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Beyond price shocks: Developing resilience indices for measuring EU energy vulnerabilities

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Abstract: This paper aims to study the effects of geopolitical tensions on the European Union's oil and natural gas markets from 1990 to 2022. The purpose of this research is to critically assess the impact of geopolitical risks on energy security and market volatility. A literature review is conducted, focusing on tensions between Russia and Ukraine over the past two decades, providing evidence and examples of how geopolitical tensions influence oil and gas markets. No other specific geopolitical events are covered within this paper. The review considers current metrics and the effects of geopolitical risk on the international oil and gas markets. The key findings indicate significant vulnerability; analyzing data from the European Commission and other international organizations, this paper concludes that, although progress has been observed in energy efficiency and renewable energy generation, the EU's dependence on fossil fuel imports has increased, while domestic production has declined, despite price volatility caused by previous disruptions.
Keywords: *Energy economics, Energy, Geopolitical risk, Natural gas, Oil, UN SDG 12.*

1. Introduction

There is no denying the impact of geopolitical events on the oil and gas sector, and this impact has been thoroughly researched. One of the primary concerns of governments and businesses involved in this industry is energy security; other major concerns include price variations and supply chain disruptions [1]. Indicators such as the Supply Disruption Index, Energy Dependency Index, and Energy Security Risk Index are developed and used to quantify impact [2-5]. These indicators provide an invaluable resource for methodically evaluating and quantifying the effects of geopolitical changes on energy and industry, as well as for formulating strategic responses to these obstacles. In addition to providing energy for production, transportation, and heating, the oil and gas sector also has a significant impact on international relations and politics [6]. The prices of oil and natural gas can fluctuate, supply chains can be disrupted, and energy security can be threatened by geopolitical tensions, conflicts, and political decisions [7]. Events related to geopolitics, such as trade conflicts, revolutions, wars, and sanctions, can impact the supply and cost of energy both immediately and over time [8]. The development of instruments and indicators that enable measuring the impact of these occurrences is essential for understanding and managing these risks.

International supply chains can be negatively affected by a number of factors, including natural disasters, supply and demand shocks, and geopolitical tensions [9]. European oil markets have been proven to be affected not only by open conflict in oil-producing countries but also by geopolitical decisions such as sanctions [10]. Research has also suggested that fossil fuel-producing nations engaged in conflicts and targeted by sanctions, namely Russia, can also be affected and ought to

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diversify the markets they supply in order to avoid risks [11]. This paper emphasizes the latter disruption factor on the oil and natural gas markets of the European Union, in the years between 1990 and 2022.

Past research has focused on the EU's lack of diversification when it comes to oil and natural gas supplies [12] as well as the risks posed by political instability and other possible disruption factors in supplier countries as well as in regions crossed by transit routes [13]. A prime example of the latter risk is the conflicts between Russia and Ukraine over the past decades, with the latter country being a transit country, and the former being both a transit and a producing country. In January 2006, a disagreement between Turkmenia, Russia, and Ukraine concerning payments made on natural gas transited through pipelines crossing all three countries resulted in the failure of deliveries to European customers. These pipelines, in 2004, transited 80% of Russian gas delivered to Europe [14] with Russian gas amounting to 40% of European imports on 2004 [14, 15]. Three years later, in January 2009, another price and tariff dispute between Russia and Ukraine resulted in halting the pipeline's operation between 7 January and 20 January of that year [16]. The Russian annexation of Crimea in 2014 resulted in the EU applying sanctions on Russian energy companies, further spurring the discussion on energy source diversification as well as European dependence on Russian natural gas [17]. The Russo-Ukrainian conflict in 2022 resulted in the EU imposing stronger sanctions than before, disrupting supply chains and causing price spikes [18]. Studying the effects of EU sanctions on Russia on the performance of EU-27 fossil fuel companies, research suggests that partners outside the EU benefited from acting as substitute sources of oil, LNG, and natural gas, outperforming their EU and Russian counterparts [19].

Widening the scope of the present literature presentation, the work investigates the dynamics of global oil and gas supply chains. It has surfaced that geopolitical risks provide positive net spillover effects on oil and gas markets in the long and medium term, albeit they cause high levels of price instability in the short term [20, 21] evidently, during such periods of geopolitical tensions, the connectedness of markets increases, with new paths being created between the allied blocs' markets [22]. Energy dependence has historically been affected by the "multidimensional proximity" of partners, economic factors such as cost efficiency, and perceived national identities and (dis)similarities [23]. Further research on LNG freight rates and natural gas market connectedness has concluded that it is more pronounced in the short term, with transportation costs (which are not strongly affected by geopolitical risks) being a key factor in the price of natural gas [24, 25]. Disturbances in energy safety provide an initial boost in the consumption of renewable energy, which later dissipates, with a negative impact on the consumption of all types of energy [26]. A special case study for China has revealed a negative effect of geopolitical risks on energy imports in the short term, with a tendency to recover in the long term [27]. After analyzing data provided by the European Commission and other international organizations, this study aims to investigate the quantifiability of the effects of geopolitical events on the oil and gas sector, with particular emphasis on key areas such as price volatility, total oil and petroleum products production and consumption, and energy security [28]. The relevance of various metrics is examined in this context.

2. Existing Metrics and Review

Quantifying the impact of geopolitical geographies on the oil and gas industry is critical to understanding the risks the global economy faces and developing strategies that ensure the stability of energy markets. Known metrics are:

2.1. Price Analysis and Price Volatility Index

Geopolitical potential to cause significant fluctuations in oil and natural gas prices. Price volatility indices (such as the Crude Oil Volatility Index) track daily, weekly, or monthly price changes, as well as market reactions to news related to geopolitical events [29]. Statistical analyses of price movements are

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combined with qualitative price analyses to understand geopolitical tensions and make insights into the necessary decisions and actions to mitigate the impact on the global economy.

2.2. Energy Security

Energy security refers to a state's ability to ensure continued access to energy sources, avoiding interruptions or over-reliance on vulnerable or unstable production areas. Geopolitical tensions increase the risk of energy insecurity, especially for countries that are heavily dependent on oil or gas imports from politically unstable regions.

The Energy Security Risk Index (ESR) is a tool that quantifies the risk arising from geopolitical turmoil [5]. This indicator considers a country's dependence on imported energy, diversity of supply sources, and storage or alternative generation capacity. Countries with high dependence on a particular supplier or a vulnerable region are at greater risk during times of geopolitical instability.

2.3. Supply Chain Disruptions

Geopolitical instability can cause significant disruptions in the energy supply chain. The transportation of oil and natural gas depends on international routes and systems, such as pipelines, ships, and terminals, which can be easily affected by geopolitical events. An example is the conflict in Syria, which cut off pipelines passing through the country, or the attacks on tankers in the Persian Gulf.

To measure the extent of these disruptions, the Supply Chain Disruption Index (SCDI) is used, which quantifies the effects geopolitical events have on energy transport. SCDI can take into account loss of capacity on supply routes, delays in delivery, as well as increases in transportation costs due to geopolitical disturbances [30].

2.4. Price Fluctuations

The price of natural gas and oil can fluctuate significantly due to geopolitical concerns. Examples of factors that can lower supply and drive up prices include Middle East tensions, sanctions placed on major suppliers, and conflicts in important locations for energy trading or production. The sanctions imposed on Iran serve as a prime example of how this reduced supply of oil raised global prices. Using the Supply Disruption Index (SDI), price variations resulting from geopolitical events can be measured.

The SDI measures the change in oil or gas availability due to geopolitical disturbances. A high SDI indicates that the global market is experiencing a severe reduction in energy supply, which is leading to higher prices [31]. This quantification is performed by recording events that impact supply, such as wars, sanctions, or natural disasters, and assessing their effect on prices.

2.5. Integrated Risk Analyses

Even more comprehensive geographic analyses can also be developed, combining political, economic, and technical variables to quantify overall risk and impact. These analyses are usually linked to scenarios that examine potential proposals in specific regions (e.g., the Middle East, Russia, Eastern Mediterranean) and cases in the global energy market.

2.6. Energy Independence Index

This indicator measures the extent to which a country can meet its energy needs from domestic sources or the degree of its energy independence [32]. Energy autonomy can reduce the impact of geopolitical tensions, as domestic energy sources are less susceptible to disruptions caused by international events.

Applying these known indicators to historical data clearly shows how geopolitical events affect oil and gas prices, supply chain disruptions, and energy security. For example, SDI and SCDI rose dramatically during the 2003 Iraq War as the global oil market experienced severe supply disruptions [33]. Similarly, the ESR showed increased risk to Europe during the Ukraine crisis in 2014, as sanctions on Russia and conflicts in the region put natural gas supplies at risk.

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Going a step further, a statistical analysis of indices such as energy import dependency, energy mix, energy production and consumption, energy intensity, and energy per capita, effects of Russian gas supply disruptions are needed to understand the trends and quantify the need to use new indices that reveal new trends, identifying new dependency risks in the world oil and gas market. Quantifying impacts through these indicators provides governments and businesses with a powerful tool for predicting and responding to the impact of geopolitical disruptions. These indicators make it possible to take preventive measures, such as the diversification of suppliers, the increase of strategic energy reserves, and the strengthening of investments in renewable energy sources.

3. Statistical Analysis and Results

3.1. Energy Import Dependency

The following statistical analysis was made with yearly data provided by the European Commission (energy.ec.europa.eu). It concerns the 27 member states of the European Union (as of 2020) for the time period between 1990 and 2022.

The energy import dependency index (Net Imports by Total Consumption) by fuel type (Fig. 1), as calculated by the Commission, reveals a steady increase in dependence on imported fossil fuels of all types since 1990, with the exception of crude and NGL imports, as well as oil and petroleum products import dependency, which remained relatively stable, at values close to (the latter exceeding) 100%.

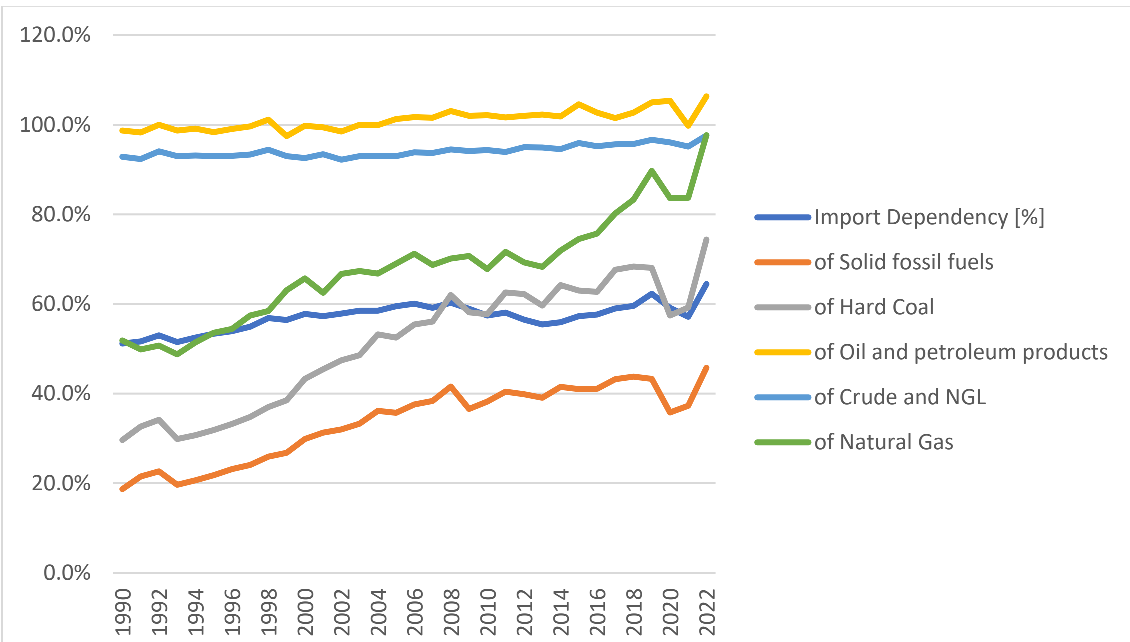

Figure 1.
EU27 – 2020 Energy Import Dependency (%) by Fuel Type.

3.2. Energy Mix

Concerning the energy mix, we observe a successful transition towards renewable energy sources, which in 2023 amounted to 38.2%, compared to 13.3% in 1990. Oil and petroleum products, solid fossil fuels, oil shale and sands, peat, and nuclear power have decreased in importance within the energy mix over the reviewed period, while natural gas and manufactured gases have increased their share (with a decrease in demand observed from 2010 to 2014 and a resurgence from 2014 onwards) (Figure 2).

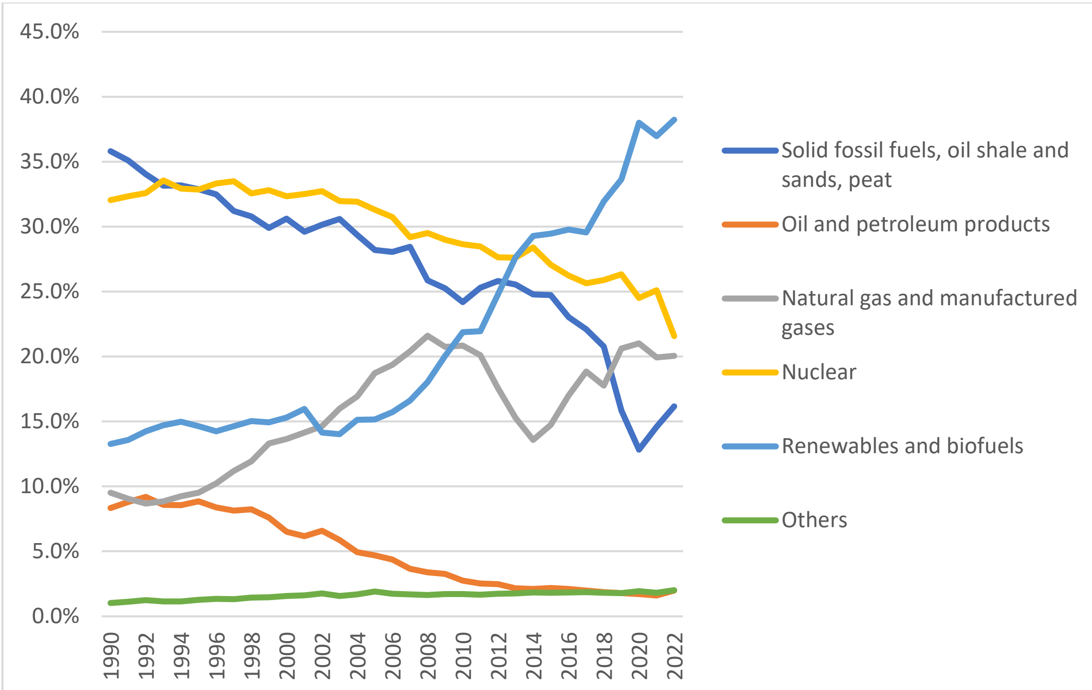

Figure 2.
EU27 - 2020 Energy Mix (%) by Source.

3.3. Energy Production and Consumption

In the following chart (Fig. 3), we can observe energy production measured in Mtoe (by IEA standards) by primary, recycled, and recovered products. Here, we observe a general declining trend in all types of energy products, with the exception of renewables. Combining this information with the increasing energy import dependency, we can deduce that while production drops, consumption must remain constant or increase, which will be verified in the following. We observe that energy production has not been greatly affected by geopolitical events (omitting the 2022 Russo-Ukrainian conflict due to a lack of data); rather, the most decisive disturbances in overall energy production have been the COVID-19 pandemic, the 2008 global financial crisis, and possibly the 1997 Asian financial crisis.

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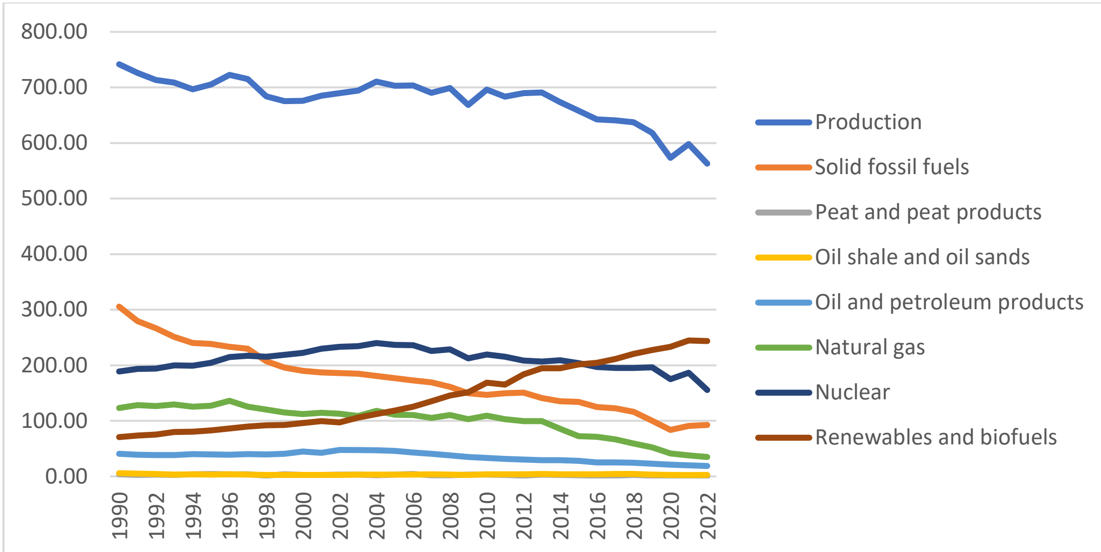

Figure 3.
Energy Production [Mtoe].

In Figure 4, it is observed that, while total energy production has been steadily declining, final energy consumption is increasing, thus increasing the energy products deficit and the need for imports. Note that final energy consumption takes into consideration both transformation and distribution losses.

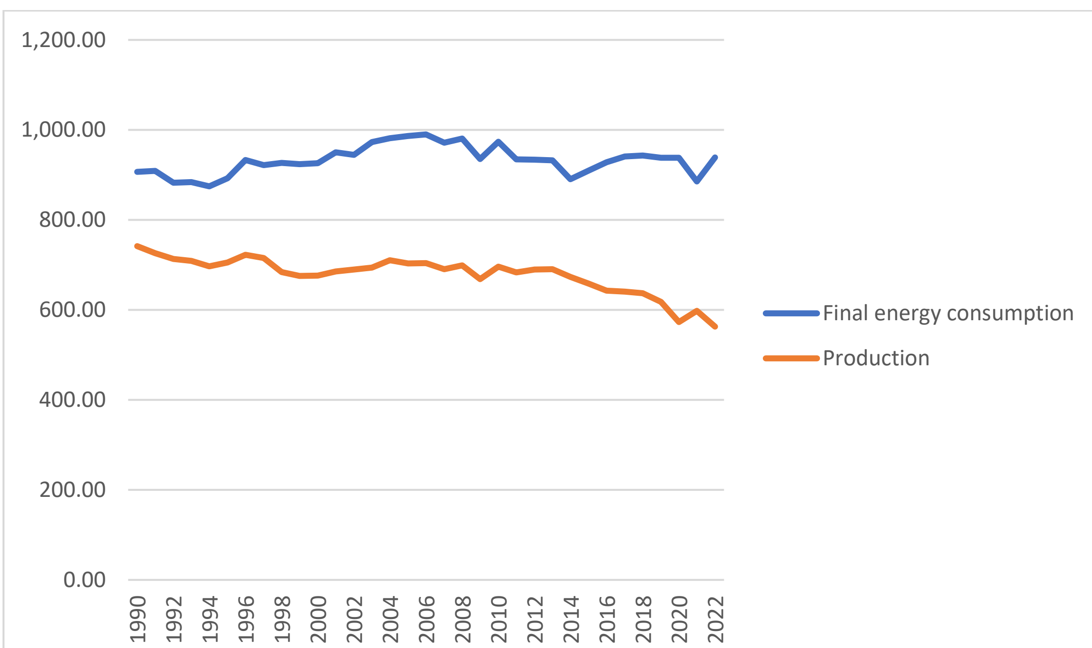

Figure 4.
Total Production and Consumption [Mtoe].

3.4. Energy Production and Consumption in Relation to Energy Commodities' Prices

In this part, we will benchmark the Commission's data with the Europe Brent Spot Price FOB (Dollars per barrel) provided by the US Energy Information Administration, and with the global price of natural gas in the EU (in U.S. Dollars per Million Metric British Thermal Unit), published by the St. Louis Federal Reserve Bank.

Table 1.
Descriptive Statistics for Key Energy Metrics.

	Standard Deviation	Average	Coeff. of Variation
Final energy consumption	31.82	932.78	0.03411
Final Energy Production	41.89	677.99	0.06179
Natural Gas Price	6.68	6.81	0.98003
Brent Price	32.38	51.18	0.63256

Calculating the coefficients of variation (defined as the standard deviation divided by the mean), we can deduce that over the span of 1990-2022, energy consumption has been less prone to variations than energy production. Moreover, Brent prices have been less volatile than natural gas prices, with the latter exhibiting extreme instability, reflecting geopolitical and logistical vulnerabilities in gas markets.

Table 2.
Correlations Between Energy Flows and Market Prices.

Correlation Coefficients	Natural Gas Price	Brent Price
Final energy consumption	0.126	0.298
Final Energy Production	-0.549	-0.349

Calculating the coefficients of correlation, we observe that while energy consumption has a positive correlation with natural gas prices and Brent prices, energy production has a strong negative correlation. This fact cannot allow us to draw any conclusions about the relationships of causation between those variables, but it signifies the importance of international commodities' prices affecting domestic European energy production. While further research is required to answer this question, one possible reason behind these strong negative correlations in energy production could be the cost-efficiency of domestic production. The positive correlation between consumption and these commodities' prices could be due to price increases as a result of demand increases.

3.5. Energy Intensity and Energy per Capita

While energy intensity has been steadily declining from 1990 to 2022, energy per capita has proven to be more resilient, with a significant reduction occurring since 2008. This indicates that although the European economy has been shifting towards less energy-demanding industries, energy consumption per capita has remained relatively stable. Meanwhile, GDP per capita, as reported by the World Bank Group, has been increasing, which suggests that the value chains are becoming more energy-efficient relative to the population (Figures 5, 6, and 7).

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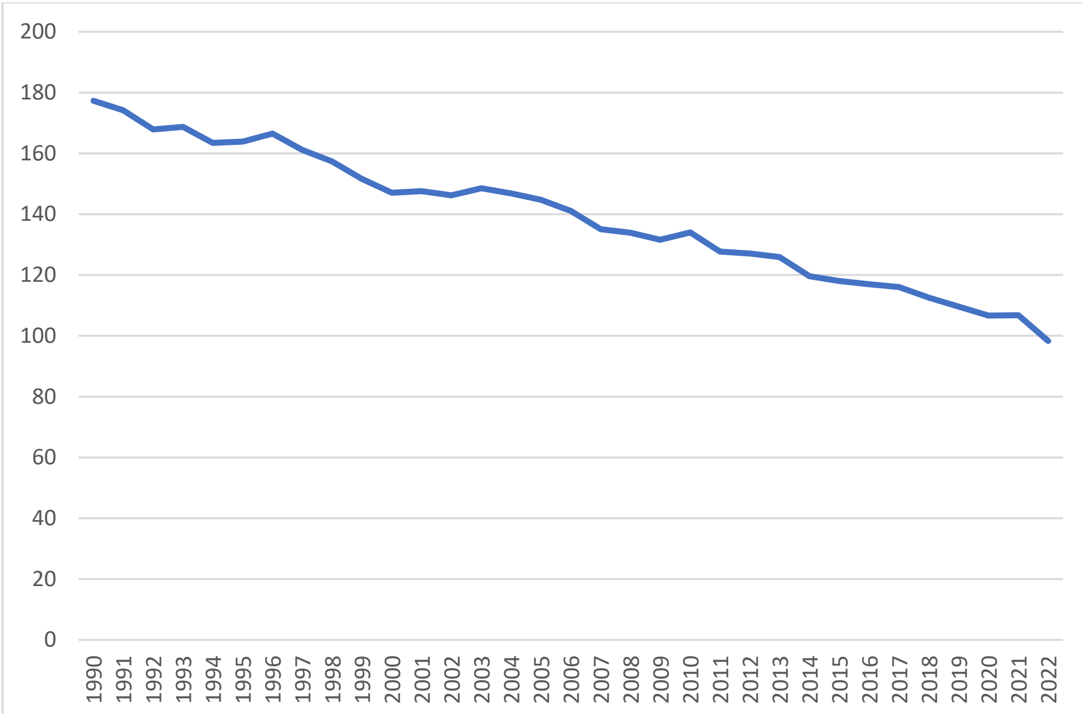

Figure 5.
Energy Intensity (GAE/GDP2015) [toe/M€'15].

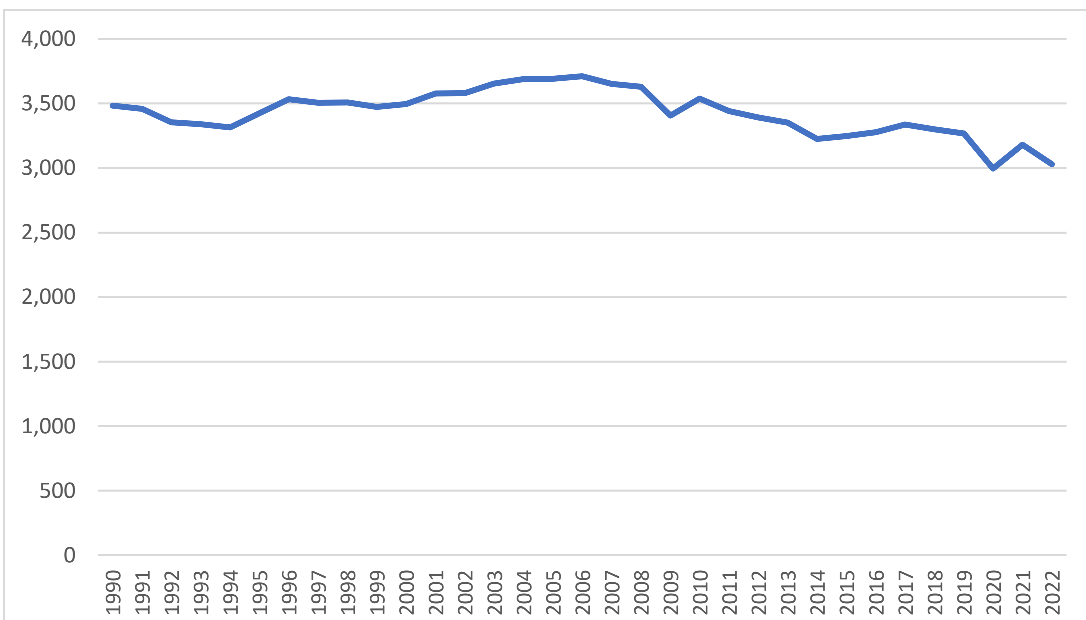

Figure 6.
Energy per Capita (GIC/pop) [kgoe/capita].

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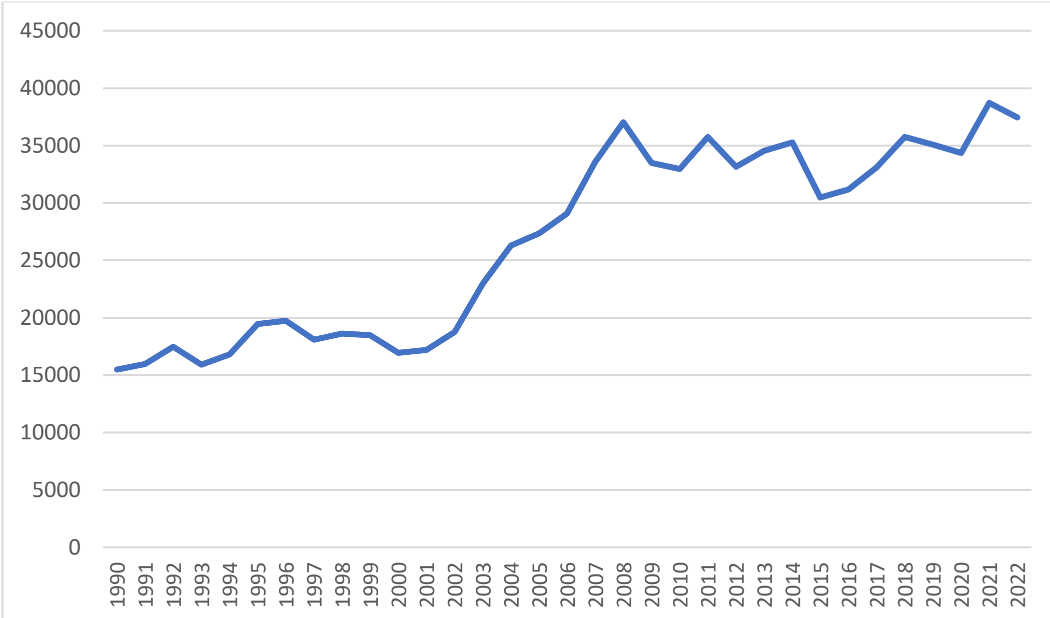

Figure 7.
GDP per Capita (Current USD).

3.6. Effects of Russian Gas Supply Disruptions

Figure 8 was produced with data extracted from the St. Louis Federal Reserve Bank. It provides the prices of natural gas measured in U.S. Dollars per Million Metric British Thermal Units. As can be seen in the graph, past Russian gas supply disruptions were not sufficient to cause major price spikes. Only the disruptions caused by European sanctions, responding to the 2022 Russo-Ukrainian conflict, have had a major effect on natural gas prices.

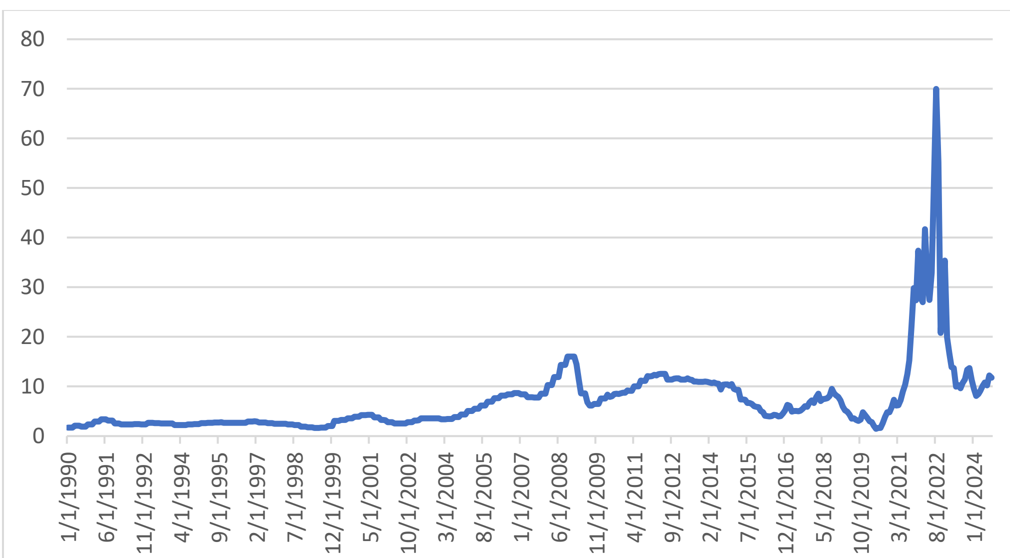

Figure 8.
Global price of Natural gas, EU.

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Statistical calculations of natural gas prices for the landmark years of 2006, 2009, 2014, and 2022, as outlined in the introduction, suggest that volatility did indeed peak in 2022. Although, when comparing the respective coefficients of variation, it could seem as if the 2009 disruptions, it must be noted that the standard deviation was significantly smaller than that of 2022. While both years have the common characteristic of complete halting of Russian gas supplies, the 2009 disruptions lasted only for 13 days, while the 2022 ones would be of a more permanent nature. The similarities in the coefficients could be a result of the global crises that preceded these years (the Global Financial Crisis and the COVID-19 Pandemic).

Table 3.
Temporal Trends in Prices: Volatility and Average by Selected Year.

Year	Standard Deviation	Average	Coeff. of Variation
2006	0.38272	8.213	0.046602
2009	3.38212	8.855	0.381945
2014	0.39948	10.463	0.038179
2022	14.41433	37.519	0.384179

3.7. Further Energy Indices

In this section, the authors attempt to create a few indices with data drawn from the aforementioned sources and compare their values with the findings in the sections above, where possible.

The first index is the Crude Oil and NGL Production, divided by the total oil and petroleum products (all measured in Mtoe). This index aims to provide a measure of the risk faced by domestic refineries in case of shortages of foreign supply. The lower the index's value, the greater the risk of disruptions in the domestic refining industry, creating risks of increased unemployment as well as stranded assets related to this specific industry. The other possible uses of crude oil and NGL are not considered, and therefore, this index provides an inaccurate approximation of the situation at hand. Moreover, the total demand for oil and petroleum products is also not taken into account. The idea behind this index is that in case of international shortages, it should represent the ability of the common market to at least provide a minimum quantity of oil and petroleum products, in order to support some of the essential functions until a solution to the shortage problem is found (Figure 9).

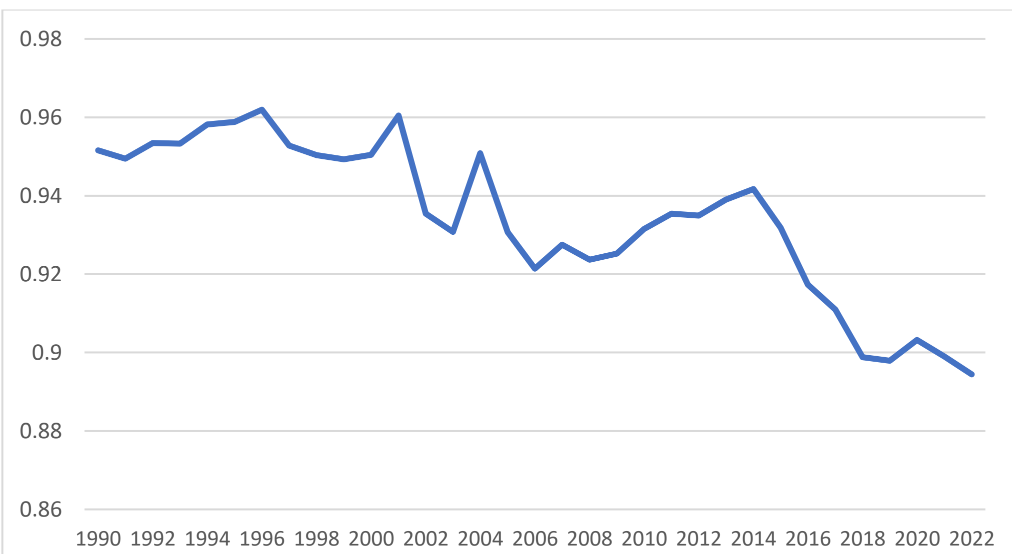

Figure 9.
Crude/Total Index.

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We observe that the index has declined from 0.95 in 1990 to 0.89 in 2022. By taking into account the findings of section 2.3, we conclude that crude oil production within the EU has been declining at a faster rate than the oil refining sector, leaving the latter more exposed to international shortages risks. Nevertheless, the value remains high enough to support the refining sector with domestic raw resources production. Another possible version of this index would be to multiply it by the difference between total oil and petroleum products production and consumption, divided by the total consumption ($\frac{Production - Consumption}{Consumption}$, *the percentage of consumption that production covers*). Thus, considering the capabilities of the domestic market to supply these refined resources and the sector's dependence on imports at the same time.

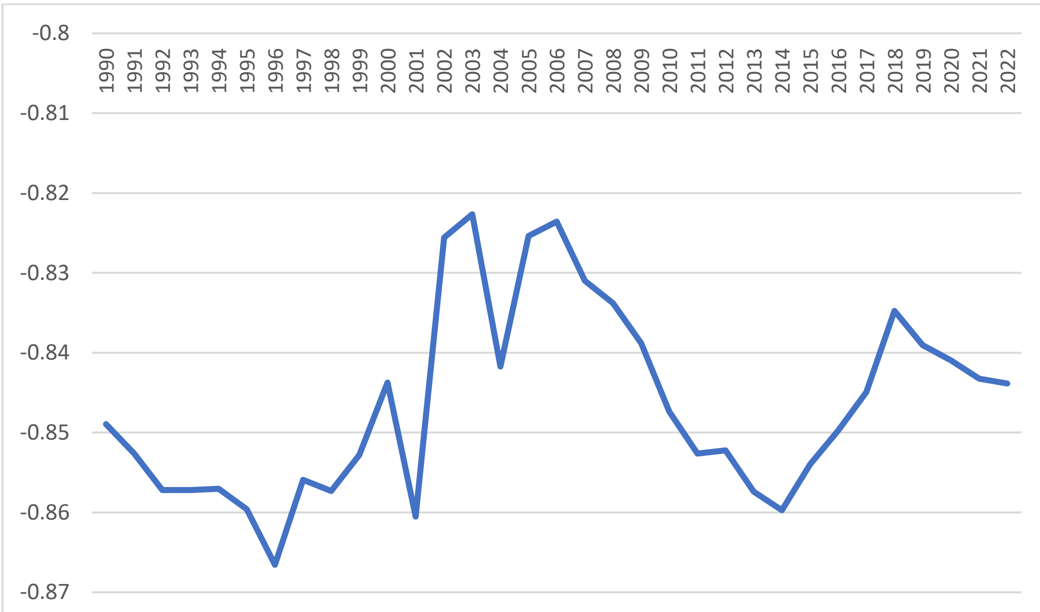

Figure 10.
Crude/Total Index Variation.

The negative values of this index (Fig. 10) signify a reliance on imports, and its values should be a rough estimate of the percentage of total oil and petroleum products that need to be imported, taking into consideration the domestic refining industry.

Another index would be the Total Losses/Gross Available Energy index, where Total Losses are the sum of the distribution and transformation losses, and Gross Available Energy is the energy products supplied in the market for any use (not only as energy plant fuels). This index should provide information on the efficiency of energy distribution (including imports), use, and production systems, signifying the Mtoe worth of losses per Mtoe available in the market. Multiplying this index by the Energy Intensity index should provide an approximation of the energy losses costs in terms of GDP, meaning the GDP units lost due to energy losses.

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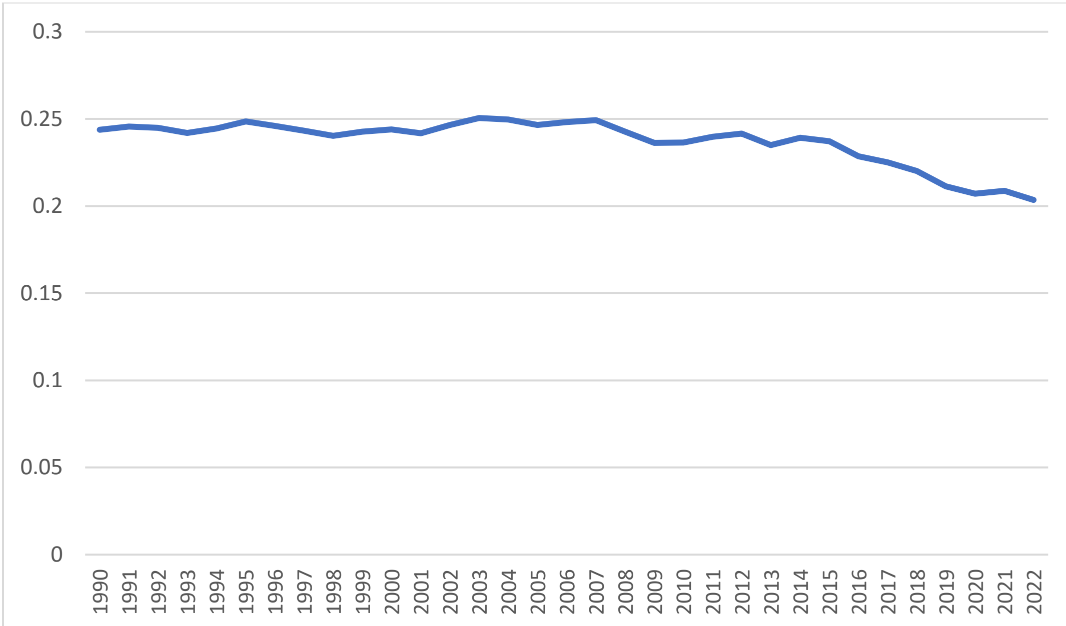

Figure 11.
Loss/Gross Available.

This index shows a declining trend from 2007 onwards (Fig. 11), reinforcing the arguments made in the previous section. From 24.38% of gross energy lost in 1990, 20.35% was lost in 2022. Now reviewing the index multiplied by energy intensity (Fig. 12).

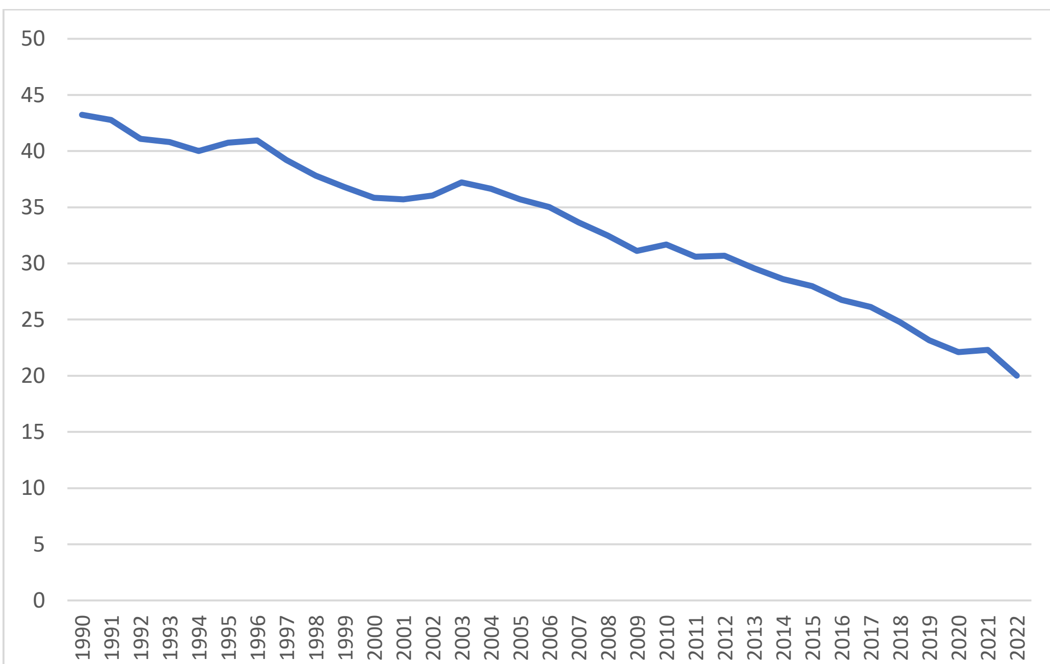

Figure 12.
Loss Cost Index

This index has been declining faster than the "Loss/Gross Available" index, signifying a decreasing energy loss cost measured in toe/M€'15, in other terms, for every million euros (with 2015 as the basis year) added in the European economy's value, how many millions of tons of oil equivalent of energy were lost. From 43.23 in the year 1990 to 20 in 2022. This decline is thanks to the decreasing energy losses observed, but mostly thanks to economic growth, as can be deduced from the growth of GDP per capita, as seen previously.

4. Conclusions

The European economy is becoming increasingly dependent on energy imports, despite the geopolitical tensions experienced in the past decades and their effects on natural gas prices. Geopolitical risks and their subsequent supply chain disruptions have not jeopardized the share of natural gas in the energy mix of the European Union, while other fossil fuels have been declining, giving way to an increasing renewable energy share in the mix. The importance of natural gas as an energy source has been increasing as well. Oil and petroleum products have been steadily decreasing and have retained the status of one of the smallest contributors to the mix, lately becoming the smallest. Both primary and refined total energy production have been diminishing, while renewable energy sources' production has increased significantly, whereas consumption has not appeared to follow the same downward trend. Moreover, the final energy production appears to be moving contrary to market forces, diminishing while fossil fuel prices increase, with consumption following the opposite direction. Energy efficiency indices have been improving in the past decades, without this fact being apparent on the energy dependence indices. The novel indices proposed within this paper suggest an increase in the risk faced by the fuel refining sector and stable levels of import dependency on this sector's products. The past fifteen years have seen a decline in energy losses within the European market, as well as a decline in their effect on the GDP of the 27 member states.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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