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The relationship between macroeconomic variables and oil prices and analysis of global oil prices

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Abstract

This study unravels the complex web of factors influencing OPEC crude oil prices, going beyond the immediate impact of isolated events. To this end, it has developed a multifaceted approach that uses nonparametric regression, correlation analysis, ARIMA forecasting, and spatial analysis with ArcGIS in a combined and integrated manner to reveal the interaction of variables that make up the family of macroeconomic factors and oil prices. The analysis confirms the expected positive correlations between oil prices and factors such as inflation, exchange rates (when the local currency weakens), and GDP (indicating increasing demand with economic growth). But it also explores the more complex relationship between oil production and price. Through the use of visualizations and forecasts, the study offers valuable insights into these relationships and provides projections for future price movements. This comprehensive approach provides a richer understanding of the multifaceted influences on oil prices, informing the decisions of policymakers, industry leaders, and investors navigating the complexities of the global oil market.

1. Introduction

Crude oil remains the epitome of great energy and is one of the most traded commodities in the world. Its price volatility has had a major impact on the macroeconomic stability of the country, both for oil-producing and non-producing countries (Berument et al., 2010). The formulation of a government's fiscal strategies is significantly influenced by oil price trends (Al Jabri et al., 2022). Most sectors of the economy, such as the automotive, transportation, and airline industries, link their operational success to fluctuations in the price of oil. Meanwhile, accurate oil price forecasting is considered essential for efficient planning and decision making in macroeconomics. This is because price forecasting is complicated by various factors such as political, economic, and regional stability in oil-exporting countries, economic sanctions, and trade conflicts (Xu et al., 2023). This simply shows the difficulty of predicting oil prices, as major events such as the drop in crude oil prices caused by the Covid-19 pandemic have occurred. Today, such oil prices have risen to levels not seen for many years, symbolizing a volatile face of the oil market (OPEC, 2024).

The relationship between oil price and macroeconomic variables has continued to mark an important area of study in economic studies, reflecting the proper role that oil plays in the international economy (Guo et al., 2022). Changing oil prices have been found to have far-reaching effects on everything from GDP growth rates to inflation, exchange rates, balance of payments, interest rates, and unemployment rates (Mukhtarov et al., 2020).

Starting from GDP, the movement of oil prices must have different effects depending on the conditions that exist for a country as an exporter or importer of oil (Charfeddine et al., 2020). Higher oil prices typically lead to higher production costs and more money for consumers to spend on energy, resulting in less spending on non-energy goods (Alsalman, 2021). In contrast, oil-exporting countries may experience an increase in GDP due to higher oil revenues. The impact on inflation is much clearer. Typically, higher oil prices lead to cost-push inflation, as the higher transportation and production costs are passed on in the final prices of most goods and services (Wen et al., 2021).

Another important area strongly affected by oil prices is the exchange rate. In oil-exporting countries, high oil prices can strengthen the national currency as foreign exchange earnings increase; however, in the case of oil-importing countries, it could leave their currencies worse off, most likely depreciating due to larger trade deficits (Kilian & Zhou, 2022). Exchange rates are also affected by such movements through changes in investor sentiment and speculative positions in global financial markets (Demirer et al., 2020). In general, the increase in

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the price of oil causes the current account balance of oil importers to deteriorate and that of oil exporters to improve. However, the overall impact on a country's balance of payments is subject to the interaction that currently exists between the current account and the capital account (Chang et al., 2023).

In addition, the price of oil affects other macroeconomic variables such as interest rates and unemployment. Thus, the need for central banks to raise interest rates to combat high oil price inflationary pressures may lead to different shifts in employment in sectors that affect the energy, manufacturing, and transportation sectors. The net impact on unemployment will thus be determined by the balance between job creation in some sectors and losses in others, which in turn will depend on the ability of the economy to adjust to changes in energy prices and the effectiveness of policy responses (Kocaarslan et al., 2020).

Current estimates put global oil consumption at up to 95 million barrels per day (OPEC). The scope of crude oil price forecasting is wider than we think, the forecast used applies to large and small industries and countries that benefit from the predicted prices. Thus, a comprehensive analysis of oil price changes is highly needed to get a clear perspective on the changing global economic dynamics, especially regarding the critical place of oil in energy markets and national economies (Hong et al., 2024). Econometric models have been developed over time for this purpose: to accurately predict a complex and volatile oil price by applying different methodologies. Notable among these are nonlinear regression analysis (He, 2020), nonparametric regression analysis (Lin & Xu, 2021), and ARIMA models (Ariyanti & Yusnitasari, 2023), each of which attempts to capture the nuances of oil price movements with different analytical tools.

Nonlinear regression analysis, a very important tool in studies involving oil prices, can model very complex behaviors that the linear models might not capture (Safari & Davallou, 2018). The method does not assume linearity between variables; therefore, it has provided sufficient insight into the multiple factors that influence oil prices. Among these dynamics, studies have provided some insight into how market sentiment, geopolitical tensions, and economic indicators interact in complex ways to define the dynamics of oil price movements using nonlinear regression (Moshiri & Foroutan, 2006).

On the other hand, the nonparametric regression analysis brings out a very flexible framework where it does not assume a pre-specified functional form for the independent relationship between dependent and independent variables (Álvarez-Díaz, 2020). In particular, the method follows the natural structure of the data in cases such as the analysis of oil price fluctuations, without imposing a model assumption. Research using nonparametric regression has demonstrated its ability to reveal subtle patterns in oil price data, providing a nuanced understanding of market dynamics (Zhu, 2013). However, the method's strengths are offset by challenges in bandwidth selection and computational requirements, particularly for large datasets.

ARIMA models have been widely adopted for their effectiveness in forecasting time-series data, including oil prices (Ahmed & Shabri, 2014). By integrating autoregression, differencing to achieve stationarity, and moving averages, ARIMA models excel at capturing time dependencies and trends in oil prices. The literature is rich with examples of the application of ARIMA in oil markets, where it has been praised for its predictive accuracy (Tularam & Saeed, 2016). Nevertheless, ARIMA models are not without limitations, as they assume linearity and require the underlying data to be stationary, conditions that are not always met in the volatile oil market.

The following sections provide a more comparative look at the specifics of the advantages and limitations of these econometric methods, which certainly require a very careful choice of methods based on specific forecasting objectives and data characteristics. Recent developments in econometric modeling, integrating machine learning models and hybrid models, open very promising avenues for improving forecasting accuracy beyond what has been possible so far with traditional approaches (Safari & Davallou, 2018).

Geographic Information Systems (GIS) are an effective system for analyzing the distribution of data. GIS refers to a complex set of software and methodologies used to collect, store, manipulate, analyze, manage, and visualize spatial or geographic data (Erdogan et al., 2022). Essentially, GIS is a tool that visualizes the earth and its phenomena in a digital form so that raw data is transformed into something more understandable and accessible through eyes in a plane (McHaffie et al., 2023). This system supports the integration of statistical analysis and database technologies into an environment for spatial analysis and mapping (Ali, 2020).

These price changes are analyzed using GIS, a very sophisticated combination of technology and economics that provides a multi-dimensional view of a very complex market. This can be combined with economic indicators in spatial data to further show and analyze the geographic distribution of oil reserves, production facilities and transportation networks under fluctuating oil prices. In other words, such space-time analysis helps to detect patterns and trends that would otherwise be missed by conventional statistical methods (Erdogan et al., 2022). For example, it can help identify areas where political risks or logistical constraints may disrupt supplies and thus affect prices. In fact, overlaying environmental data predicts the impact of either regulatory changes or environmental incidents on oil production and thus its prices (Mahmood & Furqan, 2021). This is a powerful predictive tool to tell the future movement of price under different scenarios, including changes in demand, technological changes, and shifts in political landscapes, all due to the dynamic mapping and modeling capabilities of GIS (Balogun, 2021). In this way, GIS is one of the most powerful weapons in the arsenal of analysts and policymakers to make more informed decisions, as it provides a comprehensive and deep insight into the factors that drive changes in crude oil prices.

This connection between oil prices and various macroeconomic variables can be understood in a holistic manner. All these dynamics can be largely quantified using econometric models and empirical analysis, further shedding light on how economies deal with the problems posed by oil price volatility and change.

The aim of the study is to examine how the evolution of the world oil price is related to, and possibly influenced by, certain selected macroeconomic variables. This will identify the factors that make up the relationship, the parameters that affect them, and the reasons for changes from past to present in the oil price. For the change in oil price, the way and changes would be inquired, and the relevant method would be applied with the chosen method of analysis. In addition, the use of GIS map production techniques will enable the change in data over time to be revealed. It will thus explain the global effect on countries guided by the changes occurring in the prices of oil.

2. Method

In this study, we examine the major events that have occurred over the past four decades that could affect the crude oil market. To do this, daily closing prices for the benchmark crude oil price are obtained from online data-sharing platforms such as OPEC. It consists of opening, high, low and closing prices, but only the closing price is used in the analysis. The data is sorted from oldest to newest and outliers that may affect the data analysis are removed.

2.1. Data

This study uses monthly and annual oil price data provided by OPEC. The data are available from 1972 to 2022 (Figure 1).

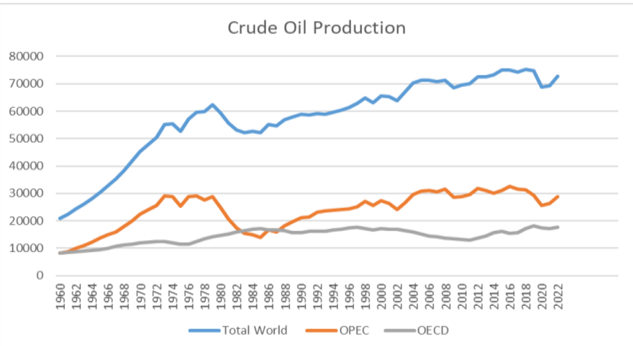

Figure 1. Crude oil production changes (produced from the OPEC data)

The collection and analysis of monthly crude oil price data, as well as related time series such as inflation rates, GDP growth, and exchange rates, is of great importance in various sectors of the economy (Figure 2). For economists and policymakers, these data are a benchmark for understanding economic trends and designing monetary and fiscal policies to stabilize and stimulate the economy. Fluctuations in crude oil prices have a direct impact on inflation, affect trade balances, and thus affect the overall health of the economy. By closely monitoring these changes, policymakers can adjust monetary policy in advance to counter inflationary or deflationary pressures.

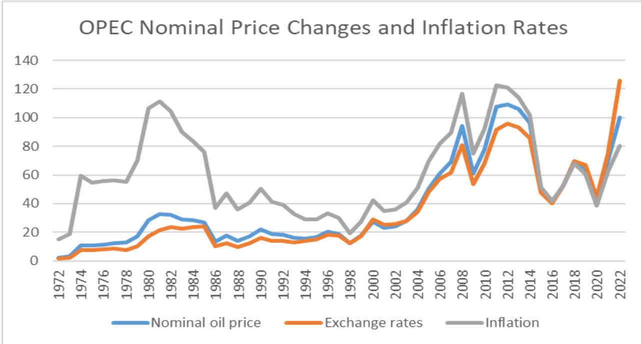

Figure 2. Price and Inflation changes in OPEC countries (produced from the OPEC data)

In addition, monthly crude oil prices are an investor's and financial analyst's toolkit for making wise decisions about various types of investments. Oil is so central to the global economy that its price fluctuations can reverberate through stock markets and investment portfolios to indicate broader economic trends. These price swings therefore have a direct impact on the energy sector, and investors in this industry must either change their strategies to hedge against potential losses or take advantage of emerging opportunities.

This data is needed by companies, especially those in sectors directly affected by oil prices, such as transportation, manufacturing, and agriculture. This forecasting capability helps companies to hedge against further price volatility and to better manage their costs to remain competitive.

In the same vein, monthly data are used to identify the causes of price changes, and annual data are used to analyze OPEC's spatial data on crude oil. Monthly data go back to 1983, while annual data go back to 1972. Therefore, monthly data will be a very good reference to identify geopolitical events that cause a sudden change in oil prices.

To follow this change analysis and relate price changes to historical events, the price change graph in Figure 3 is used.

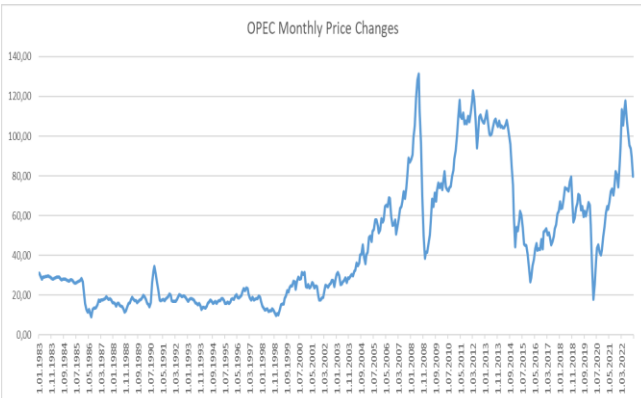

Figure 3. OPEC Monthly Price Changes (produced from the OPEC data)

2.1.1. October 1985 – April 1986

Crude oil prices ranged from $28 to as low as $9 during the period from November 1985 to April 1986.

The reasons that were attributed to such a massive drop were varied in nature, such as OPEC's change in strategy, large production of oil, weak global demand for oil, and technological advancement with alternative sources along with geopolitical factors. OPEC decided to increase production, while Saudi Arabia increased its own production to levels far beyond what was necessary to maintain its market share. Rising economic growth and an increased focus on energy efficiency reduced demand, while the discovery of new fields and the development of alternatives added supply to the system. At this point, the geopolitical conjunctures may be smooth, but very strong indirect impact on the global economy and repercussions on the respective energy policies. All of this combined to create a serious oversupply that caused prices to fall sharply and had a very deep impact on the global oil markets.

2.1.2. June 1990-November 1990

Between June and November 1990, the price of crude oil shot up from $14 to a monstrous $34 due to Iraq's invasion of Kuwait on August 2, 1990. There were many reasons for this, including the disruption of oil supplies from Kuwait and Iraq, heightened geopolitical tensions in the Middle East and international reactions, and uncertainties caused by U.S. speculation and market psychology. Other important reasons include insufficient strategic reserves and supply adjustments, as well as OPEC's limited effectiveness in managing the crisis. These factors caused oil prices to rise rapidly and raised fears of supply disruptions in the market. In January 1991, the outbreak of the Gulf War exacerbated the situation. However, this was really a period of rapidly rising prices, especially with the shock of the invasion and the uncertainties it created.

2.1.3. November 1990-March 1991

The decline in crude oil prices from $34 to $17 between November 1990 and March 1991 is closely linked to the end of the Gulf War and the reduction of immediate threats to oil supplies from the Middle East. During this period, the quick victory of the U.S.-led coalition and the absence of major damage to Kuwaiti oil production facilities reduced fears of an expected prolonged disruption of oil supplies. Factors such as Kuwait's resumption of oil production, the use of the Strategic Petroleum Reserve, reduced demand, and economic stagnation, reduced speculative activity, and OPEC countries adjusting production all contributed to lower prices. These factors helped to stabilize the market and return prices to levels that better reflect global supply and demand dynamics.

2.1.4. January 1997-January 1999

As a result, crude oil prices fell from $23 a barrel in January 1997 to $10 a barrel in January 1999, in part due to the Asian financial crisis, which caused economic contractions in Thailand, Indonesia, South Korea, and Malaysia, as well as sharp declines in regional oil demand. Meanwhile, non-OPEC oil production increased, and OPEC itself faced challenges in establishing production discipline. At the same time, supply received a technological boost from oil exploration and production, and these gains coincided with a lack of sufficient demand due to a strong US dollar and warm winters in the northern hemisphere. This also pushed prices down through market speculation and a delayed response from OPEC. This was a period of great sensitivity to global economic conditions and technological improvements.

2.1.5. February 1999-September 1999

Between February 1999 and September 2000, a confluence of events drove crude oil prices from $10 to $30 per barrel. Key developments that have been cited as the most important causes of this price movement period include OPEC cuts, economies recovering from the AFC, strong global economic growth, increased demand for heating oil and diesel, and market speculation. Other important factors include technical and investment factors within the oil industry and geopolitical tensions. Prices were higher, driven by a cocktail of factors that included decisions by OPEC and some non-OPEC producers to cut production, the economic recovery in Asia, and global economic growth that boosted energy demand. A cold winter and higher demand for diesel, speculators entering the market, geopolitical uncertainties, and the decline in exploration and development investment that has delayed new supply have all pushed prices higher. These are the sophisticated dynamics that underlie the speed at which price changes occur in energy markets and how many factors can have a very strong impact on prices.

2.1.6. November 2000-November 2001

Between November 2000-November 2001, the fall in crude oil prices from $31 to $17 was a result of several combined factors such as the global economic slowdown, the September 11 terrorist attacks, growth in oil production and OPEC's below-average production, improvements in energy efficiency and technology along with market sentiment and speculation along with the possibility of strategic exploitation of oil reserves. This would lead to reduced demand for oil at a time when it was falling in the USA and slowing in different major economies. Economic uncertainty also increased after the attacks, and the reduction in air travel affected the demand for jet fuel, and thus crude oil. Major increases in production, to which OPEC's initial response was inadequate, would have put too much supply on the market, while technological advances and improvements in energy efficiency would also have put downward pressure on oil prices. Speculative trading and outflows from the Strategic Petroleum Reserve would have exerted more pressure than necessary at the level of demand indications. This chain of events led to a significant decline in crude oil prices.

2.1.7. May 2003-October 2004

Between May 2003 and October 2004, the price of crude oil rose by $25 to $45 due to a massive combination of factors. Economic growth around the world was more widely felt, with the U.S. and China experiencing tremendous growth, creating massive demand for oil. Increasing geopolitical tensions, most acute in the Middle East and other oil-producing regions, had raised concerns about supply disruptions. Other factors that contributed to the rise in prices included limited spare capacity and market speculation. In addition, there was the fact of the depreciation of the US dollar, OPEC's production policy and, apart from all this, concerns about refining capacity. This period vividly illustrates the dynamics of supply and demand, combined with geopolitical and economic factors, and how they can sometimes affect oil prices.

2.1.8. December 2004-August 2006

Between December 2004 and August 2006, crude oil prices rose from $35 to $69. The rise was the result of a cocktail of factors, including global economic growth, political tensions around the world, limited spare production capacity, and increased investment and speculation in the markets. Others include supply disruptions and concerns over Iran's nuclear program, energy and investment policies, and market dynamics and psychological factors. This period, characterized by continued expansion in the advanced economies along with Chinese growth, boosted oil demand, while geopolitical events in Iraq, Nigeria and Venezuela raised supply concerns. Large oil price spikes during this period followed the events of September 11, 2001, and were catalyzed by natural disasters such as Hurricane Katrina and international tensions over Iran, which increased supply risks. In addition, such high prices raised further questions about the security of energy supply and the level of investment in new production capacity. In addition, the combination of rising demand, supply constraints and market speculation exacerbated the upward pressure on prices.

2.1.9. January 2007-July 2008

From January 2007 to July 2008, a cocktail of factors caused the price of crude oil to rise from $50 per barrel to $131 per barrel. During this period, a new wave of strong economic growth, particularly in China and India, fueled increased demand. Geopolitical tensions, as well as the lack of spare production capacity in the Middle East or Nigeria, have increased supply concerns, which could push prices higher. The fall in the US dollar means that oil is cheaper in other currencies, increasing demand for the fuel. Speculative trading activity drove prices higher, with both futures markets and market sentiment acting in tandem. The main factors that pushed prices to their highest levels ever by mid-2008 were technical problems, which, in addition to political instability, led to supply disruptions and ever-increasing production costs. However, in the second half of 2008, it was the global financial crisis that triggered a sharp drop in demand and, consequently, in prices.

2.1.10. July 2008-December 2008

Between July and December 2008, the price of crude oil fell from $131 per barrel to $38 per barrel, influenced by a sharp decline in economic activity and oil demand. Prices had fallen sharply due to several other factors, including the impact of the financial crisis in world and economic recession and the resulting strengthening of the U.S. dollar, which led to a flight from commodities. OPEC's delayed response, coupled with a sharp rise in oil production and inventories, also had a devastating effect on market psychology and led to a destruction of demand. These factors illustrate how quickly the oil markets can react to changing economic conditions, market sentiment and geopolitical developments, and how quickly the price can change.

2.1.11. January 2009-April 2010

From January 2009 to April 2010, the price of crude oil rose from $40 per barrel to $82 per barrel due to several factors. These include economic stimulus from the global financial crisis, rising demand, OPEC production cuts, the weakness of the U.S. dollar, speculative investment, and other factors such as inventory adjustments, geopolitical tensions, and improvement in financial markets. The period highlighted the impact on oil prices: the fragile recovery in the global economy, OPEC's production policy and speculative investments that may have helped shape market expectations. It has shown a sharp increase from the sharp fall in prices witnessed in the second half of 2008, therefore global economic conditions and supply and demand dynamics are the key determinants of price movements.

2.1.12. July 2010-April 2011

Between July 2010 and April 2011, the price of crude oil rose from $72 to $118 based solely on global supply and demand, geopolitical tensions, market dynamics, and speculative investment that accumulated around it. During this period, the recovery of the global economy, particularly the growth of China and India, boosted oil demand, while anti-government protests, also known as the Arab Spring, depressed production, especially in oil producer Libya, raising supply concerns. The weakness of the U.S. dollar increased the demand for oil against other currencies and thus its price, as the dollar is the world's currency in oil denomination. Speculative investments put upward pressure on prices by influencing market dynamics. Geopolitical factors and supply concerns in the MENA region, along with OPEC's production policies, pushed prices significantly higher. This period is well represented in the sense that the price of oil can really spike when a number of different reasons combine to push prices up; no single reason for the spike.

2.1.13. March 2012-June 2012

Between March 2012 and June 2012, crude oil prices fell from $123 to $94 per barrel. In addition to global economic concerns, such as the European debt crisis and slowing growth in China, other important factors included a stronger US dollar against other currencies, increased oil supply, strategic releases of oil reserves and easing geopolitical tensions, changes in market sentiment and speculative trading, technical factors, and price corrections. These developments, together with lower demand expectations and perceptions of adequate or increasing supply levels, have thus driven prices lower, reflecting the sensitivity of oil to changes in the economic outlook, geopolitical developments, and market dynamics.

2.1.14. June 2014-January 2016

Crude oil prices plummeted from $108 per barrel to $26 per barrel between June 2014 and January 2016, one of the steepest selloffs in modern history. Some of the reasons include increased shale oil production in the United States, a market share strategy by OPEC, as well as weak global demand and the strengthening of the U.S. dollar. All these factors have, to some extent, affected the global economy, energy companies and oil-dependent countries in ways that will lead to adjustments in the energy sector and a rebalancing of the market in the coming years.

2.1.15. January 2016-October 2018

Between January 2016 and October 2018, crude oil prices rose from $26 to $79 per barrel, driven by several factors. These include OPEC and non-OPEC production cuts, global economic growth, declining US shale oil production, geopolitics, market sentiment and speculative trading. Lower global growth will also be reflected in global oil inventories, fluctuations in the U.S. dollar, and increased investment in oil infrastructure. This period has been indicative enough of how oil markets operate in cycles and how the price level is significantly affected by the supply/demand imbalance, geopolitical conditions, and the general pulse of the markets.

2.1.16. October 2018-April 2020

Between October 2018 and April 2020, the price of crude oil fell from $79 to $17 per barrel. This was a massive drop due to a combination of several factors, such as a global economic slowdown, fears of oversupply, trade disputes between the US and China, concerns about storage capacity, and of course the price war between Saudi Arabia and Russia, in addition to negative oil prices due to COVID-19. With the global economy sluggish and trade tensions already in place, oil demand was subdued, but the new wave of the novel coronavirus has hit it like never before around the world. In addition, a price war between Saudi Arabia and Russia, at a time when storage capacity was already being stretched to the limit, further tightened the market. All of this has led to one of the most volatile periods in the history of the oil market, pushing prices to historic lows that show vulnerability as the market shifts with changes in global demand and geopolitical tensions or market dynamics.

2.1.17. April 2020-June 2022

Between April 2020 and June 2022, crude oil prices rose from $17 to $117 per barrel. The support came from a cocktail of factors, including the post-COVID-19 economic recovery, OPEC+ production cuts, various types of supply disruptions, and robust demand for transportation fuels. There was also inflationary support from geopolitical tensions and investment concerns around the energy transition. As a result, the introduction of the vaccine, the easing of quarantine measures and the lifting of travel restrictions eased the pace of economic activity and supported oil demand. Decisions by OPEC+ countries on production cuts and geopolitical events put pressure on the supply side, while on the other hand, the general upward trend in commodity prices and speculative trading also contributed to pushing prices higher. This period consolidated how dynamic the oil market could become and the complexity associated with managing the economic recovery coupled with the supply-demand balance in the post-COVID period.

2.1.18. June 2022-December 2022

Between June 2022 and December 2022, crude oil prices fell from $117 to $80 per barrel due to various factors. This was mainly due to fears of global economic slowdown, increase in oil supply, unbridled oil reserves and strategic COVID-19 restrictions in China, among some other geopolitical events, currency exchange and market speculations. All these factors combined to pull oil prices due to the interaction of several dynamics, such as fears of reduced demand, production increases by OPEC+ and non-OPEC countries, release of oil from strategic reserves by countries, particularly the US, lockdown in China and conflict in Ukraine, and market sentiment at a time when the US dollar strengthened with speculative trading in futures markets.

2.2. Application

The study tracks annual data on crude oil prices, production, reserves, and demand, and links them to key historical events to determine their impact on the global oil market. This research therefore adopts a multifaceted econometric approach that seeks to analyze the dynamics in the OPEC data using an Excel package called XLSTAT.

Predicting the future of oil prices is a crucial exercise that usually falls under the cluster of time series analysis techniques. Historical price data has been used to identify patterns and predict future movements using models such as ARIMA or nonparametric regression. These are typically forecasts in econometric models such as VAR with external variables, including geopolitical events, technological developments, and changes in global supply and demand. These models provide a nuanced view of how different factors interact to influence oil prices.

Complementing these quantitative methods, forecasting focuses on looking at the likely range of certain future events and how they may affect oil prices. This approach is therefore flexible and useful in preparing stakeholders for many possible situations in a volatile market. The forecasting process is dynamic and needs to be constantly reviewed and modified with new data and information. At this point, stakeholders should be able to interpret the complexity of the oil market. Through in-depth analysis and a range of forecasting tools, they should be able to make informed decisions to mitigate risks and capitalize on market opportunities. It also reemphasizes the importance of monthly crude oil price data in economic planning, investment strategies and operational decision-making processes on a sectoral basis within boards of directors.

Our main dataset consists of annual records from the OPEC database. Secondary data sources are used to enrich our analysis. These sources will include data from international financial institutions, supplemented by historical archives that reference original OPEC data, thus providing a robust dataset suitable for use in this study.

The analysis of price volatility, a key indicator of the global energy market, provides insight into supply and demand dynamics, geopolitical tensions, and economic trends. Evaluation of production data reveals OPEC's role in market equilibrium and explores how strategic production adjustments affect global oil supply. Reserves represent the long-term sustainability of oil production and influence future market strategies and investment decisions. Demand analysis emphasizes consumption patterns that reflect economic growth, technological advances, and shifts toward renewable energy. The inclusion of inflation as a variable allows for an examination of how oil prices relate to broader economic indicators, affecting purchasing power and economic policy.

This paper formulates models and obtains forecasts using the XLSTAT an Excel package, known for its advanced capabilities in econometric analysis and time series forecasting. The reason for this choice is that XLSTAT can be used to efficiently handle very large data sets and difficult and complex econometric models. This allows for an intensive analysis of the relationships between the variables under study. First, descriptive statistics are calculated to get an idea of the distribution, central tendencies, and variability of the data. This step aims to reveal any anomalies, trends, and patterns in the data set and to provide a basis for more detailed econometric modeling.

The core of our analytical methodology involves multiple regression and time series analysis to explore the dynamics between crude oil prices and key economic indicators such as production volumes, reserve estimates, demand figures and inflation rates. Non-parametric regression analysis is used to quantify the impact of each variable on crude oil prices, while time series models such as ARIMA are used to identify trends, cyclicality, and seasonal variations in the data. These econometric models will provide the basis for forecasting and identifying underlying patterns in the oil market.

An important aspect of our methodology is the study of historical events, which involves a systematic approach to identifying and categorizing significant historical events based on their expected impact on the oil market. For each selected event, market indicators before, during and after the event are examined through a comparative analysis using interrupted time series analysis and counterfactual scenarios to isolate the impact of the event from other variables.

2.3. The relationship between macroeconomic variables and description of the methods

Understanding the relationship between macroeconomic variables and OPEC crude oil prices is critical to understanding global economic dynamics. As one of the largest groups of crude oil producing countries, OPEC sets oil prices through quotas and effects the global supply level. Prices are the result of the interaction of various macroeconomic variables such as GDP growth, exchange rates and inflation. For example, global GDP growth means that there will be greater demand for energy from developed and emerging economies, and thus oil prices will rise. On the other hand, during periods of economic recession, demand for oil tends to decline, putting downward pressure on oil prices.

Exchange rates have an indirect but very important effect on OPEC oil prices. This is because most oil-related transactions are denominated in dollars, so any change in the value of currencies can affect the affordability of oil in some markets that use other currencies. A weak dollar makes oil cheaper for countries with stronger currencies, potentially increasing demand and thus prices. On the other hand, a stronger dollar in the medium term could reduce demand for oil, which could lead to lower prices. This shows that monetary policies and currency valuations in major economies are interrelated with the energy sector and thus affect OPEC's pricing strategies and even the revenues it generates. Information on all these variables is presented in Table 1.

Table 1. Changes in OPEC nominal oil prices and macroeconomic data by years (assembled using OPEC data)

Date	Nominal Oil Price ($)	Exchange Rates	Inflation	GDP	Oil Production (1000 b/d)	Oil Demand (1000 b/d)
1972	2,29	1,8	14,87	78774,42	25592,052	844,7132686
1973	3,05	2,16	18,6	106362,7	29023,138	971,0353584
1974	10,73	7,67	59,23	203017,8	28827,615	1064,043914
1975	10,73	7,45	54,78	218723,6	25412,581	1239,07646
1976	11,51	8,27S	55,57	275364	28724,135	1484,599384

Table 1. (Continued)

Date	Nominal Oil Price ($)	Exchange Rates	Inflation	GDP	Oil Production (1000 b/d)	Oil Demand (1000 b/d)
1977	12,39	8,56	56,28	314419,3	29152,263	1704,479023
1978	12,7	7,77	55,11	330183,8	27680,694	1906,348939
1979	17,25	10,19	70,33	431881,1	28801,423	2104,636821
1980	28,64	17,04	106,39	575304,2	24834,709	2494,867231
1981	32,51	21,69	111,55	600923,4	20518,12	2625,324862
1982	32,38	23,73	104,67	595770,6	17441,068	2819,617591
1983	29,04	22,39	89,87	602225,5	15521,164	3051,017954
1984	28,2	23,71	83,51	577870,7	14808,722	3261,914773
1985	27,01	24,01	76,26	478332,3	13966,467	3400,555356
1986	13,53	10,37	37,22	448529	16660,718	3468,273016
1987	17,73	12,59	47,23	458950,3	15999,725	3496,268137
1988	14,24	9,87	35,93	458535,1	18198	3689,16028
1989	17,31	12,52	40,92	462226,6	19667,047	3677,096006
1990	22,26	16,17	50,38	483492,7	21220,323	3660,372019
1991	18,62	14,15	41,29	483891,9	21357,169	3831,529455
1992	18,44	14,03	39,14	527047,7	23091,562	4059,943568
1993	16,33	13,13	32,77	480853,6	23519,741	4202,108068
1994	15,53	14,15	28,86	453561,2	23927,832	4273,144326
1995	16,86	14,9	29,04	535153,6	24021,569	4289,927986
1996	20,29	18,31	33,47	595559,4	24313,114	4390,430571
1997	18,68	17,76	30,03	616349,5	25074,938	4540,301377
1998	12,28	12,14	19,42	578635,9	27194,056	4686,377291
1999	17,48	17,34	27,41	630100,7	25662,436	4669,327627
2000	27,6	28,78	42,47	734686	27227,118	4891,949761
2001	23,12	24,99	34,8	737377,4	26458,592	5058,143917
2002	24,36	26	36,04	738746,6	24224,377	5194,984114
2003	28,1	28,02	40,66	830790,3	26691,44946	5341,879067
2004	36,05	34,58	50,71	1054929	29533,63181	5703,082627
2005	50,64	48,05	69,54	1337571	30772,308	6075,356705
2006	61,08	57,51	81,85	1611337	31014,20769	6410,460859
2007	69,08	61,85	89,61	1929021	30514,893	6678,457474
2008	94,45	80,81	116,87	2415450	31505,957	7044,066044
2009	61,06	53,83	74,86	2030800	28491,886	7272,69502
2010	77,45	68,04	92,16	2581341	28829,806	7645,370292
2011	107,46	91,46	122,62	3081477	29646,867	7986,857429
2012	109,45	96,04	121,19	3369941	31924,78	8336,357459
2013	105,87	93,39	114,17	3230116	31024,734	8640,126915
2014	96,29	85,62	101,56	3221916	30075,003	8807,185121
2015	49,49	47,72	51,51	2696360	31061,71	8886,477558
2016	40,76	40,39	41,69	2627045	32467,373	8873,695279
2017	52,43	52,43	52,43	2782931	31636,264	8810,460159
2018	69,78	69,87	67,8	2801984	31216,587	8691,884596
2019	64,04	67,18	60,39	2711519	29375,778	8769,314034
2020	41,47	44,29	38,38	2332772	25659,265	7878,295258
2021	69,89	74,41	62,42	2766706	26363,078	8273,598838
2022	100,08	125,85	80,14	3374636	28894,931	8842,402753

It seems that inflationary pressures and interest rates are the key factors. In terms of cost-push inflation, an increase in oil prices should increase in cost-push inflation. Such an event usually encourages central banks to change monetary policy, under which there is the potential of interest rate pressure. Higher interest rates could strengthen the national currency, making oil more expensive in other currencies and potentially reducing demand. In addition, geopolitical events and shifts in energy policy toward sustainability and efficiency can affect the global supply and demand balance by affecting demand for OPEC oil. Understanding these relationships is critical to analyzing oil market trends, as it highlights the sensitivity of OPEC oil prices to broader economic forces and policy decisions.

To analyze the data and interpret the results, nominal oil prices and macroeconomic variables are analyzed using various statistical methods.

To examine the relationship between macroeconomic variables and OPEC crude oil prices, we first use nonparametric regression analysis. This method allows us to model these relationships without assuming a specific functional form for the underlying data distribution, making it particularly useful for analyzing complex, non-linear patterns that may exist between oil prices and macroeconomic indicators. Non-parametric regression is implemented through the kernel smoothing technique, where the regression function is estimated locally for each point x:

$$f(x) = \frac{\sum_{i=1}^{n} K_h(x-x_i)y_i}{\sum_{i=1}^{n} K_h(x-x_i)} \quad (1)$$

where $K_h()$ is the kernel function, a weighted function that assigns weights to observations near the point x, h is the bandwidth parameter that controls the width of the kernel, x_i are the independent variable observations and y_i are the dependent variable observations (Tibshirani & Wasserman, 2013).

To further understand the interdependencies between the variables, we conduct a correlation analysis, generating both correlation maps and matrices. Correlation coefficient, r, calculates the strength and direction of relationship between two values, calculated as:

$$r_{xy} = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \quad (2)$$

where n is the number of observations, x and y are the individual observations of the two variables (Asuero et al., 2006). This analysis helps visualize the relationships and identify potential predictors for inclusion in the regression model.

AutoRegressive Integrated Moving Average (ARIMA), a time series model, will be used to predict the future of nominal oil price. The model is written as ARIMA (p, d, q), where p is the autoregressive terms value, d is the differences required to render the series stationary, and q is the lagged forecast errors. The model is formulated as:

$$y'_t = c + \phi_1 y'_{t-1} + \cdots + \phi_p y'_{t-p} + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} + \varepsilon_t \quad (3)$$

where y'_t differenced series (if d>0), c is a constant value, ϕ_i are autoregressive terms parameters, θ_i are moving average parameters, and ε_t is noise (Sahai et al., 2020).

ARIMA's integrated approach, combining autoregression, differencing, and moving averages, allows for an accurate capture of time dependencies and trends within the oil market, making it an ideal choice for this study. Its effectiveness is further evidenced by its widespread adoption and success in previous oil market forecasts, where it has demonstrated predictive accuracy and reliability.

Moreover, the inherent flexibility of the ARIMA model to adapt to the stationary requirements of time series data, by differencing, addresses the challenge posed by the volatile nature of oil prices. This adaptability is crucial for accurately forecasting oil prices, given their susceptibility to abrupt changes due to geopolitical events, supply-demand imbalances, and other exogenous shocks. This approach not only enhances the understanding of oil price dynamics but also contributes to more informed and strategic decision-making in the face of market volatility.

This comprehensive methodology, which combines nonparametric regression, correlation analysis, and ARIMA forecasting, allows for a nuanced understanding of the dynamics between macroeconomic variables and OPEC crude oil prices, as well as the prediction of future price movements based on historical trends.

Along with all these analyses, data on World Oil Production and Demand from OPEC data are positioned by country. They were then analyzed with the help of Kernel Density Analysis in GIS environment. In this way, it was revealed in which regions the data are concentrated. The following formulas define how the kernel density for points is calculated and how the default search radius is determined within the kernel density formula.

The predicted density at a new (x,y) location is determined by the following formula:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} [\frac{3}{\pi} pop_i (1 - \left(\frac{dist_i}{radius}\right)^2)^2] \quad (4)$$

Where i = 1,…,n are the input points. Only include points in the sum if they are within the radius distance of the (x,y) location. pop_i is the population field value of point i, which is an optional parameter. $dist_i$ is the distance between point i and the (x,y) location.

The calculated density is then multiplied by the number of points or the sum of the population field if one was provided.

3. Results

Although crude oil price changes show sudden changes due to the impact of periodic events, analyzing these price changes can provide a better understanding of oil price changes with different indicators. In this regard, it is important to interpret oil prices and macroeconomic indicators together and analyze their relationship. In this way, price reactivity can be calculated, and future price forecasts can be made.

Our comprehensive analysis, which includes nonparametric regression, correlation, ARIMA forecasting, assessment of the impact of historical events, and spatiotemporal examination using ArcGIS and kernel density analysis, provides deep insights into the complex interplay between macroeconomic variables and OPEC crude oil prices. The results underscore the multifaceted influence of economic indicators, geopolitical events, and the spatial distribution of resources on the oil market, providing valuable perspectives for understanding future price movements and policy implications.

Nonparametric regression analysis examines various macroeconomic variables in relation to the nominal oil price. The inflation-based regression chart shows the relationship between inflation and nominal oil prices. A positive trend would suggest that as inflation rises, so do oil prices, which could be due to a decline in the purchasing power of the currency or cost-push inflation, where rising oil costs drive up the prices of a wide range of products (Figure 4).

The exchange rate-based regression chart plots the exchange rate against the nominal price of oil (Figure 4). If you observe that the red prediction points form an upward trend as the exchange rate increases, this implies that there is a positive relationship between the exchange rate and oil prices. An upward trend suggests that as the value of the currency falls, the nominal price of oil also rises.

The GDP-based graph correlates gross domestic product with the nominal price of oil (Figure 4). Typically, a positive relationship would indicate that higher GDP is associated with higher oil prices, which could reflect greater demand for oil as the economy expands.

In the graph based on oil production, you are looking at how the amount of oil produced affects its nominal price. The relationship can be more complex, as increased production can lead to both a decrease in the price of oil due to a supply glut, or an increase if production is associated with higher costs or risk factors. In the case of oil demand, the graph analysis shows how changes in oil demand are related to changes in the nominal price of oil. A positive trend, where projected oil prices rise with demand, would be consistent with basic economic principles of supply and demand - higher demand for oil typically leads to higher prices, all else being equal.

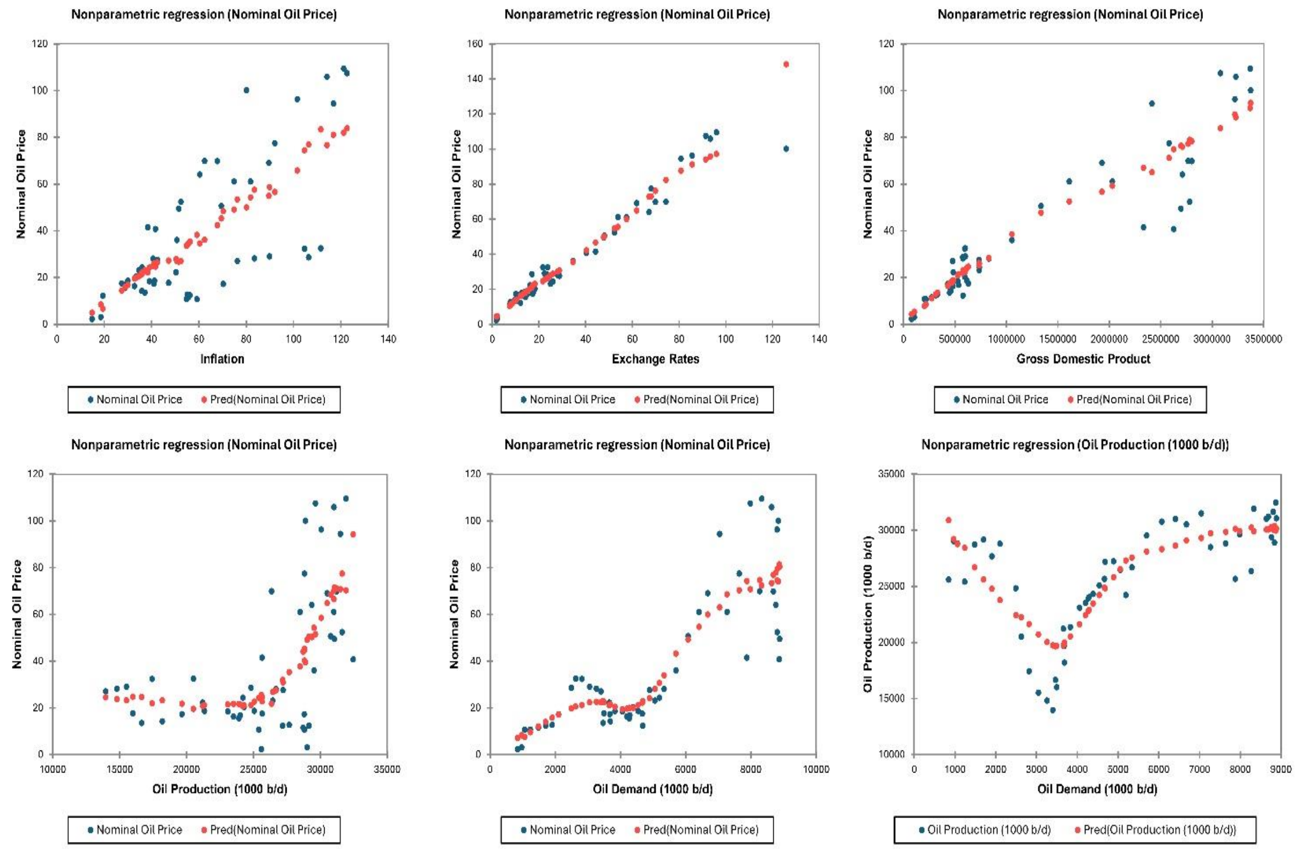

Figure 4. Non-parametric regression analysis results

In addition to nonparametric regression analysis, correlation analysis was performed, and a scatterplot graph was created to examine the relationship between the data. Correlation analysis analyzes the distribution of oil prices and other macroeconomic data. The scale on the side of the correlation matrix corresponds to the correlation coefficients. If the value is close to 1 that means a strong positive relationship, if the value is close to -1 means a strong negative relationship, and around 0 means no relationship (Figure 5). Taken together, the scatterplot graph (Figure 6) allows you to quickly assess the potential relationships among multiple variables and identify patterns that may warrant further statistical testing or inclusion in predictive models.

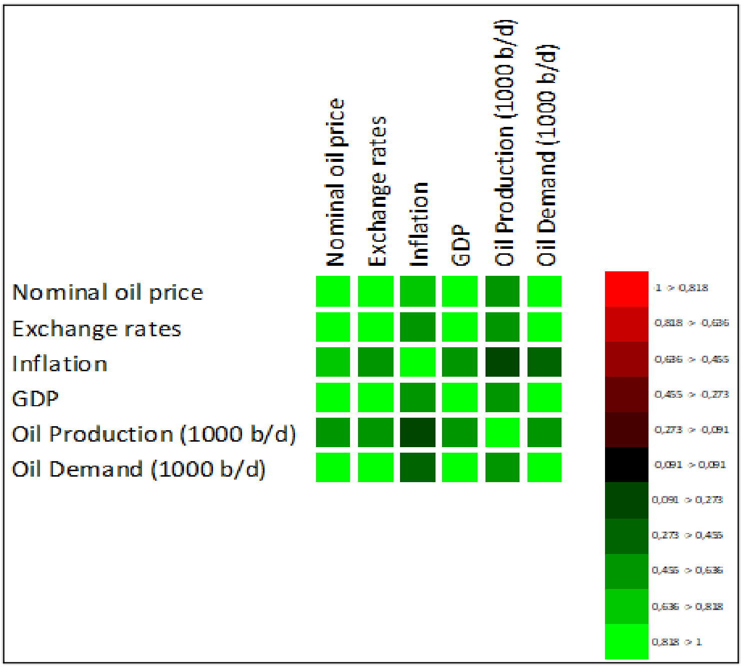

Figure 5. Correlation matrix

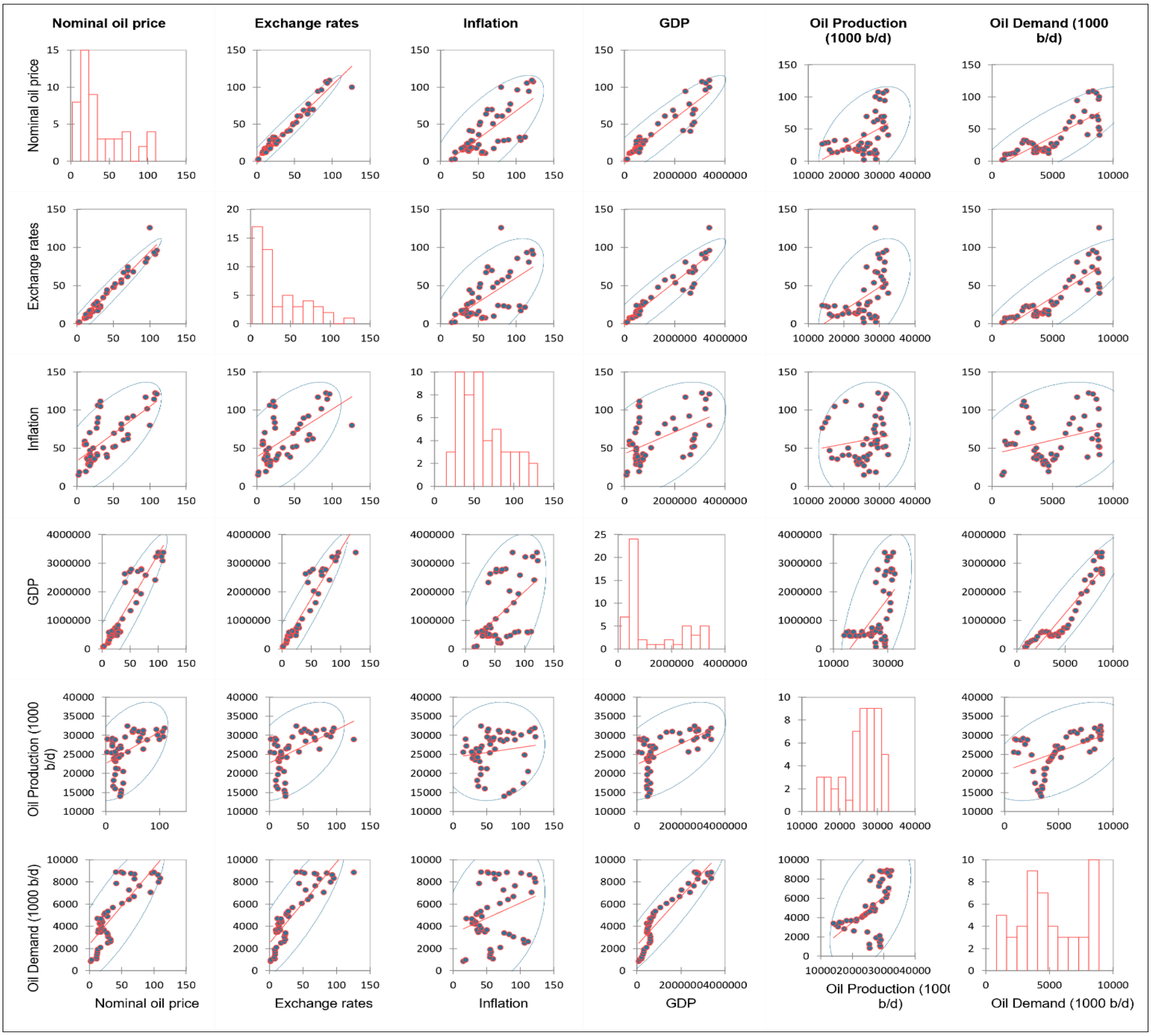

Figure 6. Scatter plot graph for correlation

In addition to nonparametric regression analysis and correlation analysis, time series analysis was used to understand the trend of each of the data and to estimate the direction of movement. ARIMA was selected as the most appropriate time series analysis. In the ARIMA analysis, the relationship of the data over time and the changes in macroeconomic changes and oil prices are calculated for the period 1972-2022 and the future forecasts are expressed in Figure 7.

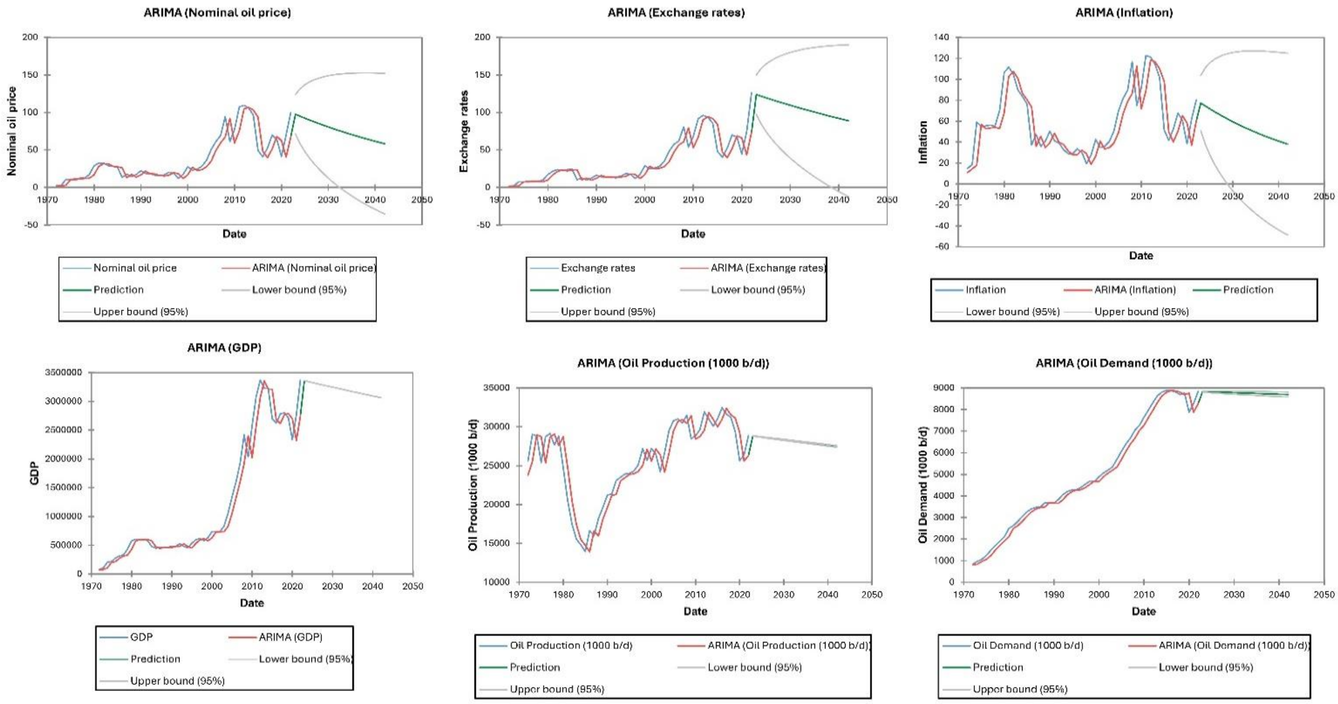

Figure 7. ARIMA analysis for nominal oil price and macroeconomic variables

The Nominal Oil Price chart includes history and forecasts for oil prices. The forecast may include history, seasonality, and past shocks. On the other hand, "Exchange Rates" always shows the relative value of one's own currency against the other, usually against the U.S. dollar. The forecast trend reflects expected economic conditions, policy changes and trade dynamics of countries. The "Inflation" chart reflects a trend showing a rate of increase in the general level of prices for goods and services, followed by a decline in purchasing power. Inflation forecasts are important inputs for monetary policy and economic planning. The GDP graph shows the market value of all final goods and services produced by a nation each year. Forecasts of GDP trends help to understand likely future economic health and possible policy interventions. The Oil Production graph shows the amount of oil produced over time. Forecasting production can help inform discussions not only about resource depletion, but also about investments and technologies for extraction and energy policy. The "Oil Demand" graph shows the willingness of consumers to buy oil at different prices. Its forecast helps to manage the supply aspect.

The ARIMA analysis of crude oil prices, in conjunction with nonparametric regression and correlation analysis, yields substantial insights into the intricate interrelationship between oil prices and macroeconomic variables, including inflation, exchange rates, GDP, oil production, and oil demand. The results indicate a strong positive correlation, confirming that as inflation and GDP rise, so do oil prices. This reflects higher demand and cost-push inflation. The analysis also elucidates the intricate relationship between oil production and prices. It reveals that increased production can result in either price declines due to oversupply or price increases if associated with higher costs. The geospatial analysis, conducted using GIS, adds a valuable dimension, demonstrating the geographic shifts in oil production and demand. This underscores China's growing economic influence. These findings provide a comprehensive understanding of the factors driving oil prices, offering policymakers and industry leaders critical insights for strategic decision-making in the global oil market.

In addition to all statistical analyses, country-based data from OPEC were recorded in their locations on GIS and a different perspective was tried to be put forward in the analysis of oil-related variables through spatial analysis. A GIS-based analysis following the temporal and spatial criteria of the paper is presented in the sequel. The time series variation is correlated with the spatial data of the macroeconomic variables crude oil production and crude oil demand. In this context, the kernel density function of the density tool of the ArcGIS Pro application is applied to these data, which have been recorded since the 1960s and allow us to obtain information on the production and demand of crude oil in the subject countries. Without these statistical and spatial analysis capabilities of ArcGIS, we would not be able to reveal the distribution of oil production and demand in the world. The following series of maps, shown in Figure 8, allows us to observe the changes in the intensity of crude oil production from the 1960s to the 2020s. In Figure 9, we look at the change in crude oil demand intensities from the 1960s to the 2020s in a series of maps. It also shows changes that have a global impact and further changes in prices.

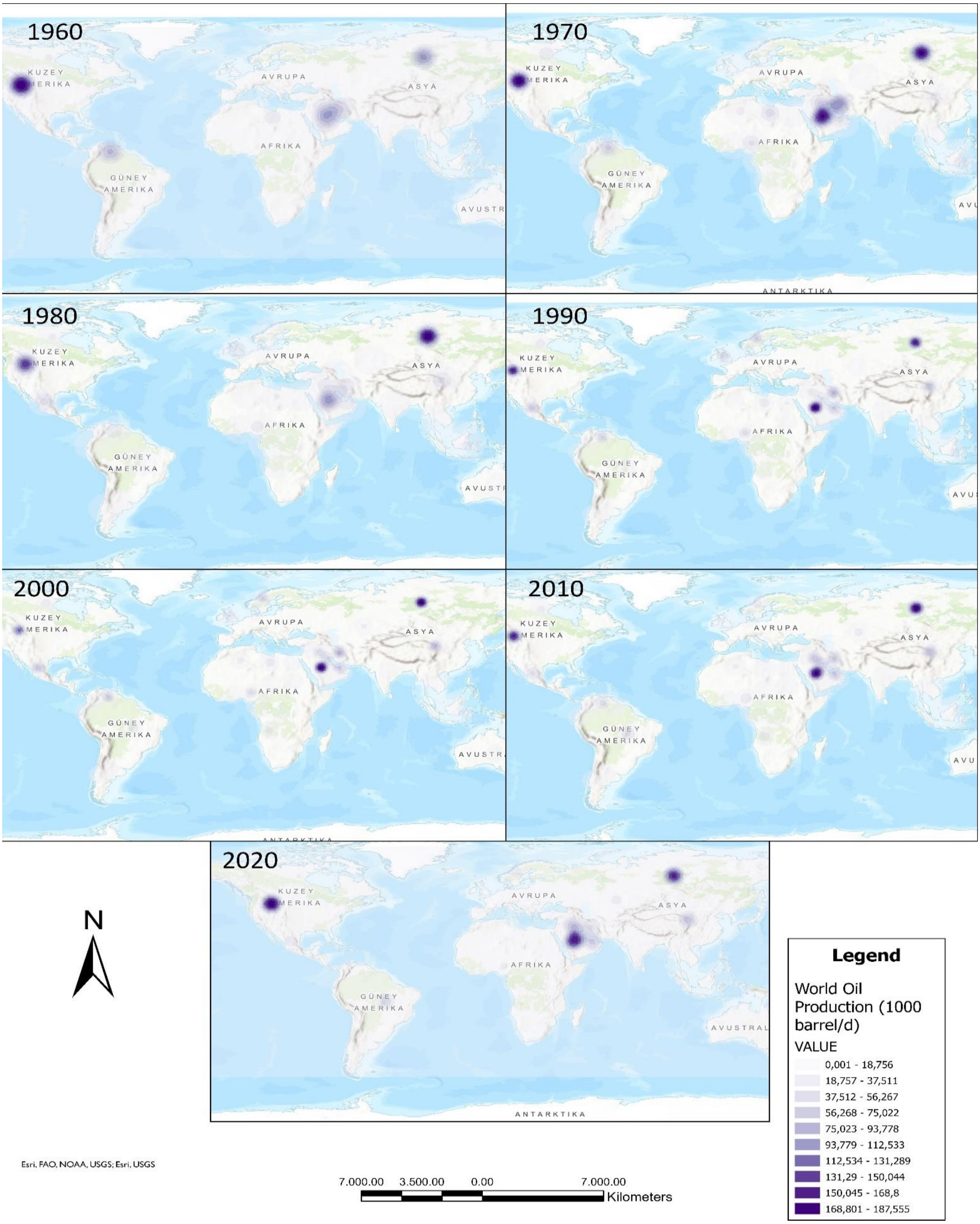

Figure 8. 1960s to 2020s global crude oil production

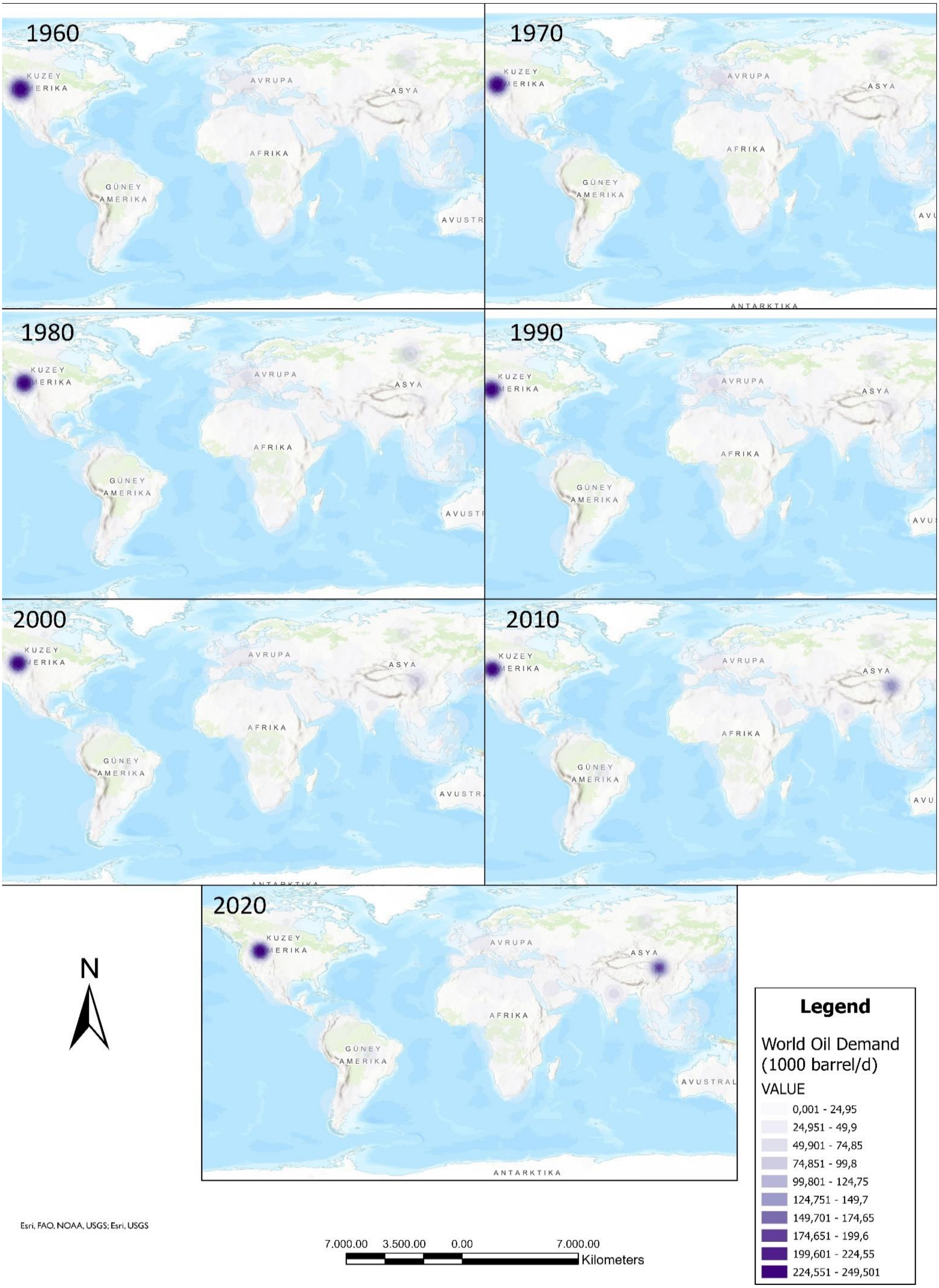

Figure 9. 1960s to 2020s global crude oil demand

4. Discussion

This study examines the relationship between certain macroeconomic indicators and OPEC crude oil prices. It follows a multifaceted approach that includes nonparametric regression, correlation analysis, ARIMA forecasting, assessment of the impact of historical events, and spatial analysis using ArcGIS.

The analysis confirmed the expected positive correlations between oil prices and factors such as inflation, exchange rates (when the local currency weakens), and GDP (indicating rising demand with economic growth). One interesting finding was the complex relationship between oil production and price. Increased production can lead to both price declines due to oversupply and price increases if production becomes more expensive or risky. The correlation matrix and scatter plots provided a quick way to visually assess potential relationships between oil prices and various economic factors. The ARIMA forecasts were particularly valuable as they provided insight into the projected trends of oil prices and key macroeconomic variables. This allows stakeholders to anticipate future market conditions.

Spatial analysis using ArcGIS revealed how geographic shifts in oil production and demand intensity over time contribute to global price fluctuations. This will be a major strength of the study, as it will provide a comprehensive view of the factors that influence the determination of oil prices. There was a time in the 1960s when much of the oil demand dominance belonged to the United States. Today, this leadership in oil demand is observed by China (Figure 10). This shows how economically powerful China has become and how influential it will be on price changes in the future.

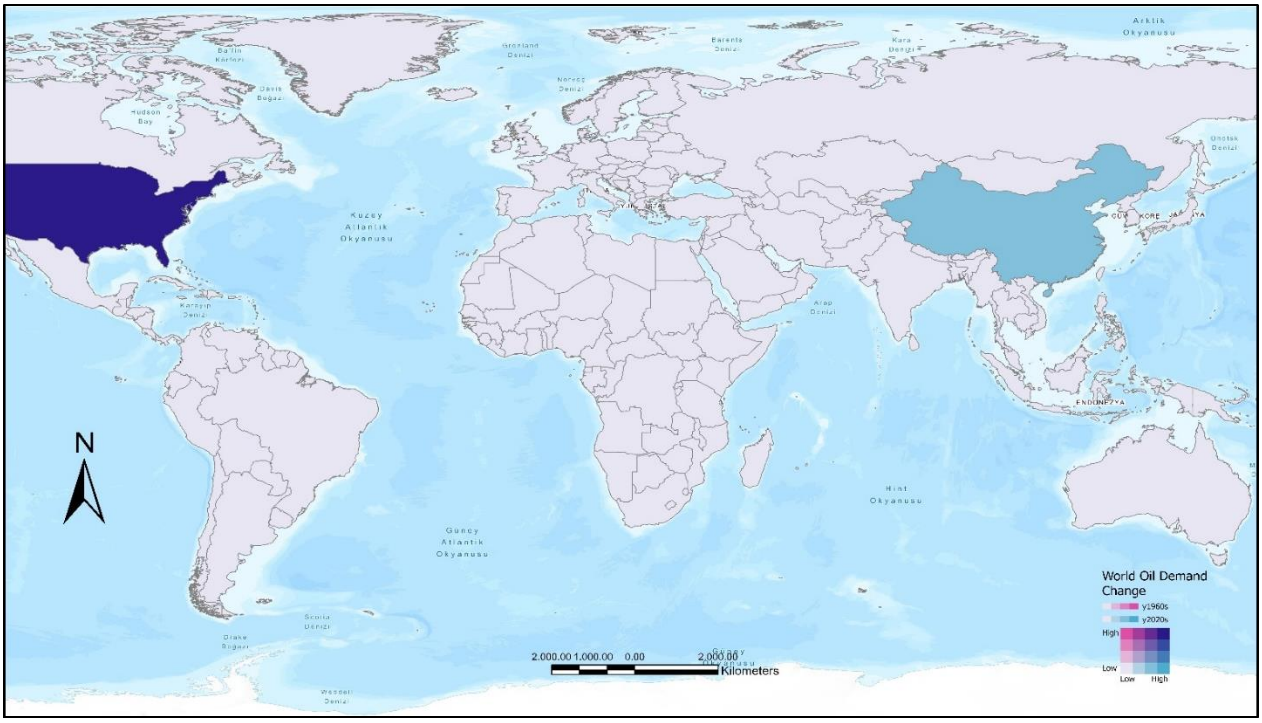

Figure 10. Global crude oil demand change between 1960s to 2020s

5. Conclusion

This study makes a significant contribution to the oil economics literature by employing a multifaceted analytical framework that captures the complexity of the oil market. Its findings are invaluable to stakeholders across the global oil industry, providing a richer understanding of oil price dynamics and guiding decision making in a volatile market environment. The research combines various analytical approaches, including ARIMA forecasts and spatial analysis, to anticipate future market conditions and develop effective strategies. This comprehensive methodology not only confirms the relationship between oil prices and macroeconomic variables but also introduces a spatial component that provides a more detailed landscape of oil market dynamics.

As discussed above, this research has proven useful in unraveling some of the very many opaque factors that influence OPEC crude oil prices. What makes it valuable is the fact that the research combines so many of the analytical approaches and thus makes it really have some relevant insights for the stakeholders in the global oil market. It considers the expected trends from the ARIMA forecasts and spatial analysis of production and demand patterns, in fact providing one of the most powerful means to anticipate future market conditions and effective strategies.

By comparing our findings with those of the existing literature, our study extends the understanding of the complex dynamics between macroeconomic variables and oil prices through its comprehensive methodology. While previous research, such as the work of Kilian & Vigfusson (2013) and Cologni & Manera (2008), has primarily focused on the linear impact of economic indicators on oil prices, our multifaceted approach reveals nuanced interdependencies and spatiotemporal dynamics that have not been previously highlighted. For example, our use of ARIMA forecasting and GIS-based spatial analysis has revealed patterns of global oil demand shifts and production intensities that provide a more granular view of market fluctuations. Moreover, our findings on the predictive value of macroeconomic variables for oil prices are consistent with the incorporation of spatial analysis to illustrate geographical shifts in oil production and demand. Thus, our research not only confirms the consensus on the relationship between oil prices and macroeconomic variables found in studies such as Mukhtarov et al. (2020) and He et al., (2010), but also introduces a spatial component that improves predictive accuracy and provides a richer, more detailed landscape of oil market dynamics.

The integration of GIS analysis and macroeconomic data analysis offers a synergistic approach that significantly enhances the understanding of the factors influencing crude oil prices. By integrating GIS's spatial visualization capabilities with traditional econometric models, such as ARIMA, the study provides a more nuanced and comprehensive view of how geographic patterns and economic variables interact. This integrated approach enables more accurate predictions, enhanced risk management, and informed decision-making for policymakers and industry leaders. GIS analysis reveals geographic trends and spatial dependencies that are crucial for anticipating the impact of regional economic changes and geopolitical events on global oil prices. This offers a powerful tool for navigating the complexities of the oil market.

On the other hand, there are some limitations. The accuracy of ARIMA forecasts can be affected by unforeseen events and changing market dynamics. In addition, the study focused on OPEC oil prices, and further research could explore how the findings apply to other oil benchmarks.

Some of the limitations of the study also point to further exploration, such as the possibility that actual events may have had an impact that can disrupt the forecasts and the OPEC price focus. Further research could also be done on price changes and isolated historical events. Third, a larger set of variables alternative to energy sources and climate policies could also be included in the forecasting models. Extending their approach to a more global scale, including non-OPEC oil benchmarks in the analysis, would provide a more comprehensive picture of the relationship between different market segments. This needs to be further developed to help researchers provide policymakers, industrialists, and investors in the global oil market with knowledge on how to operate and invest their resources most effectively and efficiently within this dynamic.

For future studies, there are several promising directions. Researchers could delve deeper into the impact of specific historical events on oil price fluctuations by developing more complex forecasting models that include additional variables, such as alternative energy sources and climate policies. Expanding the analysis to include non-OPEC oil benchmarks would provide a more comprehensive view of the global market. Additionally, integrating machine learning models with traditional econometric approaches could improve forecasting accuracy. By continuing to build on these insights, future research can enhance the understanding of oil price dynamics, empowering stakeholders to navigate the global oil market more effectively.

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Author Contributions

Merve Şenol: Conceptualization, Data curation, Methodology, Analysis, Writing-Original draft preparation, **Hüseyin Çetin**: Validation, Editing

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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