UNIVERSITY OF ECONOMICS AND LAW

FACULTY OF FINANCE – BANKING

GRADUATION THESIS

Topic:

ANALYZING THE IMPACT OF ENERGY USAGE, CARBON DIOXIDE EMISSIONS, FOREIGN DIRECT INVESTMENT, CONSUMER PRICE INDEX, AND MARKET PRICE REPRESENTATION ON ECONOMIC DEVELOPMENT OF COUNTRIES USING MACHINE LEARNING METHODS

Instructors: Assoc. Prof. Nguyen Anh Phong

Student: Nguyen Van Thanh

Student ID: K204140640

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Ho Chi Minh , March 24, 2024

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INSTRUCTOR'S COMMENTS

SCORE	INSTRUCTOR *(Sign and clearly state name)*

COMMENTS

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To complete this internship report, I first and foremost would like to express my sincere gratitude to all the professors and teachers in the Faculty of Finance – Banking at the University of Economics and Law for imparting to me the knowledge of both general and specialized subjects. This education has solidified my theoretical foundation and supported me throughout my learning process. In particular, I extend my deepest thanks to Professor Nguyen Anh Phong for his dedicated guidance, comments, and suggestions that helped me to complete this internship report.

Given the limited time and experience of a student, this thesis inevitably has shortcomings. I am eager to receive advice and feedback from the faculty to improve and enhance my awareness, serving better in my future work.

I sincerely thank you!

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List of acronyms

STT	Acronyms	Full word	Vietnamese
1	CO2	Carbon dioxide	Khí Cacbonic
2	FDI	Foreign direct investment	Đầu tư trực tiếp nước ngoài
3	CPI	Consumer price index	Chỉ số giá tiêu dùng
4	OPEC	Organization of Petroleum Exporting Countries	Tổ chức các nươc xuất khẩu dầu mỏ
5	IEA	International Economic Association	Cơ quan năng lượng thế giới
6	EKC	Environmental Kuznets Curve	Đường cong Kuznets môi trường
7	NAFTA	North American Free Trade Agreement	Hiệp định Mậu dịch Tự do Bắc Mỹ
8	DT	Decision Tree	Cây quyết định
9	EFB	Enhanced Flooded Battery	Pin ngập nước nâng cao
10	GOSS	gradient-based one-side sampling	Lấy mẫu một phía dựa trên độ dốc
11	RMSE	Root mean square error	Căn bậc hai sai số bình phương
12	R2	Coefficient of determination	Hệ số xác định
13	BRICS	Brazil, Russia, India, China and South Africa	Các quốc gia có nền kinh tế mới nổi

SUMMARY

This study offers a comprehensive view of the relationship between environmental, economic, and social factors on the economic development of countries. Utilizing data from 47 countries, including variables such as CO2 emissions, Foreign Direct Investment (FDI), Consumer Price Index (CPI), market price index, and energy consumption from sources like oil, gas, coal, hydro, and nuclear energy, the study employs advanced machine learning techniques such as Decision Tree, Random Forest, XGBoost, LightGBM, and CatBoost to analyze the impact of these factors on GDP.

The research found that, despite significant differences in the use of various energy sources among countries, oil is the most influential energy source on economic development, while nuclear energy has the least impact. The relationship between energy consumption and GDP growth does not follow a clear trend, reflecting the diversity in economic structures and development levels of the countries. At the same time, CO2 emissions and the Consumer Price Index (CPI) also show a complex relationship with GDP growth, reinforcing the viewpoint that environmental and economic measures need to be carefully balanced to achieve sustainable development. This study also highlights the role of the market price index as a significant factor affecting economic growth.

Results from the machine learning models indicate that XGBoost performs best in predicting the impact of variables on GDP growth, with high generalizability and significant accuracy.

Keywords: *Market Price Index, Energy Usage, CO2 Emissions, FDI, CPI, Machine Learning, Decision Tree, Random Forest, XGBoost, LightGBM, CatBoost.*

1. Introduction to the Topic

1.1. Reason for Choosing the Topic

In recent decades, the relationship between economic development and environmental sustainability has garnered significant attention from policymakers, economists, and researchers worldwide. While we benefit from the robust development of the global economy, we are also facing its consequences, including environmental pollution, ecosystem degradation, and the depletion of natural resources. Food security, social development, and the global economy are all severely impacted by climate change. Among the determinants affecting economic development, the impacts of market representative prices, energy usage, carbon dioxide ($CO2$) emissions, foreign direct investment (FDI), and the consumer price index (CPI) have emerged as key factors in understanding economic growth dynamics.

The development of the stock market plays a crucial role in the economic growth of countries, especially in economies with high market liquidity and active operations. This relationship has been studied through the lens of stock market liquidity, market capitalization, total transaction value, turnover ratio, and their impact on GDP and FDI, using data from Euronext member countries (Belgium, France, Portugal, the Netherlands, and the United Kingdom) from the first quarter of 1995 to the fourth quarter of 2008. Ake & Dehuan (2010). The results indicate that for countries like France and the United Kingdom, where the stock market is more liquid and active, there is a significant positive relationship between stock market development and economic growth.

However, the impact of stock market development on economic growth is not always positive for all countries. In smaller and less liquid markets, such as during the study period in Belgium and Portugal, the positive relationship between stock market development and economic growth is not clear.

The increase in CO_2 emissions, mainly due to industrial activities and the production of non-renewable energy, has led to growing concerns about its adverse impact on climate change and environmental degradation. The world's economies primarily use coal, natural gas, and petroleum for urbanization and globalization (Mohsin et al., 2021). Some studies have found a linear relationship between economic growth and CO_2 emissions (Grossman & Krueger, 1995; Azomahou et al., 2006), indicating that economic growth often comes with an increase in greenhouse gas emissions. Other studies have found an inverted U-shaped relationship between economic growth and CO_2 emissions, described through the Environmental Kuznets Curve theory (Dinda, 2004; Galeotti et al., 2006). According to this theory, in the early stages of growth, CO_2 emissions increase due to the intensified use of fossil fuels. However, once a certain level of development is reached, countries gradually shift to cleaner energy sources and more efficient technologies, leading to reduced emissions even as the economy continues to grow.

Furthermore, FDI and CPI are also considered to play a crucial role in shaping the economic landscape of countries worldwide. In the era of economic globalization, foreign capital investment and inflation rates not only reflect economic activity but also profoundly impact productivity, employment, overall economic efficiency, technology transfer, and infrastructure improvement (Gui-Diby, 2014). According to the study by Moran and Graham (2005), FDI has a positive impact on economic growth in developed countries through job creation and technology transfer. Similarly, Alfaro and Chen (2018) found a link between FDI and economic growth in countries in the Asia-Pacific region, with FDI creating long-term benefits by enhancing labor productivity and improving technology. Ahmed and Mortaza (2005) studied the relationship between CPI and GDP of Bangladesh. The results show an inflation threshold at 6% for the Bangladesh economy. Empirical evidence indicates a long-term inverse correlation between CPI and GDP. These studies provide clear evidence of the important role of FDI and CPI in promoting global economic growth.

While traditional econometric methods have served the study of the correlation between market representative prices, energy consumption, CO_2 emissions, FDI, CPI, and economic growth, these methods often fall short in capturing nonlinear interactions. Machine learning techniques, with their capability to analyze complex data, open new approaches to explore patterns and interactions among variables in large and heterogeneous datasets.

This study applies machine learning techniques including Decision Tree, Random Forest, XGBoost, LightGBM, and CatBoost to comprehensively analyze the impact of CO_2 emissions, FDI, CPI, and energy usage on the economic development process of countries. Using machine learning not only helps identify the cause-effect relationships between variables but also detects trends and fluctuating patterns not easily discernible, thereby bringing fresh and unique contributions to the field of economic and environmental research.

Additionally, the study performs analysis on 47 developing and developed countries worldwide, including countries in Africa, Asia, Europe, North America, Oceania, and South America during the period from 1970 to 2021. This broad scope ensures diversity and represents various cases of economic growth and environmental development across the globe.

In summary, by applying machine learning, this study provides a new perspective on the relationship between market.

1.2. Research Objectives

1.2.1. General Objective

The general objective of this study is to analyze and better understand the impact of energy usage, CO_2 emissions, FDI, market representative prices, and CPI on the economic development of 47 countries. The research aims to identify the complex relationships among environmental, economic, and social variables, while providing useful information to support policy-making decisions regarding economic development and environmental protection.

1.2.2. Specific Objectives

To assess the impact level of each independent factor (market representative prices, energy usage, CO_2 emissions, FDI, CPI) on economic growth.

To identify energy factors that have the most significant impact on the economic development capabilities of countries.

To compare and evaluate the effectiveness of different Machine Learning models in assessing the impact of these factors on economic development.

1.3. Study Subjects and Scope

1.3.1. Study Subjects

The subjects of this study include 47 developed and developing countries worldwide, including countries in Africa, Asia, Europe, North America, Oceania and South America. Countries during this time have the most complete data published on the World Data Bank and the country's public price market page (Investing.com). With the goal of analyzing the impact of energy use, CO_2 emissions, FDI and CPI on their economic development. These countries belong to every continent and are diverse in economic size, level of development and natural conditions.

1.3.2. Research scope

Regarding spatial scope, the research was conducted in 47 developed and developing countries in the world.

Regarding time range, research data was collected from 1970 until 2021.

2. Overview of theory and previous studies

2.1. Theoretical overview

2.1.1. Kuznets curve theory of the environment

The theory of the Environmental Kuznets Curve (EKC) is an important theoretical framework based on the original findings of Simon Kuznets. He presented these findings at the 67th Annual Meeting of the American Economic Association in December 1954. Kuznets initially described a U-shaped relationship between economic development and income inequality. In particular, income inequality increases in the early stages of economic growth and then decreases when the income level reaches a certain threshold through income redistribution mechanisms.

The application of this theory in environmental economics began in the early 1990s, especially through Grossman and Krueger's (1991) study of the potential impacts of the North American Free Trade Agreement (NAFTA).). Later, this theory was mentioned in the World Bank's 1992 World Development Report. According to this theory, economic growth is not necessarily a threat to the environment; On the contrary, it can create conditions for environmental improvement over time. This leads to the assumption of a U-shaped relationship between the level of economic development and environmental pollution: environmental pollution increases in the early stages of economic development, but after passing a threshold for certain imports, environmental quality improves and pollution levels decrease.

Stern (2004) explains the EKC curve through four main economic factors: production scale, economic industry structure, resource changes and technological development. The early stages of economic development often involve a shift from agriculture to heavy industry, causing high levels of pollution due to resource intensification and waste discharge. However, in the later stages of development, the economy shifted to developing services and light industry, reducing energy demand and pollution. Changing production resources and developing technology increases efficiency and reduces waste, contributing to the EKC curve.

The pioneering studies of Grossman and Krueger, along with later contributions such as those of Panayotou (1997) and Shahbaz & Lean (2012), expanded the theoretical basis for understanding the complex relationship between economic growth, foreign direct investment (FDI), energy consumption and environmental pollution. These studies not only confirm the existence of the EKC curve but also emphasize the role of human capital and technology in transforming energy consumption and reducing CO2 emissions, thereby supporting economic development. sustainable economy along with environmental protection. The Environmental Kuznets Curve Theory provides an important theoretical framework for understanding the relationship between economic development and the environment. The interaction of economic, technological, and social factors in shaping and reversing the EKC curve emphasizes the importance of policy and technological innovation in achieving the goal of sustainable economic development .

2.1.2. Economic theory of the environment

Drawing on Mark Sagoff's "Economic Theory and Environmental Law," the essay examines perspectives on the use of economic theory in environmental law. Sagoff challenges the prevailing view in the economic community that environmental problems are fundamentally economic problems, arising from market failures when private and social costs do not coincide. He argues that this economic perspective leads to trying to correct market failures by internalizing externalities, thereby ensuring commodity prices reflect all relevant costs, including environmental damage. However, Sagoff asserts that this approach, while aimed at economic efficiency by maximizing satisfaction from incentives revealed in the market, is insufficient to reflect values and Complex principles govern public and political action towards the environment.

Sagoff criticizes the view that economic efficiency should be the sole goal of environmental policy, pointing out that such views ignore the public or community priorities that often drive environmental legislatures. school. He argues that these priorities reflect deeper environmental values and ethical considerations that cannot be fully captured or addressed through market mechanisms alone. Sagoff goes on to examine how economists attempt to account for these non-market values, especially through the use of shadow prices to assign monetary value to non-organic benefits and costs. related to environmental protection. However, he argues that this approach undermines the integrity of political and moral beliefs by reducing them to an economic level, which can justify any policy based on determined values. price.

2.1.3. Green environmental theory

In the current context, the transition from a "brown" economic model to a "green" economic model is becoming increasingly urgent in the face of environmental and sustainable development challenges. Bondarenko et al.'s (2020) study analyzes the theoretical basis, methodological framework as well as practical value of applying a green economic model based on sustainable development principles. The authors studied the initiatives and experiences of several countries and international alliances in implementing "green" innovation. They also pointed out specific difficulties in developing the Russian economy according to the "green" scenario, and positively evaluated the prospects for applying these efforts in the long-term future. The study emphasizes the importance of absorbing experience from other countries and their alliances in implementing "green" initiatives, especially when the Russian economy is shifting towards development and focus. into innovation.

Based on the comprehensive analysis in "Green growth: Economic theory and political discourse" by Michael Jacobs (2012), the concept of green development emerges as an important evolution in international policy, emphasizing its feasibility. of economic development in parallel with significant environmental conservation. This document delineates green development from its prototype, sustainable development, by directly engaging with the need for economic growth, affirming not only the compatibility of growth with environmental conservation but also proposing environmental policies that can promote economic expansion. This debate draws on several key economic theories and empirical evidence, distinguishing between a "standard" green development argument that focuses on the long-term economic benefits of environmental protection - and a "strong" version that sees environmental policy as a direct source of growth through mechanisms such as Green

Keynesianism, correcting market failures and leveraging comparative advantage in industry. environmental technology. Jacobs's research explores the subtle political and economic landscapes that shape the debate on green development, highlighting both the potential and the challenges to realizing this paradigm shift toward a future economically sustainable and prosperous. The document presents green development as a complex but promising path, dependent on strategic investments in environmental policies and technologies, and emphasizes the important role of political economy in steer the transition towards sustainable development models without threatening ambitions for economic growth.

2.2. Previous studies

According to Armenia Androniceanu and Irina Georgescu 2023, based on estimation procedures such as first and second-generation data panel root unit tests (CIPS) and data panel ARDL based on three estimates PMG, MG and DFE showed that there is a short-run causal relationship from CO2 emissions, energy consumption and FDI to GDP growth rate, while the MG estimate shows the existence of a short-run causal relationship as well. and long term. These findings can provide recommendations for policymakers to encourage the renewable energy sector to improve sustainable development.

The link between energy consumption and CO2 emissions affects economic growth, but this relationship depends on the country's income level and how it uses technology. For higher-income countries, reducing CO2 emissions does not necessarily reduce GDP due to the adoption of new technology. Meanwhile, low-income countries may experience a more negative impact on economic growth due to CO2 emissions (Héctor F. Salazar-Núñez et al., 2019).

Abdulhadi Ieweedat Ali Lamah et al. 2019 analyzing the impact of the Consumer Price Index (CPI), Foreign Direct Investment (FDI), Bank Credit (BC), and Labor Force (LB) on Economic Growth in Indonesia, shows that FDI is an important factor contributing to economic growth in Indonesia, while CPI, bank credit, and labor force do not have a significant influence. The study recommends that policymakers and the Indonesian government focus on attracting and effectively managing FDI to promote economic growth, as well as consider other measures to enhance the effectiveness of FDI. other economic factors..

The study by Nawaz et al. 2020, shows a bilateral relationship between CO_2 emissions and economic growth in the EE, SE, NE, and WE regions for the GVA-A, SGVA, and CGVA industries, while there is no relationship between CO_2 emissions and economic growth when considering manufacturing GVA in the SE region.

The relationship between FDI, CO_2, energy use, and economic growth is complex and multidimensional. FDI can act as both a cause of increased CO_2 emissions and a solution to minimizing environmental impacts through improving technology and resource efficiency. Energy use plays an important role in shaping CO_2 emissions patterns and influencing economic growth, while CPI is a factor that influences inflation and can have an indirect impact on growth. economy. Policies aimed at promoting FDI in green technology projects, improving energy efficiency and controlling inflation can support a sustainable economic development model (Dissanayake et al., 2023).

The study was conducted by Saint Akadiri & Chigozie Akadiri (2019) to understand the impact of natural gas consumption on Iran's economic growth from 1980 to 2013. Using a multivariate model including Real Fiscal Fixed Capital Formation Along with, the study aims to determine the impact of natural gas consumption and real fiscal fixed capital formation on Iran's domestic output. Through the application of the autoregressive distributed lag (ARDL) method for autoregressive convergence, the study shows that natural gas consumption, both transient and long-term, does not significantly affect output. In contrast, real financial fixed capital formation has a positive and statistically significant impact on economic growth, both within and in the long run. The study notes that natural gas consumption does not play a significant role in stimulating economic growth in Iran, while real fiscal fixed capital formation does. In summary, the study concludes that natural gas consumption does not positively affect Iran's economic growth, suggesting that policies focusing on energy exploitation or enhancing natural gas consumption may not directly affect Iran's economic performance in the short or long term. This neutrality, along with the unidirectional impact from real GDP on natural gas consumption, suggests that Iran's economy can grow independently of its natural gas consumption. The study expressed that focusing on real financial fixed capital formation could be more helpful for sustaining economic growth in Iran.

In the study of Fadiran et al. (2019), natural gas consumption (NGC) has a positive impact on economic development in some European countries. Specifically, analysis across 12 European countries, including the top 10 natural gas (NGV) markets in Europe, shows that there is a long-term relationship between NGC and economic growth. . However, this relationship is not clear in the short term. The study also shows that in Austria, Bulgaria and Switzerland the growth hypothesis exists, while in the UK and Italy the conservation hypothesis is supported. This shows that in some countries, increased natural gas consumption can drive economic growth, while in others, economic growth can lead to increased natural gas consumption .

Oguz et al (2013) explored the relationship between coal consumption and Gross Domestic Product (GDP) in Turkey based on data from 1980 to 2006. To explore this relationship, a systematic A multivariate system is used by including fixed capital and variable labor force in the model. Empirical results obtained from asymmetric causality tests show that coal energy consumption and economic growth in Türkiye do not influence each other. This means that reducing coal consumption does not affect economic growth and, on the contrary, has a neutral impact on each other.

For developed countries, there is no long-term relationship between coal consumption and economic growth, while in developing countries there is a relationship. Based on the research of Jin & Kim (2018), the “growth hypothesis” (positive impact of coal energy consumption on economic development) takes place in developing countries.

According to research by Apergis et al. (2016), the impact of hydroelectric energy consumption on economic development is considered positive. The study is based on analysis of data from dashboards of the top 10 hydropower energy consuming countries from 1965 to

2012. In the study, researchers used statistical methods such as testing Bai and Perron's (2003) cointegration and the nonlinear panel smooth transition vector error correction model. The results show that economic growth and per capita hydropower energy consumption have a long-term link. In particular, from 1988 onwards, there is evidence of a bidirectional causal relationship between per capita hydropower energy consumption and real GDP per capita, both in the short and long run.

In Chang et al.'s (2014) study on the relationship between nuclear energy consumption and economic growth in G6 countries, Granger causality analysis is based on meta-analysis in mixed data panels. shows the existence of a one-way relationship between economic growth to nuclear energy consumption. However, this result is not consistent across all countries studied. Especially in the UK, the results show a bidirectional causal relationship between nuclear energy consumption and economic growth, i.e. both variables interact with each other. For Germany, the study supports the growth hypothesis – that is, nuclear energy consumption has a positive impact on economic growth. In contrast, for the remaining countries in the G6 group, it is neutral, finding no clear cause-and-effect relationship between nuclear energy consumption and economic growth.

However, research by Omri et al (2015) shows that the impact of nuclear energy consumption on economic development is mainly positive, especially in the cases of Belgium and Spain. , but this impact is not comprehensive and uniform for all countries, some cases show a two-way relationship or have no clear cause and effect.

Fossil energy consumption (including coal, oil, and natural gas) has a positive and significant influence on economic growth in BRICS countries. Specifically, the regression coefficient for coal energy consumption is 0.786, meaning that if coal energy consumption increases by 1%, economic growth will increase by 0.786%. For oil and natural gas energy consumption, the results show that although they have a positive relationship with economic growth, the relationship is not statistically significant. Meanwhile, renewable energy consumption has a negative and significant effect on economic growth, with a regression coefficient of -0.0136, meaning economic growth decreases when renewable energy consumption increases. (Sasana and Ghozali, 2017)

Short-run impact tests in Turkey indicate that there is a positive unidirectional relationship from oil consumption to economic growth rates, and that oil consumption stimulates growth rates. economic growth (Terzi and Pata, 2016). However, the results do not show a long-term positive relationship between economic growth and oil consumption.

According to Žiković and Vlahinić-Dizdarević (2011), small European countries can be divided into two groups based on the relationship between oil consumption and economic growth. The first group includes countries whose economic growth has led to increased oil consumption, mainly developed countries with strong post-industrial societies and developed service sectors. The second group is countries where oil consumption impacts economic growth. In this study, the impact of oil consumption on economic development is positive in some cases, but is not comprehensive for all countries studied. Specifically, the study classifies small European countries into two groups based on the relationship between oil consumption and economic growth, with some countries showing that economic growth leads to increased oil consumption. and vice versa.

In the study by Rahman et al. (2020), the impact of CO2 emissions on economic growth in South Asian countries is explored using data from 1990 to 2017. The results show that emissions CO2 have a positive impact on economic growth in this region. Specifically, the study shows that there is a positive relationship between CO2 emissions and economic development, with the economic growth of South Asian countries being closely related to increased CO2 emissions. This reflects the fact that economic activity, especially industrial production and energy use, contributes to increased emissions but also drives economic growth.

The study by Christos et al. (2018) found a strong inverse relationship between the level of corruption and GDP per capita in most European countries, except for non-EU countries in Central and Eastern Europe, including Turkey.

FDI has a positive and marginally significant impact on economic growth, with economic convergence conditions at a 5% level, no significant impact from FDI to domestic investment, and the correlation between domestic investment and trade openness in the region according to Zekarias Minota Seiko (2009). Furthermore, Seiko (2016) also demonstrated that FDI is a key factor in driving economic development in East Africa, helping to narrow the technology gap, create jobs, and reduce resource shortages and trade deficits.

Pradhan et al. (2020) using a vector autoregression (VAR) model on panel data found that the development of the bond market and the stock market along with the inflation rate and real interest rate are uniform. are important factors that have a positive and significant impact on long-term economic growth. Bilal et al (2016) also showed that there is a positive and significant impact of stock market development on economic growth.

3. Research Methods

3.1. Collect data

The data used in this study was collected from Our World in Data, World Bank Open Data, and Investing.com. The study uses mixed data (Panel data) for 47 developed and developing countries in the period from 1970 to 2021, in which data is fully published on the necessary indicators for the study. rescue.

Table 1: Description of variables used in the model

Variable	**Symbol**	**Measure**	**Study**
Dependent variable			
Percent economic growth	gdp_growth	GDP growth per capita (percentage)	Cosimo Magazzino, , Marco Mele and Giovanna Morelli 2020
Independent variables			
Level of energy consumption from gas	Gas	Average energy consumption from Gas per capita (K wh)	Seyi Saint Akadiri and Ada Chigozie Akadiri 2018 (+/-), Gideon Fadiran, Adebisi T. Adebusuyi and David Fadiran (2019) (+)
Level of energy consumption from coal	Coal	Average energy consumption from coal per capita (K wh)	Oguz Ocal, Ilhan Ozturk and Alper Aslan (2013) (+/-), Jin, T., & Kim, J. (2018) (+)

Level of energy consumption from hydroelectricity	Hydro	Average energy consumption from hydropower per capita (K wh)	According to Apergis et al (2016) (+)
Level of energy consumption from nuclear	Nuclear	Average energy consumption from nuclear per capita (K wh)	Omri et al (2015) (+), Chang et al (2014) (+/-)
Level of energy consumption from fossil fuels	Fossil	Per capita consumption is calculated in Kilowatts per hour (K Wh	Sasana và Ghozali (2017) (+)
Level of energy consumption from oil	oil	Per capita oil consumption is calculated in Kilowatts per hour (K Wh)	Terzi và Pata (2016) (+/-), Žiković and Vlahinić-Dizdarević (2011) (+/-)
CO2 emissions	CO2	Average CO2 emissions per capita	Rahman, Saidi và Ben Mbarek (2020) (+)
Consumer price index	cpi	Consumer price index	Papageorgiou et al,(2018) (+)
Foreign direct investment index	FDI	Foreign direct investment, net cash flow (% of GDP)	Zekarias Minota Seiko (2009)(2016) (+)

Price index represents countries	Price index	Average price by year, million USD	Rudra P. Pradhan et al (2020) (+),Bilal, Chen, and Komal (2016) (+)

3.2. Data processing process

Step 1: Collect data from Worldbank, Our World in Data and Investing.com.

Step 2: Filter the data, select countries that provide complete indicators, and combine the data into a panel table.

Step 3: Choose a machine learning model, determine the appropriate model.

Step 4: Train the model Divide the data into training and testing sets.

Step 5: Evaluate the model, compare the performance between models based on R2 and RMSE.

Step 6: Analyze the impact, consider the impact of factors on economic development.

Step 7: Make conclusions, recommendations and point out limitations of the research.

3.3. Machine learning model

3.3.1. Model

Machine learning is a crucial branch of artificial intelligence, focusing on developing algorithms and statistical models that enable computers to learn from data and improve performance on specific tasks without being explicitly programmed. The theoretical foundation of machine learning is built upon probability theory, statistics, linear algebra, optimization theory, and computer science (Samuel, 1959).

Within the framework of machine learning, the goal is to develop models capable of generalizing patterns from input data, rather than memorizing specific patterns. The training process involves presenting the algorithm with a set of examples, and then the algorithm adjusts its internal parameters to minimize the difference between the predicted output and the actual output. This process is often referred to as model fitting or model training.

The experimental method used in this study involves the application of Machine Learning models, including Decision Tree, Random Forest, XGBoost, LightGBM, and CatBoost, to evaluate capabilities and extract significant information. These models are commonly applied to analyze the impact of energy use on the economic development capabilities of countries around the world.

The Decision Tree (DT) analysis was chosen for this study due to its ability to analyze and process datasets from simple to complex, identifying variables that may impact the output variable. DT is particularly suited for studying complex relationships between multiple factors and the impact of environmental variables on economic development capabilities. Through iterative processes, DT is trained to create a hierarchical structure that facilitates the identification of factors and evaluates their impact potential and relative importance in promoting economic development capabilities (Zagow et al., 2024).

Random Forest (RF) is a typical machine learning method originally developed based on the bagging algorithm with a minor change. Leveraging the bagging algorithm, RF can combine both regression and classification trees. Moreover, distinctly different from traditional linear regression models in terms of performance, RF can fit complex nonlinear relationships based on predictions and predictor heterogeneity (Ye et al., 2019). Due to its ability to measure variable importance, the corresponding Gini index from RF is applied in this paper to measure the relative importance of factors affecting CO2 emissions in CCD.

XGBoost, short for eXtreme Gradient Boosting, is a renowned gradient boosting algorithm known for its capability to handle large data, high performance, and accuracy in classification and regression problems (Berkay Akışoğlu, 2019). By applying a series of decision trees, each subsequent tree attempts to correct the errors of the previous one, thereby optimizing the loss function. XGBoost has a powerful capability in analyzing the impact of observed variables on the target, thus assessing the level of influence.

LightGBM, short for Light Gradient Boosting Machine, is described as a powerful gradient boosting framework with low computational cost, high training speed, and low memory consumption compared to traditional decision tree algorithms. LightGBM utilizes two innovative strategies: "gradient-based one-side sampling" (GOSS) and "exclusive feature bundling" (EFB), which help reduce complexity and increase the model's speed without sacrificing performance (Jabeur et al., 2021).

CatBoost is described as an extremely efficient machine learning algorithm for prediction, capable of handling categorical data without the need for cumbersome preprocessing, and stands out for its ability to automatically process categorical features and provide high-accuracy prediction results compared to other machine learning algorithms. CatBoost achieves high accuracy through techniques "gradient-based one-side sampling" (GOSS) and "exclusive feature bundling" (EFB), reducing complexity and speeding up training without compromising model performance (Saravanan et al., 2022). Furthermore, Shafiullah Qureshi (2023) utilized CatBoost for forecasting the actual GDP growth of Canada. This algorithm was chosen due to its efficient handling of nonlinear data and interactions between variables. CatBoost, along with other nonlinear decision-tree-based algorithms like LightGBM, demonstrates excellent forecasting and classification performance.

3.3.2. Estimation method

During the experimental process, machine learning models were trained on a dataset containing information about energy usage and economic development indicators of countries. Subsequently, the models were used to predict economic development indicators based on information about energy usage. The predicted results were compared with actual values to calculate evaluation metrics such as RMSE (Root Mean Square Error) and R^2 (Coefficient of Determination), aiming to assess the accuracy and effectiveness of the models.

Throughout this process, the models also had the ability to identify the importance levels of input variables (feature importance). This allows for the identification of energy factors that have the greatest impact on the economic development capabilities of countries.

3.2.1. Square Root of Mean Squared Error (RMSE)

One commonly used method to assess the accuracy of predictions is the mean squared error, also known as the root mean squared error. It illustrates the Euclidean distance between the actual measured values and the forecasts. The error (the difference between the prediction and the reality) is calculated for each data point and the norm, the average, and the square root of it to determine the root mean squared error (RMSE). Because it requires and uses actual measurements at each predicted data point, RMSE is often used in supervised learning applications.

Formula: RMSE = $\sqrt{\frac{\sum_{i=1}^{n}(0_i - \hat{O}_i)^2}{n}}$

Where: n is the number of data points, 0_i is the ith measurement i, and $\hat{O}_i$ is the corresponding prediction.

3.2.2. Coefficient of determination (R2)

The percentage of variation in the dependent variable that can be predicted from the independent variable is called the coefficient of determination in statistics. R-squared (R2) is a statistical measure that shows the extent of variation of the dependent variable explained by one or more independent variables in a regression model. R2 measures how much of the variation of one variable explains the variance of the second variable, as opposed to correlation which describes the strength of the relationship between independent and dependent variables. Therefore, if a model's R2 is 0.50, it means that the model's inputs can explain approximately half of the observed variation. A value of 1 indicates that the model's performance has improved.

Formula: $R^2 = 1 - \frac{\sum_i(0_i - \hat{O}_i)^2}{\sum_i(0_i - \bar{O}_i)^2}$

Where: 0_i is the ith measurement i, $\hat{O}_i$ is its corresponding prediction, and $\bar{O}_i$ is the average of the actual data points.

3.2.3. Mean absolute error (MAE)

The Mean Absolute Error (MAE) is a metric commonly used to assess the quality of a regression model. It measures the average of the absolute values of the errors between the predicted values and the actual values. MAE provides a direct way to measure the accuracy of a regression model by calculating the average distance between predictions and actual outcomes without considering the direction of the error. A low MAE value indicates that the model's predictions are close to the actual values, and vice versa.

Formula: MAE = $\frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i\ |$

Where: n is the number of observations, y_i is the actual value of the ith observation, $\hat{y}_i$ is the predicted value of the ith observation.

3.2.4. Mean square error (MSE)

Mean Squared Error (MSE) is another commonly used metric to evaluate the performance of a regression model. MSE measures the average of the squared differences between predicted values and actual values. By squaring the errors, MSE penalizes larger errors more heavily, highlighting the impact of outliers and providing a clear indication of model quality. A lower MSE value indicates a more accurate regression model.

Formula: MAE = $\frac{1}{n}\sum_{i=1}^{n}(|y_i - \hat{y}_i\ |)^2$

Where: n is the number of observations, y_i is the actual value of the ith observation, $\hat{y}_i$ is the predicted value of the ith observation.

4. Analysis results

4.1. Descriptive statistics

Table 2: Descriptive statistics

	Number of observations	Medium	Standard deviation	Min	Max
oil	1078	13565.082	8936.439	1043.141	39816.453
gas	1078	7266.276	6842.335	0	32708.826
coal	1078	7017.216	7024.135	0	32216.773
hydro	1078	3731.9	10052.372	0	84030.45
nuclear	1078	2823.696	4994.801	0	25343.982
fossil	1078	27848.573	17282.597	2166.067	82240.42
co2	1078	6.936	4.269	0.628	21.282
cpi	1078	96.879	36.494	0.017	318.936
gdp_growth	1078	2.307	3.71	-14.759	23.201
fdi	1078	3.631	7.197	-37.676	86.479
price index	1078	3072.518	5544.547	0.002	50281.028

Source: Author

Comment on table 2: There is a significant disparity in the consumption of different energy sources. Oil has the highest average production, while nuclear energy has the lowest average production. This reflects the heavy dependence on oil in many countries' energy mix and the limitations on nuclear energy utilization. The high standard deviation of most variables indicates large fluctuations in the data, indicating differences in energy potential and usage between regions, as well as the volatility of economic indicators over time. Although the standard deviation of CO2 emissions is relatively low compared to the mean value, suggesting the possibility of some changes but not excessively large.

4.2. Correlation graph between variables and economic growth index

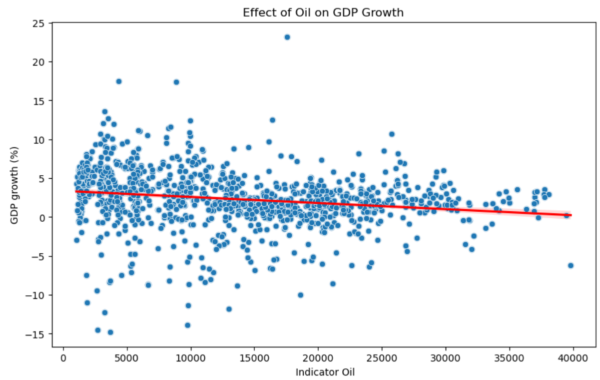

Figure 1: Impact of Oil on GDP growth

Source: Author

Comment on chart 1: Based on the scatter plot, which shows the relationship between average oil consumption per capita and GDP growth (%), there is a general trend of a slight decrease in the relationship between oil consumption and GDP growth. However, this relationship is not strong due to the wide dispersion of data and lack of a clear trend. The distribution indicates that there are high GDP growth rates despite average oil consumption, while others have low GDP growth even with high consumption levels.

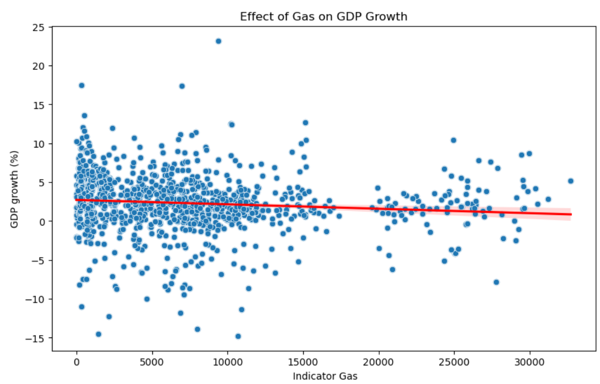

Figure 2: Impact of Gas on GDP growth

Source: Author

Comment on chart 2: The scatter plot depicting the relationship between average gas consumption per capita and GDP growth (%) shows a slight downward trend in GDP growth as the average per capita gas usage increases, as indicated by the red trend line drawn through the data points. However, this relationship is not particularly strong, with data points scattered widely and not following a clear pattern.

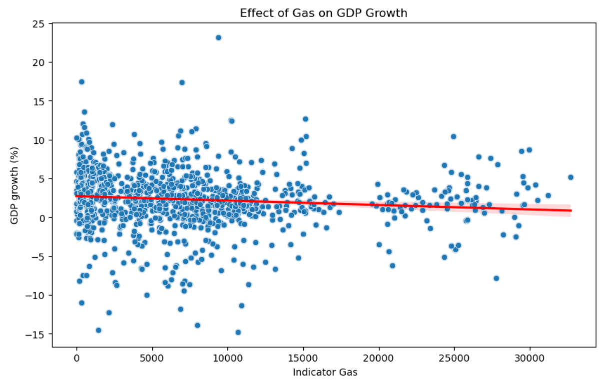

Figure 3: Impact of Coal on GDP growth

Source: Author

Comment on chart 3: The scatter plot illustrating the relationship between average coal consumption per capita and GDP growth (%) shows that there is almost no significant relationship between coal consumption and economic growth. The red trend line indicates a nearly flat relationship, suggesting little to no discernible change in GDP growth regardless of whether coal usage increases or decreases. Although there are some outliers with high GDP growth that does not correspond to coal consumption, or vice versa, these cases are not sufficient to generate a clear trend.

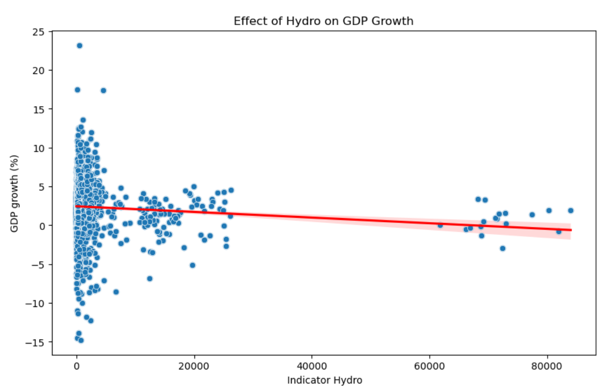

Figure 4: Impact of Hydro on GDP growth

Source: Author

Comment on chart 4: The scatter plot depicting the relationship between average hydroelectric consumption per capita and GDP growth (%) shows a slight downward trend in GDP growth as the average hydroelectric usage increases, as indicated by the red trend line running through the data points. The observations exhibit a wide and uneven distribution, with some observations lying far from the trend line, indicating that GDP growth is not solely dependent on hydroelectric consumption. This could be due to various factors, including energy efficiency, dependence on other energy sources, and the economic structure of each country. This may reflect the reality that while hydroelectric power is a renewable and clean energy source, it is not the primary determining factor for economic growth in the modern environment, where renewable energy is becoming increasingly popular.

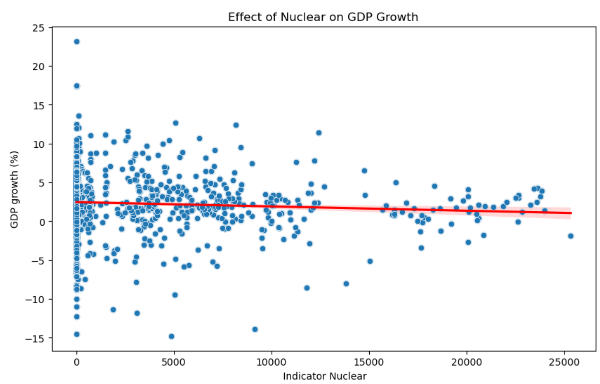

Figure 5: Impact of Nuclear on GDP growth

Source: Author

Comment on chart 5: The scatter plot illustrating the relationship between average nuclear energy consumption per capita and GDP growth (%) shows that the red trend line is nearly flat, indicating that there is no significant relationship between average nuclear energy usage and GDP growth in percentage terms. The data points are scattered around the trend line and do not exhibit a specific concentration, suggesting that the variations in GDP growth may be influenced by various factors other than nuclear energy consumption. It can be observed that some countries have high GDP growth rates despite low nuclear energy usage, and vice versa.

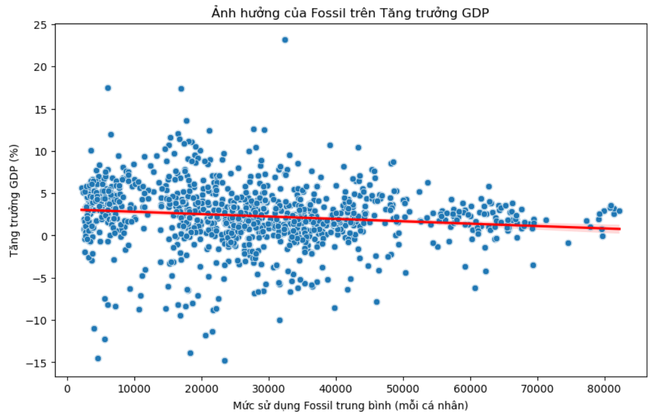

Figure 6: Impact of fossil on GDP growth

Source: Author

Comment on chart 6: The scatter plot depicting the relationship between average fossil fuel consumption per capita and GDP growth (%) shows that the red trend line indicates a slight decrease in GDP growth as fossil fuel usage increases. The data points are widely dispersed on the plot, suggesting that there is no clear relationship between fossil fuel consumption and economic growth.

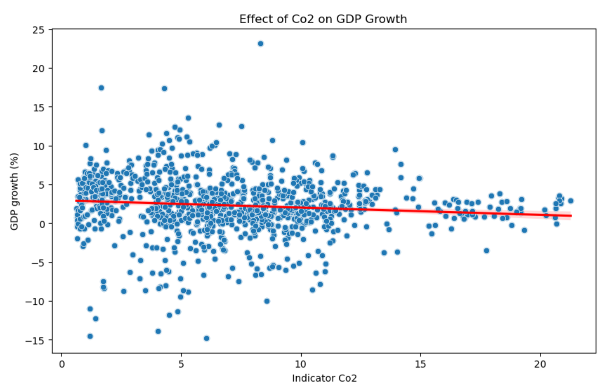

Figure 7: Impact of CO2 on GDP growth

Source: Author

Comment on chart 7: The scatter plot depicting the relationship between average CO2 emissions per capita and GDP growth (%) shows that the red trend line indicates a slight decrease in GDP growth as CO2 emissions increase. However, this relationship is not strong, as evidenced by the wide dispersion of data points. It appears that some countries with high CO2 emissions do not necessarily have high GDP growth, while others with low CO2 emissions have good GDP growth. This may reflect the fact that countries adopt different approaches to economic development and environmental management.

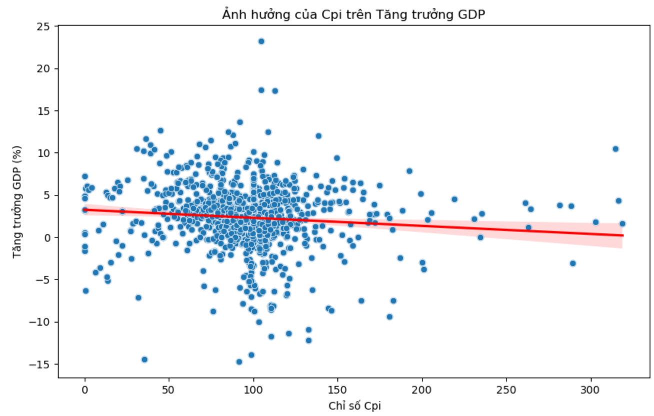

Figure 8: Impact of CPI on GDP growth

Source: Author

Comment on chart 8: The scatter plot illustrating the relationship between average Consumer Price Index (CPI) and GDP growth (%) shows that the red trend line, along with the red outer band representing confidence intervals, indicates a slight upward trend of GDP as the CPI increases. The scattered data points suggest that there is no strong correlation between these two variables, with some countries experiencing high GDP growth and low CPI, and vice versa.

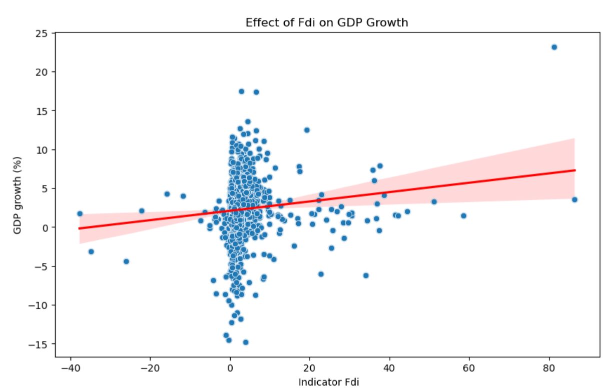

Figure 9: Impact of FDI on GDP growth

Source: Author

Comment on chart 9: The scatter plot depicting the relationship between average Foreign Direct Investment (FDI) per capita and GDP growth (%) shows that the red trend line, along with the pink surrounding band (representing confidence intervals), indicates a slight relationship between average FDI per capita and GDP growth. Specifically, there is a slight upward trend in GDP growth as FDI per capita increases. The wide dispersion of data points around the trend line suggests that FDI is just one of many factors influencing a country's economic growth. The wide pink band of confidence intervals indicates uncertainty in estimating this relationship and suggests the possibility of significant fluctuations in GDP growth even when the level of FDI is held constant. There are some observations in the plot where FDI values are negative.

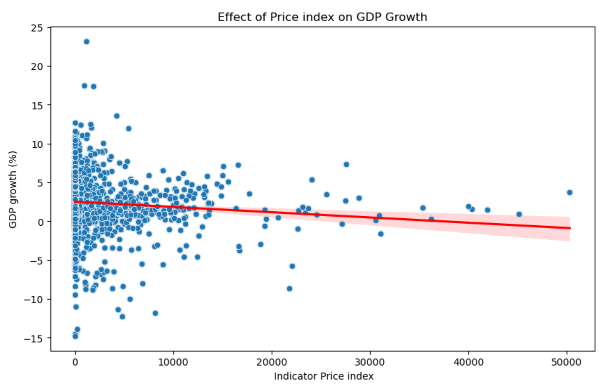

Figure 10: Impact of Price index on GDP growth

Source: Author

Comment on chart 10: The scatter plot illustrates the relationship between the price index and GDP growth (%). The red trend line, along with the pink surrounding band, indicates a slight negative relationship between the price index and GDP growth. However, this relationship appears to be unclear due to the wide dispersion of data points. The data points are not strongly concentrated around the trend line, suggesting that the price index may not be the sole determining factor for GDP growth. The wide confidence interval indicates a high level of uncertainty, and future data points may vary in relation to this trend line.

4.3. Model performance

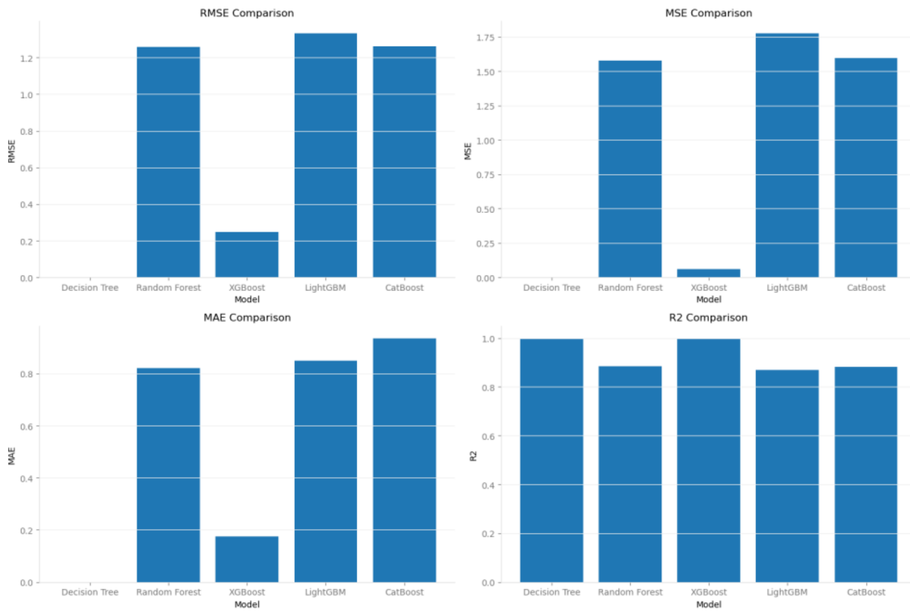

Figure 11: RMSE, MAE, MSE and R2

Source: Author

Comment on chart 11: The Decision Tree model has RMSE and MSE values of 0, along with an R2 value of 1. This could indicate that the model is overfitting the data. The Random Forest model has significantly higher RMSE and MSE values compared to XGBoost, but it has a relatively high R2 value of 0.88. The XGBoost model has very low RMSE and MSE values, along with a high R2 value close to 1. This suggests that the XGBoost model performs exceptionally well and is the best model among the ones compared. The LightGBM model shows similar performance to the Random Forest model, with relatively high RMSE and MSE values and an R2 value of 0.87, indicating that it can explain a large amount of data variance but not as effectively as XGBoost. The CatBoost model has similar results to Random Forest and LightGBM, with high RMSE and MSE values and an R2 value of 0.88. This suggests that the model is a good choice but slightly less effective than XGBoost for this dataset. Based on the evaluation and observations, XGBoost appears to be the best-performing model on this dataset, with low RMSE and MSE values and a high R2 value. It shows no signs of overfitting and demonstrates the ability to predict well on new data.

Table 3: Summary of index results

Model	RMSE	MSE	MAE	R2
Decision Tree	0	0	0	1
Random Forest	1.257053	1.580182	0.820611	0.883897
XGBoost	0.248034	0.061521	0.175519	0.99548
LightGBM	1.33266	1.775984	0.849799	0.869511
CatBoost	1.26302	1.595219	0.935874	0.882793

4.3. The role of variables in the economic development ability of countries

4.3.1. Comment on the influence of variables on economic development

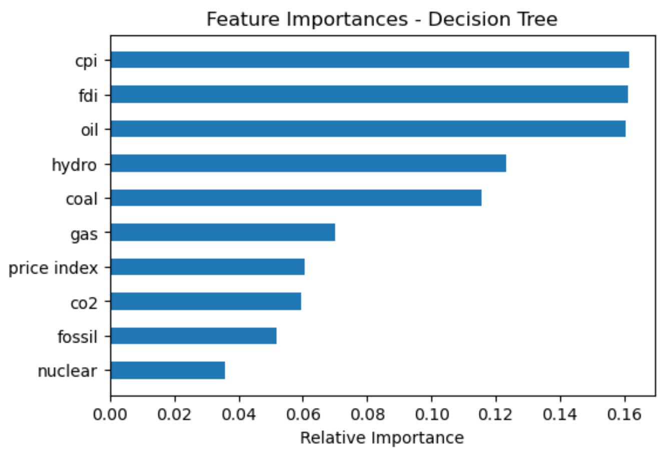

Figure 12: Decision Tree important variables

Source: Author

Comment on chart 12: The Consumer Price Index (CPI) appears to have the highest importance, indicating that it has a strong influence on GDP growth. Foreign direct investment and oil also have significant importance, suggesting that these factors play a crucial role as well. On the other hand, nuclear energy consumption has the lowest importance, indicating that it has the least impact on GDP growth among the features analyzed in the chart.

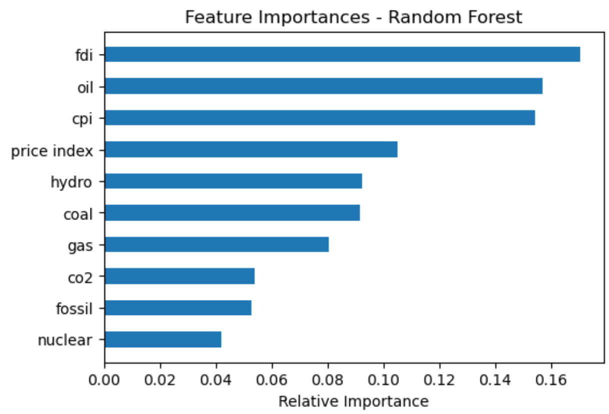

Figure 13: Random Forest important variables

Source: Author

Comment on chart 13: It can be observed that the investment index is the most important factor in the Random Forest model, followed by 'oil' and 'cpi,' which is similar to the Decision Tree model. The change in feature importance compared to the Decision Tree model suggests that Random Forest may be considering interdependencies among the features.

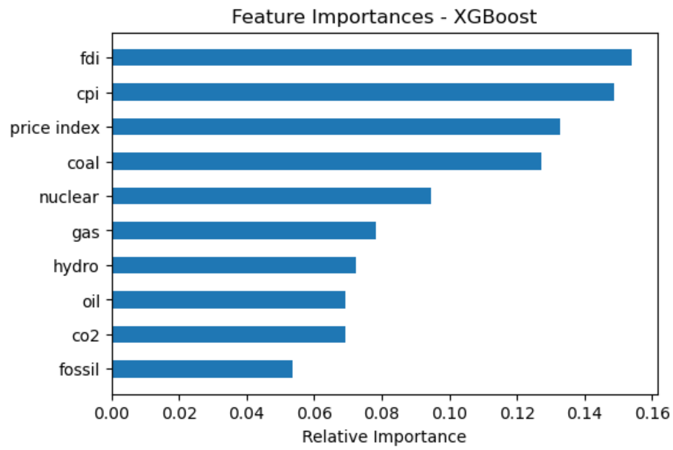

Figure 14: XGBoost important variables

Source: Author

Comment on chart 14: The investment index continues to lead in terms of importance, followed by 'cpi' and 'price index.' Other energy sources like 'coal' and 'nuclear' have relatively lower impacts.

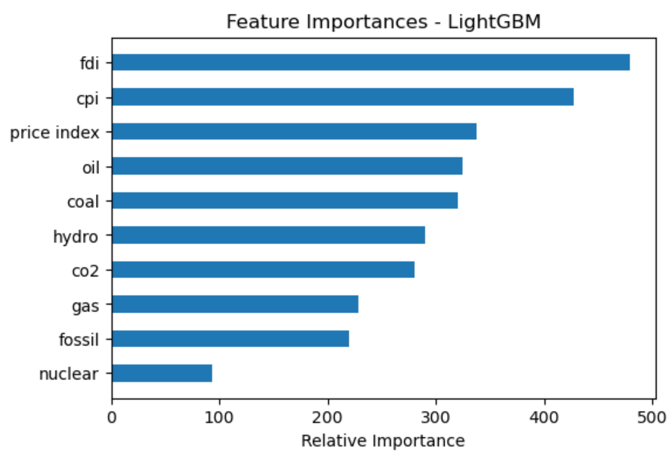

Figure 15: LightGBM important variables

Source: Author

Comment on chart 15: It can be observed that 'fdi' and 'cpi' still remain among the most important features, although their order may have changed. Interestingly, 'oil' is no longer the top feature as in other models. This could be due to the way LightGBM handles features and their relationships.

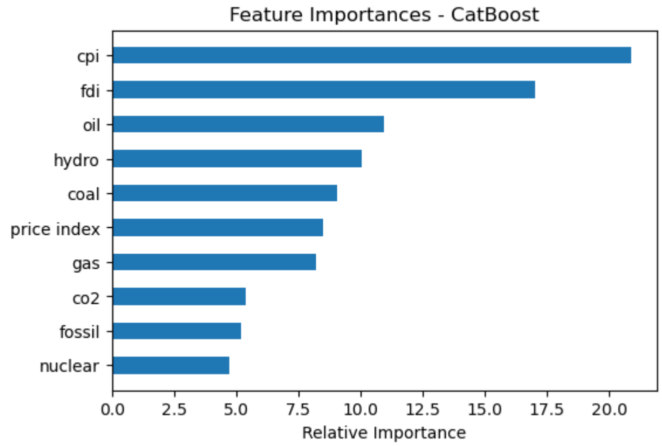

Figure 16: CatBoost Important Variables

Source: Author

Comment on chart 16: In CatBoost, 'cpi' has the highest importance, indicating its significant impact. 'fdi' and 'oil' still maintain their importance, although their order may have changed.

4.3.2. General comments on the influence of variables

'fdi' and 'cpi' consistently appear as important features across different machine learning models, indicating that foreign direct investment and consumer price index have a significant impact on economic growth. While each model may have different feature importance evaluation characteristics, there is a certain level of consensus among them regarding the features that have strong influence and those that are less important. 'oil' frequently appears in the list of highly important features but not always in the top position. Energy-related features such as 'coal', 'gas', 'hydro', and 'nuclear' often do not appear among the variables with strong impact on economic development.

5. Conclusions and recommendations

5.1. Conclusions

The study analyzed the performance of machine learning models in predicting the impact of variables such as market price index representing 47 countries, energy consumption, CO2 emissions, and FDI on economic growth. Based on RMSE and R2 scores, the XGBoost model was evaluated as the best-performing model, demonstrating high accuracy and reliability in predictions. The study also indicated that among the considered variables, oil production, coal production, gas production, and FDI have significant impacts on GDP, while CO2 emissions and hydroelectric energy production have relatively weaker influences. Regarding gas consumption: Seyi Saint Akadiri and Ada Chigozie Akadiri (2018), as well as Gideon Fadiran, Adebisi T. Adebusuyi, and David Fadiran (2019), have shown that gas consumption has a positive effect on GDP growth. However, in this study, the results indicate that the relationship between gas consumption and GDP growth is not strong. Regarding coal consumption: Oguz Ocal, Ilhan Ozturk, and Alper Aslan (2013), as well as Jin T. & Kim J. (2018), have indicated that coal consumption has a neutral or positive relationship with GDP growth. The study also observed that this impact is almost negligible, which aligns with previous findings. In contrast to the positive influence of hydroelectric energy consumption on economic development (Apergis et al., 2016), the results of this study suggest that this relationship is not strong.

According to the studies by Omri et al. (2015) and Chang et al. (2014), a neutral or positive relationship was found between nuclear energy consumption and GDP growth. However, in this study, no significant relationship was found, emphasizing the different role of nuclear energy in different economies and the need for specific country-level assessments. Consistent with the studies by Omri et al. (2015) and Chang et al. (2014), this research did not find a significant relationship between nuclear energy consumption and economic development. The study highlighted that the impact relationship between fossil fuel consumption and CO2 emissions is positive, but Sasana and Ghozali (2017) and Rahman Saidi and Ben Mbarek (2020) found contrary results.

For the Consumer Price Index (CPI), although Papageorgiou et al. (2018) emphasized a positive relationship between CPI and economic growth, this study only found a weak correlation, indicating that price stability is not always the sole key to growth. Regarding Foreign Direct Investment (FDI), while Seiko (2009, 2016) mentioned the positive impact of FDI on GDP, the research results in this study also indicated a similar but not high result. Finally, concerning the Price Index, Rudra P. Pradhan et al. (2020) and Bilal Chen and Komal (2016) recorded a positive relationship between this index and GDP growth, contrary to the findings of this study, which showed a slight negative correlation, reflecting the complexity and differences among markets and economies, where price increases do not always lead to growth.

5.2. Recommendations

In the current context, the transition to renewable and cleaner energy is becoming a top priority for countries worldwide. Our research findings show a slight negative relationship between fossil fuel consumption and GDP growth, along with the insignificance of coal consumption on economic growth. These findings suggest that strong investment in renewable energy sources such as hydroelectric power, solar energy, and wind energy not only contributes to reducing CO_2 emissions but also ensures a sustainable future for the global economy. This also includes enhancing energy efficiency through investment in safe and efficient nuclear technology, as well as promoting the use of renewable energy through tax incentives and financial support policies.

Furthermore, controlling inflation through prudent monetary and fiscal policies is crucial to maintaining economic stability and supporting sustainable growth, ensuring that inflation remains at manageable levels. This not only protects the purchasing power of individuals but also helps alleviate cost pressures on businesses' production.

Additionally, enhancing research and development (R&D) in the energy sector is key to discovering new, efficient, and sustainable energy solutions. Investing in R&D helps improve existing technologies and optimize energy usage, thereby contributing to economic growth without harming the environment.

Finally, implementing measures for green economic development, including reducing dependence on fossil fuels, promoting green production and consumption, and undertaking environmental protection projects, is essential for transitioning to a sustainable economic development model. In doing so, countries will not only contribute to minimizing negative environmental impacts but also create a solid foundation for long-term economic growth.

5.3. Limitations and development directions

This research, while providing valuable insights into the relationship between economic growth and related variables such as energy consumption, CO2 emissions, and economic policies, has some limitations that need to be addressed in the future.

Firstly, the most significant limitation is the scope and diversity of the data. The lack of information from certain regions and countries can affect the accuracy and comprehensiveness of the analysis. Additionally, the current study focuses only on static analysis, failing to fully capture the dynamic and complex nature of economic relationships, especially in the context of evolving environmental changes and changing economic policies.

Furthermore, the study does not consider non-quantifiable factors such as the quality of governance, political stability, and cultural values, which can play significant roles in shaping and driving economic growth. Expanding the database to include information from a broader range of countries and regions, as well as integrating real-time data, would significantly improve the quality and reliability of the analysis.

Applying more complex multivariate models would enable a deeper analysis of the relationship between economic growth and variables, allowing for a more comprehensive understanding of the impact of each factor. Conducting comparative studies between countries or regions would provide deeper insights into the interactions and influences of economic, environmental, and cultural factors on economic growth.

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Appendix

Appendix 1. List of countries used in the study

Area	Quantity	Country name
Africa	3	Morocco, Egypt, South Africa
Asia	15	Saudi Arabia, Vietnam, India, South Korea, Malaysia, Thailand, Pakistan, Israel, China, Hong Kong, Kazakhstan, Philippines, Japan, Turkey, Indonesia
Europe	23	Netherlands, Ireland, Hungary, Denmark, Switzerland, Romania, Austria, Russia, Germany, France, Italy, Norway, Portugal, United Kingdom, Finland, Ukraine, Greece, Croatia, Czechia, Spain, Sweden, Lithuania, Poland
North America	2	United States, Mexico
Oceania	2	New Zealand, Australia
South America	2	Colombia, Peru

Appendix 2. Codes representing markets of countries

Country	Market Code Name
Australia	S&P_ASX 300
Austria	ATX EUR
Colombia	COLCAP
Croatia	CROBEX
Czechia	PX
Denmark	OMXC20
Egypt	EGX
Finland	OMX Helsinki 25 (OMXH25)
France	CAC All Shares (PAX)
Germany	DAX
Greece	Athex 20
Hong Kong	Hang Seng Index
Hungary	BUX
India	S&P BSE-500 (BSE500)
Indonesia	IDX
Ireland	ISEQ 20
Israel	TA125
Italy	FTSE MIB (FTMIB)
Japan	Nikkei 500
Kazakhstan	KASE
Lithuania	Vilnius SE General (OMXVGI)
Malaysia	FTSE Bursa Malaysia Top 100 (FTFBM100)
Mexico	MSCI
Morocco	Moroccan All Shares (MASI)
Netherlands	AEX
New Zealand	S&P/NZX 50 Index

Norway	OBX
Pakistan	KSE
Peru	SPBLPGPT
Philippines	PSEi
Poland	WIG
Portugal	PSI (PSI20)
Romania	BET
Russia	RTSI
Saudi Arabia	TASI
Singapore	STI
South Africa	FTSE/JSE All Share (JALSH)
South Korea	KOSPI (KS11)
Spain	IBEX 35 Historical Data
Sweden	OMX Stockholm 30 (OMXS30)
Switzerland	SMI
Thailand	S&P 500 Settlement Historical Data
Turkey	BIST
Ukraine	PFTS index
United Kingdom	FTSE All-Share (FTAS)
United States	NYSE TOP US 100 Historical Data
Vietnam	VNIndex