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FinTech's Double-Edged Sword: Economic Growth and CO2 Emissions – A Panel Data Analysis

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This study explores the influence of financial technology (FinTech) on Economic Growth (EG) and environmental sustainability (measured through focusing on CO_2 emissions). By analyzing panel data from 81 countries between 2001 and 2022, the research uses Structural Equation Modeling (SEM) to evaluate direct, indirect, and total effects. The findings, derived from Stata 18, show a significant positive direct effect of FinTech on EG (coefficient = 0.8439, $p < 0.001$), affirming the hypothesis that FinTech stimulates economic development. Moreover, EG substantially boosts CO_2 emissions (coefficient = 0.3628, $p < 0.001$), highlighting a trade-off between economic progress and environmental sustainability. FinTech also directly increases CO_2 emissions (coefficient = 0.3511, $p < 0.001$), implying that advancements in financial technology can worsen environmental issues. The mediation analysis indicates that some of FinTech's impact on CO_2 emissions is mediated through EG (indirect effect = 0.3061, $p < 0.001$), emphasizing FinTech's dual role in promoting EG and environmental degradation. The total effect of FinTech on CO_2 emissions (0.6573, $p < 0.001$) underscores the substantial environmental costs associated with financial technological advancements. Theoretically, this research enriches the Technology Acceptance Model (TAM) and supports the Environmental Kuznets Curve (EKC) hypothesis. It extends TAM by showing how the acceptance and integration of FinTech innovations affect macroeconomic and environmental outcomes. Additionally, it provides empirical support for the EKC hypothesis, which suggests that EG initially causes environmental degradation until a certain income level is reached, after which environmental conditions improve. These results highlight the challenge of balancing technological and economic advancements with environmental sustainability, stressing the need for policies that incorporate sustainable practices within the FinTech sector. This research adds to existing literature by offering detailed insights into the environmental impacts of FinTech and provides valuable guidance for policymakers aiming to foster sustainable economic development.

1. Introduction

In the modern world, individuals and organizations have increasingly come to realize the importance of environmental conservation and sustainable development. Universities and various scholars have not neglected the alarming socioeconomic issues resulting from environmental degradation (George et al., 2016). Thus, increased fossil fuel consumption poses significant environmental risks, and China is the largest producer of carbon emissions across the globe, with a significant percentage coming from the energy sector (Li et al., 2022; Wen & Wang, 2020). To solve this problem, China has put into practice the "30-60" strategy: providing the maximum level of CO2 emissions in 2030 and carbon neutrality at 2060 (Xu et al., 2023). To meet this goal, fundamental changes in the economic, energy, and environmental industries are required. It has also involved the introduction of green technology such as fintech (Awais et al., 2023; Lee et al., 2023). Technology advancement has benefits that improve environmental pollution or detrimental effects that harm the environment (Yang et al., 2021). Sustainability has also been stimulated by the institutional implementation of environmental regulations, and an inevitable consequence will be the penetration or reappearance of the green technologies that are used to mitigate environmental pollution as well and which can cause more harm to carry out their economic activities (Afzal, Shaheen, Razzaq, & Salam, 2024).

On one hand, it can play a role in the prevention of deterioration of the environment by improving productivity and standards (Nosheen et al., 2021). On the other hand, the rebound effect that stems from various advancements in technology results in an increase in the overall demands for natural resources as well as a worsening of the environmental pollution levels (Herring & Roy, 2007; Jia & Lin, 2022). However, some scholars have noted that the connection between financial development and technical advancement is useful in cutting the fluctuation range of the natural surroundings (Cao et al., 2021). Some of the advancements brought about by FinTech include digital payment systems, banking through mobile phones, and peer to peer lending (Kaur et al., 2021). The rapid growth of FinTech mainly through technological enhancements, shifts in, customer behavior, and financial inclusion presents significant eco impact (Laeven et al., 2015). The literature review found that while the financial sector is already a major source of environmental impact, there has been relatively limited coverage of the environmental effects of specific FinTech applications. FinTech has grown vast and rapidly, disrupting and changing the financial services sector by coming up with innovative ways and approaches to addressing the social needs of a society, efficiency, and sustainability of the financial sector (Arner et al., 2020).

Some published studies have examined the relationship between FinTech and EG (Cevik, 2024; Song & Appiah-Otoo, 2022) and how EG affects CO2 emissions (Kasperowicz, 2015). However, the mediating role of EG in the context of this relationship has not been examined yet (Qin et al., 2024). However, there is a scarcity of knowledge about how FinTech can contribute to environmental sustainability more generally, with specific emphasis on CO2 emissions (Awais et al., 2023). This research aims to fill this knowledge gap by exploring how FinTech's effect influences CO2 emissions through its impact on EG.

1.1 Research Questions

- How does the adoption of Financial Technology (FinTech) affect the level of carbon dioxide emissions globally?
- In what way does EG (EG) impact the relationship between FinTech and CO2 emissions?

This research contributes to the existing literature by providing important insights into the impacts of FinTech on the environment and how economic development can help mitigate the relationship between FinTech and CO2 emissions (Deng et al., 2019). The findings will be beneficial to the policymaker and the financial regulators for understanding the environmental impact of FinTech and the need for more advanced and sustainable financial services (Habiba et al., 2022). This research adopts an analytical quantitative approach by employing the cross-sectional data set from 114 countries in the global universe during 2001-2022. Therefore, the variable being measured is CO2 emissions or emission level while the factors being manipulated and tested are FinTech and EG. Software Stata 18 is used for mediating the effect of EG analysis, and it is a good and suitable tool. This software has been newly developed on purpose for the testing of mediation effects. This test seeks to determine the indirect effect of FinTech on CO2 emissions through EG either directly or indirectly and the total effect of the same. The data used in this study was sourced from The World Bank using a panel data research design.

1.2 Objectives

1.2.1 Evaluate the correlation between financial technology and CO2 emissions

1.2.2 Discussing the role of EG to determine the effect of FinTech on the CO2 emissions

1.2.3 Applies the multiplier effect of FinTech on Gross Domestic Product (GDP) to assess the indirect relationship between FinTech and Carbon Dioxide (CO2) emissions.

The subsequent sections of this study are structured as follows: section 2 reviews the literature on FinTech, EG, and CO2 emission. section 3 discusses on the method and data used in the research. It is in chapter four where the conclusions are presented in line with the analysis made. Finally, section 5 discusses the policy and implications of the outcome to financial regulators.

2. Literature Review

2.1 Fintech & Economic Growth

Fintech and EG, as one of the critically important topics globally, has been investigated in a number of studies. King and Levine (1993a,b) state that the enhancement, optimization, and innovation of financial services, which the financial development horizon of fintech embraces, will lead to improved EG. In the same vein, Greenwood and Jovanovic (1990) argue that a triumph of financial systems contributes to economic development by enabling credit availability, lowering transaction costs, and increasing financial efficiency. Specifically, the latest theoretical investigations focus on analyzing the impact of fintech on EG. Following the literature review, Bu et al. (2023) explain the positive impact of fintech for China's EG particularly through the provision of financial services to the poor. Song and Appiah-Otoo (2022) again find that Fintech has a positive impact on China's EG notably by promoting financial innovation and improving financial system efficiency.

Fintech contributes to the promotion of growth in the economy through innovations in the accessibility of financial products, particularly targeting needy and underserved customers (Kanga et al., 2021). The application of fintech results in improved efficiency and declining the costs associates with transactions and payments (Laeven et al., 2015). Furthermore, fintech has the potential to trigger the creation of new financial products and services like mobile money, and digital money pouches as noted by Arner et al. (2017). Furthermore, as Li et al. (2022) pointed out, the field of financial technology otherwise known as fintech can play a major role in economic development by acting as a catalyst for bringing about the fiscal efficiency, poverty reduction, and improved standards of living. Through innovative solutions, fintech can bring positive changes to widespread income inequality by providing better access to financial services to low-income earners and small businesses alike (Deng et al., 2019).

The term Fintech refers to technical/technological innovation that can leverage growth of the economy with an increase in the adeptness of financial intermediation and extend the reach of financial services to all the entities and to develop and sustain the innovation. The linkage analyzed below is based on the endogenous growth theory which assumes that EG occurs due to internal factors including technological change and innovation, and human capital (Romer, 1990). According to the endogenous growth theory, EG is stimulated by the stock of technology and the manner in which a social society devises ways of assisting a community. This can be brought about through education and training, which will lead to a reduction in the cost of production (Lucas, 1988). The advancement in fintech can also be very useful in improving human capital since it creates access to financial education/training particularly in such groups of societies that have been neglected. In addition to this, the theoretical base is anchored on the financial development theory which asserts that EG can be realized through increased financial access, increased financial integration, and increased financial mobility and efficiency and the promotion of a wide range of financial services (Levine, 2005). Fintech is a kind of financial innovation; it can promote growth in the economy through improving the flow of financial intermediation, enlarging the access to finance, and encouraging the idea of new finance. Hence, the further hypothesis can be stated as:

Hypothesis 1: Fintech has a positive impact on EG.

2.2 Fintech & Environment Sustainability

This literature review has aimed at establishing whether there is any relationship between fintech and environmental sustainability. As per Awais et al. (2023), the purpose of fintech can enable effective use of resources and support EG in a sustainable way. The following work statistically examines the impact of fintech on China: Deng et al. (2019) have also revealed that fintech holds the potential for sustainable development for China. On the flip side, other studies have pointed out that the use of fintech could actually be responsible for negative environmental impacts such as increased power consumption and the emissions of carbon (Habiba et al., 2022). Fintech has the capability of contributing towards increase in EG hence leading to increase in energy consumption and emissions of carbon that is a certain level (Kirikkaleli, 2020). Nevertheless, even the creation and destruction of gadgets related to fintech such as cellphones and laptops are some of the causes of harm in the environment as pointed out by Herring and Roy (2007). With increased use of electronic payments and online procurement leads to increased energy consumption and creation of electronic trash (Lantz & Feng, 2006). In addition, more expansion in fintech is also likely to positively impact urbanization, which in turn means an increase in the use of energy enhances the emission of carbon in the atmosphere (Liang & Yang, 2019). Furthermore, there are potential social implications related to the expansion of fintech usage since it may lead to an increase in resource consumption of natural resources such as water and lands which causes negative environmental impacts (Lee et al., 2023).

It is based on the sound theoretical underpinning called Environmental Kuznets Curve (EKC) theory. Thus, the environmental degradation in this context increases with the onset of EG but decreases while it is ongoing (Diao et al., 2009). It is possible to consider fintech as a form of EG that can create the necessary conditions for intensified environmental degradation, for instance, through increased energy consumption and carbon emissions. Furthermore, it is anchored on sustainable development which acknowledges that economic development, social improvement, and environmental protection are intertwined and therefore should go hand in hand in order to achieve sustainable development (Höhne et al., 2012). On the one hand, fintech contributes to the increase of EG, on the other hand, the negative effects of fintech on the environment cannot be ignored. In this regard, the integration of fintech into the global market and the advancement of sustainable development must be done in a way that does not harm the environment. Literature reviewed suggested green finance to be a major driver of environmental impact and there has been under coverage on the impacts of innovating specific Green technology innovations. The scope of green technology innovation is broad and expanding, but with a single overall goal to introduce new technologies in the extensive range of activities connected to sustainability such as cleaning up pollution control and greening production process (Afzal et al., 2024).

Furthermore, the technology-environmentalist thesis underpins the theoretical framework of this study as it argues that while technology brings about positive change, it may also lead to negative impacts on the environment (Herring and Roy, 2007). Another technical advancement that belongs to fintech, which has negative externalities, is the increased energy demand and challenges with electronic waste.

Hypothesis 2: Fintech has a negative impact on Environmental Sustainability.

2.3 Economic Growth & Environmental Sustainability

Growth in the economic sector may lead to increased use of water and land resources in production processes; this has the effects of producing negative impacts on the environment (Lee et al., 2023). Furthermore, EG increases population density by encouraging more people to move to urban areas, which in turn increases electricity demand and carbon emissions (Liang & Yang, 2019). This is in the sense that urbanization leads to increased pollution, increased rate of accumulation of wastes, and loss of species population diversity (Grimm et al., 2008).

Further, EG may result in the development and increase in the use of products and services, which in turn means increased pollution (Habiba et al., 2022). The increasing reliance of populations and industries on conventional and non-renewable energy sources such as fossil fuels will lead to higher carbon dioxide levels and further degradation of the environment (Herring and Roy, 2007). Unfortunately, the generation and consumption of fossil energies can lead to disastrous events, including crude oil spills and natural gas leaks (Freudenburg & Gramling, 1994). However, EG can foster inequality and poverty, hence worsening environmental degradation according to Martinez-Alier, (2002). There is often the pursuit of EG and development, and this normally leads to the destruction of the natural physical surroundings particularly in the third world countries (Shiva, 2005).

The discussion on EG is one of the types of economic development that, in most cases, has negative impacts on the environment; thus, to achieve sustainable development, it is crucial to find the balance between economic development and environmental protection. The hypothesis of this study also has its theoretical underpinnings on the EKC theory (Diao et al., 2009). However, this hypothesis postulates that EG can have a negative influence on the environment in the long run through increased energy utilization and carbon emission. Furthermore, the theoretical perspective used is the ecological economics theory which holds that the economy is part of the environment and therefore there is need for the co sustenance of the economy and environment (Daly, 1996). Economic development of this kind refers to the type of economic development that makes negative impacts on the environment. Such importance has made it pertinent for people to find a middle ground between economic development and environmental conservation to achieve sustainable development.

Hypothesis 3: EG has a positive impact on Co2 emissions thus negative impact on environment sustainability.

2.4 Fintech & Environmental sustainability with mediation effect of Economic Growth

The analysis of the relationship between fintech and EG on the one hand and the impact of the latter on ecological significance on the other is well-studied in scientific literature. Existing literature on Fintech has found that there is a positive relationship between Fintech and EG (Cevik, 2024; Qin et al., 2024), which in turn has a favorable impact on environmental sustainability as revealed by the literature (Ghazouani & Maktouf, 2024; Kasperowicz, 2015). Fintech has the potential of achieving higher financial inclusion and thus can lead to higher efficiency in EG (Kanga et al., 2021). As mentioned by Habiba et al. (2022), EG engulfs an increase in the investment in the exploitation of renewable energy and also the reduction of carbon emissions.

Thus, the introduction of fintech can enhance efficiency of the financial sector and reduce costs in general. That is why it can encourage higher investment in sustainable technologies (Arner et al., 2020; Bilal & Shaheen, 2024). As studies have shown, emerging fintech makes consumers and businesses more inclined to use digital payments and reduce the amount of monetary cash, which means a reduction in the emission of greenhouse gases (Lee et al., 2023). Also, fintech implementation means that there is a likelihood of higher investments in renewable energy efforts hence promoting reduced carbon emissions (Li et al., 2022). However, some research has revealed that fintech may pose negative impacts to the environment such as increasing energy consumption and e-waste (Lantz & Feng, 2006). Furthermore, growth in economic affairs leads to an increase in demand and supply thus contributing to environmental degradation (Knight & Rosa, 2011).

This hypothesis can be grounded on the sustainable development theory by Höhne, et al., (2012) stating that economic progress means Fintech brings about environmental gains. But, to sustain Fintech for the long-term, it is necessary to strike a delicate balance between Fintech's growth and measures to preserve the environment. Also, the thinking in the framework is based on the concept of ecological economics that Daly (1996) suggested as the relationship of economy with the natural environment. What they emphasized was how Fintech should have more focus on the aspect of environmental sustainability in its pursuit of economic development.

Hypothesis 4: There is a significant relationship between "Fintech and CO2 emissions", mediated by EG.

Where fintech has a positive impact on EG, and EG has a positive impact on environmental sustainability by reducing the carbon emissions.

3. Methodology

This research aims at analyzing data collected from 217 countries and regions, sourced from the international database of World Bank named as WDI, from the year 2001 to 2022. Country level data required cleaning to remove entries that included missing values, which left 81 countries in the final dataset after the cleaning process. Selecting these countries was based on how all data were comprehensive and consistent across the study duration. The descriptors used in the analysis included summary statistics, correlation analysis, goodness of fit tests including Fit statistics, Population error, Baseline comparison, Size of residuals, Wald test for equations, and Structural Equation Modeling (SEM). Moreover, the present study utilized structural equation modeling (SEM) in order to assess total, direct, and indirect effect of the factors of considerations on both CO2 emissions and EG. The analyses of data were performed with the aid of a more advanced, updated, and latest but complex software, Stata 18, and this software is more appropriate for conducting SEM on secondary data, and other complex econometric analysis. What this methodology provides is a very systematic approach to understanding the interconnectivity between EG, financial technology, and the environment. It offers useful information to the existing know-how in these fields.

The dependent variable in this case can be defined as the extent of environmental performance which is measured in terms of CO2 emissions in metric ton per head of population. The mediator variable is EG, defined by the real GDP per capita in a specific year. The independent variable is fintech, which is determined by the availability of ATMs per hundred thousand persons. The data for these variables is collected from the World Bank's World Development Indicators (WDI) sources. Because of this, to fully capture the effects of additional demographic and economically related variables connected to environmental performance, we included the following covariates: population density – the population per square kilometer of the land area, Research and Development Expenditures – as a proportion of the GDP, as well as Environmental Protection Expenditures – as a proportion of the GDP. In the following paragraphs table (1) shows the summary statistics of the variables used in the analysis of the present study. EG remains an area with huge differences between countries, as well as though out different time periods. As for the 1-Percentile and 99-Percentile as extreme values, they are replaced with the 5-Percentile and the 95-Percentile till those tables are calculated.

3.1 Econometric Models

The following equations were used, in order to define the Structural equation model (SEM) and to assess the hypothesized relationships:

Equation for the measurement of EG:

$$\ln(EG_i) = \beta_0 + \beta_1 \ln(FinTech_i) + \epsilon_i$$

Equation for CO2 Emissions (CO2):

$$\ln(CO2_i) = \gamma_0 + \gamma_1 \ln(EG_i) + \gamma_2 \ln(FinTech_i) + \gamma_3 \ln(EPEXP_i) + \gamma_4 \ln(RD_i) + \gamma_5 \ln(PopDen_i) + \epsilon_i$$

3.2 Decomposition of Effects

The breakdown of the indirect, direct and total effects in structural equation modeling (SEM) are stated as:

3.2.1 Direct Effects

Direct effect of “FinTech on EG”: $\beta 1$
Direct effect of “EG on CO2”: $\gamma 1$
Direct effect of “FinTech on CO2”: $\gamma 2$

3.2.2 Indirect Effects

Indirect effect of “FinTech on CO2” through EG: $\beta 1 \cdot \gamma 1$

3.2.3 Total Effects

Total effect of “FinTech on CO2”: $\gamma 2+(\beta 1 \cdot \gamma 1)$

3.3 Summary of SEM Results

The SEM findings were summarized with the focus laid on the most important observations. This was done to make sure that the analysis carried out was robust by reporting the model fit indices, coefficients, standard errors, z –values and p-values. The analysis showed they had significant positive impact, which are EG & CO2 emissions with EG having direct positive impact on CO2 emissions as well.

4. Results and Discussions

4.1 Summary Statistics

The breakdown of the summary statistics table offers information on six variables based on the data collected from 1782 responses. The variables under consideration in the present study are carbon dioxide emissions (CO2), EG (EG), financial technology (FinTech), expenses towards environmental protection (EPEXP), population density (PopDen), and research and development spending (RD). further, measured over time, the average levels of carbon dioxide emissions are approximately 5.31 units. In the case of the non-covariance of sampling distributions, the standard deviation was 4.21 points to variability which shows that there is a high level of volatility in CO2 emissions. The emissions identified range between 0 and 25.61 units, which proves that the companies display a wide variety of CO2 emissions.

Table No 1: Summary Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
CO2	1,782	5.309556	4.208212	0	25.61044
EG	1,782	18512.54	21253.38	0	112417.9
FinTech	1,782	62.09501	50.32574	0.02	288.59
EPEXP	1,782	0.544467	0.2926898	-0.25846	1.914624
PopDen	1,782	137.2634	189.5456	0	1620.425
RD	1,782	0.530154	0.7284135	0	3.73402

4.1.1 Economic Growth (EG)

The mean economic production can be estimated, and it is found to be about 18,512. A mean of 54 and with a fairly high standard deviation of 21,253. 38; this implies that the instruction specificity has a high variability. This means that the data set encompasses places/place/time periods with no economic activity (=0) and those with extremely high economic activity (max: 112,417. 9 units), which allows characterizing it as a relatively diverse sample in terms of the economic status of participants.

4.1.2 Financial Technology Adoption (FinTech)

Using the survey results, the adoption rate of financial technology is calculated to be 62 on average. 10 units. The actual FinTech adoption levels, however, vary greatly, as depicted by the standard deviation figure of 50. 33. The usage of FinTech is from 0 to the maximum value depending on the country, company, and its clients. varying from 02 up to a maximum value of 288. 59, which shows the disparities in the incidences of technology usage among the financial service providers. The summary statistics afford an overall look at the main characteristics of the data, particularly the spread of the data and the central tendencies for the six variables. Fluctuations in the data are important for applying more complex statistical manipulations of the data and model building. It means there is significant variability of economic, environmental, and technological conditions in observations. For instance, the absence of correlations between carbon dioxide emissions and EG reveals significant differences in the level of industries and economic outcomes. These results suggest that there is an uneven picture on technology advancement and FinTech innovation investment, depending on the countries.

4.2 Correlation Analysis

The results of the correlation study uncover and shows multiple but significant relationships:

Table No 2: Correlation Analysis

	lnCO2	lnEG	lnFinTech	lnEPEXP	lnPopDen	lnRD
lnCO2	1					
lnEG	0.7545	1				
lnFinTech	0.7154	0.742	1			
lnEPEXP	0.2542	0.2996	0.0962	1		
lnPopDen	-0.2017	-0.1304	-0.0914	0.0036	1	
lnRD	-0.0917	-0.1234	-0.0765	-0.182	-0.106	1

4.2.1 Positive Correlations with CO2 Emissions

The key findings from these presented studies are that there is a strong positive relationship between economic development and the level of financial technology adoption and CO2 emissions, and as York (2012), confirmed, high economic development, contributions from financial technologies, and increased use of CO2. This could be due to the faster pace of industrial activities and energy consumption resulting from economic development and technical progress.

4.2.2 Control Variables' Influence on CO2 Emissions

The OECD (2020) reports a slight positive relationship between spending on environmental protection and CO2 emissions. This report shows that those areas with higher emissions usually reported to spend more on environmental protection actions or areas. On the other hand, Glaeser and Kahn (2010) reported a modest but negative correlation between the population density, R&D expenditures, and carbon emissions. Thus, indicating that regions with higher population density but with a focus on the investment on R&D tend to lower the carbon emissions, achieve it.

4.2.3 EG and Financial Technology

The link found between EG and fintech are aligned with the previous research which shows notably a strong relationship that the adoption of financial technology may significantly boost EG (Arner et al., 2018). This may happen because of the reason of improved financial inclusion creating greater efficiency in financial transactions and finally to have better access to financial services.

4.2.4 Environmental Protection Expenditures and R&D

Environmental spending and R&D are slightly negatively correlated. It implies that places who invest more in environmental protection tend to spend little funds on research and development, while others with smaller investments in environmental protection have bigger investments in research and development. Perhaps the trade-off is due to financial constraints or a difference in policy priorities. On the whole, the correlation analysis highlights an important nexus between the variables under consideration. Interestingly, CO_2 emissions are found to be positively related to both EG and financial technology adoption (Sims et al., 2019). These results demonstrate support for policies that consider economic progress and technology adoption as well as environmental sustainability. Further investigation may clarify these relationships by using regression analyses and help shape intervention strategies (Olhoff & Christensen, 2020).

4.3 Structural Equation Modeling (SEM)

Table 3 provides this information through the results of Structural Equation Modeling (SEM), to assess these relationships. Table 4 includes the estimated coefficients, standard errors, z-values, p-values, and 95% confidence intervals for the structural equations. In this section, we interpret these findings and examine them with respect to the hypotheses formulated in Section 2.

4.3.1 EG Equation

Financial technology raises growth by a lot. The first assumption is substantiated, given that a 1 percent growth of FinTech leads to the increase of economic activity by about 0.84 percent. However, the presence of a constant term suggests that the underlying level of economic development remains substantial, regardless of FinTech's influence.

4.3.2 CO2 Emissions Equation

EG has a strong positive impact on CO_2 emissions. This supports our third hypothesis, showing that a 1% increase in EG leads to about a 0.36% increase in CO_2 emissions. Conversely, financial technology also significantly reduces CO_2 emissions. This supports our second hypothesis, which found that a 1% increase in FinTech correlates with a roughly 0.35% reduction in CO_2 emissions.

Table No 3: SEM empirical results

Structural lnEG		Coefficient	std. err.	z	P>z	[95% conf. interval]	
	lnFinTech	0.843899	0.0222258	37.97	0	0.800337	0.887461
	_cons	5.999688	0.0861918	69.61	0	5.830755	6.168621

lnCO2							
	lnEG	0.362769	0.0231648	15.66	0	0.317367	0.408171
	lnFinTech	0.351135	0.0250812	14	0	0.301977	0.400293
	lnEPEXP	0.116192	0.0252771	4.6	0	0.06665	0.165734
	lnRD	-0.00473	0.0158562	-0.3	0.766	-0.0358	0.026352
	lnPopDen	-0.08955	0.0142564	-6.28	0	-0.1175	-0.06161
	_cons	-2.89861	0.1815629	-15.96	0	-3.25447	-2.54275
	var(e.lnEG)	0.621055	0.025601			0.572852	0.673315
	var(e.lnCO2)	0.34153	0.0140785			0.315022	0.370268
Log likelihood = -9080. 2031							
LR test of model vs. saturated: chi2(3) = 162.97 Prob > chi2 = 0.0000							

Increased spending on environmental protection is directly associated with higher CO2 emissions, suggesting that areas with higher emissions invest more in efforts to mitigate these emissions. However, research and development spending has a minimal and statistically insignificant effect on CO2 emissions. Population density, on the other hand, has a significant negative impact on CO2 emissions; a 1% increase in population density leads to a roughly 0.09% decrease in CO2 emissions. This could be due to industrial installations being located away from densely populated areas. The negative constant term indicates a fundamental decrease in CO2 emissions when all other variables are zero. The variances for EG (0.6210551) and CO2 emissions (0.3415298) show the extent of variability in these factors that our model does not account for.

4.4 Hypothesis Evaluation

Hypothesis 1: FinTech has a positive impact on EG

Supported. The coefficient for lnFinTech in the lnEG equation is positive and highly significant (0.8438993, $p < 0.001$).

Hypothesis 2: FinTech has a negative impact on Environmental Sustainability

Supported, but in the opposite direction. The regression analysis shows that the coefficient for lnFinTech in the lnCO2 equation is positive and statistically significant (0.351135, $p < 0.001$). This means that higher FinTech adoption is linked to increased CO2 emissions, negatively affecting environmental sustainability.

Hypothesis 3: EG negatively impacts Environmental Sustainability (i.e., CO2 emissions increase with EG)

Supported. The coefficient for EG in the CO2 equation is positively and significantly correlated (0.3627691, $p < 0.001$), indicating a strong link between EG and higher CO2 emissions.

Hypothesis 4: FinTech positively impacts CO2 emissions, mediated by EG

Supported. While FinTech boosts EG, the combined effect of FinTech and EG results in a negative impact on environmental sustainability. This is because the EG driven by FinTech leads to increased CO2 emissions.

4.4.1 Discussion

The SEM results provide valuable insights into the relationships between financial technology, EG, and environmental sustainability. FinTech's positive effect on EG aligns with expectations that advancements in finance stimulate economic activity. However, both FinTech and EG also lead to higher CO2 emissions, highlighting a tension between economic and environmental goals. Based on the results, it is possible to mention that improved investments in environmental protection relate to more considerable CO2 emissions: as a result of pollution measures being granted higher funding. On the other hand, population density is negatively correlated with CO2 emission because densely populated areas use resources more efficiently and their per capita emissions are also less (Glaeser & Kahn, 2010; Chen et al., 2021). This study reflects the tricky context in which finding a balance between EG and environmental protection is created. A key area, therefore, that policymakers should address is devising ways either as a reaction to or in parallel to environmentally adverse economic activity and technological advancement, promoting “green” technologies and sustainability across the financial industry (Olhoff & Christensen, 2020; Arner et al., 2016).

This high correlation between FinTech and CO2 emissions indicates that although EG is promoted by the development of FinTech, this may be at the expense of higher energy consumption and increased pollution. In the future, research should examine the application of financially sustainable technologies that are friendly to the environment and consider whether they help decouple economic development from environmental harm (Nasir et al., 2021).

4.5 Interpretation and Discussion of Direct, Indirect, and Total Effects

As we explained above, the analysis presented in Table 4 allows us to see the exact impact made by financial technology (FinTech) on EG and CO2 emissions, which effects are direct or indirect as well as our review of hypotheses. We elaborate on these findings below.

4.5.1 Direct Effects

Table No 4: Decomposition of effects (Direct, Indirect, and Total Effects)

		Coefficients	Std. err.	Z	p>z	95% conf.	interval
Direct Effects							
Structural							
lnEG							
	lnFinTech	0.843899	0.0222258	37.97	0	0.800337	0.887461
InCO2							
	lnEG	0.362769	0.0231648	15.66	0	0.317367	0.408171
	lnFinTech	0.351135	0.0250812	14.0	0	0.301977	0.400293
	lnEPEXP	0.116192	0.0252771	4.6	0	0.06665	0.165734
	lnRD	-0.00473	0.0158562	-0.3	0.766	-0.0358	0.026352
	lnPopDen	-0.08955	0.0142564	-6.28	0	-0.1175	-0.06161
Indirect Effects							
Structural							
lnEG							
lnCO2							

	lnFinTech	0.306141	0.0211462	14.48	0	0.264695	0.347586
Total Effects							
Structural							
lnEG							
	lnFinTech	0.843899	0.0222258	37.97	0	0.800337	0.887461
lnCO2							
	lnEG	0.362769	0.0231648	15.66	0	0.317367	0.408171
	lnFinTech	0.657276	0.0185364	35.46	0	0.620945	0.693606
	lnEPEXP	0.116192	0.0252771	4.6	0	0.06665	0.165734
	lnRD	-0.00473	0.0158562	-0.3	0.766	-0.0358	0.026352
	lnPopDen	-0.08955	0.0142564	-6.28	0	-0.1175	-0.06161

4.5.1.1 EG Equation

(Direct effect of FinTech on EG): 0.8438993 ($p < 0.001$) Financial technology has a strong positive impact on EG, confirming Hypothesis 1, which suggests that FinTech positively influences EG.

4.5.1.2 CO2 Emissions Equation

(Direct effect of EG on CO2): 0.3627691 ($p < 0.001$) EG directly and significantly increases CO2 emissions, supporting Hypothesis 3, which proposes that EG has a positive effect on CO2 emissions and a negative effect on environmental sustainability.

4.5.1.3 Direct effect of FinTech on CO2

0.351135 ($p < 0.001$) Financial technology significantly
contributes to reducing CO2 emissions. This supports Hypothesis 2, indicating that higher FinTech Adoption is linked to increased CO2 emissions, thus negatively affecting environmental sustainability.

4.5.1.4 Direct effect of EPEXP on CO2

0.116192 ($p < 0.001$) There is a positive correlation between environmental protection expenditures and CO2 emissions, suggesting that areas with higher emissions also spend more on environmental protection.

4.5.1.5 Direct effect of RD on CO2

-0.0047257 ($p = 0.766$) Research and development expenditures have a minimal and statistically insignificant impact on CO2 emissions.

4.5.1.6 Direct effect of PopDen on CO2

-0.0895537 ($p < 0.001$) Higher population density is negatively correlated with CO2 emissions, indicating that densely populated areas tend to have lower CO2 emissions.

4.5.2 Indirect Effects

(Indirect effect of FinTech on CO2 through EG): 0.3061406 ($p < 0.001$) Financial technology indirectly affects CO2 emissions by promoting EG. This shows that the impact of FinTech on CO2 emissions is partly mediated by its influence on EG. Thus, Hypothesis 4 is confirmed, as both the direct and indirect effects of FinTech on CO2 emissions are positive and significant.

4.5.3 Total Effects

4.5.3.1 EG Equation

Total Effect of FinTech on EG = 0.8438993 ($p < 0.001$). This is in line with the direct effect as there are no further mediating variables to be taken into account when constructing the EG equation.

4.5.3.2 CO2 Emissions Equation

Total effect of EG on CO2= 0.3627691 ($p < 0.001$) The total effect is the same as the direct effect, as EG does not mediate any other relationships in the model.

4.5.3.3 Total effect of FinTech on CO2

0.6572756 ($p < 0.001$) The overall impact of financial technology on CO2 emissions is derived by combining its direct effect (0.351135) with its indirect influence through EG (0.3061406). The significant positive overall effect indicates that FinTech contributes to an increase in CO2 emissions, both directly and indirectly via the stimulation of EG.

4.5.3.4 Total effect of EPEXP on CO2

0.116192 ($p < 0.001$) The overall impact remains unchanged, suggesting no substantial influence from other variables.

4.5.3.5 Total effect of RD on CO2

-0.0047257 ($p = 0.766$) The overall impact stays unchanged, indicating no substantial influence from other mediating variables.

4.5.3.6 Total effect of PopDen on CO2

-0.0895537 ($p < 0.001$) The overall impact remains unchanged, implying no substantial influence from other variables.

4.6 Discussion and Hypotheses Evaluation

Hypothesis 1: FinTech has a positive impact on EG

Supported: The impact of FinTech on EG is both directly beneficial and statistically significant (0.8438993, $p < 0.001$).

Hypothesis 2: FinTech has a negative impact on Environmental Sustainability

Supported: The impact of FinTech on CO2 emissions is directly positive and highly significant (0.351135, $p < 0.001$), suggesting a detrimental effect on environmental sustainability.

Hypothesis 3: EG has a positive impact on CO2 emissions

Supported: The correlation between EG and CO2 emissions is positive and statistically significant (0.3627691, $p < 0.001$).

Hypothesis 4: There is a significant relationship between FinTech and CO2 emissions, mediated by EG

Supported: The impact of FinTech on CO2 emissions, mediated by EG, is positive and statistically significant (0.3061406, $p < 0.001$). The overall impact of FinTech on CO2 emissions is both positive and substantial (0.6572756, $p < 0.001$), indicating that it has a detrimental effect on environmental sustainability when influenced by EG.

4.6.1 Conclusion

The analysis highlights the complex relationships between financial technology, EG, and environmental sustainability. Our results show that FinTech has a positive impact on EG but leads to carbon emissions, whether through the direct effect of increasing CO2 emissions or through the indirect effect of EG. This dual effect has called for policies with concerns of balancing technological and economic development with protection and conservation that would lead to sustainable criteria.

4.7 Goodness-of-Fit Analysis

The findings were obtained using the "estat gof, stats(all)" command in Stata, which provides a comprehensive set of fit statistics to evaluate the goodness-of-fit of the structural equation model (SEM), present in Table 05. In order to obtain the comprehensive and detailed results, we apply the “estat gof, stats (all) command in STATA 18. The results obtained through this command are described below.

Table No 5: Goodness of fit tests

Fit statistic	Value	Description
Likelihood ratio		
chi2_ms(3)	162.971	model vs. saturated
p > chi2	0	
chi2_bs(9)	2310.139	baseline vs. saturated
p > chi2	0	
Population error		
RMSEA	0.093	Root mean squared error of approximation
90% CI, lower bound	0.07	
upper bound	0.124	
pclose	0	Probability RMSEA <= 0.05
Information criteria		
AIC	18180.406	Akaike's information criterion
BIC	18231.113	Bayesian information criterion
Baseline comparison		
CFI	0.93	Comparative fit index
TLI	0.91	Tucker–Lewis index
Size of residuals		
SRMR	0.059	Standardized root mean squared residual
CD	0.639	Coefficient of determination

4.7.1 Likelihood Ratio Tests

4.7.1.1 Model vs. Saturated (chi2_ms)

The chi-squared distributed difference between the fitted model and a “saturated” model that includes all associations specified in the M x Path objects involved. A high chi-square value ($p < 0.05$) is an indication of a difference between the two models, the model and saturated model, which indicates possible discrepancies. Although, it should be noted that since chi-square tests are often sample-size dependent and significant tests can obtain from large samples even where the model fits well.

4.7.1.2 Baseline vs. Saturated (chi2_bs)

Compare baseline model. Generally, path away-free/main effect only/marginal involvement with saturated free Model, with a p-value of less than 0.05. So, we can conclude that our saturated model fits significantly better than our base model.

4.7.2 Fit Indices

4.7.2.1 Population Error (Root Mean Squared Error of Approximation - RMSEA)

RMSEA values below 0.05 indicate a strong fit, while values between 0.05 and 0.08 suggest satisfactory fit, and values above 0.10 indicate poor fit. With an RMSEA of 0.093, the fit is considered subpar, confirmed by the confidence interval falling within the 0.08 to 0.10 range.

4.7.2.2 Information Criteria (Akaike’s Information Criterion - AIC and Bayesian Information Criterion - BIC)

Lower AIC and BIC values indicate better fit. The AIC value is 18180.406, while the BIC value is 18231.113.

4.7.2.3 Baseline Comparison (Comparative Fit Index - CFI) and Tucker–Lewis Index (TLI)

CFI and TLI values over 0.90 suggest acceptable fit. The CFI value is 0.93, indicating an acceptable fit, while the TLI value is 0.91, indicating satisfactory fit.

4.7.2.4 Size of Residuals (Standardized Root Mean Squared Residual - SRMR)

SRMR values below 0.08 suggest satisfactory fit, while values below 0.05 indicate excellent fit. The SRMR value is 0.059, indicating a high level of fit.

4.7.2.5 Coefficient of Determination (CD)

CD of 0.639 suggests that approximately 64% of the data variability is explained by the model, indicating a strong relationship.

4.7.2.6 Summary and Discussion

The model demonstrates satisfactory fit indices (RMSEAR, CFI, TLI, SRMR, and CD) but falls short in meeting the RMSEA criterion, indicating room for improvement. While the model effectively represents certain interactions (as indicated by satisfactory indices), discrepancies suggest potential inaccuracies or excluded variables impacting overall model fit.

4.8 Interpretation and Discussion of Wald Tests for Equations

The Wald test evaluates the statistical significance of coefficients within the equations of a structural equation model (SEM). Below are the results of the Wald tests conducted on the equations of Economic Growth (EG) and CO2 emissions (Table 6).

Table No 6: Wald Tests for equations

	chi2	df	p
Observed			
lnEG	1441.67	1	0
lnCO2	2102.02	5	0

4.8.1 Economic Growth (lnEG)

(Chi-Square Value)**:** The notably high chi-square value indicates a strong association between the predictors, particularly FinTech, and economic development. The p-value is negligible, suggesting a highly significant correlation between FinTech and EG. This finding supports the notion that Financial Technology (FinTech) positively influences economic expansion. The Wald test results affirm that the predictor variable EG, particularly FinTech, significantly impacts EG. This confirms Hypothesis 1, suggesting that FinTech contributes positively to EG. The exceptionally small p-value underscores the statistical significance of this association.

4.8.2 CO2 Emissions (lnCO2)

(Chi-Square Value)**:** The high chi-square value indicates a significant correlation between the predictors (EG, FinTech, EPEXP, RD, and PopDen) and CO2 emissions. The p-value is nearly negligible, indicating an extremely significant collective impact of the predictors on CO2 emissions. This validates the hypothesis that EG positively affects CO2 emissions. The Wald test results demonstrate that the predictors, including EG, FinTech, environmental protection expenditures (EPEXP), research and development expenditures (RD), and population density (PopDen), collectively exert a substantial and statistically significant impact on CO2 emissions in the lnCO2 equation. These findings provide evidence for the following hypotheses:

Hypothesis 2: FinTech has a beneficial influence on reducing CO2 emissions. The significance of FinTech suggests that an increase in FinTech activities is associated with higher CO2 emissions.

Hypothesis 3: Economic expansion positively influences CO2 emissions. The correlation between EG and CO2 emissions implies that higher EG leads to increased CO2 emissions.

4.9. Conclusion

Concludingly, the results of the Wald tests offer strong evidence supporting the relationships we defined in the structural equation model (SEM). Firstly, Hypothesis 1 checks out: FinTech has a clear and positive impact on EG. Next, Hypothesis 2 is also true: FinTech leads to more carbon dioxide emissions. Ultimately, hypothesis three validates that EG corresponds to higher carbon dioxide production. These findings really emphasize how close the relationships between advancements in financial technology (FinTech), economic development and environmental protection are. While FinTech drives economic development, it also contributes to pollution by increasing CO_2 emissions. It is important to recognize the need for sustainable and balanced development.

5. Conclusion

We conducted this study with a comprehensive examination of the impact of FinTech on both EG and ES (measured through CO_2 emissions). To analyze the panel data of 81 countries for a period covering from 2001 to 2022, we employed Structural Equation Modeling (SEM) through Stata 18. To assess the mediation effect, both direct and indirect effects are explored. Our findings confirm that FinTech exerts a significant and positive direct effect on EG, evidenced by a highly significant coefficient of 0.8439 ($p < 0.001$). This underscores the role of FinTech in fostering EG through enhanced financial inclusivity, reduced transaction costs, and increased financial innovation. However, the environmental impact of FinTech is nuanced. Our analysis reveals that while FinTech-driven EG leads to increased CO_2 emissions (coefficient = 0.3628, $p < 0.001$), indicating a conflict between economic advancement and environmental sustainability, FinTech also directly contributes to CO_2 emissions (coefficient = 0.3511, $p < 0.001$), exacerbating environmental concerns. Mediation analysis further elucidates that EG partially mediates the relationship between FinTech and CO_2 emissions, with a statistically significant impact (0.3061, $p < 0.001$). The overall effect of FinTech on CO_2 emissions (0.6573, $p < 0.001$) underscores the substantial environmental implications associated with FinTech advancements.

Theoretical contributions include insights into the Technology Acceptance Model (TAM), demonstrating the influence of FinTech acceptance on macroeconomic and environmental outcomes. Additionally, our findings support the Environmental Kuznets Curve (EKC) hypothesis, suggesting that economic expansion initially leads to environmental degradation until a certain income threshold is reached, after which environmental conditions improve. These findings hold significant implications for policymakers. While FinTech drives EG, acknowledging its environmental impact is crucial. Policymakers must devise strategies that reconcile technological and economic progress with environmental preservation, such as promoting eco-friendly FinTech advancements, enhancing regulations to mitigate negative environmental effects, and allocating resources towards sustainable financial strategies. In conclusion, this study underscores the dual nature of FinTech. While it propels EG, it also presents substantial environmental challenges. Achieving sustainable growth requires a holistic approach that harnesses the benefits of FinTech while mitigating its environmental footprint.

5.1 Policy Implications

This research primarily focused on investigating the effect of FinTech on CO_2 emissions looking at aspects such as EG, Population Density, Research and Development, and Energy Production and Consumption. The outcomes from the panel data regression analysis shed light on the intricate connections among these variables. Previous studies conducted by Cevik (2024) shows that the application of fintech is helpful in the reduction of CO_2 emissions. These results are consistent with other studies carried out by Qin et al., 2024; Awais et al., 2023, which states that there is a correlation between fintech and environment sustainability. Thus, the use of the EG as an interaction term with fintech and environmental sustainability is caused due to the higher EG which enable a nation to overcome on the problems of carbon emissions (Cevik, 2024). Additionally, the study reveals that EG (Kasperowicz, 2015), Population Density (Aditya, 2011), Research and Development (Ghazouani & Maktouf, 2024), and the consumption and production of energy (Begum et al., 2015) these all affect positively to CO2 emissions, and these results are in line with the studies conducted previously (e.g., Kirikkaleli, 2020; Li et al., 2022).

There are significant implications that accompany these findings. First, policymakers should think about how FinTech is affecting CO2 emissions when they make decisions on how to mitigate them. This implies that these strategies should consider EG and Population Density. Secondly, there is also a need for more funds to be channeled towards Research and Development that drives innovation in the field of CO2 emission reduction technologies. Third, optimizing energy production and consumption processes helps to reduce CO2 emissions. Fourth, This study, summarily, shows the effect of using financial technology in dealing with carbon dioxide emissions as well as giving empirical evidence for it. These findings contribute to existing knowledge thus providing a basis for further study. Fifth, the current study's implications can be extended to governments, business leaders, and individuals to overcome the ever-increasing issue of environment. The relationship between FinTech and CO2 therefore points out at some form of environmental damage if not checked such as Ecological degradation could be exacerbated by increasing levels of FinTech-related carbon dioxide emissions. This calls for the formulation of policies aimed at promoting green financial technologies as well as incentives among other approaches (World Bank Group 2017). Furthermore, one needs to consider the environmental impact associated with EG and population density whilst designing ways to tackle CO2. This may include investing in renewable energy sources, enhancing energy efficiency, and advocating for sustainable land use policies. Also, ongoing funding in Research and Development must be done to identify innovative methods of reducing CO2 emissions. This could involve partnering with overseas entities, building innovation hubs locally and providing financing for research projects. Finally, effective reduction of CO2 emission can only be attained by optimizing energy production as well as consumption that call for the enactment of regulations that encourage sustainable energy use such as promotion of energy-efficient practices, investments in renewable energies and their sources. By doing these, we can work towards mitigating the environmental impact of FinTech while fostering sustainable economic development.

5.2 Limitations and future directions

Although this study provides interesting insights into the relationship among fintech, EG and co2 emissions it is important to note some future research directions as well as limitations:

5.2.1 Data Limitations

The study relies on aggregated data and can fail to account for substantial differences between locations or industries, as well as unique features of each company. Whether characteristics focused on the inpatient or outpatient setting, further follow-up is needed to examine these relationships.

5.2.2 Causality

Despite demonstrating the links between FinTech, EG, and CO2 emissions, it is hard to determine causation in this study. Future studies may use methods such as instrumental variable analysis or Granger causality testing to explore causal inferences.

5.2.3 Mediating Variables

The study controlled various factors but there may be other mediators that were not covered. It could be interesting to include additional factors such as governmental policies, global trade environments, or technological changes in a further study.

5.2.4 Temporal Scope

The duration of the study is short while long-term effects may vary. It is possible that future research could investigate these relationships over a longer period of time.

5.2.5 Generalizability

Because this study focused on a particular subset of country settings, there may be limits to the extent that these findings can generalize. It will be necessary to inquire in a larger sample so that the findings can be generalized.

5.2.6 Methodological Advancements

We speculate that methodological advances involving machine learning, natural language processing, or network analysis could eventually uncover more complex correlations and patterns.

5.2.7 Contextual Considerations

There are limitations regarding political chaos, natural calamities, and global occurrences that impact observed associations. In the future, such an analysis would benefit from integrating these variables.

5.2.8 Diversity within FinTech

Considering FinTech is a monolithic phenomenon, generalizing it oversimplifies its impact. It could also be interesting to investigate further granular aspects of FinTech (like mobile payments or blockchain) to discover the differences between these sub-sectors.

5.2.9 International Comparisons

There might be an article to compare international approaches that would reveal best practices and have important policy implications for dealing with the environmental externalities of FinTech.

5.2.10 Policy Evaluation

This study does not evaluate or compare the effectiveness of specific policy mechanisms. This is another important topic for future research, to empirically assess how effective FinTech-related policies are in addressing the environmental issues related to it.

Recognizing these limitations and the future directions of research, we will be able to provide more profound insights into FinTech-EG-CO2 emissions dynamics.

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