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# Evaluation of Green Financing Mechanisms in Renewable Energy Projects and their Impact on Economic Growth in Peru

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**ABSTRACT**

This article examines the impact of green bonds on renewable energy generation and economic growth in Peru through an empirical analysis that incorporates robust econometric models, including OLS, GMM, and VAR, along with Johansen cointegration tests. Through these approaches, we assess the influence of green bonds on the energy sector, identifying how these financial instruments have boosted renewable energy projects and contributed to sustainable economic growth. The findings reveal a positive and significant relationship between green bonds and the expansion of renewable generation, further highlighting the crucial role of fiscal policies and regulatory frameworks in fostering these instruments. This analysis also identifies challenges, such as the need to strengthen institutional capacity and infrastructure to optimize the use of green bonds. This study provides a comprehensive perspective on the relevance of green bonds in the transition to a low-carbon economy in Peru, serving as a basis for future sustainable energy policies.

**Keywords:** Renewable Energies, Green Financing, GDP per Capita, Peru
**JEL Classifications:** Q42; O13; G32

## 1. INTRODUCTION

The push towards a more sustainable economy, less reliant on conventional energy sources, has gained momentum in recent decades, particularly in countries like Peru, where an abundance of natural resources creates opportunities for the development of renewable energy. In this context, green financing sources in general—and green bonds in particular—have emerged as innovative financial mechanisms (Paudel et al., 2024) aimed at channeling resources into environmental sustainability and clean energy generation projects.[1] Peru, with an energy matrix in the process of diversification, has adopted initiatives to promote investment in these types of projects, seeking not only to mitigate the environmental impacts of energy generation but also to foster resilient and sustainable economic growth. However, there is a growing need to understand the extent to which these financial instruments influence the composition of the energy matrix and the economy as a whole.

This article focuses on assessing how the issuance of green bonds affects renewable energy generation as a percentage of Peru's energy matrix and the impact of both on per capita GDP growth. The research aims to provide a solid empirical basis to analyze whether green bonds fulfill their objective of promoting the development of clean energy infrastructure and fostering economic

1 The green bond is intended to finance or refinance environmental projects such as renewable energy production (wind, photovoltaic and small hydroelectric plants), information and communication technologies, sustainable forestry, clean transportation, sustainable aquaculture, sustainable agriculture, sanitation (wastewater treatment), among others.

growth that addresses environmental challenges.[2] By examining the impacts of these financing instruments, we aim to understand the channels through which green bonds can act as catalysts in the development of a more sustainable energy matrix.

The relevance of this study lies in its ability to offer empirical evidence to guide the design of public policies focused on optimizing the use of green bonds in key sectors of the Peruvian economy, particularly in the energy area. The proper channeling of these financial instruments could facilitate a more effective and faster integration of renewable energies into Peru's energy matrix, reducing its dependence on conventional energy sources and promoting sustainable development. Previous studies such as Morel and Bordier (2012) and Flammer (2021) in OECD economies have shown that green bonds can attract significant investments in renewable energies; However, they also show that the economic impact of these bonds is variable and depends on the local context, such as the structure of the energy market and the level of infrastructure development. Peru is a country with a structural reality marked by inequality and informality (Paredes-Valverde et al., 2024), so a renewable energy strategy can have high economic impacts and poverty reduction. Additionally, de Deus et al.'s (2022) analysis for Brazil and China underscores that, beyond increasing the share of clean energy in the energy matrix, green bonds can boost sectoral GDP, generating economic growth within the renewable energy industry. However, as any process involving environment, energy and markets are not neutral (Costa Ribeiro, 2024), these positive effects are susceptible to external factors, such as the volatility of energy prices in international markets and changes in government policies. In this context, this study seeks to contribute to the understanding of these dynamics in Peru, evaluating how green bonds influence not only the expansion of renewable energies, but also the economic stability of this sector in an emerging and developing market.

To contribute to the emerging literature on green finance in developing economies, this study employs a time-series approach with monthly data obtained from Peruvian public sources, focusing on the influence of green bonds and the share of renewable energy in the energy matrix on GDP per capita. First, Johansen cointegration tests were performed to verify the long-term relationship between the key variables of the model. Next, Ordinary Least Squares (OLS) and Generalized Moments Method (GMM) models were estimated using a robust variance-covariance matrix to ensure consistency in the presence of autocorrelation and heteroskedasticity.

Subsequently, Vector Autoregression Models (VAR) were applied to capture the dynamic relationships between green bonds, the percentage of renewable energies in the energy matrix and economic growth. Finally, the Impulse Response Function was used to analyze the magnitude, duration, and sustainability of the effects of green bonds, looking at how GDP per capita and renewable energy generation respond to variations in green financing over time. This approach allows us to capture more accurately the temporal and sequential interaction of these elements, providing a detailed view of the effects that green bonds can have on economic activity and the sustainability of the energy matrix in Peru.

Monthly data from Peruvian public sources were used, mainly from the Central Reserve Bank of Peru (BCRP), the Ministry of Energy and Mines (MINEM) and the Superintendence of the Securities Market (SMV). The data includes variables such as GDP per capita, the percentage of renewable energies in the energy matrix, financing through green bonds and other relevant economic indicators. The time series cover a 10-year period, from January 2013 to December 2022, which allows us to analyze the evolution and effects of green financing in a context of changing energy policies in Peru. All the data were transformed in their logarithmic form, with the aim of facilitating interpretation in terms of elasticities and percentage relationships, in addition to complying with the assumptions of normality and reducing heteroskedasticity in the econometric models applied. Likewise, before proceeding to the econometric analysis, seasonality and unit root tests were carried out to verify the integrability of the series and confirm the stability of the models implemented in the research.

The structure of the article is organized into five main sections: The introduction, where the problem is presented and the importance of the study in the energy and economic context of Peru is discussed; the theoretical framework, which reviews the literature on the impacts of green bonds on the economy and the energy matrix; methodology, which describes the econometric data and techniques used; the results, which present and analyze the empirical findings obtained, with a discussion of their scope and limitations; and, finally, the conclusions, which synthesize the contributions of the research and suggest directions for future studies in the area of green finance and renewable energy.

## 2. BRIEF HISTORY AND EVOLUTION OF GREEN FINANCE AND GREEN BONDS IN PERU

Globally, green financing has emerged as a crucial tool to address global environmental challenges and promote sustainable development. Since the 2000s, the urgency to combat climate change and reduce greenhouse gas emissions has driven governments, financial institutions, and companies to adopt financing mechanisms that channel investments toward sustainable projects. One of the primary vehicles for this type of financing has been the green bond, a debt instrument aimed exclusively at raising funds for projects with environmental benefits, such as renewable energy, energy efficiency, climate-resilient infrastructure, and waste management. The green bond market has grown exponentially since the first issuance by the World Bank in 2008

2 The Peruvian energy matrix is diversified and is characterized by a notable participation of renewable sources, especially hydropower. Approximately 60% of the electricity in the country comes from hydroelectric sources, taking advantage of the potential of the Andean rivers. In addition, Peru has been actively promoting the development of non-conventional renewable energies, such as solar and wind, which have seen sustained growth in recent years. Despite this diversification, the country still relies on fossil sources, mainly natural gas, to meet domestic energy demand.

and now stands as a fundamental pillar of sustainable financing on a global scale. This growth reflects the increasing interest of investors and regulators in funding activities that contribute to the transition toward a low-carbon economy.

In Peru, the adoption of green financing instruments has followed a path of gradual evolution, shaped by both economic development and the strengthening of environmental policies. Over the past decade, Peru has intensified its efforts to diversify its energy matrix and reduce dependence on fossil fuels, aligning with its international commitments under the Paris Agreement.[3] These commitments have spurred greater integration of renewable energies into the national energy matrix, with green financing serving as a key tool to support this structural shift. In this context, green bonds have started gaining traction as a viable and attractive instrument for financing renewable energy projects and other sustainable infrastructure projects.

Starting in 2018, Peru entered the green bond market with the support of multilateral organizations such as the Inter-American Development Bank (IDB) and the International Finance Corporation (IFC), as well as the technical cooperation of international institutions, including the World Bank. That year, the development bank of Latin America (CAF) and other actors in the financial system collaborated to issue the first green bonds in the country, whose initial objective was to finance solar and wind energy projects, as well as strengthen resilient infrastructure. One of the projects financed with these bonds was the Wayra I wind farm, located in the Ica region, which with an installed capacity of 132 MW, became the largest wind energy project in Peru. This park allows the reduction of approximately 285,000 tons of $CO_2$/year, contributing significantly to the national goal of reducing carbon emissions by 20% by 2030, established in the Paris Agreement.[4]

Since these first steps, the Peruvian government has implemented various policies and tax incentives to promote the issuance of green bonds, encouraging the private sector to adopt these instruments. For example, the Ministry of Environment (MINAM) has led initiatives to integrate sustainability principles into the country's fiscal and financial policy, resulting in targeted incentives for projects that reduce environmental impact. In 2021, the Ministry of Economy and Finance (MEF) issued a guide to Sustainable, Green and Social Bonds, establishing clear guidelines for companies and regional governments interested in issuing this type of bond. This regulatory framework, aligned with the international standards of the International Capital Markets Association (ICMA), ensures transparency and correct labeling of bonds, in addition to including certification and verification processes for projects to guarantee their environmental impact.

To gain the trust of domestic and international investors, the Peruvian capital market has also adopted the certifications and regulatory frameworks recommended by international initiatives, such as the ICMA Green Bond Principles. This alignment has been fundamental for companies such as Engie Energía Perú and Enel Green Power to attract financing for sustainable projects in the country. In 2022, Engie Energía Perú issued green bonds worth US$100 million, aimed at the construction of a photovoltaic solar park in Moquegua, with an estimated capacity of 300 MW, enough to supply approximately 200,000 homes in the southern region of the country.[5] This green bond issuance was verified by independent bodies, which increased its attractiveness to international investors and consolidated the country's credibility in the field of green financing.

The expansion of the use of green bonds in Peru has been welcomed by the financial market, which is increasingly identifying investment opportunities in sustainable projects. In the last 5 years, the growth of green bond issuance in Peru has followed a moderate trend and is similar to that of other Latin American countries such as Chile and Colombia, although with a lower volume due to the size and degree of development of the Peruvian financial market. However, the country has shown great potential, especially in the energy sector, thanks to its abundant solar and wind resources in several regions of the territory.

Despite the aforementioned advances, the green bond market in Peru still faces several important challenges that hinder its consolidation and expansion. One of the main challenges is the need to create a more stable and predictable demand for these financial instruments. Although green bond issuances have grown in recent years, there is still a dependency on external factors, such as the availability of sufficiently attractive and viable projects for investors. Often, companies and public entities in Peru lack the experience or technical know-how to structure projects that meet the requirements of international standards for green bonds. This creates a barrier to accessing financing, especially in sectors such as infrastructure and agriculture, which, although key to the transition to a green economy, have not yet fully benefited from such instruments.

Moreover, external factors, including fluctuations in international energy prices and global economic uncertainty, have profoundly influenced the adoption rate of green bonds in Peru. Volatility in fossil fuel prices, which can vary sharply due to geopolitical tensions or shifts in global supply and demand, often leads investors to be cautious about committing capital to long-term projects, including green bond initiatives aimed at supporting renewable energy. Additionally, periods of global economic crisis, such as the downturns experienced during the COVID-19 pandemic, have dampened investment flows towards sustainable projects, as economic instability encourages a preference for lower-risk assets and short-term returns (Pilloni et al., 2022).

Peru's heavy reliance on exports of minerals and energy products, like copper and natural gas, further heightens the economy's

3 The Paris Agreement is an international treaty adopted in 2015 within the framework of the United Nations Convention on Climate Change (UNFCCC), with the main objective of limiting the increase in global temperature to <2°C above pre-industrial levels, and making efforts not to exceed 1.5 °C. This agreement seeks to reduce greenhouse gas emissions through climate action by all participating countries, incentivizing the transition to renewable energy sources and the adoption of clean technologies.

4 For more information, see: Report Osinergim

5 For more information, see: https://engie-energia.pe/medio-ambiente

vulnerability to fluctuations in global demand. These dependencies not only impact the nation's fiscal stability but also make financial market conditions less predictable, complicating the assessment of future returns on renewable energy investments. Given these constraints, the development of green financing mechanisms in Peru requires a supportive policy environment that can mitigate external risks and attract sustainable capital, especially during periods of economic volatility.

The evolution of green financing in Peru, especially through the issuance of green bonds, reflects a growing trend towards sustainability and energy diversification in the country. Although there is still a long way to go to consolidate a robust green bond market, the policies implemented and alignment with international standards position Peru as a potential relevant player in sustainable financing in Latin America.

## 3. DATA AND ESTIMATION TECHNIQUES

### 3.1. Data

To estimate the effects of green financing on renewable energy generation, as well as the impact of both variables on economic activity, relevant data were collected to capture each of these phenomena in an accurate and representative manner. The analysis was conducted over the period from January 2018 to December 2023, selecting this time window based on the availability and quality of green bond data. The monthly frequency of variables allows for detailed and continuous monitoring of fluctuations and patterns over time, providing a solid foundation for a time series analysis approach. This data structure is suitable for identifying dynamic and long-term relationships between green financing, renewable energy generation and economic indicators.

The economic impact of green finance and, in particular, green bonds on the energy sector remains a limited area of research and with potential for further development. Most existing studies on sustainable finance focus on effects at the microeconomic level, but few studies examine the cumulative impact of these instruments on the economy as a whole, especially in the context of developing countries. This study uses financial and energy data from Peru to assess how green financing, through green bonds, influences the expansion of renewable energy and overall economic activity. Thanks to this database, it is possible not only to observe the effect of green bonds on the adoption of clean technologies, but also to quantify their contribution to increasing the share of renewable energy in the country's energy matrix, which has direct implications for progress towards a more sustainable economy.

The main dependent variable of this study, renewable energy generation as a percentage of Peru's total energy matrix, was calculated using data from the Economic Operation Committee of the National Interconnected System. This measure represents the proportion of renewable energy generated in relation to the country's total energy production, allowing an evaluation of the progress of sustainable sources within the national energy matrix. This variable is key to capturing the degree of adoption of clean technologies and the drive towards a more sustainable energy transition. In addition, it allows us to analyze how changes in green financing, in particular through instruments such as green bonds, can influence the growth of renewable energies and the composition of the energy supply in Peru.

For its part, the other key variable of this study, sustainable financing, is measured through green bonds issued according to data provided by the Climate Bonds Initiative.[6] This variable allows us to capture the magnitude of the investment specifically allocated to projects with positive environmental impact, including those that seek to promote the generation of renewable energy. By including this metric, it is possible to analyze how the flow of green finance influences the transition to clean energy, facilitating the adoption of sustainable technologies and potentially contributing to a reduction in carbon emissions from the energy sector. This approach is essential to assess the effect of green financial incentives in the context of public policies oriented towards sustainability and green economic development in Peru. In the following graph in Figure 1 we show how these data correlate a priori.

As can be seen in Figure 1, the scatter plot, together with the adjusted regression line, shows a positive correlation of 30% between the issuance of green bonds and the percentage of renewable energy in Peru's energy matrix. This correlation, although moderate, is indicative of a direct relationship in which the increase in green financing is associated with an increase in the share of renewable energy. Although the coefficient is not particularly high, this value is consistent with expectations, given that the transition to clean energy is a gradual process and depends on several additional factors, such as government policies, macroeconomic conditions, and the country's existing technological infrastructure. Thus, green bonds represent only one of the sources of financial incentive, and their effect tends to manifest itself progressively as the energy sector adapts and expands its capacity to integrate clean energy technologies.

Table 1 presents the descriptive statistics and sources of the variables collected, treated and used in this study, providing a comprehensive view of the characteristics and variability of each of the key indicators in the analysis of green finance and its relationship with renewable energy generation in Peru. In particular, the data reflect variability and trends in economic and energy factors, such as the monetary policy reference rate, the global price of Brent crude oil, GDP per capita and effective generation capacity, essential elements to capture the determinants of renewable energy generation in the country.

It is important to highlight the breadth and range of these variables, which underlines the underlying dynamics in the Peruvian economic and energy context. The variable of green

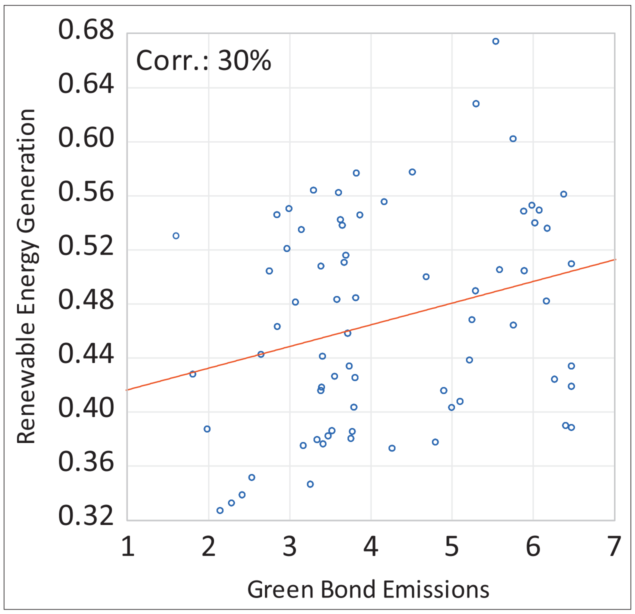
6 The Climate Bonds Initiative (CBI) is an international non-profit organization that works to mobilize the climate bond market, promoting investments that finance projects and assets that help mitigate climate change. Its main objective is to increase investment in climate change adaptation and mitigation solutions, offering technical guidance and leadership in creating responsible financial markets that support the transition to low-carbon economies. The CBI also publishes regular reports on the evolution and trends of the green bond market globally.

**Table 1: Descriptive statistics and source of variables**

| Stats | Source | Mean | Median | Maximum | Minimum | Standard deviation |
|---|---|---|---|---|---|---|
| Average load factor | COES | 0.4 | 0.4 | 0.4 | 0.2 | 0.0 |
| Effective capacity | COES | 12621 | 12528 | 13885 | 11949 | 302 |
| Energy intensity | COES | 26.4 | 26.1 | 29.8 | 23.9 | 1.4 |
| GDP per Capita | CRBP | 5167 | 5271 | 5886 | 3165 | 436 |
| Global price of brent crude | CRBP | 72 | 73 | 118 | 27 | 19 |
| Green bond emissions trend | CBI | 157 | 43 | 653 | 5 | 199 |
| Maximum demand | COES | 6920 | 6923 | 7606 | 5173 | 403 |
| Monetary policy reference rate | CRBP | 3.3 | 2.8 | 7.8 | 0.3 | 2.6 |
| Renewable energy percentage of total | COES | 0.6 | 0.6 | 1.0 | 0.4 | 0.1 |

COES: Economic operation committee of the system, CRBP: Central Reserve Bank of Peru, CBI: Climate bonds initiative

**Figure 1:** Scatter chart of correlation between green bond issuances and renewable energy generation




Source: Authors' own elaboration with data from the COES and CBI

bond issuances, for example, shows a high standard deviation, indicating significant variations in the sustainable financing available for clean energy projects, which could influence the adoption of renewable energies. Likewise, the measure of energy intensity and the percentage of renewable energy generation of the total allow us to evaluate how efficiency in energy use and installed capacity respond to green financing policies and the macroeconomic context. This table provides, therefore, a reference base to understand the behavior of each variable in the period analyzed and its potential relationship with the development of renewable energies in the Peruvian energy matrix.

In this study, the data comes from three main sources that allow us to assess the impact of green financing on renewable energy generation in Peru. Energy data, such as effective capacity and energy intensity, were obtained from the Economic Operation Committee of the National Interconnected System (COES), providing a detailed view of the Peruvian energy structure. Macroeconomic indicators, such as GDP per capita and the monetary policy rate, were provided by the Central Reserve Bank of Peru (BCRP), contextualizing the economic environment. Finally, the trends in green bond issuance were collected from the Climate Bonds Initiative (CBI), a recognized source that monitors sustainable financing globally.

## 3.2. Model Specification

This section describes the specifications of the models used to estimate the effects of green financing on renewable energy generation and its relationship with economic activity in Peru. For this purpose, three methodological approaches were used: the Ordinary Least Squares (OLS) model, the Generalized Least Squares (GMM) model and the Autoregressive Vector (VAR) model. The OLS model was used to obtain initial estimates of the relationship between the variables, providing a view of the direct effects of the explanatory variables on the dependent variable, in this case, renewable energy generation. The results of the OLS model, as seen in the estimation tables, showed that GDP per capita and green bonds have a positive impact on renewable energy production, although with certain variable effects depending on the period of analysis. Likewise, a Johansen cointegration test is performed to determine if there is a long-term relationship between the key variables in our study, specifically between renewable energy generation and GDP per capita.

The GMM model was applied to address possible endogeneity and serial correlation problems in errors, which allows more robust estimates to be obtained.[7] The use of the GMM is crucial in this study due to the possibility that some of the explanatory variables, such as green financing, may be endogenously related to renewable energy generation. According to the results obtained, the GMM confirmed the existence of a positive and significant relationship between green bonds and renewable energy generation, although the coefficients were smaller compared to those estimated by the OLS model. Finally, the VAR model was used to capture the dynamic interactions and effects of shocks between variables over time. Impulse-response graphs obtained from the VAR showed how shocks in green bond issuance affect both renewable energy generation and GDP per capita, providing a more detailed understanding of long-term mechanisms.

7 Endogeneity in a regression model occurs when one or more of the independent variables are correlated with the model's error term. This can cause biased and inconsistent estimates of parameters, as independent variables are not exogenous, i.e., they are influenced by unobserved factors that also affect the dependent variable. Endogeneity can arise due to reverse causality, omission of relevant variables, or measurement errors.

In summary, our model is as follows:

$$RE_t = \alpha_1 GBE_t + \alpha_2 GDP_{pc_t} + \alpha_3 MP_t + \alpha_4 GCP_t + \alpha_5 EC_t + \alpha_6 MD_t + \alpha_7 EI_t + \alpha_8 LF_t + \varepsilon_t \quad (1)$$

Where $\varepsilon_t \sim N(0,\sigma^2)$

Control variables capture financial, macroeconomic and structural elements that influence the performance of the renewable energy industry. Specifically, they are:

- Green bonds (GBE): are financial instruments specifically designed to finance renewable energy-related projects and other sustainable projects. These instruments allow investments to be channeled towards clean technologies and help diversify the sources of financing for renewable energy projects. According to Baker et al. (2018), the issuance of green bonds has grown significantly in recent years, allowing companies to raise capital to finance projects that contribute to the reduction of carbon emissions and the promotion of renewable energies. Through this channel, an increase in green bonds is expected to have a positive impact on the adoption of renewable technologies, facilitating the energy transition towards cleaner and more sustainable sources (Flammer, 2021).
- Gross domestic product per capita ($GDP_{pc}$): GDP per capita is a key variable in the analysis of the relationship between economic growth and renewable energies. GDP per capita growth is expected to be positively correlated with the adoption of renewable energy, as rising incomes can facilitate investments in clean technologies (Salahuddin et al., 2015). This effect is mainly observed in advanced economies, where a higher level of economic development is often accompanied by a greater capacity to finance and adopt sustainable energy solutions (Gielen et al., 2019).
- Monetary policy rate (MP): The benchmark interest rate, as a monetary policy tool, can have a significant impact on investment decisions, including those in the renewable energy sector. In general, lower interest rates make it easier to finance renewable energy projects by reducing the cost of capital, which can encourage investment in sustainable projects. However, the impact of the monetary policy rate may vary depending on the macroeconomic context and inflation expectations (Campiglio, 2016). In economies with low interest rates for prolonged periods, as has been observed in advanced economies (Claessens et al., 2018), there may be a boost to investment in renewable energy.
- Global price of brent crude (GPC): The price of oil is a critical factor affecting the competitiveness of renewables compared to fossil fuels. As the price of oil increases, renewable energy becomes more competitive, as the costs associated with the use of fossil energies also increase (Hirth, 2013). This creates an incentive for countries and companies to diversify their energy sources towards more sustainable alternatives, such as solar, wind and hydroelectric power.
- Effective capacity (EC): Effective capacity refers to the amount of installed capacity in the system to generate renewable energy. This component is crucial, as higher installed capacity facilitates the production of renewable energy, which, in turn, can increase the share of renewable energy in the national energy mix. The expansion of installed capacity is one of the main drivers of the transition to a cleaner energy matrix, allowing a greater part of the energy demand to be met with renewable sources (Jacobson et al., 2017).
- Maximum demand (MD): Peak energy demand represents the maximum amount of electricity that is required in a given period of time. An increase in peak demand can generate pressures to incorporate more renewable energy sources into the energy matrix, as these sources are increasingly competitive in terms of costs and responsiveness to peak demand (Gielen et al., 2019). In this way, the behavior of peak demand may be a determining factor in the need to expand the installed capacity of renewable energies.
- Energy intensity (EI): Energy intensity measures the amount of energy consumed per unit of economic output. Higher energy intensity is generally associated with greater use of non-renewable energy sources, which can hinder the growth of the share of renewables in the energy mix. Therefore, low energy intensity is a positive indicator of a transition towards greater energy efficiency and greater use of renewable energies (Sorrell et al., 2009).
- Average load factor (LF): The load factor is an indicator of how efficiently installed capacity is used to generate power. A higher load factor means that installed capacity is being used more efficiently, implying that a greater proportion of the energy generated comes from available renewable sources. According to Hirth (2013), a high load factor in renewable technologies, such as wind or solar energy, can improve the economic viability of these projects, by optimizing production and the performance of installed capacity.

The model also incorporates dummy-type controls to capture monthly seasonality, a crucial component when analyzing renewable energy generation, especially in sources such as solar and wind, which are highly dependent on climatic and seasonal factors. The incorporation of monthly dummy variables allows the model to adjust for fluctuations that can be expected depending on the season of the year, such as the variability of solar irradiance or wind speed at different times of the year. This type of control is essential to avoid the omission of seasonal factors that could bias the results and to improve the accuracy of the estimates, since renewable energies have cyclical characteristics related to climate and energy demand that vary by month.

Equation (1) is estimated using two methodological approaches: Ordinary Least Squares (OLS) and the Generalized Momentum Method (GMM), with the inclusion of the Newey-West matrix (HAC) to correct possible autocorrelation and heteroskedasticity problems that may arise in the model's errors. The use of MQO is common when explanatory variables are assumed to be non-endogenous, while GMM is employed to address potential endogeneity issues and to obtain efficient estimators when explanatory variables are correlated with errors. The HAC matrix, on the other hand, is key to strengthening the estimators in the presence of heteroskedasticity and autocorrelation, common problems in time series analyses.[8] In addition, all the variables of the model are transformed to their logarithmic form in order to obtain elasticities, which allows the results to be interpreted more intuitively, such as the percentage effects of a variation in the explanatory variables on the dependent variable.

Regarding the validation of the stationarity of the time series, unit root tests are performed to ensure that the series are stationary before the estimation of the model. Fisher's unit root tests, such as the Augmented Dickey-Fuller test (ADF) and the Philips-Perron test (PP), are applied to evaluate the presence of unit roots in series. The significance of these tests indicates the need to transform the series before estimation, which is crucial to avoid problems of bias or distortion in inferences. The results of these unit root tests can be found in the following Table 2.

The results show that all the series used in the analysis are not integrated I(0). This implies that the series are stationary at level, meaning that they do not require transformations such as differentiation to make them stochastically stable. This behavior is important because it suggests that the variables do not contain long-term trends or unit-root structures, which facilitates direct estimation in levels. In situations such as these, estimates can be made using the series in their original form (in levels), without the need to take differences, which in turn allows a more direct interpretation of the estimated coefficients and avoids the possible loss of information. In addition, the fact that the series are stationary also increases the reliability of the results obtained, as it minimizes the risks of obtaining spurious or inconsistent results that could arise if working with non-stationary series.[9]

For the Generalized Moment Method (GMM) models, we have used the variables of the model with a phase lag of up to three periods as instruments, which allows us to capture the dynamic relationships between the variables over time. In addition, we incorporated external control to capture the specific impact of the crisis period generated by the Covid-19 pandemic, a factor that could have significantly altered economic and energy relations in the period under study. The validation of these models is carried out by means of two fundamental tests: the J-Statistic test and the Durbin-Wu-Hausman test (D-W-H).

The J-Statistic test is used to evaluate the validity of the GMM model specification. This test compares the empirical moments with the theoretical moments derived from the model, allowing to verify if the selected instruments are adequate and if the model is correctly specified. The validity of this test is crucial to ensure that the estimates obtained are consistent and efficient, implying that the estimated coefficients correctly reflect the underlying relationships between the variables without bias. On the other hand, the Durbin-Wu-Hausman test (D-W-H) is essential to examine the presence of serial correlation in the model residuals. Autocorrelation in the residuals indicates that the model has not fully captured the temporal dynamics of the data, which could lead to biased and inefficient estimates. This test is essential to verify the reliability of the model estimates and to ensure that the residuals do not violate the assumptions of non-autocorrelation, which would ultimately affect the quality of the results. Both tests ensure that the GMM models used are robust and capable of providing valid and accurate estimates.

Following the work of Pesaran and Shin (1998), we applied the generalized impulsive response function (GIRF) to obtain an impulsive response that is invariant to any rearrangement of the variables in the VAR (Vector Autoregression) model. This approach is particularly useful to avoid the interpretation problems that can arise from choosing the order in which variables are entered into the model, which is a common concern in traditional VAR models. The generalized impulsive response function allows the dynamic impact of a shock on the variables of the system to be identified and measured, without this impact depending on the temporal structure imposed by the order of the variables.[10] Accordingly, the reduced form of the VAR model is specified as follows:

$$X_t = \delta_0^0 + \sum_{i=1}^{p} \delta_i^1 X_{t-i} + \sum_{i=1}^{p} \delta_i^2 Y_{t-i} + \mu_t \quad (2)$$

where: $i = 1, \ldots, p$ (order); $\delta_0^0$ is constant term; $\propto_t$ is an innovation term (impulse or shock), $X = \{\Delta RE, \Delta GBE, \Delta GDP\}$ and $Y = \{\Delta MP, \Delta GPC, \Delta EC, \Delta MD, \Delta EI, \Delta LF\}$.

Through the impulsive response function of the VAR model, we seek to obtain a detailed estimate on the duration and magnitude of the effects that green bonds, as well as the share of renewable energies in the energy matrix, have on the Gross Domestic Product per capita (GDP per capita). In addition, it is intended to analyze the impact of green financing on renewable energy generation. The impulsive response function allows us to measure how a shock in one of these variables—for example, an increase in green bonds or a change in the share of renewables in energy production—propagates over time, affecting variables of interest, such as GDP per capita and clean energy production capacity.[11]

This analysis is crucial to understand not only the direct relationship between green finance and renewable energy generation, but also to identify the potential indirect effects that these elements may

8 The Newey-West matrix is crucial in the analysis of Ordinary Least Squares (OLS) regressions applied to time series, as it adjusts for autocorrelation and heteroskedasticity problems, ensuring consistency and efficiency of estimates. Its implementation allows for more reliable hypothesis testing, resulting in robust and valid estimates, especially when working with time series data in the econometric context. Its use is essential to obtain reliable results in the presence of possible correlations and non-constant variability in errors.

9 A stationary series is a sequence of data whose statistical behavior does not change significantly over time. In other words, its properties do not depend on the specific moment in which the series is observed.

10 In this way, the estimates obtained using the GIRF provide a more robust representation of the dynamic relationships between the variables, eliminating possible biases derived from causality that can be influenced by the order of entry of the variables in the VAR. This methodology allows us to estimate shock responses more accurately and reliably, ensuring that causal interrelationships between variables are captured correctly.

11 The data processing and modeling of the equations of this work was carried out through the Eviews 12 software.

have on the economy as a whole, in terms of economic growth measured by GDP per capita.

## 4. EMPIRICAL RESULTS

The results of the Johansen cointegration test in Table 3 demonstrate a long-term relationship between renewable energy generation as a percentage of total and GDP per capita, suggesting a structural dependence between both variables in the context of Peru. The Trace test indicates the presence of up to two cointegration relationships in trendy and non-trended models, and up to five ratios when linear or quadratic trend terms are included. This suggests that, over time, economic growth, reflected in GDP per capita, and the increase in the share of renewable energies in the energy matrix are co-integrated, implying that temporal deviations from this relationship tend to be corrected, returning to a long-term equilibrium. The inclusion of trend terms reinforces the robustness of these results, indicating that the interaction between these variables is not only present, but is relevant and consistent across different trend configurations in the model.

On the other hand, the Max-Eigen statistic (Max-Eig) also supports the existence of a cointegration relationship between these variables, since it identifies a cointegration relationship in models without a trend and in models with a linear or quadratic trend. This finding is consistent with economic theory suggesting that economic growth and renewable energy development may be interrelated in emerging economies, where green finance and increases in GDP per capita can facilitate greater investments in sustainable energy infrastructure. The critical values of the Schwarz Information Criterion reinforce the statistical validity of the cointegration relationships found, indicating that the combination of economic growth and renewable energy policy tends to remain in a long-term equilibrium, which is crucial to evaluate sustainable policies in Peru.

The objective of this research is to evaluate how green financing, mainly represented by the issuance of green bonds, influences the proportion of renewable energy in the total energy matrix in Peru. Using both Ordinary Least Squares (OLS) and Generalized Moment Estimation (GMM) estimates, this analysis examines the impact of financing, monetary, macroeconomic, and energy structure variables on the growth of renewable energy production. The models allow us to identify the relationship between green financing and the expansion of clean energy, as well as the influences of the macroeconomic and energy context, underlining the role of financial and structural factors in the change towards a more sustainable energy matrix.

Table 4 presents the results of the OLS and GMM estimates, detailing the impact of the variables of interest on renewable energy production as a percentage of the total energy generated. The estimates include the effect of green bond issuances and the monetary policy reference rate as key financing variables, as well as macroeconomic factors such as GDP per capita and the global price of Brent crude oil. The country's energy structure is also included through variables such as effective capacity, peak demand, energy intensity, and average load factor.

**Table 2: Unit root test**

| Variable | ADF | | | PP | | |
|---|---|---|---|---|---|---|
| | Lag | Probability | Max Lag | Stat. | Bandwidth | CV (10%) MZt |
| Average load factor | 9 | −2.94478 | 11 | 0.865 | 66 | −3.164 |
| Effective capacity | 11 | −2.88189 | 11 | 0.370 | 29 | −3.164 |
| Energy intensity | 9 | −1.83144 | 11 | 0.067 | 59 | −3.164 |
| GDP per Capita | 10 | −1.96155 | 11 | 0.000 | 8 | −3.164 |
| Global price of brent crude | 3 | −0.85061 | 11 | −1.883 | 2 | −3.164 |
| Green bond emissions trend | 1 | −0.99916 | 11 | 0.472 | 3 | −3.164 |
| Maximum demand | 6 | −3.74901 | 11 | 0.562 | 5 | −3.164 |
| Monetary policy reference rate | 3 | −2.16196 | 11 | 0.134 | 1 | −3.164 |
| Renewable energy percentage of total | 3 | −2.16196 | 11 | −3.458 | 1 | −3.164 |

Akaike and Schwarz information criteria were used to determine the exogenous terms of the test equation (intercept only - I or trend and intercept - I+T), when tied, the Hannan-Quinn criterion was used as the deciding vote

**Table 3: Cointegration test**

| Number of cointegrating relations by model - equation (1) | | | | | |
|---|---|---|---|---|---|
| Test type | No. Intercept | Intercept | Intercept | Intercept | Intercept |
| | No. Trend | No. Trend | No. Trend | Trend | Trend |
| Data trend | None | None | Linear | Linear | Quadratic |
| Trace | 2 | 2 | 5 | 4 | 7 |
| Max-Eig | 1 | 1 | 1 | 2 | 2 |
| Rank ou n. de E.C. | | | | | |
| 0 | 35.68555 | 35.68555 | 36.10486 | 36.10486 | 36.49278 |
| 1 | 35.67536* | 35.73315 | 36.09851 | 36.10084 | 36.4342 |
| 2 | 36.04289 | 36.07805 | 36.38315 | 36.37504 | 36.65569 |
| 3 | 36.60647 | 36.64325 | 36.88701 | 36.91029 | 37.13383 |
| 4 | 37.23021 | 37.26912 | 37.45187 | 37.49057 | 37.65381 |
| 5 | 37.89257 | 37.95438 | 38.0766 | 38.17666 | 38.27896 |

Selection (level 0.05) - critical values based on MacKinnon-Haug-Michelis (1999); Schwarz's informational criterion by Rank (rows) and Model (columns)

**Table 4: OLS and GMM estimates of the effect of green finance on renewable energy production (% of Total)**

| DV: Renewable energy (% of Total) | | Equation 1 | |
|---|---|---|---|
| **Groups** | **Regressors** | **OLS** | **GMM** |
| Financing Variables | Green bond emissions trend | 0.008*** | 0.010** |
| | | (0.096) | (0.124) |
| | Monetary policy reference rate | −0.010*** | −0.007** |
| | | (0.077) | (0.121) |
| Macroeconomic variables | GDP per Capita | 0.617** | 0.498*** |
| | | (0.009) | (0.063) |
| | Global price of brent crude | 0.124** | 0.073** |
| | | (0.888) | (0.960) |
| Energy structure | Effective capacity | 0.629** | 0.723* |
| | | (0.085) | (0.165) |
| | Maximum demand | −1.104* | −1.001* |
| | | (1.494) | (1.549) |
| | Energy intensity | −0.319* | −0.538* |
| | | (0.733) | (0.766) |
| | Average load factor | 0.524** | 0.391* |
| | | (1.023) | (1.044) |
| | Adj. $R^2$ | 0.771 | 0.339 |
| | F-stat | 19.632 | |
| | P-value (F-stat) | 0.001 | |
| | LM test | 6.127 | |
| | Prob (LM) | 0.118 | |
| | ARCH test | 5.739 | |
| | Prob (ARCH) | 0.135 | |
| | J-statistic | | 10.474 |
| | P-value (J-stat) | | 0.518 |
| | D-W-H test | | 6.185 |
| | P-value (D-W-H) | | 0.276 |
| | No. Instr./No. Obs. | | 19/72 |

Levels of significance: ***denotes 0.01, **denotes 0.05 and *denotes 0.1. Standard errors in parentheses. OLS equation based on Newey and West (1987) estimators

The first section of the statistics presents the adjusted $R^2$, which measures the proportion of variability in renewable energy production explained by the model variables, adjusted for the number of regressors. In the case of the OLS model, the adjusted $R^2$ of 0.771 indicates that approximately 77.1% of the variability of renewable energy production is explained by the included variables, suggesting a good fit of the model. The F statistic and its corresponding p-value (0.001) allow us to test the joint significance of the coefficients in the OLS regression; Given the low value of p, the null hypothesis that all coefficients are zero is rejected, indicating that the explanatory variables are, as a whole, significant in the model.

The results of the diagnostic tests provide information about possible problems with the specification and validity of the model. To evaluate possible problems of autocorrelation of the residuals, the Breusch-Godfrey test (LM test) is used, which has a P = 0.118. This value, being higher than the common significance level of 0.05, suggests that there is insufficient statistical evidence to reject the null hypothesis of absence of autocorrelation in the residuals. The lack of autocorrelation in the residuals is a favorable result, as it suggests that the errors are not time-correlated, which is desirable to ensure that the coefficients are efficient in the OLS model. The ARCH test is used to detect conditional heteroskedasticity in residuals, i.e. whether the variability of errors changes systematically with the value of the independent variables. With a P = 0.135, the test does not reject the null hypothesis of homoscedasticity, suggesting that there is no systematic variation in the errors of the model and that the standard errors calculated are reliable to interpret the significance of the coefficients.

In the case of the GMM model, the Hansen statistic (J-statistic) allows the validity of the instruments to be evaluated. With a P = 0.518, Hansen's test does not reject the null hypothesis that the instruments are valid and uncorrelated with model errors. This indicates that the instruments used in the GMM estimation are adequate and that the model is correctly specified in terms of instrument validity, strengthening the robustness of the coefficients obtained in this estimation. Finally, the Durbin-Wu-Hausman test (D-W-H) is used to test the presence of endogeneity in the explanatory variables. With a P = 0.276, the D-W-H test does not reject the null hypothesis of exogeneity in the variables, suggesting that there is no significant evidence of endogeneity in the model. This result supports the choice of variables and instruments in the GMM model, increasing confidence in the coefficients as representative of the causal relationship between green finance and renewable energy production.

The results obtained in the estimation of the relationship between green bonds and renewable energy production show a positive and significant coefficient for the variable "Green Bond Issuances" in both models (0.008 in OLS and 0.010 in GMM). This finding suggests that an increase in the trend of green bond issuance is associated with a growth in the share of renewables in total energy production. This supports the idea that green finance can be a key factor in fostering the transition to a cleaner energy matrix, by providing the necessary resources for renewable energy projects. Previous studies, such as those by Flammer (2021) and Ehlers and Packer (2017), have shown that green bonds facilitate access to capital on more favorable terms, reducing financing costs for sustainable projects and improving the competitiveness of renewable energies against conventional energy sources.

This result can also be interpreted through the theory of green financing, which argues that access to capital through sustainable financial instruments, such as green bonds, facilitates the development of clean infrastructure projects and more environmentally friendly technologies (Baker et al., 2018). In the case of Peru, the funds raised from these issuances allow for continued investment in key renewable energy sectors, such as solar, wind and hydropower, reducing the country's dependence on fossil fuels and favoring more sustainable energy growth. This not only increases the share of renewable energies in the energy matrix, but also contributes to the reduction of greenhouse gas emissions, thus supporting national climate change mitigation commitments and the Sustainable Development Goals (Flammer, 2021). The economic theory of sustainable finance also suggests that these mechanisms allow developing countries to capture international capital flows that prioritize environmental, social, and governance (ESG) criteria, generating a positive impact on long-term investment in green sectors (Tang and Zhang, 2020).

The positive and statistically significant effect of green bond issuances on renewable energy production, observed in both estimation models (OLS and GMM), reinforces the hypothesis that green finance is an effective tool to accelerate the energy transition in Peru. This finding is consistent with previous research highlighting how targeted financial incentives can accelerate the adoption of clean energy technologies, even in developing countries, where access to capital is a critical factor for the expansion of sustainable infrastructure (Ehlers and Packer, 2017; Tang and Zhang, 2020). The robustness of this relationship suggests that a consolidated green bond market in Peru could not only facilitate the fulfillment of its energy objectives, but also strengthen its position as a sustainable investment destination in the region. This indicates a considerable opportunity for Peru to continue strengthening its renewable energy infrastructure through green financing policies to ensure more resilient and low-carbon economic growth.

The negative and significant effect of the monetary policy reference rate on renewable energy production indicates how financing costs impact investment in sustainable projects. In general, an increase in the reference rate raises the cost of credit, limiting investments in long-term infrastructure, especially in renewable energies, which require high initial outlays and recover their returns in extended terms (Claessens et al., 2018). This result is consistent with opportunity cost theory, where capital is directed to projects with higher risk-adjusted returns when rates increase, which can reduce the attractiveness of investments in sectors such as clean energy (Campiglio, 2016). In addition, in emerging economies such as Peru, this effect is intensified due to greater limitations in access to financing for renewable energies compared to developed markets, where green financing alternatives are more mature.

The results for the macroeconomic variables also show clear statistical significance and agreement with the economic theory that supports them in the model. GDP per capita, for example, has a positive effect on renewable energy production, which is in line with economic growth theory, which suggests that more developed economies have greater resources to invest in clean infrastructure (Lyeonov et al., 2019). As GDP per capita increases, so does the ability to finance clean technology projects, including energy, through both public and private investments. This positive effect is consistent with previous research suggesting that wealthier economies can absorb the upfront cost of transitioning to renewable energy, which favors their adoption (Salahuddin et al., 2015). However, the global price of oil (Brent Crude) shows a positive effect on renewable energy production, which can be explained by the inverse relationship between fossil fuel prices and hydrocarbon-based energy investments: when oil prices fall, renewable energy projects become less economically competitive in relative terms and vice versa (Sorrell et al., 2009).

Energy structure variables, such as effective capacity and peak demand, are crucial to understanding how a country's energy matrix is shaped. In the case of effective capacity, which represents the total electricity generation capacity, an increase in this variable has a positive effect on renewable energy production as a percentage of the total. This result is consistent with energy efficiency theory, which suggests that greater access to power generation infrastructure allows for greater flexibility in the mix of energy sources. In other words, an increase in installed capacity facilitates the integration of more renewable sources into the energy system without compromising supply stability (Gielen et al., 2019). According to previous studies, the expansion of energy infrastructure is key to improving the penetration of renewables in a country's energy mix, especially when the existing infrastructure is insufficient (Al-Shetwi, 2022).

On the other hand, the peak demand variable has a negative effect on the proportion of renewable energy produced, which may be related to the limitations of renewable sources to cover peak demand. During periods of high demand, the energy system may be forced to turn to non-renewable sources due to the variability and intermittency of renewable sources. This phenomenon is a common challenge in many economies, especially those that rely on renewable energy sources with seasonal or daily variability, such as solar or wind (Jacobson et al., 2017). Energy resilience theory points to the need for investments in storage infrastructure and demand management systems so that renewable energies can more efficiently cover peak demand without relying on fossil sources (Hirth, 2013).

The autoregressive factor of the Gross Domestic Product (GDP) of the energy industry, out of phase over a period, exhibits a positive and significant coefficient in relation to the explanation of the GDP of this same industry. This feature highlights the importance of considering the past behavior of energy GDP when modeling its current dynamics. The positivity of the autoregressive coefficient suggests that previous trends in energy GDP growth have a persistent impact on its current behavior. This finding is consistent with the academic literature that highlights the presence of economic inertia in the energy industry, where growth and decline patterns tend to persist over time due to the nature of long-term investments and the physical infrastructure required. Furthermore, these results indicate that econometric models that incorporate the history of energy GDP can more effectively capture the underlying dynamic relationships in the industry, thus providing a better understanding of its behavior and facilitating the formulation of appropriate policies and strategies for its sustainable development.

The coefficient of the reference interest rate of monetary policy is revealed to be positive and highly significant in its ability to explain the Gross Domestic Product (GDP) of the energy industry. This result is supported by the economic literature, which has examined the relationship between monetary policy and the performance of different economic sectors. For example, research such as that by Wright (2002) and Driffill et al. (2006) shows that an increase in interest rates can help maintain financial stability by discouraging excessive borrowing and reducing the risks of speculative bubbles. This can contribute to greater financial strength and resilience in the companies and households that consume energy products, which in turn promotes a more stable environment for investment and long-term growth. In addition, according to the study by Kearns and Manners (2018), a higher interest rate environment can make financial assets denominated in the national currency more attractive to foreign investors, which can boost the inflow of foreign capital into the energy industry. This can facilitate the financing of energy infrastructure projects and encourage the transfer of technology and knowledge in the sector, thus contributing to the development and modernisation of industry.

Table 5 presents a detailed analysis of how the key variables annually impacted renewable energy generation in Peru as a percentage of the total energy matrix. The data show both the annual impacts in percentage terms and the elasticities associated with each variable, which allows us to observe the sensitivity of renewable energy generation to changes in economic, financial and structural factors in the energy system. This analysis is critical to understanding how variations in the macroeconomic context (such as GDP per capita and the global price of crude oil) and energy market conditions (such as effective capacity and peak demand) have influenced the growth of renewables in recent years.

The importance of these results lies in their ability to evidence the annual fluctuations in the drive towards renewable energy sources and how these responses may be conditioned by external and internal factors. In particular, the table allows for the identification of patterns or trends that could inform the formulation of energy policies and the design of green financing instruments. In addition, by showing the specific effects of each variable on the percentage of renewable energy generation, it provides a solid empirical basis to evaluate the effectiveness of different strategies for promoting renewable energies in the face of economic and market changes.

The green bond issuance variable has modest annual impacts, reflecting the limited progress still experienced by the green bond market in Peru. This result suggests that, despite a growing interest in sustainable finance, the country is at an early stage in the development of green financial instruments, especially compared to other emerging economies that have implemented more robust policies and incentives to facilitate such financing. Peru, although it has issued some green bonds, still faces significant challenges, such as the need to strengthen regulations, improve transparency in the allocation of funds, and increase the availability of viable projects that meet international sustainability standards.

**Table 5: Impacts of the effect of green finance and other determinants on renewable energy production (% of Total)**

| Determinants renewable energy generation (% of Total) | | | | | | |
|---|---|---|---|---|---|---|
| **Impact (%)** | **Elasticities** | **019** | **020** | **021** | **022** | **023** |
| GDP per capita | 0.62 | 0.3 | −8.0 | 7.5 | 0.7 | −1.2 |
| Green bond emissions trend | 0.01 | 1.8 | −0.7 | −1.1 | 0.1 | −0.8 |
| Monetary policy reference rate | −0.01 | 0.1 | 1.5 | −0.1 | −1.9 | −0.3 |
| Global price of brent crude | −0.12 | 2.5 | 10.3 | −11.3 | −7.5 | 4.2 |
| Effective capacity | 0.63 | 1.1 | −0.1 | 0.7 | 0.7 | 1.7 |
| Maximum demand | −1.10 | −3.9 | 6.6 | −7.0 | −4.0 | −3.4 |
| Energy intensity | −0.32 | −0.6 | −1.5 | 1.2 | −0.4 | −1.5 |
| Average load factor | 0.52 | 1.2 | −3.8 | 4.5 | 1.4 | 0.7 |

Levels of significance: ***denotes 0.01, **denotes 0.05 and *denotes 0.1. Standard errors in parentheses. OLS equation based on Newey and West (1987) estimators

The slightly negative impact in 2021 and 2022 could be explained by the combination of national and international factors. In the global context, uncertainty and financial constraints stemming from the COVID-19 pandemic reduced investors' ability to allocate resources to sustainable projects, while in Peru, economic and political instability added additional obstacles. The pandemic affected the Peruvian economy, decreasing tax revenues and limiting the resources available to support green initiatives, which may have slowed down the implementation of sustainable infrastructure projects. This suggests that, in order to harness the potential of green bonds, Peru will need to overcome structural barriers and strengthen coordination between the public and private sectors to foster an environment conducive to green investments.

Other results allow for an in-depth interpretation of both the Peruvian and international economic and political context. GDP per capita shows a fluctuating behavior that, as of 2021, is influenced by the economic recovery after the COVID-19 pandemic. The positive elasticity (0.62) indicates that an increase in per capita income in Peru translates into a higher proportion of renewable energy generation. This effect may be due to the fact that higher GDP per capita facilitates investment in sustainable infrastructure and green technologies, a phenomenon observed in several developing economies that have opted for the diversification of their energy matrix in the context of sustainable policies driven internationally by agreements such as the Paris Agreement.

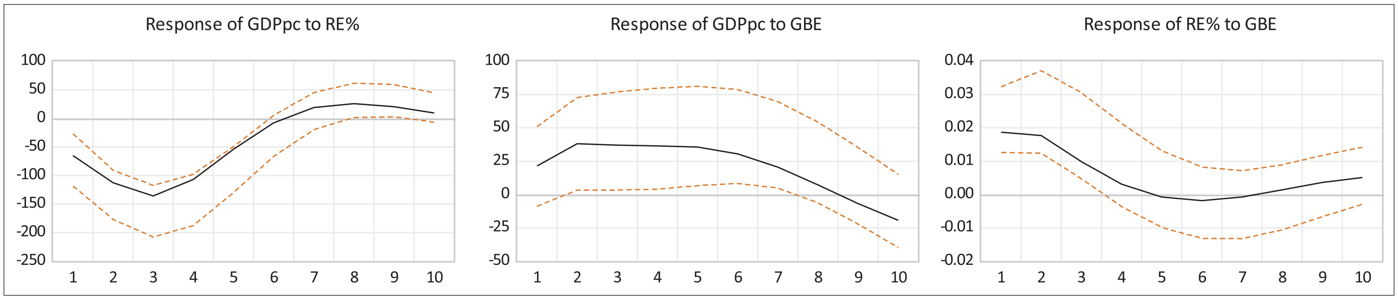
The monetary policy reference rate has an inverse relationship with the share of renewables (−0.01), and its impact is most evident in 2022, when the Central Reserve Bank of Peru increased rates to control post-pandemic inflation. Globally, tight monetary policies have also reduced the attractiveness of financing for clean energy projects due to higher capital costs, a trend seen in many emerging markets.

The global price of Brent crude oil shows a significant negative elasticity (−0.12), with variable annual effects. During 2020 and 2021, oil prices fluctuated markedly due to the pandemic and, in 2022, with the war in Ukraine, which led to unexpected spikes in oil prices. In this context, the increase in the price of fossil fuels increases the relative attractiveness of renewable energies, reflecting greater competitiveness for these sources in the Peruvian energy matrix, although fluctuations in crude oil prices can also complicate long-term planning in renewables.

On the other hand, effective capacity and maximum demand have an expected relationship: a higher effective capacity (elasticity of 0.63) is positively associated with an increase in renewable generation, while a higher maximum demand (−1.10) decreases their proportion. These results show the need to increase renewable energy infrastructure to meet the growing energy demand in a sustainable manner, a challenge that Peru faces due to the growth of its domestic demand, which sometimes exceeds the installed capacity of renewables, reinforcing dependence on conventional sources when demand is high.

Figure 2 shows the impulse-response graphs of the VAR model, which allow analyzing how different variables respond to specific

**Figure 2:** Response of the variables of interest to the generalized innovations of their selected determinants




Note: Response to Generalized One S.D. Innovations 90% CI using Hall's percentile bootstrap with 100000 bootstrap reps

**Table 6: Recommendations for methods and topics for future research**

| No. | Method | Dependent variables | Independent variables | Research proposal |
|---|---|---|---|---|
| 1 | Quantile regression models | Proportion of renewable energy in the energy matrix | Green bonds, government subsidies, energy prices, access to finance | Assessing the relationship between green bonds and the uptake of renewable energy at different stages of the business cycle |
| 2 | Time series analysis (ARIMA Models, GARCH) | Green bond yields | Interest rates, energy market risks, regulatory policies, investment volatility | Study of the profitability and financial stability of green bonds in comparison with other investment alternatives in the Peruvian market |
| 3 | Difference-in-Difference Analysis | Renewable energy generation | Green bond issuance, energy policies, green infrastructure, climate change policies | Evaluation of the effectiveness of green bonds in renewable energy generation in the face of the lack of adequate public policies |
| 4 | Environmental and social impact analysis | Effects on rural communities | Green bonds, renewable energy projects, rural infrastructure development, access to clean energy | Analysis of the social and environmental effects of green bond-financed projects in rural areas of Peru |

shocks within the system. First, it looks at the reaction of GDP per capita to a shock in renewable energy generation as a percentage of the total. This answer is critical, as it offers insight into the relationship between progress in renewable energy and economic growth per capita. The results indicate that, after an increase in clean energy generation, GDP per capita initially experiences a slight decrease in the first half of the year after the shock. This initial negative impact may reflect transition costs and structural adaptation in the economy, given that renewable energy projects often require upfront investments and adjustments in related sectors.

However, from the second half of the year after the shock, the response of GDP per capita stabilizes and begins to show a positive impact, suggesting that, once the adaptation phase is over, growth in renewable energy generation begins to contribute to per capita economic growth. This shift towards positive impact could be interpreted as a sign that the transition to cleaner energy fosters sustainable economic benefits, possibly by reducing energy costs in the long term and promoting investment in technology. Impulse-response charts therefore underline the importance of supporting energy transition policies that consider upfront costs to maximise the economic benefits of a greater share of renewables.

Figure 2 also illustrates how GDP per capita and renewable energy generation respond to shocks in green bond issuance, offering insight into the role of this financial instrument in boosting sustainable infrastructure. The response of both variables to the shocks in green bonds suggests that green financing plays a relevant role in the expansion of clean energy sources and in short-term economic growth.

In the case of GDP per capita, the positive impact of green bonds is mainly seen in the first 6 months after the shock, suggesting that green finance initially contributes to an increase in economic activity, although the effect tends to wear off after the 1st year. For renewable energy generation as a percentage of the total, the response to the shock in green bonds is even more immediate but of shorter duration, showing a positive effect during the first 3 months. This indicates that green bonds can quickly facilitate investments in clean energy, although their effect at the structural level requires complementary policies to achieve sustained growth. These results highlight the importance of maintaining a continuous flow of green finance to maximize long-term benefits in economic growth and the energy transition.

The results of this study show a positive and statistically significant effect of green financing, specifically green bonds, on renewable energy generation in Peru as a percentage of the total, confirming its facilitating role in the energy transition. Through the OLS and GMM models, it was observed that the coefficients of the green bond issuance trend suggest a stable and favorable relationship between sustainable financing and the increase in renewable energies, although with an impact of moderate magnitude. Impulse-response analyses of the VAR model also support this conclusion, showing that positive shocks in green bond issuance trigger increases in the share of renewables, although the effects tend to be concentrated in the short term and dissipate in the first few months. Taken together, the findings underscore that while green bonds are effective in fostering renewable energy growth, their structural impact on the Peruvian energy matrix could be amplified by continued and robust development of the green finance market, as well as policies that bolster infrastructure and long-term investments.

## 5. CONCLUDING REMARKS

This study has conducted an in-depth analysis of the impact of green bonds on renewable energy generation and economic growth in Peru, utilizing a robust empirical methodology grounded in time series analysis. By employing advanced econometric techniques—specifically, Johansen cointegration tests, Ordinary Least Squares (OLS), Generalized Method of Moments (GMM), and Vector Autoregression (VAR) models—this research evaluates how green bond issuance influences the share of renewable energy within Peru's overall energy matrix, while also examining its broader relationship with the nation's Gross Domestic Product (GDP). The empirical findings generated by this analysis contribute a well-defined perspective on the role of green bonds in promoting renewable energy adoption and supporting economic expansion, highlighting the particular relevance of this financial instrument within the unique dynamics of the Peruvian market.

The analytical results indicate a positive and statistically significant impact of green bonds on the proportion of renewable energies in Peru's energy matrix, reinforcing their utility as a critical instrument for advancing the country's energy transition agenda. This evidence aligns with the global shift towards green bond usage to mobilize funding for sustainable projects, underscoring the applicability of this financial tool in developing economies. Additionally, the observed impact appears particularly strong in the short and medium term, suggesting that green bond issuance could serve as an effective catalyst for expediting the integration of renewable energy sources. These findings indicate that, as Peru's demand for sustainable energy solutions grows, green bonds may play an increasingly pivotal role in accelerating the deployment of renewable energy infrastructure, thereby supporting both environmental and economic goals in the region.

Regarding the macroeconomic impact, it was found that green bonds also have a positive effect on economic growth, measured through GDP per capita. This finding highlights the bidirectional relationship between the energy transition and economic development, suggesting that increased use of renewable energy not only contributes to environmental sustainability, but also to the dynamism of the Peruvian economy. However, the effects were more evident in sectors that already have a certain growth structure, which points to the need for complementary policies that facilitate the implementation of green projects in more vulnerable sectors.

The analyses carried out through the VAR model and the Impulse Response Functions (IRF) provided a dynamic and temporal view of the impact of green bonds, showing how these financial instruments can influence the development of the energy industry and the economy in a sustained way over time. In addition, the analysis showed that the effects of green bonds are not immediate, but are spread over several periods, underscoring the importance of a long-term approach in their implementation. This reinforces the need to continue implementing fiscal and regulatory policies that support the issuance of green bonds, while considering the economic context and the country's institutional capacity to take advantage of these financing opportunities. For these instruments to be even more effective, it is essential that international alliances and access to technical knowledge are strengthened to facilitate the structuring of viable projects aligned with global standards.

In summary, this study offers empirical evidence on the positive impact of green bonds on the Peruvian energy sector and on overall economic growth. The findings suggest that, in order to maximize the benefits of green bonds, Peru should continue to strengthen its regulatory framework, improve the capacities of private and public actors in structuring eligible projects, and create additional incentives that encourage investment in renewable energy. In addition, the importance of long-term strategic planning is highlighted to ensure that these financial instruments are used efficiently and sustainably.

This work contributes to the debate on the importance of green bonds in emerging economies, providing a solid empirical basis that can be used both for public policy design and for future research in the field of green finance. In addition, it is suggested that the future of green bond issuance in Peru is closely linked to improving macroeconomic conditions and stabilizing energy markets, key aspects to ensure an effective energy transition and inclusive economic growth. Finally, Table 6 contains structured future research recommendations.

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