
New Vision for Energy Consumption: A Change in Polish Chemical Industry

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Abstract:

Purpose: The study examines the change in energy consumption in Polish chemical industry.

Design/Methodology/Approach: The research underlines the necessity for decentralized energy systems that integrate diverse technologies, including wind, solar, and biomass, to enhance energy efficiency and reduce carbon emissions in chemical industry.

Findings: The findings reveal that many companies are motivated by regulatory pressures and competitive necessities to embrace sustainable practices, despite facing organizational and financial constraints. The study concludes that the implementation of a circular economy and improved resource management, including pollution control and lifecycle assessments, is essential for achieving sustainability goals in the sector, as these measures can effectively mitigate environmental impacts and foster innovation within the industry.

Practical Implications: It links the energy consumption and industry efforts to implement sustainable development policies in Poland, highlighting the perspectives of entrepreneurs on operational changes.

Originality/Value: It emphasizes the transition towards renewable energy and the adoption of practices such as electrosynthesis to minimize waste generation by utilizing electrons instead of stoichiometric reagents, thereby significantly reducing waste streams.

Keywords: Energy consumption, chemical industry, Poland, energy efficiency, industrial transformation.

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1. Introduction

The chemical industry plays a crucial role in the economy of Poland and the European Union, contributing significantly to GDP growth and employment. However, the increasing emphasis on sustainability requires profound transformation across the sector, as companies implement new practices aligned with environmental and social objectives.

According to data from Statistics Poland, in 2023 the chemical industry accounted for 4.84% of total sold production value, while its productivity was notably higher than in the industrial sector overall. The value of sold production per employee reached PLN 1,172,227.8 in the chemical industry, compared to PLN 861,468.5 for industry as a whole.

At the same time, the chemical industry remains Poland's main industrial energy consumer, responsible for 13.03% of total industrial electricity consumption (6,885 GWh) (Statistics Poland, 2024).

These figures underline that the chemical sector must be regarded as a key branch supporting Poland's sustainable economic development and a central actor in ensuring the green transformation of national industry.

The ongoing transition toward sustainability has already produced measurable results. In 2013, the chemical industry consumed 7,206 GWh of electricity (Statistics Poland, 2015); consumption increased to 7,884 GWh in 2018 but subsequently declined to 6,885 GWh in 2023 (Statistics Poland, 2024).

The reduction of energy use in such a vital industrial sector provides a foundation for Poland's future economic growth. Our research shows that top managers in the energy sector recognize the importance of reducing energy consumption—both for the success of the European Green Deal and for enhancing the competitiveness of the Polish chemical industry.

2. Literature Review

Sustainable development is commonly described as development for the future. According to the definition adopted by the United Nations (UN) and derived from the 1987 report of the World Commission on Environment and Development, it is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Achieving this goal requires integrating three interdependent dimensions: economic growth, social inclusion, and environmental protection (Sustainable Development and Sustainable Development Goals).

Initially, sustainable development was understood primarily as minimizing the impact of economic activity on the natural environment (Mohammadzadeh *et al.*, 2024). Over time, the concept has evolved to encompass multiple dimensions. Today, it represents a balanced approach that gives equal weight to ecological responsibility, economic growth, and social progress. Sustainable development is no longer limited to specific environmental actions; it has become a horizontal principle influencing all sectors of the global economy and shaping public policy at international, national, and local levels.

In Poland, the principle of sustainable development has been granted the status of constitutional law. Article 5 of the Constitution of the Republic of Poland states: “The Republic of Poland safeguards the independence and integrity of its territory, ensures freedoms and rights of individuals and citizens, protects the national heritage, and ensures environmental protection, adhering to the principle of sustainable development” (Republic of Poland, 1997; Niemiec *et al.*, 2024).

The European Union has established a comprehensive policy framework for sustainable development that strongly influences the actions of member states, including Poland. The European Green Deal, published in 2019, sets out a roadmap for transforming the EU into a modern, resource-efficient, and competitive economy. Its over-arching goal is to make Europe the first climate-neutral continent while supporting post-pandemic economic recovery.

Key principles of the European Green Deal include:

- decoupling economic growth from resource use,
- ensuring that all regions and stakeholders contribute to shared sustainability goals.

The Green Deal directly affects all industrial sectors within EU economies. The chemical sector, as a cornerstone of Europe’s sustainable transition, has been given special attention through the EU Chemicals Strategy for Sustainability, adopted by the European Commission on 14 October 2020. This strategy aims to stimulate innovation in safe and sustainable chemicals and to enhance protection of people and the environment from hazardous substances (European Commission, 2020).

The document emphasizes the positive and enabling role of chemistry in supporting both environmental and societal goals: “The fundamental importance of chemicals for human well-being and for the ecological and digital transformation of the Europe-an economy and society has been fully recognized.” (European Commission, 2020).

Policies promoting sustainability in the chemical industry seek to balance economic performance, environmental protection, and social responsibility. Companies implement strategies to minimize their environmental footprint while fostering innovation and responsible business practices. The main directions include:

- Reduction of emissions and pollutants: limiting greenhouse gases and hazardous substances through energy efficiency, renewable sources, and carbon-capture technologies;
- Resource efficiency: increasing the use of renewable raw materials, advancing recycling and material recovery;
- Green chemistry: designing safer products and developing cleaner processes that minimize waste and energy use;
- Renewable energy: expanding the use of solar, wind, hydro, and bioenergy in industrial operations;
- Corporate social responsibility: ensuring worker safety, promoting community engagement, and supporting education and sustainability projects (European Commission, 2019)

Globally, the chemical industry is the third-largest industrial source of greenhouse gas emissions. Growing demand for chemical products underscores the urgency of developing sustainable production pathways (Mallapragada *et al.*, 2022).

Expanding the share of renewable electricity in chemical production is crucial for decarbonization and CO₂-emission reduction, especially for high-impact chemicals such as ammonia, ethylene, propylene, methanol, and BTX. Moreover, energy carriers such as methanol or ammonia offer potential for renewable-energy storage and enhanced energy efficiency (Xia, Overa and Jiao, 2022)

One promising avenue is electrosynthesis, which can substantially reduce emissions by replacing fossil fuels with renewable electricity. It employs electrons instead of stoichiometric reagents, minimizing waste and improving process efficiency. When powered by renewable energy, electrosynthesis can even yield net-negative CO₂ balances, contributing to carbon sequestration and mitigating environmental impacts. (Biddinger and Modestino, 2020)

Comprehensive decarbonization requires an integrated approach across electricity generation, transmission, buildings, transportation, and industry (De Luna *et al.*, 2019, Davis *et al.*, 2018) Three complementary areas can be identified (Waisman *et al.*, 2019):

- Decarbonizing power generation — replacing fossil fuels with zero-emission sources such as wind, solar, hydro, geothermal, and tidal energy, while using carbon capture and storage, smart grids, and long-distance transmission to address intermittency and improve efficiency;
- Enhancing energy efficiency — improving end-use applications across transport, buildings, industries, and households (Williams *et al.*, 2012);
- Expanding sustainable bioenergy — using biofuels and biomass for clean thermal energy in ways that respect food security, biodiversity, and other sustainability goals.

Achieving the Sustainable Development Goals also requires pollution management and the implementation of circular-economy principles. Efficient water and waste management and lifecycle-based product design are central to resource optimization and pollution reduction (Searchinger *et al.*, 2018, Kümmerer *et al.*, 2015)

The circular economy maximizes the value of products and materials for as long as possible, eliminating waste and conserving resources. It closes the product life cycle by promoting reuse, recovery, and recycling, including internal recycling within production chains. Effective design ensures minimal environmental impact throughout a product's lifespan and facilitates maintenance, reuse, refurbishment, and recycling (Wiedmann *et al.*, 2015, Adamczyk, 2016, Foltynowicz and Stróżyk, 2015, Tundys, 2015).

For the circular economy to advance sustainable development, its three pillars—state, enterprises, and society—must cooperate effectively. EU member states are obliged to transpose relevant directives, communications, and strategies into national legislation to operationalize these principles.

At the enterprise level, sustainability can be supported through Integrated Management Systems (IMS), Cleaner Production (CP), Environmental Technology Verification (ETV), and the 5Rs approach (Reduce, Reuse, Recycle, Recover, Renew). These frameworks promote clean production, industrial symbiosis, and cost minimization. Importantly, many cleaner-technology investments are cost-effective, as even minor process improvements can significantly reduce waste and energy or water consumption. (Zarębska and Joachimiak-Lechman, 2016).

Public awareness and environmental education play an equally important role. By choosing environmentally responsible products and companies, consumers actively contribute to circular-economy processes. Increased waste recovery, sorting, and recycling enhance resource efficiency and reduce landfill waste, turning waste into valuable secondary raw materials (Polak *et al.*, 2025).

Because the chemical industry involves high risks, substantial pollution, and high productivity, it requires systematic and sustainability-oriented supply-chain management. Suppliers are essential partners in achieving social, environmental, and economic goals.

However, research integrating these dimensions in supplier evaluation remains limited, pointing to the need for holistic frameworks for sustainable supplier selection (Cindrić, Dujmović, and Blažević, 2025).

3. Research Methodology

The research employed a mixed-methods design combining quantitative and qualitative approaches. The study consisted of two major components:

- Statistical analysis of energy consumption in the Polish chemical industry (2010–2023),
- Empirical research based on focus group interviews (FGI) and an online survey (CAWI).

3.1 Statistical Analysis

The first stage involved analysing statistical data on energy consumption in the Polish chemical industry. The data set covered the years 2010–2023, which enabled the observation of long-term trends.

A methodological limitation arises from the change in national reporting methods between 2010 and 2012, which slightly affects comparability. The data were primarily obtained from Statistics Poland (GUS) and complemented with Eurostat to provide a broader EU perspective.

The analysis relied on descriptive statistics, designed to present a general picture of energy consumption dynamics in the Polish chemical industry over the past decade.

3.2 Empirical Research

The second stage comprised two sub-phases:

- Stage 1: qualitative research through focus group interviews (FGI), and
- Stage 2: a quantitative survey conducted using the CAWI (Computer-Assisted Web Interview) technique.

Each stage corresponded to specific research objectives and sub-objectives.

Focus group interviews:

The FGI stage aimed to:

- identify areas of key interest for sector representatives;
- determine the appropriate level of detail for survey questions related to awareness of sustainable development;
- explore additional sector-specific issues.

The focus group interviews were held between November and December 2021. Sessions took place on 29 November (hybrid, Kraków iLab), 2 December (in person, Kędzierzyn-Koźle), and 16 December (online).

A total of 21 participants took part across the three sessions, representing a range of stakeholders in the chemical sector — including company executives, representatives of educational institutions and universities, research institutes, and industry organizations. Each session was moderated and observed.

The interviews were recorded (audio for the in-person session; audio and video for hybrid and remote formats) in compliance with ethical and data-protection standards. Participants were informed about the recording and assured of anonymity.

Most participants were based in southern Poland, particularly in the Małopolska and Opolskie regions.

The data collected during the interviews were analysed using MAXQDA Analytics Pro software for qualitative data analysis. Coding followed the structure of the final report, organizing insights into three analytical categories:

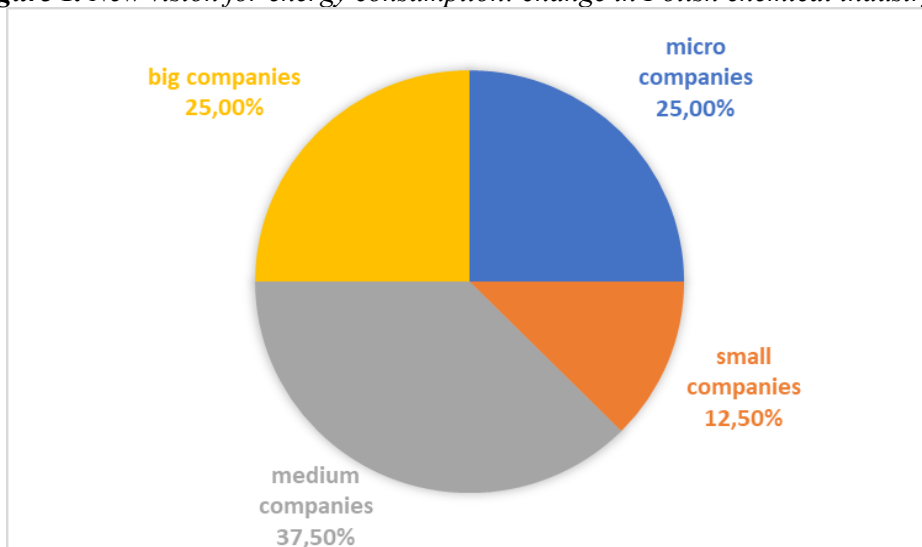
1. Sustainable today — current sustainability actions;
2. Sustainable tomorrow — future plans and concerns;
3. Green competencies — existing and emerging skills needs in the labour market and education.

Online survey (CAWI):

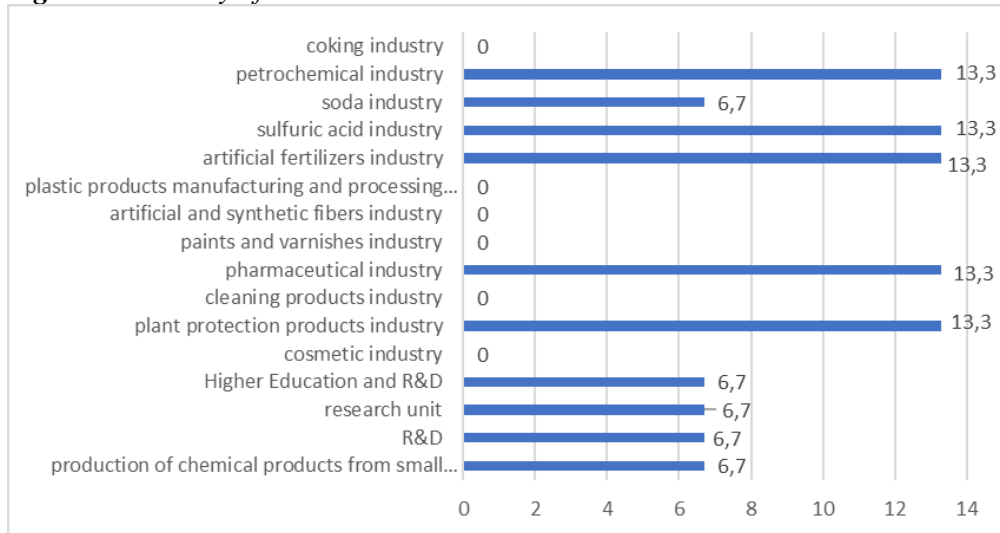
The CAWI survey was conducted between December 2021 and April 2022. The invitation to participate was sent twice (in December 2021 and again at the turn of January and February 2022) to over 400 entities in the sector. Ultimately, 18 representatives of chemical-industry enterprises completed the survey.

The survey sample consisted solely of entrepreneurs representing micro, small, medium, and large enterprises (Figure 1). These firms reflected the diversity of industries within the chemical sector (Figure 2).

Figure 1. New vision for energy consumption: change in Polish chemical industry



Source: Own study.

Figure 2. Diversity of industries within the chemical sector

Source: Own study.

The survey focused on the implementation of sustainable development policies, particularly how companies translate public policy frameworks into practical actions, including those supported by public funding.

Summary of methodological rationale:

The combination of FGI and CAWI methods enabled the triangulation of perspectives — qualitative insights into the context and challenges faced by the chemical sector, and quantitative data illustrating broader trends. The mixed-methods approach thus allowed for both depth and generalizability in analysing the sector's adaptation to sustainable development goals.

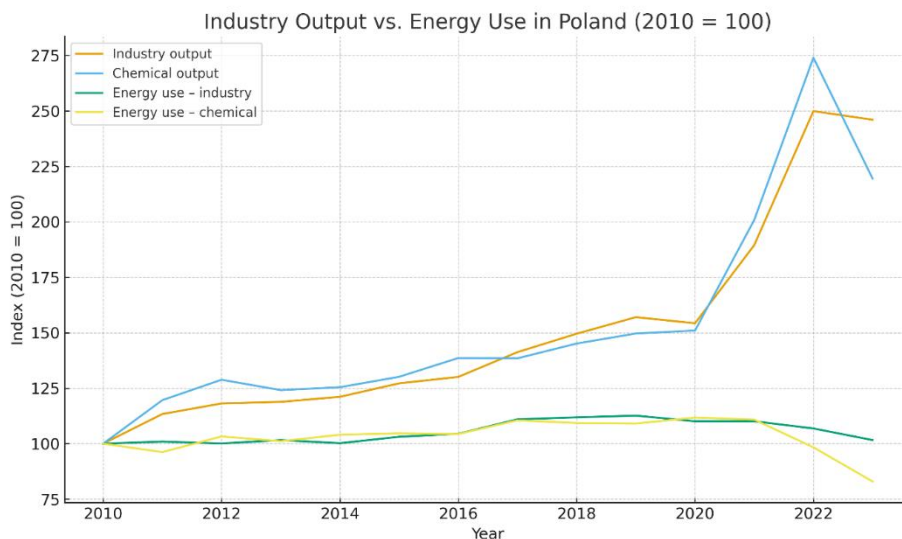
4. Research Results

4.1 Energy Consumption in Chemical Industry

Statistical data on the Polish chemical industry reveal two major, simultaneous trends over the analysed period (2010–2023): a significant increase in production value and a notable decrease in energy consumption.

Between 2010 and 2023, the value of sold production in the chemical industry increased by PLN 13,819.5 million, while total energy consumption declined by approximately 3,000 TJ. These opposing trends — growing industrial output and falling energy use — are illustrated in Figure 3.

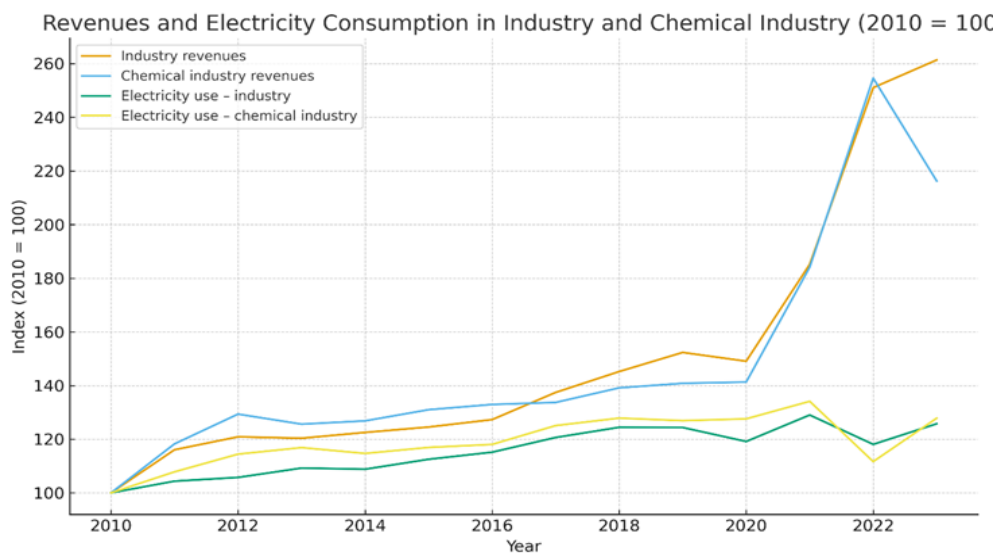
Figure 3. Companies participating in the study by sector of chemical industry.



Source: Own study.

Similarly, Figure 4 compares the revenues and electricity consumption of the chemical industry and total industry in Poland. The data show that revenue growth in the chemical sector closely mirrored the general trend for Polish industry. Only in the final year of the analysed period did general industry slightly outperform the chemical industry in revenue growth.

Figure 4. Revenues and electricity consumption in industry and chemical industry in Poland.



Source: Own study.

While revenue increased markedly, electricity use grew much more modestly. Over the decade, industrial revenues more than doubled ($\approx +150\%$), whereas electricity consumption rose by only about 50%.

Table 1 presents the main indicators of the Polish chemical industry and the broader industrial sector between 2010 and 2023. The data indicate that the chemical industry's contribution to total industrial value added remained stable at around 3%, con-firming that the sector's growth was steady and not driven by short-term fluctuations.

Table 1. Polish chemical industry and industry economic condition in the years 2010 – 2023.

Year	Output of chemical industry (in million PLN)	Output of industry total (in million PLN)	Gross value added of chemical industry (in million PLN)	Gross value added of industry total (in million PLN)	Revenues of chemical industry (in million PLN)	Revenues of industry total (in million PLN)
2010	47130,1	1067640	11708,6	320373	49016,8	1144854
2011	56375,4	1210271	12580,5	332498,5	57965,2	1328754
2012	60713,9	1261200	13335,5	361295,7	63404,1	1384032
2013	59124,7	1293148	14016	386652,4	62167,4	1402686
2014	58508,4	1268787	13154	366052,9	61572,2	1378047
2015	61336,7	1357912	16272,6	419211,7	64209,5	1425763
2016	65326,4	1389054	18248,8	435749,7	65167,7	1457385
2017	65266	1508227	16107,8	443014,8	65536,3	1573406
2018	68405,1	1596824	15574,3	463399,5	68201,8	1662465
2019	70537,5	1676495	17261,1	491640,3	69032,1	1744044
2020	71168	1647217	18298,8	506793,3	69260,5	1706646
2021	94660	2023129	21086,8	573390,7	90243,4	2120129
2022	129144,7	2668387	25591,7	723767,8	124793	2874019
2023	103451,2	2626957	25528,1	805413	105985	2992196

Source: Own study.

Table 2 summarizes energy consumption patterns for both the chemical industry and total industry. The figures show that in 2010 the chemical industry accounted for over 16% of total industrial energy use and about 9% of total electricity consumption. By 2023, these shares had decreased to 13.5% and 9%, respectively.

Table 2. Energy Consumption in Polish chemical industry and industry total in the years 2010-2023.

Year	Consumption of electricity in chemical industry (in GWh)	Consumption of electricity in industry total (in GWh)	Direct consumption of energy in chemical industry (in TJ)	Direct consumption of energy in industry total (in TJ)
2010	6166	69289	179635	1090480
2011	6649	72312	172793	1100629
2012	7056	73275	185488	1091401

2013	7072	75395	186862	1092794
2014	7206	75692	181644	1108014
2015	7210	77961	187967	1124276
2016	7279	79790	187404	1138892
2017	7712	83589	198563	1210131
2018	7884	86219	196351	1219849
2019	7825	86173	195911	1228293
2020	7867	82557	200798	1200573
2021	8270	89395	199122	1200564
2022	6885	81816	176662	1165245
2023	7883	87137	148997	1108127

Source: *Own study.*

When expressed as an index (2010 = 100), the data reveal a strong increase in industrial output with almost no rise in energy consumption, demonstrating a relative decoupling between economic growth and energy use (Table 3).

Table 3. *Trends in the chemical industry growth and energy consumption.*

Indicator	2010	2023	Change (%)
Total industrial output	100	246	+146%
Chemical industry output	100	220	+120%
Total industrial energy use	100	102	≈ 0%
Chemical industry energy use	100	83	-17%

Source: *Own study.*

This decoupling reflects substantial improvements in energy efficiency, driven by process modernization, fuel substitution, automation, and shifts toward higher value-added production. The negative correlation between output and energy use in the chemical industry suggests that production expansion has been achieved alongside real reductions in energy demand.

A correlation analysis (Table 4) between total industrial output, chemical-industry output, and energy use confirms that industrial growth in recent years has not been accompanied by proportional increases in energy consumption. Instead, progress has been achieved through technological upgrades, process optimization, and structural transformation within production systems.

Table 4. *Correlations between selected indicators*

Relationship	Pearson correlation coefficient	Interpretation
Total output ↔ Chemical output	0.97	very strong positive correlation – the chemical sector grows in line with the overall industrial economy
Total output ↔ Total energy use	0.31	weak correlation – output increases much faster than energy consumption
Chemical output ↔	-0.29	slightly negative correlation – higher

Chemical energy use	production coincides with lower energy use (improved efficiency)
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Source: Own study.

Table 5 further quantifies these energy-efficiency improvements. Between 2010 and 2023, overall industrial energy efficiency improved by approximately 140%, while the chemical industry's efficiency increased by around 165%. In practical terms, by 2023, the chemical sector produced more than twice the economic value per unit of energy (TJ) compared to 2010.

Table 5. Energy efficiency analysis.

Year	Industry total	Chemical industry
2010	0.98	0.26
2019	1.36	0.36
2023	2.37	0.69

Source: Own study.

From a broader European perspective, Poland's energy consumption declined faster than the EU average between 2017 and 2022, though Poland remains a relatively high energy consumer, accounting for around 6.5% of total EU energy use (Table 6).

Table 6. Poland and EU 27 energy consumption index.

Year	2017	2018	2019	2020	2021	2022	2023
European Union - 27 countries (from 2020)	240	242	240	231	242	226	214
Poland	841,049	863,814	365,088	779,371	602,277	860,705	730,243
	15	16	16	15	16	15	13
	820,047	327,935	492,204	921,165	274,112	074,146	723,846
Indicator EU-27	100	103	101	97	102	93	91
Indicator Poland	100	101	99	96	105	94	95

Source: Own study.

These findings highlight the significant progress of the Polish chemical industry in improving energy efficiency and demonstrate that industrial growth can coexist with reductions in energy use — a key precondition for sustainable economic transformation.

4.2 Managing Energy Consumption

The implementation of sustainable development policies has become a strategic priority at both international and national levels. For enterprises, this entails

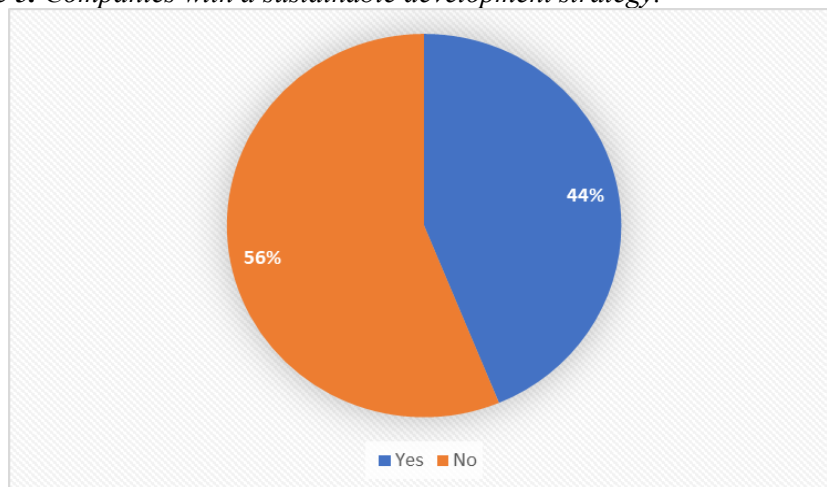
adopting concrete actions derived from these frameworks and integrating them into business strategies.

A key element of such implementation is the development of corporate sustainability strategies that define long-term growth directions and operational goals aligned with the European Green Deal and the United Nations Sustainable Development Goals (SDGs). Both frameworks strongly influence national policies aimed at reducing environmental impacts and promoting collaboration that benefits society and local communities.

According to surveyed entrepreneurs, the Polish chemical sector performs relatively well in responding to these challenges: “Poland stands out very favourably in comparison to the European Union; we have reached the necessary standards and requirements. There is a balance maintained between the EU industry and the Polish one.” More than half of the surveyed companies reported having a formal sustainability strategy (Figure 5).

Focus-group interviews and desk research confirm that most large enterprises not only possess such strategies but also actively implement them, directly referencing international frameworks such as the SDGs, the European Green Deal, and relevant national regulations.

Figure 5. *Companies with a sustainable development strategy.*

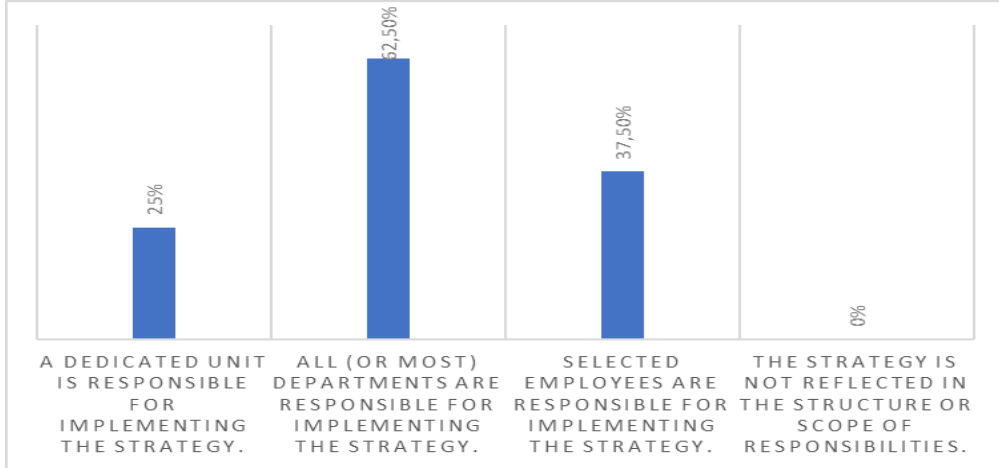


Source: *Own study.*

Most companies with a sustainability strategy apply it across all or most organizational departments. About one-quarter have created dedicated sustainability units, while roughly 40% assign implementation responsibilities to designated employees (Figure 6). Focus-group discussions further revealed that even firms without formal strategies recognize that compliance with sustainability-related public policies has become unavoidable:

“(…) either we adapt, or we fall out of the market, while at the same time we must meet consumer needs.” (FGI #3)

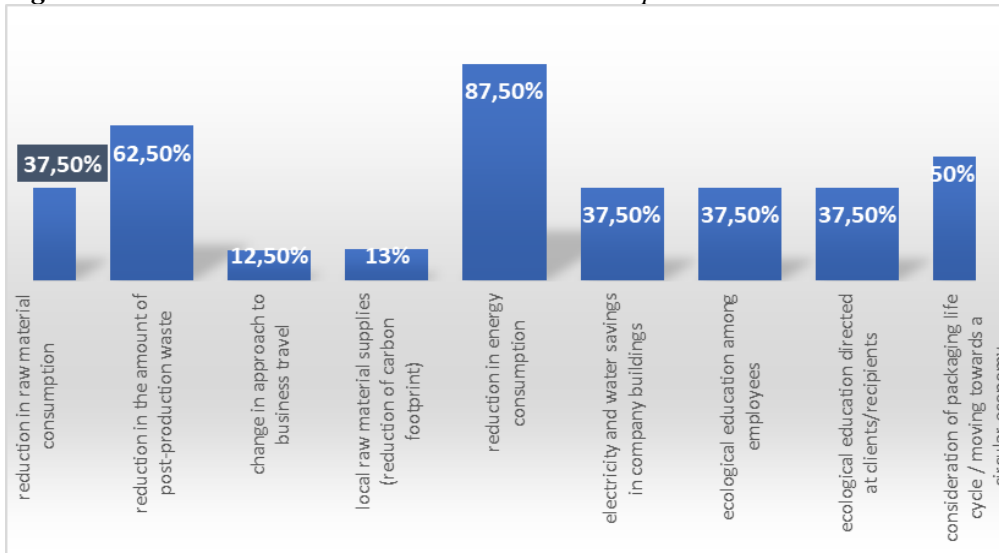
Figure 6. Responsibility for realisation of sustainable development strategy.



Source: Own study.

Chemical companies are required to align their operations with European and national regulations, particularly regarding waste management and the environmental impact of production. Although the adjustment process often increases administrative and reporting burdens, most companies actively engage in a range of environmental initiatives (Figure 7).

Figure 7. Environmental initiatives in the studied companies.



Source: Own study.

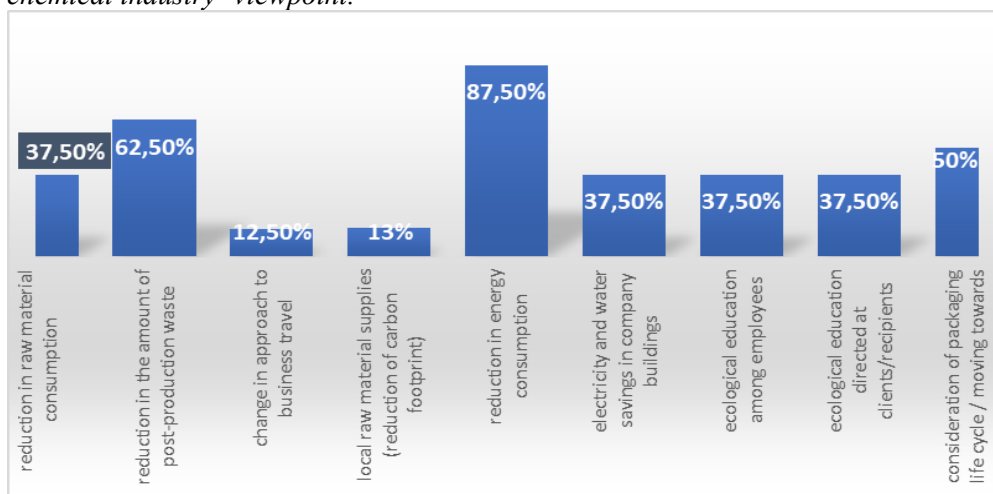
The survey shows that 87.5% of respondents undertake environmental actions. The majority (62.5%) focus on reducing post-production waste, while half also address the life cycle of product packaging.

More than one-third (37.5%) work on reducing raw-material use and conserving electricity and water, as well as educating employees and customers about sustainable practices. Smaller but noteworthy shares report modifying business-travel policies (12.5%) or preferring local suppliers (13%) to minimize their carbon footprint.

These findings align with respondents' assessment of key sustainability priorities: 87.5% identified energy-consumption reduction as the most critical element of their sustainability strategies (Figure 8). This emphasis reflects a growing awareness of environmental and climate-related challenges and a recognition that improving energy efficiency yields both ecological and economic benefits.

Lower energy use reduces operational costs and enhances competitiveness, while strong performance in this area improves corporate reputation in an increasingly eco-conscious marketplace. Moreover, energy-efficiency measures help firms comply with tightening environmental regulations at national and EU levels.

Figure 8. *Most significant actions for the sustainable development from the chemical industry' viewpoint.*



Source: *Own study.*

However, entrepreneurs emphasized that company size and resources affect the scope of implemented changes.

“Large companies, particularly private ones like Synthos S.A., operate best. In such companies, there is a greater emphasis on change and adaptation to trends. (...)

When it comes to smaller companies, the awareness is lower; however, they draw inspiration from groups like Grupa Azoty, PKN Orlen, or Synthos.” (FGI #1)

Thus, transformation drivers vary — from reputational and economic factors to regulatory obligations:

“(…) indicators that need to be achieved to avoid penalties (…)” (FGI #2)

Entrepreneurs agreed that the primary obstacle is not a lack of willingness to implement sustainability measures but limited time and financial capacity to reorganize production processes:

“A challenge for our country is the preparation for specific implementations and securing the appropriate time perspective. Lack of preparation generates problems, as exemplified by the implementation of the BDO Waste Database, which the industry in Poland was unprepared for.” (FGI #2)

Rapid legislative changes and insufficient transitional periods have imposed heavy financial burdens. The cost of waste disposal, for example, has reportedly increased five- to six-fold, from PLN 700 per ton to around PLN 4,000 per ton. Entrepreneurs also underlined that industry stakeholders are rarely consulted in drafting or implementing sustainability regulations:

“The substantive community (entrepreneurs and key industry organizations) does not constitute a voice of influence, and their recommendations are often disregarded. (..) An unrealized project means no benefits for the environment.” (FGI#2)

Overall, both survey and qualitative results indicate that sustainability and circular-economy principles are already an operational reality for Polish chemical companies. Their implementation is driven by a mix of regulatory, market, and technological factors rather than by long-term strategic vision alone.

5. Summary Discussion

The transition of the Polish chemical industry toward sustainable development is no longer a distant objective but a strategic necessity. The data clearly demonstrate that over the past decade, the sector has achieved a significant reduction in energy consumption while maintaining stable and continuous growth. This dual outcome reflects the industry’s capacity to adapt effectively to sustainability goals without compromising economic performance.

The findings confirm that regulatory compliance and market competitiveness are now the primary drivers of transformation within the chemical sector. However, the extent and pace of change remain uneven across subsectors and strongly dependent on external political and economic factors. These disparities raise important

questions about the long-term resilience and sustainability of the sector's adaptation processes.

The evolving geopolitical context—including the ongoing war in Ukraine, energy-security concerns, and global political shifts following U.S. elections—has intensified uncertainty regarding Europe's green transition. Supply-chain disruptions and volatility in energy markets directly affect the Polish chemical industry, one of the country's largest industrial energy consumers.

Addressing these challenges requires a more coherent and forward-looking public policy approach. Policy instruments should go beyond compliance and focus on fostering innovation, supporting small and medium-sized enterprises (SMEs), and strengthening sectoral dialogue.

Financial mechanisms, public procurement strategies, and regulatory frameworks must be better aligned with the specific characteristics and needs of the chemical sector, particularly in accelerating the circular-economy model and scaling up energy-efficiency solutions.

Equally important is the development of institutional capacity to support long-term systemic transformation. Without coordinated action across European, national, and regional governance levels, the sustainability transition risks becoming fragmented and vulnerable to political and economic shocks.

Future research should explore policy instruments that reinforce the sustainability agenda in high-impact industries while ensuring that the costs of transformation are distributed fairly among stakeholders.

In the coming years, it will not be enough for companies merely to adapt to policy requirements. What will matter most is their ability to lead—to anticipate regulatory, technological, and market shifts and to view sustainability not as a constraint but as a core driver of innovation and competitiveness.

This leadership imperative applies equally to public authorities, which must create enabling conditions for ambitious industrial transformation, and to enterprises, which must translate sustainability commitments into measurable actions.

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