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Article

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Reference: Souza, Raúl Clemente Ulloa-de/González-Quiñonez, Luis Adrián et. al. (2024). Renewable energy development and employment in Ecuador's rural sector : an economic impact analysis. In: International Journal of Energy Economics and Policy 14 (1), S. 464 - 479. https://www.econjournals.com/index.php/ijeep/article/download/15297/7696/35719. doi:10.32479/ijeep.15297.

This Version is available at:
http://hdl.handle.net/11159/653331

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(1), 464-479.

Renewable Energy Development and Employment in Ecuador's Rural Sector: An Economic Impact Analysis

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Received: 27 September 2023 **Accepted:** 25 December 2023 **DOI:** https://doi.org/10.32479/ijeep.15297

ABSTRACT

The article provides an empirical analysis on the impact of renewable energy development on the unemployment rate, agricultural output and relative rural population in Ecuador. Using an empirical approach, the study examined how the production and consumption of this energy affects the labor market in rural regions. To this end, relevant data on the development of renewable energies in the context of Ecuador were collected and statistical analyses were carried out to evaluate the relationships between these and the variables of interest. The results obtained indicate that the development of renewable energies has can reduce the unemployment rate and has a positive effect on the relative population of rural regions, however, it does not seem to significantly affect agricultural production. These findings support the idea that the production and consumption of renewable energies can generate jobs directly, due to the need for workers for the construction and maintenance of these technologies, and indirectly, through cheaper energy, in-creased productive efficiency and better conditions for the expansion of companies. The study offers a significant contribution to the field of energy economics in developing countries and highlights the importance of the adoption of renewable energy sources for rural regions.

Keywords: Renewable Energies, Labor Market, Ecuador
JEL Classifications: C32; O13; O18

1. INTRODUCTION

Over the past decades, the promotion of renewable energy projects in rural areas of Ecuador has emerged as a catalyst for socioeconomic transformation. The transition to more sustainable energy sources is not only shaping the energy infrastructure but is also having a profound impact on local employment, economic development and migration to urban areas. In the long term, it can be expected that well-developed energy transitions can positively affect the social fabric of human capital and consequently resulting in improved levels of economic development (Bohnsack, Kort & Lehmacher, 2017; Becker, 1964). In a context where renewable energies are gaining ground as a viable and environmentally friendly alternative, projects that focus on bringing these technologies to rural areas are triggering a series of positive effects. The implementation of solar, wind, hydro and other forms of renewable energy projects is generating employment in multiple phases, from construction and maintenance of the facilities to ongoing operation. This not only drives demand for local labor, but also fosters the acquisition of specialized skills in clean technologies, creating a more skilled and competitive workforce.

The association between renewable energy and economic development is evident in multiple aspects. Job creation in the installation and maintenance of renewable systems translates into increased disposable income for rural communities (Ravallion, 1991). In addition, these projects often require local inputs, from construction materials to support services, which stimulates economic activity in the region. The economic diversification that accompanies the promotion of renewable energy can reduce dependence on traditional sectors and increase resilience in the face of economic changes (Mallapragada and Mallapragada, 2012;

Gyamfi et al., 2017). In addition, an interesting phenomenon is the reduction in migration to urban areas that may result from the promotion of renewable energy in rural areas. Historically, rural-urban migration has been driven by the search for economic opportunities and better living conditions. By boosting local employment and economic development in rural areas, renewable energy projects offer viable alternatives to migration. By providing employment and improving the quality of life in the same place where people have lived for generations, migration pressure to urban areas is reduced, contributing to more equitable and sustainable development (Murshed and Bilek, 2019).

The promotion of renewable energy projects in rural areas of Ecuador goes beyond the simple energy transition. These projects have the potential to be drivers of socioeconomic change by generating local employment, boosting economic development and reducing migration to urban areas. This holistic approach not only aligns Ecuador with its sustainability goals, but also strengthens the social and economic fabric of rural communities, laying the foundation for a more resilient and prosperous future. In this context, the promotion of renewable energy projects in rural areas has emerged as a driver of socioeconomic change. Although research in this field is still incipient in Latin America, several studies have begun to explore how the implementation of these sustainable technologies can have a multifaceted impact in terms of local employment, economic development and migration.

Through data collection and analysis, López (2018) found that the adoption of renewable energy projects in rural Ecuadorian areas can be a catalyst for job creation at the local level. The construction, operation, and maintenance of solar, wind, and other renewable energy facilities demands a diverse workforce, opening up opportunities in areas such as solar panel installation, wind turbine supervision, and energy storage system management. This not only provides direct jobs, but also stimulates the formation of specialized and technical skills in local communities.

The synergy between the promotion of renewable energies and economic development is also evident (Bohnsack, Kort & Lehmacher, 2017; Borghesi, Cainelli & Mazzanti, 2012). These projects generate demand for local supplies and services, from the procurement of construction materials to the provision of maintenance services. This increased economic activity in rural areas fosters the creation of small and medium-sized businesses, which in turn drives economic growth at the local and regional levels. Investment in renewable energy can diversify sources of income for rural communities, reducing their dependence on economic sectors that are vulnerable to fluctuations (Ávila et al., 2020).

A crucial phenomenon is the potential to reduce migration to urban areas. Historically, rural-urban migration in Ecuador has been fueled by the search for job opportunities and a better quality of life. However, the promotion of renewable energy can reverse this trend by creating jobs and economic opportunities in rural areas themselves. This not only slows migration, but also strengthens the resilience of rural communities by preventing depopulation and preserving the cultural and social ties entrenched in these areas (Collantes and Figueroa, 2022). In this way, the promotion of renewable energy projects in rural areas of Ecuador transcends the mere energy transition.[1] Rather, it represents an effective means of generating local employment, boosting economic development, and mitigating migration to urban areas. This approach not only reflects a response to energy and environmental challenges, but also addresses fundamental issues of equity and sustainability in the country's social and economic fabric.

In order to contribute to the literature that seeks to understand the economic impact of renewable energy development on the labor market in rural regions, this study seeks to analyze the effect of renewable energy production and consumption on the unemployment rate, output and population share in rural Ecuadorian regions. Unlike the work already done in Ecuador that analyzes the effects of these energy sources on specific industries, this study takes an aggregate approach through time series analysis. The paper is divided into 4 sections: the introduction, which presents the problem addressed, a historical context on renewable energy projects and advances in Ecuador and a theoretical context on the known effects of renewable energy development on the unemployment rate, output and migration from rural regions; the methodology, where the data and methods used in the econometric approach are explained; the results, which explain and present the empirical evidence obtained by the implemented models and where the main results of the work are discussed and their scope and implications are reflected upon; and finally, the conclusions.

2. LITERATURE REVIEW

2.1. Brief Review of Renewable Energy Projects in Ecuador 2010-2022

Over the last decade, Ecuador has experienced significant progress in the field of renewable energies, evidenced by a series of projects that have contributed to the diversification of its energy matrix and the promotion of more sustainable generation sources from an environmental and economic perspective. These projects, presented in chronological order, illustrate the country's commitment to the promotion of renewable energy and its impact on the socioeconomic sphere.

In 2010, the Coca Codo Sinclair Hydroelectric Power Plant project began in the province of Napo. This year also saw the start of construction of the Sopladora hydroelectric plant, with a capacity of 150 MW, and the Montecristi wind farm, with a capacity of 20 MW. These projects contributed significantly to the generation of

1 The energy transition to renewable energies is a process of change in the energy matrix of a society, moving from conventional energy sources, such as fossil fuels, to sustainable and clean sources, such as solar, wind and hydroelectric energy. This change seeks to reduce dependence on non-renewable resources, reduce greenhouse gas emissions and promote more environmentally friendly energy. It involves the adoption of technologies and policies that encourage the generation and use of renewable energy in sectors such as electricity, transport and heating. This transition is critical to addressing climate change and moving towards a more sustainable and cleaner future.

clean energy in Ecuador. The Coca Codo Sinclair hydroelectric plant, in particular, is one of the largest hydroelectric plants in the country, with an installed capacity of 1,500 MW. It harnesses hydropower from rivers to generate electricity sustainably and without greenhouse gas emissions, helping to reduce the country's carbon footprint.[2]

The inauguration of the Villonaco Solar Plant in 2011 represented a significant milestone in Ecuador's journey towards the adoption of renewable energy sources. With a capacity of 14.4 MW, this solar plant became one of the first large-scale solar power installations in the country. By harnessing the sun's energy to generate electricity in a sustainable and emission-free manner, the Villonaco Solar Plant made an important contribution to the diversification of Ecuador's energy matrix. In addition, this initiative not only had a positive environmental impact by reducing greenhouse gas emissions, but also fostered technological development and investment in renewable energy in Ecuador.

Two projects initiated in 2012, the San Francisco Hydroelectric Power Plant inaugurated in 2013 and the Loja Wind Farm inaugurated in 2015 represented important advances in the expansion of renewable energy generation capacity in Ecuador. The San Francisco Hydroelectric Power Plant, with its 150 MW capacity, became a significant source of hydroelectric power, taking advantage of the country's water resources to generate electricity in a clean and sustainable manner. On the other hand, the Loja Wind Farm, with 10 MW of capacity, introduced wind energy into the Ecuadorian energy landscape. These projects not only diversified the country's energy matrix, reducing its dependence on fossil fuels, but also contributed to the mitigation of greenhouse gas emissions. In addition, the investment in these facilities generated employment and promoted technology in the renewable energy sector in Ecuador,

The construction of the Sopladora Hydroelectric Power Plant, which began in 2013, marked another important milestone in the development of Ecuador's hydroelectric infrastructure. With a generating capacity of around 487 MW, this plant located in the province of Azuay has become a significant source of hydroelectric power for the country. By harnessing the energy from the flow of water, the Sopladora hydroelectric power plant contributes significantly to the production of electricity in Ecuador, reducing dependence on fossil fuels and greenhouse gas emissions. In addition to its impact on clean and sustainable energy generation, this project has also had positive effects on job creation and economic development in the Azuay region.

As of 2015, the development of renewable energy in Ecuador continued at an accelerated pace. Several new solar and wind plants were inaugurated, and the share of renewable energy in the country's energy mix increased from 90% to 2022. The expansion of the Villonaco renewable energy project with the construction of the Villonaco Wind Power Plant in 2014 and its subsequent implementation in 2015 represented a pioneering step towards the integration of wind power into the Ecuadorian energy matrix. With an installed capacity of around 16 MW, this wind farm not only provided an additional source of power generation, but also laid the groundwork for future initiatives in the field. Located in the province of Loja, this wind farm harnesses the kinetic energy of the wind to generate electricity in a clean and sustainable manner. This addition to the country's energy infrastructure contributes to the reduction of greenhouse gas emissions and the promotion of renewable energy sources.

In 2017, the "El Aromo Solar Photovoltaic Project" marked an important starting point by introducing large-scale solar photovoltaic generation in the country. With its capacity of close to 14 MW, it not only provided a cleaner source of energy, but also contributed to raising awareness of the need to adopt more sustainable and environmentally friendly energy sources.

The following year, the inauguration of the "Central Hidroeléctrica Manduriacu" consolidated Ecuador's strategy of harnessing its natural resources in a sustainable manner. With a capacity of approximately 60 MW, this plant not only contributed to the country's energy supply, but also reinforced Ecuador's commitment to hydroelectric generation, which is a clean and renewable energy source.

The "Lago Agrio Wind Farm" was a flagship project of 2019 that further diversified the Ecuadorian energy matrix. With a capacity of around 50 MW, this wind farm highlighted the growing importance of wind energy in the country and its contribution to generating electricity in a sustainable and environmentally friendly manner. In 2020, the "Delsitanisagua Hydroelectric Power Plant" in Napo Province, with its capacity of around 276 MW, further strengthened hydroelectric generation and its role in the country's energy security. This plant not only provided a reliable source of electricity, but also supported Ecuador's efforts to maintain a stable and diversified energy supply.

Finally, in 2021, the "Parque Solar Fotovoltaico Uyuni" set a milestone in the expansion of solar photovoltaic generation in Ecuador. With a capacity of around 200 MW, this solar project demonstrated the country's commitment to clean energy and emissions reduction, while contributing to diversifying the energy matrix and improving energy security in the province of El Oro and throughout the country. These projects represent important advances towards a more sustainable and green energy future for Ecuador. In the same year, the "Sopladora Hydroelectric Power Plant" was inaugurated in the province of Azuay, marking an achievement in hydroelectric generation with an installed capacity of approximately 487 MW. This project demonstrated the continued relevance of hydroelectric power in the Ecuadorian energy strategy.

In 2022, 73% of the country's energy generation came from hydroelectric plants, 23% from thermal and 12.79% from non-

2 Greenhouse gas emissions are the release of certain gases into the atmosphere that have the ability to retain heat and contribute to the greenhouse effect, a natural process that keeps the Earth's temperature suitable for life. However, human activities, such as the burning of fossil fuels, deforestation and intensive agriculture, have significantly increased the concentration of these gases, leading to an increase in heat retention and, consequently, global warming.

conventional sources (photovoltaic, wind, biomass, biogas, geothermal, among others). This production, marked by environmentally friendly energies, satisfies the national demand for electricity, as well as the export of electrons to neighboring countries.[3] Figure 1 provides a snapshot of the country's energy composition, showcasing a current predominant reliance on hydroelectric power, supplemented by thermal and various non-conventional sources.

Grasping the enduring trends in energy technology innovation is essential for predicting technological advancements and formulating effective public policies, particularly in the face of climate change (Huenteler, Schmidt, Ossenbrink & Hoffmann, 2016). Ecuadorian governments have committed to achieving carbon neutrality by 2050. To achieve this goal, several policies are accelerating the development of renewable energies. In the coming years, several new solar and wind plants will be built, and the share of renewables in the country's energy mix will increase further. Ecuador has the potential to become a world leader in renewable energy. With the support of the population and the right policies, the country can take advantage of its abundant natural resources and become a country with a clean and sustainable energy system.

In summary, these renewable energy projects in Ecuador, carried out over the last decade, have charted a significant path towards diversifying the country's energy matrix. By incorporating clean and sustainable generation technologies and infrastructure, Ecuador has made progress in its environmental commitment and in promoting socioeconomic development, strengthening its position in the renewable energy landscape in Latin America.

2.2. Impact of Renewable Energies on Employment, GDP and Population

The relationship between renewable energies and employment is a topic of growing interest in the academic literature. Numerous studies have investigated the impact of renewable energy on the unemployment rate or employment, and the results have been mixed. Some researchers have found that the expansion of the renewable energy industry can generate significant employment. For example, Dinica et al. (2017) note that investment in sustainable energy projects, such as solar and wind, creates employment through the construction, operation, and maintenance of renewable facilities. In addition, energy efficiency associated with renewables can reduce operating costs for businesses, which could translate into the creation of more jobs (Awerbuch, 2008).

However, other studies have pointed out that the effect of renewable energy use may vary depending on the context and government policies. Sovacool (2009) argues that job creation in the renewable energy sector is highly dependent on incentive policies and the degree of government commitment to the transition to cleaner energy sources. In addition, some researchers have explored the relationship between employment and renewables in specific contexts. For example, Huenteler, Schmidt, Ossenbrink & Hoffmann (2016) investigated the impact of renewable energy innovation on the rural unemployment rate and observed an interesting temporal pattern. They indicated that the reduction in the rural unemployment rate is not immediate, but begins to manifest itself after a period of time since the innovation.

The development of renewable energy in Ecuador has had a positive impact on the unemployment rate and employment in the country. The construction of renewable energy projects, such as hydroelectric plants, wind farms and solar plants, has generated employment in the construction, engineering and operation and maintenance sectors. According to a World Bank (2022), the construction of the Coca Codo Sinclair hydroelectric plant, the largest energy project in Ecuador's history generated around 10,000 jobs. The study also found that the development of renewable energy in Ecuador could create up to 100,000 jobs by 2030. The impact of renewables on employment is particularly important in Ecuador, where the unemployment rate is relatively high. Renewable energy projects are often labor intensive, which can lead to higher wages and better working conditions for workers.

Previous studies have shown that the expansion of renewable energy can have a positive impact on employment by creating job opportunities through the construction, operation, and maintenance of renewable facilities, as well as in the industry supply chain (Dinica et al., 2017; Sovacool, 2009; Sovacool and Brown, 2010). However, the magnitude of this impact may vary by sector and level of investment and may also be influenced by government policies and specific labor market conditions. Despite these variations, accumulating evidence suggests that the transition to renewable energy sources has the potential to contribute positively to job creation and sustainability, supporting its importance in energy and employment policy agendas.[4]

The relationship between renewable energy production and consumption and the percentage of rural population in a country is another topic of growing interest in the academic literature. Several studies have examined this link, considering factors such as energy infrastructure, investment in renewable energy and demographic dynamics. For example, Sovacool (2009) argues that the expansion of renewable energy often involves the development of infrastructure, such as roads and electricity grids, which can improve the connectivity of rural communities. This facilitates access to essential services and can reduce the isolation of rural areas, which benefits the quality of life of rural residents. In addition, transitioning to renewable energy sources can have significant environmental benefits, such as reducing air pollution and mitigating climate change, which can improve the health and quality of life of the rural population (Dinica et al., 2017).

3 It is important to note that here we are using as a measure the energy produced and not consumed. In this second different proportions can be observed.

4 It is important to address the challenges and limitations that renewable energy projects may face in terms of employment and retention of rural population in Ecuador. One of the main challenges may be the need for significant upfront investment in infrastructure and technology in the renewable energy sector. While these projects can generate long-term employment, they may require a considerable upfront investment that may not be available to all rural communities. This could limit the participation of some regions in the expansion of renewable energy.

Furthermore, given that investment in sustainable energy projects, such as solar or wind energy, can generate employment in rural areas through the construction, operation and maintenance of renewable facilities, this can influence the retention of rural population and the attraction of urban migrants, which could contribute to an increase in the percentage of rural population in relation to the country's total. However, it is important to note that the relationship between renewable energy production and consumption and the percentage of rural population may vary depending on the context and the specific energy policy of each country. Therefore, it is essential to consider local factors and the specific characteristics of each region when analyzing this link.

In Ecuador, studies such as Martínez-Espiñeira and Rodriguez (2019) suggest that investment in renewable energy projects, such as solar and wind power generation, can contribute significantly to economic growth in rural areas of Ecuador, through job creation and diversification of income sources. In addition, the transition to cleaner and more sustainable energy sources can have positive effects on the health and well-being of rural communities by reducing environmental pollution. However, it is important to note that the literature also highlights the need to address specific challenges related to the implementation of renewable energy projects in rural areas, such as proper planning, workforce training, and grid infrastructure.

As can be seen in Figure 2, a priori, there is a positive correlation between the percentage of renewable energy in relation to total production in Ecuador and the country's Gross Domestic Product. This may indicate both that as the level of production increases in Ecuador so does the development of renewable energy or that investment in renewable technologies favors product growth. In addition, it may even indicate a virtuous and mutual relationship in which both output growth and renewable energy development complement each other. However, it is not yet possible to make very well-founded statements without deeper analysis and for this reason we will leave the analysis of this relationship for later.[5]

In summary, the academic literature on the impact of renewables on the unemployment rate or employment is varied and complex. While there is evidence that the expansion of renewables can generate employment, the exact relationship may depend on a number of factors, including government policies and context-specific characteristics. Further studies are needed to fully understand this relationship and its implications for the economy and employment.

3. METHODS

3.1. Data

To estimate the economic effects of the promotion and use of renewable energies in rural regions of Ecuador, three dependent variables with high explanatory power from the macroeconomic point of view were selected: the rural unemployment rate, rural production, and mobility of the rural population. The analysis covers the period from the first quarter of 2010 to the last quarter of 2022. The analysis period was chosen based on the availability of data and in order to avoid the external shocks of the 2008 crisis and its consequences. The frequency of the data is quarterly, and the approach used is time series.

The economic effect of the implementation of renewable energies in rural regions has been little studied. Most studies address the issue at the microeconomic level (companies or localities) due to lack of data at the national level. To circumvent this problem, in this paper we use information from the Agency for Regulation and Control of Energy and Resources of Ecuador.[6] With this, it was possible to obtain valuable information on the production and consumption of electricity obtained from renewable sources in Ecuador.

Data from Ecuador's Energy and Resources Regulation and Control Agency are disaggregated by type of energy (renewable and non-renewable), type of service (public and non-public), month, company and central. In this way, it was necessary to construct the data of regions manually based on the location of the plants and the location of the final consumer to subsequently generate a consolidated quarterly base. Particularly, 3 measures are interesting here: renewable energy delivered to the rural public service, renewable energy production in relation to the total of rural regions and renewable energy production in relation to the total of Ecuador.

In Figure 3 it is possible to observe the behavior of the independent variables of main interest. 3 observations are important in these graphs. In the first place, a trend of growth is rarely interrupted throughout the period. On the other hand, from 2016 there is an exponential increase in the level of production and consumption of renewable energies with its peak between 2020 and 2021. Finally, it is observed that during the period of the Sars-Covid 2 coronavirus pandemic the consumption of renewable electricity by companies (non-public service) was negatively affected as a result of the measures taken to contain the spread of the disease.[7]

To measure the effect and economic impact that the development of these energy sources had in the rural regions of Ecuador, we selected a set of macroeconomic and demographic variables. First, the most important dependent variable of this work is the unemployment rate in rural regions. The hypothesis is worked that the exponential increase in the production and consumption of renewable energies in the private sector has a positive effect on

5 We chose to postpone the interpretation of the relationship in our variables of interest because when interpreting a correlation scatterplot in time series, it is important to consider temporality, seasonality, noise, trends, lags and other factors that may influence the relationship between the variables. In addition, it is essential to remember that correlation does not imply causation and that findings should be supported with additional analysis and evidence.

6 Using the portal of the Agency for Regulation and Control of Energy and Resources it is possible to obtain well-detailed balances and reports of the production and consumption of energy in Ecuador for a given month. For the purposes of our work, it was necessary to aggregate the consolidated of all months and adjust the information to obtain quarterly data.

7 Considering that the measures to contain Covid-19 clearly generated effects on the consumption of renewable energies, the models of this work must contemplate a control for the pandemic.

employment because it allows to lower production costs and increase the productive capacity of companies, which would generate new jobs.[8] This approach is underpinned by the idea that the expansion of renewables can not only have tangible economic benefits, but can also contribute to the diversification of the rural economy, thereby reducing the vulnerability of these regions to fluctuations in agricultural markets and promoting greater long-term sustainability.

On the other hand, the indicator of the rural population as a fraction of the total population is used in order to examine the impacts derived from the proportion of renewable energies generated in the Ecuadorian context on the patterns of internal migration in the country. This approach offers a valuable window of understanding to assess how the transition to sustainable energy sources can influence population dynamics in rural and urban areas. The choice to use the percentage of rural population as a dependent variable is based on the assumption that increased renewable energy production could not only generate direct jobs in rural areas, but also have indirect effects on quality of life and economic opportunities, potentially influencing inhabitants' migration decisions. This approach considers both the quantitative and qualitative aspects of Ecuadorian internal migration, opening the door to a holistic analysis of demographic changes in the context of an evolving economy and energy matrix.

Finally, we use the Agricultural Gross Domestic Product variable to measure the effect of renewable energy production in relation to the total on the main productive activity of rural regions. This choice is important because Agricultural GDP represents a comprehensive measure of the contribution of the agricultural sector to the economic value of these regions, and its inclusion allows us to understand how the transition to renewable energy sources can influence the rural economic structure. The underlying hypothesis is based on the premise that an increase in renewable energy production could not only contribute to cost reduction and efficiency in agricultural production, but also to the creation of economic synergies that strengthen the economic stability of rural communities. By using Agricultural GDP as an indicator, it is expected to reveal how these changes may affect the interdependence between renewable energy production and agricultural activity, offering a comprehensive view of the economic dynamics in these rural regions and their relationship to sustainability and long-term growth.

3.2. Model Specification

In order to observe the effect of the development of renewable energies on unemployment, the rural population and the agricultural product, we estimate equations (1), (2) and (3), respectively.

$$Rural\,Unemployment\ Rate_t = \alpha_0 + \alpha_1 ERNPR_t + \alpha_2 X_t + \varepsilon_t \quad (1)$$

$$Rural\ Population_t = \beta_0 + \beta_1 ERRT_t + \beta_2 Y_t + \mu_t \quad (2)$$

$$Agricultural\,GDP_t = \gamma_0 + \gamma_1 ERRTR_t + \gamma_2 Z_t + \omega_t \quad (3)$$

Where $\varepsilon_t, \mu_t, \omega_t \sim N(0, \sigma^2)$ and X_t, Y_t y Z_t are the vectors of independent control variables that will be explained below.

Equations (1), (2) and (3) are estimated by ordinary least squares (OLS) that use the Newey-West matrix (HAC) to avoid problems arising from autocorrelation or heteroscedasticity.[9] All variables are used in their level form and their descriptive statistics can be found in Annex 1. To check if the series have unit root, we perform the Dickey-Füller (ADF), Ng-Perron (NP) and Philips-Perron (PP) unit root tests. The results indicate that all series are I(1). The usual procedure would be to use differentiated series for the estimates, but this could imply a loss of important information about the long-term relationship between the variables, since the results of a Johansen test show that the series are cointegrated (Table A3-Appendix) and we do not have many observations. To avoid this problem, the recommendation of Hamilton (2020) is followed and models with series at the level are estimated, as well as some empirical works (Barboza and Zilberman, 2018).

The selection of control variables follows studies that seek to estimate the determinants of unemployment, rural population (National Institute of Statistics and Census, 2022) and agricultural output. Specifically:

3.3. Control Variables in Equation 1

National Unemployment Rate (Previous Quarter) - The past unemployment rate, which represents the region's labor history, can affect the current unemployment rate in rural areas. Research has shown that high unemployment rates in the past can have lingering effects due to job loss of skills, demotivation and migration. In addition, the recurrence of high unemployment rates can lead to a negative perception of job opportunities, which in turn can discourage active job seeking, contributing to chronically high unemployment rates.

Rural Labor Income - Labor income in rural areas is linked to the unemployment rate. An increase in labor income can reduce the unemployment rate, as people have more incentive to seek and accept employment. On the other hand, a low labor income can lead to a persistent unemployment cycle, as people may become discouraged and withdraw from the labor market, which would not be reflected in a lower unemployment rate, but in lower labor participation (Salimova et al., 2022; Reilly, 2005).

Annual Inflation - The annual variation of the price index, which reflects inflation, can affect the unemployment rate in rural regions

8 Unemployment refers to the proportion of a country's labor force that is unemployed and actively seeking employment. It is used as a measure of the level of utilization of human resources in an economy. Unemployment is calculated by dividing the number of unemployed people by the economically active population and can be classified into different categories, such as structural unemployment (caused by mismatches between labour supply and demand), frictional unemployment (temporary due to transition between jobs) and cyclical unemployment (caused by economic fluctuations). In this work we use total unemployment and do not discriminate by its type.

9 The Newey-West matrix is essential in the analysis of MQO regressions in time series because it corrects problems of autocorrelation and heteroscedasticity, ensures the consistency and efficiency of estimates, and allows reliable hypothesis testing. Its use is fundamental to obtain valid and robust results when working with time series data in econometrics.

in several ways. A sustained increase in prices can decrease the purchasing power of real wages, which could lead to increased demand for employment to compensate for the loss of income. On the other hand, a high level of inflation can also be detrimental to business investment and thus to job creation. The relationship between inflation and unemployment has been explored through the Phillips Curve, which shows an inverse relationship between inflation and short-run unemployment (Phillips, 1958).

3.4. Control Variables in Equation 2

Rural Unemployment Rate - The rural unemployment rate can influence the proportion of rural population due to its impact on migration decisions. An increase in the unemployment rate in rural areas tends to encourage migration to urban areas in search of better employment opportunities (Deller, 2010). Rural-urban migration is a key factor in urbanization and can decrease the proportion of the rural population.

Urban Unemployment Rate - The unemployment rate in urban areas can also affect the proportion of rural population, but in the opposite direction. An increase in the urban unemployment rate can motivate the migration of people from urban areas to rural areas in search of a lower cost of living and greater access to land (Oliveira et al., 2020). This could increase the proportion of the rural population.

Rural Labor Income - Labor income in rural areas is an essential component of the quality of life and economic balance of these communities. A stable and competitive labor income in rural areas can serve as an incentive for people to stay in these communities, thus contributing to their economic sustainability and the preservation of the proportion of rural population in the country (Salimova et al., 2022).

Urban Labor Income - This income often attracts people from rural areas in search of better economic prospects and employment opportunities. However, the cost of living in urban settings can also be significantly higher, which can influence migration decisions. Urban labour income plays a critical role in urbanization and can contribute to change in the proportion of a country's rural population.

Annual Price Index Change - The annual change in the price index, which reflects inflation, can influence the proportion of the rural population because of its impact on the cost of living. A sustained increase in average prices can lead to greater migration to rural areas, where costs tend to be lower and purchasing power is easier to maintain (Phillips, 1958; Keshri et al., 2017).

3.5. Control Variables in Equation 3

GDP (Previous Quarter) - The economy as a whole sets the context for the performance of the agricultural sector as it affects the demand for agricultural products and the resources available for agriculture. Previous positive national GDP growth is often associated with an increase in demand for food and agricultural products, which can boost Agricultural GDP. On the other hand, a declining national GDP can reduce the population's ability to spend on food and thus negatively affect agricultural production (FAO, 2017; FAO, 2020).

Rural Labour Income - Labour income in rural areas is closely related to Agricultural GDP. An increase in rural labor income can boost demand for local food and agricultural products, which in turn can increase agricultural production and thus agricultural GDP (Salimova et al., 2022). In addition, higher rural labor income can lead to investments in agricultural technology and more efficient practices, which can also contribute to agricultural GDP growth.

Rural Unemployment Rate - A high rural unemployment rate could indicate underemployment or a lack of job opportunities, which could lead to lower agricultural production due to a lack of available labor. On the other hand, a low rural unemployment rate could increase the labor force dedicated to agriculture, which could increase production and therefore agricultural GDP.

Annual Price Index Change- The annual price index change, which reflects inflation, is important for Agricultural GDP as it affects production costs and prices of agricultural products. High inflation could increase the costs of agricultural inputs such as fertilizer and fuel, which could reduce profitability and agricultural production. On the other hand, moderate inflation could increase the prices of agricultural products, benefiting farmers and contributing to agricultural GDP (Phillips, 1958; Piesse and Thirtle, 2010).

3.6. Control Variable in all Models

Positive Covid-19 Cases - The COVID-19 pandemic has had a significant impact on employment around the world, including rural areas. Academic literature has shown that pandemic-related lockdowns and restrictions have disproportionately affected certain economic sectors, such as tourism and hospitality, which are often important in rural regions. This has led to an increase in unemployment rates and a reduction in production in these areas (Bartik et al., 2020). The COVID-19 pandemic has had heterogeneous impacts on the rural and urban population. On the one hand, the need for social distancing and movement restrictions could have incentivized some people to move to rural areas in search of a safer environment. On the other losses in urban sectors could have led to reverse migration to rural areas (Hart, 2020). The influence of the pandemic on the proportion of the rural population will depend on specific contextual and policy factors.

In order to increase the robustness of the results, all equations are reestimated in a GARCH(0,1) model. A GARCH(0,1) model is a model that includes only one GARCH component and does not have an ARCH component. In a GARCH(0,1) model, the conditional variance in period t is modeled as follows:

$$\sigma_t^2 = \omega + \beta_1 \sigma_{t-1} \quad (4)$$

Where:

σ_t^2 is the conditional variance in period t.

ω is a constant representing the constant conditional variance.

β_1 is the coefficient that measures the impact of the past conditional variance on the current conditional variance.

σ_{t-1} is the conditional variance in the period t-1.

The GARCH(1) component in the model allows conditional volatility in period t to depend on conditional variance in period t-1. This makes it possible to capture short-term memory effects on volatility, which can be relevant in many financial contexts.[10] Finally, we perform a complementary analysis by using an autoregressive vector model (VAR) among the variables of interest to analyze the dynamic relationship between them, identify the existence of causality, analyze short- and long-term responses, make forecasts and examine the effects of shocks or exogenous changes.

4. EMPIRICAL RESULTS

In order to measure the effects of energy destined to the non-public service on the rural unemployment rate in Ecuador, Table 1 shows the estimates by means of OLS for Equation (1).[11] First, the p-value associated with the F-stat are very low (close to zero), suggesting that the model as a whole is statistically significant and provides a significantly better fit than a model without explanatory variables. The P-values associated with the Lagrange Multiplier Test are relatively high, ranging from 0.434 to 0.510. This suggests that there is no significant evidence of serial autocorrelation in model errors, which is a good sign for the validity of the estimates. Finally, the P-values associated with the ARCH test (Autoregressive Conditional Heteroskedasticity test) are also relatively high, especially in the latter case (0.997). This suggests that there is no significant evidence of conditional heteroscedasticity in model errors in most cases.

The estimated coefficient associated with the consumption of renewable energies by the non-public service, expressed in megawatt-hours (MWh), reveals a negative and significant relationship with the unemployment rate. This finding suggests that an increase in renewable energy consumption in the private sector has a favorable impact on decreasing unemployment in rural regions. A plausible explanation for this phenomenon could be found in the concomitant growth of the renewable energy industry, which generates employment through investment in sustainable energy projects and the expansion of operations. In addition, the adoption of more energy-efficient practices and technologies by companies opting for renewables can reduce their operating costs, allowing them to expand their activities and ultimately hire more workers.

Regarding the control variables, the statistically significant results are aligned with what was expected. The overall unemployment rate in the previous period and its coefficient is interpreted as the effect of the past unemployment rate on the current unemployment rate in rural regions. In all models, the coefficient is positive and highly significant, suggesting that a higher unemployment rate in the previous period is positively associated with a higher unemployment rate in the current period. This observation is quite compatible with the theory of business cycles. On the other hand, the coefficient of rural labor income is not statistically significant in any of the estimates ($P > 0.1$). This indicates that, in the models, labor income in rural areas does not have a statistically significant effect on the unemployment rate. Furthermore, Appendix 1 provides a comprehensive overview of descriptive statistics, shedding light on key variables sourced from reputable institutions. Also, in Appendix 2, unit root tests are conducted, offering insights into the stationarity of variables through Fisher-ADF, Ng-Perron, and Philips-Perron tests.

The results of the annual variation of the Price Index do not allow clear conclusions to be drawn, since the coefficients were not significant in all models. However, when considering the most complete model, where this control also presents statistical significance, we observe that for each additional unit of increase in the annual variation of the price index, the unemployment rate decreases on average by 0.53% points. Greater variation in prices could indicate greater economic activity or an environment in which companies have the flexibility to adjust prices based on market conditions, which could result in higher demand for employees and therefore a lower unemployment rate.

Finally, the variable controlling for the status of the Coronavirus pandemic is significant in most estimates, indicating that the number of positive COVID-19 cases has a significant and positive impact on the unemployment rate. Every increase in COVID-19 cases is associated with an increase in the unemployment rate. In addition, the estimates in the GARCH model maintained the signs and significance that in the OLS model, but without gaining significance for the variance forecast.

When analyzing the impact of an innovation boost in the use of renewable energy in the rural non-public sector on the rural unemployment rate using the VAR model with the same previous specifications, an interesting pattern is observed. In particular, it is identified that the reduction in the rural unemployment rate does not manifest itself immediately in response to marginal increases in the production and consumption of renewable energy. On the other hand, this reduction effect begins to become evident from the third quarter after the moment of innovation. In Figure 4, the graphical representation succinctly captures the behavioral trends associated with this insight.

This observation suggests that the introduction of renewable energy innovations in the rural non-public sector does not have an immediate impact on decreasing rural unemployment, but takes an appreciable time before its economic benefits are reflected in the employment rate. The delay could be related to business cycles. There may be time to adapt before rural employers respond to the opportunities generated by renewable energy innovation. This could be linked to the decision to hire more staff in response to an increase in renewable energy production. In summary, this delay in effects underscores the importance of considering the temporal dynamics in the relationship between renewable energy innovation and the rural labor market.

To measure the effects of the proportion of renewable energy produced over the total in Ecuador on the rural population as a proportion of the total in Ecuador, Table 2 shows the estimates by

10 Despite their simplicity, GARCH(0,1) models often fit well with real data. They are able to capture many of the characteristics of financial time series, such as the clustering of volatility and the persistence of variance fluctuations.

11 The explanatory variables of the model were added gradually in the table and estimated with each change as a way of showing that the model is robust.

Table 1: OLS estimators of the effect of renewable energy destined for non-public service on the unemployment rate of rural regions in ecuador

VD: Rural unemployment (%)	Estimations results				
Regressors	Eq reduced (a)	Eq reduced (b)	Eq reduced (c)	Eq 1 (OLS)	Eq 1 (GARCH)
C	1.205***	1.932***	1.914***	250.672***	2.506***
	(0.312)	(0.505)	(0.539)	(52.387)	(2.866)
Unemployment Rate (-1)	0.466***	0.421***	0.413***	34.512***	0.344***
	(0.136)	(0.114)	(0.116)	(11.616)	(0.125)
Rural Labor Income		−0.001	−0.001	−0.223	−0.002
		(0.001)	(0.002)	(0.146)	(0.002)
Price Index			0.000	−0.053*	0.000
Annual variation			(0.000)	(0.030)	(0.001)
Energy delivered to the				0.001***	0.001***
Rural Non-Public Service				(0.000)	(0.000)
Positive Cases Covid-19	0.001**	0.001***	0.000***	0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GARCH(-1)					0.081
					(2.866)
Adj. R2	0.271	0.270	0.257	0.283	0.283
F-stat	10.283	7.163	5.313	4.946	
P-value (F-stat)	0.000	0.000	0.001	0.001	
LM test	0.775	0.758	0.745	0.584	
Prob (LM)	0.436	0.435	0.434	0.510	
ARCH test	0.329	0.019	0.023	0.000	0.000
Prob (ARCH)	0.560	0.888	0.876	0.997	0.996

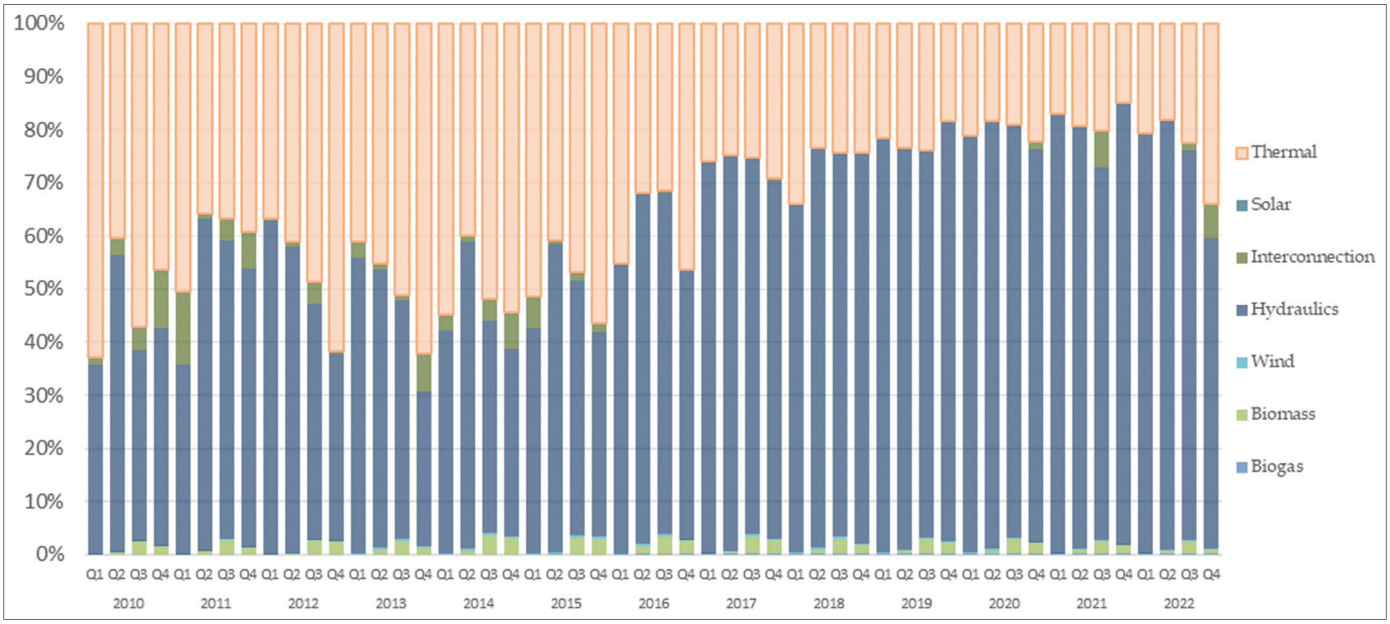
Significance levels: *** denotes 0.01, ** denotes 0.05 and * denotes 0.1. Standard errors in parentheses. OLS equation based on Newey and West estimators (1987)

Table 2: OLS estimators of the effect of renewable energy relative to the total on the rural population relative to the total.

DV: Rural population (%)	Estimates					
Regressors	Eq reduced (a)	Eq reduced (b)	Eq reduced (c)	Eq reduced (d)	Eq 2 (OLS)	Eq 2 (GARCH)
C	106.464	34.477	117.428	396.482	242.982	243.007
	(103.512)	(74.174)	(127.415)	(249.079)	(200.886)	(169.061)
Rural population	96.587***	98.61***	99.189***	91.311***	94.395***	94.396***
(% of Total) (-1)	(3.243)	(2.521)	(3.346)	(6.496)	(5.496)	(4.061)
Rural Unemployment Rate		−8.693	−8.848**	−8.973**	−5.948**	−5.915
		(4.353)	(3.980)	(3.613)	(2.386)	(7.314)
Urban Unemployment Rate		4.557	2.478	3.031	2.948	2.959
		(2.698)	(1.952)	(2.094)	(1.816)	(2.851)
Rural Labor Income			0.104	0.019	0.093	0.093
			(0.121)	(0.110)	(0.112)	(0.115)
Urban Labor Income			−0.227	−0.235**	−0.237**	−0.237**
			(0.120)	(0.115)	(0.101)	(0.113)
Price Index				0.03	0.040*	0.04***
Annual variation				(0.020)	(0.022)	(0.011)
Renewable energy					0.311*	0.309*
(% of Total)					(0.184)	(0.159)
Positive Cases Covid-19	0.001	0.000	0.001*	0.000*	0.000**	0.000**
	(0.000)	(0.000)	(0.003)	(0.000)	(0.000)	(0.000)
GARCH						0.339
						(3.209)
Adj. R2	0.972	0.973	0.976	0.979	0.980	0.980
F-state	863.947	455.609	341.247	326.902	305.896	
P-value (F-stat)	0.000	0.000	0.000	0.000	0.000	
LM test	5.492	4.891	7.376	5.369	3.904	
Prob (LM)	0.007	0.010	0.001	0.005	0.016	
ARCH test	11.779	9.971	7.485	11.393	6.103	6.093
Prob (ARCH)	0.002	0.003	0.009	0.002	0.018	0.018

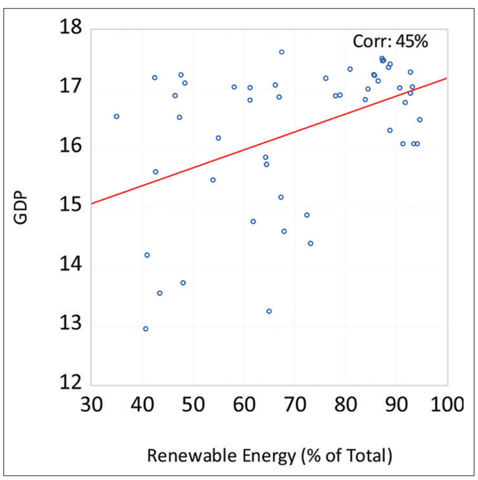
Significance levels: *** denotes 0.01, ** denotes 0.05 and * denotes 0.1. Standard errors in parentheses. OLS equation based on estimators from Newey and West (1987)

Figure 1: Ecuadorian energy matrix by energy produced



Source: Own elaboration with data from the Agency for Regulation and Control of Energy and Resources

Figure 2: Correlation between renewable energy (% of total) and GDP in Ecuador



Source: Own elaboration with data from the Agency for Regulation and Control of Energy and Resources.

means of OLS and GARCH for Equation (2). First, the p-value associated with the F-stat are very low (close to zero), again suggesting that the model as a whole is statistically significant and provides a significantly better fit than a model without explanatory variables. The p-values associated with the Lagrange Multiplier Test are relatively low, ranging from 0.001 to 0.016. Finally, the p-values associated with the ARCH test (Autoregressive Conditional Heteroskedasticity test) are also relatively low, especially in the first case (0.002). This suggests that there is significant evidence of serial autocorrelation and conditional heteroskedasticity in model errors in most cases and highlights the importance of using the Newey-West matrix.

The positive and significant coefficient of Renewable Energy as a proportion of total energy produced in Ecuador in all estimates suggests that a greater use of renewable energy with respect to total energy is positively related to the proportion of rural population in Ecuador. This was the expected outcome, as investment in renewable energy projects often involves the development of infrastructure, such as roads and power grids, that can improve the connectivity of rural communities. This facilitates access to essential services and can reduce the isolation of rural areas, benefiting the quality of life of rural residents. In addition, the transition to renewable energy sources can also have significant environmental benefits, such as reducing air pollution and mitigating climate change. These benefits can improve the health and quality of life of rural people by reducing exposure to pollutants and extreme weather events. All of these benefits influence people's decisions about migration to urban and rural regions.

The trend variable of the proportion of rural population is also positive and significant in all regressions. This indicates that there is a powerful factor of permanence in population dynamics. This finding suggests that historical trends in rural-urban migration have a lasting impact on migration patterns, implying that past migration decisions continue to influence future migration decisions, and vice versa.

The negative and significant coefficient of the rural unemployment rate in most estimates suggests an important relationship between unemployment in rural areas and the distribution of the rural population in Ecuador. This finding points to the possibility that an increase in the unemployment rate in rural areas is acting as a motivating factor for the migration of the rural population to urban areas, in search of better job prospects and economic opportunities. However, it is essential to highlight that the lack of statistical significance in relation to the urban unemployment rate in all estimates indicates that labor dynamics in urban areas do not appear to be a determining factor in the distribution of the rural population. This suggests that other factors, such as access to services, quality of life or economic development, may be playing a more influential role in rural Ecuadorian population's migration decisions.

Regarding rural labor income, the positive coefficient and the lack of statistical significance in all estimates suggest that the level of income derived from work in rural areas does not exert a statistically significant impact on the distribution of the rural population in Ecuador. This suggests that, surprisingly, income from employment in rural areas does not appear to be the main factor influencing migration decisions of the rural population in the country. On the other hand, the finding of a negative and significant coefficient in relation to urban labor income in most estimates suggests an interesting dynamic. This result indicates that an increase in income generated by work in urban areas is associated with a decrease in the proportion of rural population in Ecuador. This could suggest that the country's urban areas, with their seemingly more favorable economic prospects, may be attracting the rural population in search of better job and economic opportunities. This relationship underscores the importance of economic disparities between rural and urban areas in the country's internal migration process.

The positive and significant coefficient observed in relation to the annual variation of the price index in most estimates reveals an interesting connection between price fluctuations and the distribution of the rural population in Ecuador. This finding suggests that an increase in the annual variation of the price index, indicative of a certain level of inflation or price volatility, is positively associated with a higher percentage of the rural population. This could suggest that rural communities may be more resilient or less affected by economic fluctuations than urban ones, which could influence people's decision to stay in rural areas.

Likewise, the positive and significant coefficient related to positive cases of COVID-19 in all estimates points to an interesting relationship between the pandemic and the distribution of the rural population. This could indicate that a higher number of positive COVID-19 cases is positively related to the proportion of rural population in Ecuador. Specifically, the pandemic could have had an impact on migration decision-making, as some people might have chosen to move from more densely populated urban areas to rural areas in search of environments less affected by the pandemic. This finding underscores the interconnection between economic and health events in rural-urban population dynamics.

Table 3: OLS estimators of the effect of renewable energy (% of the Total) to the rural total on agricultural GDP

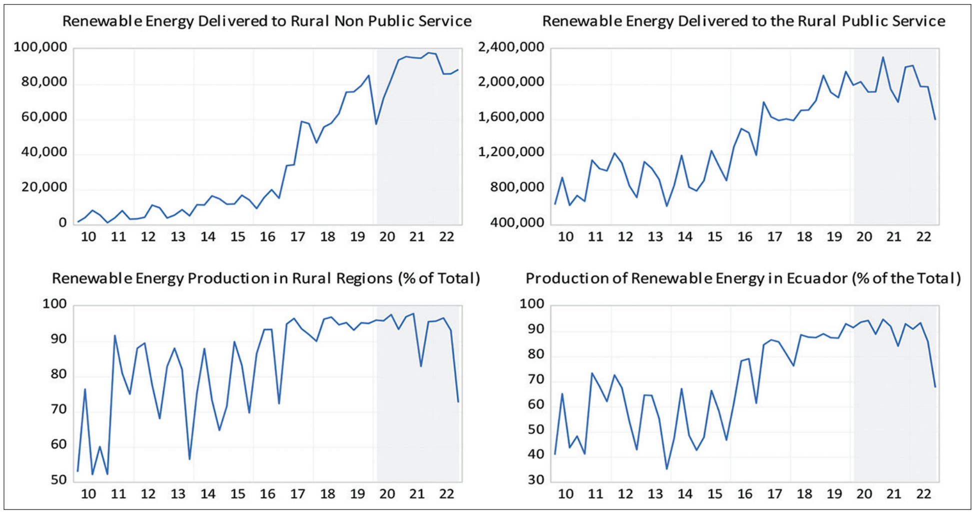
VD: GDP Agriculture	Estimates					
Regressors	Eq reduced (a)	Eq reduced (b)	Eq reduced (c)	Eq reduced (d)	Eq 3 (OLS)	Eq 3 (GARCH)
C	134840.2*	131349.4*	55735.26	58754.76	336797.2***	336751.4***
	(67239.39)	(69615.92)	(111289.80)	(111937.40)	(63489.55)	(125283.40)
GDP (-1)	0.071***	0.065***	0.067***	0.07***	0.051***	0.051***
	(0.004)	(0.005)	(0.005)	(0.006)	(0.005)	(0.009)
Renewable energy		1282.853***	1359.924***	1266.693***	573.792	574.67
(% of Rural Total)		(454.459)	(459.842)	(458.779)	(344.723)	(479.518)
Unemployment Rate			15235.63	15745.06	1388.377	1304.875
Rural			(14604.98)	(14525.69)	(8512.94)	(12807.78)
Labor Income				−135.94	310.801*	310.802
Rural				(233.268)	(183.099)	(326.081)
Price Index					−140.961***	−140.799***
Annual variation					(28.649)	(29.929)
Positive cases	0.000	0.000	0.000	0.000	0.001	0.001*
Covid-19	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
GARCH(-1)						0.318
						(6.550)
Adj. R2	0.857	0.875	0.876	0.874	0.926	0.926
F-state	150.295	117.946	89.464	70.459	105.148	
P-value (F-stat)	0.000	0.000	0.000	0.000	0.000	
LM test	36.577	21.823	19.879	19.941	10.388	
Prob (LM)	0.000	0.000	0.000	0.000	0.000	
ARCH test	27.523	20.238	17.805	18.862	6.075	6.002
Prob (ARCH)	0.000	0.000	0.000	0.000	0.018	0.018

Significance levels: *** denotes 0.01, ** denotes 0.05 and * denotes 0.1. Standard errors in parentheses. OLS equation based on estimators from Newey and West (1987)

Table 4: Research agenda that could contribute to extend the results found in this study

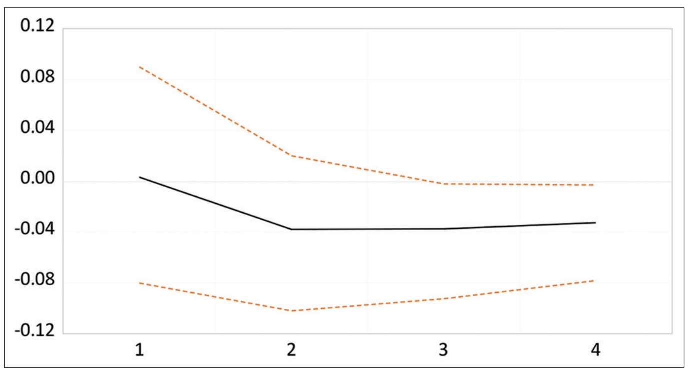
Method	Dependent variables	Independent variables
Panel: OLS, GMM	Labor Income of Solar Plant workers; Hydroelectric; etc., (differentiate by type of energy)	Plant Productivity; Inflation; energy produced; situational dummy variables; Dynamic variables of energy produced*Dummy variables (capture situational effects)
Cross Section: OLS	Cost of Energy (differences per Municipalities)	Represent the presence of renewable energy sources that feed the region/municipality.

Figure 3: Variables of interest-consumption and production of renewable electricity in Ecuador



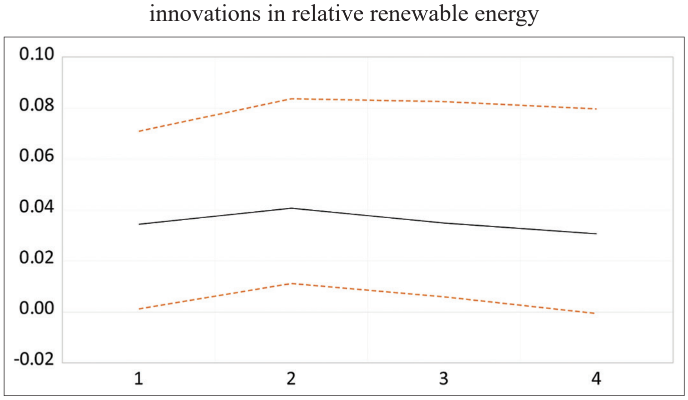
Source: Own elaboration with data from the Agency for Regulation and Control of Energy and Resources

Figure 4: Unemployment rate response to generalized innovations in non-public service energy



Innovations of a standard deviation of 90% CI are used using the Hall's percentile bootstrap with 1500 repeats

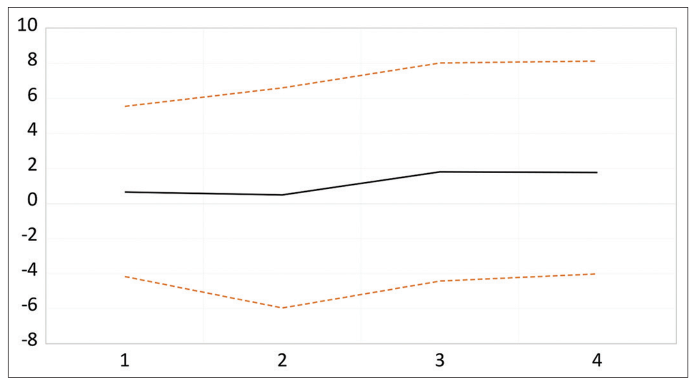
Figure 5: Response of the rural population (% of total) to generalized innovations in relative renewable energy



Innovations of a standard deviation of 90% CI are used using the Hall's percentile bootstrap with 1500 repeats

In Figure 5 it is possible to detect that the generalized impulses of the relative renewable energy share over the relative rural population have an immediate effect that remains over a year in the VAR model. Its point of greatest influence is the second quarter. These findings may suggest that the two types of demographic

Figure 6: Response of agricultural production to generalized innovations in renewable energy relative to rural total



Innovations of a standard deviation of 90% CI are used using the Hall's percentile bootstrap with 1500 repeats

decisions that influence the relative rural population are made at different times. On the one hand, some people who already live in rural regions may be incentivized by new technical work opportunities and by the environmental impact of renewable energies and desist from migrating to urban regions or even having more children. Moreover, some people living in more urbanized regions may be incentivized by new opportunities in the countryside and migrate to rural regions. These demographic movements are expected to happen at different times throughout the first year following innovation.

The last table of estimates, Table 3, shows the effects of the proportion of renewable energy produced in rural regions on Ecuador's agricultural production by means of OLS and GARCH for the Equation (3).

First, the p-value associated with the F-stat are very low (close to zero), again suggesting that the model as a whole is statistically significant and provides a significantly better fit than a model without explanatory variables. The P-values associated with the Lagrange Multiplier Test are low enough to know that there is evidence of heteroscedasticity in the residuals. Finally, the P-values associated with the ARCH test (Autoregressive Conditional Heteroskedasticity test) are also low enough to intuit that there is serial autocorrelation in the residuals. Again, the use of the Newey-West Matrix is fundamental in our models.

The statistical significance of Renewable Energy as a proportion of total energy produced in rural regions in this third estimate is limited to the first three specifications. Although the coefficient is positive as expected and in the incomplete models it has significance at 0.01, the estimate and final model does not allow us to affirm that our main variable of interest positively affects the agricultural product. The results suggest that, in the Ecuadorian context, the increase in the proportion of renewable energy generated in rural areas does not have a statistically significant impact on the country's Agricultural Gross Domestic Product. This indicates that fluctuations in renewable energy production and use in rural areas do not appear to be correlated with substantial changes in agricultural economic activity. In other words, the production of renewable energy in rural areas, although beneficial from an environmental and sustainable development perspective, does not seem to be a determining factor in the variations of Agricultural GDP in Ecuador.

The lack of a statistically significant relationship between the rural unemployment rate and rural labor income with Ecuador's Agricultural Gross Domestic Product (GDP) suggests that, in the context of this study, these variables are not key determinants of changes in agricultural production. This finding aligns with previous research that has highlighted the complexity of the factors that affect Agricultural GDP and that go beyond employment and income in the agricultural sector (Ribeiro, 2018). For our research, the added value of this result is to understand that the production of renewable energies, despite reducing the unemployment rate, apparently does not have significant effects on agricultural production. Future work can explore this relationship and try to understand which sectors are the most benefited by the reduction in unemployment, in addition to the energy sector itself.

On the other hand, the finding that past Agricultural GDP has a significant impact on future Agricultural GDP is consistent with the idea that historical trends, such as investments in agricultural infrastructure and technology, can influence agricultural productivity in the long run (Jain, 2020). In addition, the variation of the price index with a positive impact on Agricultural GDP suggests that fluctuations in the prices of agricultural products can play an important role in determining agricultural incomes, thus supporting the economic theory that changes in prices directly affect the profitability of the agricultural sector (Baffes et al., 2020). Figure 6 shows this tendency mentioned above.

The results of the VAR model confirm what was found in the OLS model. As can be seen, innovations from a standard offset of renewable energy relative to the total in rural regions do not have a significant effect on agricultural output in any quarter throughout the year. This suggests that agricultural production is insensitive to the type of energy produced. It is important to mention that this is a short and medium term relationship. In the long term, however, future research could find positive effects of the use of renewable energies in rural production due to beneficial effects on the environment.

It is important to mention that the finding that an increase in renewable energy consumption in the non-public sector is related to a significant decrease in the rural unemployment rate is consistent with the idea that the renewable energy industry can be an important driver of employment in rural areas. Numerous studies have shown that investment in sustainable energy projects can generate employment through the construction, operation and maintenance of renewable facilities (Dinica et al., 2017; Sovacool, 2009). Investment in sustainable energy projects can generate employment through the construction, operation and maintenance of renewable facilities. In addition, energy efficiency associated with renewables can reduce companies' operating costs, which could translate into the creation of more jobs (Awerbuch, 2008).

In addition, the observation that the reduction in the rural unemployment rate is not immediate, but begins to manifest itself from the third quarter after innovation in renewable energy, suggests an interesting temporal dynamic. This may be related to the process of implementing renewable energy projects, which often require time to plan, build and start operations (Huenteler, Schmidt, Ossenbrink & Hoffmann, 2016). In addition, the effects on employment may not be instantaneous, as they depend on the maturity of projects and job creation throughout their life cycle.

The positive and significant relationship between the share of renewable energy and the proportion of rural population supports the idea that investment in renewable energy can improve the quality of life in rural areas. Previous studies have shown that access to a reliable and clean energy source can have a positive impact on quality of life in remote areas (Alstone et al., 2015). In addition, the creation of infrastructure associated with renewable energy, such as roads and power grids, can improve the connectivity of rural communities (Jacobsson and Lauber, 2006). This can have a positive effect on rural population retention and attraction of urban migrants.

The observation that impulses in the share of renewable energy have an immediate effect that lasts for a year, with a peak in the second quarter, suggests that different demographic decisions influencing the rural population may occur at different times. Some rural residents may be incentivized by new job opportunities and the environmental impact of renewable energy, which could influence their decision to stay in rural areas or even have more children. At the same time, some individuals from urban areas may be attracted by emerging opportunities in the countryside and choose to migrate to rural regions.

In summary, the results of this study are consistent with the academic literature in terms of the positive effects of renewable energy adoption on rural employment and population. In addition, they highlight the importance of considering temporality in the response of these indicators to innovation in renewable energy and the need to understand demographic dynamics at different times after the implementation of these technologies.

5. CONCLUDING REMARKS

This paper presents a rigorous analysis of the impact that renewable energy development is having on the economies of rural regions in Ecuador. This study is distinguished by its sound empirical approach and rigorous methodology. A comprehensive collection of relevant data related to renewable energy production and consumption was carried out in the specific context of Ecuador. Subsequently, these data were subjected to a thorough statistical analysis, allowing an accurate assessment of the complex and dynamic relationships that exist between these energy sources and the dependent variables of greatest interest, particularly with regard to the labor market and employment in rural areas of the country. The significant contribution of this study lies in its ability to provide valuable and evidence-based information, offering a more complete understanding of how renewables are driving economic development in these regions, which may be useful for both policy-making and future research in this field.

We obtained results that provide valuable insight into how renewable energy adoption impacts the economy and demographics of rural regions. First, our results indicate that an increase in renewable energy consumption in the non-public sector is associated with a significant decrease in the unemployment rate in rural areas of Ecuador. In addition, we observe a positive and significant association between the share of renewable energy and the proportion of rural population in Ecuador. This relationship supports the idea that investment in renewable energy can have a positive impact on life in rural areas. Although the relationship between the proportion of renewable energy generated in rural areas and agricultural GDP initially seemed promising, our results do not show a statistically significant relationship in the Ecuadorian context. This suggests that, in the short and medium term, fluctuations in the production and use of renewable energy in rural areas are not correlated with substantial changes in agricultural economic activity. However, it is highlighted that, in the long term, future research could find positive effects on rural production due to environmental and sustainable development benefits.

This study significantly highlights the importance of renewable energy adoption in rural areas, not only as a means to boost job creation, but also as a key catalyst for improving the quality of life of rural communities. At the same time, however, it highlights the imperative need for a more comprehensive and long-term analysis. This deeper analysis should carefully address demographic dynamics, considering factors such as disaggregated migration and rural population retention. These factors are crucial to gain a full and accurate understanding of the effects of the ongoing energy transition in Ecuador's rural regions and potentially in other countries with similar challenges and contexts. It is therefore clear that continuous research and a comprehensive approach are required to fully exploit the potential of renewables in these areas.

One of the difficulties of this study was working with variables strongly prone to endogeneity. To address this limitation, we use dynamic OLS, GARCH and VAR models, however, a more careful treatment of this possibility requires higher levels of freedom that the number of available observations does not allow. In addition, this work was limited by the use of proxies for key variables, by the limited information available and the time of capture of some data, however, in a few years the databases of Ecuador should offer a greater number of observations, higher quality in the data and allow more extensive studies. In time series, an example that future researchers interested in this topic can follow would be to discriminate unemployment by industries or sectors.

Finally, Table 4 presents a comprehensive research agenda aimed at expanding the findings of this study. By employing various methods such as OLS and GMM, exploring diverse dependent variables including labor income and energy productivity across different energy types, and investigating dynamic factors like situational dummy variables, this agenda lays the groundwork for a nuanced understanding of the intricate relationships within the renewable energy sector. These efforts strive to contribute valuable insights, ultimately enriching our comprehension of the broader implications for plant productivity, inflation, and the cost of energy across municipalities with distinct renewable energy source.

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APPENDIX

A. 1: Descriptive statistics and source of variables

Statistics	Source	Mean	Median	Max	Min	Std. D.
Rural Unemployment Rate	National Survey of Employment, Unemployment and Underemployment	2.223	2.252	3.345	1.287	0.437
Urban Unemployment Rate	National Survey of Employment, Unemployment and Underemployment	5.783	5.576	9.100	4.203	1.034
Unemployment Rate	National Survey of Employment, Unemployment and Underemployment	2.232	2.242	3.345	1.287	0.452
Rural Labor Income	National Survey of Employment, Unemployment and Underemployment	321.660	319.850	410.754	272.452	29.852
Urban Labor Income	National Survey of Employment, Unemployment and Underemployment	533.8883	536.1952	614.1499	460.9458	36.76268
Energy delivered to the Rural Non-Public Service	Energy and Resources Regulation and Control Agency	38775.33	16423.27	97726.62	988.25	35346.91
Renewable Energy (% of total)	Energy and Resources Regulation and Control Agency	71.22519	72.83914	94.67276	35.06181	18.22673
Renewable Energy (% of Rural Total)	Energy and Resources Regulation and Control Agency	84.22269	89.62815	97.83516	52.0945	13.36283
Gross Domestic Product	Central Bank of Ecuador	16311591	16864758	17615448	12941210	1224564
Agricultural Gross Domestic Product	Central Bank of Ecuador	1300106	1338528	1426246	1079721	98391.36
Rural Population (% of total)	Central Bank of Ecuador	32.40887	32.00083	33.75471	31.67986	0.780397
Price Index Annual Change	Consumer Price Index Viewer	221.1377	266	612	-93	201.8981

A. 2: Unit Root Test

Variable	Fisher - ADF			Ng-Perron					Philips-Perron		
	Statistic	CV (10%)	Lag	Lag	MZa Test	CV (10%) MZa	MZt Test	CV (10%) MZt	Choi Z-stat	CV (10%)	Bandwidth
Rural Unemployment Rate	−1.19597	−1.61273	1	0	−18.99	−5.700	−2.86773	−1.620	−1.004	−1.613	22
Rural Population (% of total)	−1.25305	−1.61273	1	0	−0.5873	−5.700	−0.36232	−1.620	−1.810	−1.613	1
Total Unemployment Rate	−1.31131	−1.61273	1	2	−10.051	−5.700	−1.98525	−1.620	−1.428	−1.613	1
Urban Unemployment Rate	−1.45288	−1.61273	0	0	−4.197	−5.700	−1.23955	−1.620	−1.550	−1.613	8
Rural Labor Income	0.335318	−1.61273	2	2	−1.9663	−5.700	−0.98252	−1.620	0.239	−1.613	18
Renewable Energy (% of Rural Total)	−0.21449	−1.61273	4	4	−5.3891	−5.700	−1.63881	−1.620	0.037	−1.613	19
CPI Annual Variation	−0.74346	−1.61273	0	0	−2.6278	−5.700	−1.12591	−1.620	−1.011	−1.613	4
Energy delivered to the Rural Non-Public Service	0.500443	−1.61273	10	10	−2.2749	−5.700	−1.04406	−1.620	−0.006	−1.613	17
Urban Labor Income	0.791287	−1.61273	0	0	0.2988	−5.700	0.19587	−1.620	1.063	−1.613	2
Covid - Positive Cases	−12.9484	−1.61273	0	10	1.2085	−5.700	4.54921	−1.620	−0.315	−1.613	0
Gross Domestic Product	2.464456	−1.61273	0	1	−0.0993	−5.700	−0.0645	−1.620	1.744	−1.613	4
Renewable Energy (% of total)	0.032158	−1.61273	5	5	−1.6015	−5.700	−0.89145	−1.620	0.040	−1.613	15
GDP Agriculture	1.379722	−1.61273	0	1	−1.0157	−5.700	−0.55626	−1.620	1.355	−1.613	4

A. 3: Series Cointegration Test

Number of cointegration relations per model - Equation (1) - Unemployment

Test Type	No intercept No trend	Intercept No trend	Intercept No trend	Intercept Trend	Intercept Trend
Data Trend	No	No	Linear	Linear	Quadratic
Trace	1	1	1	1	0
Max-Eig	1	0	0	0	0
Rank or n. of E.C.					
0	76.37856*	76.37856*	76.64272	76.64272	76.82562
1	76.53808	76.58144	76.79001	76.79351	76.90249
2	77.03383	76.98858	77.13744	77.14897	77.18373
3	77.59975	77.61926	77.69047	77.74428	77.71766
4	78.25977	78.32551	78.37859	78.39207	78.41549
5	79.01748	79.11378	79.11378	79.18958	79.18958

Number of cointegration relations per model - Equation (2) - Population

Test Type	No intercept No trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Data Trend	No	No	Linear	Linear	Quadratic
Trace	2	2	2	2	2
Max-Eig	1	1	1	2	2
Rank or n. de E.C.					
0	43.07836	43.07836	43.44542	43.44542	43.79927
1	43.06932*	43.14774	43.45121	43.26483	43.53988
2	43.49472	43.63814	43.86221	43.35211	43.54825
3	44.16742	44.27043	44.47685	43.89614	44.04101
4	44.92472	45.08674	45.27106	44.67477	44.74216
5	45.84149	46.0261	46.13414	45.58453	45.63158

Number of cointegration relations per model - Equation (3) - GDP

Test Type	No intercept No trend	Intercept No trend	Intercept No trend	Intercept Trend	Intercept Trend
Data trend	No	No	Linear	Linear	Quadratic
Trace	1	2	2	2	2
Max-Eig	1	1	2	1	1
Rank or n. of E.C.					
0	54.31625*	54.31625*	54.63672	54.63672	54.84939
1	54.38414	54.46323	54.71049	54.72589	54.88301
2	54.75625	54.76836	54.93942	55.0233	55.1017
3	55.30009	55.3786	55.51823	55.44825	55.44838
4	55.99766	56.0553	56.13447	56.10748	56.15419
5	56.7815	56.851	56.851	56.90324	56.90324

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