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Energy mix diversification and financial development: Electricity in G20 countries

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ABSTRAK

Diversifikasi bauran energi bersifat unik karena perbedaan potensi sumber daya, ekonomi dan kondisi lingkungan di setiap negara. Transisi ke energi terbarukan merupakan salah satu agenda pembangunan berkelanjutan, sekaligus target G20 dalam menjawab isu lingkungan dan membangun ketahanan energi. Namun dalam melaksanakannya, dibutuhkan sistem finansial yang baik untuk dapat mengakomodasi pengembangan dan pembangunan infrastruktur. Studi ini bertujuan untuk menganalisis peran financial development dalam mempengaruhi diversifikasi bauran energi, dengan berfokus pada bagaimana kemajuan di sektor keuangan dapat mendorong transisi energi yang lebih beragam dan berkelanjutan. Metode pendekatan model fixed effect dan estimator System-GMM digunakan dalam studi ini, dengan sampel data panel dari 19 negara anggota G20 selama periode 22 tahun. Hasil estimasi menunjukkan bahwa financial development berpengaruh positif dan signifikan terhadap diversifikasi bauran energi. Penguatan sistem keuangan dari sisi institusi maupun pasar keuangan, dapat memainkan peran krusial dalam mendorong transisi energi yang lebih seimbang dan inklusif. Hasil penelitian juga menunjukkan bahwa variabel kontrol efisiensi energi, emisi karbon dan FDI memiliki hubungan negatif terhadap diversifikasi bauran energi, sedangkan pertumbuhan ekonomi memiliki hubungan positif terhadap diversifikasi bauran energi. Temuan ini mengindikasikan bahwa peningkatan aktivitas ekonomi mendorong kapasitas negara untuk memperluas diversifikasi energi, sementara peningkatan efisiensi energi, tingginya emisi karbon, serta arus investasi asing yang berorientasi pada keuntungan jangka pendek cenderung membatasi upaya diversifikasi energi.

ABSTRACT

Energy mix diversification is unique due to differences in resource potential, economic and environmental conditions in each country.

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The transition to renewable energy is one of the sustainable development agendas, as well as the G20's targets in addressing environmental issues and building energy security. However, in its implementation, a good financial system is needed to accommodate infrastructure development and construction. This study aims to analyze the role of financial development in influencing energy mix diversification, focusing on how progress in the financial sector can encourage a more diverse and sustainable energy transition. The fixed effect model and System-GMM estimator are employed in this study, using panel data samples from 19 members of G20 countries over a 22-year period. The estimation results show that financial development has a positive and significant effect on energy mix diversification. Therefore, strengthening financial systems both from the institutions and financial market side can play a crucial role in promoting a more balanced and inclusive energy transition. The results also show that the control variables energy efficiency, carbon emissions and FDI have a negative relationship to energy mix diversification, while economic growth has a positive relationship to energy mix diversification. These findings suggest that higher economic activity enhances a country's capacity to expand energy diversification, whereas improvements in energy efficiency, higher carbon emissions, and profit-oriented foreign investment flows tend to limit efforts toward greater energy diversification.

INTRODUCTION

Standing at 8 billion people, the global population is currently estimated to increase by around 140 people every minute, with the number of births exceeding the number of deaths in almost all countries (World Population Review, 2024). Population growth has the potential to drive increased economic activity, but on the other hand, demand for energy, especially in the electricity sector, will also increase (Satrovic & Adedoyin, 2022). Referring to the Global Electricity Review 2023 published by Ember, it was found that global electricity demand has increased by an average of 2.6 percent annually over the past decade. There have only been two declines in demand in the electricity sector since 2000. The first was due to the global recession in 2009 and the second occurred as a result of the Covid-19 pandemic in 2020 (IEA, 2024).

Historically, most of the increase in global electricity demand has been met by fossil fuel power plants (Wiatros-Motyka, 2023). This problem has become a global issue and cannot be resolved in a short time. In addition to environmental issues, fossil fuel price movements are also an important reason for diversifying energy sources. Risks due to price volatility and supply disruption cannot be avoided, but diversification can mitigate the risks that a country could receive (Worldbank, 2013).

In recent years, the issue of renewable energy transition has shifted towards energy and economic security issues. Each country's natural resource is unique, as is

the alternative energy potential that can be developed (Roy, 2024). One of the things that can encourage sustainable development with these differences in potential is to choose a diversified energy policy and utilize natural resources appropriately (Singh et al., 2024). Diversifying the energy mix by incorporating renewable and alternative energy sources is essential to achieving sustainability and resilience. However, energy diversification requires substantial financial investments in infrastructure, technology, and innovation. The lack of adequate financial mechanisms, investment incentives, and efficient capital allocation often hinders the transition toward a more diversified and sustainable energy system.

The driving factors for energy diversification generally come from the internal economic, political and environmental conditions of a country. In a study conducted by Shahbaz et al. (2023), the economic factor that has the potential to determine the development of energy diversification to a higher level is financial development. Policies related to financial development will affect the economic activities of a country (Samargandi et al., 2015). The performance of an efficient and healthy financial system is a prerequisite for sustainable energy diversification (Worldbank, 2013). Therefore, financial development plays a crucial role in energy diversification.

The link between financial development and energy mix diversification lies in how financial instruments from the market and financial institutions play a role in increasing access to capital, reducing risk, and supporting the development of renewable energy projects. From a financial market perspective, the development of the financial sector creates better access to infrastructure project development (Xu et al., 2022). Instruments such as stocks and bonds, as well as special investment funds can provide capital to developers to invest in renewable energy infrastructure.

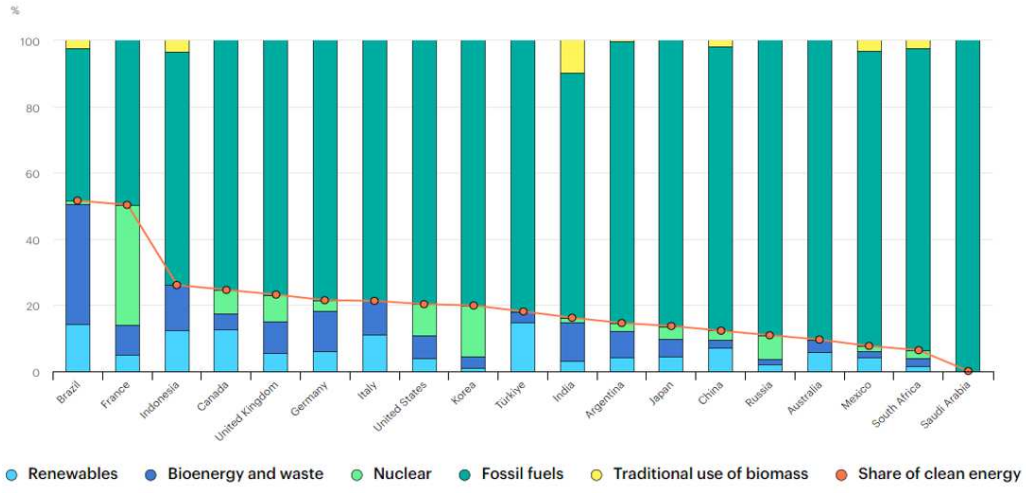
Well-developed financial sector also allows for better risk mitigation in managing energy price risk (Worldbank, 2013). This helps reduce the risk of investing in the renewable energy sector, which often requires large initial capital and faces market risks. Reduced risk increases the attractiveness of investment in the renewable energy sector and accelerates the diversification of the energy mix. In addition to the financial market side, financial development also includes the development of financial institutions. Banks and financial institutions have an important role in facilitating financial services such as providing credit and loans. Advanced financial institutions will be able to provide insurance, credit guarantees, and other risk mitigation services for renewable energy projects.

The determinants of energy mix diversification, apart from financial development, were further investigated by Irfan & Ojha (2023) and Nibedita & Irfan (2024), who brought up other factors such as economic growth, carbon emissions and energy efficiency, and foreign direct investment (FDI). These factors are supported by De Freitas & Kaneko (2011), Omri et al. (2015), Sadorsky (2010), and Udemba & Yalçıntaş (2021), who stated that a certain level of carbon emissions, economic growth

and FDI could increase government and investor attention to clean energy, and energy diversification can develop along with the energy transition. Meanwhile, energy efficiency is related to diversification of the energy mix in the context of sustainability and energy security (Shahbaz et al., 2023). Energy efficiency could accelerate energy diversification by reducing dependence on fossil fuels, encouraging the adoption of renewable energy sources, and increasing energy stability and security (Baldini & Jacobsen, 2016; Özbuğday & Erbas, 2015).

After the 1997 Kyoto Protocol and the 2015 Paris Agreement, several international forums have again adjusted their development targets, especially those related to energy and economic security. The search for affordable, environmentally friendly and sustainable energy alternatives is one of the targets of sustainable development (United Nations, 2024). However, it cannot be denied that global financial stability, security of resource supply, investment development, as well as energy efficiency are goals in almost all international forums. One of the forums that is active in matters related to energy and economic security is the G20 (United Nations Environment Programme, 2023).

The G20 is a group of countries with the most advanced economies in the world, and has a great influence in terms of economy, technology, and resources. Its member countries contribute about 85 percent of the world's GDP, more than 75 percent of global trade, have a population of about two-thirds of the world's population, and an area that covers about half of the earth's total land area (World Population Review, 2024). In several G20 member countries such as China, India and Indonesia, the most dominant energy production is still met from the combustion of fossil fuels (IEA, 2024). G20 member countries have begun to make a gradual transition to renewable energy since several years ago. However, in the case of several countries which have high populations, increased energy consumption is unavoidable and the main solution to meet energy demand still comes from fossil fuels.



Source: IEA (2024)

Figure 1
Energy Supply of G20 Member Countries by Energy Source

In recent years, total carbon dioxide emissions produced by G20 countries have decreased quite significantly, but until 2022 the majority of its members' energy supplies still use fossil fuels as the main energy source (IEA, 2024; Worldbank, 2013). The high industrial activity and population have driven G20 member countries to consume more than 80 percent of the world's energy production and produce around 75 percent of the total emissions produced by all countries (Instititute for Essential Services Reform, 2022).

In the context of financial development and energy mix diversification, previous studies have employed diverse approaches and produced varied findings. Much of the existing literature tends to emphasize the broader effects of financial development on economic growth and environmental sustainability, while limited attention has been given to its direct influence on energy diversification. On the other side, most studies on energy mix diversification has been largely country-specific, such as those conducted by De Freitas & Kaneko (2011) in Brazil, Udemba & Yalçıntaş (2021) in Algeria, Shahbaz et al. (2023) in Australia and Xu et al. (2024) in China. Within these studies, energy diversification appears as the main analysis topic while considering energy consumption, environmental challenges, efficiency and suitability of utilization unique to each subject. Additionally, besides financial development, foreign direct investment frequently emerges as a relevant factor, given their potential role in accelerating the renewable energy transition and diversification.

When these countries are grouped into one research subject, differences are found in several research results. In one of the studies by Gozgor & Paramati (2022), which used panel data from low-income & high-income countries, the European Union, OECD, and G20, it was revealed that in the long term, major economies including the G20 experienced positive growth. However, in the short term, several countries (including the OECD and G20) experienced negative economic growth due to energy diversification. The results of the study also revealed that energy diversification does not support economic growth in low-income countries, both in the short and long term.

The combination of various economic and environment constraints makes energy planning complicated and energy diversification can have both positive and negative impacts on the environment. Many diversification scenarios have proven to be unrealistic because they result in high use of imported fuels for electricity production, while other scenarios have proven to be environmentally or economically inefficient (Rampidis et al., 2010). In order to achieve energy and economic security, energy diversification must be carried out in line with financial system in each country.

Accordingly, this study investigates the role of financial development to energy mix diversification in G20 countries with economic growth, energy efficiency, carbon emission and foreign direct investment as control variable. This study seeks to contribute to economics and energy literature. The findings contain the conditions of

energy mix diversification and financial development in G20 countries, along with an analysis on how economic growth, energy efficiency, carbon emissions and foreign direct investment could influence the energy mix diversification.

LITERATURE REVIEW AND HYPOTHESIS FORMULATION

Energy Mix Diversification

Currently, the electricity and heat generation sector is the largest contributor to global carbon emission (IEA, 2023). Several previous studies conducted by Sheraz et al. (2021), Solarin & Sahu (2023), and Xu et al. (2024), showed that meeting electricity demand through reliance on fossil fuels leads to environmental degradation. In this context, energy diversification plays a critical role. Energy diversification refers to expanding the use of various energy sources, including increasing the use of renewable energy to reduce dependence on one energy source (Asif & Muneer, 2007). Meanwhile, energy mix diversification is the composition and proportional balance of those different energy sources within the overall energy mix (the shares of coal, oil, natural gas, renewables, nuclear, etc. in total of energy consumption or production). Efficient resource diversification can address the problem of increasing energy demand and reduce environmental impacts (Islam et al., 2022).

There were many factors that could be influencing energy mix diversification. From the economic side, one of the factors that may change the condition of energy transition is financial development (Shahbaz et al., 2023). Financial development refers to the process that a country's use to become more effective, efficient, and inclusive in mobilizing savings, allocating capital, facilitating investments, managing risks, and supporting economic growth. To measure the impact and level of financial development in each country, International Monetary Fund (IMF) developed financial development index by the by taking into account some macroeconomics and financial indicators that have a complex multidimensional nature. The index reflects the progress level of financial institutions and financial markets based on three main aspects, namely the depth aspect (including size and liquidity components), the access aspect (calculating how much ability individuals and companies have to access financial services) and the efficiency aspect (the ability of institutions to provide financial services at low cost and with sustainable income and the level of capital market activity).

The Link Between Financial Development and Energy Mix Diversification

The development and diversification of the energy mix is inherently capital-intensive, requiring substantial long-term financial resources for infrastructure, adopt new technologies, and expand energy capacity (Xu et al., 2022). One of the key factors that ensures the availability of long-term capital is the development in the financial sector, which strengthens financial institutions and markets to mobilize and allocate

resources effectively (Alam et al., 2015). In research related to energy diversification conducted by Shahbaz et al. (2023), developments in the financial sector have a positive effect in economic growth, mitigating risks, and developing infrastructure and technology to support electricity production. Under stable conditions, financial development has the potential to reduce cost for development and innovation, attract greater investment flows, broaden funding channels, and optimize asset allocation for new project development (Omri et al., 2015; Sadorsky, 2010).

This linkage between financial development and energy diversification is particularly evident in the electricity sector, where clean energy investments are highly attractive to investors (IEA, 2024). A robust financial system not only improves the efficiency of funding but also enables broader portfolio diversification across different sectors, thereby channelling resources toward energy diversification (Kim & Park, 2016; Wang et al., 2022). By lowering barriers to capital access and enhancing the overall investment climate, financial development has the ability to contributes to energy mix diversification, supporting the transition to a more resilient and sustainable energy system (Sheraz et al., 2021). Thus, the hypothesis that may be put out is as follows:

H1: Financial development has a positive relationship with energy mix diversification.

RESEARCH METHODOLOGY

This study uses a compilation of annual data from the International Energy Agency (IEA), International Monetary Fund (IMF), World Bank. The data taken relates to energy, economic and environmental indicators for the period 2000-2021. The subjects studied were the G20 member countries, consisting of South Africa, the United States, Saudi Arabia, Argentina, Australia, Brazil, China, India, Indonesia, the United Kingdom, Italy, Japan, Germany, Canada, Mexico, the Republic of Korea, Russia, France, and Turkey. The European Union was not the subject of the study because it is an organization and does not represent a single state entity.

Financial Development Index data from IMF is used in this study. Whereas, in measuring diversification, the Herfindahl-Hirschman Index (HHI) is employed as it is one of the most commonly used indices (Akrofi, 2021; Chalvatzis & Ioannidis, 2017; Nibedita & Irfan, 2024). HHI can be used as an index to measure energy security and describe whether a country is still dependent on one energy source (Das et al., 2021; Irfan & Ojha, 2023). HHI is calculated by summing the squared shares of each energy source in the energy mix, with the following formula:

$$HHI_{it} = \sum_{s=1}^{s} p_{sit}^{2} \quad \text{.....1}$$

In equation 1, p is the percentage of s which is the energy source in the energy

mix, i is the individual (country) taken as the research subject, and t is time. Energy mix diversification (EMD) can then be measured using the inverse of the HHI value (Nibedita & Irfan, 2024), which can be formulated as follows:

$$\boldsymbol{EMD = \frac{1}{HHI}} \quad \text{..... 2}$$

The higher the EMD value obtained from the results of equation 2, it can be interpreted that the energy diversification of a country is higher/more diverse with an even percentage. The high value of energy diversification indicates that a country has a low dependence on an energy source.

Table 1
Operational Definition of Variables

Variable	Description	Units	Sources
EMD	The use of various energy sources to produce electric power. Measured using the inverse of the Herfindahl-Hirschman Index (HHI)	Index > 0	IEA, Electricity Generation by Sources
FD	Financial development measured by macroeconomic variables. Includes indices of financial institutions and financial markets calculated by considering 3 dimensions (depth, access, and efficiency).	Index 0 to 1	IMF, Financial Development Index
GDP	GDP per capita is measured by real gross domestic product (GDP) per person, expressed in US dollars.	GDP per capita (constant 2015 USD)	World Bank, World Development Indicators
CE	Carbon emissions per capita is the average carbon emissions produced by each person in a country or region. This data is calculated by dividing total emissions by the population	Metric tons per capita	World Bank, World Development Indicators
EE	Energy efficiency ratio is measured by the ratio of total economic output (GDP) to total energy consumption	GDP per unit of energy use	• World Bank, World Development Indicators • IEA, Total Electricity Consumption by Sector
FDI	FDI net inflows divided by GDP	FDI net inflows (% of GDP)	World Bank, World Development Indicators

Research Model

The model used in this study serves to analyze the relationship between financial development and energy mix diversification. The model in this study refers to the model used by Nibedita & Irfan (2024); Shahbaz et al. (2023) in the context of investigating economic and environmental factors that contribute to energy mix diversification. The research model uses the natural logarithm form, with the following model specifications:

$$\ln EMD_{i,t} = \alpha + \beta_1 \ln FD_{i,t} + \beta_k \ln Controls_{k,i,t} + \gamma_i + \lambda_t + \varepsilon_{i,t} \quad \text{..... 3}$$

In equation 3, $EMD_{i,t}$ is Energy Mix Diversification in country *i* in year *t*, as the dependent variable of this study. $FD_{i,t}$ is Financial Development in country *i* in year *t*, which is the independent variable. $Controls_{k,i,t}$ is the control variable in this study, which includes (energy efficiency, economic growth, carbon emissions, and

foreign direct investment) in country i in year t. α is a constant, β is the coefficient of the independent variable and the control variable. γ_i is a fixed effect for individual units (countries). λ_t is a fixed effect of time (year). $\varepsilon_{i,t}$ is the residual.

In this study, there is a potential for endogeneity that may occur due to causal feedback or simultaneity. In several previous studies conducted by Omri et al. (2015) and Samargandi et al. (2015), it was found that financial development is a variable that has the potential for endogeneity. The development of the financial system has the potential to influence and can be influenced by economic growth (GDP). In addition, there is also the potential for the influence of financial development in encouraging foreign direct investment flows (Haque et al., 2022; Pham et al., 2022). Due to the potential for endogeneity, panel data estimation using fixed effects may show biased and inconsistent results. The regression model with the within group approach takes into account the specific effects of unobserved countries with a fixed time period, and tends to produce biased coefficients in dynamic models (Nickell, 1981).

To overcome this problem, this study uses the System Generalized Method of Moment (Sys-GMM) model. The GMM estimation model is a model developed by Arellano & Bover (1995), Blundell & Bond (1998). This model can overcome the problems of dynamic panel bias and potential endogeneity, and can produce unbiased and consistent estimates (Arellano & Bover, 1995; Blundell & Bond, 1998, 2000). In research models where the independent variables are not completely exogenous, the GMM system produces consistent and more efficient parameter estimates in regression. This estimation manages the endogeneity problem by instrumenting the lag of the dependent variable and/or other endogenous variables with variables that are considered uncorrelated with the fixed effects (Nickell, 1981). When compared to the first difference GMM estimator (Arellano-Bond), the GMM system is more efficient because of the assumption that the instruments of the first difference are uncorrelated with the fixed effects, thus allowing the addition of more instruments (Blundell & Bond, 1998). In addition, the GMM system can also eliminate potential bias because it combines two regression systems, namely the first-difference equation form of the first difference GMM model, and the level equation, namely the addition of regression in the form of levels, and using lag instruments from independent variables to improve efficiency (Blundell & Bond, 2000). The following is the form of the estimation model specification using the GMM system:

$$\ln EMD_{i,t} = \gamma \ln EMD_{i,t-1} + \lambda_1 \ln FD_{i,t} + \lambda_k \ln Controls_{k,i,t} + \varepsilon_{i,t} \quad \text{..... 4}$$

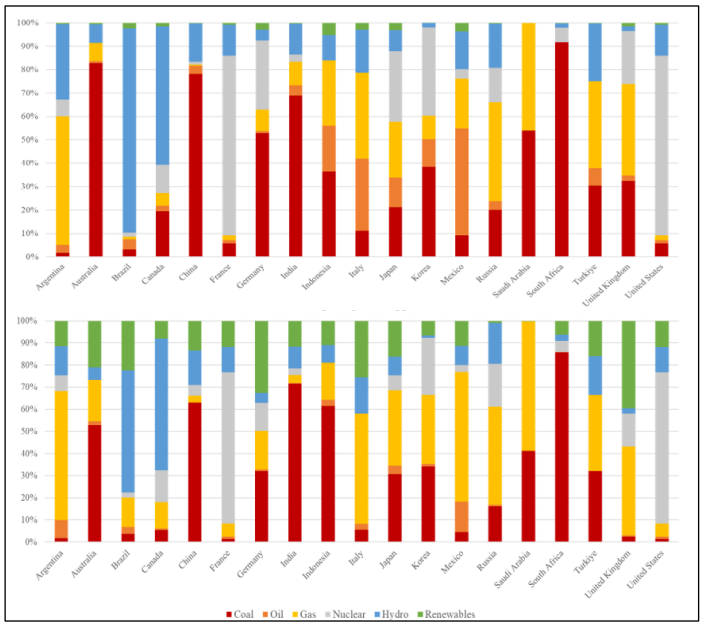
In equation 4, $EMD_{i,t}$ is Energy Mix Diversification in country i in year t, as the dependent variable of this study. $EMD_{i,t-1}$ is the lag of the dependent variable. $FD_{i,t}$ is Financial Development in country i in year t, which is the independent variable. $Controls_{k,i,t}$ is the control variable in this study, which includes (energy efficiency, economic growth, carbon emissions, and foreign direct investment) in country i in year t. γ is the coefficient of the lag of the energy mix diversification variable. λ is the

coefficient of the independent variable and the control variable. $\varepsilon_{i,t}$ is the residual.

ANALYSIS AND DISCUSSION

Descriptive Analysis

In 2000, fossil fuels such as coal, oil, and natural gas still dominated the energy mix of most G20 countries. Regarding the type or variation of the mix chosen, there are also quite significant differences in the composition used in each G20 member country. A comparison of the energy mix composition used by G20 member countries in 2000 and 2021 can be seen in Figure 2.



Source: Processed IEA Data (2000 and 2021)

Figure 2
Comparison of Energy Mix Diversification in G20 Member Countries 2000 and 2021

In 2000, the composition of renewable energy use was still relatively small. Hydroelectricity is the only type of renewable energy power plant used in almost all G20 member countries, except Saudi Arabia. Saudi Arabia is the only G20 member country that has not used renewable energy at all in its energy mix composition. In addition to Saudi Arabia, several other countries are also very dependent on fossil fuels. South Africa, Australia, China, India, and Indonesia generate more than 80 percent of their electricity from fossil fuels.

Meanwhile, other countries such as France and the United States have a portion of nuclear energy of more than 70 percent of their total energy mix composition. In smaller percentages, several developed countries such as Germany, Japan, and the Republic of Korea have also switched to low-carbon nuclear energy. In the case of countries with abundant water resources, Brazil and Canada have switched to

hydroelectricity since 2000. The potential of water resources drives a fairly large portion of hydroelectric energy in the energy mix of the two countries. However, the use of hydroelectricity in large capacities cannot yet be said to be the best solution in the long term. Natural conditions will change over time, although hydroelectricity is included in renewable energy, dependence on one resource cannot guarantee affordable and sustainable energy security.

When compared to the initial conditions in 2000, at the end of the research period in 2021, the results of data processing still showed a high dependence on fossil fuels, especially coal. The highest cases still occur in China, India, Indonesia and South Africa. The four countries have a percentage of coal use above 60 percent of the total composition of their energy mix. In addition of their large population and very high energy demand, these four are developing countries that are densely packed with industrial activity. However, because the transition to renewable energy is still slow, the pace of electricity fulfilment is still focused on fossil fuels as the main alternative.

Natural gas is the alternative energy with the second highest use. The percentage of natural gas use in 2021 has increased in almost all G20 member countries, gradually replacing some of the coal mix composition. On the other hand, the use of nuclear energy has decreased. France and the United States, which previously relied on nuclear with a percentage of over 85 percent, have gradually diversified until in 2021 the composition of the nuclear energy mix was at 68 percent.

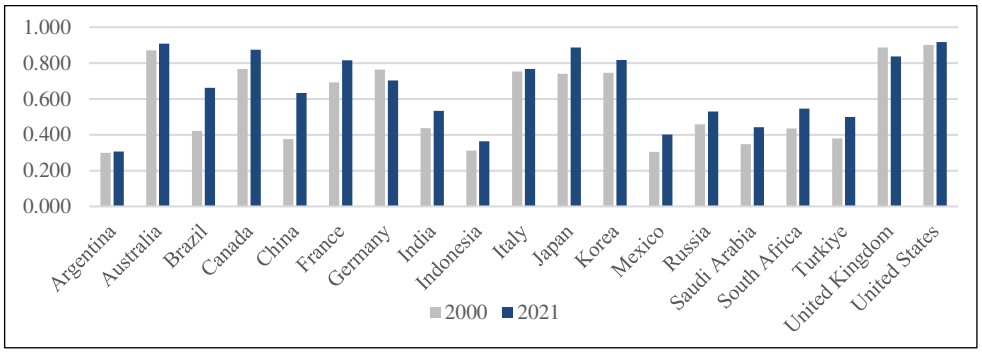
On the other hand, in extreme cases of fossil fuel use such as in Saudi Arabia, although the transition to renewable energy began in 2010, until 2021 the composition of renewable energy was still at 0.29 percent of its total energy mix. If traced, the transition process of this country is much slower compared to other G20 member countries because its main resources are oil and gas. The transition to renewable energy has been carried out gradually by all G20 members at different speeds. Brazil and Canada are still the countries with the highest composition of hydroelectric and renewable energy. Meanwhile, specifically for diversification in renewable energy (excluding hydroelectric), the UK leads with a total mix composition of 39.5 percent followed by Germany at 32.6 percent.

Overall, the condition of the six types of alternative energy source groupings for electricity generation, coal is still the only type of resource owned by all G20 member countries. The average percentage of coal use in G20 countries is at 33.6 percent and ranks first when compared to other diversification alternatives. Besides coal, gas is the second diversification alternative with an average percentage of use of 24.2 percent followed by hydroelectric power with an average percentage of use of 16.4 percent.

In several other energy diversification alternatives, a fairly large diversification percentage gap was found from the variety of diversification alternatives chosen by G20 member countries. The highest percentage of fossil energy use was found in South

Africa. Fossil energy, especially coal, once reached 93.7 percent of its total energy mix. On the other hand, Brazil at one point used water energy as its main source of electricity production with a percentage above 87 percent. The percentage for renewable energy in addition to hydroelectricity also tends to increase every year, with an average percentage of 5.6 percent across all G20 member countries.

In addition, in some countries there is also a unique choice not to use one or several alternative energy diversifications. For example, in Australia, Indonesia, and Turkey, all three do not use nuclear as an alternative in their energy mix. In the case of Australia and Indonesia, which do not use nuclear at all, both use coal to meet more than 50 percent of electricity production each year. Meanwhile, Turkey diversified it again by using natural gas as a second alternative energy mix with an average percentage distribution ranging from 60 percent to 70 percent with each composition of coal and gas being above 30 percent of its total energy mix. In addition to the condition of energy mix diversification, the financial development index of G20 member countries also tends to be better when compared to other countries. The financial development index value indicates the condition of a country's financial institutions and markets. Figure 3 below shows a comparison of the financial development index values of G20 member countries in 2000 and 2021.



Source: Processed IMF Data (2000 and 2021)

Figure 3
Financial Development Index of G20 Member Countries in 2000 and 2021

In general, almost all G20 member countries experienced an increase in index values except Germany and the United Kingdom. In early 2000, countries with high financial development index values consisted of developed countries (Australia, Canada, France, Germany, Italy, Japan, Korea, the United Kingdom and the United States) with an average index of > 0.700. However, when assessed in terms of improvement and development, the index in developing countries tends to experience a more stable increase, although at varying speeds. This can be due to differences in space for innovation. In the case of developing countries, the financial development aspect related to current market conditions and financial institutions still has potential room for improvement. Meanwhile, conditions in developed countries have been in better condition since 2000.

Estimation Result

To find out the relationship between financial development and energy mix diversification, panel regression with fixed effect model in equation 3 and system GMM model as explained in equation 4 was conducted and showed the results as in Table 2 below.

Table 2
Panel Regression Results

Variable	Model Estimation		
	Fixed Effect	Fixed Effect All Var	System GMM
Financial Development	-0.090 (0.059)	-0.049 (0.074)	0.168** (0.071)
Energy Efficiency		-0.023 (0.021)	-0.038** (0.016)
Carbon Emission		-0.220*** (0.055)	-0.132* (0.076)
Gross Domestic Product		0.195*** (0.050)	0.188* (0.096)
Foreign Direct Investment		-0.014** (0.007)	-0.003** (0.001)
Constant	0.936*** (0.032)	-0.218 (0.454)	-0.680 (0.595)
L. EMD			0.487*** (0.162)

* p<0.10; ** p<0.05; *** p<0.01
Source: Processed data using Stata 18 (2024)

The estimation results in Table 2 above show that by using fixed effect panel regression, the coefficient of the independent variable (financial development) is negative and not significant when regressed with its dependent variable, or with all variables in the research model. The energy efficiency control variable also has a negative and insignificant relationship to energy mix diversification. Meanwhile, other control variables (carbon emissions, gross domestic product and foreign direct investment) have a significant effect on energy mix diversification. Carbon emissions and FDI have negative coefficient values, while GDP has a positive coefficient value.

To overcome the potential endogeneity and bias that may occur in the research model specifications, the system GMM model was used and the estimation results in Table 2 above show that the coefficient of the independent variable (financial development) is positive and significant at the 5 percent level. The variable coefficient value of 0.1678 indicates that every 1 percent increase in the financial development index will increase the energy mix diversification index by 0.1678 units (16.78 percent). This finding is consistent with the hypothesis that financial development has a positive relationship with energy mix diversification. This result is also in line with the research of Shahbaz et al. (2023) and Nibedita & Irfan (2024).

In addition to financial development, all control variables studied also showed

significant results on the energy mix diversification. There were three control variables that showed significant negative results on energy mix diversification, and one control variable showed significant positive results. Energy efficiency has a negative and significant relationship with energy mix diversification. These results are in accordance with the explanation that there is a trade-off relationship between energy efficiency and energy mix diversification. Higher levels of energy efficiency could be achieved by increasing economic growth with less energy consumption. This condition frequently associated with dependence on concentrated and cost-effective fossil fuels, which provide stable energy output at lower costs compared to renewables. While this enhances economic performance, it reduces the share of alternative energy sources and thereby lowering energy mix diversification.

Carbon emissions also have a negative and significant relationship with energy mix diversification. Carbon emissions are closely related to the use of fossil fuels, and increased use causes a decrease in the energy mix diversification value. In contrast to energy efficiency and carbon emissions, GDP has a positive and significant effect on energy mix diversification. Countries with higher GDP have better financial access and have the potential to encourage the development of energy mix diversification. Meanwhile, the estimation results for foreign direct investment variable have a negative and significant effect on energy mix diversification. This is in line with the explanation that the notion that FDI is primarily driven by profit maximization and rapid returns, which often directed toward sectors with faster payback periods rather than long-term initiatives such as energy diversification.

To evaluate the validity of the instruments in the GMM model, the Sargan and Hansen tests can be used. In this study, the Sargan and Hansen tests were carried out with the collapse function, which aims to reduce the number of instruments produced by the model. This function is aimed at the lag variable from the estimation results. The results of the Sargan and Hansen tests with a p-value > 0.05 indicate that the instrument is considered valid and has no correlation with error. While the results of p-value ≤ 0.05 indicates that the instrument is invalid, and there is an indication of the possibility of overidentification bias. Table 3 below contains the results of the Sargan and Hansen tests.

Table 3
Sargan and Hansen Test Results

Type of Test	p-value
Sargan test	0.370
Hansen test	0.906

Source: Processed data using Stata 18, 2024

Based on the results of the Sargan and Hansen tests in Table 3 above, the p-value of the two test instruments has a value above 0.05, which means that the GMM system model in this study is valid and has no correlation with error.

CONCLUSIONS, LIMITATIONS AND SUGGESTIONS

The findings of this study provide empirical evidence on the link between financial development and energy mix diversification, particularly in the context of G20 countries. Additionally, this research contributes to the existing literature by highlighting that financial development could support energy transition, through financial institution and financial market indicators. The results of the study show that financial development has a positive and significant relationship with energy mix diversification. Stable financial conditions play an important role to support the financing of renewable energy projects and technologies that improve energy efficiency. Countries with stable financial infrastructure have a better ability to drive energy transition and diversification.

Financial development has a positive and significant relationship with energy mix diversification in accordance with the research hypothesis. In addition, the results of the study for the control variables also have significant results. Energy efficiency, carbon emissions and FDI have a negative relationship with energy mix diversification. While economic growth has a positive relationship with energy mix diversification. Dependence on one or two types of energy mix is still common in G20 member countries that are more advanced in terms of technological development and economic conditions. Fossil fuels, especially coal and gas, are still the main alternative resources used by G20 members in diversifying their energy mix. Meanwhile, hydroelectric is in third place, and the only renewable energy used in almost all G20 member countries.

Based on the research findings that state a positive and significant relationship between financial development and energy mix diversification; to increase energy mix diversification in G20 member countries, the main suggestion of this study is to develop policies that encourage financial development. Indicators of the financial development index consist of institutional development and financial markets, while aspects that can be focused on in the policies developed can be related to the dimensions of depth, access and efficiency, respectively, from the institutional and financial market side.

Related to other variables studied in this study, it is also necessary to consider energy efficiency at the beginning of the energy transition process. Energy efficiency in the transition process may not be as good as the initial conditions when using fossil fuels. Almost all G20 member countries have been in the transition stage with certain targets, but the increasing need for energy makes fossil resources still become the main alternative. To support the implementation of energy mix diversification and ensure energy demand is met during the transition period, future research could explore topics such as transition policies, diversification strategies, and country-specific planning approaches.

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