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Navigating the Nexus: Renewable Energy Consumption and Financial Development in the EU Context*

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Abstract

This paper investigates the nexus between Renewable Energy (RE) consumption and financial development within the European Union (EU), drawing from a wide array of financial indicators, including novel measures from the International Monetary Fund (IMF) alongside country-specific metrics for renewable pricing and the OECD Market Based Environmental Policy Stringency Index (EPS). Employing a system GMM estimator over the period 2005-2019 for a panel of 14 EU advanced economies, the empirical findings exhibit a significant positive association with RE consumption, underscoring the key role of robust financial markets in supporting renewable energy demand. Furthermore, lower RE prices and higher environmental stringency also drive increased RE consumption significantly, aligning with conventional inverse demand dynamics and the regulatory push towards sustainability. Finally, the paper estimates the the long-run elasticities of the renewable consumption with respect to the financial variables. These figures are potentially useful for the calibration of theoretical models including renewable energy, financial development, and environmental issues.

Keywords: Renewable energy consumption; financial development; European Union

JEL classification: Q42, Q43, O16, O38.

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1. Introduction

Numerous empirical studies have emphasised the role played by financial factors in accounting for energy consumption, uncovering a significant impact of financial development on the demand for energy when financial development is measured by the traditional financial indicators (see, among others, Sadorsky 2010 and Sadorsky 2011). However, different theoretical channels have been proposed to rationalise the impact of financial variables on energy decisions, highlighting the interplay between financial factors and energy consumption from various perspectives. By and large, financial development, shaping the conditions through which funds are transferred, modifies the willingness to consume energy in a way reflecting the evolving dynamics of economic systems. As financial institutions become more developed, the mechanisms through which credit is granted can significantly influence energy consumption behaviors. Possible changes in energy consumption can be attributed to several key mechanisms related to the financial system as follows.

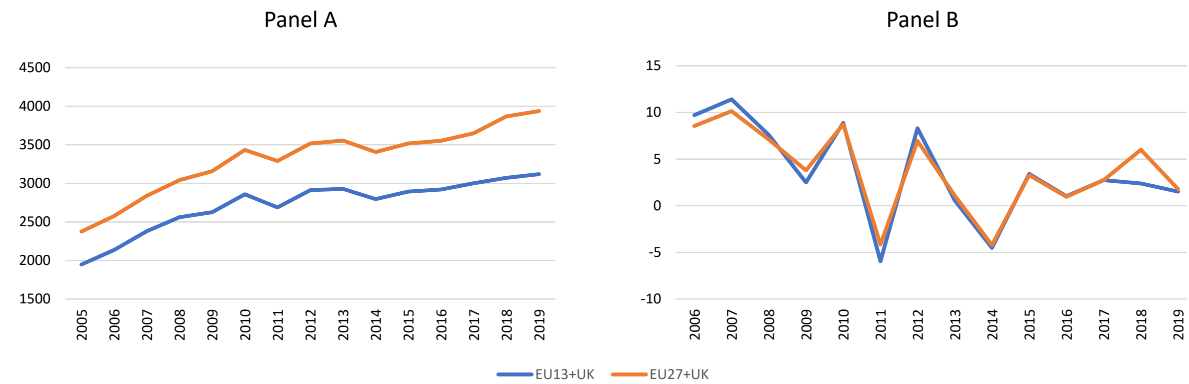
First, a well-managed and properly developed financial sector provides enough financial resources to the energy sector, assisting the maintenance of a good balance between energy supply and demand (see Furuoka 2015).

Second, the initial capital required for installing renewable energy infrastructures, such as solar panels or wind turbines, is a significant financial factor. It might reduce the costs of external financing in the Renewable Energy (RE) sector, help overcoming information asymmetries and at the same time narrowing the financing gaps of low-carbon energy projects (see Kim and Park 2016, Best 2017, Xie et al. 2021).

Third, consumers can borrow money more easily to meet their requirements, such as purchasing automobiles, houses, and household equipment, which increases energy consumption (see Yao et al. 2019, Anton and Nucu 2020 and Kayani et al. 2020).

Our paper contributes to this ongoing debate by specifically examining the relationship between the RE consumption and financial development within a sample of 13 European Union (EU) countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden) plus the UK, thus addressing a key aspect of the global transition towards sustainable energy practices. The selection of the 14 countries was based on their representativeness of the overall EU aggregate in terms of aggregate output and renewable energy consumption. RE consumption has expanded dramatically in the EU over the last two decades as a result of targeted policies and actions specifically designed to achieve the goal of decarbonising the entire

Figure 1: Renewable energy consumption in the EU (2005-2019; PJ in Panel A, growth rates in Panel B)



Source: World Energy Balances, IEA.

EU economy by 2050.[1] Figure 1 plots the levels of RE consumption in the EU27+UK and EU13+UK aggregates (Panel A), as well as the related annual rates of change (Panel B). In the sample of 14 selected countries (blue lines), RE consumption increased from approximately 1,950 petajoules (PJ) in 2005 to 3,120 PJ in 2019, accounting for an average of nearly 82% of the total RE consumption within the overall EU aggregate (orange lines). The annual rates of change exhibit a similar trend for the two aggregates, showing positive growth rates from 2006 to 2019, with the exceptions of 2011 and 2014; the average annual growth rate over the 2006-2019 period is 3.8%, which aligns with the projections made by the International Energy Agency regarding renewable energy demand within the European Union. This increase in RE adoption not only reflects a commitment to environmental sustainability, but also emphasizes the EU view of the energy sector as crucial to attaining climate goals.

Simultaneously, the European Climate Law establishes a legal framework to ensure the EU's transition to a climate-neutral continent by 2050. These initiatives mark a paradigm shift in energy policy, with an emphasis on innovation, efficiency, and the integration of renewable energy sources into the mainstream energy matrix.

This paper provides a fresh look at the relationship between the demand of renewables and financial development by using a comprehensive set of financial variables that take into account the multifaceted issues connected to the financial systems, going beyond the financial indicators widely used in this strand of the literature. To do so, we have

[1]The European Green Deal, with its comprehensive roadmap, sets ambitious targets for reducing carbon emissions and fostering a circular economy. In the wake of recent global events, such as the Russia-Ukraine conflict, the European Commission's unveiling of the REPowerEU Plan demonstrates the EU adaptability and commitment to ensuring energy security. This plan not only addresses immediate challenges but also emphasizes the long-term vision of creating a resilient and self-sufficient energy ecosystem within the EU.

gathered and integrated different data from multiple sources, which have been employed to compute specific indicators, including the prices of renewable energy sources, essential for conducting our econometric analysis. Our paper contributes to the current empirical literature introducing three relevant innovations.

First, in addition to the financial variables that are commonly used in the academic literature as relevant measures for financial development (private credit provided by banks and non-bank financial intermediaries, stock market capitalization, and total value of traded stocks), our analysis makes use of the newly issued IMF indexes, which focus on the depth, accessibility, and efficiency of the financial system's modern and sophisticated design (Svirydzenka 2016). While traditional banks are the most prevalent form of financial institution, non-bank financial organizations such as finance and insurance companies, investment banks, mutual funds and others play vital roles in capital mobilization. The depth, access, and efficiency of the financial system are also critical factors to consider: huge financial systems and effective financial services give limited benefits if they do not reach a sufficiently substantial proportion of the population and businesses. Channeling private funds in areas such as sustainable infrastructure, technologies, and environmental innovations, can provide substantial economic, social, and environmental benefits.[2]

Second, to establish country-specific metrics for renewable pricing, we compute a weighted average of the global levelized cost of electricity (LCOE) derived from diverse renewable energy technologies such as solar, hydro, wind, bioenergy, and geothermal sources. This analysis has required a two-step approach. In the first step, we have collected data for the global Levelized Cost of Electricity (LCOE, in 2021 USD/KWH) and global installed RE capacity by technology (KWH) from IRENA (2023), with the global installed renewable energy capacity serving as the weighting factor. In the second step, the weighted average LCOE was converted into local currency units using exchange rates and then standardized by the consumer price index (CPI) specific to each country in order to take into account of cross-country differences in the average price level. Exchange rates and CPI data were sourced from the World Bank's World Development Indicators (WDI).

Third, we take into account the potential impact of government-related environmental

[2]Green bonds, green banking, market-based instruments for energy efficiency, fiscal policy, ESG funds, etc., are what is nowadays known as "green finance". Green finance goes beyond the mere financing of green investment, since it also deals with an environmentally and climate-friendly design of the financial system as a whole and the management of environmental risks in finance institutions (Brockmann 2017; Sachs et al. 2019).

policies on both the deployment of renewable technologies and on RE consumption. Specifically, we incorporate into the analysis the OECD Market Based (MB) Environmental Policy Stringency Index (EPS). Stringency, in this context, refers to the extent to which environmental regulations put an explicit or implicit price on activities that contribute to pollution or environmental harm.[3] Such metric enables cross-national comparisons on a global scale. The index is based on the degree of stringency of several MB environmental policy instruments implemented in OECD countries, primarily related to climate and air pollution. MB policies include feed in tariffs for solar and wind, taxes, certificates (White, Green and CO2) as well as the presence of deposit and refund schemes (see Galeotti et al. 2020 for more details). We rely upon the MB EPS index as it is representative of the predominant tools frequently employed by European Union (EU) governments to implement environmental policies and initiatives aligned with the objectives of the European Green Deal. These efforts are geared towards facilitating the green transition within the EU economy with a target year of 2050.

The empirical analysis is carried out using a system Generalized Method of Moments (GMM) estimator for a panel of 14 EU advanced economies over the 2005-2019 period. To control for current economic factors we consider a reduced form dynamic panel model of RE demand where RE LCOE, and EPS are also included. In this case energy prices, market conditions, and environmental policies are assumed to influence the access to renewable technologies. As an additional control variable, we incorporate Real GDP per capita, taken from the WDI, to provide a metric for the scale of each country. In addition, we use the regression results to compute short- and long-run elasticities of RE demand, providing a valuable backing for future studies concerning the calibration of macroeconomic models associated with renewable energy, financial development, and environmental issues.

The results are as follows.

First of all, financial development, measured either by traditional financial indicators or by the more recent IMF indexes, is positively correlated with RE consumption, showing that larger, more active, and more efficient credit or stock markets support a larger amount of energy demand from renewable sources. Fostering RE technologies requires well-functioning and efficient financial markets and institutions providing easier access to debt and equity financing, mostly allowing to overcome moral hazards and ad-

[3] Specifically, the EPS index is a country-specific metric assessing the rigor of environmental policies exerted, whose value ranges ranges from 0 (not stringent) to 6 (highest degree of stringency). All the countries that are included in the analysis have applied such policy instruments such as feed-in tariff, feed-in premium, carbon tax, and tax credit for investment, to make renewable projects more economically attractive and accelerate their adoption.

verse selection problems, and reducing the cost of external financing. Promoting financial instruments targeted to the financing of environmental technologies is therefore crucial in achieving sustainable development goals. Secondly, RE consumption emerges to be negatively correlated with RE LCOE, supporting the existence of a conventional inverse demand function. Finally, a greater degree of environmental stringency encourages the consumption of RE.

The paper is structured as follows. Section 2 reviews the relevant literature. Section 3 is devote to the econometric approach, in which subsection 3.1 describes the dataset and subsection 3.2 explores the methodology. Results are reported and discussed in Section 4, while Section 5 provides estimates of long-run elasticities of RE consumption with respect to each regressor. Section 6 concludes.

2. Related Literature

This paper locates at the intersection of two main strands of literature. It builds upon the existing body of research that empirically examines the long-standing relationship between financial development and conventional energy consumption; however, it also addresses the emerging issue concerning the relationship between financial development and RE consumption. Early studies investigating the relationship between financial development and conventional energy consumption yield different conclusions, specifically that financial development can be positively, negatively, non-linearly, or even not related to consumption. In contrast, contributions exploring the nexus between renewable energy and finance largely indicate a positive correlation. Therefore, this paragraph reviews the relevant literature investigating the empirical relationships between i) financial development and conventional energy consumption (Section 2.1), and ii) between financial development and RE consumption (Section 2.2).

2.1. Financial Development and Conventional Energy Consumption

The relationship between financial development and energy consumption has been explored in numerous empirical studies, producing varied results. These differences are associated with the use of distinct country samples and differing time spans.

Several works show that as financial systems become more advanced and provide enhanced access to credit and capital market, they support economic activities that result in increased energy consumption. Sadorsky (2010) uses GMM estimator to investigate the relationship between financial development and energy consumption for 22 emerging economies during the period 1990-2006. The author finds that financial development has a positive effect on energy consumption when using stock market variables, suggesting that as financial markets grow, they drive higher energy demand through increased investments in infrastructure and industry. Same empirical approach for Sadorsky (2011), which considers a panel of nine Central and Eastern European frontier countries from 1996 to 2006. The author finds a significantly positive relationship between financial development and energy consumption when using banking variables; however, when stock market variables are considered, only stock market turnover exhibits a positive and statistically significant effect on energy consumption. Both contributions emphasize the need for policymakers to take into account the environmental implications of financial development, as well as the importance of integrating financial development with energy policies to manage the environmental effects in these transitioning economies. Çoban and Topcu (2013) explore the renewable and finance nexus in the EU over the period 1990–2011, using a system GMM. Interestingly, no statistically significant relationship is found in the EU27 aggregate, while greater financial development increases energy consumption when considering the old members of the EU, confirming the need for EU policymakers to implement coordinated strategies that actively address the implications of financial development on energy use. The system GMM estimator is also used by Xu (2012) to show a positive significant relationship between financial development, measured using the ratio of loans in financial institution to GDP and the ratio of FDI to GDP, and energy consumption for a panel of 29 provinces of China during the period 1999-2009. The development of the banking sector emerges to be positivity linked with energy consumption according to, among all, Al-Mulali and Lee (2013) for Gulf Cooperation Council (GCC) countries using panel data for the 1980–2009 period, Komal and Abbas (2015) for Pakistan using a GMM estimator with data between 1972 and 2012, Ahmed (2017) for BRICS countries (Brazil, Russia, India, China, and South Africa), Gaies et al. (2019) in Middle East and North Africa (MENA) countries during the 1996-2014 period.

Still on the relationship between financial development and energy consumption, other studies show that the former can reduce or not influence at all the latter. Furuoka (2015) finds no evidence supporting the effect of financial development on energy consumption in Asia for the period 1980-2012. Topçu and Payne (2017) find that a high development of stock markets may cause a decline in energy consumption in a sample of 32 high-income countries during the period 1990-2014. Farhani and Solarin (2017) show that, in the U.S., financial development stimulates energy demand in the short term, while it generates the opposite effect in the long term. Destek (2018) show that the development of the banking and bond markets in 17 emerging economies has a significantly negative effect on energy consumption, while Ouyang and Li (2018) show a similar result for a panel data of 30 Chinese provinces during the period 1996-2015. Gómez and Rodríguez (2019) find a negative relationship in North American Free Trade Agreement (NAFTA) countries between 1971 and 2015. More recently, Chiu and Lee (2020) explore the country risk effect between the two variables for 79 countries by employing the smooth transition regression model, and they found that under a stable country risk environment, financial development decreases overall energy consumption.

2.2. *Financial Development and RE Energy Consumption*

The growing body of research which focuses on the link between financial development and RE consumption broadly shows that financial development, mostly measured by the share of domestic credit to the private sector over GDP, has a statistically significant and positive influence on RE consumption.

Among all, Anton and Afloarei Nucu (2020) analyze the effect of financial development on renewable energy consumption using a panel data approach in the EU-28 aggregate during 1990-2015. The study finds that financial development has a positive impact on renewable energy consumption, indicating that as financial systems become more developed, they provide better access to funding for renewable energy projects. This facilitates increased investments in renewables, supporting their growth. The paper emphasizes the importance of advancing financial development as a means to promote renewable energy consumption globally, highlighting its role in the broader transition to sustainable energy systems. Wu and Broadstock (2015) investigate the influence of economic, financial, and institutional development on renewable energy consumption using data from a panel of emerging economies. The results suggest that stronger financial markets, better institutional frameworks, and economic growth are crucial for driving the adoption of renewable energy in these regions, and underscore the need for common development strategies that integrate these elements to enhance renewable energy uptake. Khan et al. (2020) study the heterogeneity of renewable energy consumption, CO2 emissions, and financial development for a panel of 192 countries using panel quantile regression. Among the results, it emerges that financial development positively affects renewable energy consumption. A positive long-run relationship between renewable energy consumption and financial development has been found also by Shahbaz et al. (2021) using the FMOLS approach for a panel of 34 upper middle income developing countries from 1994 to 2015. The research emphasizes the role of a well-developed financial sector in supporting the transition to renewable energy in developing countries, highlighting the need for policies that promote financial development to foster sustainable energy consumption.

Lin et al. (2016) analyze the factors driving renewable electricity consumption in China. The authors identifies GDP per capita, trade openness, foreign direct investment, financial development, and fossil fuel as the key determinants. Among these, economic growth and financial development increase renewable electricity consumption. In addition, Ji and Zhang (2019) investigate the contribution of financial development to renewable energy development in China. The results show that about 40% of the variation in renewable energy growth is explained by financial development, with capital market financing exhibiting the most important impact. Similar outcomes have been observed for India by Eren et al. (2019), using time series data for the period 1971-2015. The authors find that both financial development and economic growth positively influence renewable energy consumption, indicating that as India's financial sector expands and the economy grows, there is a corresponding increase in investments and demand for renewable energy. The previous studies underscore the importance of enhancing financial development and sustaining economic growth to promote the adoption of renewable energy both in China and India, contributing to a more sustainable energy future.

Kim and Park (2016) show that renewable sectors that are relatively more dependent on debt and equity financing can grow faster in countries with developed financial markets, and in addition, the positive influence of the Clean Development Mechanism on the deployment of RE is more pronounced in countries with less developed domestic financial markets, since the mechanism plays an active role in improving access to financing for RE sectors (see also Kim and Park 2018). Stock market development emerges to be beneficial for RE consumption in India, China, Brazil, and South Africa (see Kutan et al. 2018).

Mukhtarov et al. (2022) explore the effects of financial development, economic growth, and energy prices on renewable energy use in Turkey. Using time series data, their study reveals a positive correlation between financial development and renewable energy consumption, suggesting that advancements in the financial sector promote increased investments in renewable energy initiatives, thus enhancing the proportion of renewables within the overall energy mix. The authors underscore the critical role of financial development in facilitating Turkey's green transition. Similarly, Mukhtarov et al. (2020) report a positive and statistically significant relationship between financial development and economic growth with renewable energy consumption in Azerbaijan, whereas energy prices, measured by the CPI, negatively affect renewable energy consumption. Dimnwobi et al. (2022) analyze the impact of financial development on renewable energy consumption in Nigeria employing annual data from 1981 to 2019. The study finds that financial development, measured by the broad financial development index provided by the IMF (Svirydzenka 2016) has a positive effect on renewable energy consumption, indicating that improvements in the financial sector facilitate investments in renewable energy technologies, thus stimulating the shift towards the use of clean energy in Nigeria.

3. Econometric Approach

This section describes the econometric approach to estimating the relationship between RE consumption and financial variables. Section 3.1 describes the data used for estimation, while Section 3.2 outlines the econometric methodology.

3.1. Data description

The analysis is carried out over the 2005-2019 period for a strongly balanced dataset of 14 countries, including 13 advanced economies of the EU plus the UK.[4] Data on RE consumption have been collected from the World Energy Balances dataset provided by the International Energy Agency (IEA), where RE comprises the use of hydro, geothermal, solar, wind and tide/wave/ocean energy for electricity and heat generation, as well as biogases, industrial/municipal waste, and solid/liquid biofuels (IEA 2023). RE consumption reflects mostly deliveries to consumers.

Energy price data are in general not easily available for all countries, and this task is even more difficult if we focus on renewable sources only.[5] Initially, we have computed a weighted average of the global LCOE deriving from different technologies of RE sources, such as solar, hydro, wind, bioenergy, and geothermal. In other terms, we have gathered data of LCOE (2021 USD/KWH) and of global installed RE capacity by technology (KWH) from IRENA (2023) using the latter as weight. Then, in order to provide a country-specific measure of renewable price the weighted average LCOE was converted into local currency units using exchange rates, and finally normalized by the consumer price index of each country. Exchange rates and CPI have been collected from the World Bank's WDI.

The OECD Environmental Policy Stringency Index (EPS) is a country-specific metric assessing the rigor of environmental policies exerted, whose value ranges ranges from 0

[4]Included countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, and the UK. The selection of countries was based on their representativeness of the overall EU area in terms of aggregate output, renewable energy consumption, and the availability of data for carrying out our research. The sample offers a wide range of variation across countries of RE consumption as well as degree of financial development.

[5]For instance, Sadorsky (2010) proxied energy prices using the consumer price index, while Sadorsky (2011) used real oil prices measured using West Texas Intermediate crude oil futures prices (the nearest contract to maturity) divided by each country's consumer price index. The author also suggests the strategy to construct a country-specific oil price variable by multiplying the US price of NYMEX crude oil with the country-specific exchange rate. However the author rejects a price variable constructed in this way since it could not provide much meaningful information on energy demand.

(not stringent) to 6 (highest degree of stringency). Stringency, in this context, refers to the extent to which environmental regulations put an explicit or implicit price on activities that contribute to pollution or environmental harm. Such metric enables cross-national comparisons on a global scale. The index is based on the degree of stringency of 15 different Non-Market Based (NMB) and Market Based (MB) environmental policy instruments implemented in OECD countries, primarily related to climate and air pollution. [6] In this paper, we use the MB EPS index as it is representative of the prevalent tools commonly adopted by EU countries to address environmental policies and actions aimed at achieving the goals of the European Green Deal and foster the green transition in EU economy by 2050.

National income is incorporated into our analysis to account for the dimensional factor of each country. In this regard, we have collected data on real GDP per capita from the World Bank's World Development Indicators (WDI).

Financial indicators have been collected from both the World Bank's Global Financial Development Database (GFDD) and from the Financial Development Database (FDD) released by the IMF. Financial variables taken from the GFDD are those ones that are commonly used as relevant measures for financial size, depth, and efficiency in the existing literature. Such measures include credit provided by banks to the private sector, credit provided by banks and non-banks to the private sector, total value of all listed shares in domestic stock markets, and the value of domestic shares traded on domestic exchanges; henceforth we will refer to them as "traditional" financial indicators. Variables taken from FDD consider financial development as a combination of depth (size and liquidity of markets), access (ability of individuals and companies to access financial services), and efficiency (ability to provide efficient financial services). Each indicator is normalized between 0 and 1, thus, higher values indicate greater financial development (Svirydzenka 2016). The (FD) index captures the degree of development for both financial institutions (FI) and financial markets (FM). FI include banks, insurance companies, mutual funds, pension funds, and other types of non-bank financial institutions, while FM indicators refer to bond and stock markets. FI and FM are further assessed in terms of depth (D), access (A), and efficiency (E). The resulting six sub-indices, FID, FIA, FIE for financial institutions and FMD, FMA, FME for financial markets, complement the traditional financial indicators related to the banking sector and to stock market. This level of

[6] NMB policies include limits to pollutants (SOx, NOx, Particulate Matters and Sulphur Content of Diesel) and government energy-related R&D expenditures as a percentage of GDP, while MB policies include feed in tariffs for solar and wind, taxes (on CO2, SOx, NOx and Diesel), certificates (White, Green and CO2) and the presence of deposit and refund schemes.[7]

detail allows for a more comprehensive assessment of financial development, including both the bond markets and non-bank financial intermediation.

A detailed description of variables and data sources is available in Table 1. Descriptive statistics and pairwise correlation coefficients are reported, respectively, in Table 2 and Table 3.

Table 1: Data description and sources

Variable	Definition	Source
ln_ren_cons	Natural logarithm of renewable energy consumption measured in PJ. Equal to the sum of the consumption in the end-use sectors. Energy used for transformation processes and for own use of the energy producing industries is excluded. Final consumption reflects for the most part deliveries to consumers.	World Energy Balances, IEA, 2023.
ln_constant_gdp	Natural logarithm of GDP per capita (constant 2015 US$)	WDI, The World Bank (indicator code NY.GDP.PCAP.KD).
ln_ren_lcoe	Natural logarithm of the levelized cost of RE by technology (2021 USD/KWH) weighted for installed global RE capacity by technology (KWH), then converted by official exchange rates (LCU per USD) and finally divided by the CPI of each country.	IRENA (2023) for LCOE and renewables capacity. WDI, The World Bank for official exchange rates (indicator code PA.NUS.FCRF) and for CPI (indicator code FP.CPI.TOTL).
ln_eps	Natural logarithm of the Environmental Policy Stringency Index based upon market-based environmental policy instruments implemented in each country. Such policy instruments include feed in tariffs for solar and wind, taxes on CO2 emissions, certificates (White, Green and CO2) and deposit and refund schemes	OECD.
ln_bank_credit	Natural logarithm of credit by deposit money banks to the private sector. Obtained by multiplying the bank credit over GDP ratio times the nominal GDP	GFDD, The World Bank for bank credit ratio (indicator code GFDD.DI.01) and WDI, The World Bank for nominal GDP (indicator code NY.GDP.MKTP.CD).
ln_private_credit	Natural logarithm of credit by deposit money banks and other financial institutions to the private sector. Obtained by multiplying the private credit over GDP ratio times the nominal GDP	GFDD, The World Bank for private credit ratio (indicator code GFDD.DI.12) and WDI, The World Bank for nominal GDP (indicator code NY.GDP.MKTP.CD).
ln_mkt_cap	Natural logarithm of market capitalization of listed domestic companies. Obtained by multiplying the market capitalization over GDP ratio times the nominal GDP	GFDD, The World Bank for private credit ratio (indicator code GFDD.DM.01) and WDI, The World Bank for nominal GDP (indicator code NY.GDP.MKTP.CD).

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Variable	Definition	Source
ln_tvt	Natural logarithm of total value traded of stocks. Obtained by multiplying the total value traded over GDP ratio times the nominal GDP	GFDD, The World Bank for private credit ratio (indicator code GFDD.DM.02) and WDI, The World Bank for nominal GDP (indicator code NY.GDP.MKTP.CD).
ln_FD	Natural logarithm of the financial development index, obtained through the aggregation of sub-indices FI and FM	FDD, IMF.
ln_FI	Natural logarithm of the financial institutions index obtained through the aggregation of sub-indices FID, FIA, and FIE; financial institutions included are banks, insurance companies, mutual funds, pension funds, and other types of nonbank financial institutions	FDD, IMF.
ln_FM	Natural logarithm of the financial markets index obtained through the aggregation of sub-indices FMD, FMA, and FME; financial markets included are mainly stock and bond markets	FDD, IMF.
ln_FID	Natural logarithm of the financial institutions depth index, including credit by banks to the private sector, assets of the mutual fund and pension fund industries, as well as the scale of life and non-life insurance premiums	FDD, IMF.
ln_FIA	Natural logarithm of the financial institutions access index, measured by the number of bank branches and ATMs per 100,000 adults	FDD, IMF.
ln_FIE	Natural logarithm of the financial institutions efficiency index, measured by considering the net interest margin, lending-deposit spread, non-interest income to total income and overhead costs to total assets, ROA and ROE.	FDD, IMF.
ln_FMD	Natural logarithm of the financial markets depth index, including the size and the degree of activity of stock markets (capitalization, total value of listed shares, total value of stocks traded), the outstanding volume of international debt securities of sovereigns, and of international and domestic debt securities of financial and non-financial corporations	FDD, IMF.
ln_FMA	Natural logarithm of the financial markets access index, measured by the percentage of market capitalization outside of top 10 largest companies to proxy access to stock markets, and the number of financial and non-financial corporate issuers on the domestic and external debt market in a given year per 100,000 adults	FDD, IMF.
ln_FME	Natural logarithm of the financial markets efficiency index, measured by the stock market turnover ratio	FDD, IMF.

Table 2: Descriptive statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
ln_ren_cons	210	4.813844	1.04034	2.042023	6.579485
ln_constant_gdp	210	10.70701	0.931956	9.681308	13.01357
ln_ren_lcoe	210	-7.145686	0.8129134	-7.94576	-4.690725
ln_eps	210	0.3718634	0.5186757	-0.6931472	1.427116
ln_bank_credit	210	27.33045	1.030709	25.67815	29.3426
ln_private_credit	210	27.33045	1.030709	25.67815	29.3426
ln_mkt_cap	149	26.72481	1.357743	24.2431	28.99677
ln_tvt	135	26.21719	1.898526	22.77774	29.06364
ln_FD	210	-0.3113118	0.1177553	-0.6998285	-0.0542253
ln_FI	210	-0.2659447	0.1250799	-0.7348037	-0.0643298
ln_FM	210	-0.4116077	0.193097	-0.8243456	-0.055668
ln_FID	210	-0.3937165	0.3086491	-1.33457	0
ln_FIA	210	-0.4071619	0.3802418	-1.811192	0
ln_FIE	210	-0.3414097	0.1313067	-0.9027997	-0.1552899
ln_FMD	210	-0.3462243	0.2376833	-0.8987542	-0.0092602
ln_FMA	210	-0.7137384	0.4314298	-1.775394	0
ln_FME	210	-0.4050191	0.5290902	-2.503004	0

3.2. Econometric Methodology

To investigate the determinants of RE demand, we employ a dynamic panel data approach using a system GMM estimator. This econometric technique is particularly useful when dealing with panel data where endogeneity might be a concern. Specifically, we employ the system GMM estimator from Blundell and Bond (1998) and Arellano and Bover (1995) to control for possible endogeneity between RE demand, RE LCOE, GDP, and financial variables.[8] To address endogeneity, the system GMM estimator uses lagged levels of endogenous variables as instruments for their differenced counterparts, and lagged differences as instruments for levels. This process involves: 1) first-Difference transformation by which the original variables are differenced to remove unobserved country-specific effects μ_i; 2) the use of instrumental Variables: in this case the lagged levels of the endogenous variables serve as instruments in the differenced equation, and lagged differences serve as instruments in the level equation. By using internal instruments (lagged values of the variables), system GMM effectively controls for endogeneity,

[8] Endogeneity arises when explanatory variables are correlated with the error term, leading to biased and inconsistent estimates. This can happen due to omitted variable bias, measurement error, or simultaneity (when the explanatory variables are determined jointly with the dependent variable). In our analysis, endogeneity may occur because renewable energy (RE) demand, RE LCOE, GDP, and financial variables could influence each other simultaneously.

Table 3: Pairwise correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) ln_ren_cons	1.00																
(2) ln_constant_gdp	-0.054	1.00															
(3) ln_ren_lcoe	-0.057	0.875***	1.00														
(4) ln_eps	0.148**	0.691***	0.572***	1.00													
(5) ln_bank_credit	0.517***	-0.089	-0.107	0.140**	1.00												
(6) ln_private_credit	0.517***	-0.089	-0.107	0.140**	1.00***	1.00											
(7) ln_mkt_cap	0.522***	0.246***	0.046	0.351***	0.904***	0.904***	1.00										
(8) ln_tvt	0.625***	0.026	0.103	0.335***	0.928***	0.928***	0.940***	1.00									
(9) ln_FD	0.287***	-0.020	-0.003	0.248***	0.713***	0.713***	0.700***	0.724***	1.0000								
(10) ln_FI	-0.046	0.048	0.099	0.197***	0.479***	0.479***	0.416***	0.342***	0.685***	1.00							
(11) ln_FM	0.430***	-0.068	-0.085	0.178***	0.605***	0.605***	0.686***	0.795***	0.820***	0.148**	1.00						
(12) ln_FID	-0.087	0.552***	0.351***	0.511***	0.268***	0.268***	0.442***	0.268***	0.521***	0.512***	0.292***	1.00					
(13) ln_FIA	-0.010	-0.417***	-0.229***	-0.252***	0.314***	0.314***	0.079	0.222***	0.194***	0.591***	-0.179***	-0.312***	1.00				
(14) ln_FIE	0.108	-0.053	0.078	-0.130*	-0.038	-0.038	0.128	0.052	0.186***	0.159**	0.119*	0.018	-0.129*	1.00			
(15) ln_FMD	0.271***	0.159**	0.116*	0.289***	0.492***	0.492***	0.803***	0.775***	0.724***	0.349***	0.698***	0.527***	-0.235***	0.328***	1.00		
(16) ln_FMA	-0.142**	-0.056	-0.173**	-0.045	0.085	0.085	-0.107	-0.237***	0.131*	-0.116*	0.283***	0.004	-0.059	-0.159**	-0.204***	1.00	
(17) ln_FME	0.631***	-0.086	0.023	0.151**	0.511***	0.511***	0.523***	0.799***	0.509***	0.004	0.687***	-0.015	-0.063	0.087	0.502***	-0.304***	1.00

*, **, *** denote, respectively, statistical significance at 10%, 5% and 1% level.

which is crucial when variables are potentially correlated with the error term. The inclusion of lagged dependent variables in the model allows system GMM to appropriately account for dynamic relationships in the data.[9]

Specifically, the theoretical framework underlying the GMM estimator employed in this study assumes that the number of time periods remains fixed and the number of cross sections becomes relatively larger. Given that the panel data set used in this paper comprises an almost equal number of observations (15 years) and cross-sectional groups (14 countries), standard t or F statistics can be used to conduct unit root tests effectively (as shown in Bond et al. 2003).[10] We thus check the stationarity of the variables, since non-stationarity could lead to spurious regression results. Table 4 reports the estimated coefficients obtained from a linear regression model of each variable on a one period lag of itself. Real GDP and the FIA index show the highest degree of persistence since their estimated coefficients are the closest to one, while EPS, FM and FMA shows the lowest amount of persistence. The unit root hypothesis is rejected for all the variables involved in our analysis.

To estimate the relationship between RE demand and financial development we consider a reduced form dynamic panel model of RE demand, where the latter is supposed to depend on four relevant channels: an income channel measured by the real GDP per capita (y), the price channel that is reflected in the RE LCOE (p), the policy channel that is summarised in the EPS (eps) index, and the financial channel incorporated in financial indicators (fin). The basic model specification is given by:

$$ren_{i,t} = \alpha ren_{i,t-1} + \beta_1 y_{i,t} + \beta_2 p_{i,t} + \beta_3 eps_{i,t} + \beta_4 fin_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t} \tag{1}$$

where $y_{i,t}$ denotes the real GDP for country i (with i=1, ..., 14) at year t (with t=2005, ..., 2019), $ren_{i,t}$ and $ren_{i,t-1}$ denote, respectively, the RE consumption at time t and at $t-1$, $p_{i,t}$ is the LCOE of renewable energy, while $eps_{i,t}$ is the environmental policy stringency index based on MB policies. $fin_{i,t}$ denotes the financial variable included one-at-a-time in the regression equation, while μ_i denotes country-fixed effects used to control for unobserved heterogeneity across countries and thus accounting for common factors and unobservable, time-invariant, country-specific effects on RE consumption, while λ_t denotes time-fixed effects. $\epsilon_{i,t}$ is the error term. For modeling purposes, all variables are

[9] Compared to the difference GMM estimator (developed by Arellano and Bond 1991), system GMM offers efficiency gains by incorporating the level equation in addition to the differenced equation. This means it exploits more moment conditions, leading to more precise estimates.

[10] See also Sadorsky (2011) for an application of this methodology in the energy sector.

Table 4: Unit root tests from panel estimation fixed effects regression results.

	one-lag estimated coeff.	t-stat	F-stat
ln_ren_cons	0.802***	21.89	479.29***
ln_constant_gdp	0.971***	18.12	328.20***
ln_ren_lcoe	0.773***	104.58	10936.55***
ln_eps	0.496***	4.28	18.32***
ln_bank_credit	0.818***	12.98	168.58***
ln_private_credit	0.818***	12.98	168.58***
ln_mkt_cap	0.460***	4.49	20.16***
ln_tvt	0.717***	11.08	122.87***
ln_FD	0.637***	8.18	66.92***
ln_FI	0.884***	9.31	86.62***
ln_FM	0.501***	6.82	46.52***
ln_FID	0.778***	8.84	78.19***
ln_FIA	0.993***	21.48	461.32***
ln_FIE	0.611***	5.94	35.31***
ln_FMD	0.298***	5.80	33.60***
ln_FMA	0.511***	6.24	38.90***
ln_FME	0.571***	12.25	149.99***

*, **, *** denote, respectively, statistical significance at 10%, 5% and 1% level.

expressed in natural logarithms to avoid problems associated with dynamic properties of data. Moreover, this transformation helps to facilitate a more straightforward interpretation of the coefficients in terms of elasticity. The coefficients obtained from the estimation of (1) provide elasticities that indicate the responsiveness of renewable energy consumption to changes in GDP, RE prices, EPS, and financial development. Positive coefficients on GDP, EPS, and financial development would suggest that higher economic output, stricter environmental policies, and better financial conditions promote greater renewable energy consumption. Conversely, a negative coefficient on RE LCOE would imply that higher prices discourage RE consumption.[11]

4. Results

We employ different model variants of (1) to explore the relationship between renewable energy consumption (RE) and various financial indicators, as well as other control variables.

In a first set of regressions, we present the results using the traditional financial indicators under several variants (see Table 5). Specifically, *Model* 1 includes bank credit as the key financial indicator. The focus is therefore on how the availability of credit provided by banks influences RE consumption. In *Model* 2 private credit is used as the main financial variable. This model version examines the role of credit extended by both banks and non-bank financial institutions in driving RE consumption. In *Model* 3 variant, market capitalization is the financial indicator of interest. The model explores the impact of the overall size of the stock market on RE consumption. *Model* 4 focuses on total value traded (TVT) in stock markets. It looks at how the liquidity and trading volume in financial markets affect the demand for renewable energy.

Subsequently, we estimate the model (1) using the IMF Financial Development Indicators under nine variants (see Table 6) . *Model* 1 uses the overall Financial Development (FD) index, which combines measures of financial institutions and financial markets. *Model* 2 focuses on Financial Institutions (FI), analyzing how the development of banks, insurance companies, and other non-bank institutions affects RE consumption. *Model* 3 examines the role of Financial Markets (FM), assessing how developed and sophisticated stock and bond markets influence the demand for RE. *Model* 4 looks at the Depth of Financial Institutions (FID), measuring the size and liquidity of financial institutions. *Model*

[11] Eq. (1) is thus consistent to a linear dynamic panel model as specified by Arellano and Bond (1991). In this sense, in Eq. (1), RE consumption, real GDP, RE LCOE, eps, and financial indicators (one-by-one), are treated as endogenous considering two, three and four lags.

5 focuses on the Access to Financial Institutions (FIA), considering how easily individuals can access financial services. *Model* 6 assesses the Efficiency of Financial Institutions (FIE), evaluating how effectively financial institutions provide services. *Model* 7 analyzes the Depth of Financial Markets (FMD), considering the size and liquidity of bond and stock markets. *Model* 8 looks at the Access to Financial Markets (FMA), measuring the ease with which individuals can participate in financial markets. *Model* 9 focuses on the Efficiency of Financial Markets (FME), assessing the effectiveness of financial markets in allocating resources.

Each of these models also includes the control variables as in (1) (Lagged RE consumption, Real GDP per capita, RE LCOE, Environmental Policy Stringency (EPS)). As already mentioned, all these models are estimated using the system GMM which helps address potential endogeneity. Tests for autocorrelation and instruments validity are displayed in the lower panels of Tables 5 and 6. AR(1) and AR(2) are tests for first- and second-order serial correlations in the first differenced errors (Arellano and Bond 1991). For all the regression models reported in Table 5 and Table 6, AR(1) tests are statistically significant at the 1% level, showing first-order serial correlation due to the lagged dependent term, and AR(2) tests show no second-order autocorrelation. Sargan tests show no evidence of miss-specification at conventional levels of significance.

4.1. Traditional Financial Indicators

Table 5 reports estimates for regression models including traditional financial indicators. The coefficient for the lagged dependent variable ($L1.ln\_ren\_cons$) is consistently high across all four models, ranging from 0.970 to 0.975. This indicates a strong persistence in renewable energy consumption over time, meaning that past consumption is a significant predictor of current consumption. The statistical significance at the 1% level ($p < 0.01$) across all models reinforces the robustness of this finding. In *Model* 1, the coefficient for bank credit (ln_bank_credit) is 0.022 (with a standard error of 0.004), indicating that a 1% increase in bank credit is associated with a 0.022% increase in renewable energy consumption. This result is highly significant at the 1% level ($p < 0.01$), suggesting that greater availability of bank credit strongly supports the expansion of renewable energy use. Similarly, *Model* 2 shows the same results, highlighting the crucial role of private credit in facilitating investments in renewable energy projects. In *Model* 3, the coefficient for market capitalization (ln_mkt_cap) is 0.016 (standard error of 0.005). This suggests that a 1% increase in stock market capitalization leads to a 0.016% increase in RE consumption. Although the effect is smaller compared to bank and private credit, it is still significant at the 1% level, underscoring the importance of developed stock markets in supporting renewable energy investments. *Model* 4 shows that a 1% increase in the total value of stocks traded (*ln_tvt*) is associated with a 0.015% increase in RE consumption. This result is also statistically significant at the 1% level, indicating that higher liquidity in the stock market can enhance renewable energy consumption by making it easier to raise capital. The coefficient for real GDP is consistently positive across Models 1, 2, and 4, with values of 0.028 in Models 1 and 2, and 0.016 in *Model* 4. These coefficients indicate that a 1% increase in real GDP is associated with approximately a 0.028% increase in RE consumption, although the effect in *Model* 4 is slightly weaker. The statistical significance varies, with *Models* 1 and 2 showing significance at the 1% level, while *Model* 4 is significant at the 10% level ($p < 0.1$). The LCOE of renewable energy is estimated to have a negative effect on its consumption, as expected. The coefficient is -0.022 (standard error of 0.008) in *Models* 1 and 2, significant at the 5% level ($p < 0.05$). This suggests that a 1% increase in the LCOE of renewable energy leads to a 0.022% decrease in its consumption, reinforcing the inverse relationship between price and demand. The coefficient for the Environmental Policy Stringency Index (EPS) ranges from 0.025 to 0.028 across the models. This indicates that a 1% increase in the stringency of environmental policies is associated with a 0.025% to 0.028% increase in RE consumption. These results are statistically significant at the 1% level, highlighting the effectiveness of stringent environmental policies in promoting renewable energy use. All in all, the results show the significant role of financial development, particularly in the banking and stock market sectors, in driving renewable energy consumption in the EU. Indeed, RE investment projects are indeed highly dependent on external sources of financing, with financial institutions and financial markets playing a crucial role in reducing the related market frictions, mostly transaction costs, excessive risk-taking, and asymmetric information. The persistence of RE consumption, coupled with the positive impact of economic growth and environmental policies, suggests that sustainable financial and regulatory frameworks are crucial for the continued expansion of renewable energy. The strong statistical significance of the coefficients across different models reinforces the robustness of these findings, indicating that both credit availability and market liquidity are key enablers of renewable energy investments.

4.2. IMF Financial Development Indicators

Estimation results related to IMF financial development indicators are reported in Table 6.

The coefficient for the lagged RE consumption variable (*L1.ln_ren_cons*) is consistently high across all nine models, ranging from 0.974 to 0.985. This persistence suggests that current RE consumption is strongly influenced by past consumption, and the coeffi-

Table 5: RE consumption and finance (traditional financial indicators, 2005-2019, 14 EU countries).

	Renewable energy consumption			
	Model 1	Model 2	Model 3	Model 4
ln_bank_credit	0.022***			
	(.004)			
ln_private_credit		0.022***		
		(.004)		
ln_mkt_cap			0.016***	
			(.005)	
ln_tvt				0.015***
				(.003)
L1.ln_ren_cons	0.973***	0.973***	0.975***	0.970***
	(.005)	(.005)	(.006)	(.006)
ln_constant_gdp	0.028***	0.028***	0.016	0.028*
	(.009)	(.009)	(.014)	(.016)
ln_ren_lcoe	-0.022**	-0.022**	-0.136	-0.119*
	(.008)	(.008)	(.087)	(.069)
ln_eps	0.025***	0.025***	0.025**	0.028***
	(.006)	(.006)	(.010)	(.010)
Countries/Obs.	14/196	14/196	11/138	11/124
AR(1)	0.005	0.005	0.008	0.009
AR(2)	0.574	0.574	0.686	0.967
Sargan test	174.5 (0.292)	174.5 (0.292)	120.0 (0.308)	108.3 (0.245)

The regression coefficients are estimated using the Arellano and Bover (1995) and Blundell and Bond (1998) system GMM estimation approach. The dependent variable is the natural logarithm of renewable energy consumption. L1 stands for the one-lag variable. Standard errors are reported in parentheses. The estimated coefficients on the time dependent dummy variables and constants are not reported for brevity. AR(1) and AR(2) are Arellano and Bond (1991) tests for autocorrelation in differences. Sargan is the test for overidentifying restrictions (Arellano and Bond, 1991); p-values for this test are reported in parentheses. *, **, *** denote, respectively, statistical significance at 10%, 5% and 1%.

cients are statistically significant at the 1% level ($p < 0.01$) in every model. In *Model* 1, the coefficient for the overall financial development index (ln_FD) is 0.136 (with a standard error of 0.043), indicating that a 1% increase in financial development is associated with a 0.136% increase in RE consumption. This large and statistically significant effect at the 1% level highlights the importance of a well-developed financial system in supporting renewable energy consumption. *Model* 2 focuses on financial institutions (ln_FI), with a coefficient of 0.041 (standard error of 0.044), suggesting a positive but not statistically significant relationship with RE consumption. In contrast, *Model* 3 examines financial markets (ln_FM), where the estimated coefficient is 0.087 (standard error of 0.027), indicating that a 1% increase in financial market development results in an 0.087% increase in RE consumption. This result is statistically significant at the 1% level, underscoring the critical role of financial markets in promoting renewable energy use. *Models* 4, 5, and 6 investigate the depth (ln_FID), access (ln_FIA), and efficiency (ln_FIE) of financial institutions. *Models* 7, 8, and 9 focus on the depth (ln_FMD), access (ln_FMA), and efficiency (ln_FME) of financial markets. The coefficient of depth (ln_FMD) is 0.062 (standard error of 0.016), indicating that a 1% increase in financial market depth results in a 0.062% increase in RE consumption. This result is statistically significant at the 1% level, highlighting the importance of larger and more active financial markets for renewable energy. The coefficient of access (ln_FMA) is 0.005 (standard error of 0.017), which is positive but statistically insignificant, suggesting that access to financial markets alone may not significantly drive RE consumption. The coefficient of efficiency (ln_FME): is 0.037 (standard error of 0.007), indicating that a 1% increase in the efficiency of financial markets leads to a 3.7% increase in RE consumption. This result is statistically significant at the 1% level, emphasizing the role of efficient financial markets in supporting renewable energy investments.

Across all models, real GDP has a positive impact on RE consumption, with coefficients ranging from 0.027 to 0.051. The statistical significance varies across models, being strongest in *Model* 9 (coefficient of 0.051, $p < 0.01$). This indicates that higher economic output consistently supports greater renewable energy consumption. The LCOE of renewable energy consistently shows a negative impact on RE consumption across all models, with coefficients ranging from -0.022 to -0.032. These results are statistically significant at the 1% level in each model, reinforcing the inverse relationship between energy prices and demand.

The EPS index continues to show a positive and statistically significant impact on RE consumption, with coefficients ranging from 0.020 to 0.037. The effect is statistically significant at the 10% level in *Model* 1 and at the 1% to 5% levels in the other models, indicating that more stringent environmental policies encourage greater renewable energy consumption.

Results in Table 6 show that financial development, particularly in terms of financial market depth and efficiency, is strongly associated with higher renewable energy consumption. The overall financial development index and financial market indicators (depth and efficiency) show the most substantial and significant positive impacts, suggesting that well-developed and efficient financial markets are crucial for supporting renewable energy investments. These outcomes are in line with those emerging from the large strand of the literature which shows a positive and significant link between RE consumption and financial development.

At this stage of the analysis, we can provide a joined interpretation of results from traditional financial metrics and IMF financial indexes to elucidate the nexus between renewable energy (RE) consumption and finance. The finding that financial markets are more relevant than financial institutions in promoting RE consumption - according to IMF indicators - can be attributed to the critical role of bond market financing. This conclusion is further supported by the estimation results on traditional financial indicators, which demonstrate that neither stock market capitalization nor total value traded in stock markets significantly influences RE consumption. Firms and public institutions (sovereign bond markets are included in IMF financial metrics) are better positioned to invest in RE technologies and infrastructures compared to households. The latter face financial barriers such as information asymmetries, high upfront capital costs, and long payback periods; these barriers also hinder households' access to financing from financial institutions, particularly banks.

Real GDP and environmental policy stringency also play significant roles in driving renewable energy consumption, while energy prices have the expected negative impact. The results highlight the importance of a comprehensive financial system and supportive regulatory frameworks in promoting the transition to renewable energy in the EU.

5. Long-run elasticities and Policy Implications

Short-run elasticities can be obtained from the GMM regressions results of Tables 5 and 6. In this case, the estimated coefficient represent the short-run elasticities, as they measure the immediate response of energy demand to changes in price, income and financial factors, holding other factors constant.

The long-run elasticity can be calculated by considering the effect of a change in price or income after all adjustments have taken place. Mathematically, the long-run elasticity

Table 6: RE consumption and finance (IMF financial development indicators, 2005-2019, 14 EU countries).

	Renewable energy consumption								
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
ln_FD	0.136***								
	(.043)								
ln_FI		0.041							
		(.044)							
ln_FM			0.087***						
			(.027)						
ln_FID				0.018					
				(.027)					
ln_FIA					0.006				
					(.014)				
ln_FIE						-0.006			
						(.044)			
ln_FMD							0.062***		
							(.016)		
ln_FMA								0.005	
								(.017)	
ln_FME									0.037***
									(.007)
L1.ln_ren_cons	0.980***	0.985***	0.978***	0.984***	0.984***	0.984***	0.981***	0.985***	0.974***
	(.006)	(.006)	(.006)	(.006)	(.006)	(.006)	(.006)	(.006)	(.005)
ln_constant_gdp	0.034*	0.038**	0.032**	0.027	0.041**	0.038**	0.031*	0.037**	0.051***
	(.019)	(.019)	(.015)	(.033)	(.019)	(.018)	(.018)	(.017)	(.019)
ln_ren_lcoe	-0.022***	-0.029***	-0.024***	-0.031***	-0.031***	-0.032***	-0.028***	-0.031***	-0.029***
	(.007)	(.010)	(.007)	(.010)	(.011)	(.011)	(.008)	(.010)	(.008)
ln_eps	0.020*	0.032**	0.027**	0.033**	0.036**	0.036**	0.027**	0.037**	0.028***
	(.011)	(.015)	(.010)	(.015)	(.017)	(.018)	(.013)	(.017)	(.011)
Countries/Obs.	14/196	14/196	14/196	14/196	14/196	14/196	14/196	14/196	14/196
AR(1)	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.006	0.005
AR(2)	0.595	0.566	0.600	0.573	0.566	0.571	0.557	0.570	0.616
Sargan test	177.8	181.6	177.5	183.0	182.7	184.2	178.6	182.4	178.1
	(0.235)	(0.179)	(0.240)	(0.160)	(0.164)	(0.145)	(0.223)	(0.168)	(0.231)

The regression coefficients are estimated using the Arellano and Bover (1995) and Blundell and Bond (1998) system GMM estimation approach. The dependent variable is the natural logarithm of renewable energy consumption. L1 stands for the one-lag variable. Standard errors are reported in parentheses. The estimated coefficients on the time dependent dummy variables and constants are not reported for brevity. AR(1) and AR(2) are Arellano and Bond (1991) tests for autocorrelation in differences. Sargan is the test for overidentifying restrictions (Arellano and Bond, 1991); p-values for this test are reported in parentheses. *, **, *** denote, respectively, statistical significance at 10%, 5% and 1%.

of the estimated coefficient β_j is computed by dividing the short-run elasticity by one minus the estimated coefficient on the lagged RE consumption variable:

$$\epsilon_{\beta_j} = \frac{\beta_j}{1-\alpha} \quad \text{for } j = 1, 2, 3, 4.$$

In this case α represents the speed of adjustment to the long-run equilibrium. The higher the α (closer to 1), the slower the adjustment, and vice versa. Elasticities of RE demand can be extremely useful for the calibration of macroeconomic models dealing with renewable energy and environmental issues.

Table 7 provides short- and long-run elasticities for regression models including traditional financial variables (as reported from Table 5). Following this interpretation, the short-run price elasticity denotes that an increase by a percentage point in RE LCOE decreases RE consumption by 0.022% when using banking indicators in the regression models. Long-term elasticities exhibit greater coefficients compared to short-term ones, indicating that a 1% change in the control variables yields more substantial effects in the long-run. For instance, the long-run GDP elasticity ranges between 0.64 and 1.037, implying that a 1% increase in real GDP produces an increase in RE consumption which is larger than the short term. Stock market indicators show small values of both short- and long-term elasticities relatively to banking variables. A one percent increase in stock market capitalization or total value traded decreases the share of RE consumption by, respectively, 0.016% or 0.015% in the short-run, and by, respectively, 0.64% or 0.5% in the long-run. Banking variables show identical values of elasticities: a 1% increase in bank private credit or overall private credit increases RE demand by 0.022% in the short-term, and by 0.814% in the long-term.

Table 8 reports elasticities of RE demand for the regression results attached to IMF financial indicators. Both short- and long-run elasticities show a larger variation range than those reported in Table 7. The percentage change on RE demand following a 1% change in i) GDP, ranges from 0.031 to 0.051 in the short-term and from 1.454 to 2.563 in the long-term, ii) RE LCOE, ranges from -0.022 to -0.032 in the short-run and -1.1 to -2.067 in the long-run, iii) EPS, ranges from 0.02 to 0.037 in the short-term and from 1 to 2.467 in the long-term. These financial indicators that provide a more synthetic expression of the degree of development of the overall financial system (FD), of financial intermediaries (FI), and of financial markets (FM), exhibit larger values of elasticity, either in the short- or in the long-run, than other specific financial indicators. For instance, a one percent increase in one of these three financial indicators generates a short-term change to RE demand which ranges between 0.041% to 0.136%, while the same percentage variation in other specific financial indicators potentially increases RE consumption by about 0.005%

Table 7: Renewable energy consumption elasticities calculated using estimates from Table 5.

	Model 1	Model 2	Model 3	Model 4
Short-run				
bank_credit	0.022			
private_credit		0.022		
mkt_cap			0.016	
tvt				0.015
constant_gdp	0.028	0.028	0.016	0.028
ren_lcoe	-0.022	-0.022	-0.136	-0.119
eps	0.025	0.025	0.025	0.028
Long-run				
bank_credit	0.814			
private_credit		0.814		
mkt_cap			0.640	
tvt				0.500
constant_gdp	1.037	1.037	0.640	0.933
ren_lcoe	-0.814	-0.814	-5.44	-3.967
eps	0.926	0.926	1.000	0.933

to 0.037%, except for the FIE index which show a short-run elasticity equal to -0.006. In the long-run perspective, a 1% increase in FD, FI, and FM generates, respectively, a change in RE demand of 6.8%, 2.733%, and 3.954%, while a 1% change in FID, FIA, FIE, and FMA is associated to a change in RE consumption by, respectively, 1.125%, 0.375%, -0.375%, 0.333%. Interestingly, the FMD and FME indicators show long-run elasticities equal to 3.263 and to 1.423. To sum up, these results highlight that: increases in the (i) private credit provided by banks and non-bank financial intermediaries, (ii) the degree of development of the overall financial system, and (iii) the degree of development of both financial institutions and, particularly, of financial markets, boost RE demand in the countries belonging to our sample. The long-run elasticities of financial indicators (both "traditional" and IMF's ones) are larger than the corresponding long-term price elasticities. Financial variables show not only a positive link with RE when controlling for the effects of GDP, RE LCOE, and EPS, but they also show larger long-run impacts on the share of RE consumption than national income, energy prices, and environmental policies do.

These outcomes suggest policy makers consider the valuable role of the financial sector, either banks and non-banks financial institutions as well as bond and stock markets, when modeling the RE demand, or even defining energy policies. As highlighted by

Table 8: Renewable energy consumption elasticities calculated using estimates from Table 6.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Short-run									
FD	0.136								
FI		0.041							
FM			0.087						
FID				0.018					
FIA					0.006				
FIE						-0.006			
FMD							0.0062		
FMA								0.005	
FME									0.037
constant_gdp	0.034	0.038	0.032	0.027	0.041	0.038	0.031	0.037	0.051
ren_lcoe	-0.022	-0.029	-0.024	-0.031	-0.031	-0.032	-0.028	-0.031	-0.029
eps	0.020	0.032	0.027	0.033	0.036	0.036	0.027	0.037	0.028
Long-run									
FD	6.800								
FI		2.733							
FM			3.954						
FID				1.125					
FIA					0.375				
FIE						-0.375			
FMD							3.263		
FMA								0.333	
FME									1.423
constant_gdp	1.850	2.533	1.454	1.688	2.563	2.375	1.632	2.466	1.961
ren_lcoe	-1.100	-1.933	-1.091	-1.938	-1.938	-2.000	-1.474	-2.067	-1.1115
eps	1.000	2.133	1.227	2.063	2.250	2.250	1.421	2.467	1.077

Zindler and Locklin (2016), major banks financed most of the debt for clean energy power generation, hence, there is a large potential for banks to engage in green finance instruments. However, the large-scale deployment of bank finance for clean energy can be limited by several barriers, such as 1) decreased confidence related to crisis events, to severe recession periods (such as the global financial crisis, government-debt crisis, Covid-19 crisis), and to tighter regulation (strict capital requirements and constraint in lending capacity with respect to the financing of long-term infrastructure projects), 2) unattractive risk/return profile of green investments, 3) sizable maturity mismatch between long-term loans for clean energy projects (for instance energy efficient buildings) and short-term liabilities, 4) difficulties in assessing environmental and technology risks, and 5) severe informational asymmetries attached to RE investments (Campiglio 2016; Group 2016, 2018). To foster the role played by bond and stock markets in supporting the deployment of renewables, it is important to take into consideration implications for different types of investors. The Group (2018) reports that private sector financing of green projects mostly stems from bank loans. The securitization of these sustainable loans could provide a range of green securitized-bonds targeted to institutional investors with different risk-return profiles, that may be used to finance or refinance additional green investment in the debt market. Furthermore, the development of sustainable venture capital could provide a great chance to handle the lack of adequate funding for early-stage companies and SMEs working on green projects. At the time being, financial institutions and financial markets are in the early stages of developing methodologies and tools to identify and assess financial risks associated with sustainable investments and many other institutions are yet to be engaged in this process. From this perspective, governments and other regulatory bodies should implement policies aimed to: i) foster the financing of EI and, in the meantime, gradually reduce the financing of brown energy project (for instance through promotional funds, tax relief and lower minimum capital requirements for green investments, target quota or volumes for green finance instruments), ii) raise the awareness of the benefits of green finance products and improve the quality and transparency of sustainability taxonomies, iii) support environmental and climate risk management both at project- and at portfolio-level, and promote incubators for sustainable start-ups as well as a range of sustainable green finance instruments suitable for a broad range of private equity investors.

6. Conclusions

This study contributes to the ongoing debate on green finance and environmental sustainability by exploring the complex relationship between financial development and renewable energy consumption within the EU, using a comprehensive set of indicators related to financial markets and institutions.

The empirical findings show several key observations. It broadly emerges a statistically significant positive correlation between financial development and renewable energy consumption, highlighting that well-developed financial systems, characterized by robust, in-depth, and efficient financial markets and institutions, promote the adoption and consumption of renewable energy. The availability of financial resources facilitates investments in renewable energy infrastructure, reducing the barriers to entry for renewable technologies. In particular, the outcome that financial markets are more relevant than financial institutions in promoting RE consumption can be attributed to the critical role played by green bond financing.

The findings also underscore the importance of stringent environmental policies in driving renewable energy consumption. Policies that impose costs on pollution and incentivize cleaner energy sources, such as feed-in tariffs and carbon taxes, have a positive effect on the adoption of renewable energy. This indicates that regulatory frameworks aligned with environmental goals are essential for encouraging the transition to a sustainable energy future. As expected, the analysis confirms an inverse relationship between RE consumption and the related price, expressed by the LCOE of renewable sources. Higher prices for renewable energy reduce its demand, which highlights the importance of maintaining cost-competitive renewable energy sources to ensure their broader adoption across the EU. Moreover, the short- and long-run elasticities of renewable energy demand with respect to financial and economic variables provide valuable insights for policymakers. In the long run, the impact of financial development on renewable energy consumption is more pronounced, suggesting that sustained improvements in financial systems could lead to significant increases in renewable energy adoption over time. The findings imply that policymakers should focus on strengthening financial markets and institutions to support the growth of renewable energy. This includes promoting green finance instruments, enhancing the efficiency and depth of financial markets, and ensuring that environmental policies are robust and effectively enforced. Additionally, efforts should be made to keep renewable energy prices competitive to stimulate demand further.

Overall, this research contributes to bridging the gap between financial development and sustainable energy transitions, offering valuable insights for policymakers, practitioners, and researchers alike. The implications of these findings extend to policy and practice, emphasizing the importance of fostering well-functioning financial markets and instituting environmental policies conducive to renewable energy adoption. In addition, by elucidating the mechanisms through which financial factors influence RE consumption, this study provides insights for designing targeted policies and interventions aimed at accelerating the transition towards a greener and more sustainable energy future. Such an integrated approach is vital to support the EU's ambitious renewable energy and climate goals. The results of this study have several important policy implications. First, there is a clear need for policymakers to design integrated strategies that align financial development with renewable energy goals. Financial instruments and markets specifically targeting renewable energy investments—such as green bonds, sustainable investment funds, and green banking—should be encouraged. Moreover, the role of government and regulation cannot be overstated. Strong regulatory frameworks that support the growth of renewable energy markets, including stringent environmental policies, are essential in creating an enabling environment that attracts both domestic and international investments.

While this study provides relevant insights, it also opens up paths for future research. One potential direction is to expand the scope of analysis to include emerging markets, low-income countries, or specific industries, offering a more nuanced understanding of how financial systems impact renewable energy adoption across different contexts. Additionally, future studies could delve into the role of technological innovation within the financial sector—such as fintech—in supporting renewable energy financing and deployment, as the intersection of technology and finance could be a key driver for future renewable energy growth.

Moreover, although the findings presented in this paper underscore the critical role of financial systems and environmental policies in shaping energy consumption patterns, more work should be devoted to investigating the impact of innovative financial instruments, such as green bonds, emission permits, on the deployment of renewable energy technologies. Besides, because climate change, environmental policy focuses on long-term objectives, a promising research area might assess the long-term impacts of environmental policies, such as carbon pricing mechanisms and renewable energy mandates, on the development of renewable energy markets. Future research should also focus on improving data quality and availability, particularly in emerging and developing economies, to more accurately assess the impact of financial development on renewable energy consumption. Comprehensive datasets would enhance the robustness of empirical findings. Additionally, employing more advanced econometric techniques in future studies could better address potential endogeneity issues and capture the dynamic relationship between financial development and renewable energy consumption more effectively. We leave these points for future research.

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