EXPLORING THE NEXUS BETWEEN ENERGY EFFICIENCY AND STRUCTURAL CHANGES IN ROMANIA'S MANUFACTURING INDUSTRY

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Abstract
The recent geopolitical upheavals have significantly impacted manufacturing, with volatile energy prices disrupting firms' cost structures and competitiveness. In this context, assessing the readiness of Romania's manufacturing sector structure to face these geopolitical challenges is crucial. The present paper explores the nexus between energy efficiency and structural changes in Romania's manufacturing industry over the past two and a half decades, analyzing the dynamics of energy consumption and efficiency. The analysis shows that structural changes were crucial in decreasing energy consumption, as the manufacturing activities with the lowest energy efficiencies underwent the most significant output reductions. Moreover, the evolution of investment intensities in the manufacturing industry activities reflects both the sectors that have undergone successful restructuring and those that have proven attractive to investors. In terms of structural breaks, the results of the Bai-Perron (2003) test conducted on the output of the manufacturing activities revealed that the activities identified as the most energy-efficient, such as the Manufacture of furniture; other manufacturing, and the Manufacture of machinery and equipment not elsewhere classified (n.e.c.) also exhibit a considerable number of structural breaks.

Keywords
Manufacturing activities, energy efficiency, structural changes, Bai-Perron test

JEL Classification
L16, L60

Introduction

Strategic decisions regarding energy consumption and the enhancement of energy efficiency are influenced by rapid technological changes, increasingly stringent emission regulations, and energy market volatility. The recent geopolitical upheavals

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have significantly impacted the financial stability of manufacturers due to the unpredictability of energy prices, leading to strategic adjustments to manage costs and maintain competitiveness. The sharp rise in energy prices has escalated the pressure on profitability, compelling manufacturers to seek and implement strategies to reduce energy consumption and optimize industrial processes.

In a broader context, the European economy faces one of its greatest challenges in the form of achieving climate neutrality by the middle of the century, which requires a substantial reduction in greenhouse gas emissions. The ambitious energy-saving targets set by the European Union are pivotal in this endeavor but also pose a considerable challenge to Romania's economy, which is closely integrated into Europe's trade and technological networks.

In this context, the present analysis investigates the energy efficiency of Romania's manufacturing industry and its component activities, exploring the connection between energy efficiency and structural change. This paper examines the structural transformation of Romania's manufacturing industry over the last two and a half decades, analyzing the dynamics of energy consumption and efficiency within this structural context.

This research contributes to the ongoing discussions about the competitiveness of the Romanian manufacturing industry amid the current uncertain economic climate and the significant pressures resulting from the economic impact of the recent geopolitical tensions. It illuminates the disparities in competitiveness within specific manufacturing industry activities, emphasizing structural vulnerabilities and areas where measures to enhance competitiveness are imperative.

1. Review of the scientific literature

The connection between structural changes and energy efficiency is bidirectional in terms of causality. Energy efficiency advancements can catalyze sectoral transformations and bolster competitiveness. As noted by Ürge-Vorsatz et al. (2018), the implementation of energy-efficient technologies can instigate shifts in industrial production, leading to enhanced productivity and a gravitation towards less energy-intensive sectors. This is particularly pronounced in developed economies, where there's a marked transition from conventional manufacturing to more sophisticated, service-oriented industries, culminating in a reduction of the overall energy footprint, as Sorrell (2015) observed.

The interplay between energy efficiency and structural economic evolution is also integral to decarbonization strategies. Arroyo and Miguel (2020) contend that energy-efficient initiatives in manufacturing can curtail energy demand and pave the way for sustainable production practices, including the adoption of electrification and renewable energy sources. Yousefi et al. (2017) point out that industries that integrate energy-efficient technologies typically report lower carbon emissions, which in turn fosters structural shifts towards eco-friendly growth.

This relationship is further influenced by policy frameworks, technological accessibility, and capital investments, particularly in developing countries where industrial development is more energy-dependent. Fokeer et al. (2018) emphasize that

policy interventions, such as subsidies and regulations, are pivotal in promoting energy efficiency and guiding structural changes.

The application of statistical and econometric methodologies, particularly in the context of testing for structural breaks, is critical to understanding the dynamic relationship between structural changes and energy efficiency. Rao and Rao (2009) applied the Bai-Perron test to identify structural breaks associated with major oil shocks and pointed out that the shocks led to improved energy efficiency. The Bai-Perron test was also applied by Kahkonen et al. (2019) in the case of the Finnish pulp and paper industry, and the authors concluded that structural changes played a key role in energy efficiency improvements in the analyzed sector. In addition to structural break tests, cointegration analysis and the Granger causality test are widely applied to assess long-run relationships and the directionality of causality between energy efficiency and structural changes. For example, Stern (2011) used cointegration techniques to analyze the relationship between economic growth, energy use, and structural shifts in developed economies, revealing that improvements in energy efficiency often precede structural changes in industrial sectors. Apergis and Payne (2010) applied the Granger causality test and cointegration techniques in their study of OECD countries, showing a bidirectional relationship between energy consumption and economic growth, demonstrating the critical role energy efficiency plays in driving structural transformations across industries.

2. Research methodology

To explore the nexus between energy efficiency and structural changes, the paper investigates the structural breaks associated with the production activity of the main manufacturing branches. The analysis also focuses on the dynamics of energy efficiency in the context of Romania's economic transition, which led to substantial changes in the structure of the manufacturing industry.

The research methodology employs an econometric approach to investigate structural breaks in manufacturing activities output, focusing on the Bai-Perron multiple structural break test. This test identifies shifts in the parameters of a time series regression model, allowing the detection of significant changes in industry patterns related to energy efficiency. The Bai-Perron test is an appropriate choice for detecting multiple structural breaks in manufacturing output, particularly during Romania's economic transition. It enables the identification of shifts in time series regression parameters, providing insights into how structural changes and energy efficiency improvements have influenced industry dynamics. Its ability to detect multiple breakpoints allows for a detailed understanding of periods with significant industrial shifts. However, the test assumes constant variance within each segment and requires sufficient observations between breaks, which can be limiting in shorter time series. However, the current paper mitigates the problem by applying the test over a longer timeframe, spanning from 1995 to 2022. This extended period captures the economic transition of Romania and the associated structural transformations in its manufacturing industry. In this vein, the Bai-Perron (2003) test will be applied to detect structural breaks in manufacturing output, determining the points in time where significant changes occurred, thereby highlighting the impact of energy efficiency improvements on industry dynamics.

3. Results and discussion

Structural transformations in the Romanian economy, including the reduced importance of key industrial sectors such as the chemical industry, have led to an increase in energy efficiency. These improvements were not necessarily the result of massive investments in advanced technologies but rather due to economic adjustments and the reduction of production capacity in certain industrial branches (see figure no. 1).

To address current challenges, Romanian producers must adopt a holistic approach to managing energy consumption and associated costs. This approach includes monitoring energy use, adopting innovative technologies, and improving industrial processes to minimize losses and optimize the use of available resources. Additionally, adapting to new environmental regulations and standards imposed by the European Union will be essential to maintain competitiveness in the European market.

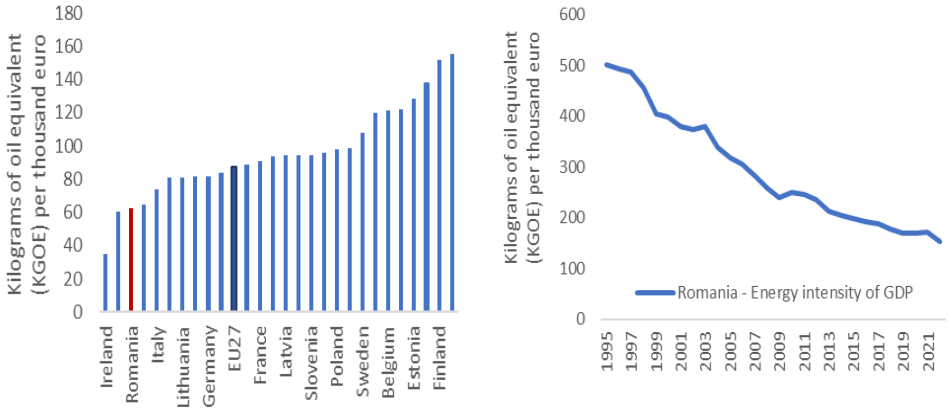

Figure no. 1: The energy efficiency of Romania's economy. European comparisons

a. Energy intensity of GDP - European comparisons (2022)

b. The evolution of GDP energy intensity in Romania, 1995-2022

Source: Eurostat data

Note: Most recent available data

An analysis of the distribution of energy consumption within the EU reveals that the share of sectors with high energy consumption in the Member States differs. In Romania, data shows that the manufacturing industry consumes a significant proportion of energy resources. With a value of 56.1% of energy consumption in 2022, Romania is at a comparable level with other European countries such as Spain or Poland.

EU member states with economies characterized by similar structural profiles, such as Poland and the Czech Republic, exhibit comparable energy profiles. However, as states seek to optimize their energy mix and reduce carbon emissions in line with European Union objectives, the pressure on these industrial sectors is increasing. In this context, for Romania, a sustainable approach to industrialization is crucial to improving

competitiveness in the European market and complying with new energy regulations. Investments in more energy-efficient technologies and renewable energy sources could play a crucial role in transforming the industrial sector and enhancing its competitiveness.

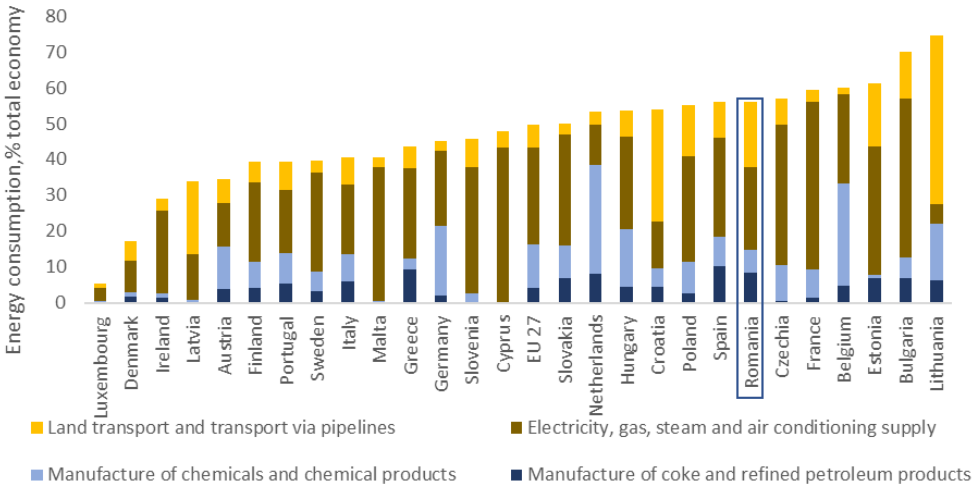

Figure no. 2: Energy consumption at the sectoral level. European comparisons (energy consumption,% total economy, 2021)
Source: Eurostat
Note: Most recent available data

Four specific activities within the manufacturing industry account for approximately 80 percent of the total energy consumed at the branch level (see figure no. 3). The highest consumption is recorded by the Manufacture of coke and refined petroleum products, with about 23.6% of the total consumption at the branch level, followed by the Manufacture of fabricated metal products, except machinery and equipment, at 18.9 %, Manufacture of chemicals and chemical products at 17.9%, and Manufacture of rubber and plastic products at 17.4%.
These industrial sectors are important pillars of the national economy and have a significant impact on the environment. Activities such as the Manufacture of chemical substances and the Manufacture of rubber and plastic products support a wide range of industries, from agriculture to electronics, with the potential to significantly influence innovation and technological development. In the context of global climate change, energy efficiency becomes a priority for these industrial sectors, and the adoption of sustainable technologies can significantly reduce their environmental impact.

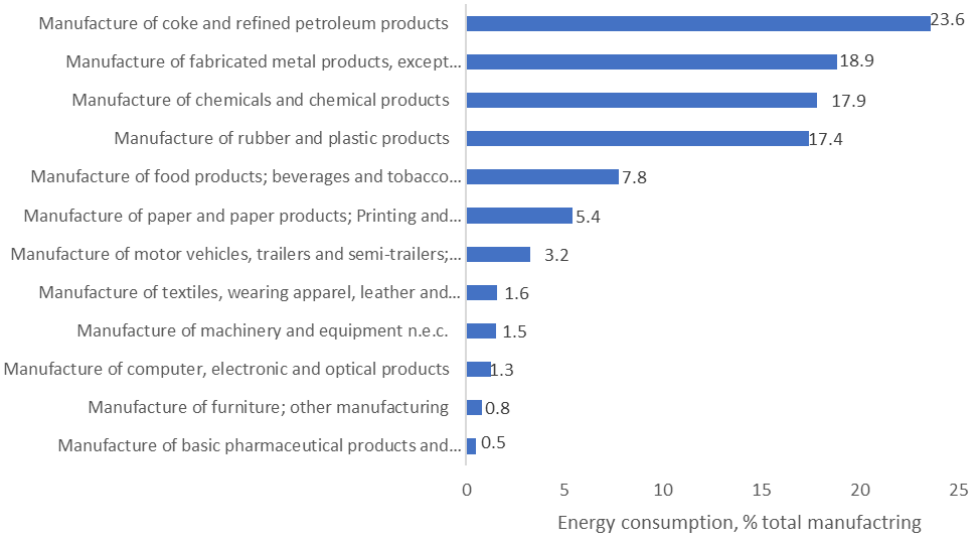

Figure no. 3: Energy consumption in the manufacturing industry (Energy consumption,% total manufacturing, 2021)

Source: Eurostat

Note: Most recent available data

The Manufacture of coke and refined petroleum products and the Manufacture of chemicals and chemical products are the least energy-efficient activities within the manufacturing industry, and high-consumption activities are also those that, on average, exhibit low energy efficiency (see figures no. 3 and no. 4 for comparison). The Manufacture of coke and refined petroleum products is three times more energy-efficient in Austria compared to Romania (Eurostat 2024), while the Manufacture of chemicals and chemical products is twice as energy-efficient in Germany compared to Romania (Eurostat 2024). Investments in modern technologies could significantly improve the energy efficiency of these sectors in Romania, reducing dependency on energy resources and contributing to lower pollutant emissions. Such a transition could also support the country's environmental and climate goals, aligning with the European Union's strategic directions on sustainability and combating climate change.

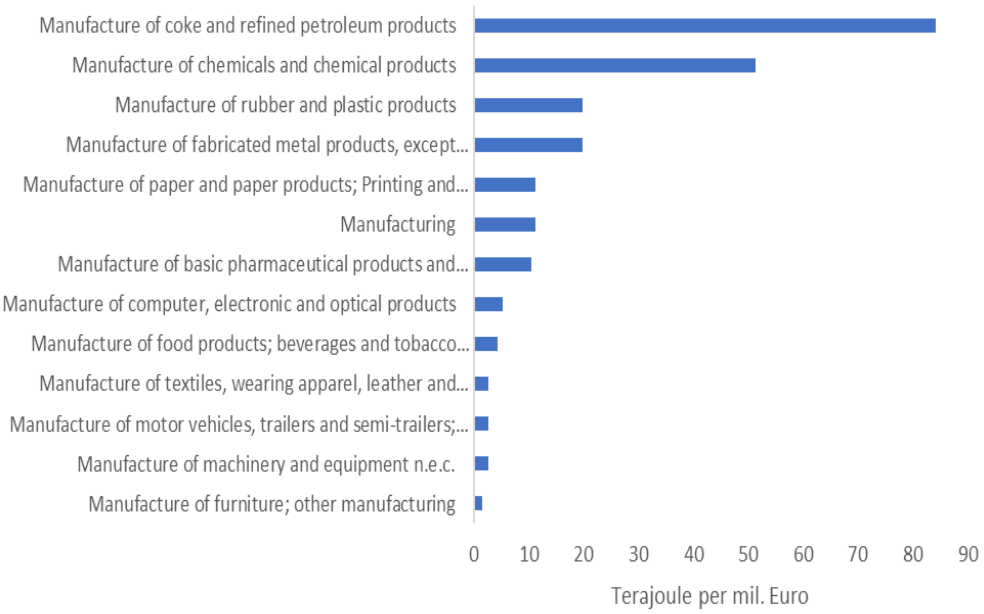

Figure no. 4: Energy efficiency in the manufacturing industry, 2021
Source: Eurostat
Note: Most recent available data

The energy efficiency of the activities within the manufacturing industry highlights the existence of sectoral heterogeneities that should be considered when designing a policy to improve energy efficiency. Previous studies indicate two main reasons that drive companies in the manufacturing industry to adopt energy efficiency measures (European Commission 2018, Dolge et al. 2020, Kubule et al. 2020). First, energy efficiency helps reduce the environmental impact of industrial processes and CO2 emissions and lowers costs associated with carbon taxes imposed by the European Union (European Court of Auditors, 2022). Second, reducing energy consumption costs positively impacts the financial and economic position of companies, as well as their competitiveness in global markets.

The transformation and modernization of the manufacturing industry is imperative for Romania to enhance the sustainability and energy efficiency of its economy. Through strategic investments in green technologies and the implementation of smart energy policies, Romania can strengthen its position within the European economy and actively contribute to global efforts to combat climate change.

The top four activities within the manufacturing industry with the highest share of total energy consumption (see table 1) employed approximately 110,000 people in 2022, representing about 9.6% of the total workforce employed in the manufacturing sector.

The workforce in these four activities has experienced a negative trend over the last 30 years, with the number of employees declining.

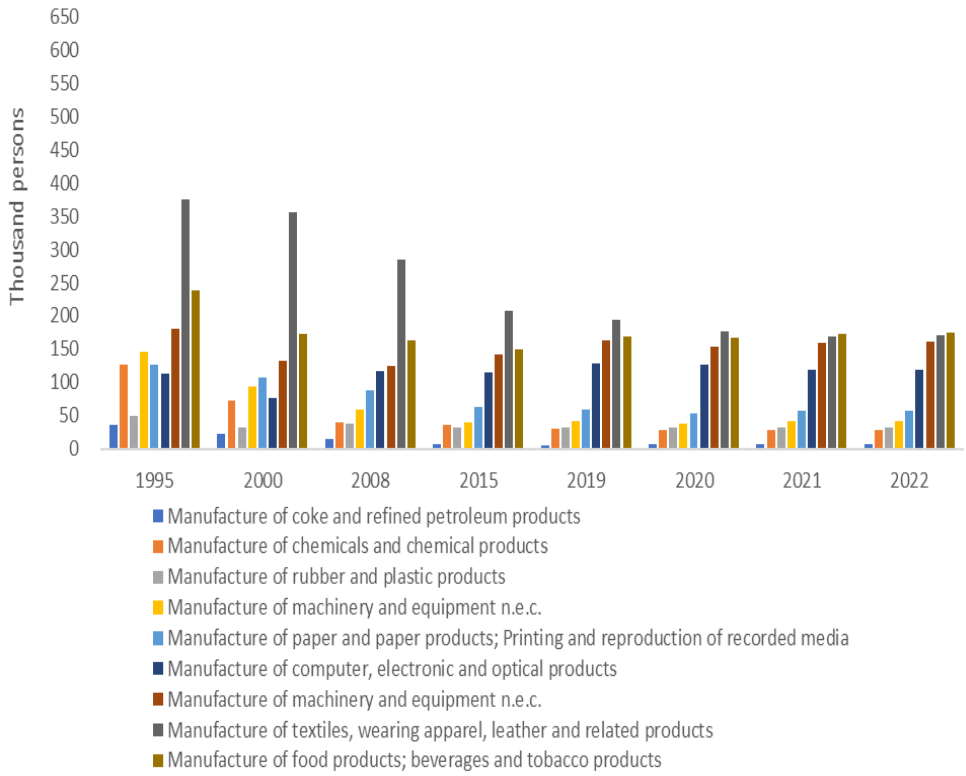

Figure no. 5: The evolution of the workforce structure employed in the main activities of the manufacturing industry according to NACE Rev. 2
Source: National Statistical Office, Eurostat
Note: Estimated values for 2022

Investment declined less than the workforce in Romania's manufacturing industry. In most activities within this sector, gross fixed capital formation showed a positive trend. However, investment declined in activities where production faced significant contractions, such as Manufacture of chemicals and chemical products and Manufacture of textiles, wearing apparel, leather and related products.

On the other hand, there was also observed a positive relation between production and investment. The Manufacture of machinery, equipment, and n.e.c. experienced significant production growth from 2000 to 2022, alongside a substantial increase in investments, which were 23 times higher in 2022 compared to 2000.

Significant increases in gross fixed capital formation were also recorded in activities that generate approximately 50% of the total added value in the manufacturing industry,

namely Manufacture of food products, beverages and tobacco products and Manufacture of machinery and equipment n.e.c.. These increases underscore the crucial role of investments in manufacturing activities that have seen positive developments.

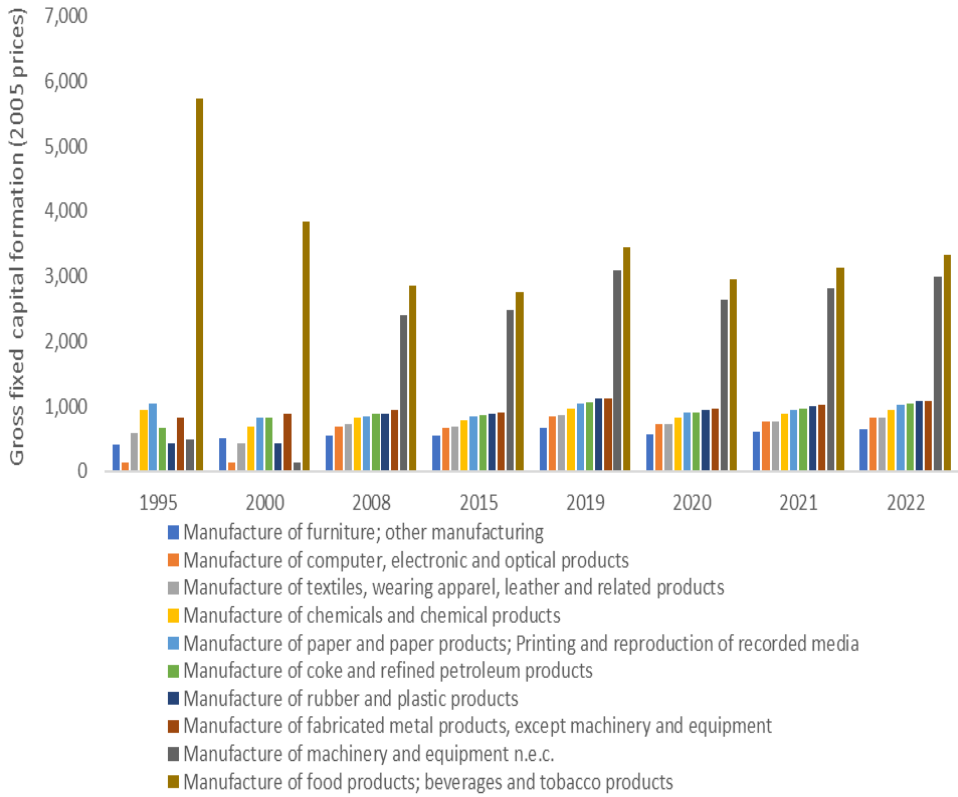

Figure no. 6: The evolution of the investment structure in the main activities of the manufacturing industry according to NACE Rev. 2.
Source: National Statistical Office, Eurostat
Note: Estimated values for 2022

The historical evolution of investment intensities in the manufacturing industry activities reflects both the sectors that have undergone successful restructuring and those that have proven attractive to investors. In this context, the investment intensity increased in 2022 compared to 1995 in activities that attracted foreign investments, such as the Manufacture of motor vehicles, trailers, and semi-trailers, the Manufacture of other transport equipment, and high-tech activities such as the Manufacture of computers and electronic and optical products. As expected, high-tech activities and those that have adopted new technologies in the production process are also the activities with the highest investment intensity (see figure no. 7).

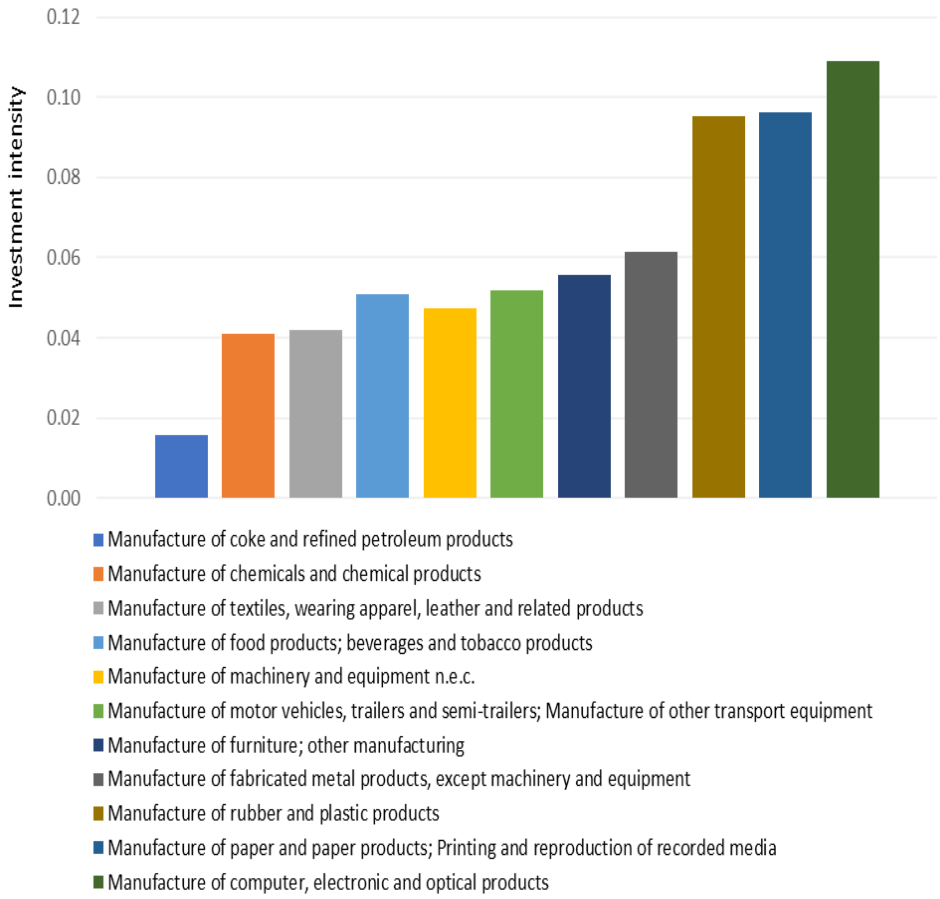

Figure no. 7: Investment intensity in the manufacturing industry, 2022
Source: Author's calculations based on Eurostat data
Note: Investment intensity is defined as the ratio of gross fixed capital formation to output

Manufacturing activities with high energy consumption tend to report lower levels of investment intensity. In this regard, the Manufacture of coke and refined petroleum products and the Manufacture of chemicals and chemical products, which are responsible for approximately 42% of energy consumption in the manufacturing industry, exhibit the lowest investment intensities among the analyzed activities. This

result indicates the need for investment policies at the level of specific manufacturing activities to enhance energy efficiency.

The analysis of the relationship between production in specific manufacturing activities and energy consumption highlights the reduction in structural shares of activities with high energy consumption (see Table no. 1). This primarily concerns activities such as the Manufacture of coke and refined petroleum products, Manufacture of fabricated metal products, except machinery and equipment, and the Manufacture of chemicals and chemical products, which have experienced dramatic reductions in their share in the total manufacturing output. These changes represent important factors contributing to the decrease in the energy intensity of gross domestic product. The Manufacture of coke and refined petroleum products stands out as having a significantly higher energy intensity compared to other branches. This suggests the high potential impact that investments at the activity level could have in reducing energy consumption, leading to increased competitiveness of the analyzed activity and further reduction in the energy intensity of gross domestic product.

Tabel no. 1. High energy consumption activities in the manufacturing industry vs. changes in the structural weight in production

	Energy consumption, % total manufacturing 2021	**Energy intensity, Terajoule per mil. Euro 2021**	**Production by activity, % total manufacturing 1995**	**Production by activity, % total manufacturing 2022**
Manufacture of coke and refined petroleum products	23.6	84.2	11.9	5.8
Manufacture of fabricated metal products, except machinery and equipment	18.9	19.8	20.5	11.1
Manufacture of chemicals and chemical products	17.9	51.4	8.5	3.8
Manufacture of rubber and plastic products	17.4	19.9	14.2	9.3

Source: Author's calculations based on the National Statistical Office and Eurostat data

The analysis of structural breaks in key manufacturing activities in the manufacturing industry allows for the identification of these activities' ability to withstand significant economic shocks over the past 25 years. This analysis provides insights into the adjustment capacity of key activities in the context of challenges posed by the transition to a green economy. In the early years of the transition, the manufacturing industry in

Romania experienced a significant contraction suggesting that the manufacturing industry was affected by strong structural changes, leading to substantial shifts in production growth rates. In this context, an econometric analysis was conducted to determine whether the main activities in the manufacturing industry experienced structural breaks. The analysis focused on: (1) identifying activities with the most frequent structural breaks; and (2) grouping structural breaks into specific sub-periods.

Tabel no. 2. Econometric estimation of structural breaks for the major manufacturing activities according to NACE Rev. 2

Activity	**Structural breaks (***Bai-Perron test)**	
	Number of structural breaks	Years
Manufacturing	3	2005; 2006; 2015
Manufacture of food products, beverages and tobacco products	1	2005
Manufacture of textiles, wearing apparel, leather and related products	0	
Manufacture of paper and paper products; Printing and reproduction of recorded media	3	2001; 2005; 2009
Manufacture of coke and refined petroleum products	1	2014
Manufacture of chemicals and chemical products	0	
Manufacture of rubber and plastic products	4	2006; 2007; 2017
Manufacture of fabricated metal products, except machinery and equipment	1	2017
Manufacture of computer, electronic and optical products	1	2005
Manufacture of machinery and equipment n.e.c.	4	1998; 2011; 2013; 2018
Manufacture of furniture; other manufacturing	3	1996; 2004; 2005; 2012

Source: Author's calculations using E-views 12

Note: * Statistical significance at the 0.05 significance level

The most frequent structural breaks were observed in two activities: the Manufacture of machinery, equipment, and n.e.c. and the Manufacture of rubber and plastic products. In both activities, there was an increase in production in 2022 compared to 1995. Activities without structural breaks, such as the Chemical industry and the Manufacture of textile products, experienced the highest production contractions during the analyzed period.
In this context, structural breaks reflect cases where successful restructuring occurred within the main activities of the manufacturing industry. This suggests that adaptations and restructurings were crucial for revitalizing these sectors. Activities that recorded

production increases benefited from investments, modernization, and adjustments to market demands, while sectors without structural breaks were less able to adapt, leading to significant production contractions.

Tabel no. 3. Structural breaks in the output of main manufacturing industry activities

Perioad	Number of structural breaks
1995-2008	11
2009-2022	10

Source: Author's calculations

The majority of structural breaks took place in the period of economic expansion that preceded the economic crisis of 2009-2010, reflecting critical economic restructuring at the activity level and setting the stage for the subsequent positive dynamics in output. This finding aligns with the upward trend in production noted in the sectors with the highest number of structural breaks. Investment dynamics serve as one explanatory variable for this phenomenon. For instance, the Manufacture of machinery, equipment, and n.e.c. experienced a surge in investments by 60% in 2019 compared to 2007, illustrating the attractiveness of the activities which went through a successful restructuring.

When considering the connection between energy efficiency and structural breakes, the activities identified as the most energy-efficient namely, the Manufacture of furniture; other manufacturing, and the Manufacture of machinery and equipment not elsewhere classified (n.e.c.) are also among those that have experienced a significant number of structural breaks (see table no. 2.).

Conclusions

Structural changes within the Romanian manufacturing industry have played a critical role in reducing the energy consumption of the sector and the overall economy. In this respect, key activities in terms of output, which exihibitied also high energy consumption and low energy efficiency such as Manufacture of coke and refined petroleum products and Manufacture of chemicals and chemical products refistered a significant reduction in their share in manufacturing output.

Investment played a critical role in terms of output dynamics, energy consumption and efficiency over the analyzed period. The evolution of investment intensities in the manufacturing industry activities reflects both the sectors that have undergone successful restructuring and those that have proven attractive to investors. These are also the sectors which exibit one of the highest energy efficiencies among the analyzed activities as is the case of Manufacture of machinery and equipment n.e.c.

The most frequent structural breaks were observed in the Manufacture of machinery, equipment, and n.e.c. and the Manufacture of rubber and plastic products, both of which recorded increased output in 2022 compared to 1995. Conversely, sectors like the Chemical industry and Textile manufacturing, which lacked structural breaks, faced the

steepest declines in production over the period studied. Notably, the most energy-efficient sectors, including Manufacture of furniture; other manufacturing and the Manufacture of machinery and equipment n.e.c., were also among those with numerous structural breaks.

In future research, the analysis in this paper could be expanded by investigating the influence of technological advancements and government policies on driving structural changes and energy efficiency improvements within Romania's manufacturing sector. Analyzing the impact of policy measures, such as subsidies for energy-efficient technologies, could provide insights into how investment patterns have shaped sectoral dynamics. Additionally, exploring the sustainability of energy efficiency gains, particularly in sectors like Manufacture of machinery and equipment n.e.c., could reveal whether these improvements are enduring under evolving economic conditions.

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