuations in electricity prices influence overall expenses for manufacturing process. Electricity prices are used as the independent variable, and the dependent variable is presented by total cost components, including raw materials, labor and utilities. As a result, I see how much production costs increase or decrease during energy price fluctuations.

The general mathematical form of simple linear regression model for each Product Group is:

$$\Delta \ln(Product\ Costs_t) = \beta_0 + \beta_1 \Delta \ln(Electricity\ Prices_t) + \epsilon_t, \qquad (3.1)$$

where $\Delta \ln(Product\ Costs_t)$ – the change in the natural logarithm of Product Costs for each Brand Product Group at time t,

β_0 – the intercept,

β_1 – the slope,

$\Delta \ln(Electricity\ Prices_t)$ – the change in the natural logarithm of Energy Prices at time t,

ϵ_t – the error term.

The important preparation step before estimating the model is to check the stationarity of the time series data using the Augmented Dickey-Fuller (ADF) test. It is a statistical hypothesis test that indicates the present of unit root in the time series. If the data is stationary, its mean, variance and autocorrelation are all constant over time (no trends), whereas for non-stationary data these measures change over time. Such test is more commonly used as it accounts for potential autocorrelation in the error terms. It is more suitable for real data.

The general form of the Augmented Dickey-Fuller test regression is:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-1} + \varepsilon_t, \tag{3.2}$$

where α – constant,

βt – time trend,

γ – coefficient on the lagged level of the series,

δ_i – coefficients on the lagged differences,

p – number of lagged difference terms,

ε_t – error term at time t.

In case of non-stationarity, I apply appropriate transformations such as differencing and log transformation to be sure that datasets are in line with the statistical requirements to perform a reliable analysis. Firstly, to stabilize the variance I do a logarithmic transformation using the *log()* function. It normalizes the data distribution and makes the variance more constant across periods. Secondly, to remove linear trend and seasonality I use function *diff()*. The differencing process turns levels to growth rates. As the result, after all manipulations, the regression model is being estimated by using ordinary least squares (OLS).

The next step is to interpret obtained regression coefficients to understand the magnitude of the impact of energy prices on production costs. The values of coefficients indicate the change, in percentage term, in production costs with one percent change in energy prices.

Additionally, there is an important check that should be conducted to ensure the robustness and reliability of the model.

The Durbin-Watson Test is a diagnostic check which is used to detect the presence of serial correlation in the residuals of a regression analysis. It tests whether the residuals are independent from each other, or they have systematic patterns over periods. If the results show value close to zero, it means that there is a positive autocorrelation. On the other side, if the result is close to 4, a negative autocorrelation is presented. In case there is a correlation between variables, it indicates that the analyzed model may neglect other important explanatory variables.

The general formula of the Durbin-Watson Test:

$$DW = \frac{\sum_{t=2}^{n}(e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2}, \tag{3.3}$$

where e_t – the residual at time t.

As Durbin-Watson Test designed to detect only first-order autocorrelation, there is a need to perform additional test for higher-order autocorrelation. The Ljung-Box (L-Box) Test is a diagnostic check that shows whether the residuals are not autocorrelated. In case a p-value is greater than 0.05, it means that the specific model is adequate and reliable for future forecasting modelling, and vice versa.

The general formula of the Ljung-Box Test:

$$Q = n(n+2)\sum_{k=1}^{h}\frac{\hat{\rho}_k^2}{n-k}, \tag{3.4}$$

where n is the sample size,

$\hat{\rho}_k -$ the autocorrelation at lag k.

In addition to mentioned tests, analysis also includes Breusch-Pagan Test. It tests the presence of heteroscedasticity, or, in other words, whether the variance of the residuals is constant over time or changes systematically. In case of detected heteroscedasticity, it means that errors in the model are not consistent over different time periods. It suggests that statistical results are not considered to be reliable. Moreover, it affects the accuracy of predictions.

The general formula of the Breusch-Pagan Test:

$$BP = nR^2, \tag{3.5}$$

where R^2 – R-squared value from regression,

n – number of observations.

3.2 Forecast Modelling

Second part of the analysis in this research is dedicated to development of forecasting model. I build an Autoregressive Integrated Moving Average with Explanatory Variable (ARIMAX) model. Such model is a representation of econometric approach which is used to analyze and predict future values based on historical data patterns and external factors. This instrument is highly suitable for my research as it enables to incorporate external variables like pulp and carbon prices, paper chemicals, Producer Price Index (PPI), and other macroeconomic metrics. By performing ARIMAX model I generate accurate forecast for the future production costs, which is highly valuable for company's competitive strategy and pricing decisions. Also, my model underlines trends, patterns and seasonality in production costs that can be applicable to the whole paper industry for better understanding dynamics and market behavior.

ARIMAX model itself combines two components: ARIMA modeling, which is a traditional core part, and X, which includes exogenous variables. In turn, ARIMA part can be divided into another three parts, more detailed:

- AR (Auto Regressive) part helps to understand how past values influence present values.
- I (Integrated) part is needed for differencing the time series to obtain stationarity as it is significant for reliable forecasting.
- MA (Moving Average) part models the error term as a linear combination of error terms from the past.

External or exogenous variables are not, basically, a part of primary time series model. These factors are rather supplements for the model to achieve a more comprehensive analysis and better forecasting performance. Such variables represent outside world that can seriously affect the reaction of the dependent variable.

Since in the first part of my analysis I have already converted all datasets to achieve stationary, I implement an ARMAX (Autoregressive Moving Average with Explanatory Variables) model to be more methodologically precise.

The general mathematical form of the ARMAX model:

$$y_t = \alpha + \sum_{i=1}^{p} \varphi_i y_{t-1} + \sum_{j=1}^{q} \theta_j \epsilon_{t-j} + \beta^T x_t + \epsilon_t, \tag{3.6}$$

where y_t – predicted variable,

α – constant term,

y_{t-1} – historical values of the time series,

φ_i – AR part coefficients,

ϵ_{t-j} – past error terms,

θ_i – MA part coefficients,

x_t – external variables,

β^T – coefficients of external variables,

ϵ_t – white noise.

Another additional step is data preparation of external factors. I have chosen two extra variables which are Producer Price Indexes. I perform log – transformation and differencing on the exogenous variables. The first is PPI for Wood Pulp, and another one is PPI for Carbon Black. It is necessary to be sure that data in the model is stationary.

In this section, there are also developed two ARMAX models since it is important to simulate each forecasting performance separately. The first one includes Electricity Prices as the only independent variable. In the second model there is added Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black. It allows to understand the predictive accuracy and general behavior of each model more preciously.

The general mathematical form of linear regression model for each Product Group with three exogenous variables is:

$$\Delta \ln(Product\ Costs_t) = \beta_0 + \beta_1 \Delta \ln(Electricity\ Prices_t) + \beta_2 \Delta \ln(PPI\ for\ Wood\ Pulp_t) + \beta_3 \Delta \ln(PPI\ for\ Carbon\ Black_t) + \epsilon_t, \quad (3.7)$$

where $\beta_1, \beta_2, \beta_3$ – slopes,

$\Delta \ln(PPI\ for\ Wood\ Pulp_t)$ – the change in the natural logarithm of PPI for Wood Pulp at time t,
$\Delta \ln(PPI\ for\ Carbon\ Black_t)$ – the change in the natural logarithm of PPI for Carbon Black at time t.

After executing these models, it is crucial to complete some checks to evaluate their rationality and solidity. This includes testing for autocorrelation, stationarity, heteroscedasticity and others.

The closing part of my research involves generating a three-month-ahead forecast to evaluate the accuracy of models' predictiveness. Also, after that, there is a back transformation of obtained results into real numbers for production costs, expressed in Euros per ton. Finally, I conduct a comparison analysis of forecasted values against actual production costs during the period from May through July.

CHAPTER 4. DATA

As it was mentioned previously, there were collected two sets of data: historical and current prices of electricity, and aggregate production costs for tissue paper. The following subclauses describe each dataset in turn to understand and show a holistic picture for the analysis.

4.1 Historical and current prices of electricity

Table 2. Descriptive Statistics for prices of electricity

Statistic	*Price EUR/Mwh (Europe)*	*Price EUR/Mwh (Germany)*
n	3,751	128
mean	79.13	72.32
median	55.15	44.44
sd	67.59	68.60
min	1.85	17.51
max	543.55	463.59
range	541.70	446.08
trimmed	65.48	58.05
mad	32.94	24.76
skew	2.70	2.84
kurtosis	9.64	10.09
se	1.10	6.06

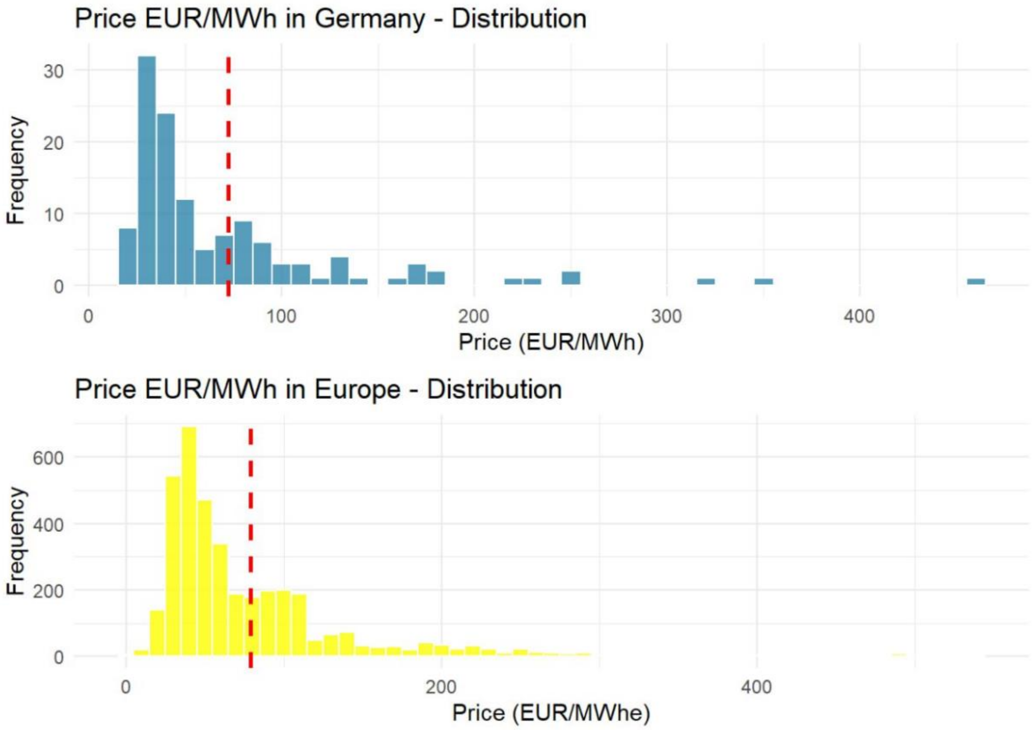
Source: author's analysis

The table above shows descriptive statistics for the dataset with the information of the whole Europe and its sample for Germany (Table 2).

The size of dataset for Europe is 3751 observations with the mean of EUR 79.31 per MWh. Looking at the median value of EUR 55.15 per MWh, which is significantly lower, comparing to mean, it suggests that the value of average is being affected by some extreme values of outliers. The data seems to be highly scattered which is proved by high value of standard deviation. The skewness value of 2.7 shows a strong positive skew, indicating long right tail. It is also not a normal distribution as the kurtosis value of 9.64 means heavy tails and sharp peak. By removing a certain percentage of extreme values, trimmed mean of EUR 65.48 is becoming closer to median.

The sample size for Germany is 128 observations. Similarly to the European data, the value of mean is higher than median (72.32 vs 44.44), suggesting a positively skewed distribution. The same for standard deviation that shows a wide spread of prices. The skewness value of 2.84 and kurtosis of 10.09 are slightly higher than for European data, indicating more noticeable right tail and very sharp peak. Overall, by comparing Europe and Germany separately, they are very similar in term of skewness and kurtosis, but the price variability in Germany is slightly higher than the European average.

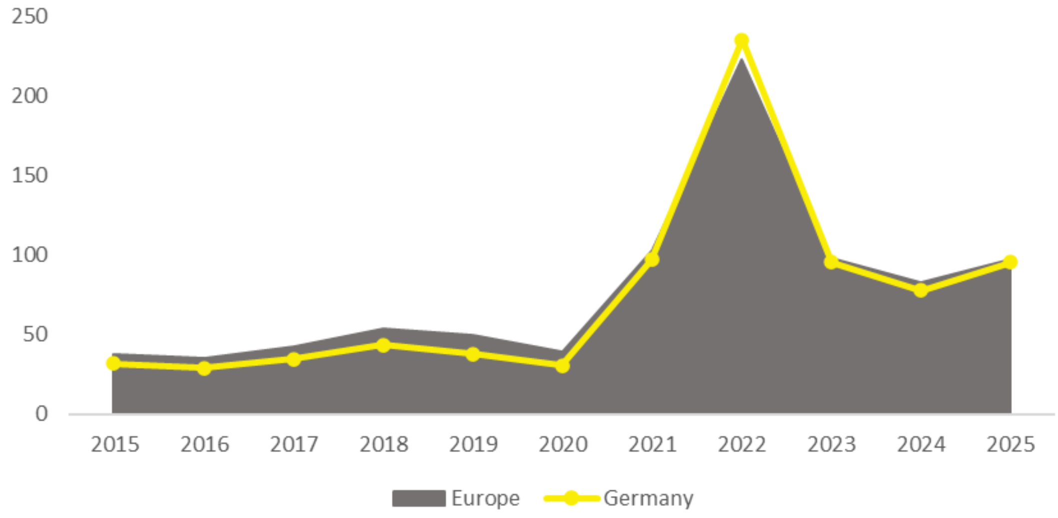
Figure 8. Visual representation of price distribution in Europe and Germany (EUR/MWh)



Source: author's analysis

The histograms above with visual representations confirm the findings from the descriptive statistics (Figure 8). Overall, it can be concluded that electricity market in Germany operates in line with general European market.

Figure 9. Yearly Average Electricity Prices in Europe and Germany (2015-2025) in EUR/MWh



Source: EMBER

The graph above illustrates some periods in transformation of European electricity markets over 10 years (in average term) (Figure 9). It can be divided by three main parts: market stability (2015-2020), market disruption (2021-2022), and new equilibrium (2023-2025). Looking at the first part, it can be said that market is relatively stable and electricity costs averaging 30-50 EUR/MWh across both Germany and Europe, proving the pre-crisis period. The next period is absolute crisis in electricity sector in Europe as prices increased by approximately 400-500% from baseline levels. This situation can be explained by various factors such as post-pandemic recovery, reduced Russian gas imports, renewable energy sources. Interesting insight that in 2022 the average price in Germany was higher than in Europe since main part of closed nuclear power plants was situated in Germany. The last current period shows decreasing in prices to the level of 80-95 EUR/MWh which is still higher by approximately 160-190% comparing to pre-crisis levels. Obviously, there are lots of structural changes in European energy markets such as more expensive supply sources, infrastructure costs, and renewable transitions.

4.2 Production Costs for Zewa tissue paper

The dataset contains the total cost of production of tissue paper, including raw materials, utilities and storage. Besides, the information has been collected on monthly bases in terms of four product groups:

- BRT Dry,
- HHT Dry,
- Facial,
- Hanky.

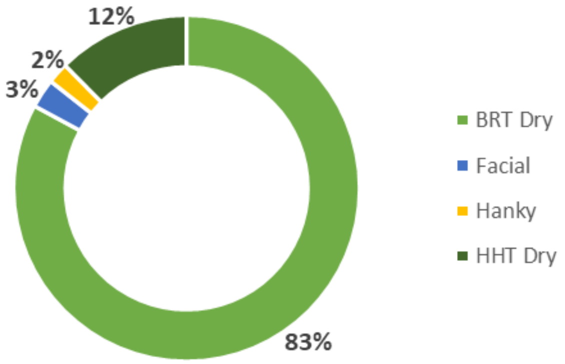
The first product group is Dry Crepe Tissue (BRT Dry) which is a type of tissue paper mostly used as toilet paper. In general, it manufactured from pulpwood trees or bamboo. The mechanism of production includes usage of a paper machine with a large, steam-heated cylinder that adjust paper's stretch, thickness and softness. After that a huge roll of paper is being cut into small rolls. The main difference that exists in different types of such paper is its layering. Typically, there are single-ply, 2-ply, 3-ply, and 4-ply products.

The next product group is Absorbent Household Towel (HHT Dry) which is widely used for housekeeping routine and personal care. The most crucial element for the effectiveness is its absorbency. Their main purpose is rapid absorption of liquid. It can be manufactured either from wood pulp fibers or recycled fibers.

The last two groups Facial and Hanky are similar as they are both Small Portable Tissues, which is commonly used for personal hygiene. A key distinguish characteristic of these groups is their superior softness and silky texture to avoid irritation on any zones. They are both produced from 100% virgin pulp, known to have high quality and strength, which is essential for premium personal hygiene products. The company analyze these groups separately because of type of packaging, target audience and sales places.

The figure below shows what part of the total production volume each group occupies. Such information is important for understanding the impact on the final cost for brand is general (Figure 10).

Figure 10. Share of product groups in total brand volume in tons



Source: Essity LLC

Table 3. Descriptive Statistics for Product Groups of Zewa tissue paper

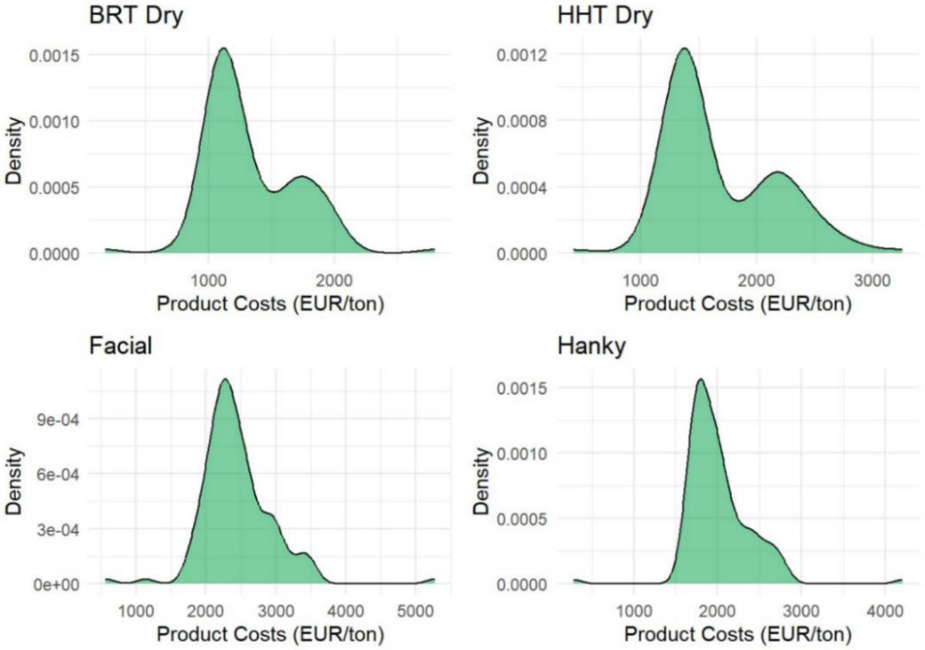
Statistic	*BRT Dry*	*HHT Dry*	*Facial*	*Hanky*
n	124	124	124	124
mean	1,333.59	1,687.96	2,446.07	2,008.48
median	1,199.55	1,476.26	2,352.25	1,947.21
sd	364.03	484.29	520.56	396.56
min	184.95	420.09	565.51	279.35
max	2,796.43	3,259.99	5,271.25	4,206.87
range	2,611.48	2,839.90	4,705.75	3,927.52
trimmed	1,303.83	1,641.94	2,411.7	1,970.96
mad	246.7	298.18	349.96	273.24
skew	0.76	0.75	1.15	1.12
kurtosis	1.29	0.02	6.84	8.57
se	32.69	43.49	46.75	35.61

Source: author's analysis

The dataset with monthly Product costs from 2015 to 2025 represents 496 observations in total and 124 for each Product Group. Looking at the values of mean and median, Facial group has the highest values comparing to others, and it is almost double to BRT Dry group, which has the lowest average value. Facial, also, has the huge standard deviation of 520.56 and wide range, suggesting a large spread of values and the highest variability across other groups. Its distribution is far from normal, which is proved by sharp peak and heavy tails according to values of skewness and kurtosis (Table 3).

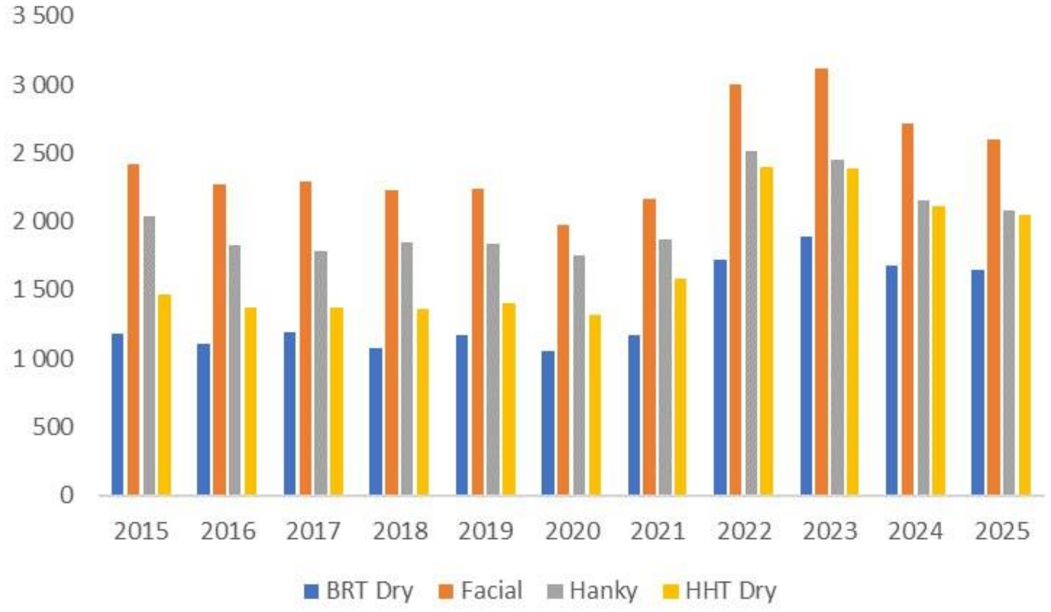
By contrast, Production Costs of BRT Dry seems to have the most stable performance as it has the lowest variability and smallest standard deviation. As its mean value is a little bit higher than median, the distribution is positively skewed. The situation with HHT Dry group is pretty like with BRT Dry, but the value of kurtosis is very close to zero, indicating a distribution that can be considered as normal in terms of peakedness. The graphical representation of descriptive statistics is below (Figure 11).

Figure 11. Visual representation of Product Costs distribution (EUR/ton)



Source: author's analysis

Figure 12. Yearly Average Production Costs for Product Groups of Zewa tissue paper in EUR/ton (2015-2025)



Source: Essity LLC

The graph above demostrates the average cost of paper production for each product group (Figure 12). As we can see Facial tissues represent the highest production cost across all years, whereas BRT Dry maintains the lowest costs throughout the period. Pre-crisis period shows relatively manufacturing economics that can support stable pricing strategies and profit margins. Over the next three years, the cost price increased by an average of 20-30%, which can be explained by difficulties in supply chains, the cost of raw materials and energy resources. Overall, all Product Groups follow the same trend pattern. In recent years, the dynamics shows a slight decrease in production costs, which can be explained by relative stabilization of costs in European Energy sector.

CHAPTER 5. RESULTS

This chapter presents the results, building on the methodology and data described in Chapter 3 and Chapter 4. It is included general description of OLS Models, detailed results of ARMAX Models and Forecast block.

In methodology part I have mentioned that there is a necessity to conduct a preliminary analysis of the datasets on stationarity. There are five unique datasets in this block: Electricity Prices data, Product Costs for BRT Dry tissue paper, Product Costs for HHT Dry tissue paper, Product Costs for Facial tissue paper and Product Costs for Hanky tissue paper.

The statistical Augmented Dickey-Fuller (ADF) test showed that all five time - series are non-stationary. All p – values are much higher than typical 0.05 (Energy Prices – 0.4895, BRT Dry – 0.6863, HHT Dry – 0.6864, Facial – 0.6386, Hanky – 0.6141). It means that we fail to reject null hypothesis and confirm non – stationarity.

As a result, these time series were not suitable for using in future forecasting models. The further steps included log – transformation and differencing. After the application of two-step transformation all datasets became stationary. The results of p-value indicated 0.01, which is much smaller than 0.05. After all preparational stages, time series was ready for modelling.

The values of intercept term in models for all Product Groups (BRT Dry, HHT Dry, Facial and Hanky) are not statistically significant. In this case, there is not enough evidence to state that there is a strong relationship between changes in Electricity Prices and Production Costs in the models. It is also supported by extremely high p – values (Appendix A).

Talking about explanatory power, the value for each model is very low, it is smaller than 1%, which is almost nothing. It means that differenced log of energy does not explain the variance in the differenced log of costs at all.

There were done some robustness checks to test autocorrelation and heteroscedasticity. The Durbin-Watson Test and Ljung - Box Test confirmed the presence of strong autocorrelation in residuals. It is supported by very small p – values (Appendix C1, C2). On the other side, the Breusch-Pagan Test showed that all four models are homoscedastic with a constant variance for the residuals. It is positive and expected result for linear regression (Appendix C3).

In conclusion, the main problem is that none of the OLS regression models show linear relationship between two variables. Also, autocorrelation suggests that the residuals are not independent over time. On the other hand, there is no heteroscedasticity in the models, but it is not the most important aspect in this analysis.

The results above proved that the simplest linear regression model is not efficient for forecast modelling. It is supported by absence of statistical significance and independence in residuals. So, there is a need in more complex and sophisticated models.

5.1 ARMAX Models

As simple linear regression models showed insignificant and unreliable results, I have developed two more comprehensive disparate ARMAX models for each Product Group. The first model is simpler because it contains only Electricity Prices as independent variable. The second model is more complicated option which includes two more variables in addition to Electricity Prices: Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black. This approach is chosen to compare whether Electricity Prices affect the Product Costs separately, or there is a need to add additional exogenous regressor for higher reliability and forecasting power.

Moreover, during the analysis process, I enhanced ARMAX models to improve basis for more accurate forecasting. It was added GARCH part, and the final version was ARMAX-

GARCH models. This combination is ideal for my research. It captures both the dynamics of the mean and volatility simultaneously.

1. BRT Dry

1.1) ARMAX model with Electricity Prices for BRT Dry tissue paper

For constructing this model I used auto.arima function to indicate the right order for each part. The result shows that the mean of the time series is explained by the past three error terms as order for MA part is 3. The volatility is presented by GARCH (1,1) that is the most common model. It bases on the variance of previous period and the most recent residuals. Also, I have specified Student's t-distribution, and it is value of 2.238661 indicates the presence of long tails.

Table 4. Parameters of ARMAX model with Electricity Prices for BRT Dry tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	0.003620	0.003558	1.01722	0.309050
ma1	-0.346307	0.163853	-2.11352	0.034556
ma2	-0.111529	0.111725	-0.99825	0.318158
ma3	-0.009402	0.018984	-0.49526	0.620419
mxreg1	0.047660	0.021437	2.22330	0.026196
omega	0.000161	0.001385	0.11600	0.907649
alpha1	0.000000	0.359857	0.00000	1.000000
beta1	0.974653	0.023305	41.82204	0.000000
shape	2.238661	0.386852	5.78687	0.000000

Source: author's analysis

We can see that mean of the model and third moving average coefficient are not statistically significant, whereas the coefficients for the first and second moving average indicate the importance of the past two error terms for predicting current values. The coefficient of the Electricity Prices shows the existence of strong linear relationship with series' average.

By surprise, past shocks do not impact directly on current volatility. The beta term suggests that high or low volatility periods, most likely, cluster together since the value of 0.974653 is very close to 1 (Table 4).

The Ljung-Box Test on Standardized Squared Residuals revealed that the GARCH component captured the volatility clustering, even though, there were remains of autocorrelation in the model (Appendix E1). Looking at the result of Nyblom Stability Test, parameters in the model are stable over the period. It is proved by joint statistic value of 2.1461, which is less than the 5% of crucial value (Appendix F1). Sign Bias Test indicated both positive and negative shocks which influence the volatility differently (Appendix G1).

Overall, model fits good for my time series data despite remaining autocorrelation and leverage effect from the significant negative shocks.

1.2) ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for BRT Dry tissue paper

The second model for BRT Dry tissue paper includes Electricity Prices, the same as for the first model, and two extras independent regressors PPI for Wood Pulp and PPI for Carbon Black.

Table 5. Parameters ARMAX model with Electricity Prices, PPI for Wood Pulp and the PPI for Carbon Black for BRT Dry tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	0.003828	0.003932	0.97355	0.330281
ma1	-0.378494	0.163178	-2.31951	0.020367
ma2	-0.108646	0.115221	-0.94293	0.345715
ma3	-0.007262	0.029265	-0.24813	0.804031
mxreg1	0.039409	0.021154	1.86299	0.062464
mxreg2	0.126516	0.104441	1.21137	0.225753
mxreg3	0.061428	0.238304	0.25777	0.796583
omega	0.000161	0.001204	0.13393	0.893461
alpha1	0.000000	0.327625	0.00000	1.000000
beta1	0.973520	0.019423	50.12136	0.000000
shape	2.255724	0.422628	5.33737	0.000000

Source: author's analysis

Looking at the result, there is the only change in significance of Electricity Prices that is became lower, suggesting the possibility that new variables can explain the same relationship. However, both PPI indexes are not statistically significant which means that their adding is useless, and it does not improve the level of model's predictivity (Table 5).

Volatility parameters are almost the same, comparing to the previous model. However, LogLikelihood factor is slightly higher, indicating a better fit. At the same time, Information criteria tell that simpler model with only one independent variable is preferable in this case (Appendix D2).

Altogether, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black not only did not improve the model' predictivity but also decreased the significance of Electricity Prices. What is more, it led to worse model fit due to unnecessary complexity.

2. HHT Dry

There is the same approach for HHT Dry tissue paper as for BRT Dry. The first model includes only Electricity Prices as independent variable. In the second model I also added two indices which are exogenous variables.

2.1) ARMAX model with Electricity Prices for HHT Dry tissue paper

Table 6. Parameters of ARMAX model with Electricity Prices for HHT Dry tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	0.002594	0.003771	0.688020	0.491440
ma1	-0.500541	0.013069	-38.299608	0.000000
ma2	-0.080689	0.113662	-0.709906	0.477762
mxreg1	0.086524	0.043908	1.970578	0.048772
omega	0.000000	0.000037	0.000003	0.999997
alpha1	0.000001	0.014318	0.000085	0.999932
beta1	0.991713	0.002861	346.642143	0.000000
shape	2.279885	0.168305	13.546186	0.000000

Source: author's analysis

According to these results, when price for electricity increases by 1%, the Production Costs for BRT Dry tissue paper also increase by 0.08%. As the robust p – value is 0.048772, the relationship between variables in this model is statistically significant. The beta value is very close to 1, suggesting past volatility has a significant effect on current volatility. On the other hand, we can see that new information has minimal impact on volatility (0.000001) (Table 6).

The Ljung-Box Tests showed that there is no serial correlation in the residuals. It is very positive and successful result since it proves that model accounts for both conditional mean and conditional variance dynamics of the providing datasets (Appendix E3). Also, the model parameters are stable over time (Appendix F3). It is important to mention that forecasts for this model are not systematically overpredicting or underpredicting the volatility (Appendix G3). Hence, the model overall provides strong explanation for the relationship between Electricity Prices and Product Costs, and it is well-specified for the forecast modeling.

2.2) ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for HHT Dry tissue paper

Table 7. Parameters of ARMAX model with Electricity Prices, PPI for Wood Pulp and the PPI for Carbon Black for HHT Dry tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	0.001378	0.002289	0.601952	0.547206
ma1	-0.511281	0.020217	-25.289533	0.000000
ma2	-0.098765	0.031723	-3.113393	0.001849
mxreg1	0.062512	0.023929	2.612452	0.008990
mxreg2	0.178835	0.084964	2.104826	0.035306
mxreg3	0.408264	0.091054	4.483745	0.000007
omega	0.000000	0.000027	0.000000	1.000000
alpha1	0.000001	0.008640	0.000091	0.999927
beta1	0.991392	0.001751	566.046474	0.000000
shape	2.223099	0.087371	25.444505	0.000000

Source: author's analysis

By adding extra variables to the model, the two moving average terms became statistically significant, meaning to be important to model the conditional mean. All three external variables are statistically significant and has positive effect on Production Costs for HHT Dry tissue paper. Interestingly, the PPI for carbon black has the largest impact in this case. Also, additional variables increased the ability of the model to explain the data (Table 7).

In conclusion, the second model is better for explaining Product Costs of HHT Dry tissue paper. It is curious finding as it is totally opposite situation to BRT Dry tissue paper, where Producer Price Indices were unnecessary in the model.

3. Facial

3.1) ARMAX model with Electricity Prices for Facial tissue paper

Table 8. Parameters of ARMAX model with Electricity Prices for Facial tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	0.001002	0.004845	0.20674	0.836212
ar1	-0.739611	0.092928	-7.95894	0.000000
ar2	-0.036448	0.068403	-0.53285	0.594139
ma1	0.371157	0.104533	3.55061	0.000384
mxreg1	-0.024788	0.024365	-1.01737	0.308975
omega	0.003013	0.001234	2.44190	0.014610
alpha1	0.365852	0.188827	1.93749	0.052685
beta1	0.202413	0.145105	1.39494	0.163033
shape	3.484913	0.705536	4.93938	0.000001

Source: author's analysis

Looking at the results for this model, it seems that price of electricity does not significantly affect Production Costs of Facial tissue paper (Table 8). The volatility is less continuous, comparing to the previous models, and beta coefficient is not statistically significant here (Appendix G5).

There is no serial autocorrelation and ARCH effect, indicating the model is well specified. According to Nyblom Stability Test, parameters are stable and reliable over time (Appendix F5). On the other hand, Sign Bias Test tells that negative and positive shocks have different impact on volatility at the same magnitude (Appendix G5).

Even though, the model has good results from the various statistic tests, it is independent variable is insignificant, so, the model is not fully reliable.

3.2) ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Facial tissue paper

By adding more external variables the structure of the model has changed notably.

Table 9. Parameters of ARMAX model with Electricity Prices, PPI for Wood Pulp and the PPI for Carbon Black for Facial tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	-0.000428	0.003758	-0.11393	0.909292
ma1	-0.341032	0.050164	-6.79831	0.000000
ma2	0.094039	0.131585	0.71466	0.474818
ma3	-0.148478	0.068873	-2.15580	0.031099
ma4	0.023692	0.084206	0.28136	0.778436
ma5	-0.042190	0.043356	-0.97310	0.330503
mxreg1	-0.009957	0.025325	-0.39316	0.694202
mxreg2	0.235434	0.159716	1.47408	0.140459
mxreg3	0.114397	0.152883	0.74826	0.454300
omega	0.001917	0.001521	1.25987	0.207716
alpha1	0.327385	0.327848	0.99859	0.317994
beta1	0.539165	0.252208	2.13778	0.032535
shape	2.821264	0.861559	3.27460	0.001058

Source: author's analysis

Moving average terms demonstrate that the mean of the series is more dependent on past shocks rather than past values. Unfortunately, none of the external variables became statistically significant predictors for the forecast modeling of this product group. From the alpha perspective past shocks do not have an impact on current volatility. Nevertheless, as beta coefficient is significant, the volatility is constant (Table 9).

The Log-Likelihood value is 147.7174 which is much higher than the previous model (Appendix D6). It indicates that more complex model allows better fit. Also, new model has removed serial correlation in the mean and variance. One more positive change is that this model is accounted for the asymmetric volatility.

However, Nyblom Stability Test showed that parameters seem to be unstable over time (Appendix F6). It means that it can be an obstacle for long – term forecasting. Overall, despite all improvements, chosen variables are almost useless for prediction.

4. Hanky

4.1) ARMAX model with Electricity Prices for Hanky tissue paper

The last Product Group is very similar to the previous one.

Table 10. Parameters of ARMAX model with Electricity Prices for Hanky tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	0.000972	0.002738	0.354940	0.722635
ar1	0.006630	0.023966	0.276638	0.782058
ma1	-0.720413	0.026802	-26.878924	0.000000
mxreg1	0.021889	0.039690	0.551501	0.581290
omega	0.007634	0.005028	1.518189	0.128967
alpha1	0.000000	0.006460	0.000000	1.000000
beta1	0.000004	0.835160	0.000004	0.999996
shape	3.935386	1.401770	2.807440	0.004994

Source: author’s analysis

The external variable, which is represented by Electricity Prices, is not statistically significant (p – value is much higher that 0.05). Also, ar1 and ma1 coefficients indicate that the mean of the series is affected by past errors rather than past values. The biggest problem in this model is that both alpha and beta coefficients are insignificant, so there is no evidence of volatility clustering (Table 10).

Furthermore, Nyblom Test shows that parameters are unstable over time, and the mode is not reliable for the forecasting (Appendix F7). However, Ljung-Box Test did not demonstrate the presence of serial correlation (Appendix D7). Also, there is no asymmetric volatility, meaning that shocks have a similar impact on volatility.

To sum up, despite some positive results of the tests, this specific model is unreliable and did not explain relationship between Product Costs for Hanky tissue paper and Electricity Costs.

4.2) ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Hanky tissue paper

Table 11. Parameters of ARMAX model with Electricity Prices, PPI for Wood Pulp and the PPI for Carbon Black for Hanky tissue paper

	Estimate	*Std. Error*	*t-value*	*Pr(>/t/)*
mu	-0.001921	0.002569	-0.74781	0.454573
ma1	-0.713082	0.025459	-28.00911	0.000000
ma2	-0.011817	0.020169	-0.58588	0.557957
mxreg1	-0.005105	0.035024	-0.14576	0.884111
mxreg2	0.051505	0.089258	0.57703	0.563919
mxreg3	0.368825	0.228511	1.61404	0.106520
omega	0.004250	0.002081	2.04181	0.041170
alpha1	0.370339	0.350837	1.05559	0.291157
beta1	0.201278	0.160318	1.25549	0.209302
shape	3.618959	1.360724	2.65958	0.007824

Source: author's analysis

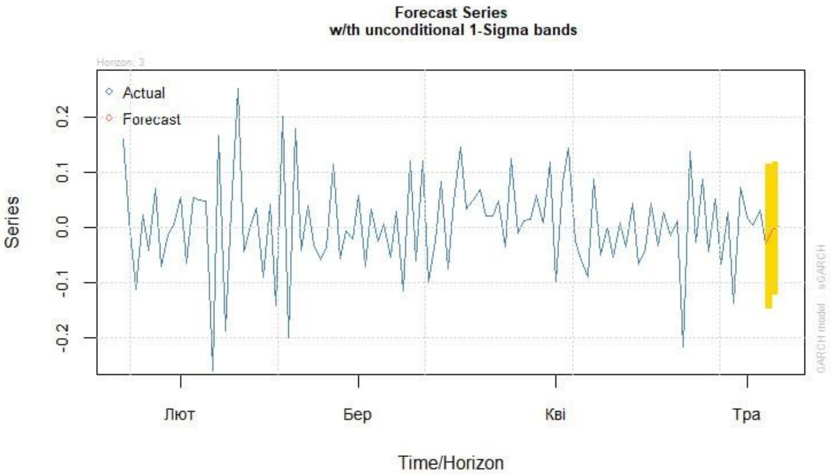
Even after adding PPI for Wood Pulp and PPI for Carbon Black, none of the exogenous regressors are statistically significant. The p – values are well above standard value of 0.05 (Table 11). The positive sign is that Log-Likelihood value of 133.9164 is higher, comparing to the previous model with only Electricity Prices as an independent variable (Appendix D8). Also, there is no evidence of serial correlation. The main difference for this model is that the model parameters became stable over time. The biggest surprise is the result of Goodness-of-Fit Test (Appendix H8). It indicated that Student's t-distribution is not a perfect fit for the residuals. Overall, the improved model is not an effective predictor for the Production Costs for Hanky tissue paper yet.

5.2 Forecast

The analysis of all ARMAX models demonstrated that only models for HHT Dry tissue paper are suitable and reliable for forecasting. They are both have significant exogenous variables which have strong predictive power. All diagnostic tests gave positive results and proved their applicability.

By using chosen developed ARMAX models, it was generated the forecast for the three months ahead. To provide a more realistic forecast, I have chosen growth coefficients for the external variables. I have determined them by my own based on news and recent market trends. Due to relatively stable situation in Energy Sector, the price for electricity is going to go down slightly. The same is for Pulp and Paper industry, where prices should remain relatively low as there is enough amount of pulp in European countries. Moreover, it is not a scarce resource now. Talking about future, due to decarbonization strategy, the price for carbon is expected to be higher.

Figure 13. Forecast Series for HHT Dry tissue paper



Source: author’s analysis

Looking at the graph, it can be said that Production Costs for group HHT Dry, as the part Zewa Brand, is expected to remain relatively stable (Figure 13). My model does not predict significant changes or shifts of the trend. Also, despite mean is not going to fluctuate, some numbers can deviate from the forecast numbers either in positive or negative direction. Yellow color indicates possible fluctuations, suggesting risk in short-term predictions. It is important to mention that graphical representation for model with only Electricity Prices and model with two Producer Price Indices is similar. However, when the results of forecast were converted to real numbers, that is expressed in Euros per ton, there were some differences.

Table 12. Comparison table for forecasted results and real numbers in Euros per ton

Month	*Model with one external variable*	*Model with three external variables*	*Real values*
May	2058.583	2050.341	2000.520
June	2055.174	2042.131	2099.258
July	2060.512	2044.947	2067.418

Source: author's analysis

The results in the table above show the numerical comparison between forecasts from two models for HHT Dry and the real actual values taken from internal system SAP of Essity LLC. Looking at the results of May, both Model with one external variable and Model with three external variables have higher forecasted values, comparing to real production costs. However, model with more external variables is closer to real value. By contrast, in June, my models underestimated the real value. In the last month, values obtained from the models are the closest to reality. The deviation in the Model with one external variable is only around 7 points, which is less than 0.01% (Table 12). Overall, the forecast of two models is relatively close to real values, following the trend. In conclusion, in two out of three months simpler model performs slightly better, although on average adding more exogenous variables improves forecast accuracy.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

In this research, I had a goal to test a hypothesis which states that higher electricity prices in Europe lead to increased Production Costs for tissue paper. Eight ARMAX models explored relationship between Production Costs, Electricity Prices and other external variables. Considering the obtained results for all Product Groups, I can only partially support this hypothesis.

The evidence for the hypothesis is different for each type of the product. The only Product Group which has strong evidence to support the hypothesis is HHT Dry Tissue Paper. Based on the results of two models (just with Electricity Prices, and including PPIs for Wood Pulp and Carbon Black), the coefficient for Electricity Prices variable is highly statistically significant in both cases. It proves that an increase in Production Costs for HHT Dry tissue paper in Zewa brand happens due to higher costs of electricity.

For all other Product Groups, Dry Crepe Tissue and Small Portable Tissue, I reject the hypothesis since Electricity Prices coefficient is not statistically significant in the models. It indicates that there is no linear relationship between dependent and independent variables. Also, the results suggest that short-term fluctuations in Electricity Prices have no impact on Production Costs, and other inputs should be included. What is much more interesting is that coefficients in Facial Tissue Paper models are negative, indicating totally controversial hypothesis. Such situation could be possible if the mill has already implemented the effective program of energy optimization or changed the manufacturing process.

The Forecast part of this research showed relatively reasonable results, despite small deviations in both positive and negative direction. To conclude, the response of Production Costs in tissue paper industry on fluctuations in Electricity Prices on European market is not consistent in general. Each business decision about this part of company's expenses should account for product specification.

To dive deeper into the topic of Production Costs dynamics and broaden existing analysis there could be done several steps. Firstly, to test hypothesis more preciously the data frequency could be increased to weekly or daily basis for all variables. Also, the term Production Costs is generic. It usually includes raw materials, labor, overheads etc. Hence, shifting to more detailed components will increase analysis accuracy. Finally, in terms of changing Electricity Prices, it makes sense to include Duration Analysis that accounts for delay between a change in independent variables.

According to the results in my research for Zewa brand, I can state for some recommendations for more efficient functioning of the whole Pulp and Paper Sector. Due to big difference in each product type, there should be implemented individual approach for energy consumption and spendings optimization. For products which are extremely sensitive to fluctuations of electricity price it is necessary to implement fixed – price purchasing agreement. This will help maintain Production Costs more stable and plan future expenses with greater accuracy.

Another reasonable recommendation is to reallocate capital investments to the production lines with higher energy consumption. As it was mentioned in the previous chapters, drying step in the manufacturing process of tissue paper is the most energy - intensive. Hence, companies can optimize this section by moving to heat recovery systems. This will help reduce energy consumption and the cost of production.

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APPENDIX A

INDEX REGRESSIONS

Appendix A1. Results of Linear Regression Model for BRT Dry tissue paper

```
Call:
lm(formula = diff_log_Costs ~ diff_log_Energy, data = stationary_data_brt)
Residuals:
     Min          1Q      Median         3Q        Max
-2.70753    -0.04985    -0.00726    0.04083    1.82734
Coefficients:
                     Estimate   Std. Error   t value    Pr(>t/)
(Intercept)           0.00584      0.02994     0.195     0.846
diff_log_Energy       0.09001      0.13806     0.625     0.516

Residual standard error: 0.3319 on 121 degrees of freedom
Multiple R-squared: 0.0035,   Adjusted R-squared: -0.004735
F-statistic: 0.425 on 1 and 121 DF,   p-value: 0.5157
```

Source: author's analysis

Appendix A2. Results of Linear Regression Model for HHT Dry tissue paper

```
Call:
lm(formula = diff_log_Costs ~ diff_log_Energy, data = stationary_data_hht)
Residuals:
     Min          1Q      Median         3Q        Max
-2.03933    -0.05399    -0.00215    0.04630    1.17606
Coefficients:
                     Estimate   Std. Error   t value    Pr(>t/)
(Intercept)           0.00549      0.02253     0.244     0.808
diff_log_Energy       0.09554      0.10389     0.920     0.360

Residual standard error: 0.2497 on 121 degrees of freedom
Multiple R-squared: 0.006939,   Adjusted R-squared: -0.001268
F-statistic: 0.8455 on 1 and 121 DF,   p-value: 0.3596
```

Source: author's analysis

Appendix A3. Results of Linear Regression Model for Facial tissue paper

```
Call:
lm(formula = diff_log_Costs ~ diff_log_Energy, data = stationary_data_facial)
Residuals:
     Min        1Q    Median       3Q      Max
-2.22558   -0.04040   -0.00454   0.04829   0.97051
Coefficients:
                    Estimate  Std. Error  t value   Pr(>t/)
(Intercept)          0.00214    0.02286    0.094    0.926
diff_log_Energy      0.05573    0.10539    0.529    0.598

Residual standard error: 0.2533 on 121 degrees of freedom
Multiple R-squared: 0.002306,   Adjusted R-squared: -0.00594
F-statistic: 0.2796 on 1 and 121 DF,   p-value: 0.5979
```

Source: author's analysis

Appendix A4. Results of Linear Regression Model for Hanky tissue paper

```
Call:
lm(formula = diff_log_Costs ~ diff_log_Energy, data = stationary_data_hanky)
Residuals:
     Min        1Q    Median       3Q      Max
-2.70351   -0.05468   -0.00178   0.05090   1.94661
Coefficients:
                    Estimate  Std. Error  t value   Pr(>t/)
(Intercept)          0.00184    0.02973    0.062    0.951
diff_log_Energy      0.06514    0.13710    0.475    0.636

Residual standard error: 0.3295 on 121 degrees of freedom
Multiple R-squared: 0.001862,   Adjusted R-squared: -0.006387
F-statistic: 0.2257 on 1 and 121 DF,   p-value: 0.6356
```

Source: author's analysis

APPENDIX B

STATIONARITY CHECKS

Appendix B1. Stationarity test results for Electricity Prices Time Series using ADF

```
data: merged_data_brt$Energy
Dickey-Fuller = -2.2095, Lag order = 4, p-value = 0.4895
alternative hypothesis: stationary

data: merged_data_brt$diff_log_Energy
Dickey-Fuller = -4.596, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```

Source: author’s analysis

Appendix B2. Stationarity test results for Product Costs for BRT Dry tissue paper Time Series using ADF

```
data: merged_data_brt$Costs
Dickey-Fuller = -1.7358, Lag order = 4, p-value = 0.6863
alternative hypothesis: stationary

data: merged_data_brt$diff_log_Costs
Dickey-Fuller = -6.9172, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```

Source: author’s analysis

Appendix B3. Stationarity test results for Product Costs for HHT Dry tissue paper Time Series using ADF

```
data: merged_data_hht$Costs
Dickey-Fuller = -1.7355, Lag order = 4, p-value = 0.6864
alternative hypothesis: stationary
```

```
data: merged_data_hht$diff_log_Costs
Dickey-Fuller = -6.629, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```

Source: author's analysis

Appendix B4. Stationarity test results for Product Costs for Facial tissue paper Time Series using ADF

```
data: merged_data_facial$Costs
Dickey-Fuller = -1.8507, Lag order = 4, p-value = 0.6386
alternative hypothesis: stationary

data: merged_data_facial$diff_log_Costs
Dickey-Fuller = -8.3429, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```

Source: author's analysis

Appendix B5. Stationarity test results for Product Costs for Hanky tissue paper Time Series using ADF

```
data: merged_data_hanky$Costs
Dickey-Fuller = -1.9097, Lag order = 4, p-value = 0.6141
alternative hypothesis: stationary

data: merged_data_facial$diff_log_Costs
Dickey-Fuller = -8.0818, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```

Source: author's analysis

APPENDIX C

ROBUSTNESS CHECKS

Appendix C1. Results of Durbin–Watson Test for Autocorrelation

```
data: ols_model_brt_dry
DW = 3.1546, p-value = 1
alternative hypothesis: true autocorrelation is greater than 0

data: ols_model_hht_dry
DW = 3.0414, p-value = 1
alternative hypothesis: true autocorrelation is greater than 0

data: ols_model_facial
DW = 2.7847, p-value = 1
alternative hypothesis: true autocorrelation is greater than 0

data: ols_model_hanky
DW = 3.1838, p-value = 1
alternative hypothesis: true autocorrelation is greater than 0
```

Source: author's analysis

Appendix C2. Results of Ljung - Box Test for Autocorrelation

```
data: residuals_brt_dry
X-squared = 54.296, df = 10, p-value = 4.274e-08

data: residuals_hht_dry
X-squared = 49.863, df = 10, p-value = 2.829e-07

data: residuals_facial
X-squared = 28.891, df = 10, p-value = 0.001298

data: residuals_hanky
X-squared = 52.155, df = 10, p-value = 1.068e-07
```

Source: author's analysis

Appendix C3. Results of Breusch – Pegan Test for Heteroscedasticity

```
data: ols_model_brt_dry
BP = 0.37387, df = 1, p-value = 0.5409

data: ols_model_hht_dry
BP = 0.27814, df = 1, p-value = 0.5979

data: ols_model_facial
BP = 0.50372, df = 1, p-value = 0.4779

data: ols_model_hanky
BP = 0.49376, df = 1, p-value = 0.4823
```

Source: author’s analysis

APPENDIX D

INFORMATION CRITERIA

Appendix D1. Information criteria for ARMAX model with Electricity Prices for BRT Dry tissue paper

LogLikelihood: 129.7557

Information Criteria:

Akaike	-1.9796
Bayes	-1.7727
Shibata	-1.9895
Hannan-Quinn	-1.8956

Source: author's analysis

Appendix D2. Information criteria for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for BRT Dry tissue paper

LogLikelihood: 130.8449

Information Criteria:

Akaike	-1.9647
Bayes	-1.7118
Shibata	-1.9792
Hannan-Quinn	-1.8620

Source: author's analysis

Appendix D3. Information criteria for ARMAX model with Electricity Prices for HHT Dry tissue paper

LogLikelihood: 130.2029

Information Criteria:

Akaike	-2.0033
Bayes	-1.8195
Shibata	-2.0112
Hannan-Quinn	-1.9286

Source: author’s analysis

Appendix D4. Information criteria for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for HHT Dry tissue paper

LogLikelihood: 137.8014

Information Criteria:

Akaike	-2.0951
Bayes	-1.8653
Shibata	-2.1072
Hannan-Quinn	-2.0018

Source: author’s analysis

Appendix D5. Information criteria for ARMAX model with Electricity Prices for Facial tissue paper

LogLikelihood: 142.8147

Information Criteria:

Akaike	-2.1937
Bayes	-1.9868
Shibata	-2.2036
Hannan-Quinn	-2.1097

Source: author’s analysis

Appendix D6. Information criteria for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Facial tissue paper

LogLikelihood: 147.7174

Information Criteria:

Akaike	-2.2085
Bayes	-1.9097
Shibata	-2.2284
Hannan-Quinn	-2.0871

Source: author’s analysis

Appendix D7. Information criteria for ARMAX model with Electricity Prices for Hanky tissue paper

LogLikelihood: 128.9624

Information Criteria:

Akaike	-1.9830
Bayes	-1.7991
Shibata	-1.9909
Hannan-Quinn	-1.9083

Source: author’s analysis

Appendix D8. Information criteria for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Hanky tissue paper

LogLikelihood: 133.9164

Information Criteria:

Akaike	-2.0314
Bayes	-1.8016
Shibata	-2.0435
Hannan-Quinn	-1.9381

Source: author’s analysis

APPENDIX E

SERIAL CORRELATION CHECKS

Appendix E1. Weighted Ljung-Box Test for ARMAX model with Electricity Prices for BRT Dry tissue paper

```
                             statistic    p-value
Lag[1]                           6.329  0.0118808
Lag[2*(p+q)+(p+q)-1][8]          6.993  0.0002008
Lag[4*(p+q)+(p+q)-1][14]         7.381  0.4857327
d.o.f = 3
H0: No serial correlation

                             statistic  p-value
Lag[1]                           1.320   0.2506
Lag[2*(p+q)+(p+q)-1][5]          1.322   0.7836
Lag[4*(p+q)+(p+q)-1][9]          1.324   0.9687
d.o.f = 2
```

Source: author's analysis

Appendix E2. Weighted Ljung-Box Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for BRT Dry tissue paper

```
                             statistic   p-value
Lag[1]                           5.078   0.02424
Lag[2*(p+q)+(p+q)-1][8]          5.737   0.02846
Lag[4*(p+q)+(p+q)-1][14]         6.116   0.73056
d.o.f = 3
H0: No serial correlation

                             statistic  p-value
Lag[1]                          0.8512   0.3562
Lag[2*(p+q)+(p+q)-1][5]         0.8530   0.8920
Lag[4*(p+q)+(p+q)-1][9]         0.8556   0.9915
d.o.f = 2
```

Source: author's analysis

Appendix E3. Weighted Ljung-Box Test for ARMAX model with Electricity Prices for HHT Dry tissue paper

```
                        statistic  p-value
Lag[1]                   0.001141    0.973
Lag[2*(p+q)+(p+q)-1][5]  0.133944    1.000
Lag[4*(p+q)+(p+q)-1][9]  0.487718    1.000
d.o.f = 2
H0: No serial correlation

                         statistic  p-value
Lag[1]                   0.0007917   0.3562
Lag[2*(p+q)+(p+q)-1][5]  0.0013738   1.0000
Lag[4*(p+q)+(p+q)-1][9]  0.0025941   1.0000
d.o.f = 2
```

Source: author's analysis

Appendix E4. Weighted Ljung-Box Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for HHT Dry tissue paper

```
                        statistic  p-value
Lag[1]                    0.04188   0.8378
Lag[2*(p+q)+(p+q)-1][5]   0.20993   1.0000
Lag[4*(p+q)+(p+q)-1][9]   0.54671   1.0000
d.o.f = 2
H0: No serial correlation

                         statistic  p-value
Lag[1]                    0.000607   0.9803
Lag[2*(p+q)+(p+q)-1][5]   0.001613   1.0000
Lag[4*(p+q)+(p+q)-1][9]   0.002757   1.0000
d.o.f = 2
```

Source: author's analysis

Appendix E5. Weighted Ljung-Box Test for ARMAX model with Electricity Prices for Facial tissue paper

```
                                statistic   p-value
Lag[1]                              1.641    0.2001
Lag[2*(p+q)+(p+q)-1][8]             3.236    0.9878
Lag[4*(p+q)+(p+q)-1][14]            4.336    0.9561
d.o.f = 3
H0: No serial correlation

                                statistic   p-value
Lag[1]                             0.9636    0.3263
Lag[2*(p+q)+(p+q)-1][5]            1.1848    0.8166
Lag[4*(p+q)+(p+q)-1][9]            1.2352    0.9561
d.o.f = 2
```

Source: author’s analysis

Appendix E6. Weighted Ljung-Box Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Facial tissue paper

```
                                 statistic   p-value
Lag[1]                              0.1278    0.7208
Lag[2*(p+q)+(p+q)-1][14]            4.8656    1.0000
Lag[4*(p+q)+(p+q)-1][24]            6.1422    0.9983
d.o.f = 5
H0: No serial correlation

                                statistic   p-value
Lag[1]                             0.0118    0.9135
Lag[2*(p+q)+(p+q)-1][5]            3.2627    0.3612
Lag[4*(p+q)+(p+q)-1][9]            3.6333    0.6515
d.o.f = 2
```

Source: author’s analysis

Appendix E7. Weighted Ljung-Box Test for ARMAX model with Electricity Prices for Hanky tissue paper

```
                        statistic  p-value
Lag[1]                     0.2061   0.6498
Lag[2*(p+q)+(p+q)-1][5]    0.4927   1.0000
Lag[4*(p+q)+(p+q)-1][9]    1.5583   0.9963
d.o.f = 2
H0: No serial correlation

                         statistic  p-value
Lag[1]                    0.002286   0.9619
Lag[2*(p+q)+(p+q)-1][5]   0.012582   1.0000
Lag[4*(p+q)+(p+q)-1][9]   0.021858   1.0000
d.o.f = 2
```

Source: author’s analysis

Appendix E8. Weighted Ljung-Box Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Hanky tissue paper

```
                         statistic   p-value
Lag[1]                   2.006e-09  1.0000
Lag[2*(p+q)+(p+q)-1][5]  2.246e-01  1.0000
Lag[4*(p+q)+(p+q)-1][9]  8.613e-01  0.9999
d.o.f = 2
H0: No serial correlation

                         statistic  p-value
Lag[1]                    0.009541   0.9222
Lag[2*(p+q)+(p+q)-1][5]   0.018562   0.9999
Lag[4*(p+q)+(p+q)-1][9]   0.026799   1.0000
d.o.f = 2
```

Source: author’s analysis

APPENDIX F

STABILITY CHECKS

Appendix F1. Nyblom stability Test for ARMAX model with Electricity Prices for BRT Dry tissue paper

```
Joint Statistic: 2.1461
Individual Statistics:
mu        0.18943
ma1       0.51651
ma2       0.55697
ma3       0.19380
mxreg1    0.08044
omega     0.03209
alpha1    0.03732
beta1     0.03712
shape     0.04046

Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:          2.1  2.32  2.82
Individual Statistic:     0.35  0.47  0.75
```

Source: author's analysis

Appendix F2. Nyblom stability Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for BRT Dry tissue paper

```
Joint Statistic: 2.361
Individual Statistics:
mu          0.20292
ma1         0.52595
ma2         0.49231
ma3         0.18228
mxreg1    0.05531
mxreg2    0.12581
mxreg3    0.11060
omega      0.02903
alpha1      0.03395
beta1        0.03421
shape       0.03925
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:           2.49  2.75  3.27
Individual Statistic:   0.35  0.47  0.75
```

Source: author’s analysis

Appendix F3. Nyblom stability Test for ARMAX model with Electricity Prices for HHT Dry tissue paper

```
Joint Statistic: 2.203
Individual Statistics:
mu          0.14136
ma1         0.53760
ma2         0.47895
mxreg1    0.11901
omega      0.07884
alpha1      0.07881
beta1        0.09291
shape       0.12155
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:           1.89  2.11  2.59
Individual Statistic:   0.35  0.47  0.75
```

Source: author’s analysis

Appendix F4. Nyblom stability Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for HHT Dry tissue paper

```
Joint Statistic: 1.7294
Individual Statistics:
mu         0.13001
ma1        0.03056
ma2        0.22413
mxreg1     0.07455
mxreg2     0.03846
mxreg3     0.09236
omega      0.03186
alpha1     0.03165
beta1      0.03782
shape      0.04985
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:          2.92  2.54  3.05
Individual Statistic:   0.35  0.47  0.75
```

Source: author’s analysis

Appendix F5. Nyblom stability Test for ARMAX model with Electricity Prices for Facial tissue paper

```
Joint Statistic: 1.1683
Individual Statistics:
mu         0.08683
ar1        0.15675
ar2        0.22403
ma1        0.11277
mxreg1     0.08164
omega      0.05437
alpha1     0.14632
beta1      0.05643
shape      0.07197
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:          2.1  2.32  2.82
Individual Statistic:   0.35  0.47  0.75
```

Source: author’s analysis

Appendix F6. Nyblom stability Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Facial tissue paper

```
Joint Statistic: 2.7561
Individual Statistics:
mu        0.05733
ma1       0.04980
ma2       0.19672
ma2       0.06999
ma2       0.81854
ma2       0.02430
mxreg1    0.05772
mxreg2    0.19362
mxreg3    0.14624
omega     0.04440
alpha1    0.15637
beta1     0.05545
shape     0.08008
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:         2.89  3.15  3.69
Individual Statistic:    0.35  0.47  0.75
```

Source: author’s analysis

Appendix F7. Nyblom stability Test for ARMAX model with Electricity Prices for Hanky tissue paper

```
Joint Statistic: 3.7625
Individual Statistics:
mu        0.21310
ar1       0.09317
ma1       0.44289
mxreg1    0.08724
omega     0.28195
alpha1    0.96065
beta1     0.81552
shape     0.30983
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:         1.89  2.11  2.59
Individual Statistic:    0.35  0.47  0.75
```

Source: author’s analysis

Appendix F8. Nyblom stability Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Hanky tissue paper

```
Joint Statistic: 1.8948
Individual Statistics:
mu         0.09282
ma1        0.13971
ma2        0.18687
mxreg1     0.05715
mxreg2     0.08895
mxreg3     0.14736
omega      0.10381
alpha1     0.04267
beta1      0.22598
shape      0.14015
Asymptotic Critical Values  (10% 5% 1%)
Joint Statistic:          2.29  2.54  3.05
Individual Statistic:     0.35  0.47  0.75
```

Source: author's analysis

APPENDIX G

ASSYMETRY CHECKS

Appendix G1. Sign Bias Test for ARMAX model with Electricity Prices for BRT Dry tissue paper

	t-value	prob	sig
Sign Bias	1.9798	5.007e-02	*
Negative Sign Bias	13.4195	1.990e-25	***
Positive Sign Bias	0.1357	8.293e-01	
Joint Effect	180.4055	7.209e-39	***

Source: author's analysis

Appendix G2. Sign Bias Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for BRT Dry tissue paper

	t-value	prob	sig
Sign Bias	1.4296	1.555e-01	
Negative Sign Bias	9.9942	2.242e-17	***
Positive Sign Bias	0.1397	8.891e-01	
Joint Effect	100.1500	1.443e-21	***

Source: author's analysis

Appendix G3. Sign Bias Test for ARMAX model with Electricity Prices for HHT Dry tissue paper

	t-value	prob	sig
Sign Bias	1.0222	0.3088	
Negative Sign Bias	0.3938	0.6944	
Positive Sign Bias	0.0491	0.9609	
Joint Effect	2.1096	0.5500	

Source: author's analysis

Appendix G4. Sign Bias Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for HHT Dry tissue paper

	t-value	prob	sig
Sign Bias	0.72951	0.4672	
Negative Sign Bias	0.37538	0.7081	
Positive Sign Bias	0.06265	0.9502	
Joint Effect	1.08005	0.7819	

Source: author's analysis

Appendix G5. Sign Bias Test for ARMAX model with Electricity Prices for Facial tissue paper

	t-value	prob	sig
Sign Bias	1.004	3.175e-01	
Negative Sign Bias	4.857	3.728e-06	***
Positive Sign Bias	1.007	2.836e-01	
Joint Effect	27.725	4.148e-06	***

Source: author's analysis

Appendix G6. Sign Bias Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Facial tissue paper

	t-value	prob	sig
Sign Bias	1.1236	0.2635	
Negative Sign Bias	0.4043	0.6887	
Positive Sign Bias	0.5115	0.6100	
Joint Effect	2.1691	0.5381	

Source: author's analysis

Appendix G7. Sign Bias Test for ARMAX model with Electricity Prices for Hanky tissue paper

	t-value	prob	sig
Sign Bias	0.5238	0.6014	
Negative Sign Bias	0.2348	0.8147	
Positive Sign Bias	0.2995	0.7651	
Joint Effect	0.2996	0.9601	

Source: author's analysis

Appendix G8. Sign Bias Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Hanky tissue paper

	t-value	prob	sig
Sign Bias	0.2529	0.8008	
Negative Sign Bias	0.5515	0.5824	
Positive Sign Bias	0.7084	0.4801	
Joint Effect	1.4032	0.7048	

Source: author's analysis

APPENDIX H

GOODNESS OF FIT

Appendix H1. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices for BRT Dry tissue paper

	group	statistic	p-value(g-1)
1	20	12.75	0.8509
2	30	18.66	0.9298
3	40	34.07	0.6942
4	50	34.56	0.9411

Source: author’s analysis

Appendix H2. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for BRT Dry tissue paper

	group	statistic	p-value(g-1)
1	20	8.820	0.9764
2	30	9.803	0.9997
3	40	26.197	0.9418
4	50	44.393	0.6601

Source: author’s analysis

Appendix H3. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices for HHT Dry tissue paper

	group	statistic	p-value(g-1)
1	20	22.59	0.2559
2	30	31.93	0.3228
3	40	30.13	0.8450
4	50	46.03	0.5942

Source: author’s analysis

Appendix H4. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for HHT Dry tissue paper

```
  group statistic  p-value(g-1)
1    20    19.64         0.4166
2    30    27.02         0.5708
3    40    32.10         0.7752
4    50    38.66         0.8555
```

Source: author's analysis

Appendix H5. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices for Facial tissue paper

```
  group  statistic  p-value(g-1)
1    20      9.475        0.9647
2    30     21.115        0.8549
3    40     24.230        0.9692
4    50     28.820        0.9905
```

Source: author's analysis

Appendix H6. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Facial tissue paper

```
  group statistic  p-value(g-1)
1    20    26.20         0.1248
2    30    23.57         0.7497
3    40    45.87         0.2087
4    50    38.66         0.8555
```

Source: author's analysis

Appendix H7. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices for Hanky tissue paper

	group	statistic	p-value(g-1)
1	20	22.26	0.2714
2	30	28.00	0.5179
3	40	38.00	0.5153
4	50	48.49	0.4936

Source: author's analysis

Appendix H8. Adjusted Pearson Goodness of Fit Test for ARMAX model with Electricity Prices, Producer Price Index for Wood Pulp and the Producer Price Index for Carbon Black for Hanky tissue paper

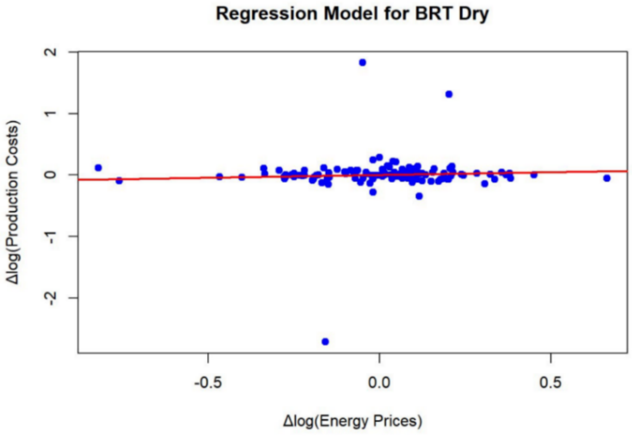
	group	statistic	p-value(g-1)
1	20	33.08	0.02352
2	30	44.23	0.03490
3	40	46.52	0.19022
4	50	52.59	0.33681

Source: author's analysis

APPENDIX I

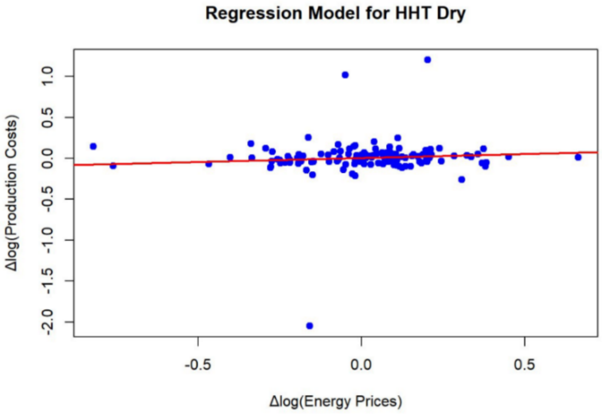
ADDITIONAL FIGURES

Figure I1. Visual representation of the linear regression model for BRT Dry tissue paper



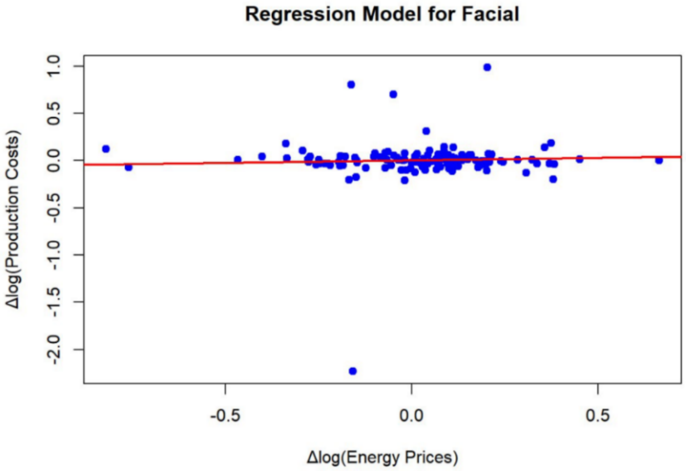
Source: author's analysis

Figure I2. Visual representation of the linear regression model for HHT Dry tissue paper



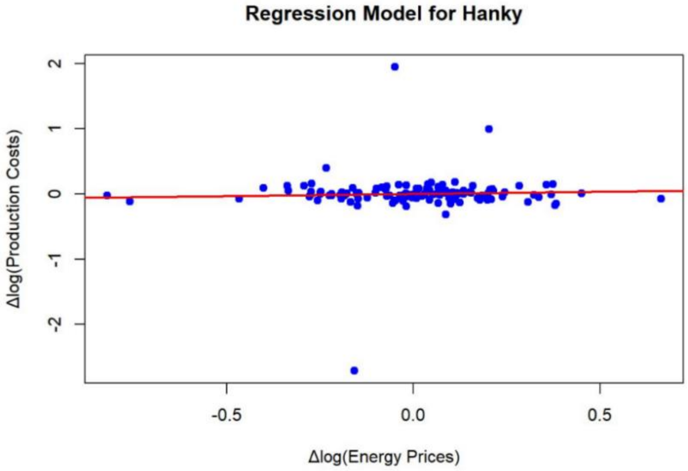
Source: author's analysis

Figure I3. Visual representation of the linear regression model for Facial tissue paper



Source: author’s analysis

Figure I4. Visual representation of the linear regression model for Hanky tissue paper



Source: author’s analysis