Analysing Green Finance and Climate Risk Mitigation Using Global Open Data

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Abstract

Green finance is increasingly viewed as an important policy and market-based instrument for supporting low-carbon transition and climate-risk mitigation. This study analyses the relationship between green finance, renewable energy adoption, CO_2 emissions, and projected physical climate risk using global open data for France, India, Indonesia, South Africa, and the United States. The study uses country-level panel data and applies descriptive statistics, trend analysis, correlation analysis, regression modelling, and scenario-based climate-risk comparison. The findings show that green bond issuance varies considerably across countries, while renewable energy consumption is more directly linked with emissions reduction. Specifically, renewable energy consumption has a negative and significant association with CO_2 emissions per capita ($B = -0.031$, $p < 0.01$). In contrast, green bond issuance does not show a significant direct relationship with renewable energy consumption or CO_2 emissions in the current sample. The climate-risk results show that warming level is positively and significantly associated with projected physical climate risk ($B = 6.870$, $p < 0.01$). However, climate-risk interpretation is limited because only 10 valid climate-risk observations are available. Overall, the study highlights the importance of linking green finance to measurable renewable energy, emissions-reduction, and climate-adaptation outcomes.

Keywords: Green finance, Green bonds, Renewable energy, Climate risk, Panel analysis

1. Introduction

The economic and environmental dimensions of climate change are among the most critical challenges to the world today due to its impact on growth, financial security, infrastructure, food security, energy security and human welfare. The growing threat from climate-related risks due to rising temperatures has made the need for enhanced climate mitigation and adaptation measures more urgent in both developed and developing economies. There are two broad categories of climate risk transition risk and physical risk. Transition risk can be defined as the financial and economic risks arising from the transition to a low-carbon economy – such as shifts in regulation, technology, investor preferences, carbon pricing and energy-market structures. Physical risk includes damages and disruption from climate hazards like extreme rainfall incidents, floods, storms, heatwaves, droughts and other weather-related events. The risks are likely to grow with climate change, and climate-risk assessment is a crucial element of economic and financial planning. (Intergovernmental Panel on Climate Change, 2023; Network for Greening the Financial System, 2024a; World Bank, 2026b)

The development of green finance has become a key way to promote climate change mitigation and low-carbon development. It denotes financial activities which seek to move money into environmentally sustainable projects such as renewable energy, energy efficiency, clean transport, climate adaptation and pollution reduction. Green bonds are one of the most significant green finance instruments as they enable governments, companies and financial institutions to fund climate and environmental initiatives. Based on the prior studies, it can be assumed that green bonds can contribute to the transition of low carbon economy by the investments in cleaner technologies and sustainable infrastructure. (Lichtenberger et al., 2022; Zhou & Kythreotis, 2024) Green finance can also help drive environmental sustainability through investment behaviour, innovation and climate performance of companies. (Khan et al., 2022; Lyu et al., 2025; Zhang et al., 2022)

Green finance and climate mitigation are commonly referred to as renewable energy uptake and emissions reduction. Where renewable energy can replace energy sources with high CO_2 emissions, it can help to decrease CO_2 emissions and reduce reliance on fossil fuels. (Attanayake et al., 2024; Sun et al., 2023; Zhu et al., 2024) With the issuance of green bonds, it is possible to provide long term financing for renewable energy projects and thus support this process. But whether green finance is effective or not hinges on the question of whether or not the money is being spent on projects that have tangible environmental results. (Pang et al., 2024) Some research indicates that green bonds and green finance can help reduce emissions, and others indicate that the relationship can be contingent on the design of green bonds, the maturity of the green bonds market, the industrial structure and the quality of green bonds reporting. (Reitsema & Scholtens, 2025; Wang & Ma, 2022)

The research problem tackled in this study is that whilst the green finance sector has expanded rapidly around the world, there is yet no clear empirical link between the issuance of green bonds, deployment of renewable energy, CO_2 emissions reductions and projected mitigation of climate-risk. Issuance of green bonds could be a sign of increased climate finance activity, but the number of green bonds issued does not necessarily mean that emissions are being reduced or climate-risk exposure is being mitigated. So, it is necessary to consider the country level data to see if there are any measurable mitigation outcomes that are green finance indicators.

This study fills three gaps in the literature. Second, although there are numerous studies focusing on green finance and emissions, few studies integrate green finance indicators with climate-risk scenario information. Second, the available evidence is mostly country studies but, in this study, selected developed and emerging economies are compared. Third, there has been much conversation around the concept of climate-risk mitigation; this study provides links between climate-risk mitigation through green bond issuance, usage of renewable energy, CO_2 emissions, GDP per capita, and projected physical climate risk through open data. The study relies on open global datasets, such as emissions data, economic indicators data from Our World in Data and the World Bank, as well as climate-risk scenario data derived from NGFS-related climate-risk sources. (Network for Greening the Financial System, 2024b; World Bank, 2026a)

2. The objective of the study:

To examine the correlation between green finance and climate-risk mitigation, by making use of open data from around the world on green bonds, renewable energy consumption, CO_2 emissions, GDP per capita and projected climate-risk scenarios. The study is focused on the countries of France, India, Indonesia, South Africa and United States. These countries offer a convenient comparison between a developed and emerging economy and allow for the analysis to account for variations in green finance capacity, RE transition, emissions, income, and physical climate-risk exposure.

3. The study tests five hypotheses:

H1: Green bond issuance is positively associated with renewable energy consumption.

H2: Renewable energy consumption is negatively associated with CO_2 emissions per capita. H3: Green bond issuance is negatively associated with CO_2 emissions per capita.

H4: Higher warming levels are positively associated with projected climate risk.

H5: Orderly transition scenarios show lower projected climate risk than current-policy scenarios.

The descriptive analysis, trend analysis, correlation analysis, regression models and comparison of climate-risk scenarios employed in the study are based on these research questions and hypotheses.

4. Methodology

4.1 Research Design

This study is a quantitative study with a secondary data open-source approach. It uses historical country-level panel data, and future climate-risk scenario data to analyse whether green finance supports climate-risk mitigation. The historical component includes the green bond issuance, the renewable energy consumption, CO_2 emission per capita, and GDP per capita from 2014 till 2024. The scenario component analyses the physical exposure to climate risks with the help of the maximum 5-day precipitation risk projected for a year, the warming level, the scenario labels, and the uncertainties. Descriptive statistics, trend analysis, Pearson, Spearman correlation, regression analysis, scenario-based comparison and climate-risk uncertainty analysis have been used in the study. These techniques can be adapted to patterns across countries, testing statistical relationships, and comparing outcomes of climate risk using various assumptions of scenarios.

4.2 Data Sources

The study is based on secondary data that is publicly available on international open data platforms and supporting documents for green finance. The data on green bond issuance come from the IMF Macroeconomic Climate Indicators Dashboard, which considers green bonds and sustainability-linked bonds to be fixed-income securities aimed at financing climate and environmental projects (IMF Climate Data). Renewable energy consumption, CO_2 emissions per capita and GDP per capita are drawn from the World Bank World Development Indicators (World Bank WDI) which are gathered from officially recognized international bodies. Other energy and sustainability indicators are double-checked using the SDG database of the World Bank, which classifies WDI indicators by SDG goals and targets (World Bank SDGs). Climate-risk projection data are gathered from the Climate Impact Explorer, which offers country-level climate impact projections at various climate warming levels and scenarios and gives access to the underlying data (Climate Analytics). (Climate Analytics, 2026; IMF, 2026; Intergovernmental Panel on Climate Change, 2023; Network for Greening the Financial System, 2024b; World Bank, 2026b)

The study is accompanied by four pdf reports. The IFC Green Bond Impact Report is intended to shed light on green bond use of proceeds reporting, projects eligible for financing, and key impact indicators including renewable energy produced and GHG emissions reduced. India Country Briefing by Climate Bonds Initiative presents evidence on the green bond market in India, such as the total volume of green bonds issued, and the share of renewables in the use of proceeds. PACE-D report on Green Bonds in India describes how Green Bonds are fixed-income securities which are used to finance projects to tackle mitigation or adaptation. The Indonesia green bonds report outlines the obstacles and potential answers for new green bond markets, such as the cost of currency hedging, credit ratings, awareness of the market and bankable green projects. (Climate Bonds Initiative, 2018; European Climate Foundation, 2019; Odaro, 2016; Vinod Kala & Vivek Garg, 2015)

Table 1: Data Sources and Variables Used in the Study

Dataset / source	Data type	Period	Main variables	Purpose
IMF Climate Change Indicators Dashboard	Country-year panel	2014–2024	Green bond issuance	Green finance analysis
World Bank WDI / SDG DataBank	Country-year panel	2014–2024	Renewable energy, CO_2 emissions, GDP per capita	Mitigation and control variables
Climate Impact Explorer	Country-year-scenario panel	2015–2100	Warming level, RX5Day risk, scenario label	Future climate-risk analysis
Green bond reports	Documentary evidence	2015 onward	Green bond market context, impact reporting, barriers	Methodological and contextual support

4.3 Sample Selection and Variables

The countries at the end of the sample are those shared by the main datasets: France, India, Indonesia, South Africa and the United States. These countries represent a diversity of markets between developed and emerging economies, and enable comparison between green finance activity, energy transition, emissions, income and exposure to physical climate risk.

Table 2: Country Codes Used Data analysis

Country code in SPSS	Country name	Economy type
1	France	Developed economy
2	India	Emerging economy
3	Indonesia	Emerging economy
4	South Africa	Emerging economy

5	United States	Developed economy

Table 3: Variable Description and Expected Relationships in the Model

Variable	Symbol	Type	Measurement	Expected effect
Green bond issuance	GB	Independent variable	Annual green bond issuance by country	Positive effect on renewable energy; negative effect on CO_2
Renewable energy consumption	RE	Mediating / outcome variable	Renewable energy share of final energy consumption	Negative effect on CO_2
CO_2 emissions per capita	CO_2	Dependent variable	Metric tons per capita	Main mitigation outcome
GDP per capita	GDPpc	Control variable	Current US dollars	Controls for income and financial capacity
Warming level	WARM	Independent climate variable	Degrees Celsius	Positive effect on climate risk
Climate risk	CRISK	Dependent climate-risk variable	pcrisk_rx5day_med	Scenario-risk outcome
Risk uncertainty	UNC	Uncertainty variable	pcrisk_rx5day_p95 – pcrisk_rx5day_p5	Measures projection uncertainty
Scenario	SCEN	Grouping variable	Climate-policy scenario	Scenario comparison

4.4 Data Preparation

The data sets were cleaned prior to analysis. Where necessary, wide format data in Excel were converted to long format data. All country names were standardised across the data sets, non-numeric data, like "..", were coded as missing, and all analysis variables were coded as numeric data. Overlapping countries were only included for combined analysis and duplicate country-year observations were removed. Care was taken in accounting for missing values, as in some cases climate-risk indicators are only available for certain years. All descriptive analyses were performed using available case analysis, whereas pairwise complete observations were used for correlation analyses and listwise deletion for regression modelling. Not much interpolation was used since this can affect the accuracy of the results.

4.5 Statistical Techniques

Green bond issuance, renewable energy consumption, CO_2 emissions per capita, GDP per capita and climate risk are presented by using descriptive statistics (mean, median, standard deviation, minimum, maximum, number of valid observations, and missing values). The trend analysis is performed using line charts, which includes analysis of green bond issuance, renewable energy consumption, CO_2 emissions per capita, GDP per capita and climate-risk projection by country and scenario.

The linearity of the relationships between the main variables is investigated using Pearson correlation. The relationships that are expected are positive between green bond issuance and renewable energy consumption, negative between renewable energy consumption and CO_2 emissions, positive between GDP per capita, and positive between warming level and climate risk. Spearman correlation also is used as a robustness check as the sample is small and some variables may not be normally distributed.

4.6 Regression and Scenario Analysis

Data are analysed statistically by SPSS. Estimation of three regression models. Model 1 tests the impact of green bond issuance on the use of renewables, after accounting for the GDP per capita, the country effects, and the year effects. Model 2 tests if there is a positive effect of green bonds issuance and RE consumption on CO_2 emissions per capita given GDP per capita. Model 3 evaluates if there is a greater climate risk in the future with warming level increases (country and scenario effects if available).

A scenario based risk mitigation analysis explores the difference between physical climate risk across current-policy and transition scenarios. The difference between the current-policy and transition-scenario risks is expressed as a percentage. The climate-risk uncertainty is the difference between the 95th percentile and the 5th percentile projections of RX5Day. These robustness checks involve running four distinct versions of the spearman correlation analysis, using either a regression with GDP per capita or without, using the median climate risk value, using the climate uncertainty band, the comparison between developed and emerging economies and the comparison between the pooled OLS and the fixed-effects estimates.

5. Results: Data Analysis and Findings

The results of the study are presented in this section. The analysis starts with a descriptive statistics analysis, followed by a country-wise trend analysis, correlation analysis, regression analysis, interpretation of the climate-risk scenarios, climate-risk uncertainty analysis, and summary hypothesis testing. There are 55 country-year observations for the main economic and environmental variables and only 10 observations for the climate-risk variables, which is a key limitation for the interpretation of climate risk and scenarios.

5.1 Descriptive Statistics

The descriptive statistics of the variables mainly used in this study are presented, as reported in table 3.1, including green bond issuance, renewable energy consumption, CO_2 emissions per capita, GDP per capita, and physical climate risk. These statistics give an overview of the distribution, variation and data availability of the variables.

Table 4: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Green bond issuance	11.1919	15.82935	0.00	57.54
Renewable energy consumption	18.7291	8.84151	7.60	36.10
CO_2 emissions per capita	6.1357	4.75239	1.65	16.04
GDP per capita	24,110.2090	26,537.05561	1,573.89	85,810.00
Climate risk	1.8073	1.01476	0.34	3.67

There is significant heterogeneity in the variables in the descriptive statistics. The highest dispersion is in GDP per capita where the standard deviation is 26,537.05561, showing large differences in the economy of the countries sampled. The standard deviation of green bond issuance is also high compared to the average and the variation is greater than the average. This suggests a lopsided distribution of green bond activity with some country-year observations exhibiting a very high issuance and others a low or no issuance. There is also a significant difference in the amount of CO_2 emissions per capita, which is related to differences in energy structure, fossil fuel reliance, and economic development.

Green bond issuance is focused primarily in Country 1 and Country 5, with Countries 2 and 3 seeing less but growing green bond issuance, and Country 4 seeing consistently low green bond issuance. This indicates the presence of more or less developed green finance markets in some countries compared to others. One of the biggest restrictions is the climate-risk variable, with only 10 valid observations and 45 missing observations, the climate-risk results should be interpreted with caution. On the whole, the descriptive statistics suggest that there are significant cross-country and temporal variations in green finance, renewable energies, emissions, economic development and climate-risk exposure. Due to the limited climate-risk observations, however, the strength of the conclusions based on climate-risk and/or scenario are limited.

5.2 Country-wise Trends

This subsection focuses on the trends of the key variables over time and across countries, between 2014 and 2024. The graphs on trends are helpful as it indicates if the levels of green finance, renewable energy, emissions and income increased steadily or varied from country to country over time.

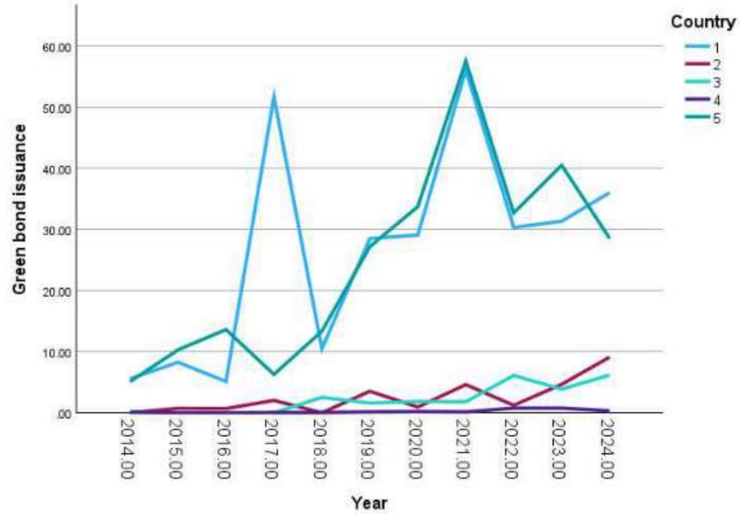

Figure 1: Green Bond Issuance Trends by Country

There is significant cross-country variation in the trend of green bonds. The highest level of green bond activity is in Country 1 and Country 5. The fluctuations in both patterns are apparent, with Country 1 having a generally high pattern with a major increase around 2017, while Country 2 has a generally low pattern with a relatively high one after 2019. With growth rising constantly until around 2021, and fluctuating after that, country 5 also demonstrates a very good performance with respect to green bond development. Issuances of green bonds in countries 2 and 3 are lower, but gradually growing, especially in the final years of the sample. There is little indication of green bond market development in country 4, which has consistently remained low. Overall, the trend indicates that green finance development is not even in the selected countries. Green bonds are issued in the most developed markets and other countries seem to be in the early stages of development in green finance.

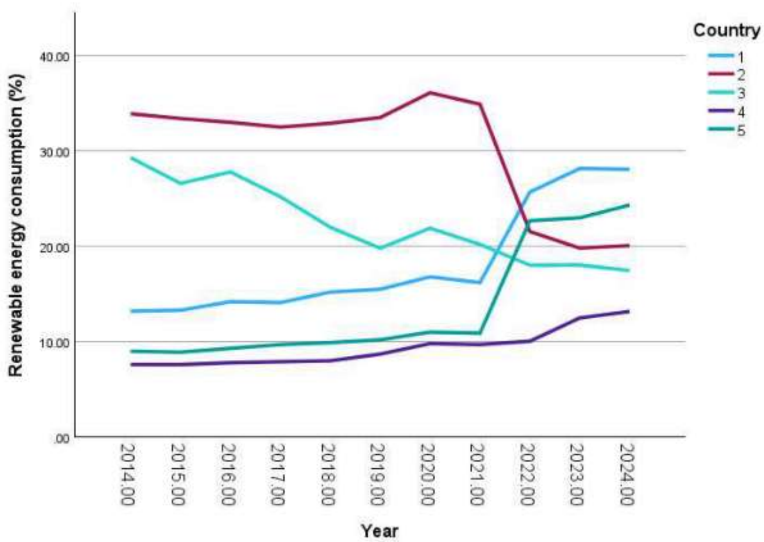

Figure 2: Renewable Energy Consumption Trends by Country

There are also significant differences between countries in terms of renewable energy use. The renewable energy share was high in the early years in country 2, with more than 30% until 2021, after which it dropped of dramatically. The data for Country 1 exhibits a definite upward trend, especially after 2021, where the figure seems to be approaching roughly 28% in 2023-2024. There was no upward or downward trend within Country 5 until the year 2021 when it jumped high from 2022 onwards. By contrast, there is a downward trajectory in Country 3, as well as the lowest share of renewable energy use in Country 4, where renewable energy consumption is beginning to increase slightly with each year. The patterns indicate that the renewable energy transition is not even. Some countries exhibit positive trends and others demonstrate negative trends or a slower rate of renewable energy adoption.

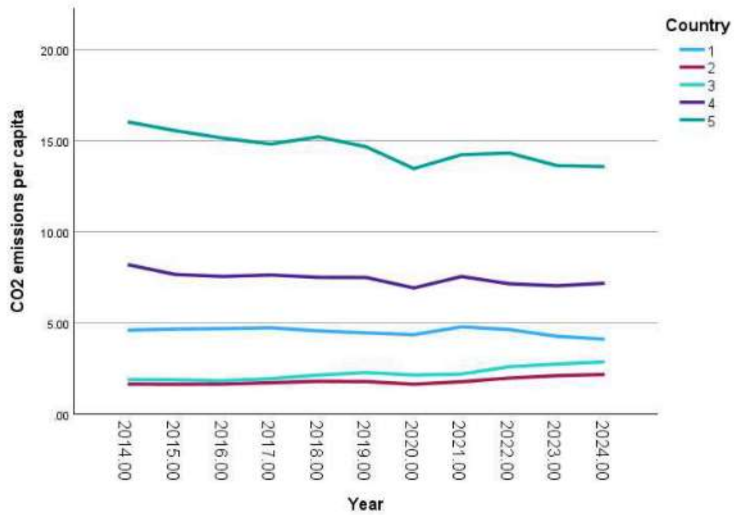

Figure 3: CO_2 Emissions Per Capita Trends by Country

There are large CO_2 per capita emission variations between countries. Throughout the period, Country 5 has the highest emissions but the emissions are also gradually decreasing from approximately 16.0 in 2014 to approximately 13.6 in 2024. As with country 4, the emissions are relatively high, although there is a small downward trend in emissions. Overall, Country 1 is stable, and experienced only a slight decrease post 2021. Countries 2 and 3, on the other hand, are displaying positive trends in emissions as they increase over time, but their levels are still lower than the emissions of Countries 4 and 5. In sum, the emissions patterns indicate that some countries are decreasing or stabilizing carbon intensity, while others are seeing an increase in emissions as a result of economic growth, industrialization or a slower clean-energy transition.

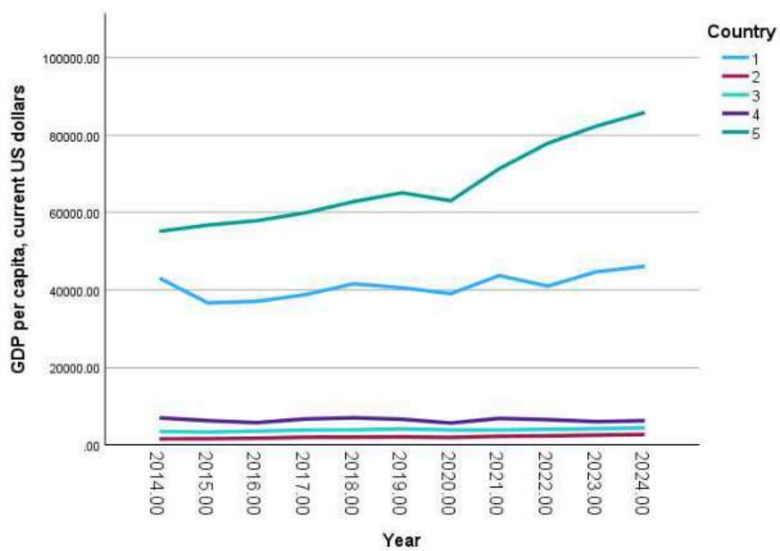

Figure 4: GDP Per Capita Trends by Country

Considerable variations can be observed between developed and emerging economies when it comes to the trends of GDP per capita. The highest GDP per capita value during the study period is observed in country 5 and the growth is very high from the year 2014 to 2024. Income in country 1 is also high with moderate variations and slowly recovers after 2015. Though there are some improvements over time, countries 2, 3 and 4 are still in lower GDP per capita levels. However, the GDP trend indicates that there is great economic diversity in the sample. There are indications that higher income countries are more likely to have strong financial capacity to mobilise green finance, and that lower income or emerging economies are more likely to be constrained in mobilising green finance, which could drive higher green bond issuance in higher income countries.

3.3 Correlation Results

The correlation matrix analyzes the linear relationships among the green bond issuance, renewable energy consumption, CO_2 emission per capita, GDP per capita and physical climate risk. Correlation results may be viewed as an association only—no causal relationship is assumed.

Table 5: Pearson Correlation Matrix

		Green bond issuance	Renewable energy consumption (% of total final energy consumption)	CO2 emissions per capita	GDP per capita, current US dollars	warming_level_c	Physical climate risk exposure: Annual Maximum 5-day Precipitation, median estimate
Green bond issuance	Pearson Correlation	1	-.074	.373	.739	.388	.452
	Sig. (2-tailed)		.590	.005	<.001	.268	.190
	N	55	55	55	55	10	10
Renewable energy consumption (% of total final energy consumption)	Pearson Correlation	-.074	1	-.610	-.283	.059	.454
	Sig. (2-tailed)	.590		<.001	.036	.872	.187
	N	55	55	55	55	10	10
CO2 emissions per capita	Pearson Correlation	.373	-.610	1	.778	-.060	-.041
	Sig. (2-tailed)	.005	<.001		<.001	.869	.910
	N	55	55	55	55	10	10
GDP per capita, current US dollars	Pearson Correlation	.739	-.283	.778	1	.038	.313
	Sig. (2-tailed)	<.001	.036	<.001		.916	.379
	N	55	55	55	55	10	10
warming_level_c	Pearson Correlation	.388	.059	-.060	.038	1	.460
	Sig. (2-tailed)	.268	.872	.869	.916		.181
	N	10	10	10	10	10	10
Physical climate risk exposure: Annual Maximum 5-day Precipitation, median estimate	Pearson Correlation	.452	.454	-.041	.313	.460	1
	Sig. (2-tailed)	.190	.187	.910	.379	.181	
	N	10	10	10	10	10	10

The correlation results provide mixed evidence. There is a positive and significant correlation between green bond issuance and GDP per capita, indicating that an increasing the GDP per capita of the economy is associated with an increase in the number of green bonds issued. It is also surprising that the issuance of green bonds shows a positive correlation with CO_2 emissions per capita, as one would expect a negative correlation. This could be because the more polluting economies have a larger demand for transition financing and therefore have a higher number of green bonds issued. There is a negative and significant correlation between renewables consumption and CO_2 emissions per capita. This is consistent with the expected correlation that the more renewable energy that is used, the less carbon emissions. But the green bond issuance is negatively and very weakly correlated with the renewable energy consumption and is not statistically significant. Based on the correlation results, this means that the positive relationship between green bonds and renewable energy is not obtained as expected. The Pearson correlation results show that there is a positive relationship between the warming level and the climate risk, which is not statistically significant. This direction is as expected, with the challenge of low numbers of climate-risk observations making for limited statistical power. In general, the findings of the correlation analysis indicate that the renewable energy consumption is correlated with emissions reduction, and green bond issuance seems to be more correlated with emissions intensity and economic development than with emissions reduction directly. Don't assume a causal relationship for these results.

5.4 Regression Results

The regression models employed to analyse the relationships between green bond issuance, renewable energy consumption, CO_2 emissions and climate-risk exposure are described in this section.This section explains the regression models that have been used to explore the relationships between the variables of green bond issuance, renewable energy consumption, CO_2 emissions and climate-risk exposure. There are also country and time fixed effects included in the models to allow for the control of unobserved country and time effects. These specifications offer empirical grounds for the analysis of the relationship between green finance and macroeconomic factors and outcomes of environmental and climate-risk.

Model Equations

Model 1: Renewable Energy Model

$$RE_{it} = \alpha + \beta_1 GB_{it} + \beta_2 GDPpc_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where $RE_{it}$is renewable energy consumption, $GB_{it}$is green bond issuance, $GDPpc_{it}$is GDP per capita, $\mu_i$represents country fixed effects, $\lambda_t$represents year fixed effects, and $\varepsilon_{it}$is the error term.

Model 2: CO_2 Emissions Model

$$CO2_{it} = \alpha + \beta_1 GB_{it} + \beta_2 RE_{it} + \beta_3 GDPpc_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where $CO2_{it}$is CO_2 emissions per capita, $GB_{it}$is green bond issuance, $RE_{it}$is renewable energy consumption, $GDPpc_{it}$is GDP per capita, $\mu_i$represents country fixed effects, and $\lambda_t$represents year fixed effects.

Model 3: Climate-Risk Model

$$CRISK_{it} = \alpha + \beta_1 WARM_{it} + \mu_i + \theta_s + \varepsilon_{it}$$

Where $CRISK_{it}$is physical climate risk exposure, $WARM_{it}$is warming level, $\mu_i$represents country fixed effects, and $\theta_s$represents scenario fixed effects. In the available output, scenario effects cannot be estimated because only the **cat_curr** scenario is available.

Table 6: Regression Results

Variable	Model 1: Renewable energy	Model 2: CO_2 emissions	Model 3: Climate risk
Green bond issuance	-0.015	-0.002	—
Renewable energy	—	-0.031***	—
GDP per capita	0.001***	-4.625E-5***	—
Warming level	—	—	6.870***
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	No / Not estimable
Scenario FE	No	No	Yes, but not estimable
Observations	55	55	10
Model explanatory power	Partial η^2 = 0.790	Partial η^2 = 0.997	Partial η^2 = 0.962

Notes: **** $p < 0.01$. The SPSS output reports partial eta squared rather than conventional OLS R^2; therefore, model explanatory power is reported using partial η^2.*

Model 1: Renewable Energy Consumption

The results in model 1 show that, despite the inclusion of GDP per capita, country fixed effects and year fixed effects, the issuance of green bonds is yet related to the use of renewable energy. Overall model is statistically significant. But green bond issuance coefficient B=-0.015 is not significant at the 5% level and has a negative sign. This means that there is not a consistent direct link between issuance of green bonds and the use of renewable energy in this sample. GDP per capita is positive and statistically significant (B=0.001, $p<0.001$) indicating that economies with higher levels of income are more likely to consume renewable energies after controlling for the country and year effects.

Model 2: CO_2 Emissions Per Capita

The relations between the green bond issuance, renewable energy consumption, GDP per capita and CO_2 emissions per capita are explored in model 2. The coefficient B is -0.002 and the p value 0.791 which indicates that green bond issuance has a negative but statistically insignificant coefficient. Hence, the model is not an indicator of a direct impact of green bond issuance on CO_2 emissions. Renewable energy consumption has negative and statistically significant coefficient B=-0.031,p=0.007. This implies that the more renewables are used, the lower CO_2 per capita emissions, all other factors being equal. This finding is in line with the anticipated mitigation function of renewable energy. Also GDP per capita is statistically significant in the fixed-effects model B=-4.625E-5,p=0.002.

The negative sign indicates that, within countries, increases in GDP per capita could be related to decreases in emissions, net of renewable energy, green bond issuance and fixed effects. The country effects are highly significant, supporting the fact that significant differences in emissions exist between countries. The overall strength of evidence for climate mitigation by renewables is strongest for Model 2. It is still not proof of impact on direct emissions reduction on the issuance of green bonds, however.

Model 3: Climate Risk

Model 3 investigates if warming level is linked with exposure to physical climate risk (AM5dP). The coefficient B for warming level is 6,870 with p=0,009 which is positive and statistically significant. This means that the more the climate is warming, the more the physical climate-risk exposure is increasing. Country effects are also relevant, with the implication that there is a wide variation between countries in climate risk as a result of their geographical location, precipitation characteristics, exposure and vulnerability. The model is only valid for the 10 observations however and for one type of scenario category (cat_curr). As a result, it is not possible to provide meaningful estimates for the scenario effects.

The overall results of Model 3 confirm the hypothesized positive association between warming level and physical climate-risk, but the results are exploratory in nature given the limited sample of climate-risk. This subsection aims to provide a comparison of the projected climate risk between scenarios. Those that are available now, however, are limited to the cat_curr scenario and climate-risk observations for 2015 and 2020. Thus, a comprehensive comparison between the outputs for a Net Zero 2050, Below 2°C, Current Policies, Low Demand or 2050/2100 projection can not be performed.

5.5 Climate-Risk Scenario Comparison

This subsection is intended to compare projected climate risk across scenarios. However, the available output contains only the cat_curr scenario and climate-risk observations for 2015 and 2020. Therefore, a full comparison across Net Zero 2050, Below 2°C, Current Policies, Low Demand, or 2050/2100 projections cannot be completed from the uploaded outputs.

Table 7: Climate-Risk Scenario Comparison — Available Output

Country	Scenario	Years available	Median / mean climate risk	Risk reduction %
Country 1	cat_curr	2015, 2020	2.1973	Not estimable
Country 2	cat_curr	2015, 2020	2.8977	Not estimable
Country 3	cat_curr	2015, 2020	1.0915	Not estimable
Country 4	cat_curr	2015, 2020	0.6088	Not estimable
Country 5	cat_curr	2015, 2020	2.2411	Not estimable

Table 3.4 illustrate the climate-risk exposure during 2015–2020 for the current scenario (cat_curr), which shows an increase in the exposure. India has the highest level of climate-risk exposure followed by the United States and France, with exposure in South Africa being the lowest. This means that climate risk from extreme precipitation is not equally distributed among countries and some countries are more physically vulnerable than others to such climate risk.

For the overall picture, there is some evidence of increasing and spatially variable risk of extreme precipitation for this scenario. However, with only one scenario available, it is not possible to conclude how whether transition scenarios like Net Zero 2050 or Below 2°C would lower climate risk in comparison to current-policy scenarios. A deeper scenario-comparison analysis would have been achieved with a number of scenario pathways and projections with longer time horizons, in particular 2050 and 2100.

5.6 Climate-Risk Uncertainty Results

Climate-risk uncertainty is calculated as the difference between the 95th percentile and 5th percentile projections:

$$Uncertainty = p95 - p5$$

A larger uncertainty range means that the range of climate-risk outcomes is larger. This implies a higher uncertainty in the exposure to climate risks in the future and more prudent adaptation and investment planning.

Table 8: Climate-Risk Uncertainty Results

Country	Scenario	Mean Uncertainty Range	Std. Dev.	Minimum	Maximum
Country 1	cat_curr	6.9012	0.59867	6.48	7.32
Country 2	cat_curr	15.3925	3.11696	13.19	17.60
Country 3	cat_curr	4.6652	1.05150	3.92	5.41
Country 4	cat_curr	10.1265	1.30638	9.20	11.05
Country 5	cat_curr	5.3724	1.67039	4.19	6.55
Total	cat_curr	8.4916	4.34699	3.92	17.60

When comparing the mean uncertainty ranges, cat_curr shows a difference between countries, with India having the highest mean uncertainty range (15.3925) followed by South Africa (10.1265) and at the bottom Indonesia (4.6652). In total there are 10 valid observations and 45 missing observations, which is an average "plus or minus" range of uncertainty of 8.4916. According to the results, the uncertainty ranges over extreme precipitation in the future are larger for India and South Africa, and smaller for Indonesia and the United States. Results of correlation tests indicate that there is a positive, but not statistically significant, relationship between the warming level and the climate-risk uncertainty. Thus, these results have to be taken with a grain of salt as the amount of observations is not very large and the only scenario available is cat_curr.

5.7 Summary of Hypothesis Testing

This subsection summarises whether the empirical results support the study hypotheses. The decisions are based on the signs and statistical significance of the correlation and regression results.

Table 8: Summary of Hypothesis Testing

Hypothesis	Expected relationship	Result	Decision
H1	Green bonds → renewable energy	Green bond issuance is negative and statistically insignificant in Model 1.	Not supported
H2	Renewable energy → CO_2 emissions	Renewable energy has a negative and statistically significant effect on CO_2 emissions.	Supported
H3	Green bonds → CO_2 emissions	Green bond issuance is negative but statistically insignificant in Model 2; correlation with CO_2 is positive.	Not supported
H4	Warming level → climate risk	Warming level is positive and statistically significant in Model 3.	Supported
H5	Transition scenarios → lower climate risk	Scenario comparison cannot be tested because only cat_curr is available.	Not supported / inconclusive

According to the hypothesis-testing results, the renewable energy consumption is the most significant variable in the analysis which is significantly related to the reduction of CO_2 emissions and hence is the most important variable in the analysis in mitigation purpose. There is no statistically significant direct impact of green bond issuance on renewable energy use or CO_2 emissions. Warming level has significant positive correlation with the climate risk, as would be expected in theory, that more warming means more physical climate-risk exposure.

In total, the results indicate that there is a stronger relationship between renewable energy adoption and reducing emissions in this data set than taking out green bonds. The direct financing of green bonds could play a role, but is not statistically proven by the current models, and rather green bonds could fund climate transition. The findings on climate-risk are consistent with the critical role of warming level, with limited conclusions from the scenario-based analyses as a result of the lack of scenario variation and the limited number of climate-risk observations.

6. Discussion

6.1 Findings

This study focused on the linkages between green bond issuance and the exposure to physical climate risks, as well as the use of renewable energy and CO_2 emissions, in France, India, Indonesia, South Africa, and the United States. The results indicate a large heterogeneity between countries with regard to green finance, energy transition and exposure to climate risk. Overall, the findings indicate that renewables use is more closely linked to the emissions reduction than the issuance of green bonds. This contributes to the overarching claim that renewable energy is crucial for climate mitigation as it helps to bring down reliance on fossil-fuel energy systems. (Attanayake et al., 2024) The results of the regression do not show a statistical significance and the relationship between the issuance of green bonds and the renewable energy consumed is not significant.

The results indicate that, while green bonds are likely to be a catalyst to renewable energy investment, a greater number of green bonds does not always translate to renewable energy growth. This could be due to the fact that green bond proceeds could be utilized for tasks other than renewable energy. It can also be due to a lag between financing and the results in energy sectors. Other studies suggest that green finance can facilitate low-carbon transition, while its impact hinges on the design of the policies and the degree of maturity of the market and the use of the funds. (Dikau & Volz, 2021; Lichtenberger et al., 2022) The findings offer more evidence of the linkages between renewables and CO_2 emissions. There is a negative relationship between the percentage of renewable energy use and CO_2 emissions per capita, meaning that countries with a higher percentage of renewable energy use have lower carbon emissions. This result aligns with the mitigation impact of renewable energy development, and is also consistent with the findings of previous research, which indicates that renewable energy development is a key component in carbon intensity reduction (Sun et al., 2023; Zhu et al., 2024)

Nevertheless, the association must still be viewed as such and not necessarily a cause-and-effect relationship. The correlation between green finance and CO_2 emission is not so obvious. The regression model does not reveal a statistically significant emissions-reduction effect of green bonds. The correlation results may seem paradoxical as green bond issuance is positively related to CO_2 emissions per capita. But this figure could be due to bigger financial markets and increased capacity of large and high emitting economies to issue green bonds. In fact, the more green bonds that are issued, the more the transition-financing needs may be, and the less the emissions reduction may be. This aligns with earlier research that indicated green bonds can play a role in carbon reduction, but this requires adequate distribution of the funds, and they must lead to tangible environmental impacts (Kartal et al., 2025; Pang et al., 2024)(MT Kartal et al., 2025; Pang et al., 2024).

6.2 Climate-Risk Scenario Implications

The climate-risk results indicate that there is a positive relationship between warming level and the physical climate risk projected. This implies an increase in exposure to extremes in precipitation risk with increased warming. This finding aligns with evidence in climate science that global warming, and specifically increased global warming, leads to an increase in physical climate hazards such as heavy precipitation, flooding, heat stress and other extreme events. (Intergovernmental Panel on Climate Change, 2023; Lee et al., 2023) There is little evidence available on the scenarios as only those for the cat_curr scenario and observations for 2015 and 2020 are available. Hence, there is no full comparison possible between the different pathways: Net Zero 2050, Below 2°C, Current Policies and Low Demand. However, the results available indicate that there was an increase in the exposure to climate risk in the period of 2015-2020 in the current scenario. India is exposed to the highest climate risk followed by the United States and France and South Africa to the lowest climate risk. This variability indicates that there is a differential exposure to physical climate risks at the country level.

Climate risk assessment based on scenarios is still relevant as the current-policy scenarios are likely to generate higher long-term climate risk while the scenarios of orderly climate transition may lower climate risk through limiting warming. The NGFS climate scenarios are helpful for this kind of analysis as they enable researchers and financial institutions to explore the implications of various transition pathways across different time horizons in terms of physical and transition risks. (Network for Greening the Financial System, 2024b) In this study however, the conclusions made by the scenarios lack some of the multiple pathways and long-term projections, in particular those for 2050 and 2100, which are not included in the final output.

6.3 Developed and Emerging Economy Comparison

The comparison of the results with the comparison between developed and emerging economies gives more insight into the result. France and the USA are developed economies and India, Indonesia and South Africa are emerging economies. The findings indicate that in general, the more developed the economy, the more activity in green bonds, in particular the United States and France. This could be attributed to more mature and developed financial markets, better institutional capacity and demand for sustainable finance products from investors.

Strong renewable energy and climate-finance needs emerge in the economies of the East, however. India, Indonesia and South Africa have energy transition challenges as they need to address four key elements: economic growth, energy security, emissions reduction and climate adaptation. Perhaps the reason is that green bond issuance is more scarce in some emerging economies, but this does not mean that they do not have climate needs. This validates the fact that building the green finance development is crucial for environmental sustainability, especially in economies with financing gaps that limit investment in clean energy. (Khan et al., 2022; Wang & Ma, 2022) There could also be a difference in climate-risk vulnerability between high- and low-income economies. The exposure to climate risk among emerging economies appears to be higher as India ranks top in the climate-risk results available. Discrepancies among countries may be due to geographical factors, level of exposure of the population, quality of infrastructure, capacity to adapt and economic structure. Climate finance, therefore, needs to not just finance mitigation, in terms of renewables and lowering emissions, but also needs to finance adaptation to the physical effects of climate change.

6.4 Policy and Investor Implications

The results have a number of policy implications. Governments should increase the transparency, reporting and framework of green bonds. While the volume of issuance is a good indicator of the growth of the green bond markets, the impact, in terms of renewable energy, emissions-reduction and adaptation outcomes, of the proceeds of such bonds should also be measured. Second, green finance needs to be more connected with national energy transition plans, in order to finance real decarbonisation. Third, there is a need to enhance the availability of green capital at affordable prices for emerging economies because green finance could constrain their mitigation and adaptation capacities. The results indicate that, to the investors, green bond indicators should be integrated to environmental performance indicators. Investors should consider asking green bond issuers if they are able to deliver measurable impact (e.g., renewable energy growth or emissions reduction). Physical risks can also impact asset values, infrastructure, sovereign risk and sector exposure and make climate-risk projection important for long-term portfolio planning. A scenario analysis can be useful to the investor to understand the potential impacts of various future warming scenarios on the financial risk.

7. Conclusion

In this study, green finance is analysed in the context of climate-risk mitigation, through open data that was gathered globally. It integrated metrics on green bond issuance, renewable energy use, per capita CO_2 emissions, GDP per capita and physical climate-risk projections to consider the links between financial mobilisation and the energy transition, and climate-mitigation outcomes. For the study, five countries were selected: France, India, Indonesia, South Africa and the United States; this enabled a comparison to be made between developed and emerging economies. Descriptive statistics, country-wise trend analysis, correlative analysis, regression models and country-wise comparison in the climate-risk scenarios was used for analysis. There was a significant variation between countries in the green bond issuance, income, emissions and climate-risk exposure in descriptive statistics. The results of the correlation and regression were exploited to evaluate if there is a link between green finance, renewable energy and lower emissions, while the climate-risk analysis was conducted to analyse the difference in the projected physical risk. The results have indicated that green finance is important in climate mitigation, and that the direct impact does not necessarily show immediate results or be statistically identifiable. The current sample does not indicate that there is a direct relationship between the amount of green bonds issued and the amount of renewables used and CO_2 emissions. This means it's not necessarily an immediate benefit for the environment in the form of green finance. But, there is more consistent and stronger relationship between renewable energy consumption and reduction of CO_2 emissions. This indicates that the effectiveness of green finance in enabling the transition towards clean energy and low carbon development is crucial for achieving climate-mitigation outcomes, as well as the amount of funds available. Because of limited data, scenario comparison is also hindered, but the climate-risk results indicated a relationship between increased physical climate-risk exposure and higher warming levels. This study is novel by combining the Green finance indicators with the data on climate-risk scenarios under one single empirical framework. The study brings together various dimensions of green finance, renewable energy transition, emissions mitigation, income, and physical climate-risk exposure in a single framework to gain a more comprehensive view of the relationship between these factors. To lower long-term climate vulnerability, it is crucial to enhance green finance, attract green investment into RE and incorporate climate-risk scenarios in economic planning. There should be a connection between green finance and the environmental results achieved, with the aim of reducing emissions and adapting to climate change. Especially emerging economies need to invest in green capital at low costs to enable sustainable development and climate resilience.

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