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DETERMINANTS OF CARBON EMISSIONS IN G-20 COUNTRIES WITH FINANCIAL DEVELOPMENT AS A MODERATION VARIABLE

Determinants of Carbon Emissions In G-20 Countries with Financial Development as A Moderation Variable

Hasbi[1]
Sekolah Tinggi Agama Islam Mulia Astuti, Wonogiri, Indonesia

Muhammad Ghafur Wibowo
UIN Sunan Kalijaga, Yogyakarta, Indonesia

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Abstrak: In the last 40 years, the continuous strengthening of the greenhouse effect has led to a significant increase in global average temperatures. Although people's understanding of climate change has improved, the world has not witnessed a significant reduction in pollutant emissions therefore, it is crucial to find the root cause. The purpose of this study is to examine and analyze the effect of trade openness, foreign direct investment, gross domestic product, human capital, industry, financial development on carbon emissions (CO2) in G20 countries during the period 2000-2019. Data analysis was carried out using the Generalized Least Square (GLS) Method model and data processing using the STATA application version 17.0. The results showed that trade openness, gross domestic product, human capital, and industry have a significant effect on carbon emissions (CO2) while foreign direct investment does not have a significant effect. In addition, the Financial Development variable is able to moderate the effect of trade openness, gross domestic product, human capital, industry on carbon emissions (CO2) but on the other hand cannot moderate foreign direct investment. The study's findings contribute to knowledge by providing new evidence on the relationship between financial development metrics and the environment. These findings are crucial for policymakers and relevant authorities to focus on economic development without jeopardizing environmental damage.

Keywords: CO2; Financial Development; Foreign Direct Investment; Gross Domestic Product; Human Capital; Industry.

Introduction

Global warming has become one of the most severe and urgent issues due to its damaging consequences on the global economic system. In industrialized and developing countries, increasing carbon emissions and ecological damage are significant problems today and human activities are to blame for rising carbon emissions and ecological damage

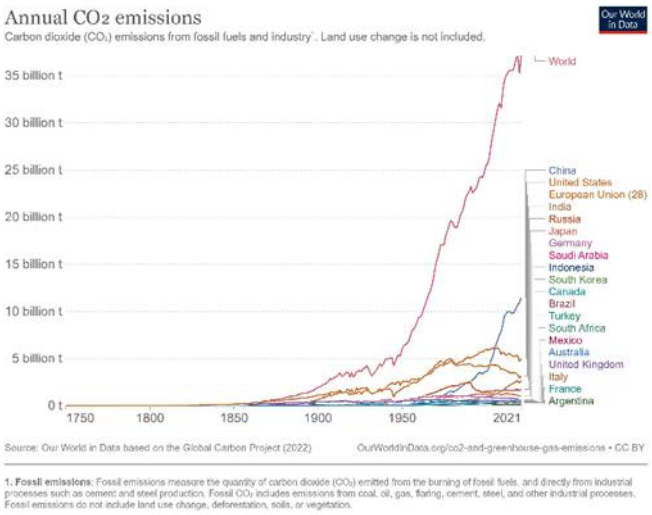
[1] Korespondensi Penulis: Sekolah Tinggi Agama Islam Mulia Astuti, Wonogiri, Indonesia
Email: haassbi@gmail.com

(Udeagha &; Ngepah, 2021). In recent years, environmental degradation and climate change have become the thorniest issues for state policymakers around the world (Ulucak, 2020). Carbon dioxide in greenhouse gas emissions is becoming one of the hot spots in climate change research, many countries are dedicated to developing appropriate energy policies (S. Wang et al., 2022).

In response, the G20, which consists of 20 countries (1 is the European Union) and which represents 85% of global GDP, 51% of the population, two-thirds of global foreign direct investment flows, and most multilateral development bank funds should be able to take a leading role in reducing emissions in the world. In contrast, the G20 is the world's largest emitter, responsible for more than 80% of greenhouse gas emissions (Climate Transparency, 2020). This is certainly inseparable from the increasingly massive use of energy in order to carry out economic activities to maintain economic growth. These transformations are the cause of climate change, global warming, rising sea levels, melting ice sheets, and flooding (Sheraz et al., 2021).

In this context, the G-20 leaders reaffirmed their commitment to fully and effectively implement the UN Framework Convention on Climate Change and the Paris Agreement. Actively respond to global climate change and undertake substantial reforms regarding energy structure and carbon emissions in line with several United Nations (UN) sustainable development goals. Carbon emissions are currently considered the highest in history (D'Orazio &; Dirks, 2021).

There are several international economic institutions that calculate and monitor carbon emissions, such as the World Bank, World Development Indicators, Our World in Data, United State Environmental Protection Agency and the like. As in figure 1 illustrates the state of global carbon emissions and G20 countries.



Source: Data processed by researchers), 2023

Figure 1. Carbon Emissions

In figure 1, from 1854 to 2021, the amount of CO2 gas from fossil burning has increased exponentially from human activities. CO2 emissions reached a level of 38.0 billion tons in 2021 and G-20 countries are responsible for about 81% of global emissions. The largest CO2 emissions among G-20 members are China, the United States and the European Union (Statistisches Bundesamt, 2023). From the data above, environmental damage is a serious problem that needs attention. This means that day by day, the world is increasingly experiencing serious environmental damage and this environmental damage is directly proportional to the damage in economic activities as mentioned above. So it is necessary to

find out what are the variables that affect environmental damage in order to do their best in order to maintain a livable environment.

There are many factors or aspects that affect the adverse impact on environmental damage, one of which is Trade Openess. International trade has been an important factor in driving global economic growth over the past few decades, but it also contributes to global carbon emissions. Empirical studies show that the expansion of international trade has a positive impact on carbon emissions initially, but this impact can be reduced through efforts to improve energy efficiency and the use of cleaner technologies (Clausen & Rudolph., 2020). Research by Mahmood et al., (2019) finding that increased trade openness increases economic activity and production, which in turn increases carbon emissions, the results are in line with research by Sun et al., (2019) and Hdom & Fuinhas., (2020). In contrast to the results of research by (Ertugrul et al., 2016; Q. Wang &; Wang, 2021; Q. Wang &; Zhang, 2021) they found that trade openness reduces carbon emissions, is due to increased access to cleaner technologies and resources, improved production efficiency, and encouraged innovation and investment in renewable energy.

Another factor that can increase carbon emissions is Foreign Direct Investment as it helps boost economic growth in recipient countries but on the other hand, especially those with polluting industries, definitely has a positive relationship on environmental pollution. Research conducted by Essandoh et al., 2020; Y. A. Khan &; Ahmad, 2021; Opoku & Boachie., 2020 found that Foreign Direct Investment increases carbon emissions because it encourages the transfer of high-emission intensive production units from developed to developing countries, while investing in fossil fuel-dependent industries increases carbon emissions. Instead research conducted by Ekwueme et al., (2021), Odugbesan & Adebayo, (2020), Salahuddin et al., (2018) Foreign Direct Investment can also improve environmental integrity because investor funds going into the energy sector can help introduce the latest and cleaner technologies in electricity production, such as solar panels or wind turbines, which can reduce CO2 emissions.

Economic growth and carbon emissions have a reciprocal relationship when high economic growth can lead to increased resource use and production, ultimately resulting in higher carbon emissions. These high carbon emissions can then exacerbate environmental problems, such as climate change, which in turn can affect economic growth (Dietz et al., 2007). Research conducted by Mikayilov et al., 2018; Schröder &; Storm, 2020; Sheraz et al., (2022) found that economic growth becomes a determinant of carbon emissions because countries focus on improving economies that encourage increased production activity regardless of their effect on the environment. Instead Dong et al., (2020) indicates that there is a negative relationship. The authors found that factors such as investment in clean energy, strict environmental policies, and increased public awareness of environmental issues can help reduce carbon emissions. Shahbaz &; Sinha, (2019) when the economy grows beyond a certain level, it tries to achieve technological advancement, which will lead to pollution control.

Carbon emissions are often linked to human capital. However, many analysts argue inconsistent results related to climate change can be attributed to the loss of human capital (Sheraz et al., 2021). Despite the role of human capital in determining a country's carbon emissions, most previous studies ignored this variable (M. Khan, 2020). Investing in human capital is essential for a sustainable environment. If a country's human development level is high, it directly impacts environmental quality, education, and technical research, increasing pro-environment measures. All of that can be achieved by raising environmental awareness and encouraging a healthy lifestyle (Bano et al., 2018). Studies conducted by Guo, (2021) shows that increased human capital allows countries to apply green technologies to transform industrial structures to more sustainable energy. In line with research Yuan Huang et al., (2019) shows that human capital is negatively related to CO2. Human resources are helpful in implementing environmentally friendly technologies, which improve energy

efficiency and hence improve environmental quality. In contrast, human capital was found to be positive and significant to carbon emissions, suggesting that increased human capital formation leads to increased carbon emissions. However, this is not surprising because human capital is important in economic growth, and increased levels of human capital lead to higher economic activity that could potentially contribute to carbon emissions based on the EKC hypothesis. Previous studies found the same conclusion as suggested that environmental pollution is closely linked to human economic activity due to increased energy demand and consumption (Gong et al., 2020; Inglesi-Lotz, 2016; Birkenmaier, 2019b).

To achieve higher economic growth, most less developed countries increase their economic activities to reduce extreme poverty by encouraging units of production and levels of industrialization (S. Khan &; Yahong, 2021). Encouraging and accelerating the process of industrialization is key to increasing economic activity which will lead to higher economic growth, and hence reducing the intensity of extreme poverty (Khan et al., 2020). This process also worsens the quality of the environment (Islam &; Abdul Ghani, 2018). Industrial production is the driving force of CO2 emissions (Hocaoglu &; Karanfil, 2011; Rahman & Kashem, 2017). Zafar et al., (2021) examined the role of industrialization in environmental pollution for 46 Asian countries. They observed the significant and positive impact of industrialization on carbon emissions. But different things were found by Jiang & Ma, (2019) that industry negatively affects carbon emissions because companies tend to invest in technological innovation but not scale expansion, and governments prefer to support the development of green finance, which results in more funding in environmental protection projects. In line with the results of the study by Khan & Yahong, (2021) that they failed to find statistically significant industrial influence, a value-added share of GDP.

In addition to the above determinants, Financial Development is widely ignored by previous researchers even though the development of the financial sector has important implications for environmental degradation (Habiba et al., 2021). Different measures of financial development have different impacts on environmental degradation (Shahbaz &; Sinha, 2019; X. Yao &; Tang, 2021). The financial sector plays an important role in delivering the necessary investments in low-carbon technologies to achieve green structural change (D'Orazio &; Dirks, 2021). So, one of the main policy options followed by many governments since 1994 to limit environmental damage is to expand the country's energy industry by providing adequate financial assistance (Haseeb et al., 2018).

The development of climate-related financial policies in recent decades shows a more complex picture that needs to be examined. First, the implementation of adaptation and mitigation strategies related to the development of green technologies whose diffusion is limited by several barriers, such as cost, lack of competence and knowledge, market structure, and lack of financial resources (D'Este et al., 2012). Second, green innovation requires long-term financial capital and is riskier than non-green innovation (Mazzucato &; Semieniuk, 2018). Third, although positive trends in the development of green finance have been detected in recent years, the flow of financial resources is insufficient to cover the green finance gap (Geddes et al., 2018).

This research is interesting to do because it seeks to explain the environmental degradation model driven by Financial Development as a factor causing environmental degradation in G-20 countries. First, the G-20 countries are major world economies comprising 75% of global trade, more than 80% of world GDP, and 60% of the world's population (Ajide &; Mesagan, 2022). Rapid industrialization, trade openness, and development patterns demanded excessive use of energy resources. Second, the manufacturing and industrial sectors are heavily dependent on energy, which consumes more than 80% of fossil fuel energy. 74% of global carbon emissions are generated by G-20 countries (IEA, 2020). G-20 countries also consume 95% of coal and 70% of gas and oil.

This research was conducted for two main reasons. First, the results of previous research on the impact of economic growth, foreign direct investment, trade openness, human capital, and financial development on environmental degradation show inconsistent results. Some studies show that these factors are driving the adoption of green technologies, while others point to increased exploitation of natural resources and carbon emissions, emphasizing the need for more research to understand their impacts more thoroughly, particularly in G-20 countries. Second, this study presents novelty by combining various factors simultaneously to analyze the interaction between economic growth, FDI, trade openness, human capital, and Financial Development in one model. This approach provides a more comprehensive analysis than previous studies that tend to separate these factors (D'Orazio & Dirks, 2021; Duan et al., 2022; Guo, 2021; Katircioğlu & Taşpinar, 2017; M. Khan & Ozturk, 2021; Shahbaz et al., 2018; Sheraz et al., 2022; Udeagha & Breitenbach, 2023; Wen et al., 2022), so that it can provide deeper insights into the dynamics of the relationship between variables to environmental degradation in G-20 countries.

Research Methods

This study used an explanatory quantitative approach. In this study, the data used was panel data, a combination of *cross-sectional data* from G20 member countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea (South Korea), Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States and European Union) with a time span of 2000-2019, this time span was chosen by researchers because data from a variable is limited, especially data *human capital.* Data sources were obtained from the *World Bank, Penn World* 10, and *the International Monetary Fund*. Data collection techniques in this study use documentation techniques, where researchers collect evidence regarding direct reporting data by visiting the required website.

Static panel data uses the *Generalized Least Square* (GLS) model, there are generally three approaches in choosing an estimation model: *Common Effect Model, Fixed Effect Model,* and *Random Effect Model.* Furthermore, to choose the right model, this study used three tests, namely *the Chow Test, Hausman Test, and Lagrange Multiplier Test.* After obtaining a suitable model, hypothesis testing continues, including the coefficient of determination test, t test, and F test. *Moderated Regression Analysis* (MRA) is part of multiple linear regression analysis. MRA analysis can be used to analyze the influence of moderation variables on the relationship between the independent variable and the dependent variable. The moderation Regression Analysis Model can be expressed in the form of the following equation:

$$CO2_{it} = \alpha + \beta_1 TO_{it} + \beta_2 FDI_{it} + \beta_3 GDP_{it} + \beta_4 HC_{it} + \beta_5 IDS_{it} + \varepsilon_{it} \quad (1)$$

After including the moderation variable in the equation, it will be:

$$CO2_{it} = \alpha + \beta_1 TO_{it} + \beta_2 FDI_{it} + \beta_3 GDP_{it} + \beta_4 HC_{it} + \beta_5 IDS_{it} + \beta_6 TO_{it}{}^{*}FD_{it} + \beta_7 FDI_{it}{}^{*}FD_{it} + \beta_8 EG_{it}{}^{*}FD_{it} + \beta_9 HC_{it}{}^{*}FD_{it} + \beta_{10} IDS_{it}{}^{*}FD_{it} + \varepsilon_{it} \quad (2)$$

Description: CO2 = Carbon Emissions; TO = *Trade Openess*; FDI = *Foreign Direct Investment*; GDP = *Gross Domestic Product*; HC = *Human Capital*; IDS = Industry; FD = *Financial Development*; β1- β10 = Regression coefficient; ε = error terms; α = constant value; i = Country; t = Period

Table 1. Variable Operational Definition

Variable	Description	Indicators	Source
• CO2	• Carbon Dioxide Emissions	• Metric kilo ton (kt)	• *World Bank*
• *Trade Openess* (TO)	• Trade value (export + import)	• *Trade (% of GDP)*	• *World Bank*
• *Foreign Direct Investment* (FDI)	• Foreign Direct Investment	• *Net Inflows (Bop, Current US$)*	• *World Bank*
• *Gross Domestic Product*	• GDP per capita	• *Current US$*	• *World Bank*
• *Human Capital* (HC)	• Based on years of education and returns from education	• *Human Capital Index*	• *Penn World 10*
• *Industry* (IND)	• Industry Value Added	• *Value Added (% of GDP)*	• *World Bank*
• *Financial Development*	• Financial Development	• *Financial Development Index*	• *International Monetary Fund*

Results and Discussion

Descriptive Statistics

Descriptive statistical analysis aims to look at the phenomena and characteristics of each sample data variable. The next step is to measure each variable against the mean, median, minimum, and maximum values of the research data. As a combination of cross-section data with time series data, the phenomena of the data generated in descriptive statistical analysis describe all the characteristics of the combination. Here are the results of the description of descriptive statistical data processed using the *stata* 17.0 application:

Table 2. Variable Operational Definition

Variable	Obs	Mean	Std. Dev	Min	Max	Prob
CO2	400	8.178838	5.049161	.883747	20.4698	0.000
TO	400	53.32325	18.29188	19.5596	105.5663	0.020
LN(FDI)	400	22.52356	8.338315	-25.06431	28.02138	0.000
LN(GDP)	400	28.06462	1.154594	25.30541	30.69352	0.042
HC	400	2.938511	.5666103	1.782071	3.773596	0.000
IDS	400	26.76482	1.077143	24.86093	29.35852	0.000
FD	400	.62955	.2070543	.27	.97	0.000

Panel Data Regression

One of the stages in panel data regression is the selection of models between fixed effect model (FEM), common effect model (CEM) and random effect (REM) as shown in table 2. The best model to be used must go through several stages, namely the Chow test, the Hausman test and the Lagrange Multiplier test. The chow test compares the CEM and FEM models, after testing found a Prob value of 0.000<0.05 then the selected model is FEM. Furthermore, the Hausman test was carried out to select the best model between FEM and REM, and found a prob value of 0.000<0.05, then the best model to use is FEM.

Table 3. Model Selection

Variable	Type		
	Common Effect	Fixed Effect	Random Effect
TO	**0.000*** **	0.145	0.111
Coef.	(0.440177)	(-0.008629)	(-0.0094564)
LN(FDI)	0.602	**0.008*** **	**0.009*** **

Coef.	(-0.0128095)	(0.0139128)	(0.013834)
LN(GDP)	**0.000*** **	**0.010*** **	**0.012*** **
Coef.	(-2.248256)	(-0.49673)	(-0.4815503)
HC	**0.015*** **	**0.000*** **	**0.000*** **
Coef.	(0.9484386)	(-2.439929)	(-2.141536)
IDS	**0.000*** **	**0.000*** **	**0.000*** **
Coef.	(1.69984)	(3.412545)	(3.128196)
FD	**0.000*** **	**0.000*** **	**0.000*** **
Coef.	(17.06279)	(5.505018)	(5.780185)
R-Square	0.4055	0.3144	0.3132
Prob F-Statistic	0.000	0.000	0.000
Test Chow		**0.000**	
Hausman Test			**0.000**
Number of Observations		400	

Classical Assumption Test

Normality Test

Table 4. Shapiro-Wilk W Normality Test Results

Shapiro-wilk w tests for normality					
Variable	**Obs**	**W**	**V**	**Z**	**Prob>Z**
CO2	400	*0.93977*	*16.581*	*6.682*	0.000
TO	400	*0.97986*	*5.545*	*4.076*	0.000
LN(FDI)	400	*0.32362*	*186.205*	*12.437*	0.000
LN(GDP)	400	0.97945	*5.658*	*4.124*	0.000
HC	400	*0.92884*	19.589	*7.079*	0.000
IDS	400	*0.94076*	16.307	*6.643*	0.000
FD	400	*0.92735*	20.001	7.128	0.000

Based on the results of the normality test in table 4.2 above, it can be seen that this study has a probability value smaller than the value of Prob. ($\alpha > 0.05$), it can be concluded that the data is not normally distributed.

Multicollinearity Test

Table 5. Multicollinearity Test Results

	TO	**FDI**	**GDP**	**HC**	**IDS**
TO	1.0000				
LN(FDI)	-0.0630	1.0000			
LN(GDP)	-0.0312	0.2149	1.0000		
HC	-0.0317	0.1611	0.3147	1.0000	
IDS	-0.0957	0.1314	0.8906	0.1640	1.0000

Based on the table of multicollinearity test results above, it can be known in this study the VIF values for variables TO, FDI, HC, and IDS. So that there is no one independent variable that has a VIF value of more than 10 (VIF < 10), then regression in this study is free from multicollinearity problems.

Heterokedasticity Test

Table 6.Heterokedasticity Test Results

chi2(1) = 0.13
Prob > chi2 = 0.7220

Based on the heteroscedasticity test table in table 4.5 above, it can be seen that in this study the value of heteroscedasticity problems does not occur. This is based on the due value of Prob. more than 0.05 (Prob. > 0.05).

Autocorrelation Test

Table 7. Autocorrelation Test Results

Durbin–Watson d-statistic (7, 400) = 0.1270781

Based on the table of autocorrelation test results above, it can be seen in this study that the Durbin-Watson value is 0.1270781. The value is between -2 to +2 (-2 < 0.7223138 < 2), hence there is no autocorrelation (passes the autocorrelation test).

The results of the classical assumption test above showed that of the 4 test stages, there was 1 test that did not pass, namely the normality test, and 3 other tests passed. In the OLS method, if the classical assumption test is not met, then the risk of regression results being biased is very large. But it is different from the GLS method. The use of the GLS method can make the estimation results immune to the problems caused by classical assumption tests that do not pass (Kurniawan, 2016). Therefore, changing the OLS method to the GLS method is the way to go if the classical assumption test is not met as in the case above. Because the model selected in this study is fixed effect no weights with the OLS method, based on the above considerations, the author changed the OLS method to GLS by using Fixed Effect Cross-Section Weights (Gujarati et al., 2006).

Table 8. Fixed Effect Cross-Section Weights

CO2	Coefficient	p> | z |
TO	0.0440177	**0.000**
LN(FDI)	-0.0128095	0.598
LN(GDP)	-2.248256	**0.000**
HC	0.9484386	**0.014**
IDS	1.69984	**0.000**
FD	17.06279	**0.000**
_Cons	10.19185	0.062

Moderated Regression Analysis (MRA) Model Analysis

Table 9. MRA Test Results

Variable	Coefficient	Std.err.	Z	P> | t |
FD*TO	0.0459109	0.0169803	2.70	**0.007**
FD*FDI	-0.0219667	0.0384419	-0.57	0.568
FD*GDP	-1.836664	0.6523787	-2.82	**0.005**
FD*HC	1.722897	0.5936644	2.90	**0.004**
FD*IDS	2.187907	0.668081	3.27	**0.001**

Simultaneous Significance Test (Statistical Test F)

The F test shows if all the independent variables in the regression model have a joint influence on the dependent variable. The F test is significant if the probability value is < α 0.05. Here are the results of the F test in this study:

Table 10. Statistical F Test Results

Prob > chi2	0.0000

Test Coefficient of Determination (R2)

The Coefficient of Determination (R^2) test is used to measure the variation of the dependent variable. Here are the test results of the R^2 regression model:

Table 11. Determination Cortex Test Results

R-squared	0.987538

Discussion

The Effect of Trade Openess on Carbon Emissions (CO2)

In table 7. Shows that trade openess has a positive effect on carbon emissions. This result is in accordance with the theory proposed by (Grossman & Krueger, 1991) when there is an unlimited expansion of international trade between countries. This expansion of trade resulted in an increase in the production of output due to increased demand for that output. This continuous increase contributes to an increase in the volume of pollution. The wider the market expansion, the greater the intensity of trade, which in turn encourages more use of fossil fuels and higher intensity exploitation of natural resources. As a result, this has the potential to lead to increased pollution.

Some previous studies have also found similar results as described by Clausen &; Rudolph (2020) International trade has been an important factor in driving global economic growth over the past few decades, but it has also contributed to global financial emissions. In line with Jun et al., (2020) Trade openness indicates the extent to which an economy is open to trade across the world economy. It helps countries to increase exports aimed at increasing domestic production, by increasing the scale of industry, which leads to increased pollution.

The results of this study indicate a significant positive relationship between trade openness and carbon emissions in G20 countries. The implications of these findings are particularly relevant in the context of global efforts to mitigate the effects of climate change. First, G20 governments need to integrate international trade policies with efforts to reduce carbon emissions. This could include imposing carbon tariffs or stricter environmental regulations on goods imported with high levels of emissions. Second, large companies and economic stakeholders also have an important role to play in reducing carbon emissions by implementing more sustainable and environmentally friendly Corporate Social Responsibility (CSR) practices. In addition, international cooperation between G20 countries in developing sustainable trade agreements can also be an effective step to address these challenges together. In conclusion, these findings provide an important basis for policy designers and stakeholders to prioritize efforts to reduce carbon emissions in the context of international trade in G20 countries in order to achieve sustainable development goals.

The Effect of Foreign Direct Investment (FDI) on Carbon Emissions (CO2)

The FDI test results in table 7 are irrelevant to previous studies. These results do not match the pollution haven hypothesis (PHH), according to Copeland &; Taylor (1994) As a conceptualizer of PHH theory, companies in developed countries also want to set up factories / offices in developing countries because the cost is cheaper in terms of labor and resources. Developing countries also generally have less stringent environmental regulations, which is another factor that ultimately cheapens production costs especially for pollution-intensive production (Christensen et al., 1996), all of these factors can be an allure to attract FDI to developing countries. FDI helps boost economic growth in recipient countries, but on the other hand, especially those with polluting industries, inevitably has a positive relationship with environmental pollution.

These results are in line with research by Rezza (2013); Shaari et al., (2014). Parent companies tend to invest less money in subsidiaries or branches that have the intention to make the product vertically (for example, making all components of the product itself) in a country with stricter environmental rules. When environmental rules in the country are stricter, production carried out by subsidiaries and resold to their parent companies tends to decrease. Although countries could attract more investment by having weaker

environmental rules, there are some issues to consider. First, vertically purposeful investments account for only a fraction of all direct investment in the world, so the impact on a country's economy may not be as great as we think. Second, attracting more polluting investment could hurt the country's environment and long-term economic growth.

FDI tends to invest in sectors that may be more energy efficient or have more modern technology. This can reduce carbon emissions per unit of production and explains why there is no positive correlation between FDI and carbon emissions. In addition, multinational companies that conduct FDI are often subject to pressure to comply with strict environmental regulations, both from their home countries and their investment destination countries (Ekwueme et al., 2021). In this context, they may be more inclined to adopt more sustainable business practices to minimize their environmental impact (Salahuddin et al., 2018). Second, these outcomes can be influenced by existing environmental policies in G20 countries. If G20 countries have implemented strict regulations related to carbon emissions and imposed carbon taxes, then companies operating in these countries, including foreign companies through FDI, may feel compelled to reduce their emissions. Therefore, the main cause of these findings may be cooperation between multinational companies that carry out FDI and strict environmental policies in their investment destination countries. This demonstrates the importance of strict regulations and incentives for sustainable business practices in controlling carbon emissions in G20 countries.

G20 leaders reaffirmed their commitment to fully and effectively implement the UN Framework Convention on Climate Change and the Paris Agreement. This agreement was made by developing and developed countries to control and reduce CO2. The Paris Climate Agreement was signed in 2015, with the aim of limiting future global temperature rise to no more than 1.5°C, and reducing carbon emissions and fossil fuel energy use (Yongming Huang et al., 2023).

The Effect of Gross Domestic Product on Carbon Emissions (CO2)

The test results in table 7 show that GDP has a significant negative effect. These results can be explained by previously existing literature such as research by Jiang & Ma, (2019) explained that the industry negatively affects carbon emissions because companies tend to invest in technological innovation but not scale expansion, and governments prefer to support the development of green finance, which results in more funding in environmental protection projects. In line with the results of the study Khan & Yahong, (2021) that they failed to find statistically significant industrial influence, a value-added share of GDP.

The negative relationship between GDP and carbon emissions in G20 countries reflects the complex dynamics between economic growth and environmental impact. One of the main factors that could explain this relationship is the economic shift from carbon-intensive industrial sectors to cleaner services and technologies (Kirikkaleli et al., 2022). Countries that have achieved high income levels are likely to undergo this structural transformation, reducing their dependence on sectors that produce high carbon emissions. In addition, investments in clean technologies and innovations can enable increased productivity and efficiency in production, which in turn reduces carbon emissions per unit of GDP. Strict environmental regulations in developed countries also play an important role in controlling carbon emissions, as it forces companies to adhere to higher environmental standards and reduce their environmental impact (Dingbang et al., 2021).

In addition, higher environmental awareness in countries with higher incomes and greater societal pressure can influence government policies and business actions. More environmentally conscious societies tend to ask companies to reduce their carbon emissions, and companies can feel compelled to invest in more sustainable business practices (Apergis et al., 2018). Thus, in G20 countries, sustainable economic growth often

goes hand in hand with efforts to reduce carbon emissions, demonstrating that environmentally wise economic development is possible through the adoption of clean technologies, strong environmental regulations, and public awareness of environmental issues.

The Effect of Human Capital on Carbon Emissions (CO2)

Findings from hypothesis testing show that *Human Capital* increase carbon emissions. This result can be explained by the findings of previous researchers as suggested by Birkenmaier (2019a) shows that increased human capital formation leads to increased carbon emissions. However, this is not surprising because human capital is important in economic growth, and increased levels of human capital lead to higher economic activity that could potentially contribute to carbon emissions based on the EKC hypothesis. Previous studies found the same conclusion as suggested that environmental pollution is closely linked to human economic activity due to increased energy demand and consumption (Gong et al., 2020; Inglesi-Lotz, 2016) (Birkenmaier, 2019b).

High levels of human capital can have a positive influence on carbon emissions through a variety of mechanisms. On the one hand, individuals with higher education and better skills tend to have higher incomes, which can encourage consumption of energy-intensive goods and services, such as private cars or air travel. However, on the other hand, strong human capital can also drive technological innovations that contribute to reducing carbon emissions, increasing environmental awareness, and supporting stricter policies related to the environment. Therefore, the effect of human capital on carbon emissions is complex and depends on factors such as social and economic context.

Industry's Effect on Carbon Emissions (CO2)

Testing the hypothesis shows that industry plays a role in increasing carbon emissions. These results are supported by the findings Zafar et al., (2021) which examines the role of industrialization in environmental pollution for 46 Asian countries. They observed the significant and positive impact of industrialization on carbon emissions. This can happen because in order to achieve higher economic growth, most countries increase their economic activities to reduce extreme poverty by encouraging units of production and levels of industrialization (S. Khan &; Yahong, 2021), but This process also worsens the quality of the environment (Islam &; Abdul Ghani, 2018). Industrial production is the driving force of CO2 emissions (Hocaoglu &; Karanfil, 2011; Rahman & Kashem, 2017).

In the case of G20 countries, several studies investigated the relationship between carbon emissions and the factors that influence them (Mardani et al., 2018; C. Yao et al., 2015) and had mixed results. Yao et al., (2015) discusses the main drivers of carbon emissions in G20 countries. Therefore, economic growth and industrial structure are the dominant drivers in all developing and developed countries in the G20 countries. The reason lies in the industrial sector responsible for more than a third of global primary energy and which is linked to carbon emissions. Secondly, the structure of the industry affects energy consumption. Countries must improve their industrial structures to shift energy demand from fossil fuel energy to renewable energy sources (Yongming Huang et al., 2023).

The Effect of *Trade Openess* on Carbon Emissions (CO2) with *Financial Development* as a moderation variable

Table 7 shows that the effect of trade openness on carbon emissions can be moderated in a significant positive way by financial development. Financial Development can increase trade openness by providing access to the financial resources needed by companies to export. Financial development can increase the capacity of firms to import and export goods and services by facilitating credit, insurance, and other financial

instruments (Arestis et al., 2001). Companies that easily get access to finance by getting a lot of capital, there will be an increase in international trade activities can increase carbon emissions because various trading activities, such as shipping goods by ship or airplane, can produce large carbon emissions. In addition, more advanced financial development can also facilitate investment in industrial sectors that can produce high carbon emissions, such as the chemical industry or power plants. With this investment, the production of goods and services produced from the industrial sector increases, which in turn can increase carbon emissions (Demirgüç-Kunt &; Maksimovic, 2002).

Trade Openness can increase global market access, which in turn can boost economic growth through exports and imports. However, if not properly regulated, high economic growth due to trade openness can result in increased industrial production and energy consumption, which can increase carbon emissions (Clausen &; Rudolph, 2020). However, financial development can promote finance in support of sustainable investment and green technology. If the financial system is able to support investment in green technologies and reduce environmental risks, then the negative influence of trade openness on carbon emissions can be muted.

The Effect of Foreign Direct Investment on Carbon Emissions (CO2) with *Financial Development* as a moderation variable

The test results show that the effect of foreign direct investment on carbon emissions cannot be moderated by financial development. There are several reasons why development finance may not be able to moderate the effect of FDI on carbon emissions. First, FDI is often aimed at carbon-intensive sectors, such as manufacturing and natural resource extraction. In cases like these, despite a thriving financial system, the negative impact of FDI on the environment can remain significant due to the intrinsic nature of such investments that tend to increase carbon emissions (Yanyan Huang et al., 2022).

Second, existing financial development may not be sufficiently mature or integrated with environmental policy. An effective financial system requires instruments and policies that can steer investment towards a more environmentally friendly direction. Without such policies, financial development alone may not be strong enough to change the course or impact of FDI on carbon emissions (Y. Wang et al., 2019). Third, there is also the possibility that FDI goes into countries with weak environmental regulations. In this scenario, although financial development in the country is developing, the lack of strict regulation could allow activities that increase carbon emissions to take place without much hindrance (Brenda, Aditama; Tripriyo; Hashim, 2016).

Financial development can theoretically help moderate the negative impact of FDI on carbon emissions, in practice many other factors play a role. These include the type of investment brought by FDI, the level of maturity and integration of financial development with environmental policy, as well as the strength of environmental regulations in FDI host countries (Nasir et al., 2019).

The Effect of *Gross Domestic Product* (GDP) on Carbon Emissions (CO2) with *Financial Development* as a moderation variable

The results of hypothesis testing show that the influence *Gross Domestic Product* Carbon emissions can be moderated by financial development, based on a prob value of 0.005 < 0.05 and a coefficient value of -1.836664. These findings are in line with Cuiyun &; Chazhong (2020) His research found that a good financial system is able to encourage environmental sustainability by promoting green projects in economic development. Green finance theory states that the development of a financial sector that supports investment in environmentally friendly projects can promote sustainable economic growth and reduce the impact of pollution or carbon emissions (Soundarrajan &; Vivek, 2016).

Financial developments increase investment rates by increasing savings rates, credit allocation and risk diversification. All this increases the level of capital formation and increases efficiency in credit allocation (Rousseau &; Wachtel, 2002) leading to higher economic development and lower environmental pollution (Shahbaz, 2013). In line with research conducted by (Katircioğlu &; Taşpinar, 2017; M. Khan &; Ozturk, 2021) that the existence of a strong financial system in the economy will reduce the negative impact of economic growth.

The Effect of Human Capital on Carbon Emissions (CO2) with Financial Development as a moderation variable

The results of hypothesis testing show that financial development can moderate the influence of human capital on carbon emissions, this is based on a prob value of 0.004 < 0.05 and a coefficient value of 1.722897. Growing financial and human capital developments can lead to increased carbon emissions when not directed towards sustainable economic practices. When financial growth occurs without a strong focus on environmental sustainability, it can result in increased consumption and production (M. Khan, 2020). Wealthier, better-developed societies tend to consume more goods and services, which are often produced by conventional methods that have a high carbon footprint. This increased economic activity can result in higher carbon emissions if the production process is not environmentally friendly (Haini, 2021).

Financial growth can also influence consumer behavior. As people become wealthier and have better access to credit and financial services, they may buy high-emission goods, such as large vehicles, appliances that use high energy, or travel frequently (Huang et al., 2021). This increased consumption can contribute to increased carbon emissions. In some cases, the growth of the financial sector may not prioritize sustainable investment opportunities. If the financial sector does not actively support green technologies, renewable energy, or sustainable practices, this can result in a situation where human capital development contributes to carbon emissions rather than reducing them (Bashir et al., 2019).

Industry Influence on Carbon Emissions (CO2) with Financial Development as a moderation variable

The results of hypothesis testing show a prob value of 0.001 < 0.05 and a coefficient value of 2.187907, it can be concluded that financial development can moderate the influence of industry on carbon emissions. Jensen (1996) argues that financial development can trigger industrialization, which can lead to industrial pollution and thus increase environmental degradation. Furthermore, financial development can have direct and indirect effects on environmental quality. One of the most direct effects is that as the financial system develops, consumers have easy access to cheap money to buy large items that consume a lot of energy and can affect energy demand (Çoban & Topcu, 2013; Kahouli, 2017; Sadorsky, 2011; Shahbaz & Lean, 2012) which in turn can reduce the quality of the environment.

Businesses also benefit from a developed financial system as it allows businesses to have access to financial capital easily and cheaper. In addition, stock market improvements can also affect businesses through the provision of additional funding sources, allowing them to expand existing businesses or create new ones (Çoban & Topcu, 2013; Sadorsky, 2011). Business expansion activities can increase energy demand and carbon emissions. In addition, increased stock market activity affects consumer and business confidence through the wealth effect. Thus, increased business and consumer confidence can promote economic growth and prosperity which in turn increases energy consumption and environmental pollution (Sadorsky 2010,2011; Çoban and Topcu2013).

A growing literature related to ecological economics has confirmed that financial development has a positive spillover effect on carbon emissions (Caselles &; Sanz, 2021). The main reason can be considered as a well-functioning financial sector can provide more financing at lower costs, so that more and more capital flows into environmental protection and energy conservation projects and companies, promote the rapid development of the environmental protection industry and drive green transformation and improvement of traditional industries as well.

Conclusion

The study's findings offer a number of policy implications for G20 countries to respond to global environmental challenges related to carbon emissions. Given the positive relationship between *Trade Openness* and carbon emissions, trade policies should be designed to support the transfer of environmentally friendly technologies and improve energy efficiency. This could involve implementing stricter environmental standards in trade agreements and promoting sustainable trade in products. Since FDI is not directly linked to increased emissions, G20 countries should seize this opportunity to attract foreign investment into cleaner sectors, by strengthening environmental policies and incentives that lead to green technology investment. Meanwhile, the negative relationship between GDP and emissions indicates the need to boost economic growth through a more efficient and sustainable sector from an environmental point of view.

The growth of *Human Capital* that has an impact on increasing emissions indicates the need for greater education and training towards capacity building for innovation and low-carbon technologies. In industry, there needs to be a faster transition to cleaner and more energy-efficient technologies, as well as restrictions on carbon-intensive industrial activities. Financial Development should be used to strengthen green finance and direct resources to investments that support climate change mitigation and adaptation. Initiatives such as carbon markets, green bonds, and tax credits for sustainable investment can play a key role in stimulating environmentally responsible economic growth. In conclusion, G20 policy should promote the integration of environmental considerations in all aspects of economic development, from trade and foreign investment to industrial and financial development, to ensure sustainable long-term growth and minimize negative impacts on the environment.

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