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The Role of Financial Market Development in Renewable Energy Generation: Evidence from European Countries

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ABSTRACT

This paper investigates the relationship between renewable energy generation and financial market development in European countries. It enhances the existing literature by analysing this relationship through three dimensions of financial market development—access, efficiency, and depth—and by categorizing renewable energy generation into three types: Wind, solar, and hydroelectric. The study also examines the mediating role of stock market capitalization in this nexus. Employing panel two-stage least squares (2SLS) based on Lewbel's instrumental variable approach, the findings reveal that wind energy generation is the most responsive to the different components of financial market development in European countries. Furthermore, using bootstrapping causal mediation analysis, the results confirm a significant mediating effect of stock market capitalization, particularly in the influence of financial market development on wind energy generation. These findings provide actionable insights for policymakers aiming to finance renewable energy initiatives to advance Sustainable Development Goal 13.

Keywords: Renewable Energy, Financial Development, Wind Generation, Solar Generation, Panel Two-Stage Least Squares
JEL Classifications: C5, G2, Q2, Q4

1. INTRODUCTION

Global warming stands as one of the most pressing issues of our time, with well-documented threats including drought, severe weather events, diseases, rising sea levels and glacier melt. Despite these threats, the global demand for fossil-fuel-based domestic and commercial production has led to significant increases in global carbon dioxide (CO_2) emissions over the last two decades (Kartal et al., 2023). Given that the energy sector contributes significantly to greenhouse gas (GHG) emissions, substantial efforts towards environmental protection revolve around renewable energy growth. With its lower GHG emissions, renewable energy has emerged as vital alternative to fossil-fuel led energy production, particularly in pursuit of the universal goal of achieving economic growth alongside environmental sustainability.

The adoption of renewable energy is often hindered by significant information requirements and substantial upfront costs, making these projects highly capital-intensive (Lehmann and Söderholm, 2018; Alsagr, 2023). Renewable energy initiatives demand considerable financial investment, with large sunk costs incurred long before energy production begins, emphasizing the critical need for robust financing mechanisms (Patel, 2010). By enabling the availability and accessibility of funding, efficient financial markets can significantly enhance renewable energy generation (Lin and Okoye, 2023) and drive renewable energy development through financial efficiency channels (Best, 2017).

A growing body of literature has examined the impact of financial development on pollution reduction as well as the consumption and production of renewable energy (Anton and Afloarei Nucu, 2020; Raza et al., 2020; Mukhtarov et al., 2022). However, these studies yield mixed results. Some suggest that financial development negatively affects renewable energy adoption (Wang et al., 2021), while others identify a non-linear relationship (Chang, 2015; Sare, 2019; McFarlane et al., 2022) or find no significant relationship at all (Denisova, 2020). These inconsistencies stem from several factors, including the use of different methodological approaches, variations in sample countries, and diverse proxies for financial development, all of which contribute to heterogeneous findings.

Many of the aforementioned studies have increasingly shifted their focus toward exploring the nexus renewable energy and financial development in general, relying on proxies such as broad money as a percentage of GDP, which represents the overall liquidity available in an economy, and domestic credit provided by the financial sector as a percentage of GDP, which serves as an indicator of access to financing. However, while these proxies provide valuable insights into the availability of financial resources, they may offer only a limited view of the broader financial landscape. Fewer studies delve into the specific role of financial market—such as the growth and efficiency of stock markets, bond markets, and the availability of green financial products—in directly supporting renewable energy production and consumption (Zeqiraj et al., 2020; Sherazet al., 2022; Bonga-Bonga and Kirsten, 2024).

Despite the critical role financial markets play in advancing the renewable energy agenda, to the best of our knowledge, no existing study has thoroughly examined this relationship in detail. Specifically, there is a noticeable gap in the literature when it comes to assessing how different dimensions of financial market development—namely, market access, efficiency, and depth—impact various sources of renewable energy production, such as wind, solar, and hydroelectric energy.

Financial market access refers to the ability of firms and investors to enter and participate in financial markets (Feghali et al., 2021; Svirydzenka, 2016), which is crucial for funding renewable energy projects. Greater access to capital markets may allow renewable energy producers to secure funding through equity offerings, debt instruments, or green bonds. However, the extent to which access to financial markets enables large-scale projects like wind farms, solar plants, or hydroelectric dams remains largely unexplored.

Financial market efficiency, on the other hand, relates to how effectively financial markets allocate capital to productive ventures (Vo, 2021; Cai, 2020; Treleaven, 2015), including renewable energy initiatives. Efficient markets ensure that the cost of capital is lower for renewable energy projects, making them more attractive to investors. Moreover, efficient pricing mechanisms in financial markets can help manage risks associated with renewable energy investments, such as fluctuating energy prices and regulatory uncertainties. Yet, the role of market efficiency in facilitating the growth of specific renewable energy sectors remains an underdeveloped area of research.

Lastly, financial market depth, which refers to the range of financial instruments available and the overall size and liquidity of the market, is another crucial factor (Díaz and Escribano, 2020). Deeper financial markets are more capable of supporting long-term investments in capital-intensive renewable energy projects. For example, countries with deep bond markets may provide better opportunities for issuing green bonds, which are specifically designed to fund renewable energy infrastructure. Yet, the connection between financial market depth and the scalability of different renewable energy sources (e.g., wind versus solar) has not been rigorously analyzed.

Given the importance of these aspects—market access, efficiency, and depth—it is crucial to uncover how each of these factors influences the financing and development of renewable energy sources. To address this gap, this paper will contribute to the literature on financial market development and renewable energy production in several ways. First, it will assess the impact of financial market development on renewable energy production, distinguishing between different aspects such as market access, efficiency, and depth, and examining their effects on various sources of renewable energy, including wind, solar, and hydroelectric energy production. Second, to address potential endogeneity in the modeling process, the paper employs a panel two-stage least squares (2SLS) approach based on Lewbel's instrumental variable technique, wherein instruments are generated internally from the model's own data, ensuring a more robust estimation process. Finally, the paper investigates the average causal mediation effect of stock markets on the relationship between disaggregated financial market development and renewable energy production, offering a nuanced understanding of how stock market capitalisation mediates the influence of financial development on renewable energy growth.

The remainder of the paper is organised as follows: Section 2 reviews the relevant literature. Section 3 details the research methodology and the data used. Section 4 presents the results, while Section 5 concludes the study with a discussion of policy implications.

2. LITERATURE REVIEW

The literature identifies three channels through which renewable energy could be influenced by financial development. The direct channel refers to the level of efficient financial intermediation that enables consumers to access financial resources for acquiring renewable energy products, such as residential solar panels. The investment channel pertains to the ease at which investors can gain access lower-cost financial capital specifically for renewable energy projects. Lastly, the wealth channel is based on the trust consumers and investors have about the financial system, which indirectly leads to higher levels of renewable energy consumption. (Kim and Park, 2016; Lin and Okoye, 2023). However, the relationship is not straightforward, as financial development has also been shown to increase CO_2 emissions through the introduction of new products and machinery, as well as through easier accessible loans, enabling consumers to purchase CO_2 intensive products like air conditioners, automobiles and other electronic products (Sadorsky, 2010).

Given the intricate relationship between financial development and environmental sustainability, an expanding body of literature has explored the link between financial development and renewable energy, often yielding mixed findings. Brunnschweiler (2010) demonstrated that financial sector development positively influences renewable energy production in a panel of non-OECD countries, emphasizing that participants in the renewable energy sector are more inclined toward countries with advanced financial systems. Similarly, Horky and Fidrmuc (2024) analysed the effect of financial development on renewable energy adoption in 32 EU and ASEAN countries, concluding that well-developed capital markets significantly promote green energy initiatives, particularly in EU countries. Additionally, a robust financial system enhances the capacity of the business community to invest in renewable energy resources (Shahbaz et al., 2021; Zhang and Razzaq, 2022).

Empirical studies further substantiate the positive relationship between financial development and renewable energy consumption. For example, Wu and Broadstock (2015), analysing data from 22 emerging economies, found that financial development significantly enhances renewable energy consumption. Similarly, Mukhtarov et al. (2022), using the vector error correction model (VECM) and the auto-regressive dynamic lag (ARDL) methodologies, demonstrated that financial development positively impacted renewable energy consumption in Turkey from 1980 to 2019. Khan et al. (2020), employing a panel quantile regression approach across 192 countries from 1990 to 2018, also concluded that financial development increases renewable energy consumption. Shahbaz et al. (2021) provided additional support, showing that financial development drives renewable energy consumption in 34 developing countries during the period 1994-2015. Moreover, Mukhtarov et al. (2020) and Eren et al. (2019) identified a positive impact of financial development on renewable energy consumption in Azerbaijan and India, respectively.

However, some studies have reported negative or non-existent relationships between financial development and Renewable energy consumption and generation. Wang et al. (2021), using the ARDL-pool mean group (PMG) technique, found that financial market development negatively effects renewable energy consumption for China. Burakov and Freidin (2017) assessed the relationship between financial development, economic growth and renewable energy in Russia between 1990 and 2014 using the VECM model, finding no causality from financial development to renewable energy consumption. Similarly, Saadaoui (2022) found that financial development has no impact on renewable energy consumption for nine MENA countries.

While the aforementioned studies primarily examine the general relationship between financial development and renewable energy, relatively few have delved into the specific nexus between financial markets and renewable energy. For example, Sheenan et al. (2024) investigate the interactions between sustainable bond markets and various financial markets in Europe, including corporate bonds, sovereign bonds, renewable energy, equity, and volatility markets. Using a Markov-switching vector autoregressive model, they uncover evidence of bi-directional contagion between sustainability-linked and green bond markets, as well as contagion effects involving other fixed-income markets and sustainable bonds. Similarly, Irfan et al. (2022) explore the dynamic influence of mineral resources and financial markets on the energy transition in the top 20 mineral-exporting countries from 1980 to 2020. Employing a family of ARDL models, their findings reveal that while mineral markets positively contribute to the transition toward sustainable energy, financial markets exhibit a negative relationship with sustainable energy in both the short and long term.

To the best of our knowledge, there is a significant gap in the literature regarding the assessment of how different dimensions of financial market development—specifically market access, efficiency, and depth—affect various sources of renewable energy production, including wind, solar, and hydroelectric energy. Furthermore, the mediating role of stock market capitalisation in the nexus between financial market development and renewable energy production remains largely unexplored, especially among European countries.

3. DATA, MODEL AND METHODOLOGY

The paper aims to assess how various aspects of financial market development—specifically, financial market depth, access, and efficiency—influence different sources of renewable energy generation, including wind, solar, and hydroelectric power, within the European countries. To achieve this, the study employs a panel two-stage least squares (2SLS) based on Lewbel's instrument approach, whereby instruments are generated internally from the model's own data. In addition, the paper investigates the average causal mediation effect of stock market capitalisation on the relationship between disaggregated financial market development and different sources of renewable energy production.

This section outlines the methodologies employed in the paper, including the data sources, model specification, estimation procedures, and diagnostic tests. We begin by detailing the source and types of data used, and the time frame covered. We then describe the theoretical framework, and the corresponding econometric model used to analyze the data. This includes an explanation of the dependent and independent variables, as well as any control variables incorporated into the model.

Next, we discuss the statistical methods and techniques related to the 2SLS based on Lewbel's instruments. Finally, we elaborate on various diagnostic tests and robustness test conducted to validate the assumptions of our econometric model.

3.1. Data Sources

The dataset encompasses annual data from 1997 to 2021 for 28 European countries, selected based on data availability. Details of these countries are provided in the appendix. Table 1 displays the various variables collected for this analysis. The data for these variables were sourced from "The Global Economy," which is accessible at https://www.theglobaleconomy.com/.

It is important to note that the level variables are transformed using the natural logarithm transformation, which enhances the robustness and interpretability of the model, providing clearer insights into the underlying relationships between the variables.

Before assessing the relationship between the different components of renewable energy and financial market development, we present the estimation of the correlation among the variables used in Table 2. The results presented in Table 2 indicate a high positive correlation between overall financial market development (FINDEV) and financial market depth (FINDEPTH) and financial market access (FINACCESS). This relationship may suggest that the overall development of financial markets is largely influenced by the component of financial market access and depth. Another significant positive correlation is observed between wind energy generation (WIND) and solar energy generation (SOLAR). This strong correlation could impact the choice between these two types of renewable energy by investors, influencing both the selection of energy sources and the decisions made regarding the financing of these renewable energy projects, particularly in terms of asset selection.

3.2. Model Specification

The empirical model for this paper is based on the following panel data regression equation:

$$Y_{it} = \alpha + \beta_1 X_{it} + \beta_2 F_{it} + \beta_3 Z_{it} + \epsilon_{it} \quad (1)$$

Where:

- Y_{it} is the dependent variable representing each of the renewable energy source at time .
- X_{it} is the candidate endogenous explanatory variable in the model, CO2.
- F_{it} represents each type of financial market development.
- Z_{it} is the vector of exogenous control variables.
- α is the constant term.
- $\beta_{1,}\beta_2$ and β_3 are the coefficients of the model.
- ϵ_{it} is the error term.

An example of a specific representation of Equation 1 can be as

$$WIND_{it} = \alpha + \beta_1 CO2_{it} + \beta_2 FINACC_{it} + \beta_3 Z_{it} + \epsilon_{it} \quad (2)$$

Where the vector Z_{it} includes key control variables such $MARKCAP_{it}$, $GDPCAP_{it}$, $ENVTAX_{it}$

Equation 2 pertains to the estimation of factors determining wind energy generation. CO_2 emission is the possible endogenous regressor due to its potential reverse causality with renewable energy generation. Specifically, an increase in CO_2 emissions may prompt a transition from fossil fuels to renewable energy following the commitment of many countries to combat climate change. Conversely, an increase in renewable energy generation may lead to a reduction in CO_2 emissions.

3.3. Estimation Procedure

To estimate Equation 1 or 2 we use the panel 2SLS based of the Lewbel's instrument approach. The general procedure of the 2SLS methodology lies in the fact that to address that endogeneity of the regressor, CO_2 in our case, instrumental variables need to be chosen. Most of the existing methodologies rely on external instruments and lagged values the endogenous regressors (Arellano and Bond, 1991). Thus, the first-stage regression in the 2SLS methodology is specified

$$X_{it} = \gamma + \delta IV_{it} + \theta Z_{it} + v_{it}$$

Where:

- IV_{it} represents the instrumental variables.
- γ, δ, and θ are coefficients.
- v_{it} is the first-stage error term.

In the second stage, we replace X_{it} with its fitted values from the first-stage regression. The second stage regression equation is:

$$Y_{it} = \alpha + \beta_1 \hat{X}_{it} + \beta_2 Z_{it} + \grave{o}_{it}$$

Where $\hat{X}_{it}$ are the predicted values of X_{it} from the first stage.

However, the essence of Lewbel's method lies in generating instruments internally from the model's own data by exploiting the heteroscedasticity in the data (Lewbel, 2012). Specifically, Lewbel's method relies on the presence of heteroscedasticity in the model's error terms to identify the structural parameters without needing traditional instrumental variables (IVs). The method requires that the regressors be uncorrelated with the product of heteroscedastic errors.

Table 1: Variables and their description

Variables	Description
WIND	Wind electricity generation, billion kilowatts
SOLAR	Solar electricity generation, billion kilowatts
HYDRO	Hydroelectricity generation, billion kilowatts
ENVTAX	Environmental Taxes and Expenditures
MARKETCAP	Stock market capitalisation (billion USD)
FINDEV	Overall financial market development index points
FINACCESS	Access to financial market: index point
FINDEPTH	Depth or size of financial market: index point
FINEFF	Efficiency of financial market: index point

Table 2: correlation of the different variables

	CO_2	ENTAX	GDPCAP	MARKCAP	FINDEV	FINDEPTH	FINACCESS	FINEFF	WIND	SOLAR	HYDRO
CO_2	1										
ENTAX	0.3491	1									
GDPCAP	−0.0785	−0.8129	1								
MARKCAP	−0.0330	0.0496	0.0442	1							
FINDEV	0.2921	0.3443	0.0763	0.3777	1						
FINDEPTH	0.252	0.2715	0.1719	0.4449	0.8234	1					
FINACCESS	0.1811	0.2678	−0.0691	0.1888	0.7358	0.2408	1				
FINEFF	0.211	0.1031	0.0394	0.0517	0.3408	0.3047	0.0249	1			
WIND	−0.1051	−0.2233	0.2459	0.6373	0.198	0.2217	0.0867	−0.1211	1		
SOLAR	−0.0652	−0.1690	0.1647	0.5293	0.0717	0.076	0.0539	−0.1576	0.847	1	
HYDRO	−0.2628	0.0939	0.0008	0.5382	0.2935	0.3677	0.0825	0.0684	0.229	0.197	1

One of the key advantages of Lewbel's approach is that it does not require external or traditional instruments, which can be difficult to find or validate. Instead, it generates instruments directly from the available data, making it a powerful tool in empirical research where external instruments are not available or are weak.

4. ESTIMATION, RESULTS AND DISCUSSION OF RESULTS

We employ the Lewbel methodology to estimate various iterations of Equation 2, with WIND, SOLAR, and HYDRO as the dependent variables. This approach primarily evaluates the influence of overall financial market development and its individual components on these dependent variables. To ascertain the endogeneity of CO_2, we conducted the Durbin-Wu-Hausman test of endogeneity on CO_2 on the various representation of Equation 2. For example, for WIND as a dependent variable, the obtained probability value of 0.003 in the Durbin-Wu-Hausman test of endogeneity reflect the rejection of the null hypothesis of the exogeneity of CO2[1].

Given that the internal choice of instruments in Lewbel's methodology is based on the heteroscedasticity of the error term, we need to ascertain that the error term in the direct estimation Equation 2 is heteroscedastic. To this end, we conducted the Breusch-Pagan test of Homoscedasticity. The null hypothesis of homoscedasticity was rejected for all the models. For example, for the equation that modes the determinants of WIND the obtained probability value 0f 0.0000 denotes the rejection of the null hypothesis of homoscedasticity for the alternative hypothesis of heteroscedasticity.

Tables 3-6 display results that primarily assess the effects of overall financial market development and its components on various aspects of renewable energy. We reported only the results of the second stage, which are the most important results in the context of the paper.

The results reported in Table 3 show that among the components of renewable energy generation, only wind energy generation varies positively with the development of financial market with an elasticity of 6.37%. The results of the solar energy and hydroelectric energy generation are not statistically different to zero regarding financial market development. Another important result reported in Table 3 is the negative relationship between CO_2 emission and the different components of renewable energy generation supporting the hypothesis that renewable energy generation contributes to the decrease in CO_2 emission (Madaleno and Nogueira, 2023; Rehman et al., 2023; Wang et al., 2021; Adams and Nsiah, 2019).

Regarding the postestimation results reported in Table 3, we reported the Anderson LM statistics, the Sargan statistics and the Cragg-Donald F-statistics. The Anderson LM statistic in the context of the post-estimation of a Two-Stage Least Squares (2SLS) model is used to test whether the instrumental variables (IVs) used in the model are relevant. Specifically, it tests the null hypothesis that the instruments are weak. If the null hypothesis is rejected, as in all our models, it suggests that the instruments are strong enough to be used in the 2SLS estimation.

1 Other results can be provided on request.

Table 3: Disaggregated renewable energy generation and overall financial market development

Variables	WIND	SOLAR	HYDRO
	Coefficients	Coefficients	Coefficients
CO_2	−11.27***	−6.44***	−0.08
GDPCAP	−0.00000079	0.000024***	−0.000000094
FINDEV	6.37***	0.14	−0.01
MARKCAP	0.68***	0.50***	0.002
Anderson LM statisitics	31.74****	40.824***	46.47***
Sargan Statisitcs	0.22	6.437**	2.01
Cragg-Donald F statistics	11.42*	15.98**	17.23**

Table 4: Disaggregated renewable energy generation and the depth of financial market

Variables	WIND	SOLAR	HYDRO
	Coefficients	Coefficients	Coefficients
CO_2	−8.62***	−5.72***	−0.24
GDPCAP	−0.000000414	0.000026***	−0.00000011*
FINDEPTH	5.84***	0.13	0.18
MARKCAP	0.82***	0.45**	0.01
Anderson LM statisitics	23.06***	28.26***	61.48***
Sargan Statisitcs	15.10***	4.93*	1.522
Cragg-Donald F statistics	8.085	10.41*	23.79**

Table 5: Disaggregated renewable energy generation and financial market access

Variables	WIND	SOLAR	HYDRO
	Coefficients	Coefficients	Coefficients
CO_2	−10.08***	−7.46***	−0.09
GDPCAP	0.000000308	0.0000225***	−0.000000084
FINACCESS	6.01***	0.17	0.01
MARKCAP	0.79***	0.58**	0.003
Anderson LM statisitics	29.39***	36.92***	53.81***
Sargan statisitcs	1.98	6.603**	1.59
Cragg-Donald F statistics	10.5	14.18	20.37

Table 6: Disaggregated renewable energy generation and financial market effectiveness

Variables	WIND	SOLAR	HYDRO
	Coefficients	Coefficients	Coefficients
CO_2	−10.01***	−7.65***	−0.10
GDPCAP	−0.000000118	0.000021***	−0.000000084
FINEFF	1.317	−1.28	−0.03
MARKCAP	0.96***	0.56**	0.003
Anderson LM statisitics	18.39***	48.99***	56.92***
Sargan statisitcs	0.828	4.3	1.81
Cragg-Donald F statistics	6.35	20.01**	21.74**

The Sargan statistic is used in the context of instrumental variable (IV) regression models, such as the Two-Stage Least Squares (2SLS), to test the validity of the instruments used in the estimation process. The test evaluates whether the instruments satisfy the orthogonality condition, which is crucial for the validity of IV estimations. Contrary to the Anderson LM test, the Sargan test the null hypothesis that the instruments are valid, meaning they are uncorrelated with the error term. However, the alternative hypothesis tests whether the instruments are invalid, meaning they are correlated with the error term. The results reported in Table 3 show that the null hypothesis of valid instrument is not rejected for the models of the determinants of wind and hydroelectric energy generations.

The Cragg-Donald F statistic is a test used in the context of Two-Stage Least Squares (2SLS) regression to assess the strength of the instruments used in the model. Specifically, it helps identify whether the instruments used for the endogenous explanatory variables are weak. The null hypothesis of the test is that the instruments are weak, and the alternative hypothesis is that the instrument are strong. The statistic is compared to critical values provided by Stock and Yogo (2005), which depend on the number of instruments, endogenous variables, and the significance level. The results reported in Table 3 show that the instruments used are strong with different levels of biases based on the Stock-Yogo critical values.

The different tests support the relevance and strength of the different models used and validate the results of the 2SLS method used, given the validity of the identified instruments.

Tables 4-7 present the results of the components of financial market development – financial market depth (FINDEPTH), financial market access (FINACCESS), and financial effectiveness (FINEFF) - on the components of renewable energy.

The results reported in Table 4 show a positive and statistically significant relationship between financial market depth and wind energy generation. However, there is no statically significant relationship between financial market depth and solar and hydroelectric energy generations. A noticeable outcome of the results depieced in Table 4 is that market capitalisation is an important contributor to different energy generations. Moreover, the test of the strength and validity of instruments used continue to support their just identification.

The results in Table 5 show the positive effect of financial market access on wind energy generation. However, there is no clear evidence of the effect of financial market access on other sources of energy generation, especially, for solar and hydroelectric energy generations. The negative relationship between wind energy and solar energy generations is evident with high elasticity for wind energy generation, showing that the decrease in CO_2 emission is attributed to the increase in wind energy generation.

Table 6 shows that there is no evidence of statistically significant relationship between financial market effectiveness and all the components of renewable energy generations. The results of the postestimation test support the strength of the instruments used justifying the use of the 2SLS methodology in assessing the relationship between the different components of the renewable energy generation and various elements of financial market development.

Table 7: Determinants of wind energy generation: 2SLS with lag instruments

Variables	WIND	WIND	WIND	WIND
	Coefficient	Coefficient	Coefficient	Coefficient
CO_2	−7.14***	−2.11***	−2.328*	−11.21**
GDPCAP	0.000013**	0.000018***	0.000017**	0.000014
MARKCAP	0.925***	1.04***	0.98**	1.224***
FINDEV	2.93***			
FINEFF				2.43
FINACCESS		0.69**		
FINDEPTH			0.51**	

The reported results emphasise the important role aggregate and components of financial market development has on wind energy generation compared to other sources of renewable energy generation. This finding may be justified by the fact that in Europe, wind power is the most consumed renewable energy source (Chang et al., 2022; Bórawski et al., 2020). Wind energy, both onshore and offshore, has been heavily developed in Europe due to supportive policies and advancements in technology, making it a key component of Europe's efforts to transition to cleaner energy sources (DeCastro et al., 2019; Bento and Fontes, 2019).

Studies show that the development of wind energy in Europe, both onshore and offshore, has been significantly influenced by the region's advanced financial markets and supportive regulatory frameworks (Gutiérrez-Negrín, 2024; WindEurope, 2024). These financial markets have played a pivotal role in ensuring that renewable energy projects, particularly wind energy, receive the necessary capital to scale and grow.

The finding that financial market access and depth have a greater impact on wind energy generation, while financial market effectiveness does not, can be explained by several key factors related to the nature of wind energy projects, the specific needs of the renewable energy sector, and how financial markets function in supporting large-scale, capital-intensive projects. Regarding the nature of wind energy projects, wind energy projects, particularly offshore wind farms, require significant upfront investment. Access to financial markets is crucial because it ensures that sufficient capital is available for such large-scale projects. Financial market access or the ease with which developers of wind projects tap into diverse funding sources such as loans, bonds, or equity markets, is key for the advancement of these projects. Likewise, Financial market depth, or the range and complexity of financial instruments, has been crucial for the development of the most important source of renewable energy projects in Europe. The introduction of innovative financial instruments like green bonds, has been instrumental in channeling investment into wind energy projects. Studies show that green bonds, issued by institutions like the European Investment Bank, have provided a means for investors with a sustainability focus to fund renewable energy initiatives, including wind farms (Maltais and Nykvist, 2020; Versal and Sholoiko, 2022; Zhao et al., 2022).

Financial market effectiveness—typically assessed by how efficiently markets allocate resources and generate returns—may play a less central role in the context of financing renewable energy projects. For developers of renewable energy projects, the primary concern often extends beyond mere market efficiency. What proves to be more critical is consistent access to ample and diversified sources of capital over the long term. This includes having a range of financial instruments—such as green bonds, concessional financing, venture capital, and public-private partnerships—that are tailored to the unique characteristics of renewable energy investments, which often involve high upfront costs, long payback periods, and dependency on regulatory support or subsidies. While effective markets provide stability and liquidity, renewable energy developers may prioritize financial structures that offer long-term stability, risk mitigation, and flexibility to navigate the evolving energy landscape and meet sustainability goals.

On the finding that financial development does not have a statistically significant effects on solar energy projects, this finding may be related to the high correlation between wind energy and solar energy generation, reported in Table 2. While solar energy generation is the fastest growing energy sector in Europe (Ember, 2024), the strong correlation with wind energy could play a crucial role in shaping investors' decisions, influencing both their selection of energy sources and their approach to financing renewable energy projects. In the context of portfolio diversification strategies, investors aiming to minimize risk through diversification may be reluctant to finance highly correlated renewable energy projects. If wind and solar energy exhibit a high degree of correlation, this limits the potential for diversification, as investments in both would not sufficiently spread risk.

Furthermore, the predominant preference for wind energy generation in Europe suggests that investors might perceive solar energy projects as offering limited additional diversification benefits. This could result in a lower appetite for financing solar energy ventures, particularly in regions where wind energy dominates the renewable landscape. Consequently, the financing of solar projects might be seen as redundant or less attractive, given the similar risk-return profiles associated with wind energy, which could lead to a more concentrated investment focus on wind energy assets. This dynamic could have broader implications for the development and growth of renewable energy sectors, as financial resources may become unevenly allocated.

On the finding that hydroelectric energy generation is not statistically related to financial development, it is important to note that hydroelectric projects tend to be much larger, more complex, and have longer development timelines (especially for large dams). These projects often have significant environmental, social, and political considerations, which may limit private sector involvement. Additionally, hydroelectric projects often involve more state-led funding or international organizations rather than relying on the private financial markets.

To assess the robustness of the results, we estimated the panel 2SLS with the lag of endogenous variables chosen as instruments. The results of the estimation confirm the findings form the Lewbel 2SLS, especially for the positive relationship between financial market development and wind energy generation.

The results reported in Table 7 confirm that our results are robust with the use of a different model.

The final analysis focuses on investigating the average causal mediation effect of stock markets on the relationship between disaggregated financial market development and renewable energy production. The aim of this analysis is to uncover the extent to which the impact of financial market development on wind generation occur through stock market compared to other pathways. To this end we follow the procedure and steps suggested by Shrout and Bolger (2002). Following these steps, we will first, assess the impact of financial market development on wind energy production, secondly, we will estimate the regression of the impact of financial development on stock market capitalisation and the last step will provide a regression that estimate the impact of both financial development and stock market (the mediation) on wind energy production. In this last step, If the effect of financial market development on wind energy production completely disappears, this will show that stock market capitalisation fully mediates between financial market development and wind energy production (full mediation). If the effect of financial market development on wind energy production still exists, but in a smaller magnitude, stock market capitalisation partially mediates between financial market development and wind energy production (partial mediation).

Tables 8 presents the estimation of the different models related to the three steps as explained above for assessing the mediation of stock market capitalisation. We controlled the three estimations with CO_2.

The results reported in Table 8 show the coefficient of FINDEV is reduced from in the equation represented in step 1-1.64 with the equation represented in step 3. The results confirm that stock market capitalisation mediate between financial market capitalisation and wind energy generation. to assess whether this mediation effect is statistically significant, we used the bootstrapping proposed by Preacher and Hayes (2004). The results of this approach are reported in Table 9.

The results reported in Table 9 show that the total effect is 5.27, which is the coefficient reported in Table 8 for the first step, showing the effects of FINDEV on WIND, without accounting for stock market capitalisation (MARKCAP). The direct effect with the coefficient 1.69 refers to the estimation in the third step when MARKCAP is accounted for. This shows the direct effect of FINDEV when MARKCAP is accounted for. The average causal mediation effect is 3.58. It is obtained as the difference between 5.27 and 1.69 (5.27-1.69). It can be shown that this coefficient is approximately the product of the coefficient of FINDEV in the second step (4.28) and the coefficient of MARKCAP in the last step (0.83). The proportion of the mediation of stock market capitalisation in the effect of financial market development on wind energy production is 68%, showing the important channel of the size of stock market in financing wind energy production.

Many studies emphasize the critical role of stock markets in driving financial market development, particularly through key mechanisms such as capital market mobilization, liquidity

Table 8: Regression of the models related to the three steps

Variables	Step 1 (WIND)	Step 2 (MARKCAP)	Step 3 (WIND)
FINDEV	5.27***	4.28***	1.64*
MARKCAP			O.83***
CO_2	−O.24***	−0.041	−0.23***
CONSTANT	4.07***	27.44***	−18.43***

Table 9: Level of significance and the extent of the mediation effect of stock market capitalisation

Effects	Mean	Probability
ACME	3.58	0.022
Direct effect	1.69	0.051
Total Effect	5.27	0.0001
Proportion mediated	0.68	0.024

enhancement, price discovery, and risk diversification (Demirgüç-Kunt and Levine, 1996; Beck and Levine, 2004; Saliya, 2022). These functions of the stock market are essential for providing the financial infrastructure needed to support a wide array of investment projects, including those in renewable energy sectors like wind energy generation.

5. CONCLUSION

This paper assessed the effects of the aggregate financial market development and its components, namely financial market access, financial market efficiency and financial market depth, on renewable energy generation, distinguishing between wind energy generation, solar energy generation and hydroelectric generation. The disaggregated analysis provides a nuanced investigation on the link between the different components of financial market development and the different types of energy generation, departing from aggregate analysis as presented by past studies.

The empirical analysis is conducted by using a panel 2SLS based of the Lewbel methodology. The advantage of this methodology compared to other methodologies that use instrumental variables is that instruments are generated internally form the model's own data by exploiting heteroscedasticity in the data.

The results of the empirical analysis show that among the three sources of renewable energy generation, it is only wind energy generation that is positively impacted by financial market development, especially financial market access and depth. This finding is attributed by the fact that, wind power is the most consumed renewable energy source in Europe and that wind energy, both onshore and offshore, has been heavily developed in Europe due to different supportive policies. Including financial market involvement.

On the finding that financial market development does not have a statistically significant effects on solar energy projects, the paper relates this finding to the high correlation between wind energy and solar energy generation. The strong correlation between these two types of renewable energy could play a crucial role in shaping investors' decisions, influencing both their selection of energy sources for portfolio optimization and diversification.

On the finding that hydroelectric energy generation is not statistically related to financial development, the paper postulated that hydroelectric projects often have significant environmental, social, and political considerations, which may limit private sector involvement, especially private sector involvement.

The last part of the paper investigated the mediating effect of stock market capitalisation in the relationship between financial market development and wind energy generation. Specifically, the paper assessed the importance of stock market capitalisation as the pathway through which financial market development affect wind energy generation.

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APPENDIX

Table A1: Selected European countries

Austria	Germany	Poland
Belgium	Greece	Portugal
Bulgaria	Hungary	Romania
Croatia	Ireland	Slovak Republic
Cyprus	Italy	Slovenia
Czech Republic	Latvia	Spain
Denmark	Lithuania	Sweden
Estonia	Luxembourg	France
Finland	Malta	Netherlands