

Article

Development of the Chemical Industry in Poland Against the Background of the European Union

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Abstract

The chemical industry is a broad sector that encompasses all the different types of industry that produce products that rely on the intensive use of chemicals. The aim of the paper was to analyze the development of the chemical industry in Poland against the background of the EU. The Polish chemical industry produces many products, which can be divided into different categories based on their application. The most important include organic and inorganic chemicals. Organic chemicals include carbon compounds such as ketones, alcohol, carboxylic acids, and cyclic compounds. They are used in the production of solvents, varnishes, paints, and adhesives, as well as in the production of drugs in the pharmaceutical industry and others. The Polish chemical industry employs over 300,000 people. The financial profit achieved by companies specializing in the production of chemicals and chemical products was PLN 9.99 billion in 2022, compared to PLN 8.16 billion in 2021. The financial profit for producers of plastic and rubber products was PLN 9.56 billion, compared to PLN 8.68 billion in 2021. These increases in profits were very noticeable for individual companies, where the scale of growth compared to the previous year was often impressive. The chemical industry is a key sector in the European Union, being the fourth largest industry in the EU. There are approximately 30,000 chemical companies in the EU, directly employing approximately 1.2 million people. Europe is the second largest producer of chemicals in the world, generating a high percentage of global sales.

Keywords: chemical industry; economy; Poland

1. Introduction

The chemical industry is a broad industry encompassing all the various industries whose products rely on the intensive use of chemicals. Currently, development requires petrol and other chemical products. [1]. The chemical industry is playing a key role in creating new products and financial growth. As a note of caution, because the market is so integrated, and chemical plants are located in clusters, major accidents in the chemical industry can have significant consequences for people [2,3].

The chemical industry is having big impact on global GDP, contributing about 7%, and the sector employs about 15 million people worldwide. More than 96% of products in the world use chemicals in their production [4].

The biggest chemical industry is in China. In 2017, the market was evaluated to be worth around \$1.5 trillion in sales, and in 2023, the market increased to 1729 trillion EUR. The chemical industry in China has had a positive impact on economic growth, not only in own country but also around the world. The growth in the chemical industry, apart from



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many advantages such as creating jobs, also has disadvantages, such as pollution, ecological and environmental problems, high consumption of energy and others [5]. In the last 25 years, there have been changes in the main producers of chemical products. Countries from Asia play a key role, delivering 65.2% of sales of chemical products (3387 EUR mld), while countries from Europe produce only 16% (862 EUR mld) and the USA accounts for 11.3% (585 EUR mld) [4].

The chemical industry is also developing well in the European Union (EU). This sector produces products in such areas as base chemicals, specialty chemicals and consumer chemicals. Base chemicals contribute 59.2% of the market, while specialty chemicals (paints and inks, crop protection, dyes and pigments) contribute 27.2%. Consumer chemicals accounted for 13.6% of the total sales of chemical products in 2016 [6]. The cost of the production of chemical products has an impact on the competitiveness of the EU economy, and it has been shown that the EU industry is more competitive than the USA, Saudi Arabia and other countries [7].

The literature concerning the chemical industry and chemical sector development is broad. The chemical industry plays an extremely important role in both the economy and everyday life. It contributes to job creation, innovation, and economic growth. Chemical products are the foundation of many industries, such as construction, automotive production, pharmaceuticals, and agriculture. They enable the production of materials essential for the production of other goods [8].

The chemical industry, from cleaning products and cosmetics to pharmaceuticals, influences many aspects of our daily lives. Chemicals are present in the products people use every day, making our lives more convenient and healthier. For example, thanks to chemistry, we have access to effective plant protection products, which allows us to increase crop yields and ensure food safety [9].

It is also worth noting that the chemical industry faces challenges related to environmental protection and sustainable development. Many companies are taking steps to reduce emissions, promote recycling, and seek more ecological solutions. This demonstrates that the chemical industry not only supports the economy but also strives for a better future for our planet [10].

One of the biggest problems with chemicals is their safe transport. Countries joining the EU have had to adjust their national legislation to the existing EU environmental laws, which has been a challenge. This process is very difficult because there are many different institutions involved, such as ministries, national chemical bureaus, enforcement inspectorates, agencies and others [11].

The development of the chemical sector is fraught with challenges, both globally and locally. Cost issues, numerous regulations, and the need for innovation are placing increasing demands on the chemical industry. In an era of ecological transformation and geopolitical shifts, the chemical sector must strike a balance between economic growth and sustainable development [12].

The chemical industry is constantly evolving and making further technological advancements, so in addition to traditional analytical skills, potential employees will also need competencies related to operating advanced control systems and data analysis [13].

The chemical industry is also important in the work market. Employers will value the ability to work with modern technology (e.g., AI) in the chemical industry. Furthermore, English language skills are becoming increasingly important, as they allow people to work in an international environment [14]. Health and safety issues have been investigated in companies in the petrochemical industries in Iran. It was found that management leadership, consultation and dissemination of knowledge, and more auditory and

regulatory actions are needed in order to decrease high levels of avoidable injuries among workers [15].

The development of the green chemical industry and environmentally friendly chemical products faces many problems when introduced to the market. The most important difficulties include financial, economic, regulatory, technical, organizational, cultural and other barriers. Overcoming these barriers is a key issue in chemical development in national and international markets [16].

Research concerning chemicals in food has been carried out by McEntaggart et al. [17]. This research proved that there is widespread anxiety among people about being subjected to the impact of chemicals in their food. Research indicates that views on risks associated with this issue are shaped by the widespread belief that synthetic chemicals present higher dangers to human health compared to other items or materials deemed natural. Variations exist among countries in how the phrasing used in questions affects consumer views, which can provide insights to inform customized communication strategies.

Dakkounea et al. [18] conducted a risk analysis of the French chemical industry. They discovered that actions associated with the French chemicals sector present a considerable risk profile. In spite of the relatively high effectiveness of current controls, the risks need to be reduced to tolerable (green) levels.

Díaz Lopez and Montalvo [19] assessed the cumulative nature of eco-innovation in the chemical industry. They found that the development of the chemical sector across history depends on promoting eco-innovation, emphasizing the interconnected relationship between regulation and innovation, and shifts in technology. It is likely that the future growth of this sector could be influenced by the frameworks of sustainability and resource optimization determined by policy.

The chemical sector occupies an essential role within the world wide economy, creating a multitude of jobs and significantly impacting GDP. By adhering to the Paris Climate Agreement, the chemical sector can effectively control its greenhouse gas emissions (Scope 1–3) while striving for impressive growth. To capitalize on these opportunities, the European Commission has developed a transition strategy specifically designed for the chemical sector [20–22].

The research gap addressed in this paper is wide, as the chemical industry has an impact on the development of the economy in the EU. It is important to analyze how big an impact on the economy the chemical industry has, and its role is increasing. Chemical products are present almost everywhere, including in food, clothes, petrochemistry and machinery. The meaning of the chemical industry for each human being is important. That is why analysis of this sector is needed in order to provide people with information about its impact on their economic situation. Little attention has been paid to the development of the sector in Poland compared to the EU. Moreover, the economic impact of the chemical sector has not yet been fully identified. The task of the author of this paper is to fill in the gaps existing in the literature. The information concerning the chemical industry in the present literature does not present its economic impact and the changes it is experiencing. Good conditions and prospects for the development of the chemical industry are needed in order to ensure the stability of many markets. Particular attention should be paid to the Polish chemical industry because this sector is delivering products needed for life. Poland has a strong chemical industry; however, its competitiveness is influenced by the impact of the EU and the world situation in this sector. Poland, which joined the EU in 2004, must achieve global competitiveness and that is why the economic situation in this sector should be of particular interest to policy makers.

The aim of the paper was to analyze the development of the chemical industry in Poland against the background of the EU. The research questions are as follows:

- (i) What are the main products of the Polish chemical industry?
- (ii) What is the sales production value of the Polish chemical industry?
- (iii) What is the production value in the EU?
- (iv) What is the prognosis for Polish chemical industry and EU industry sales?

Based on the literature review and my own research I have elaborated the following hypothesis:

H1. *The chemical industry in the European Union is losing its worldwide position due to stronger development of this sector in China and other Asian countries.*

The paper is organized as follows. In the introduction I presented the research gap. The second part is materials and methods. The third part presents results. The fourth part presents the results of the research. The fifth part presents the discussion. The final part is the conclusion.

1.1. Policy of Poland Concerning Chemicals, Against the Background of the European Union

Poland is undergoing changes in its chemical industry due to its accession in 2004 to the European Union (EU). Kryk and Kożuch [23] found some regulations concerning the chemical industry, including the following:

- The Regulation on Sustainable Finance Disclosure 2019/2088 (Regulation, 2019) [24], known as “The SFDR”, has been applicable since March 2021 and its goal is to decrease the information imbalance between the main party and the builder regarding the emergence of sustainability risks in the industry, considering negative impacts on sustainable progress and encouraging environmental or social factors and sustainable investments.
- The Taxonomy Regulation (Regulation, 2020) [25] established a framework to facilitate sustainable investment. The aim is to ensure that uniform qualification of sustainable economic activities is environmentally sustainable, while ensuring protection against so-called green washing.
- The 2022 Taxonomy Delegated Act (European Commission, 2023) [26] outlines the content, format and presentation of the details to be revealed, along with the approach taken to guarantee adherence along with it.
- Directive (EU) 2022/2464, regarding corporate sustainability reporting (CSRD) (Directive, 2022) [27], replaced Directive 2014/95/EU and has been in effect since January 2023 [28]. ESG reports created in line with its regulations should be submitted in 2024. It broadens the network of enterprises that are required to submit non-financial reports and standardizes reporting norms by implementing a required category of standards—European Sustainable Reporting Standards (ESRS). It elucidates the manner of disseminating information by suggesting a required distinct segment within the activity summary [23].

The chemical industry has also been regulated in relation to food and nutritious products. Multiple global organizations, including the European Chemicals Agency and the European Food Safety Authority, have launched research projects aimed at pinpointing hazardous chemical substances found in consumer goods [29,30]. As this data becomes accessible and widely recognized, it warrants the start of additional investigations into how particular chemicals affect human health. While regulatory bodies and organizations are officially tasked with offering guidance, such as through the REACH Regulation within the European Union, the remain unresolved questions and discussions regarding the application of certain substances [29,30]. Chemical products are found in nearly every product created: including electronics, beauty products, cleaning agents, construction

materials, and apparel [29,31–33]. The primary chemical substances are presenting dairy items (such as milk, yogurt, and cream cheese), processed meats, beverages, pasta, canned goods, various long-lasting food items [29,34–36], furniture, and industrial products for home use [29,37–39], as well as those in the construction sector [29,40–43], agricultural goods [44], pest control, household cleaners [29,45–47], and products containing lubricants and oil derivatives [29,48,49]. It has been acknowledged that both consumers and the environment face exposure to emissions from products that contain these chemicals [29,50–52].

1.2. Green Chemistry, Circular Economy, and Net-Zero Emissions in Relation to Poland

One of the most important sectors of an economy is the chemical sector, which supports a number of industries, including agriculture, manufacturing, electronics, and medicine [53]. Despite being crucial to technological and economic advancement, this industry is among the most destructive and ravenous in terms of pollution emissions and environmental degradation [54]. Due to the detrimental impacts on society, particularly those on the environment, which have alarmed both the public and the organizations in charge of the industry [55], there are more demands for accountability in the chemical industry.

Green chemistry plays a very important role in Polish agriculture. One of the markets is rapeseed, which is primarily processed into edible oils and biodiesel. Poland has seventeen enterprises that produce and process fat. The majority of them provide rapeseed oil for manufacturing food and biofuels. The sector is providing not only food but also biomass for energy purposes, which helps the development of the circular economy. The circular economy is promoting using agricultural and renewable bioresources [56–58].

The chemical industry is also participating in the development of the food industry. Since the majority of food industry businesses are located in smaller towns, they contribute favorably to the growth of rural areas. This is greatly impacted by the use of cutting-edge technology and management, as well as support for the modernization of the agricultural raw material base and service demand. The need to lower costs and increase competitiveness in global markets has led to a long-term trend in production concentration in the Polish food industry [59–61].

The chemical industry is also linked to the energy system in Poland, which relies on coal as an energy source. Fossil fuels contribute to a great extent to energy production and consumption, but their share is decreasing. For many years, Poland's power industry stood out for using the most coal in the EU to generate electricity, which resulted in massive emissions and detrimental environmental repercussions [61,62].

2. Materials and Methods

The main sources of information were data obtained from Statistics Poland. The main bulletin called Chemical Industry, published by the Polish Chamber of the Chemical Industry, was the main source of data [63]. Moreover, data from the chemical industry of Poland [64] and the European Chemical Industry Council (Cefic Aisbl) was used [65].

The value of products sold by the chemical industry and the chemical industry's share of total products sold is presented for 2005–2022. The investment outlays in the Polish chemical industry and the balance of trade for the chemical industry in Poland is presented for 2011–2022.

The production value of the chemical industry in the EU and share of the EU chemical industry in the global industry in terms of sales value is presented based on data from 2011–2021.

In the first step of the analysis, I analyzed the descriptive statistics for the sales of chemicals in the European Union. This analysis is very helpful because it can provide a

clear picture of changes which took place in the chemical industry in particular countries in the European Union.

The next step was to check if the data is stationary. That is why I have conducted the Augmented Dickey–Fuller test (ADF) test. In the course of analyzing the research data presented in quantitative form, the method is presented by the following equation [66]:

$$x_t = u + \rho x_{t-1} + \varepsilon_t \quad (1)$$

where, $x_0 = 0$; represents a constant; and $\{\varepsilon_t\}$ consists of a series of independent normal random variables with a mean of zero and a variance of σ^2 (i.e., $\varepsilon_t \sim \text{i.i.d}(0, \sigma^2)$).

In the next step I have elaborated the VAR model, which aimed to check the stationarity of the data and is commonly applied in econometric evaluations [67]. These models investigate the uncertainty presenting the fundamental distribution [68,69]. They are also employed for testing hypotheses and data interdependencies [70]. The quintile of distribution is being examined by this model [69]. These models have a wide range of applications, such as assessing risk-takers' performance, regulatory requirements, and financial analysis in banks [70–72]. The financial industry uses this method to forecast volatility [73–75]. The format is as follows:

$$Z_t = \sum_{i=1}^k [A_i Z_{t-i} + \varepsilon_t, t = 1, 2, \dots, n] \quad (2)$$

where: Z_t is a vector of observations of the current values of all n model variables; A_i is a matrix of autoregressive operators of individual processes in which no zero elements are assumed a priori; ε_t is a vector of residual processes for which it is assumed that individual components are simultaneously correlated with each other but do not contain autocorrelation; and k is the order of the VAR model.

Finally, I have elaborated a prognosis for 2025–2029.

3. Results

3.1. Production Value of the Chemical Industry in the World and European Union

A crucial aspect of chemical production is the cost of feedstock. This can significantly impact the final price of products and a company's profits. Chemical production is located in three main parts of the world: China (43%), the EU 27 (14.7%) and the USA (10.9%). Rest of the Asia (10.5%), Japan (4.7%) and Rest of Europe (4.1%) are also important in chemical industry production (Table 1).

Table 1. Value of production of the chemical industry around the world in 2024.

Part of the Word	EUR mld	%
Together the World	4026	100
Rest of the World	82	2
Africa	47	1.2
South Korea	133	3.3
India	104	2.6
Japan	190	4.7
China	1729	43
Rest of Asia	423	10.5
Latin America	121	3

Table 1. *Cont.*

Part of the Word	EUR mld	%
USA	437	10.9
Rest of Europe	167	4.1
EU 27	594	14.7

Source: own calculations based on [24].

In Figure 1, we can see the production index for chemicals in the World, EU, United States, Asia and Latin America. The production index informs us about changes that took place in 2004–2024. Asia and China increased the sale of chemicals the most. The EU increased the sale of chemicals to the smallest degree compared to Asia, China and the USA. The USA and Latin America, as whole continents, have stable positions, with very little loss of their shares, particularly in the most recent years.

While global chemical production rose by 4.2% year-on-year in the first half of 2025, the European Union fell into recession (−2.4%). The decrease was particularly seen from 2021, when the negative effects of the COVID-19 pandemic can be observed.

China maintained impressive production growth (+8%). The US and Brazil also posted positive results, with +2.6% and +4.3%, respectively. Japan and South Korea, like the EU, saw declines. The COVID-19 pandemic negatively affected the production of chemicals across the world [76].

As we can see, the production value in the chemical industry in the EU in 2011–2021 increased. A particular increase can be observed in 2020–2021, when the production increased from EUR 486.9 billion to 593.7 EUR billion (Figure 2). However, the production level in the chemical industry depends on the general situation in the economy of the EU. For example, the COVID-19 pandemic had a negative impact on production value in the chemical industry in 2020. The lockdowns in many countries decreased production values. In the following years, production decreased; for example, in 2022 (596.95 EUR billion), in 2023 (510.58 EUR billion) and in 2024 (EUR 498,71 billion).

Between January and June 2025, EU chemical production fell by 2.4% compared to the same period in 2024. Meanwhile, total EU-27 industrial production increased by 1.0%. This means that the chemical sector is performing worse than the EU economy as a whole. Furthermore, chemical production remains 10% lower than in 2014–2019, before the energy and pandemic crises. Related industries are also performing poorly, with the automotive industry experiencing a decline of over 4%. In this way the negative impact of the COVID-19 pandemic and the war in Ukraine has been confirmed [76].

The chemical industry is a key sector for the EU, being the fourth largest industry in the EU. There are approximately 30,000 chemical companies in the EU, directly employing approximately 1.2 million people. Europe is the second largest producer of chemicals in the world, generating a high percentage of global sales (Figure 3).

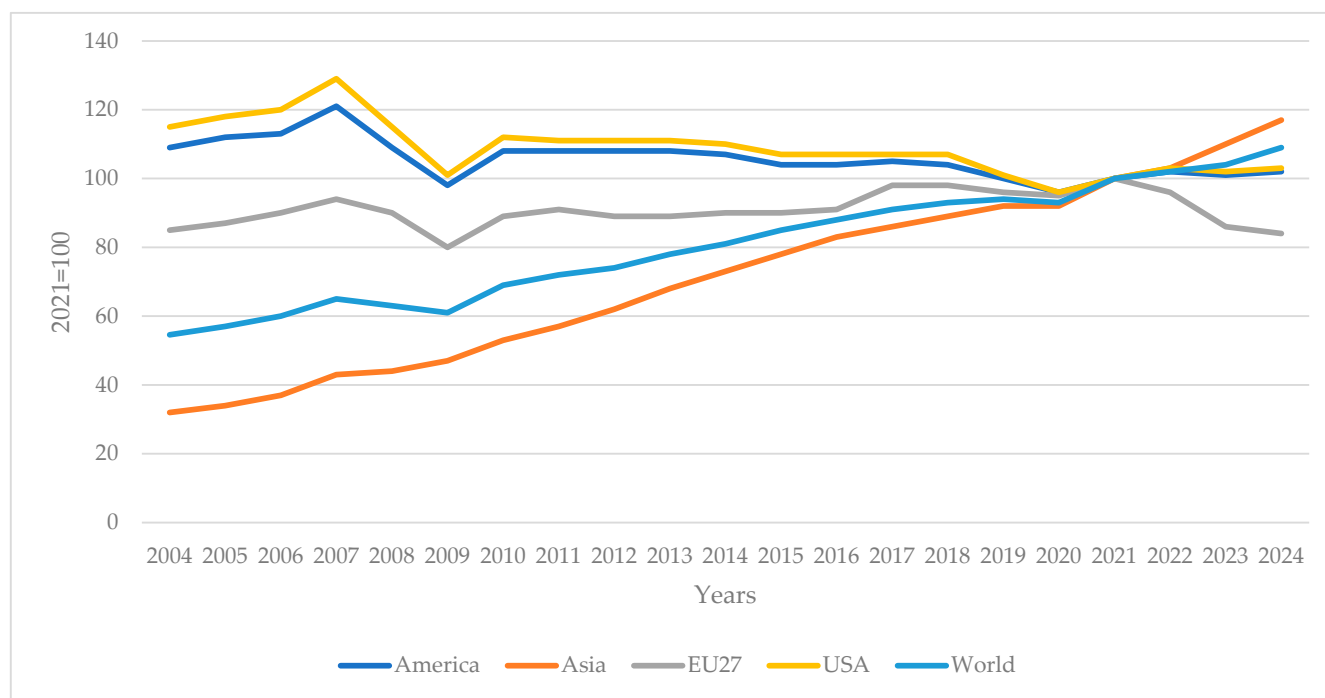


Figure 1. Production index of chemicals [2021 = 100]. Source: own elaborations based on [24].

EU chemical exports increased by just 0.5%, while imports increased by a staggering 5.4%. As a result, the trade surplus shrank to EUR 20.1 billion in the first half of 2025, a 17% decline compared to 2024. The US remains the most important export partner (EUR 23.1 billion), and China the most important source of imports (EUR 17.1 billion). It is worth noting that Europe's dependence on Chinese chemical supplies has increased almost fivefold over the past two decades—from less than 1% in 2004 to 5.6% in 2024. The global problems related to COVID-19 and the war in Ukraine negatively affected the EU-27 chemical sector, while it enhanced the position of China and Asia. The EU is losing its markets for chemical products in the world. The increasing demand for chemical products is fulfilled by China [76].

3.2. Polish Chemical Industry Production

Production in the Polish chemical industry is diversified. The chemical industry distinguishes many product categories. They can be divided into different groups/types based on their application. The most important include organic and inorganic chemicals. These are the basis of many industrial processes. Organic chemicals include carbon compounds such as ketones, alcohol, carboxylic acids, and cyclic compounds. They are used in the production of solvents, varnishes, paints, and adhesives, as well as in the production of drugs in the pharmaceutical industry. Inorganic chemicals include substances such as metal oxides and mineral salts, which are used in the metallurgical, ceramic, and food industries. Another very important product category from an agricultural perspective is artificial fertilizers. They play a key role by increasing crop yields and improving soil quality. Also worth mentioning are military products, pyrotechnics (explosives), and petrochemicals such as gasoline and diesel fuel, which are essential for transportation and energy. The value of production in the chemical industry increased from PLN 113.6 mld to PLN 442.4 mld. The chemical industry's share of total sales in 2023 was 16.7% (Table 2).

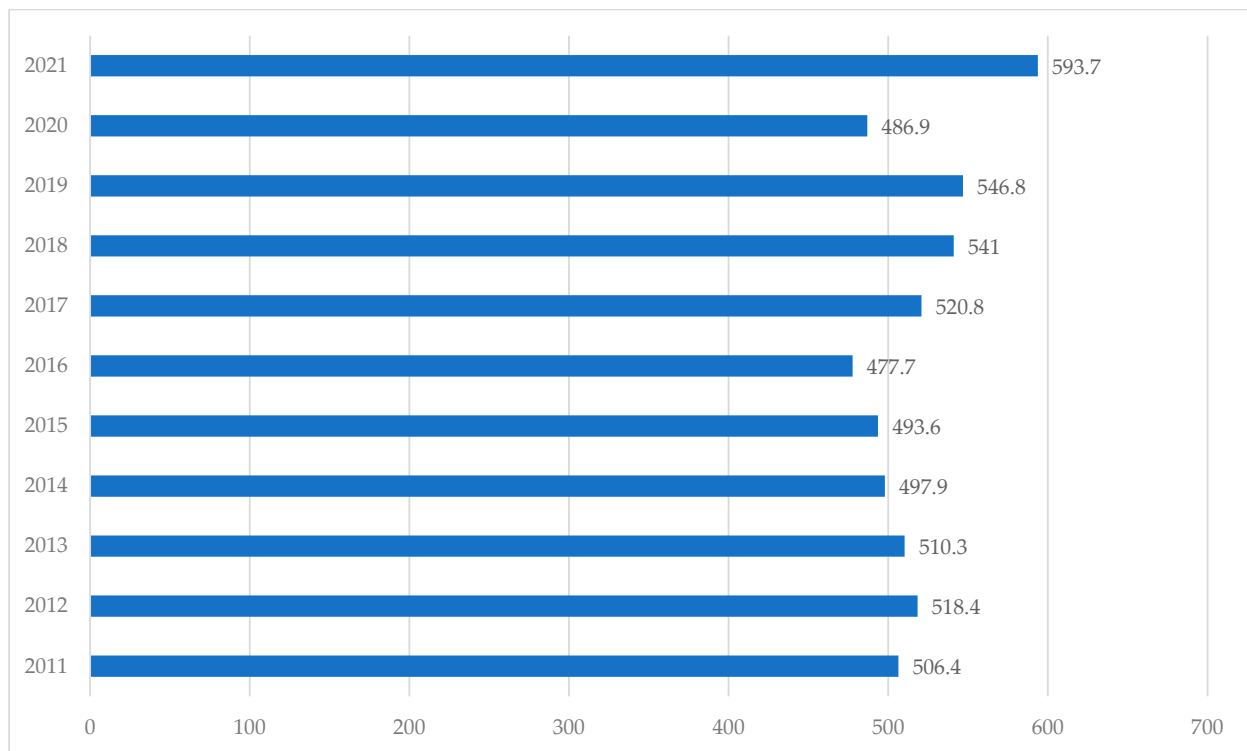


Figure 2. Production value of the chemical industry in the EU in 2011–2021 [EUR billion]. Source: own calculations based on [64].

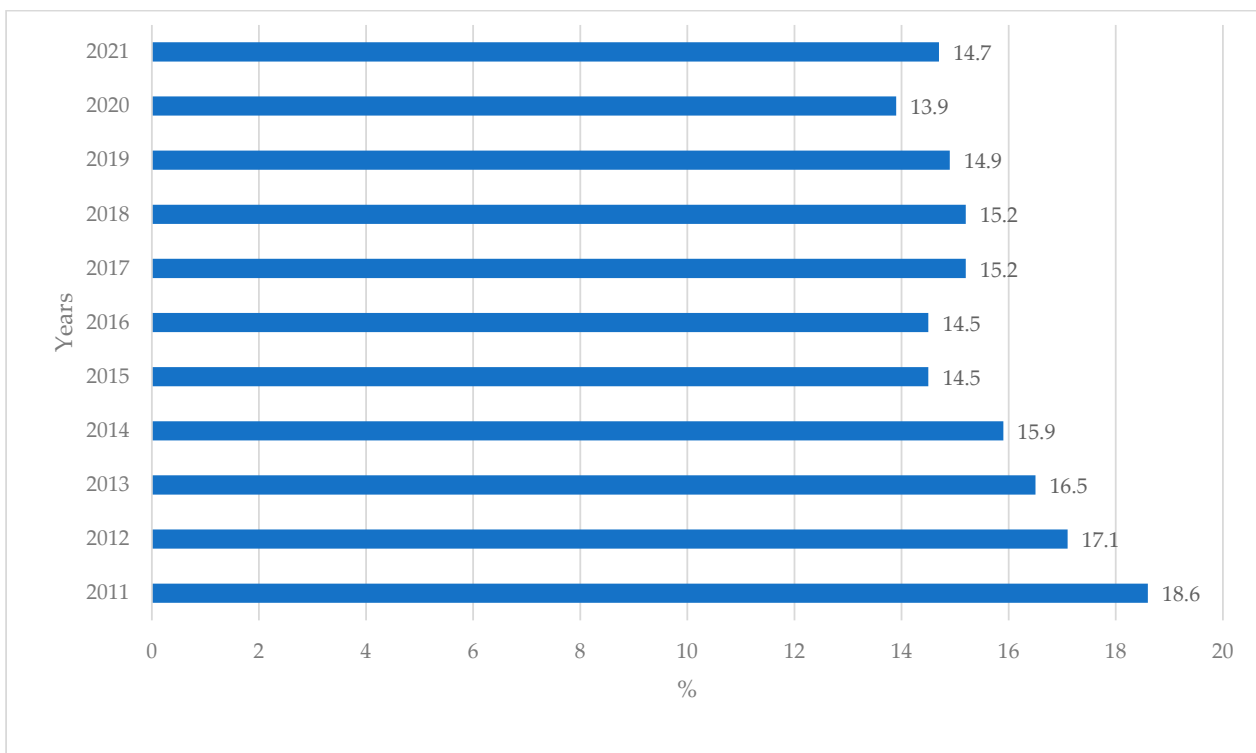


Figure 3. Share of the EU chemical industry in the global industry structure in terms of sales value, 2011–2021 (%). Source: own calculations based on [64].

Table 2. Production in the chemical industry in Poland in 2005–2022.

Year	Value of Production Sales in the Chemical Industry [PLN mld]	Chemical Industry Share of Total Industry Sales (%)	Investment Outlays in Polish Chemical Industry [PLN mld]	Trade Balance of Chemical Industry in Poland [EUR mld]
2005	113.6	16.5	7	-
2010	167.3	17.0	8	-
2011	211.2	18.6	12	0.55
2012	224.4	19.0	8.28	0.56
2013	219.1	18.5	8.78	0.70
2014	217.6	18.0	10.85	0.60
2015	209.4	16.7	11.59	0.41
2016	210.0	16.1	12.11	0.58
2017	230.5	16.3	13.14	0.67
2018	260.5	17.1	12.8	0.66
2019	266.3	16.5	14.3	0.78
2020	245.4	15.5	15.4	0.92
2021	325.6	16.7	18	0.21
2022	462.3	18.2	23.7	0.07
2023	442.4	16.7	23.3	1.60

Source: own calculations based on [14].

The chemical sector would not develop without high investment. The value of investments increased by almost 207% in 2005–2022 on one hand. On the other hand, numerous critical chemical inventions from Poland were abandoned and never marketed. Examples of value-added chemical compounds created in Poland and discarded include grapheme and gallium nitride. Poland introduced the market economy in 1989, and this had a negative impact on the chemical industry because companies had to face international competition. Lack of funding and expertise, poor management, and hostility to privatization all contributed to the bankruptcy of numerous chemical enterprises. A few instances of state-owned chemical enterprises that have failed are Zchem at Bydgoszcz, Carbochem at Gliwice and others. Most of the time, there were no legitimate reasons why the plants had to be closed. The only issues that have not yet been resolved on the sites are those related to environmental pollution [77].

The balance of trade in chemicals has also seen dramatic changes in recent years. It is still decreasing, but in 2023 there was an increase in trade balance for the chemical industry in Poland. In 2023, as in previous years, the main export destination for Polish chemicals was the EU-27. The total value of exports to EU countries amounted to almost EUR 36 billion, almost 4% less than in the previous year. The value of exports to non-EU countries amounted to approximately EUR 12.2 billion (an 8% increase compared to 2022). The total value of exports from the Polish chemical sector in 2023 decreased by 1% compared to the previous year, reaching over EUR 48 billion, or over PLN 219 billion [78].

Poland's international trade in chemical goods can greatly benefit from the increased arrival of foreign direct investments following its EU integration. Recently, the chemical industry sectors that attracted the most foreign capital, especially rubber production and plastic production, have shown higher export percentages compared to import figures.

Foreign direct investments are crucial for the modernization and reorganization of the Polish chemical sector. This is especially important considering that the investments made in the chemical industry do not align with its current development needs [79].

As one of the primary forces behind long-term sustainable development and security, the chemical sector is vital to the economy. It is at the start of every value chain and makes up 18% of domestic industrial production sold. It provides essential goods, cutting-edge materials, and technology that enhance people's quality of life and allow thousands of Polish and European businesses to grow steadily [80].

The chemical sector needs to establish a strong competitive position in order to continue to assist Poland's economic growth and guarantee its strategic raw material and product autonomy [80].

The biggest production has been observed in plastics (3409 mln tons), technical grade nitrogen acid (2.03 mln tons), anhydrous ammonia (2106 mln tons), nitrogen fertilizers (1748 mln tons), and paints varnishes (1367 mln tons) (Table 3).

The second group of products with the highest production included styrene polymers (1692 thousand tons), ethylene (459 thousand tons), and propylene (thousand tons).

The biggest increases in production in the Polish chemical industry in the period January–December 2021 were observed in butadiene-1.3 (49.5%), polyethylene (32.1%) and polyvinyl chloride (25.1%). The chemical sector in Poland is developing slowly and the main reasons for this are old technologies, low competitiveness in world markets, low budgets and low assortment. However, new trends have appeared, which are digitalization, ecology, and the sharing economy [63].

The biggest decrease in production in the Polish chemical industry in the period January–December 2021 was observed for sodium hydroxide solid (caustic soda) (−27.1%), phosphorus fertilizers (−27.4%), and potassium fertilizers (−21.3%). The main recipient of fertilizers is the agriculture industry. The decrease in fertilizer production in Poland is the effect of more imports, mainly from Russia (Table 3).

Table 3. Production in the Polish chemical industry (thousand tons, mln tons).

	Production in the Polish Chemical Industry in 2022 (Thousand Tons)	Changes January–December 2021
Native sulfur	476	7%
Evaporated salt	264.11	19.5
Sulfuric acid based on 100%	1485	−9.2
Oleum based on 100% H ₂ SO ₄	189	−17.8
Sodium hydroxide solid (caustic soda)	60.8	−27.1
Sodium hydroxide in aqueous solution (soda lye or liquid caustic soda)	410	11.6
Ethylene	459	31.7
Propylene	417	19.2
Butadiene-1.3	63.35	49.5

Table 3. Cont.

	Production in the Polish Chemical Industry in 2022 (Thousand Tons)	Changes January–December 2021
Toluene	9.66	–15
Phenol	42,801	–3.5
Acetic acid	4.51	–19.5
6-Hectosanolactam (epsilon-caprolactam)	133	–21.8
Ammonia in aqueous solution	102	–6.2
Phosphorus fertilizers	324	–27.4
Potassium fertilizers	307	–21.3
Polyethylene	319	32.1
Styrene polymers	1692	–7.2
Polystyrene for combustion	100	–8.5
Polyvinyl chloride	291	25.1
Polypropylene	317	3.1
Synthetic rubber	259	–7.4
Pesticides	62.88	–14.5
Adhesives	61.74	–8.5
Production in mln tons		
Technical grade nitrogen acid	2030	–17.4
Anhydrous ammonia	2106	–18.9
Nitrogen fertilizers	1748	–16.9
Plastics (total)	3409	0.9
Paints, varnishes	1367	–12.8

Source: own calculations based on [54].

Table 4 presents the changes in production, exports, imports and other elements of the chemical industry in Poland. During last 20 years, big changes have been observed in the chemical industry in Poland. First, Poland now has a negative trade balance for chemicals, which increased from –3713 EUR mln in 2004 to –8806 EUR mln in 2024 (137%). This is due to having more imports than exports. In 2004–2024 total exports increased by 620% and total imports by 220%.

Consumption also increased from 12,360 EUR mln in 2004 to 39,731 EUR mln in 2024 (221%). Capital spending also increased from 501 EUR mln in 2004 to 2103 EUR mln in 2024 (320%).

Table 4. Changes in production and exports in the chemical industry in Poland in 2004–2024.

Characteristics of Market Development in Poland	2004	2024	Changes (%)
Total exports [EUR mln]	3201	23,048	620.02
Total imports [EUR mln]	6914	31,854	220.24
Trade balance [EUR mln]	−3713	−8806	137.14
Consumption [EUR mln]	12,360	39,731	221.45
Capital spending [EUR mln]	501	2103	319.76
Value added [EUR mln]	2192	6850	212.5
Employment [in 1000]	77	99	28.57
Producer price [2021 = 100]	62	119	91.94
Labor Productivity (€K/FTE, Index 2004 = 100, sales/employment)	100	138.4	38.4
Production Index of Chemicals; 2021 = 100;	49	102	108.16

Source: own calculations based on [65].

The chemical industry in Poland is developing due to increased demand for products. Employment increased by 28% in 2004–2024, from 77 thousand to 99 thousand. Due to increased employment and general technical development, labor productivity also increased by 38.4%.

These observed changes in the Polish chemical industry are the effects of various factors. One of them is EU integration in 2004, which forced the industry to make further investments in order to be more competitive. The second reason is the tremendous growth of the chemical industry in China, which was responsible for increases in Polish imports of chemicals. The third was the greater requirements concerning ecology, the environment and other areas, which increased costs, making the Polish and European chemical industries less competitive in global markets.

The production levels of the Polish chemical industry have increased. Based on the production index where 2021 = 100, in 2004 it was 49 and in 2024 it was 102. Production increased 108%. When we compare Polish results to EU results, the results are totally different. In 2004, the production index for the EU was 85, whereas in 2024 it was 84. The production in the whole EU has slightly decreased or stagnated. The production of chemicals in the EU decreased because of increased competition from the Chinese industry, which is pushing European products out of international markets.

3.3. Sales of Chemicals in the European Union (EUR Mln)

At the beginning, I produced descriptive statistics for the sales of chemicals in the EU countries in 2004–2024. I had 21 years of observations that helped in finding changes in the sales of chemicals and the development of the sector (Table 5).

Table 5. Descriptive statistics for the sales of chemicals in European Union countries in 2004–2024 (EUR Mln).

Country	Average	Median	Minimal	Maximal	Std. Dev.	Coefficient of Variation	Skewness	Kurtosis
Austria	12,623.0	13,378.0	5314.5	21,580.0	4545.4	0.36010	−0.1857	−0.7502
Belgium	34,604.0	35,113.0	26,098.0	51,197.0	5686.9	0.16434	0.9497	1.5857
Bulgaria	1472.8	1407.1	611.1	2959.4	611.9	0.41550	0.8197	0.1032
Croatia	796.9	787.3	580.7	1097.2	123.3	0.15467	0.4466	0.4009
Czech Republic	8236.9	6775.6	3824.1	17,871.0	3789.9	0.46012	1.1396	0.2739
Denmark	4849.3	4719.0	2618.9	7217.9	1342.7	0.27689	0.2365	−0.8189
Estonia	490.9	513.9	282.7	730.4	104.8	0.21341	−0.0329	−0.0361
Finland	7371.5	7748.7	5284.7	9961.3	1404.1	0.19048	0.0532	−0.7809
France	80,211.0	78,438.0	66,505.0	108,869.0	11,180.0	0.13939	0.9731	0.3099
Germany	163,820.0	163,390.0	113,808.0	247,040.0	33,243.0	0.20293	0.6172	0.2113
Greece	2654.3	2469.9	2030.3	4171.2	656.7	0.24742	1.2879	0.2869
Hungary	5023.9	4644.9	2947.3	7898.7	1305.8	0.25991	0.2619	−0.6416
Ireland	8181.8	7812.9	3104.2	12,431.0	2076.1	0.25374	0.0865	0.8201
Italy	53,636.0	53,388.0	40,892.0	70,606.0	6001.3	0.11189	0.7551	1.7460
Latvia	290.9	223.0	77.5	746.5	193.8	0.66603	1.0181	−0.0279
Lithuania	2047.4	1979.2	436.1	4449.9	965.7	0.47168	0.6589	0.6991
Luxembourg	331.4	332.4	157.4	518.6	112.04	0.33811	0.0498	−1.1449
Netherlands	49,996.0	49,652.0	36,367.0	75,871.0	8366.5	0.16735	1.2257	2.5883
Poland	15,725.0	14,960.0	8361.1	30,926.0	5870.0	0.37329	1.1080	0.7794
Portugal	4628.0	4575.3	3044.7	7755.5	1053.9	0.22772	1.2211	2.0803
Romania	2762.7	2502.8	2183.1	4413.1	646.6	0.23407	1.2882	0.5998
Slovak Republic	1852.4	1768.5	837.9	3038.8	489.2	0.26405	0.1899	0.7562
Slovenia	1477.8	1450.5	1118.6	2057.7	233.0	0.15769	0.8672	0.4226
Spain	40,333.0	38,278.0	29,803.0	60,323.0	7624.1	0.18903	1.0894	0.7156
Sweden	9165.5	9011.2	7276.0	11,809.0	1202.1	0.13116	0.4226	−0.3667

Source: own calculations based on [65].

The coefficients of variation inform us about changes that took place in the sales of chemicals in the European Union. The biggest coefficients of variation were achieved in Latvia (0.66603), Lithuania (0.47168) and Czech Republic (0.46012).

Skewness measures the degree to which a variable's distribution is balanced. If the average for a variable extends toward the right or left end of the distribution, the distribution is termed skewed [81,82]. More specifically, this serves as an indicator of the absence of balance and the comparative dimensions of the two ends. Preferably, a skewness of 0 is observed in a balanced dataset or a Gaussian distribution [83]. Based on our research, I can confirm that most countries of the EU achieved positive skewness. Only Estonia and Austria have negative skewness.

Conversely, kurtosis assesses how the dataset relates to the normal distribution. The vast majority of EU countries had positive kurtosis. Negative kurtosis was only observed in Denmark, Estonia, Latvia, Luxembourg, Hungary, Austria, Finland and Sweden.

Figure 4 presents the changes in the sales of chemicals in EU countries. Based on the data, we can see that the biggest changes were observed in Latvia (720% increase), Lithuania (518% increase), Bulgaria (299% increase) and the Czech Republic (267% increase). Poland also increased sales of chemicals (257% increase) in 2004–2024. Only in Luxembourg were the changes negative in 2004–2024 (−7.5%). Such changes are the effects of increasing global demand for chemicals and the progress of innovations. Generally speaking, chemicals are present in all aspects of human life and economic activity. Chemical products are part not only of medicine but also of paints and other products used in other industries.

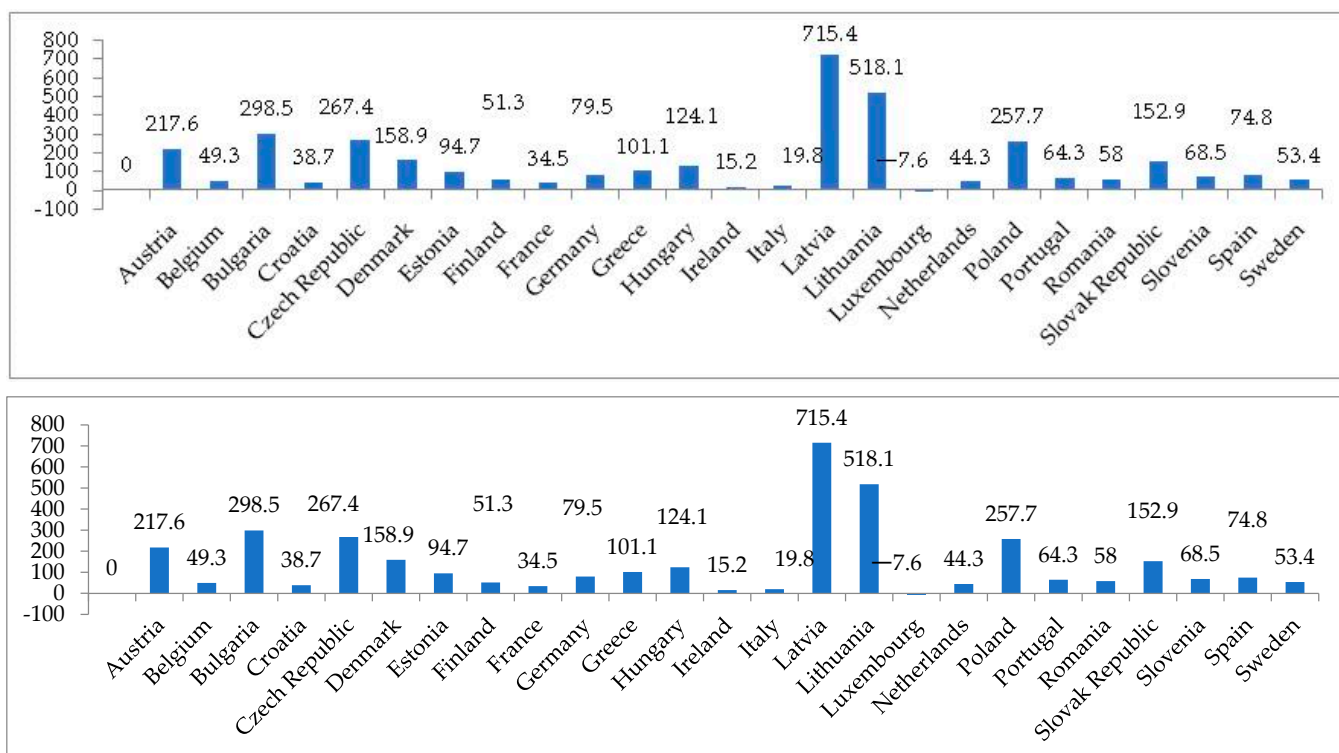


Figure 4. Changes in sales of chemicals in the EU in 2004–2024 (%). Source: own calculations based on [65].

The sales of chemicals changed in 2010–2023 (Figure 5). The highest sales of chemicals were observed in 2022 (760 EUR mld) and the smallest in 2010 (491 EUR mld). The data prove that the situation of sales in the chemical industry depends on the situation on the international market. The COVID-19 pandemic in 2019 had a negative impact on sales of chemicals in the EU because sales decreased in 2020. Moreover, the invasion of Ukraine by Russia in 2022 also had a negative impact on sales of chemicals because sales decreased in 2023.

The EU-27's share in world sales of chemicals is presented in Figure 6. The EU-27's biggest share in chemicals was observed in 2010 (27%). The EU-27 is decreasing its share in world sales of chemicals. The place of the EU-27 has been overtaken by China. The situation can be explained by increasing demand for chemical products worldwide. The EU, which has numerous energy crises and is engaged in helping Ukraine to fight Russia, is losing its markets for chemical products.

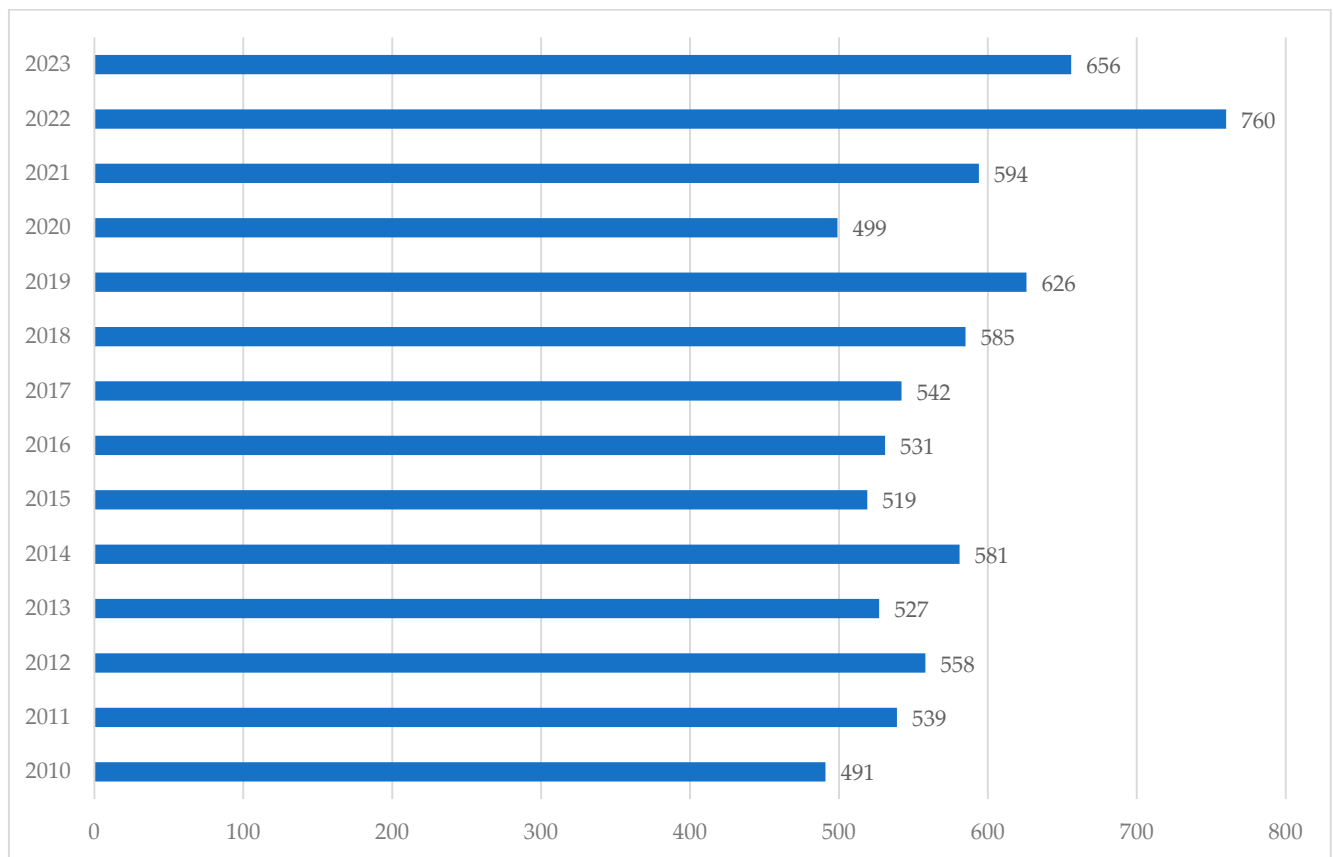


Figure 5. Sales of chemicals by EU countries [EUR mld]. Source: own calculations based on [65].

3.4. ADF Test of the Sales of Chemicals in the EU in 2004–2024

In order to analyze changes in sales of chemicals in the EU, I conducted the Augmented Dickey–Fuller Test (ADF) test (Table 6).

Table 6. ADF test of sales of chemicals in the EU.

Countries	Free Expression Test				First Differences for Free Expression Test			
	Estimated Value (a−1)	Test Stat: tau_ct(1)	Asymptomatic p-Value	Autocorrelation of First-Order Residuals	Estimated Value (a−1)	Test Stat: tau_ct(1)	Asymptomatic p-Value	Autocorrelation of First-Order Residuals
Austria	−0.155	−1.501	0.533	−0.014	−1.757	−4.749	0.000	0.001
Belgium	−0.429	−2.315	0.167	0.042	−1.783	−4.702	0.005	−0.071
Bulgaria	0.096	−0.884	0.794	−0.132	−1.849	−4.408	0.000	0.002
Croatia	−0.514	−2.809	0.056	−0.119	−1.283	−5.509	0.000	0.020
Czech Republic	−0.151	−1.102	0.717	0.003	−1.197	−6.740	0.000	0.135
Denmark	−0.024	−0.335	0.917	−0.317	−1.332	−6.013	0.000	0.105
Estonia	−0.408	−2.564	0.100	0.014	−1.644	−4.229	0.000	−0.057
Finland	−0.419	−2.377	0.148	−0.080	−2.020	−5.692	0.000	−0.185
France	−0.203	−1.325	0.620	0.053	−1.539	−4.055	0.001	0.041
Germany	−0.181	−1.437	0.565	−0.072	−1.957	−4.959	0.005	−0.138
Greece	−0.014	−0.101	0.947	0.038	−0.973	−4.006	0.001	0.004
Hungary	−0.241	−1.697	0.433	0.142	−0.935	−3.883	0.002	0.011
Ireland	−0.461	−2.310	0.169	0.152	−1.020	−4.161	0.000	−0.008

Table 6. Cont.

Countries	Free Expression Test				First Differences for Free Expression Test			
	Estimated Value (a−1)	Test Stat: tau_ct(1)	Asymptomatic p-Value	Autocorrelation of First-Order Residuals	Estimated Value (a−1)	Test Stat: tau_ct(1)	Asymptomatic p-Value	Autocorrelation of First-Order Residuals
Italy	−0.493	−2.414	0.139	0.118	−1.737	−4.491	0.000	−0.177
Latvia	−0.006	−0.076	0.950	−0.070	−1.076	−4.469	0.000	−0.024
Lithuania	−0.255	−1.915	0.326	0.108	−1.723	−5.898	0.000	0.050
Luxembourg	−0.118	−1.443	0.562	−0.318	−0.467	−2.723	0.070	−0.208
Netherlands	−0.518	−2.643	0.084	0.122	−1.929	−6.060	0.000	−0.033
Poland	0.168	1.346	0.999	−0.073	−1.440	−5.565	0.000	0.029
Portugal	−0.319	−2.079	0.253	0.175	−1.962	−5.599	0.000	−0.035
Romania	−0.186	−1.265	0.648	0.169	−1.528	−4.846	0.000	0.128
Slovak Republic	−0.625	−3.366	0.012	0.015	−1.507	−4.494	0.000	−0.022
Slovenia	−0.243	−1.503	0.532	0.058	−1.447	−4.050	0.001	−0.064
Spain	−0.182	−1.225	0.642	−0.044	−1.858	−5.235	0.000	−0.032
Sweden	−0.405	−2.082	0.252	−0.183	−2.057	−5.307	0.000	−0.110

Source: own elaborations based on [64].

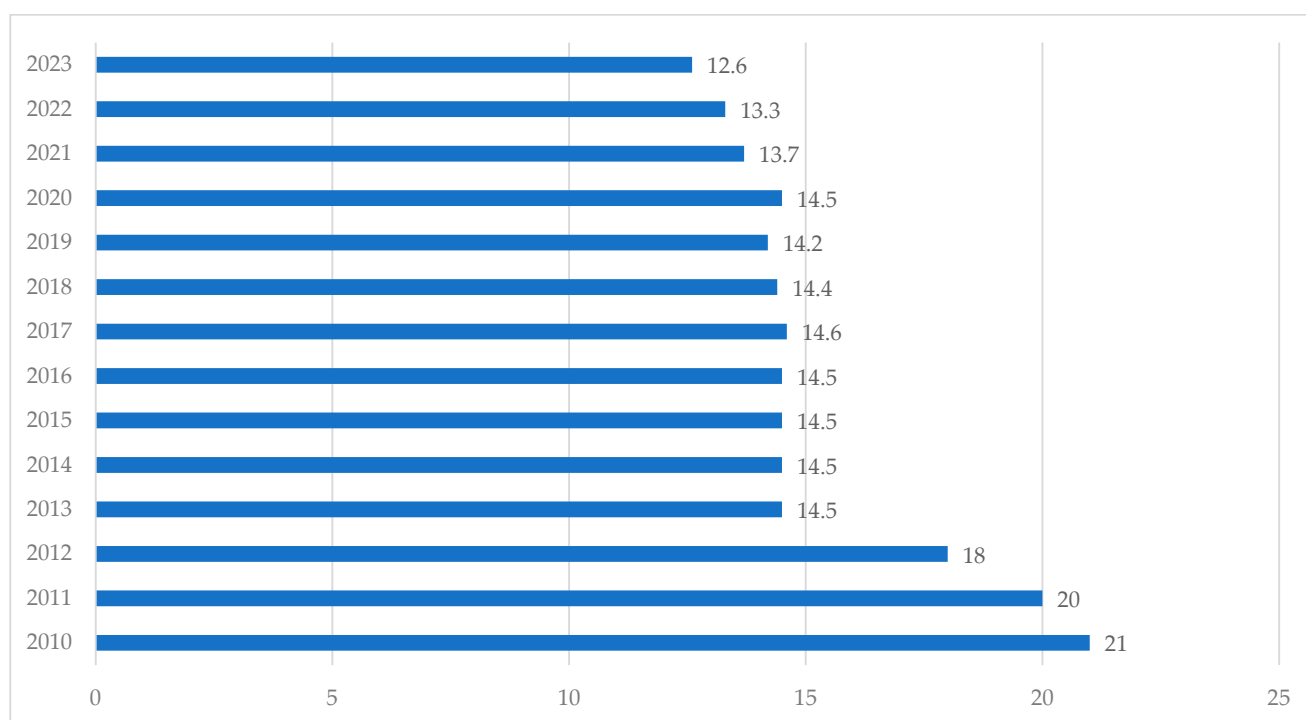


Figure 6. Share of EU-27 in the world sales of chemicals [%]. Source: own calculations based on [65].

Structural breaks are not taken into account in the traditional ADF unit root regression specification. Even asymptotically, the problem of lag selection in ADF unit root testing is crucial, since the test may not be appropriately scaled if the number of lags is not permitted to grow at a specific rate [84].

In the first step, I conducted the free expression test. Based on the result, I can conclude that the sale of chemicals in the EU countries is not stationary. The p value for all countries is high. In the next step, I calculated first differences. When analyzing the first differences for a free expression test, we can conclude that the ranks of EU countries are stationary. After that we can generate models and prepare prognoses.

3.5. Forecast of Chemicals Sales Using VAR Model

To analyze the changes in chemicals sales, the VAR model was used. This standard protocol is intended for completely specified structural VAR models. Numerous structural VAR models, nevertheless, are only partially identifiable, since only a portion of the structural shocks are recognized [85]. The VAR models have emerged as the standard method for comprehending the changes in the real oil price and its effects on the macro economy. Mainstream economists are finding it more and more challenging to comprehend the variations between different oil market models [86].

The chemical sector is developing well in the European Union. The next step was to elaborate a prognosis based on previous data. To do this, Portmanteau tests, AIC, BIC, HQC and other characteristics were evaluated. After evaluating the VAR models for sales of chemicals by EU member states, we can conclude that the data are stationary (Table 7). In this way, I can elaborate on the prognosis of sales for future years.

During the analysis the VAR model was verified positively and can be used for prognosis elaborations. The p value for F tests is generally below 0.05, which proves the importance for the models of all analyzed countries. The data proved a lack of autocorrelation of random components and proved normal distribution (Table 8).

Table 9 presents the prognosis elaborated on the VAR model, including sales of chemicals. Based on the prognosis, the sales of chemicals will increase in 2025–2029. Particular increases will be observed in Denmark, Greece, Croatia, Latvia, Lithuania, Hungary and Poland.

The prognoses are similar to other scientific elaborations showing that the worldwide chemical industry is expected to expand over the next two decades at an average yearly growth rate of 3%, primary influenced by activities in China and the Middle east, while Europe is anticipated to grow at a slightly lower rate [87,88]. In 2004, the EU, historically a frontrunner in chemical manufacturing, fell behind Asian nations in terms of production leadership [89].

The rapid progress of the chemical sector in this area has been fueled by heightened investment, both domestically and internationally, lower costs for raw materials, and more lenient environmental guidelines, especially in China and the Middle East [90]. Presently, only 24% of global chemical sales are attributed to the European chemical sector. Germany, France, Italy, and the United Kingdom contribute two-thirds of the EU's output. Among the countries most recently joining the EU, Poland stands out as the top chemical producer, holding a 2.1% share of total sales [91].

The data utilized for assessing prognoses through MAE, MAPE, and RMSE were implemented in models and future predictions. To evaluate the prognoses, Mean Absolute Error (MAE) was computed. This metric holds significant importance, as it aids in evaluating the accuracy of the prognosis. An ideal MAE value is 0, indicating no disparity between the actual and predicted values. The analysis reveals that the MAE for Luxembourg is 34.2, for Latvia is 37.4, and for Estonia is 54.2 (refer to Table 10). This analysis was conducted for the period from 2005 to 2024, as the actual value (y_i) and the predicted value ($\hat{y}_i$) were obtainable.

Table 7. VAR model of sales of chemicals.

Countries	Portmanteau Test df		AIC	BIC	HQC	Constant				Model for Sales of Chemicals			
						Coefficient	Std. Error	Student's t	p Value	Coefficient	Std. Error	Student's t	p Value
Austria	4.797	0.308	18.185	18.284	18.204	2502.81	1361.66	1.838	0.0826	0.844	0.103	8.178	0.0000
Belgium	1.632	0.803	19.801	19.900	19.820	15,390.8	6446.6	2.387	0.028	0.5709	0.185	3.091	0.006
Bulgaria	1.625	0.804	14.183	14.283	14.203	228.03	166.76	1.367	0.188	0.903	0.108	8.319	0.001
Croatia	1.922	0.750	12.159	12.259	12.179	420.49	147.43	2.852	0.0106	0.486	0.183	2.658	0.016
Czech Republic	8.929	0.063	18.306	18.405	18.325	1714.15	1195.31	1.434	0.167	0.848	0.137	6.178	0.007
Denmark	5.678	0.225	14.917	15.017	14.937	336.92	356.24	0.946	0.356	0.975	0.073	13.39	0.008
Estonia	1.398	0.844	11.538	11.639	11.557	212.43	79.378	2.676	0.015	0.592	0.159	3.721	0.0016
Finland	3.709	0.446	16.942	17.042	16.961	3215.89	1318.90	2.438	0.0253	0.580	0.176	3.287	0.0041
France	1.634	0.802	20.722	20.822	20.742	17,331.8	12,273.8	1.412	0.175	0.797	0.153	5.208	0.000
Germany	2.034	0.729	22.522	22.621	22.541	33,747.7	20,719.5	1.629	0.120	0.819	0.126	6.522	0.003
Greece	0.211	0.994	14.663	14.763	14.683	141.757	373.31	0.3797	0.708	0.986	0.141	6.965	0.006
Hungary	3.043	0.551	16.295	16.394	16.315	1375.32	724.990	1.987	0.074	0.759	0.142	5.340	0.0000
Ireland	2.951	0.566	17.971	18.071	17.990	3808.89	1674.71	2.274	0.035	0.539	0.199	2.705	0.014
Italy	2.802	0.591	20.110	20.210	20.129	26,780.1	10,959.4	2.444	0.0251	0.507	0.204	2.487	0.0229
Latvia	1.839	0.765	11.396	11.495	11.415	29.715	28.350	1.048	0.308	0.993	0.086	11.42	0.000
Lithuania	5.464	0.2429	15.619	15.719	15.6388	627.098	297.139	2.110	0.0491	0.744	0.133	5.589	0.000
Luxembourg	14.852	0.005	10.753	10.853	10.773	39.122	35.267	1.109	0.2819	0.874	0.102	8.500	0.0000
Netherlands	3.920	0.4169	20.708	20.807	20.728	26,606.4	9874.70	2.694	0.014	0.482	0.195	2.460	0.0242
Poland	4.817	0.307	18.574	18.674	18.594	−144.04	1850.75	−0.078	0.9388	1.084	0.117	9.192	0.0000
Portugal	4.324	0.364	16.092	16.192	16.111	1567.67	725.11	2.162	0.044	0.681	0.153	4.441	0.0003
Romania	4.611	0.329	14.952	15.051	14.971	571.15	409.93	1.393	0.180	0.814	0.146	5.547	0.0000
Slovak Republic	3.654	0.458	14.647	14.747	14.666	864.84	306.58	2.821	0.0113	0.564	0.161	3.503	0.0025
Slovenia	0.703	0.951	13.011	13.111	13.031	392.79	238.24	1.649	0.116	0.756	0.161	4.679	0.0002
Spain	2.778	0.5956	19.840	19.939	19.859	8385.84	6009.76	1.395	0.1799	0.8174	0.1491	5.483	0.0001
Sweden	2.295	0.681	16.673	16.772	16.692	3871.19	1778.50	2.177	0.0431	0.594	0.195	3.051	0.0069

Source: own calculations based on [64].

Table 8. Characteristics of VAR models for sales of chemicals.

Countries	Mean Arithmetic of Dependent Variable	Sum of Square Test	R-Squared Determination Coefficient	F	Autocorrelation of Rests	Standard Deviation of Dependent Variable	Standard Deviation Error	Corrected R-Square	p Value for F Test	Durbin–Watson Statistics
Austria	12,987.9	75,733,454	0.787	66.883	−0.014	4335.5	2051.2	0.776	0.0000	1.990
Belgium	34,995.7	3810	0.345	9.490	0.041	5536.2	4602.6	0.308	0.0060	1.896
Bulgaria	1515.9	13,848.82	0.794	69.212	−0.132	594.3	277.4	0.782	0.0010	2.260
Croatia	807.8	182,978	0.282	7.065	−0.119	115.8	100.8	0.242	0.0160	2.175
Czech Republic	8457.5	85,502,057	0.679	38.172	0.002	3747.4	2179.5	0.661	0.0007	1.992
Denmark	4952.4	2,884,583	0.908	179.174	−0.317	1289.6	400.3	0.904	0.0080	2.564
Estonia	501.4	98,339	0.434	13.849	0.014	95.7	73.9	0.403	0.0010	1.965
Finland	7474.3	21,863,337	0.375	10.802	−0.080	1356.9	1102.1	0.343	0.0041	2.112
France	80,692.1	9.5808	0.601	27.128	0.053	11,245.2	7296.6	0.579	0.0000	1.892
Germany	166,320.6	0.0079	0.703	42.534	−0.072	32,016.6	17,937.1	0.686	0.0030	2.129
Greece	2683.3	2,238,438	0.729	48.516	0.038	659.8	352.6	0.714	0.0060	1.909
Hungary	5127.7	11,444,321	0.613	28.513	0.141	1247.6	797.4	0.591	0.0000	1.705
Ireland	8200.9	61,180,671	0.289	7.319	0.152	2128.2	1843.6	0.249	0.0144	1.691
Italy	53,867.3	5.1908	0.255	6.183	0.118	6060.7	5372.1	0.214	0.0229	1.759
Latvia	301.6	85,275	0.878	130.415	−0.070	192.3	68.8	0.871	0.0000	2.132
Lithuania	2128.0	5,822,574	0.634	31.236	0.107	915.6	568.7	0.614	0.0000	1.746
Luxembourg	323.5	44,867	0.800	72.255	0.592	108.8	49.9	0.789	0.0000	0.671
Netherlands	50,568.7	9.4508	0.251	6.051	0.122	8150.0	7243.9	0.210	0.0242	1.754
Poland	16,078.8	1.1208	0.824	84.494	−0.509	5788.0	2492.1	0.814	0.0000	2.638
Portugal	4707.2	9,344,378	0.523	19.720	0.174	1015.2	720.5	0.496	0.0003	1.614
Romania	2788.2	2,985,609	0.631	30.765	0.169	652.5	407.3	0.610	0.0000	1.652
Slovak Republic	1903.2	2,202,965	0.405	12.269	0.080	441.6	349.8	0.372	0.0025	1.773
Slovenia	1495.8	428,890	0.548	21.895	0.058	223.7	154.3	0.524	0.0000	1.853
Spain	40,831.0	39,080	0.625	30.063	−0.044	7464.0	4692.9	0.605	0.0000	2.075
Sweden	9257.9	16,690,820	0.341	9.306	−0.183	1154.5	962.9	0.304	0.0068	2.241

Source: own calculations based on [64].

Table 9. Prognosis of sales of chemicals in Poland based on VAR model.

Country	2025		2026		2027		2028		2029	
	Prognosis	Std. Error	Prognosis	Std. Error	Prognosis	Std. Error	Prognosis	Std. Error	Prognosis	Std. Error
Austria	16,764.56	1945.94	16,667.44	2547.53	16,585.39	2901.67	16,516.06	3130.071	16,457.48	3283.42
Belgium	38,209.77	4366.4	37,207.6	5027.9	36,635.4	5225.6	36,308.7	5288.4	36,122.2	5308.7
Bulgaria	2429.55	263.14	2424.26	354.72	2419.47	414.80	2415.16	458.08	2411.25	490.63
Croatia	812.291	95.650	815.445	106.357	816.979	108.734	817.724	109.289	818.087	109.419
Czech Republic	13,638.41	2067.63	13,288.15	2711.81	12,990.89	3093.74	12,738.63	3341.86	12,524.56	3509.71
Denmark	7378.66	379.77	7535.53	530.57	7688.57	641.99	7837.88	732.48	7983.54	809.25
Estonia	538.38	70.121	531.21	81.49	526.96	85.12	524.44	86.36	522.95	86.78
Finland	7882.33	1045.55	7790.24	1208.85	7736.78	1259.09	7705.79	1275.57	7687.79	1281.07
France	93,014.54	6922.17	91,486.49	8852.78	90,268.30	9885.78	89,297.06	10,489.60	88,522.77	10,855.93
Germany	201,135.08	17,016.58	198,553.65	21,999.38	196,438.48	24,789.01	194,705.35	26,497.65	193,285.25	27,585.49
Greece	4253.30	334.55	4334.23	469.75	4413.99	571.24	4492.63	654.96	4570.13	727.13
Hungary	6385.96	756.449	6221.23	949.588	6096.23	1044.729	6001.37	1095.77	5929.39	1124.11
Ireland	8663.93	1749.01	8482.41	1987.24	8384.50	2051.37	8331.69	2069.66	8303.19	2074.95
Italy	56,583.83	5096.45	55,492.28	5715.03	54,938.39	5863.75	54,657.336	5901.440	54,514.721	5911.105
Latvia	661.367	65.297	686.735	90.0415	711.936	112.358	736.971	129.316	761.842	144.109
Lithuania	2634.64	539.56	2589.51	672.79	2555.89	736.38	2530.85	769.398	2512.20	787.119
Luxembourg	434.40	47.364	418.83	62.908	405.22	72.574	393.32	79.168	382.92	83.857
Netherlands	53,414.83	6872.07	52,352.30	7628.69	51,840.17	7793.64	51,593.32	7831.86	51,474.34	7840.64
Poland	33,381.108	2364.17	36,043.11	3486.80	38,928.89	4458.36	42,057.24	5380.38	45,448.56	6293.58
Portugal	4975.47	683.53	4956.63	827.03	4943.79	885.75	4935.05	911.70	4929.09	923.50
Romania	3468.85	386.37	3395.63	498.25	3336.01	560.239	3287.46	597.80	3247.93	621.459
Slovak Republic	2061.08	331.89	2028.49	381.13	2010.08	395.54	1999.69	400.02	1993.83	401.44
Slovenia	1820.49	146.44	1770.59	183.65	1732.83	201.90	1704.24	211.64	1682.61	217.65
Spain	51,799.88	4452.10	50,725.76	5750.12	49,847.79	6473.89	49,130.17	6915.36	48,543.60	7195.23
Sweden	10,545.39	913.53	10,139.35	1062.73	9897.99	1110.66	9754.53	1127.11	9669.26	1132.86

Source: own calculations based on [64].

Table 10. Evaluating prognoses of sales of chemicals in the EU in 2005–2024, based on the VAR model.

EU Countries	MAE for VAR Prognosis for 2005–2024	MAPE for VAR Prognosis for 2005–2024 (%)	RMSE for VAR Prognosis for 2005–2024
Austria	1423.7	11.0	192,460.7
Belgium	2679.6	7.6	6,577,246.5
Bulgaria	156.3	9.5	26,457.0
Croatia	66.9	7.9	4404.1
Czech Republic	1229.6	14.1	141,586.1
Denmark	305.2	6.8	101.9
Estonia	54.2	11.1	274.2
Finland	736.0	9.4	65,171.3
France	5479.9	6.8	5,845,338.4
Germany	10,288.6	6.0	129,347,209.1
Greece	232.5	8.7	1242.1
Hungary	533.5	10.7	26,790.5
Ireland	11,157.3	17.0	280,317.7
Italy	3655.3	6.9	2,624,494.9
Latvia	37.4	16.4	2016.3
Lithuania	317.5	18.2	109,259.7
Luxembourg	34.2	12.0	559.9
Netherlands	4591.6	8.9	13,734,853.6
Poland	1701.7	10.0	906,680.5
Portugal	441.5	9.0	246,113.2
Romania	273.6	9.5	12,256.6
Slovak Republic	252.2	13.1	39,960.4
Slovenia	104.7	7.1	2574.5
Spain	2990.0	7.1	3,785,141
Sweden	623.6	6.8	4655.7

Source: our own calculations based on [64].

Mean Absolute Percentage Error (MAPE) was the second metric used to assess prognosis. Based on [92,93], the value of MAPE was performed:

$MAPE \leq 10\%$ —High;

$10\% < MAPE \leq 20\%$ —Good;

$20\% < MAPE \leq 50\%$ —Reasonable;

$MAPE > 50\%$ —Low.

Germany (6.0%), Sweden, Denmark, France (6.8%) and Italy (6.9%) had the best prognoses, according to the findings. Lithuania (18.2%), Ireland (17.05), and Latvia (16.4%) had the highest MAPE percentages.

Root Mean Square Error (RMSE) was the last metric used to assess our prognoses. According to our interpretation of the indicators, higher values indicate greater differences between predictions and actual values, while lower values accurately predict the actual data. Denmark and Estonia were able to obtain a lower RMSE score. In the cases of Germany and the Netherlands, the highest RMSE was attained.

3.6. Financial Results for the Chemical Industry in Poland

The financial results achieved by companies specializing in the production of chemicals and chemical products was PLN 9.99 billion in 2022, compared to PLN 8.16 billion in 2021 (Table 11).

Table 11. Production sales for Polish chemical industry in the period January–September 2019, 2020, and 2021 [PLN million].

Production	2019	2020	2021
Production of rubber and plastic products	75.31	73.08	92.24
Production of coke and refined petroleum products	66.67	48.12	66.86
Production of pharmaceutical products	8.45	9.43	9.84
Production of chemicals and chemical products	51.76	49.63	61.96
Total chemical industry	202.19	180.26	230.9
Total industry	1138.6	1093.9	1337.51

Source: own calculations based on [48].

The financial results for producers of plastics and rubber products was PLN 9.56 billion, compared to PLN 8.68 billion in 2021. The increase in profits was very noticeable. This increase in profit was visible in the accounts of individual companies, where the scale of growth compared to the previous year was often impressive: for the CIECH Group it was 100%; PCC Rokita—61.7%; ANWIL—85%; Basel Orlen Polyolefins—25%; and Selena—9.1%. However, Grupa Azoty recorded a loss compared to 2021, a decrease of 7.9%, as did Synthos, a decrease of 16.4%.

The production of rubber and plastic products is the most promising in the Polish chemical industry. It recorded an increase from PLN 75.31 million in 2019 to PLN 92.24 million in 2021 (22.5% increase). The production of coke and refined petroleum products was at a stable level of PLN 66.86 million in 2021. The production of pharmaceutical products also increased in 2019–2021 (16.5%). The sales of chemicals and chemical products increased by 19.7% in 2019–2021.

4. Discussion

The chemical sector is an important manufacturing division in Western Europe and the US. In addition to the products from the chemical sector being commonly utilized in homes or for additional manufacturing, the chemical sector also plays a significant role as an employer [94]. Moreover, advancing nations can also have a significant impact on the worldwide chemical sector, particularly because they serve as host nations for pollution-intensive processing [95].

Data from the Polish Chamber of Chemical Industry (PIPC, <https://pipc.org.pl/wp-content/uploads/2024/11/PiPC-Raport-Ekonomiczny-2024-online.pdf> (accessed on 18 March 2026). [78] and the Main Statistical Office (GUS <https://www.products.pcc.edu.pl/blog/przemysl-chemiczny-w-polsce-jakie-nadchodz%C4%85-zmiany/> (accessed on 24 March 2026). [63] confirmed that the worth of the chemical industry's sales rose from PLN 113.6 billion in 2016 to PLN 442.4 billion in 2023. In 2023, the production of the chemical industry in overall sales reached 16.7% of the total industry. Significant investments are crucial for the growth of the chemical sector. The number of investments surged by nearly

207% from 2005 to 2022. The trade balance for chemicals underwent significant shift since recent times and continues to decline.

Poland's chemical sector has seen significant developments over the past 20 years. Poland's negative chemical trade balance increased from −3713 EUR mln in 2004 to −8806 EUR mln in 2024 (a 137% increase in negative trade balance). This is because imports were greater than exports. Total exports rose by 620% and total imports by 220% between 2004 and 2024. Additionally, consumption rose by 221%, from 12,360 EUR mln in 2004 to 39,731 EUR mln in 2024. Moreover, capital spending rose by 320%, from 501 EUR mln in 2004 to 2103 EUR mln in 2024. Poland's chemical sector is growing as a result of rising product demand. Between 2004 and 2024, employment rose by 28% from 77 thousand to 99 thousand. Increased employment and overall technological advancement led to a 38.4% rise in labor productivity.

The overall chemical industry in Poland increased its profits from 202.9 EUR mln in 2019 to 230.9 EUR mln in 2021. The improvement in the economic situation was particularly seen in the production of rubber and plastic products, which increased from 75.31 EUR mln in 2019 to 92.24 EUR mln in 2021. Such enterprises as the CIECG Group, PCC Rokita, ANWIL, Basel Orlen Polyolefins and Selena improved their economic situations in 2021 compared to 2019. Others, such as Grupa Azoty and Synthos reduced their earnings in the period analyzed. Other areas such as the production of coke and refined petroleum products increased their incomes from 66.67 EUR mln to 66.86 EUR mln. Pharmaceutical product production rose by 16% between 2019 and 2021.

The highest output of chemicals has been noted in plastics (3409 million tons), technical grade nitric acid (2.03 million tons), anhydrous ammonia (2.106 million tons), nitrogen fertilizers (1.748 million tons), and paints and varnishes (1.367 million tons). The next category of products with significant production levels comprised styrene polymers (1692 thousand tons), ethylene (459 thousand tons), and propylene (one thousand tons).

The chemical industry has both a negative impact on the environment and opportunities to contribute to its protection. The pursuit of sustainable development and responsible resource management is crucial to maximizing benefits and minimizing risks.

The chemical industry poses serious environmental threats:

1. **Pollution:** Manufacturing processes can lead to the emission of harmful substances into the air, water, and soil. These pollutants can negatively impact human health and ecosystems.
2. **Chemical Waste:** The production of chemicals generates waste that can be hazardous if not properly managed. Storage and disposal of this waste pose significant challenges.
3. **Climate Change:** Some industrial processes contribute to greenhouse gas emissions, contributing to global warming and climate change.

The production of chemicals creates the following opportunities:

1. **Eco-innovation:** The chemical industry has the potential to develop more sustainable and eco-friendly products, such as biofuels, biodegradable materials, and bio-based chemicals.
2. **Recycling and the circular economy:** Many companies are striving to implement the principles of the circular economy, which allow for the reuse of raw materials and the reduction of waste.
3. **Clean production technologies:** The introduction of modern technologies can reduce energy and raw material consumption and minimize emissions, thus contributing to environmental protection.

One of the most significant problems with chemicals is the production of waste which is noxious. That is why in the preparation, trade and use of products from the chemical industry, waste utilization technologies should be the aim of chemical waste management [96]. Countries in the EU have had to elaborate plans for chemical waste management. Poland, for example, elaborated the national Waste Management Plan, which aims to reduce waste. The inorganic chemical industry in Poland is developing well, which has an impact on the whole economy [97]. The European Commission has also produced a document which should be the Strategy of European Union concerning waste management, including chemical waste, which should lead to sustainable development [98].

An important aspect of the development of the chemical industry is recognizing and overcoming barriers. The literature surrounding innovation identifies no fewer than six barriers that are typically encountered: organizational, cultural, economic and financial, market-related, regulatory, and path-dependence issues. Viewed from a policy standpoint, this suggests that initiatives aimed at fostering innovation by overcoming these barriers are anticipated to benefit the advancement of green chemistry positively [18].

The chemical industry should incorporate strategies aimed at achieving net-zero greenhouse gas (GHG) emissions by 2050. These strategies encompass the use of renewable energy options, enhancing efficiency, and transitioning to new, low-carbon manufacturing methods [99]. An important role will be played by biomass feedstock use in the chemical sector. Findings indicate that the chemical sector may emerge as the leading consumer of e-hydrogen, with energy requirements estimated to be between 16,100 and 23,100 TWh_{H2}, LHV by the year 2050. A significant proportion of electricity-derived chemicals (e-chemicals) have demonstrated minimal annual emissions, implying that transitioning to an e-chemical approach could represent the most cost-effective strategy for reducing fossil fuel dependence in the worldwide chemical industry [100].

5. Conclusions

In 2023, the chemical industry in Poland employed 343,000 people. The chemical industry provides jobs in production, research, logistics, sales, and administration. Nowadays, the importance of green chemistry is increasing. The main principles of green chemistry include prevention of waste, atomic economy, reductions in hazardous chemicals, designing safer chemicals, designing for energy efficiency and others [101].

Current chemistry is becoming eco-friendly and bio-refineries draw motivation from this approach and have shifted towards industrial symbiosis with regions. The foundation of eco-friendly chemistry and its uses promotes the rapid transformation of energy. Eco-friendly chemistry is rooted in industrial ecology, which indicates that the pursuit of eco-efficiency appears to be the path to sustainability [102].

The chemical sector is one of the largest industries in many countries. The EU accounts for 22.2% of global sales. The chemical sector contributes significantly to Poland's GDP, accounting for 18.4% of industrial production in 2023.

In Poland, chemical products accounted for over EUR40 billion in exports in 2022. Poland specializes in the export of artificial fertilizers [Grupa Azoty], plastics [Synthos], medicines and pharmaceuticals [Polpharma], and fuels [Orlen].

The Polish chemical sector has a challenge in developing modern products and innovations [82]. As the economy becomes more filled with knowledge-driven processes, its profitability and productivity increase [82,87]. The most important challenge for the chemical sector was to introduce contemporary environmental management strategies, which entails embracing sustainable development principles, obtaining ecological certifications, adopting safer and cleaner technologies, and providing comprehensive information to the public [82,103].

Sustainability is crucial for the chemical sector because of the significant challenges faced when entering the industry, the repetitive patterns of growth within the field, and the current competitive landscape [82,104].

Based on the data and my own research, I have confirmed the hypothesis that the development of the chemical industry in the EU is losing its worldwide position due to stronger development in this sector in China and other Asian countries.

The chemical industry in China and other Asian countries is developing faster than in the EU-27. The reasons for this are numerous. First, China is the recipient of cheap crude oil, petrol and natural gas from Iran, which is located not far away. Second, the EU countries have not conducted investment on a large scale in the chemical industry.

The index of production within the chemical sector reveals the variations that occurred from 2004 to 2024 in the world. Asia, particularly China, stands out as the largest beneficiary of chemical sales. Conversely, the EU has experienced the most significant decline in chemical industry sales. The US and the entire American continent maintain a consistent stance, though they have seen a slight decrease in their market share, particularly in recent years.

The chemical sector within the EU experienced growth from 2011 to 2021. Notably, a substantial rise occurred between 2020 and 2021, during which the output surged from EUR 786.9 billion to EUR 593.7 billion. Nevertheless, production within the chemical sector is influenced by the overall economic conditions of the EU. For instance, the COVID-19 pandemic adversely affected production in the chemical sector in 2020. The lockdown measures implemented in numerous nations also led to a reduction in production. In subsequent years, a decline in production was noted, with figures reported at 596.95 billion EUR in 2022, 510.58 billion EUR in 2023, and 498.71 billion EUR in 2024.

The forecast detailed in the VAR model pertains to the chemical sales sector. It suggests that chemical sales are projected to rise between 2025 and 2029. Notable growth is expected in countries such as Denmark, Greece, Croatia, Latvia, Lithuania, Hungary, and Poland.

This forecast aligns with findings from other research indicating that the global chemical market is likely to grow over the next twenty years at an annual average rate of 3%, primarily driven by developments in China and the Middle East, while growth in Europe is expected to occur at a somewhat lower rate. Currently, the European chemical industry accounts for just 24% of world wide chemical sales. Germany, France, Italy, and the United Kingdom together represent two-thirds of the EU's production.

The creation of rubber and plastic items stands out as the most favorable sector in Polish Chemistry. It showed a rise from PLN 75.31 million in 2019 to PLN 92.24 million in 2021, marking a growth of 22.5%. The output of coke and processed petroleum goods remained steady at PLN 66.86 million in 2021. Additionally, the output of pharmaceutical goods witnessed a growth during the period of 2019 to 2021, increasing by 16.5%. The sales of chemicals and related products grew by 19.7% from 2019 to 2021.

The development of the chemical sector in Poland and other countries of the EU is strongly linked to other sectors such as biofuels; for example, biodiesel and bioethanol. Bioethanol is a type of biofuel in liquid form that is created from multiple biomass origins using various conversion methods. It is not as harmful as gasoline and can be mixed conveniently with standard fuels, which makes it a popular supplement that enhances ecological sustainability [105].

The development of the chemical industry in Poland has a future because the economy is based on coal. Poland is in a unique situation in the EU because it still relies on coal, but will have to transform its energy sector to RES and nuclear [106,107]. Nuclear power facilities are less harmful to the environment than fossil fuels. This aids in maintaining

the health of the environment and reducing global warming. Moreover, nuclear power facilities have the capacity to generate substantial quantities of electricity [108,109]. These changes will be possible only with the help of the chemical industry.

Globally, the chemical sector faces significant obstacles. Production has multiplied by fifty since 1950 and is expected to keep rising, especially in Asia. It is one of the sectors that uses the greatest amounts of energy and resources, thereby increasing greenhouse gas emissions and depleting limited resources. This development goes beyond the limits of the Earth and necessitates a long-term change in the sector [110].

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
CSRD	Corporate sustainability reporting directive
EU	European Union
EUR	Euros
ESRS	European Sustainable Reporting Standards
GDP	Gross Domestic Product
GUS	Central Statistical Office
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MWh	Mega Watt hour
PIPC	Polish Chamber of Chemical Industry
PLN	Polish zloty
Q	Quarter
RMSE	Root Mean Square Error
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
USA	United States of America

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