Analysis of the EU Energy Consumption Dynamics and its Impact on the Enterprise Economic Security

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Abstract: - Economic security of the EU energy is an urgent problem for all countries. The energy policy of the EU aims to diversify energy resources and achieve energy independence. However, after 2022, this issue has become more pressing. The paper also examines the dynamics of energy consumption by various countries and sectors of the economy and evaluates the impact of changes in the energy sector structure on the economic security of enterprises. The paper offers suggestions for improving the EU energy policy to ensure enterprise economic security. The paper also considers the dynamics of energy consumption by various sectors of the economy and assesses the impact of changes in the energy sector structure on the economic security of enterprises.

Key-Words: - energy consumption, energy resources, energy efficiency, enterprise economic security, data visualization methods, correlation, regression models.

Received: September 25, 2022. Revised: January 26, 2023. Accepted: February 28, 2023. Published: March 27, 2023.

1 Introduction

The issue of energy consumption and energy independence in the EU has become increasingly pressing. Unlike most countries around the world, which see economic growth through proportional increases in energy consumption, the EU economy has grown due to increased energy efficiency rather than increased energy consumption.

The authors of [12], [15], [16], present the key aspects of economic security for the EU energy in the context of climate change. Their articles discuss the concept of energy security and economic issues facing EU countries. Additionally, the problem of natural gas consumption as a "green fuel" for Europe is explored.

An important component of the economic security of the EU energy consumption is the development and implementation of renewable energy sources, as noted in sources, [1], [9], [20]. The authors of [1], [20], consider the economic aspects of implementing appropriate technological solutions and evaluate the forecasts and economic efficiency of such projects. The study presented in [9], examines the relationship between renewable energy, agriculture, and CO2 emissions in middle-income countries, and provides empirical evidence on the positive impact of renewable energy consumption on both environmental pollution and economic growth.

The impact of renewable energy sources, energy consumption, economic growth, and CO2 emissions on economic growth in the EU is investigated in other publications, [5], [11]. The results of [5], indicate that energy consumption and economic growth have a positive impact on CO2 emissions, and as a result, energy conservation policies are essential for sustainable economic growth in the region. The findings of [11], suggest that renewable energy sources have provided economic benefits, thereby improving the energy security and economic stability of the region.

Another group of authors, including [2], [6], [7], [17], defines the economic security of the EU energy market in terms of energy security, security of supply, security of demand and revenue, and other political, social, technical, and environmental risk factors, [17]. Although there is an ambition to address energy security aspects, the analysis is limited to a few quantifiable factors, and several important aspects are omitted, [6], [7]. Therefore, energy consumption in the context of low-carbon energy transitions is not only a technological problem but also requires consideration of market supply and demand aspects. Research, [2], emphasizes the significance of maintaining a balanced energy mix and a competitive energy market to enhance the economic security of the region.

Authors from the early 21st century have focused on "green fuel" and the diversification of energy sources for EU countries. However, the partial and total embargo on fossil energy imports from Russia in 2022 demonstrated an insufficient level of economic security for the EU countries in the energy sector.

The relationship between the EU foreign policy and energy strategies is another aspect of economic security, as noted in sources, [8], [10], [14], [19]. Factors exogenous to energy policy can be significant and can either contain or generate contestation, [19]. These aspects have become increasingly important in 2022. The work, [10], shows what the EU economic security needs to improve its external energy security. The author shows that the EU's response to energy security policy has been slow and primarily focused on revising the Union's internal mechanisms (as was the case after the 2009 gas crisis), rather than the creation of a common external energy policy. The results of [14], provide a critical review of the EU's energy policy framework, highlighting the significance of reducing greenhouse gas emissions and increasing the use of renewable energy sources.

The authors, [13], analyze the economic impacts of a total embargo on fossil energy imports from Russia to European energy makers. The analysis of cutting energy imports from Russia for each of the EU countries is of particular interest. Authors, [3], consider the EU energy consumption and define the security and defense measures as a response to the Russian invasion of Ukraine. The results of the crisis showed an underestimation of the aspects of economic security in the energy sector of the EU.

2 Problem Formulation

Existing developments in the field of analysis of the economic security of the EU energy consumption are focused on the problem of diversification, energy independence, and the widespread implementation of renewable energy technology. Therefore, further analysis and forecasting of structural changes in the EU energy consumption are necessary.

The purpose of this work is to analyze the effectiveness of the EU energy sector in the context of economic security and changes in the structure of energy consumption. The analytical results are based on data visualization methods, correlation, and regression models. We aim to broaden the perspective on the relationship between the EU energy efficiency and the economic security of enterprises and identify problems and further research needs.

Data visualization is used to analyze the EU energy consumption structures and dynamics. Structural plots show the proportion of energy consumption for different EU countries and energy sources, such as fossil fuels, nuclear energy, and renewable energy. Linear dynamics visualized the trends in the consumption of different energy sources over time, [1], [8], [20].

Regression analysis is used to analyze the relationship between the EU GDP and energy consumption. For example, regression analysis estimated the impact of natural gas consumption and renewable energy consumption on economic growth. The results of the analysis are used to improve energy policies that promote economic growth while minimizing the negative environmental impact, [1], [5], [20].

3 Problem Solution

3.1 Analysis of the EU GDP and Energy Consumption Trends

Fig. 1 shows the dynamics of the EU GDP from 1990 to 2020, which had an exponential trend with an average annual growth rate of 3.42%. However, during the same period, total energy consumption remained almost at the same level. This suggests that the EU began its technological breakthrough in the field of energy efficiency in the early 21st century.

In addition to the increasing level of energy efficiency of the EU economy, significant changes have occurred in the structure of the EU's overall energy consumption. In 1990, the main share of energy consumption belonged to oil and oil products (39%), solid fossil fuels (26%), natural gas (17%), and nuclear energy (13%). At the same time, renewable energy sources only accounted for 5% of the share.

At the beginning of the 1990s, the governments of many EU countries took the first steps towards the implementation of environmental norms for fuel usage. These steps were motivated by concerns about the potential negative consequences of global warming and high levels of environmental pollution.

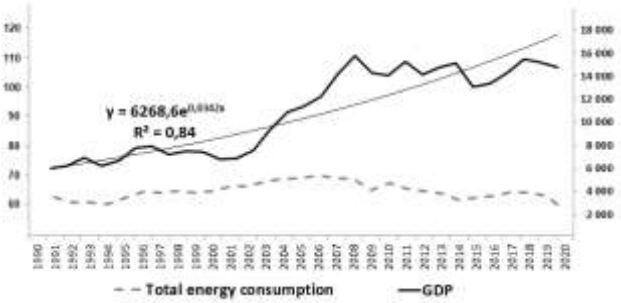

Fig. 1: Dynamics of total the EU energy consumption (Petajoules, left) and dynamics of the EU gross domestic product (billion USD, right)
Source: [authors' estimations based on data from [4], [18]]

There was a significant reduction in the share of solid fossil fuel consumption from 26% to 10% due to the successful implementation of environmental regulations and taxes between 1990 and 2020. Fig. 2 displays the decrease in the consumption of solid fossil fuels.

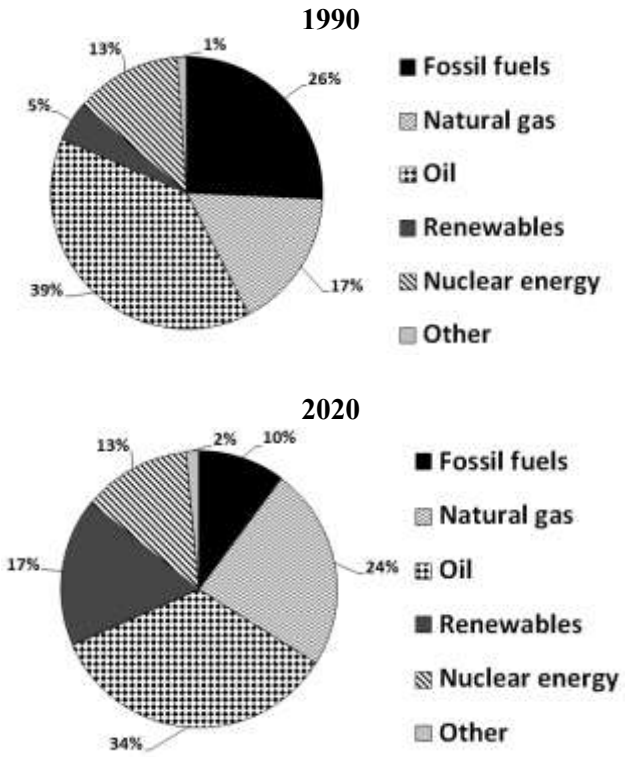

Fig. 2: The structure of the EU energy consumption in 1990 and 2020
Source: [authors' estimations based on data from [4], [18]]

The comparison of the energy consumption structures for 1990 and 2020 reveals that the reduction in the consumption of solid fossil fuels was compensated by two factors. Firstly, there was an increase in the consumption of natural gas, which has fewer polluting emissions compared to coal, and its share increased from 17% to 24%. Secondly, there was a significant increase in the production and consumption of renewable energy, with its share increasing from 5% to 17%. This increase in the consumption of renewable energy is a significant factor in explaining the growth of energy efficiency in the EU. However, it is worth noting that the current production value of solar and wind energy is still lower than that of heat and electricity.

Unfortunately, the EU countries have been unable to implement their plans to reduce the use of nuclear power plants. The share of nuclear power in total energy consumption has remained at 13% in 2020. A similar situation can be observed with the consumption of oil and oil products, which decreased from 39% in 1990 to 34% in 2020 over 30 years.

The analysis of oil and oil products consumption shows that it remained relatively stable from 1990 to 2008 (as shown in Fig. 3). The only significant negative impact on oil consumption was the global economic crisis of 2008-2009 and the COVID-19 pandemic. Therefore, the decrease in the consumption of oil and oil products in the EU is primarily related to global economic recessions rather than an increase in norms and taxes on the use of internal combustion engines.

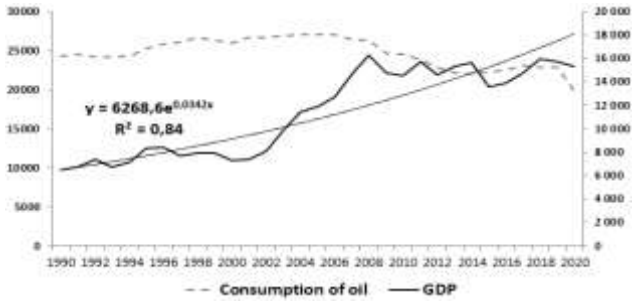

Fig. 3: Dynamics of oil consumption in the EU (Petajoules, left) and dynamics of the EU gross domestic product (billion USD, right)
Source: [authors' estimations based on data from [4], [18]]

The analysis of the dynamics of solid fossil fuel consumption (Fig. 4) shows that the process of reducing its use had a consistently negative trend, which began in 1990 and has continued until now. This reflects the EU's commitment to implementing sustainable development plans by producing fewer polluting emissions while maintaining economic growth.

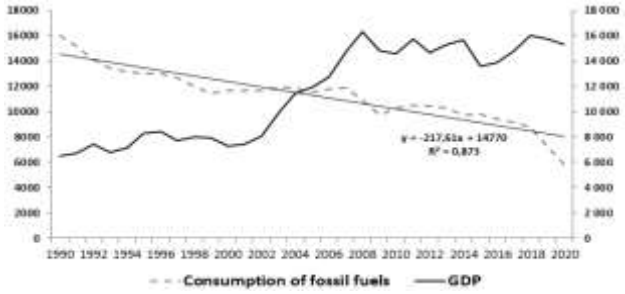

Fig. 4: Dynamics of consumption of solid fossil fuels in the EU (Petajoules, left) and dynamics of the EU gross domestic product (billion USD, right)
Source: [authors' estimations based on data from [4], [18]]

Like the consumption of oil, the consumption of solid fossil fuels in the EU was significantly affected by the global economic crisis of 2008 and 2019. In general, the consumption of solid fossil fuels in the EU has decreased by 63% over 30 years.

As mentioned earlier, the decrease in the consumption of solid fossil fuels in the EU was compensated by the increase in the consumption of natural gas and renewable energy. Until 2008, the consumption of natural gas in the EU had a linear upward trend, but after the global economic crisis of that year, the consumption of natural gas decreased somewhat, which had a negative impact on the average value of the linear trend (Fig.5).

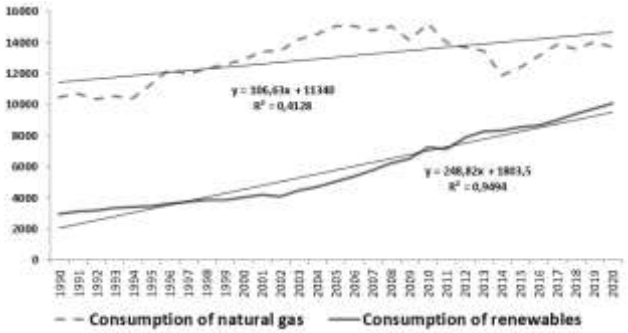

Fig. 5: Dynamics of natural gas consumption in the EU (Petajoules) and dynamics of renewable energy consumption (Petajoules)
Source: [authors' estimations based on data from [4], [18]]

If we examine energy consumption in the EU by country (as shown in Fig. 6), we can observe that Germany, France, Italy, Poland, Spain, and the

Netherlands have been the largest energy consumers since the early 1990s. All other EU countries have an energy consumption level of fewer than 50 million tons of oil equivalent. The significant volumes of energy consumption in Germany, France, and Italy can be attributed to their large populations and significant levels of industrial development, particularly in the chemical industry, metallurgy, and machinery manufacturing. Additionally, it is noteworthy that most of the EU countries have experienced a reduction in energy consumption over the past 30 years. This reduction can be attributed to the increased level of energy efficiency, which has been stimulated by technological development and a consistent increase in ecological taxation requirements.

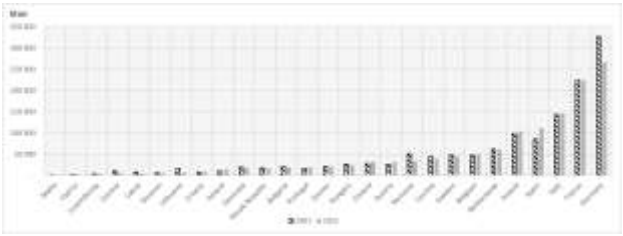

Fig. 6: Volumes of energy consumption in 1991 and 2021 by the EU member countries
Source: [authors' estimations based on data from [4], [18]]

The following Fig. 7 displays the volumes of energy consumption and nominal gross domestic product (GDP) for the EU countries in 2021, supporting the hypothesis that energy consumption is proportional to a country's economy. However, energy efficiency varies across EU countries. For instance, Ireland has the same level of energy consumption as Croatia and Denmark but shows a significantly higher level of nominal GDP. Similarly, the Netherlands and Poland have vastly different levels of energy consumption despite having similar levels of nominal GDP.

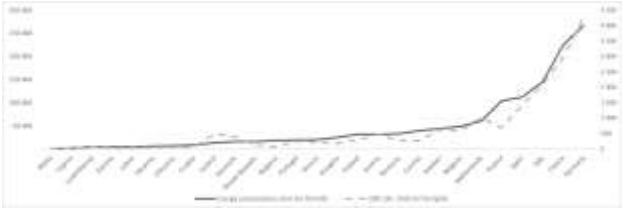

Fig. 7: Volumes of energy consumption and gross domestic product by the EU member countries in 2021
Source: [authors' estimations based on data from [4], [18]]

Looking more closely at the issue of energy independence and efficiency among the EU countries (Fig.8), it can be observed that the size of the economy and the overall level of energy consumption does not necessarily influence the level of energy independence. For example, Malta and Estonia, despite having similar levels of GDP and energy consumption, demonstrate vastly different levels of energy independence. The ratio of imported energy resources to total energy consumption in Malta is 97%, while for Estonia, the share of imported energy resources is only 1% of the total energy consumption.

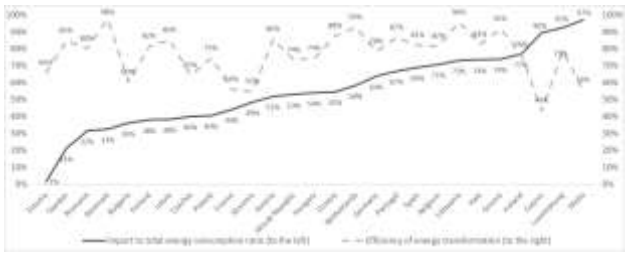

Fig. 8: Volumes of energy independence and efficiency by the EU member countries in 2021
Source: [authors' estimations based on data from [4], [18]]

Given that 65% of the total energy consumption of the EU is accounted for by 5 countries, it can be said that the average level of energy dependence in the EU is 58%. In 2021, the ratio of imported energy resources to total energy consumption for Germany was 64%, France 44%, Italy 74%, Spain 69%, and Poland 40%.

One of the main indicators of a country's energy efficiency level is the efficiency coefficient of transforming traditional energy resources into ready-to-use fuel. The average value of this indicator among the EU countries is 77%, with the lowest value being in Cyprus (44%) and the highest in Denmark.

According to Eurostat methodology, final energy consumption in the EU is divided into three main categories, [4]: industrial energy consumption, transport energy consumption, and energy consumption in other sectors of the economy. As can be seen from the presented Fig. 9, there have been no significant changes among all three categories of energy consumers from 1991 to 2021. Of course, there has been a slight decrease in energy consumption in industry, with an average annual decrease of 1.8 million tons of oil equivalent, while there has been a gradual increase in energy

consumption in the transport sector of the economy with an average annual increase of 1.7 million tons of oil equivalent.

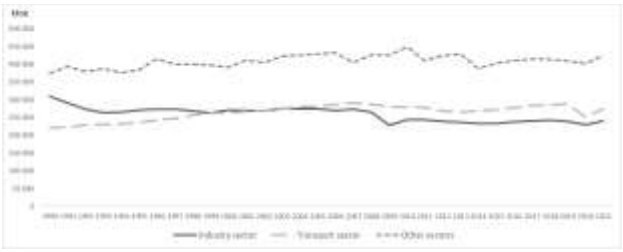

Fig. 9: Dynamics of energy consumption by main sectors of the EU economy, from 1990 to 2021.
Source: [authors' estimations based on data from [4], [18]]

The most diversified energy-consuming sector in the economies of the EU countries is the industrial sector. As shown in Fig. 10, the largest energy consumers in 2021 were the chemical and fuel industry, non-metallic mineral production, paper production and printing, metallurgy, the automotive industry, and the food industry. Together, these types of industries make up 70% of the total industrial sector of the economy.

Comparing the indicators for 2021 and 1991, it should be noted that there has been a decrease in energy consumption by the metallurgical sector and other types of industrial sectors, while there has been an increase in energy consumption by the food and paper industries, according to Fig. 10.

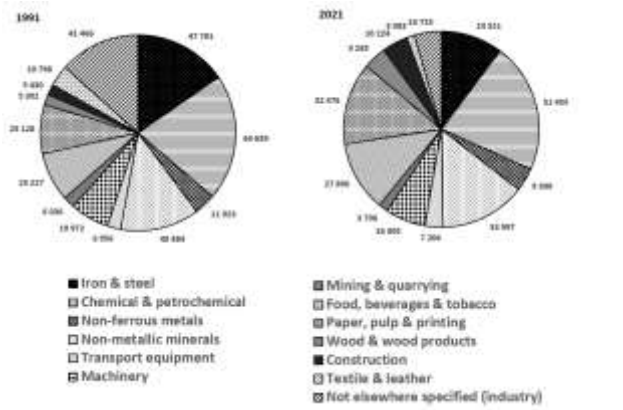

Fig. 10: The structure of energy consumption of the EU Industry according to the Eurostat methodology in 1991 and 2021
Source: [authors' estimations based on data from [4], [18]]

Unfortunately, some Eastern EU countries have long held the opinion that it is acceptable to conduct economic relations with Russia, which has acted as a reliable supplier of natural gas. However, 2022 marked the beginning of a hybrid economic war between Russia and the EU, during which the probability of a complete cessation of natural gas supplies from Russia to the EU has increased significantly.

3.2 Regression Analysis of the Natural Gas and Renewable Energy Consumption

The increase in production and consumption of renewable energy has been of particular interest, and it follows a linear trend, with the explained variance of its dynamics being 95%. Renewable energy, like natural gas, is used to generate electricity, providing a complete substitute for coal-fired power plants. From 1990 to 2020, the consumption of renewable energy in the EU grew by almost 200%.

Consider the regression dependence of renewable energy consumption (y) and solid fossil fuel consumption (x1), among which solid fossil fuel is the dependent variable (Table 1). The coefficient of determination of the linear regression model is 82%, and the coefficients of the model are significant at the level of less than 0.0001. According to the obtained results, it can be stated that with an increase in the consumption of renewable energy by 1, the reduction in the consumption of solid fossil fuels decreases by 0.82.

Table 1. Regression dependence of the consumption of solid fossil fuels in the EU on the consumption of renewable energy in the EU

N	Regression model	R2	S	T0	T1	p0	p1
31	y = 16054 - 0.82x1	0,82	924	35	11	1.8E-25	3.6E-12

Source: [authors' estimations based on data from [4], [18]]
y – Consumption of solid fossil fuels in the EU
x1 – Consumption of renewables in the EU

The analysis of the correlation between the gross domestic product of the EU and the consumption of certain types of fuel is presented in Table 2.

Table 2. Correlation table of consumption of the main types of EU energy resources and the EU gross domestic product

	Solid fossil fuels	Natural gas	Oil	Renewables	Nuclear	GDP
Solid fossil fuels	1,0					
Natural gas	-0,6	1,0				
Oil	0,5	0,2	1,0			
Renewables	-0,9	0,5	-0,7	1,0		
Nuclear	0,2	0,6	0,8	-0,3	1,0	
GDP	-0,8	0,7	-0,5	0,9	-0,1	1,0

Source: [authors' estimations based on data from [4], [18]]

The data presented in Table 2 shows that the consumption of natural gas and renewable energy has a positive correlation with the gross domestic product, at 70% and 90%, respectively. On the other hand, the consumption of solid fossil fuels has a negative correlation with GDP, but this is primarily due to targeted actions by the EU governments to reduce polluting emissions, so interpreting this indicator as having a negative marginal impact on GDP growth is incorrect. The correlation coefficient between GDP and solid fossil fuel consumption, which is -90%, supports the idea of substitution of solid fossil fuels with renewable energy.

Quantifying the impact of natural gas and renewable energy consumption on the EU gross domestic product, we obtain a regression model with a coefficient of determination of 88% (Table 3).

Table 3. Regression dependence of the GDP of the EU on the consumption of natural gas and renewable energy

N	Regression model	R2	S	T0	T1	T2	p0	p2	p1
31	y = -5158 + 0.75x1+ 1.18x2	0.88	1305	2.4	4.18	9.97	0.02	2E-4	1E-10

Source: [authors' estimations based on data from [4], [18]]
y – GDP of the EU
x1 – consumption of natural gas in the EU
x2 – consumption of renewable energy in the EU

The adequacy of the marginal coefficients exists at a significant level of less than 0.001. Thus, an increase in natural gas consumption by 1 Petajoule causes an increase in GDP by USD 0.75 billion, and with an increase in the consumption of renewable energy by 1 Petajoule, the increase in GDP by USD 1.18 billion. Therefore, the marginal impact of renewable energy on increasing GDP is greater than the consumption of natural gas by USD 0.43 billion.

To assess the impact of changes in the energy sector structure on the economic security of enterprises, the dynamics of energy consumption by various sectors of the economy should be considered (Fig. 11).

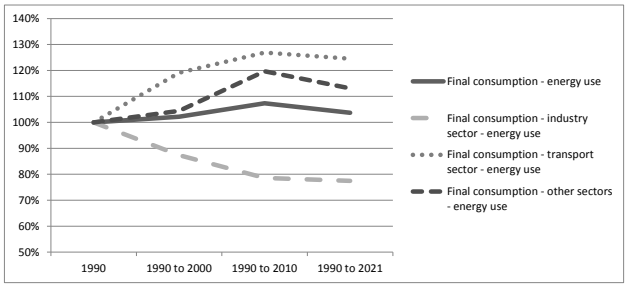

Fig. 11: Dynamics of energy use by the groups of consumption, comparing with 1990
Source: [authors' estimations based on data from [4], [18]]

Fig. 11 data shows that industry is the only sector of the economy where energy consumption decreased throughout the analyzed period. From 1990 to 2010, the industry sector of the EU countries consumed 79% of energy, and this decreased to 77% in 2021. In contrast, the other sectors demonstrated a steady increase in energy consumption until 2006-2010, after which it decreased due to improvements in energy efficiency.

The global changes in the energy consumption of the industrial sector in the EU countries began much earlier and can be traced back to the early 1990s. Changes in energy consumption, detailed by industries, are shown in Fig. 12.

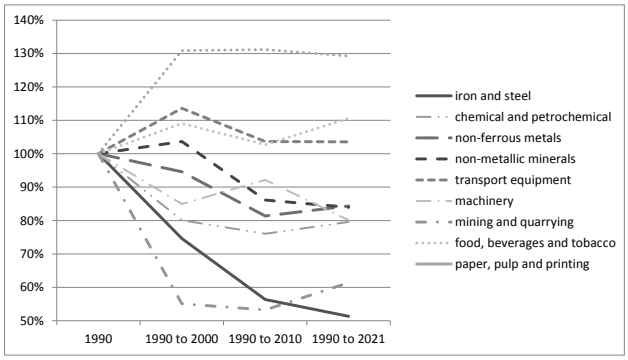

Fig. 12: Dynamics of energy consumption by the groups of industries, comparing with 1990
Source: [authors' estimations based on data from [4], [18]]

The analysis of the data presented in Fig.12 shows that in most industries, overall energy consumption has decreased. The exceptions are the printing, food, and transport industries. However, even in these industries, the increase in energy consumption has been relatively small, and in some cases, there has been a decrease in energy consumption compared to the levels in 2000.

The dynamics of decreased energy consumption in the industrial sector of the EU countries, coupled with an increase in GDP, may suggest that industrial enterprises are becoming more energy efficient or are closing. Further analysis of industrial production statistics shows that in most industries, the level of production has increased over the period from 1991 to 2021, even in energy-intensive industries such as metal production (5% growth), motor vehicle production (47% growth), and mining, among others, [4].

Overall, this indicates that industrial enterprises in the EU have been improving their energy efficiency for a long time, which is having a positive impact on their economic security in the face of potential energy disruptions, such as those caused by the current tensions with the Russian Federation.

4 Conclusion

The article provides a specific analysis of the energy consumption and GDP trends in the EU, with a focus on the role of natural gas and renewable energy sources. The paper also discusses the potential impact of the EU's energy policies on the energy security of other countries, particularly those that are dependent on fossil fuel exports. Additionally, the article uses a combination of descriptive statistics and regression analysis to explore the relationships between energy consumption, GDP, and other relevant factors, providing a more rigorous and data-driven analysis.

The analysis of the EU GDP and Energy Consumption Trends and Regression analysis of natural gas and renewable energy consumption produced several key findings:

- Renewable energy consumption in the EU has increased by almost 200% from 1990 to 2020 and follows a linear trend.
- The negative correlation between GDP and the consumption of solid fossil fuels confirms the shift towards renewable energy.
- An increase in natural gas consumption has a positive impact on GDP, but the marginal impact of renewable energy on increasing GDP is greater than that of natural gas.
- The industrial sector of the EU has been developing towards improved energy efficiency, which has had a positive effect on their economic security in the face of energy blackmail by Russia.
- The transition from pipeline natural gas from Russia to liquefied natural gas from other countries may cause a shortage of natural gas consumption, but this can potentially be offset by restarting coal-fired power plants that were previously closed as part of sustainable economic development goals.
- The possibility of a physical shortage of natural gas supply is driving the EU to develop renewable energy, reduce oil consumption, and transition to electric vehicles more quickly.

There are prospects for the growth of the EU energy security. For a long time (from 2008 to 2020), the EU purchased natural gas from the Russian Federation at prices that were significantly lower than the prices of liquefied natural gas, because of which it had the opportunity to save significant financial resources. Currently, the price of liquefied natural gas in some regional markets is approaching that of pipeline natural gas. The positive price difference between liquefied natural gas and piped natural gas in the past period can now be invested in the construction of liquefied natural gas receiving terminals.

The transition period of the EU's complete transition from pipeline natural gas of the Russian Federation to liquefied natural gas from other countries may be accompanied by a shortage of natural gas consumption, however, the negative consequences of such a transition may be compensated by the start-up of those coal-fired power plants that were purposefully closed for 30 years as part of achieving the goals of sustainable economic development.

In addition, the possibility of a physical shortage of natural gas supply forces the EU countries to develop renewable energy more quickly to reduce oil consumption and switch to the use of electric vehicles.

The industrial enterprises of the EU countries have been developing for a long time in the direction of improving energy efficiency. At present, this has a positive effect on their economic security in the face of energy blackmail by the Russian Federation.

Overall, the EU's progress in improving energy efficiency, transitioning to renewable energy, and increasing the use of liquefied natural gas can help increase energy security and reduce dependence on natural gas supplied by the Russian Federation. However, more action is needed to address the challenges and ensure a sustainable and secure energy future for the EU.

There are key potential directions for further research on the topic: exploring the potential of alternative sources of energy for the EU, such as hydrogen, and other forms of renewable energy, and assessing their economic and environmental feasibility; investigating the impact of energy efficiency policies on the EU's industrial sector and identifying best practices for promoting energy efficiency in this sector; analyzing the role of international trade and global energy markets in the EU's energy security and assessing potential risks and opportunities associated with these factors; examining the impact of the EU's energy policies on the energy security of other countries, particularly those that are dependent on the export of fossil fuels; assessing the potential risks and benefits of increased use of liquefied natural gas in the EU and reducing the environmental impacts of this energy source.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

-Olena Khadzhynova has formulated research goals and aims.
-Žaneta Simanaviciene has designed the methodology.
-Dmytro Zherlitsyn carried out the econometrics modelling and implemented them on statistical data.
-Oleksiy Mints has synthesized study data.
Yuriy Namiasenko was responsible for the statistics.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This research is/was funded by the European Social Fund under the No 09.3.3-LMT-K-712-23-0211 "Transformation of the economic security system of enterprises in the process of digitalization" measure.

Conflict of Interest

The authors have no conflict of interest to declare that is relevant to the content of this article.