Financing energy transition: the impact of financial markets on non-hydro renewable energy production and its change after the Paris Agreement

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Abstract

The present article analyzes the link between countries' non-hydroelectric renewable energy production and the characteristics of their financial markets. It also analyzes how this relation has changed since the Paris Agreement of 2015. The study is developed with an unbalanced panel of 169 countries between 2000 and 2022, with data from the World Bank, the International Monetary Fund, and the International Renewable Energy Agency. The article uses a panel model with first difference estimator, fix effects estimator, fix effects and time effects estimators, and Anderson-Hsiao estimator. The results indicate that development of capital markets is associated with higher levels of per capita production of non-hydro renewable energy. The study also indicates that since the approval of the Paris Agreement, the impact of the development of private credit by banks on non-hydro renewable energy as share of total energy produced has improved.

1 Introduction

During the last decades, a consensus has been established in the scientific community regarding the impact of greenhouse gas emissions on global warming. According to the Intergovernmental Panel on Climate Change: "Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020" (Intergovernmental Panel on Climate Change, 2023). According to the report, in 2019 around 79% of the greenhouse emissions came from the energy, industry, transport, and construction sectors. The strong link between the unsustainable use of fossil fuels as energy sources and climate change motivated the COP 28 agreement in which countries around the world agreed to "transition away" from fossil fuels (United Nations Conference of the Parties to the Paris Agreement, 2023.

At the same time, renewable energy costs have dropped sharply in the last decade, and its adoption has accelerated: "From 2010 to 2019 there have been sustained decreases in the unit costs of solar energy (85%), wind energy (55%), and lithium-ion batteries (85%), and large increases in their deployment, e.g., ¿10× for solar and ¿100× for electric vehicles" (Intergovernmental Panel on Climate Change, 2023). However, despite the progress made, the report highlights that finance flows to fossil fuels are still greater than those to renewable energy investments. Additionally, The current trajectory of greenhouse emissions implies that the world will probably fail to achieve the targets required to limit the temperature increase to 1.5°C (Intergovernmental Panel on Climate Change, 2023).

Financial markets play a fundamental role in financing energy transition, especially as renewable energy tends to be more capital intensive, and therefore it requires greater upfront investments than energy produced from fossil fuels. Capital intensity is measured by “the capital cost to produce the same amount of electricity as 1 kW of capacity operating on a continual basis” (Best, 2017). Therefore, renewable energy projects require initially bigger amounts of financing and can be strongly impacted by financing costs as upfront costs of capital can represent up to “85% of the total levelized cost of energy” (International Renewable Energy Agency, 2020).

Given the importance of financial markets in achieving energy transition, the present study evaluates if certain characteristics of financial markets have an impact on countries’ non-hydroelectric renewable energy production. The study also evaluates if there has been a change in this relation after 2016 when the Paris Agreement was signed.

The study excludes hydroelectric energy production for two reasons: First, hydro is the only source of renewable energy that has experienced an increase in its average cost of production. According to the International Renewable Energy Agency (IRENA, 2023a), the levelised cost of electricity produced from hydro sources around the world increased 47% between 2010 and 2022. Second, and consistently with this cost increase, the share of electricity produced from hydro has decreased in the 169 countries of analysis.

In contrast with previous studies, this research is done considering two levels of analysis. In the first one, I analyzed the impact of financial markets on the renewable energy produced per capita. In the second one, the study analyzes the impact of financial markets on renewable energy as a share of the total energy produced. This implies that I analyze not only how financial markets affect the absolute quantities of renewable energy production, but also how they affect renewable energy production relative to non-renewable energy production. The study also aims to understand if this relation has changed after the approval of the Paris Agreement in 2015.

The study uses unbalanced panel data of 169 countries between 1990 and 2022 from the World Bank Development Indicators Database (World Bank, 2024) the International Monetary Fund Financial Development Index Data Base (International Monetary Fund 2024), and the International Renewable Energy Agency data base (International Renewable Energy Agency, 2023b). The analysis uses a panel data model with first difference estimator, fix effects estimator, fix effects and time effects estimator, and Anderson-Hsiao estimator,

2 Literature Review

In the last fifteen years, several studies have been conducted to understand the link between financial markets characteristics and renewable energy. Sadorsky (2010) used Generalized Method of Moments estimation with a panel of 22 emerging countries between 1990 and 2006 to analyze the relation between countries and their total energy consumption. The study is not centered on renewable energy, nevertheless, it provides valuable insights for renewable energy analysis. The author used stock market capitalization as a share of GDP, stock market value traded to GDP, and stock market turnover as measures of financial markets development, he also includes the ratio of deposit money bank assets to GDP and the foreign direct investment as independent variables. The author found that all three variables related to capital markets development have a positive and significant effect on the level of energy consumption.

Brunnschweiler (Brunnschweiler, 2010) applied on the same year a panel data analysis with 119 non-OECD countries between 1980 and 2006 in which he studied the relation between financial sector development and renewable energy consumption. The study uses per capita renewable electricity generation as dependent variable. To measure the level of financial development it uses commercial banks' assets as share of the central bank's assets, and credit provided by financial institutions to the private sector as a share of GDP. It also includes the price of crude oil, coal, and natural gas as control variables.

Brunnschweiler used for the estimation Generalised Least Squares method (GLS) and dynamic Arellano-Bond Generalised Method-of-Moments (GMM). It is important to highlight that the study uses one-year lags for all relevant independent variables, as their impact on renewable energy is not instantaneous. The study found that financial sector development has a robust and significant positive effect on renewable energy production. This effect is particularly for renewable energy excluding nuclear and hydro. The study also concludes that the commercial bank assets as a share of the central bank's assets has a particularly robust effect on renewable energy.

Pfeiffer and Mulder (2013) analyzed the relation between non-hydro renewable energy with the implementation of economic and regulatory instruments, GDP per capita, and a set of development indicators: schooling levels, and stability of democratic regimes. They used a panel of 108 developing countries between 1980 and 2010. The estimations were done with a two-part model (2PM) and Heckman's two-step selection model. The study concludes that implementation of economic and regulatory instruments, higher per capita income and schooling levels and stable, democratic regimes increase the amount of non-hydro renewable energy produced.

Paramati, Ummalla, and Apergis (2016) studied the impact of foreign direct investment inflows and stock market developments on clean energy consumption for 20 emerging market economies between 1991 and 2012. The study uses cointegration analysis to study the long-term relation between the variables. The authors concluded that "FDI inflows and stock market developments have all a significant positive impact on clean energy consumption" (Paramati, Ummalla, and Apergis, 2016).

In its paper Best (2017) uses a panel of 137 countries between 1998 and 2013 to analyze the relationship between financial capital and the production of different energy from different sources. As dependent variables, the author uses the share of energy produced from each energy source: biofuels and waste; hydro; coal; oil; natural gas; nuclear; wind; solar; and geothermal. To measure the financial development of countries, the paper creates a composite variable: private debt and credit as a share of GDP, which is the sum of private sector credit from deposit money banks, outstanding domestic private debt securities, and outstanding international private debt securities divided by GDP. It also creates an aggregate public debt variable which is the sum of outstanding domestic public debt securities and outstanding international public debt securities divided by GDP.

Best (2017) controls for a series of country natural resources and includes time dummies to account for technical progress and global energy prices. Best uses ordinary least squares estimates with standard errors that are robust to heteroscedasticity. Additionally to the analysis with the full sample of 137 countries, the study considers two subsamples: one for developed countries and one for developing countries. The study concludes that higher levels of financial capital support the transition to more capital-intensive energy types as wind and solar energy have positive and significant coefficients associated with private credit. In the case of higher-income countries, this is especially true for wind energy. While in the case of lower income countries higher levels of capital help to transition from biomass to fossil fuels. In general, the study found that for oil energy there is a significant and negative relation with private credit, which "suggests that greater supplies of financial capital could encourage reductions in the use of energy types with lower capital intensity, such as some fossil fuels" (Best, 2017).

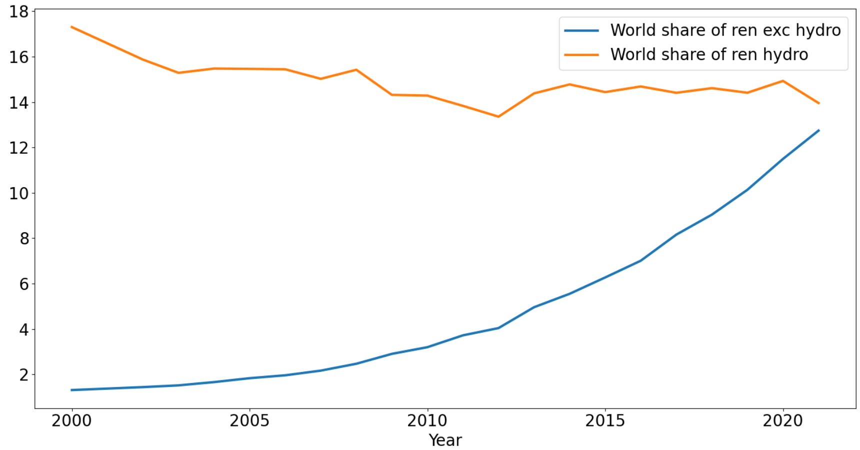
Kutan, Paramati, Ummalla, and Zakari (2018) analyze the relation between renewable energy consumption and financial markets development in Brazil, China, India, and South Africa. The authors used the Fisher-Johansen panel cointegration test on a panel with the four countries with data between 1990 and 2012. They also analyzed the long-term relation between CO2 emissions and the share of renewable energy consumed. The study concludes that there is a negative long-term relation between CO2 emissions and the share of renewable energy consumed. It also concludes that foreign direct investment and stock markets have an important effect on the amounts of renewable energy.

Anton and Afloarei Nucu (2020) analyze the impact of financial development on renewable energy consumption in the European Union. For this, they used a panel of 28 European countries between 1990 and 2015 using panel fixed effects model. The level of financial development is measured with three indicators: domestic credit provided by the financial sector, outstanding international private debt securities to GDP, and stock market turnover ratio. Authors also include as independent variables foreign direct investment inflows as a share of GDP, consumer price index, and GDP. The study concludes that the three financial development variables have a positive and significant impact on the share of renewable energy consumed. The authors also found a negative and significant relation in the European Union between renewable energy consumption and two variables: income level and foreign direct investment.

Finally, Pata, Yilanci, Zhang, and Shah (2021) study the particular case of the United States. Using the Fourier quantile causality test with wavelet transformations, they analyze the link between financial development with renewable energy consumption in the United States between 1980 and 2019. Authors conclude "that financial development encourages renewable energy consumption at high quantiles in the medium and long run" (Pata, Yilanci, Zhang, and Shah 2021). They also found that depth (measured by the ratio of pension funds, insurance premiums, mutual funds, and bank loans to the private sector to GDP) and access to financial markets (measured by the number of bank branches and ATMs per 100,000 adults) have the stronger relation with the consumption of renewable energies among the analyzed variables.

3 Data

Graph 1. Share of total electricity produced in the 169 countries of analysis that is produced from renewable hydro sources and other renewable sources between 2000 and 2022



Source: Own elaboration with data from the International Renewable Energy Agency (2023b)

For the analysis, I estimate two different specifications. The first one does not include the interaction with the Paris Agreement term, while the second one does. Each specification is estimated for two different dependent variables: the share of total electricity produced from non-hydro renewables and the total amount of non-hydro electricity produced per capita measured in Megawatt-hour per capita.
In the first specification I use as independent variables the credit to private sector provided by banks as share of GDP, the Financial Markets Index that measures the development of capital markets, the foreign direct investment as share of GDP and I control by two variables: the natural logarithm of GDP per capita and the regulatory quality index. The second specification includes the same independent and control variables, but it includes an interaction term with the Paris Agreement. The Paris Agreement dummy is constructed such that it equals 1 for all the years after the Agreement entered into force (2016), and 0 for all the previous years.
To obtain the values of non-hydro electricity produced per capita I add the different energy production values from the IRENA data set (International Renewable Energy Agency, 2023b) and divide them by the population values from the World Bank Development Indicators (The World Bank, 2023). The original values are expressed in Gigawatt per hour, I transform them to Megawatt per hour.

Table 1 presents the main descriptive statistics of the data, while Graph 2 presents the average for the 169 countries of each variable during every year. Graph 1 and Graph 2 show that during the last decade, there has been a clear growth in the share of electricity produced from renewable sources.

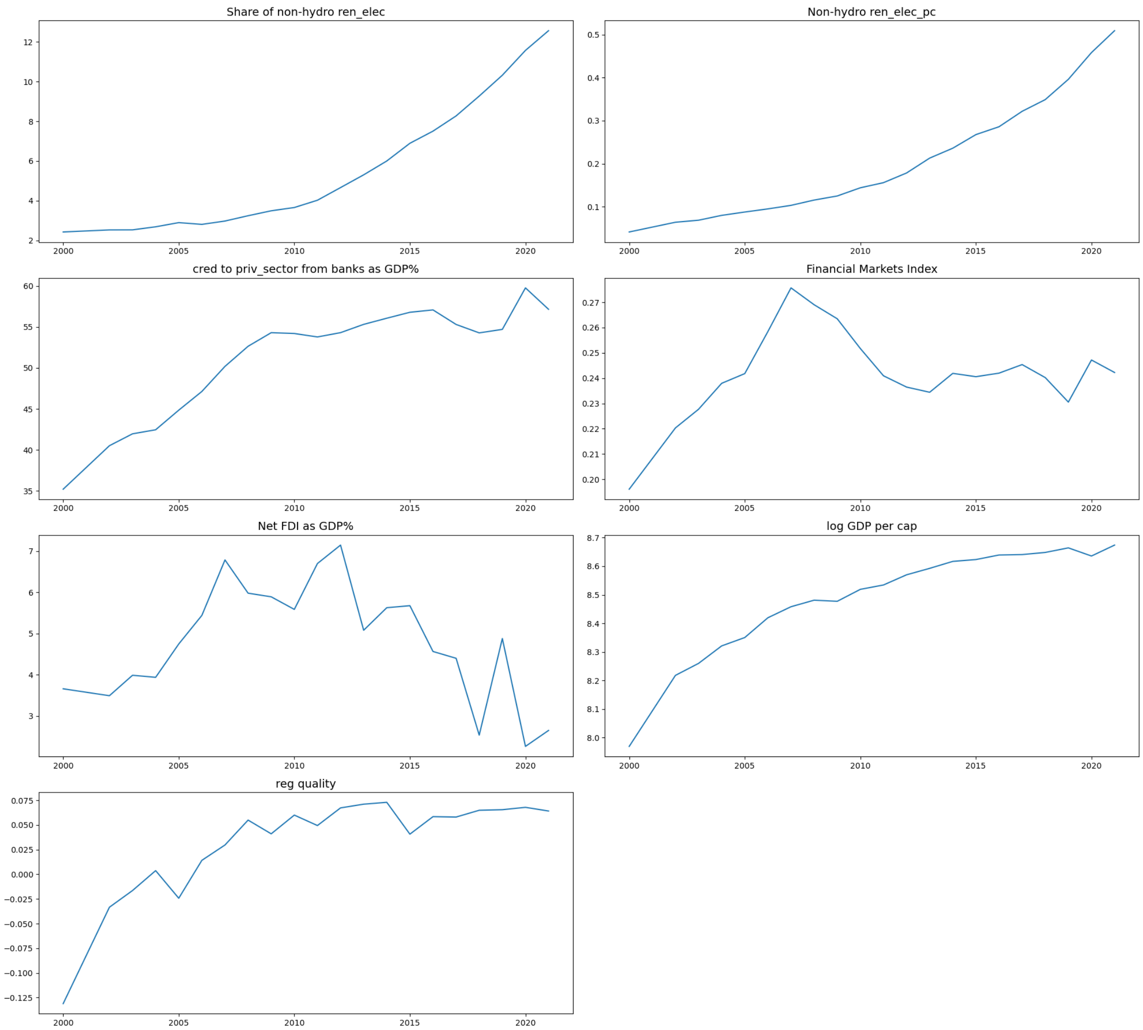
Table 1. Descriptive statistics between 2000 and 2022, 2801 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
count	2801	2801	2801	2801	2801	2801	2801
mean	5.483	0.204	51.463	0.243	4.849	8.495	0.034
std	9.938	0.483	54.364	0.273	13.169	1.457	0.940
min	0.000	0.000	0.002	0.000	-113.139	5.542	-2.349
25%	0.068	0.000	15.741	0.010	1.173	7.296	-0.661
50%	1.228	0.009	35.175	0.110	2.693	8.418	-0.133
75%	6.163	0.152	68.528	0.430	5.048	9.661	0.705
max	75.925	4.183	524.515	0.990	280.146	11.414	2.252
kurtosis	11.046	17.055	20.583	-0.453	176.336	-1.001	-0.678
skewness	3.023	3.795	3.457	0.912	10.302	0.077	0.295

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph 2. Variables average for the 169 countries between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)
Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Table 2 presents the results of Jarque-Bera test for normality. The null hypothesis of normality is rejected for all the variables. The respective histogram of each variable is presented in Graph 2.

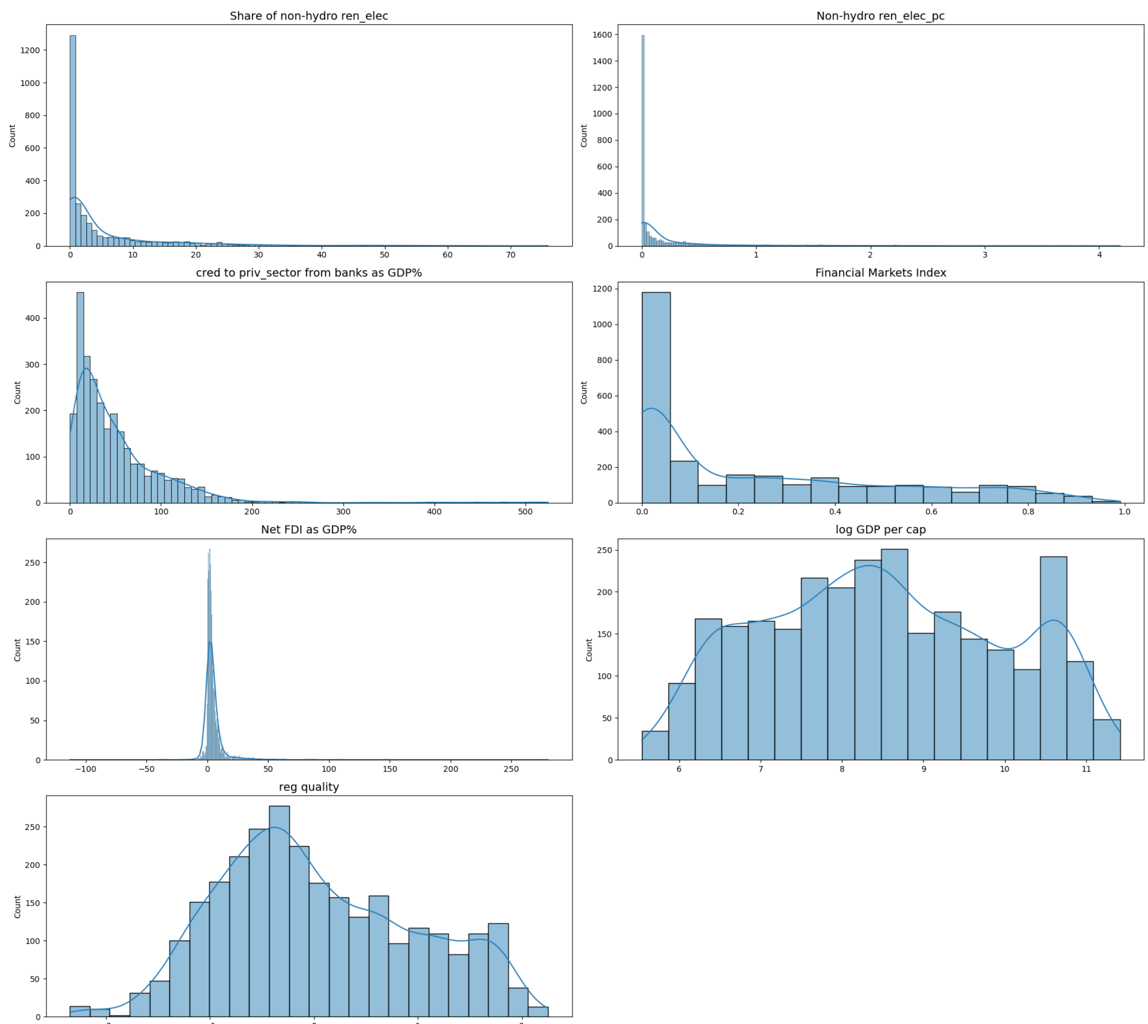
Table 2. Results of the Jarque-Bera test for normality between 2000 and 2022, 2801 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
Statistic	18443	40535	54832	412	3665425	120	94
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph 3. Histograms for all the variables between 2000 and 2022, 2801 observations

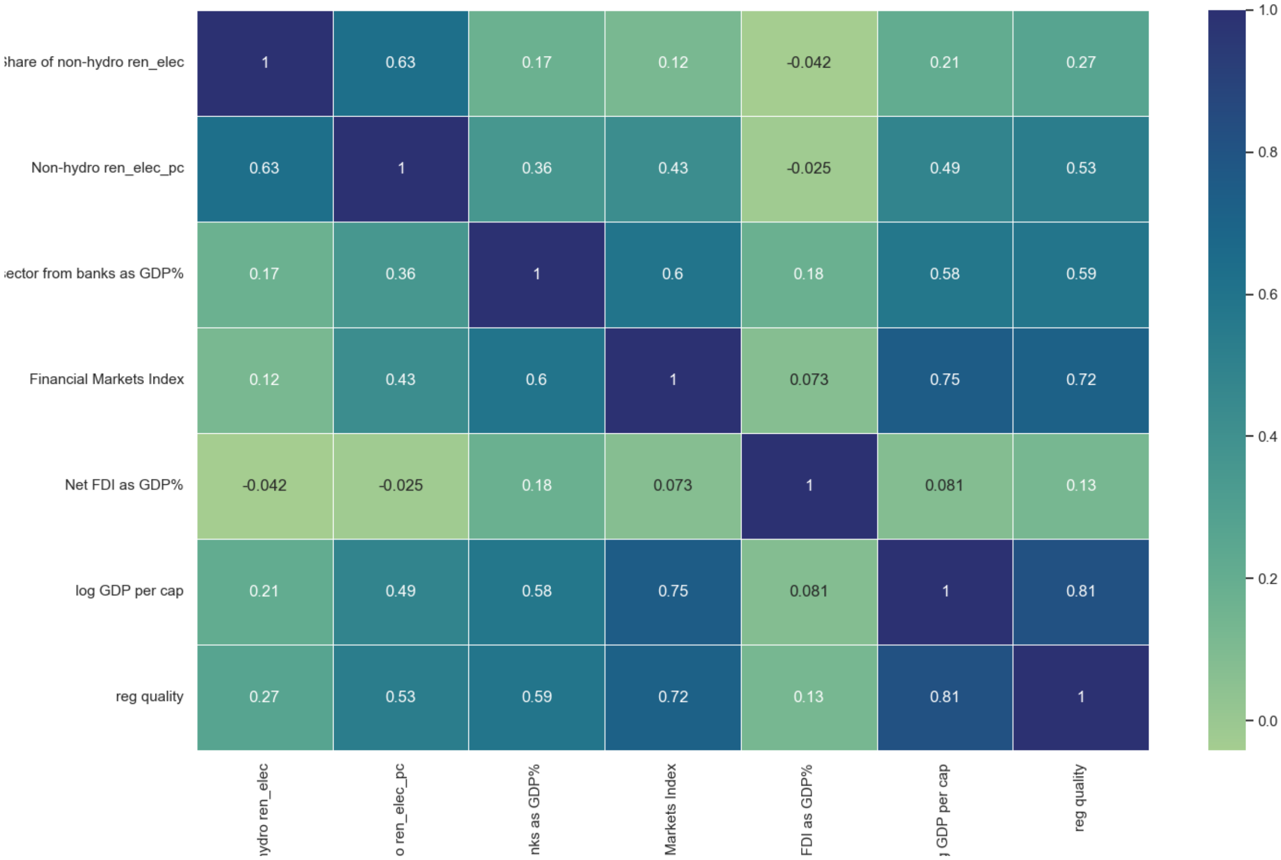


Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

The correlation heat map between all the variables is presented in Graph 4.

Graph 4. Correlation matrix and heat between 2000 and 2022, 2801 observations

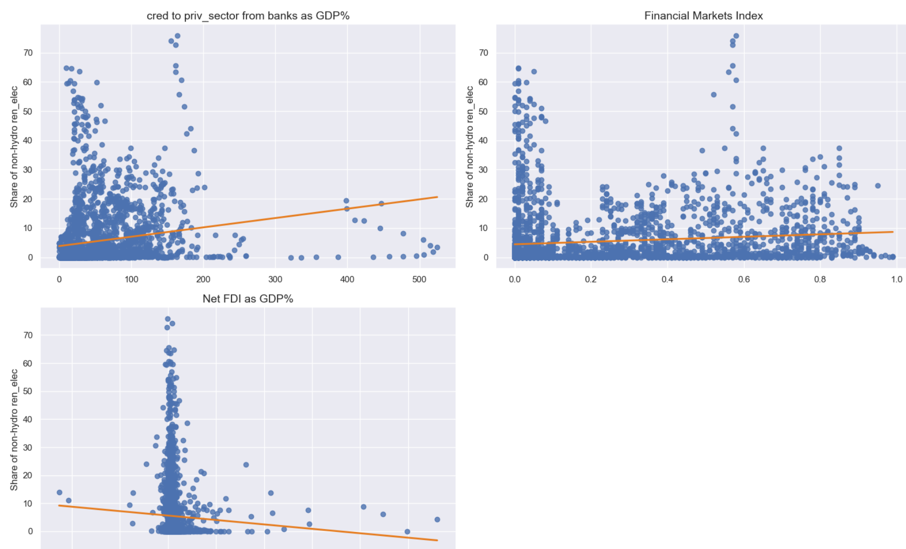


Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

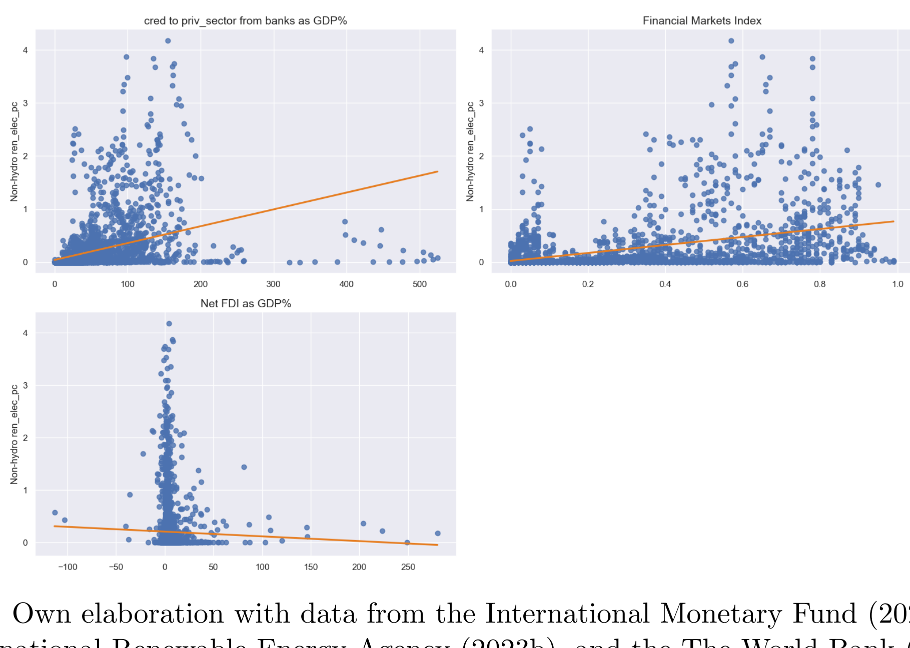
On Graph 5 I present the scatter plot of the three main independent variables with the amount of non-hydro electricity produced expressed in Megawatt-hour per capita. While in Graph 6 I present the scatter plot of independent variables with the share of electricity produced from non-hydro renewable sources.

Graph 5. Scatter plot between financial development indicators and amount of non-hydro electricity produced expressed in Megawatt-hour per capita, between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Graph 6. Scatter plot between financial development indicators and the share of electricity produced non-hydro renewable sources between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

The same descriptive statistics are presented for the first difference transformation, one-way within transformation and two-way within transformation on annexes two, three, and four respectively.

4 Methodology

Four different models are estimated to understand the relation between the variables, all of them correspond to panel data models. Each of these four specifications is estimated using first difference estimator, fix effects estimator, fix effects and time effects estimators, and Anderson-Hsiao estimator. The first specification corresponds to:

$$\begin{aligned} non\_hydro\_ren\_pc_{i,t} = \beta_0 + cred\_priv\_sec\_gdp\%_{i,t-1}\,\beta_1 + fin\_m\_index_{i,t-1}\,\beta_2 \\ +net\_fdi\_gdp\%_{i,t-1}\,\beta_3 + X_{i,t-1}\,\gamma + \varepsilon_{i,t} \end{aligned} \tag{1}$$

$$\begin{aligned} share\_non\_hydro\_ren_{i,t} = \beta_0 + cred\_priv\_sec\_gdp\%_{i,t-1}\,\beta_1 + fin\_m\_index_{i,t-1}\,\beta_2 \\ +net\_fdi\_gdp\%_{i,t-1}\,beta_3 + X_{i,t-1}\gamma + \varepsilon_{i,t} \end{aligned} \tag{2}$$

$$\begin{aligned} non\_hydro\_ren\_pc_{i,t} = \beta_0 + cred\_priv\_sec\_gdp\%_{i,t-1}\,\beta_1 + fin\_m\_index_{i,t-1}\,\beta_2 \\ +net\_fdi\_gdp\%_{i,t-1}\,\beta_3 + interaction\_paris\_2016_{i,t-1}\,\beta_4 + X\gamma + \varepsilon_{i,t} \end{aligned} \tag{3}$$

$$\begin{aligned} share\_non\_hydro\_ren_{i,t} = \beta_0 + cred\_priv\_sec\_gdp\%_{i,t-1}\,\beta_1 + fin\_m\_index_{i,t-1}\,\beta_2 \\ +net\_fdi\_gdp\%_{i,t-1}\,\beta_3 + interaction\_paris\_2016_{i,t-1}\,\beta_4 + X_{i,t-1}\gamma + \varepsilon_{i,t} \end{aligned} \tag{4}$$

Where:

- $Non\_hydro\_ren\_pc$ is the total amount of electricity produced from non-hydro renewable sources expressed in Megawatt-hour per capita.
- $Share\_non\_hydro\_ren\_pc$ corresponds to the share of total electricity produced from non-hydro renewable sources.
- $cred\_priv\_sec\_GDP\%$ is the credit provided to the financial sector by banks as a share of the GDP.
- fin_m_index is the International Monetary Fund that measures the development of capital markets.
- $net\_FDI\_GDP\%$ is the net foreign direct investment as a share of GDP
- X corresponds to the set of control variables: natural log of the GDP per capita and the regulatory quality index of the World Bank.

Following Brunnschweiler (2010), all the specifications are estimated using one lag of the independent variables, as the changes in the financial sector may take time to be reflected in new renewable energy projects.

In terms of the estimations, four different estimation methods are used for each one of the specifications. The first one is the simple difference in difference. The second one corresponds to the fixed effects model, in which the within transformation $x_{it} - \overline{x}_i$ is applied to all the variables to control for the unobservable individual heterogeneity that can arise from countries' specificities. The second estimation used is the panel data estimator with fix and time effects, which is equivalent to applying the two-way transformation $(x_{it} - \overline{x}_i - -\overline{x}_t + -\overline{x})$.

The fourth estimation method used is the AndersonHsiao estimator. The AndersonHsiao estimator is a dynamic panel data model that uses the first difference form but includes one lag of the dependent variable as an instrumental variable, therefore the generic specification of the Anderson-Hsiao has the form: $\Delta y_{i,t} = \gamma_0 \Delta y_{i,t-1} + \Delta x_{i,t}\beta_1 + \Delta\varepsilon_{i,t}$. Applying this to equations 1), 2), 3), and 4), and considering that the independent variables are used with one lag, I obtain the specifications:

$$\begin{aligned} \Delta non\_hydro\_ren\_pc_{i,t} = \lambda \Delta non\_hydro\_ren\_pc_{i,t-1} + \Delta cred\_priv\_sec\_gdp\%_{i,t-1}\, \beta_1 \\ + \Delta fin\_m\_index_{i,t-1}\, \beta_2 + \Delta net\_fdi\_gdp\%_{i,t-1}\, \beta_3 + \Delta X_{i,t-1}\, \gamma + \Delta\varepsilon_{i,t} \end{aligned} \tag{5}$$

$$\begin{aligned} \Delta share\_non\_hydro\_ren_{i,t} = \lambda \Delta share\_non\_hydro\_ren_{i,t-1} + \Delta cred\_priv\_sec\_gdp\%_{i,t-1}\, \beta_1 \\ + \Delta fin\_m\_index_{i,t-1}\, \beta_2 + \Delta net\_fdi\_gdp\%_{i,t-1}\, beta_3 + \Delta X_{i,t-1}\gamma + \Delta\varepsilon_{i,t} \end{aligned} \tag{6}$$

$$\Delta non\_hydro\_ren\_pc_{i,t} = \lambda \Delta non\_hydro\_ren\_pc_{i,t-1} \tag{7}$$

$$+ \Delta cred\_priv\_sec\_gdp\%_{i,t-1}\, \beta_1 + \Delta fin\_m\_index_{i,t-1}\, \beta_2 + \Delta net\_fdi\_gdp\%_{i,t-1}\, \beta_3 \tag{8}$$

$$+ \Delta interaction\_paris\_2016_{i,t-1}\, \beta_4 + \Delta X\gamma + \Delta\varepsilon_{i,t}$$

$$\Delta share\_non\_hydro\_ren_{i,t} = \lambda \Delta share\_non\_hydro\_ren_{i,t} \tag{9}$$

$$+ \Delta cred\_priv\_sec\_gdp\%_{i,t-1}\, \beta_1 + \Delta fin\_m\_index_{i,t-1}\, \beta_2 + \Delta net\_fdi\_gdp\%_{i,t-1}\, \beta_3 \tag{10}$$

$$+ \Delta interaction\_paris\_2016_{i,t-1}\, \beta_4 + \Delta X_{i,t-1}\gamma + \Delta\varepsilon_{i,t}$$

5 Results

First, I present in Table 3 the results of the Hausman test for all four specifications to choose between the fix effect and random effect model. In the case of specifications one and three the statistic of the tests is negative, this happens when the variance of the random effect estimators is bigger. Given this bigger variance the random effect estimators are less efficient than the fix ones, therefore I select the random effect model for these specifications. For the second specification, I reject the null hypothesis, therefore the non-observed heterogeneity is correlated with the error terms and I should use fix effects. For the fourth specification, I reject the null hypothesis for a significance level of 0.1, but not for 0.05 and 0.01. Given this ambiguity and considering that it is possible that some non-observed heterogeneity factors linked to geography and natural resources might be correlated with the errors, I select the fix effect model for this specification and include the results of the random effect model in Annex 8.

Table 3. Result of the Hausman tests for the four specifications

	Specification 1	Specification 2	Specification 3	Specification 4
Statistic	-68.8137	35.7810	-24.0692	14.9354
Degrees of Freedom	5	5	8	8
p-value	1.0000	0.0000	1.0000	0.0604

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

The estimation results for specification 1 are presented in Table 4. The first three specifications indicate that the financial markets index has a significant and positive effect on the production of non-hydro renewable energy. The net foreign direct investment is non-significant in all the specifications, while the credit to the private sector by banks has a significant and negative effect according to the fix and time effects model. Finally, the log of GDP per capita control is significant and positive in the first three estimations, and the regulation quality control is significant and negative for the first two. It is possible to conclude that the development of capital markets has a positive effect on the per capita production of non-hydro renewable energy.

Table 4. Estimation reults for specification 1

	First difference	Within estimator (Fixed effects)	Two-way estimator (fix and time effects)	Anderson-Hsiao estimator
No. Observations:	2386	2531	2531	2124
R-squared:	0.0055	0.0603	0.0609	0.105
F-statistic (robust):	3.3870	6.0555	30.6800	-
P-value	0.0047	0.0000	0.0000	-
cred to priv_sector from banks as GDP%	0.0003	-0.0008	-0.0026**	0.0002
	(0.0003)	*(0.0012)*	*(0.0011)*	*(0.0003)*
Financial Markets Index	0.0563**	0.3693*	0.4826**	-0.0221
	(0.0272)	*(0.1993)*	*(0.1874)*	*(0.0397)*
Net FDI as GDP%	-0.0001	-0.0007	0.0000	0.0000
	(0.0001)	*(0.0008)*	*(0.0005)*	*(0.0001)*
log GDP per cap	0.0446*	0.3221***	-0.2249**	-0.0384
	(0.0194)	*(0.0782)*	*(0.1024)*	*(0.0306)*
reg quality	-0.0236***	-0.1021**	0.0324	0.0007
	(0.0086)	*(0.0509)*	*(0.0514)*	*(0.0145)*
Non.hydro.ren_elec_pc_t-2	-	-	-	1.1243***
	-	-	-	*(0.0585)*

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

When the analysis is made from the perspective of the percentage of non-hydro renewable energy, the results change. None of the financial development variables is significant for the first three specifications. In the case of the fix and time effects model, the financial markets index has a positive and significant impact on the shre of non-hydro renewable energy, while the credit to private sector by banks has a small negative and significant impact.

Table 5. Estimation reults for specification 2

	First difference	**Within estimator (Fixed effects)**	**Two-way estimator (fix and time effects)**	**Anderson-Hsiao estimator**
No. Observations:	2386	2531	2531	2124
R-squared:	0.0023	0.1005	0.0487	0.0846
F-statistic (robust):	2.0990	7.0921	3.2472	-
P-value	0.0628	0.0000	0.0063	-
cred to priv_sector from banks as GDP%	0.0053	-0.0178	-0.0495***	0.0047
	(0.0045)	*(0.0175)*	*(0.0165)*	*(0.0072)*
Financial Markets Index	0.0572	6.4294	8.9399**	-1.5973
	(1.0989)	*(4.1653)*	*(3.9522)*	*(1.0876)*
Net FDI as GDP%	-0.0008	-0.0073	0.0096	-0.0007
	(0.0010)	*(0.0123)*	*(0.0068)*	*(0.0030)*
log GDP per cap	1.2173**	9.2871***	-1.1636	-0.7566
	(0.5768)	*(1.7823)*	*(1.7671)*	*(0.8414)*
reg quality	-0.3349	-4.8488***	-2.1640**	0.6242
	(0.2188)	*(1.0997)*	*(0.9645)*	*(0.4097)*
Share.of.non.hydro.ren_elec_t-2	-	-	-	1.0580***
	-	-	-	(0.1221)

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

In the case of specification 3, we can see in table 5 that the last three estimators indicate a significant effect of the interaction between the Paris Agreement dummy and the financial markets index, with the within and two-way estimators indicating a positive effect, while the Anderson-Hsiao estimator indicates a negative one. Regarding the interaction between the Paris Agreement dummy and the Foreign direct investment variables, the second and third estimators indicate the existence of a significant negative relation.

Table 6. Estimation reults for specification 3

	First difference	Within estimator (Fixed effects)	Two-way estimator (fix and time effects)	Anderson-Hsiao estimator
No. Observations:	2386	2531	2531	2124
R-squared:	0.0114	0.3091	0.2301	0.1062
F-statistic (robust):	3.7561	133.0400	7.0859	-
P-value	0.0002	0.0000	0.0000	-
cred to priv_sector as GDP%_paris_>2016	0.0002**	0.0007	0.0009	0.0000
	(0.0001)	*(0.0005)*	*(0.0007)*	*(0.0001)*
Financial Markets Index_paris_>2016	0.0180	0.6297***	0.5687***	-0.0907***
	(0.0214)	*(0.1032)*	*(0.1209)*	*(0.0264)*
FDI as GDP%_paris_>2016	-0.0001	-0.0020**	-0.0017**	0.0000
	(0.0001)	*(0.0009)*	*(0.0008)*	*(0.0002)*
cred to priv_sector from banks as GDP%	0.0003	-0.0012	-0.0026**	0.0001
	(0.0003)	*(0.0010)*	*(0.0011)*	*(0.0003)*
Financial Markets Index	0.0447	0.2381	0.3271*	0.0092
	(0.0273)	*(0.1589)*	*(0.1716)*	*(0.0409)*
Net FDI as GDP%	0.0000	0.0006	0.0007	0.0000
	(0.0000)	*(0.0006)*	*(0.0006)*	*(0.0002)*
log GDP per cap	0.0397**	0.1459**	-0.1719**	-0.0361
	(0.0189)	*(0.0628)*	*(0.0842)*	*(0.0312)*
reg quality	-0.0233***	-0.0589	0.0110	0.0015
	(0.0086)	*(0.0417)*	*(0.0440)*	*(0.0147)*
Non.hydro.ren_elec_pc_t-2	-	-	-	1.1756***
	-	-	-	*(0.0618)*

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

For specification 4, the first three estimations conclude that the interaction term between the Paris Agreement Dummy and the credit to private sector is positive and significant. This means that since the approval of the agreement, the effect of private credit development on the percentage of energy produced from non-renewable energy has increased.

Table 7. Estimation reults for specification 4

	First difference	Within estimator (Fixed effects)	Two-way estimator (fix and time effects)	Anderson-Hsiao estimator
No. Observations:	2386	2531	2531	2124
R-squared:	0.0072	0.2369	0.0902	0.0853
F-statistic (robust):	2.0741	11.778	2.9286	-
P-value	0.0351	0	0.003	-
cred to priv_sector as GDP%_paris_>2016	0.0085**	0.0407**	0.0314*	-0.0052
	(0.0034)	*(0.0162)*	*(0.0165)*	*0.0036)*
Financial Markets Index_paris_>2016	-0.8123	4.3044	1.6333	-0.7140
	(0.6769)	*(2.4787)*	*(2.4633)*	*(0.7037)*
FDI as GDP%_paris_>2016	-0.0014	-0.0289	-0.0385**	-0.0006
	(0.0026)	*(0.0203)*	*(0.0164)*	*(0.0060)*
cred to priv_sector from banks as GDP%	0.0039	-0.029	-0.0549***	0.0041
	(0.0046)	*(0.0188)*	*(0.0204)*	*(0.0074)*
Financial Markets Index	0.0255	5.1945	7.972**	-1.1747
	(1.0535)	*(3.5806)*	*(3.7375)*	*(1.1152)*
Net FDI as GDP%	-0.0002	0.0137	0.0222**	-0.0005
	(0.0014)	*(0.0126)*	*(0.0096)*	*(0.0041)*
log GDP per cap	1.1045**	6.0274***	-0.8994	-0.6990
	(0.5627)	*(1.5825)*	*(1.6239)*	*(0.8560)*
reg quality	-0.3253	-4.0374***	-2.3377**	0.6525
	(0.2207)	*(0.9597)*	*(0.9162)*	*(0.4170)*
Share.of.non.hydro.ren_elec_t-2	-	-	-	1.0956***
	-	-	-	*(0.1280)*

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

The case of the fix and time effects estimation requires special considerations, as it provides significant results for several variables. Specification 1 indicates that the development of credit to the private sector is associated with lower levels of non-hydro renewable energy production, while the development of capital markets is associated with higher non-hydro renewable production levels. The same relations apply to specifications 2,3 and 4 where the dependent variable is the percentage of non-hydro renewable energy produced. Additionally, specification 3 indicates that since the approval of the Paris Agreement, the relation between renewable energy production and financial markets development has increased. The same specification indicates a negative and significant coefficient for the interaction value with the foreign direct investment variable.

For specification 4, the fix and time effects estimator indicates a negative and significant interaction term between the Paris Agreement and the foreign direct investment variable, while the impact of the private credit on the share of non-hydro renewable energy has improved according to the positive and significant interaction term.

6 Conclusions

The present article analyzed the link between countries' non-hydroelectric renewable energy production and the characteristics of their financial markets. The analyses are done considering the per capita amount of energy production and the share of non-hydro renewable energy from the total energy produced. The research also analyzed how this relation has changed since the Paris Agreement of 2015 by using an interaction term with a dummy variable that corresponds to the period after the Agreement's approval.

The study was developed with an unbalanced panel of 169 countries between 2000 and 2022, with data from the World Bank, the International Monetary Fund, and the International Renewable Energy Agency using a panel model with first difference estimator, fix effects, estimator, fix effects and time effects estimators, and Anderson-Hsiao estimator.

A robust conclusion is that the development of capital markets measured by the financial markets index is associated with higher levels of per capita production of non-hydro renewable energy.
A second conclusion robust conclusion is that since the approval of the Paris Agreement, the impact of the development of private credit by banks on the share of non-hydro renewable energy has improved.
A second set of less robust results (only significant in two of the estimations) indicate that after the approval of the Paris Agreement, the relation between financial development and renewable energy production has improved, while the relation with foreign direct investment has weakened. Therefore, after the approval of the agreement, the positive impact of the financial market development on renewable energy is bigger.

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Annex 1: List of countries included in the analysis

Figure 1: Table A1.1 . List of countries analyzed.

Albania	Ecuador	Latvia	Qatar
Algeria	Egypt, Arab Rep.	Lebanon	Romania
Angola	El Salvador	Lesotho	Russian Federation
Argentina	Equatorial Guinea	Liberia	Rwanda
Armenia	Eritrea	Libya	Saudi Arabia
Australia	Estonia	Lithuania	Senegal
Austria	Eswatini	Madagascar	Serbia
Azerbaijan	Ethiopia	Malawi	Sierra Leone
Bahrain	Finland	Malaysia	Singapore
Bangladesh	France	Mali	Slovak Republic
Belarus	Gabon	Mauritania	Slovenia
Belgium	Georgia	Mauritius	South Africa
Benin	Germany	Mexico	South Sudan
Bolivia	Ghana	Moldova	Spain
Bosnia and Herzegovina	Greece	Mongolia	Sri Lanka
Botswana	Guatemala	Morocco	Sudan
Brazil	Guinea	Mozambique	Sweden
Bulgaria	Guinea-Bissau	Myanmar	Switzerland
Burkina Faso	Haiti	Namibia	Syrian Arab Republic
Burundi	Honduras	Nepal	Tajikistan
Cambodia	Hong Kong SAR, China	Netherlands	Tanzania
Cameroon	Hungary	New Zealand	Thailand
Canada	India	Nicaragua	Timor-Leste
Central African Republic	Indonesia	Niger	Togo
Chad	Iran, Islamic Rep.	Nigeria	Trinidad and Tobago
Chile	Ireland	North Macedonia	Tunisia
China	Israel	Norway	Uganda
Colombia	Italy	Oman	Ukraine
Congo, Rep.	Jamaica	Pakistan	United Arab Emirates
Costa Rica	Japan	Panama	United Kingdom
Croatia	Jordan	Papua New Guinea	United States
Cyprus	Kazakhstan	Paraguay	Uruguay
Czechia	Kenya	Peru	Uzbekistan
Denmark	Korea, Rep.	Philippines	Viet Nam
Djibouti	Kuwait	Poland	Yemen, Rep.
Dominican Republic	Lao PDR	Portugal	Zambia

Annex 2: Descriptive statistics for the first differences transformation

Table A2.1. Descriptive statistics for variables transformed with first difference between 2000 and 2022, 2656 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
count	2656	2656	2656	2656	2656	2656	2656
mean	0.4799	0.0211	0.9294	0.0008	-0.0704	0.0211	0.0003
std	1.7797	0.0640	6.5224	0.0376	12.2231	0.0502	0.1158
min	-12.2311	-0.3610	-88.8487	-0.3000	-306.7821	-0.6520	-1.0630
25%	-0.0002	0.0000	-1.0588	0.0000	-1.0095	0.0039	-0.0624
50%	0.0279	0.0003	0.6721	0.0000	-0.0120	0.0235	0.0007
75%	0.4800	0.0137	2.6095	0.0100	1.0154	0.0438	0.0611
max	34.8758	0.8148	84.5354	0.3600	207.9754	0.6778	0.6278
kurtosis	70.4483	29.0540	45.5630	16.7796	245.2663	31.2926	4.6175
skewness	4.6717	4.0812	-0.4673	-0.4988	-3.2451	-0.9879	-0.1857

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

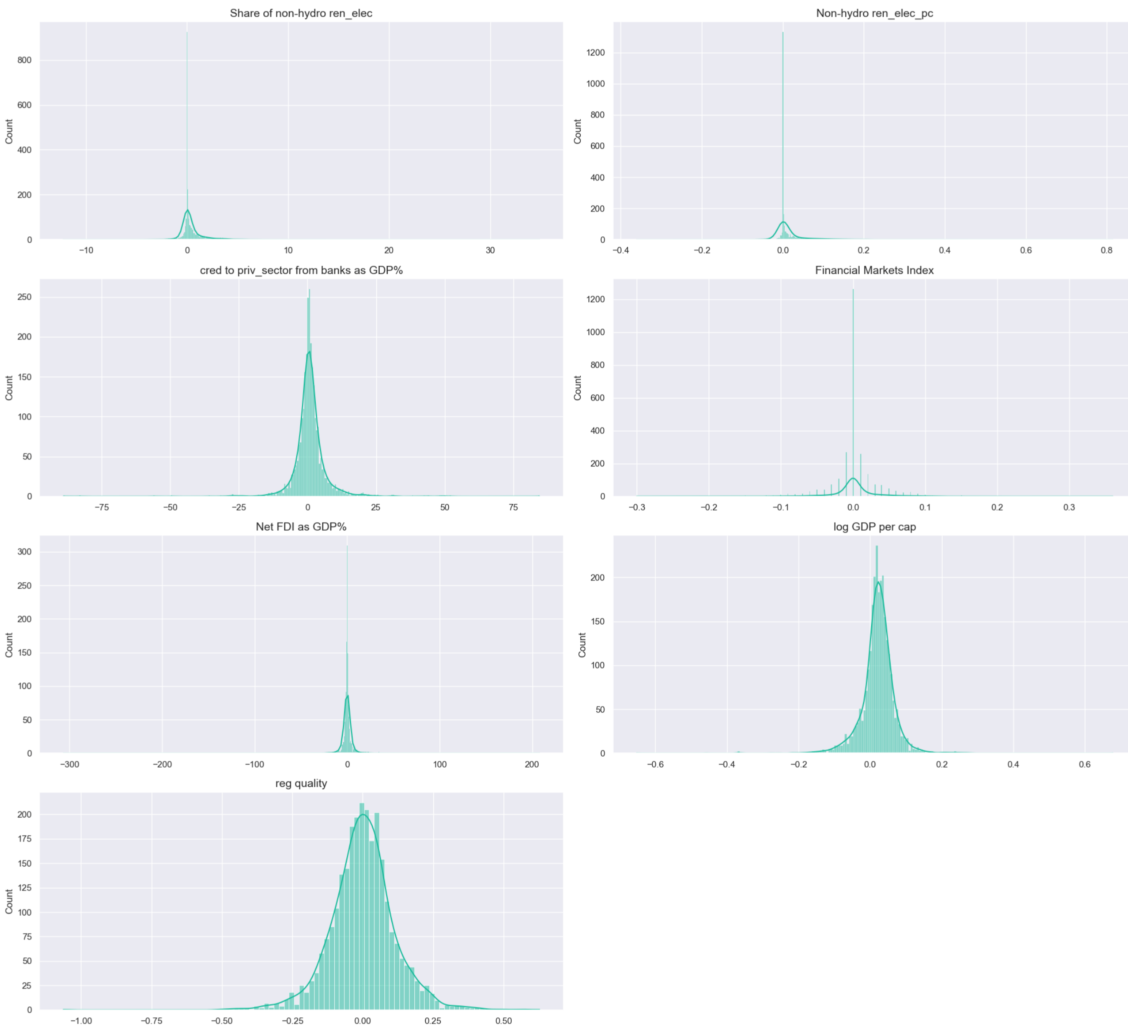
Table A2.2. Results of the Jarque-Bera test of normality for the variables in first difference between 2000 and 2022, 2656 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
Statistic	556784	100416	228953	31143	6636718	108376	2364
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A2.1. Histograms for all the variables in first difference between 2000 and 2022, 2656 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

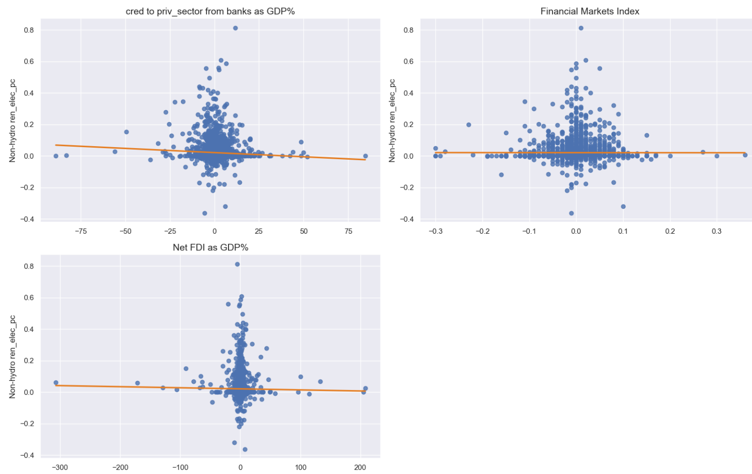
Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A2.2. Correlation matrix and heat map for the variables in first differences between 2000 and 2022, 2656 observations

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

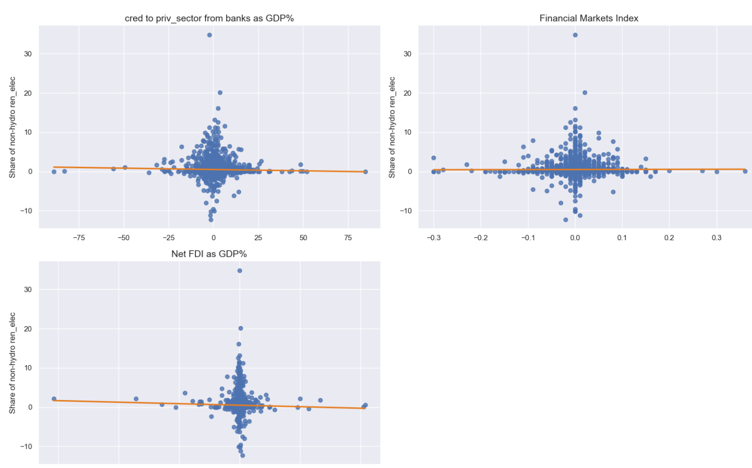
Graph A2.3. Scatter plot between financial development indicators and amount of non-hydro electricity produced expressed in Megawatt-hour per capita for first difference transformation between 2000 and 2022, 2656 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A2.4. Scatter plot between financial development indicators and the share of electricity produced non-hydro renewable sources for the first difference transformation between 2000 and 2022, 2656 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Annex 3: Descriptive statistics for the within transformation

Table A3.1. Descriptive statistics for variables transformed with the within transformation between 2000 and 2022, 2801 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
count	2801	2801	2801	2801	2801	2801	2801
mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000
std	5.332	0.252	15.014	0.052	10.848	0.176	0.189
min	-27.394	-1.484	-195.085	-0.280	-189.100	-0.997	-1.132
25%	-1.338	-0.024	-5.241	-0.013	-1.319	-0.080	-0.104
50%	-0.117	-0.001	-0.098	0.000	-0.221	0.009	0.003
75%	0.488	0.003	5.265	0.010	0.954	0.099	0.109
max	43.234	2.018	114.520	0.258	204.184	0.692	1.062
kurtosis	9.858	13.940	19.003	4.853	155.317	2.613	3.184
skewness	1.252	1.366	-0.507	-0.071	2.034	-0.655	-0.181

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

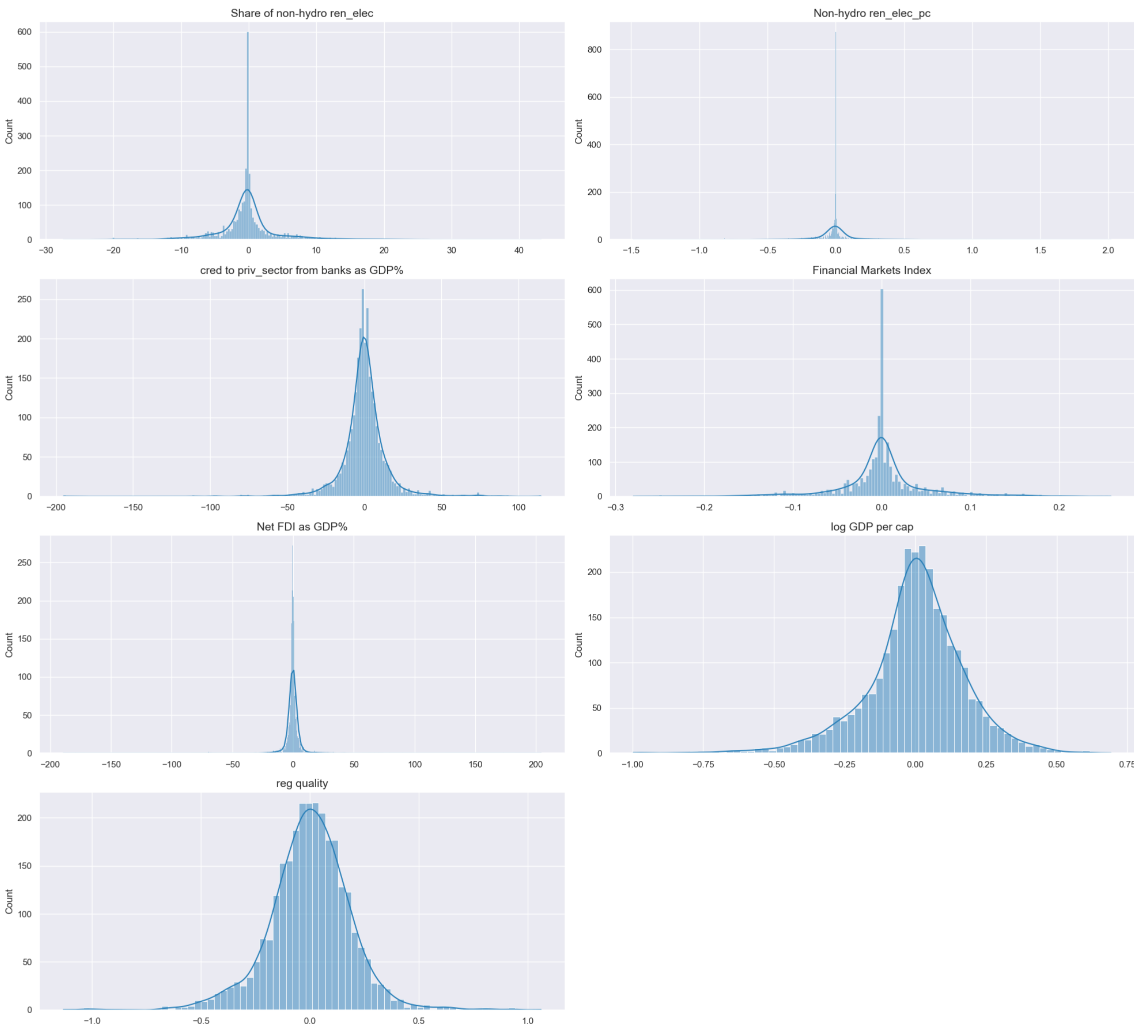
Table A3.2. Results of the Jarque-Bera test of normality for the variables with the within transformation between 2000 and 2022, 2801 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
Statistic	12028.44	23461.15	42106.13	2738.30	2807227.44	992.80	1192.74
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variables Ren elec exc biofuels_pc and Ren elec exc biofuels_hydro_pc are expressed in Megawatt-hour per capita

Graph A3.1. Histograms for all the variables with the within transformation between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

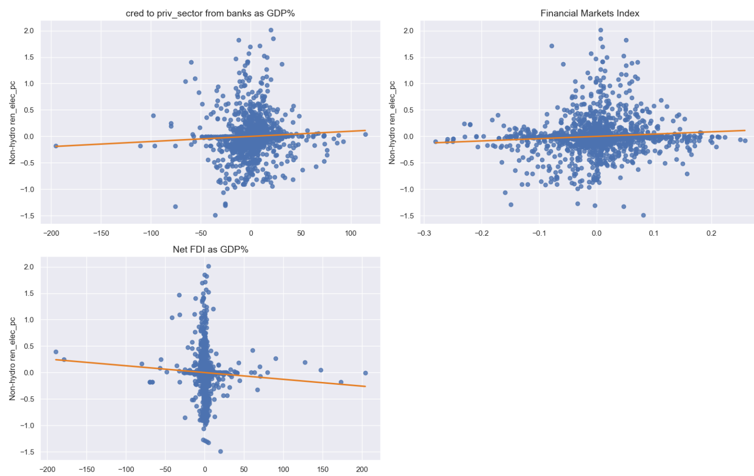
Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A3.2. Correlation matrix and heat map for the variables in first differences with the within transformation between 2000 and 2022, 2801 observations

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

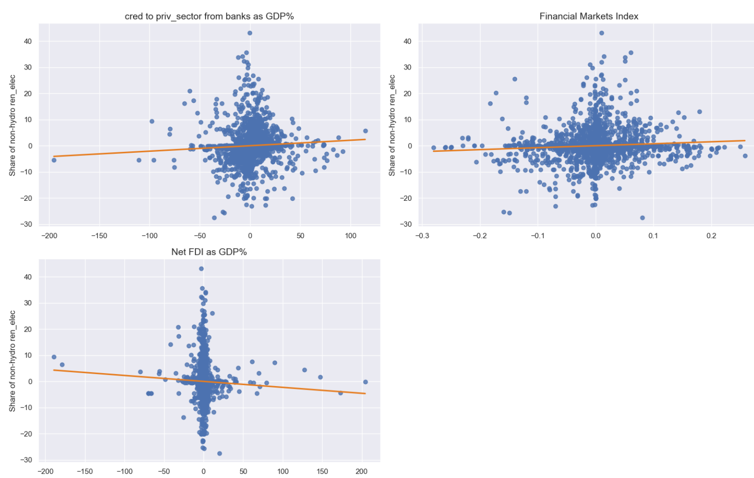
Graph A3.3. Scatter plot between financial development indicators and amount of non-hydro electricity produced expressed in Megawatt-hour per capita with the within transformation between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A3.4. Scatter plot between financial development indicators and the share of electricity produced non-hydro renewable sources for the within transformation between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Annex 4: Descriptive statistics for the two-way within transformation

Table A4.1. Descriptive statistics for variables transformed with the two-way within transformation between 2000 and 2022, 2801 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
count	2801	2801	2801	2801	2801	2801	2801
mean	0.000	0.000	0.000	0.000	0.000	0.000	0.000
std	4.486	0.219	13.810	0.050	10.767	0.140	0.191
min	-24.333	-1.321	-178.839	-0.265	-186.899	-0.631	-1.065
25%	-2.087	-0.086	-5.114	-0.021	-1.712	-0.078	-0.106
50%	0.332	0.018	-0.846	0.001	-0.192	-0.014	0.001
75%	2.114	0.100	4.933	0.017	1.424	0.064	0.107
max	37.142	1.712	108.838	0.251	201.886	0.822	1.028
kurtosis	8.694	11.065	21.165	4.239	153.776	2.917	2.874
skewness	0.726	0.871	-0.401	-0.024	2.101	0.561	0.124

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

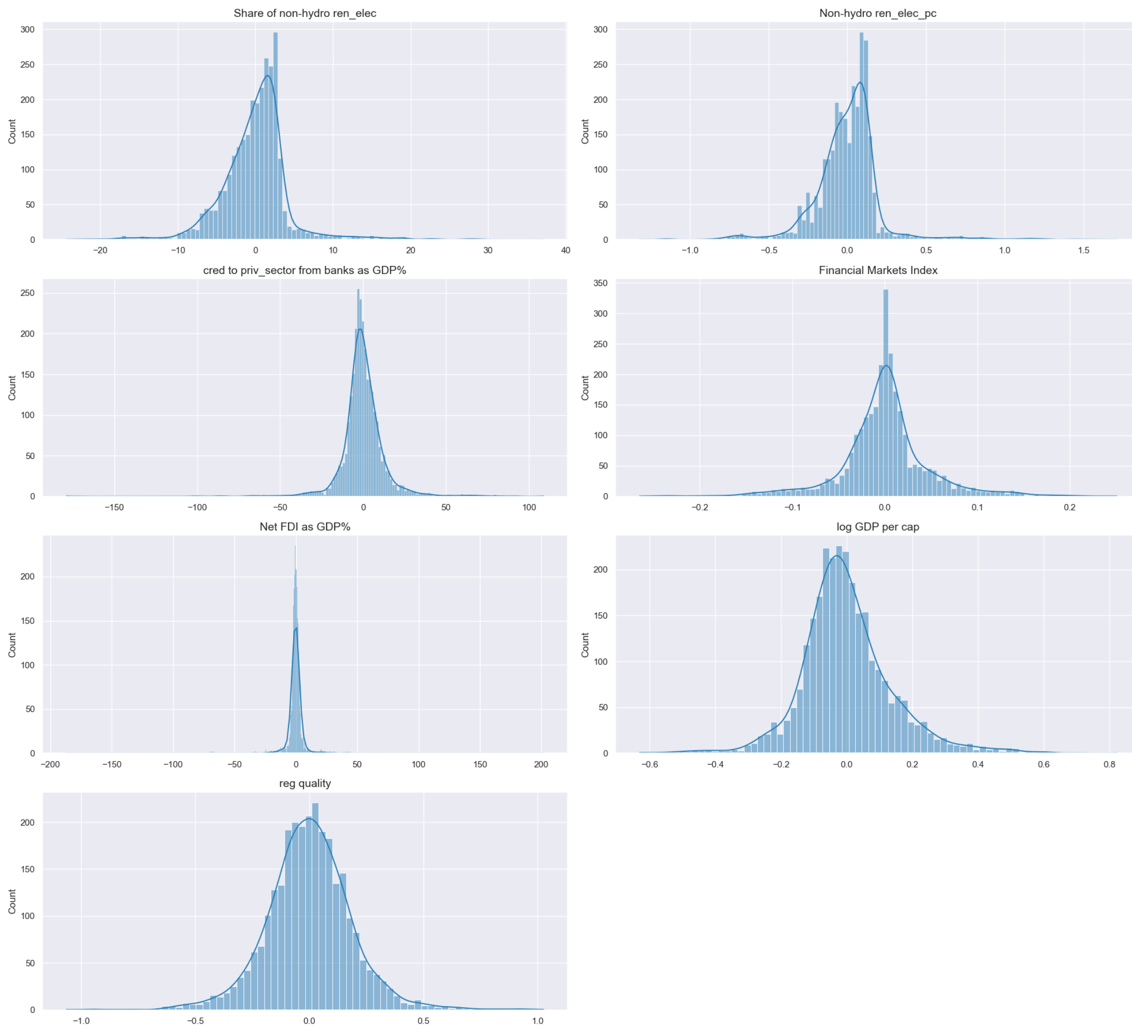
Table A4.2. Results of the Jarque-Bera test of normality for the variables with the two-way within transformation between 2000 and 2022, 2801 observations

	Share of non-hydro ren_elec	Non-hydro ren_elec_pc	cred to priv_sector from banks as GDP%	Financial Markets Index	Net FDI as GDP%	log GDP per cap	reg quality
Statistic	9031.49	14586.46	52157.01	2088.16	2751940.05	1135.17	966.08
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A4.1. Histograms for all the variables with the two-way within transformation between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

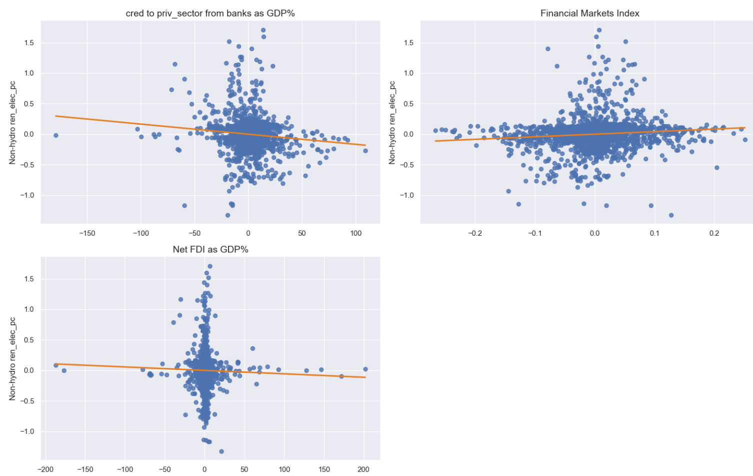
Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A4.2. Correlation matrix and heat map for the variables with the two-way within transformation between 2000 and 2022, 2801 observations

Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

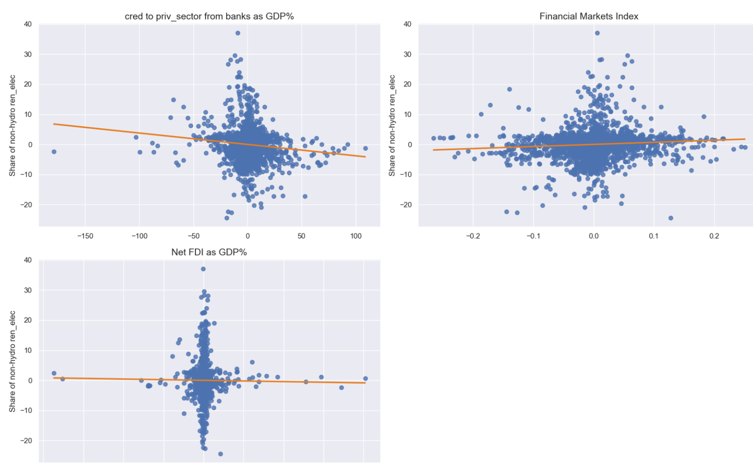
Graph A.3. Scatter plot between financial development indicators and amount of non-hydro electricity produced expressed in Megawatt-hour per capita, for the two-way within transformation between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

Note: The variable Non-hydro ren_elec_pc is expressed in Megawatt-hour per capita

Graph A4.4. Scatter plot between financial development indicators and the share of electricity produced non-hydro renewable sources for the two-way within transformation between 2000 and 2022, 2801 observations



Source: Own elaboration with data from the International Monetary Fund (2024) , the International Renewable Energy Agency (2023b), and the The World Bank (2023)

8 Annex 5: Complete estimation results of specification 1

9 Annex 6: Complete estimation results of specification 2

10 Annex 7: Complete estimation results of specification 3

11 Annex 8: Complete estimation results of specification 4