# The relationship between renewable energy demand and financial development: a global perspective

by

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Abstract

The paper empirically investigates the relationship between renewable energy consumption and financial development considering a reduced form dynamic panel model of renewable demand. The analysis is conducted over the 2000-2017 period for a sample of 37 countries, including both advanced and emerging market economies, using a system generalized method of moments estimator. We employ World Bank's financial indicators that are traditionally used in the literature, and recent indicators from the International Monetary Fund which assess depth, access, and efficiency. The results show a positive and statistically significant relationship between renewable consumption and the overall development of the financial system, as well as the dimension of financial institutions (banks and non-bank financial intermediaries). No statistically significant link emerges with stock market indicators. Our outcomes suggest that country authorities should provide clear environmental and economic policy signals for investors regarding the strategic framework for green finance instruments.

Keywords: renewable energy consumption, financial development, financial markets, financial institutions, green finance

JEL classification: G15, G20, O16, Q43

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## 1. Introduction

The rapid increase in energy consumption implies strong pressure on the environment in terms of increasing environmental degradation and global warming, which requires a fast transformation of the global energy sector towards an almost exclusive use of clean energy technologies. The investigation of the factors that influence energy consumption, and specifically renewable energy (RE) consumption, is therefore crucial in formulating energy policies aimed to sustainable development goals. According to REN21 (2020), global total final energy consumption (TFEC)[2] grew by 1.4% annually between 2007 and 2017, while the share of TFEC from modern renewables, i.e., excluding the traditional use of biomass, grew at a yearly average rate of 3.0%, though there are evident differences between OECD and non-OECD countries. In OECD countries, the share of modern renewables in TFEC rose by 44%, while in non-OECD countries the improvement was around 29%. However, we still observe slow growth in the RE share of TFEC probably due to insufficient support to investment in RE technologies: as of 2018, modern RE accounted 11% of TFEC, and 17.9% when including biomass (REN21 2020).

The demand of RE can be determined by several factors which will be analyzed in this paper. Such demand also derives from the generation of renewable sources of energy which is influenced by investments in the RE sector: at this regard, the financial system can be essential in channeling funds towards green energy sources, thus in providing the supply capacity.

Investment in environmental innovations are usually characterized by high profitability and high riskiness so that banks or other financiers could ration credit if they are not sufficiently protected by well designed, credible, and stable environmental and fiscal policies. Therefore, investment in RE can be seriously hampered by financial constraints which alter investors' perception of the risk/return trade-off of EI. Such constraints can stem from a strict regulatory framework, high upfront capital

[2] Total primary energy demand excluding the losses that occur during the processes of energy transformation, energy use, energy transmission and distribution.

cost, longer payback periods than brown alternatives, existence of dominating firms and technological lock-ins (Ghisetti et al. 2015, Mazzucato and Semieniuk 2018). The energy sector is more capital intensive than other industries because energy projects usually require high initial investment before the production begins. RE projects have low rates of return with respect to conventional energy projects and require longer pay-back periods. Furthermore, severe information asymmetries exist between firms and financiers, and given that much of the information cost is generally borne by investors, the RE sector suffers from underinvestment. High upfront capital costs, severe information asymmetries, and highly specific assets contribute to expensive external financing, which impedes a large-scale deployment of RE. Thus, promoting RE technologies requires well-functioning and efficient financial markets and institutions that provide easier access to debt and equity financing, mostly allowing to overcome moral hazards and adverse selection problems, and reducing the cost of external financing. Promoting financial instruments targeted to the financing of investments that provide environmental benefits is therefore crucial in achieving sustainable development goals. 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).

It is well known that financial development can be beneficial for economic growth and it is reasonable to suppose that the financial system can play a crucial role in the environmental development of a country as well, to the extent that financial markets and financial institutions influence RE demand through the financing of EI. As well as mitigating market frictions, financial development increases allocational efficiency, i.e., economic agents can allocate funds to the most desirable and profitable projects, or more generally economic agents devote less productive resources to better uses, and that is conducive for innovations and technological progress which stimulates economic development. A well-managed and properly developed financial sector allows the allocation of sufficient financial resources also to the energy sector, thus help maintaining a good balance between energy supply and demand (Furuoka 2015). The demand for energy can be affected by financial development in several ways. For instance, consumers can borrow money more easily to satisfy their needs, such as buying automobiles, houses, household appliances, which in turn increase energy demand; similarly, firms can access new or less costly sources of funding in order to expand their businesses (more plants, machinery, and workers) or create new ones (Sadorsky 2010, 2011).

Most of the existing research focuses on the relationship between financial development and conventional energy consumption, without paying the due attention to the potential effects on the RE sector. Channeling private funds in areas such as sustainable infrastructure and technologies, and environmental innovations, can provide substantial economic, social, and environmental benefits. Private capital is, indeed, an important source of green finance in addition to public financing. Therefore, a sound and well-developed financial system can be beneficial in promoting green finance instruments, in granting greater access to renewable investment, and in boosting RE demand. For instance, green banks can provide advantages in terms of better credit conditions, aggregation of small projects to achieve economies of scale, creation of innovative green financial instruments, and the efficient dissemination of information about the benefits of clean energy; green bonds can deliver long-term financing once a green project has passed through the construction phase and it is operating successfully (Sachs et al. 2019). In general, well-developed financial markets and institutions can foster the transition from brown to green energy generation by reducing the costs of external financing in the RE sectors and help overcoming information asymmetries, and by narrowing the financing gaps of low-carbon energy projects (Kim and Park 2016, Best 2017, Xie et al. 2020, Yao et al. 2019, Anton and Nucu 2020, Kayani et al. 2020).

We empirically investigate the relationship between RE consumption and financial development using a system GMM estimator for a panel of 37 economies located around the world over the 2000-2017 period. To pursue this goal, we consider a reduced form dynamic panel model of RE demand where national income and RE price are also included. Our panel is characterized by a large sample of countries with respect to the average number of countries usually included in the empirical literature on finance and (renewable) energy consumption.

We employ several indicators related to financial institutions and financial markets in order to gauge financial development, and to check whether and how financial institutions can affect RE consumption compared to financial markets. As well as relying upon traditional financial indicators that are commonly used in the academic literature to assess the size of the financial system, we also use the newly released IMF indexes which pay attention to depth, access, and efficiency of the modern and complex architecture of the financial system (Svirydzenka 2016). While traditional banks are the most common type of financial institution, non-bank financial institutions such as finance and insurance companies, investment banks, mutual funds, and others, play important roles in mobilizing funds. Depth, access, and efficiency of financial system are, therefore, essential aspects to take into consideration: large financial systems and efficient financial services provide limited benefits if they do not reach a sufficiently large proportion of the population and firms.

The main questions addressed by the paper are: i) Does the development of the overall financial system affect RE demand? ii) What is the role played by financial institutions and financial markets in RE demand? iii) What policy lessons can we learn?

The paper is organized as follows. Data description and descriptive statistics are presented in Section 2. Section 3 is devoted to methodology and econometric specification, while Section 4 provides results. Section 5 provides estimates of short- and long-term elasticities, and Section 6 concludes.

## 2. Related literature

We build on the literature which investigates the relationships between financial development and energy consumption on the one hand, and between financial development and RE consumption on the other hand. Such relationships have been explored by several empirical works that used different sample of countries, different time spans, and different econometric techniques. While most of the existing research explores the relationship between financial development and conventional energy consumption showing widely different conclusions (financial development can be positively, negatively, non-linearly, or not related to RE consumption), contributions investigating the renewables and finance nexus generally show a positive linkage between RE consumption and financial development.

At this regard, our paper contributes to that strand of the literature which shows a positive link between financial development and energy consumption. Sadorsky (2010) uses GMM estimation 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 and significant impact on energy consumption when financial development is measured using stock market variables. Sadorsky (2011) replicates the empirical exercise for nine central and eastern European frontier countries, and he finds that, when using banking variables, a significantly positive relationship exists between financial development and energy consumption, while when using stock market variables, only stock market turnover has a significantly positive relationship with energy consumption. 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. Domestic credit to private sector, which is one of the main indicators used to assess financial sector development, emerges to be positivity linked with energy consumption according to, among all, Al-Mulali and Lee (2013) for Gulf Cooperation Council (GCC) countries using the Pedroni cointegration test and panel data for 1980–2009, 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). Çoban and Topçu (2013) and Gaies et al. (2019) show that banking sector development accelerates energy consumption in, respectively, old members of the EU during the period 1990-2011, and 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. 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 find that under a stable country risk environment, financial development decreases overall 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, Wu and Broadstock (2015) for 22 emerging economies during the period 1990-2010, Lin et al. (2016) for China from 1980 to 2011, Alsaleh and Abdul-Rahim (2019) for the EU-28 region during the period 1990-2013, Khan et al. (2019) for 34 high-income countries from 1995 to 2017, Eren et al. (2019) for India during 1971–2015, Khan et al. (2020) for a very large sample of 192 countries during 1980-2018, and Mukhtarov et al. (2020) for Azerbaijan during 1993-2015. Also, financial markets can be beneficial to RE consumption. Ji and Zhang (2019) find that both credit market growth and stock market development are critical factors in fostering RE development in China. Anton and Nucu (2020) show that domestic credit provided by the financial sector, stock market turnover ratio, and outstanding international private debt securities positively affect RE consumption in the EU28 aggregate during 1990-2015. 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 (Kim and Park 2018). Stock market development emerges to be beneficial for RE consumption in India, China, Brazil, and South Africa (Kutan et al. 2018).

## 3. Data description

The analysis is carried out over the 2000-2017 period for a strongly balanced dataset of 37 countries, including both advanced and emerging economies.[3] This is an important feature of our work since contributions studying the renewables and finance nexus usually consider a sample of few countries, or even a single country, while only few contributions consider a large sample. 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 2020).

[3] The selection of countries stems from the need to find reliable and granular data on RE. Included countries, by region according to the World Bank classification, are: East Asia and Pacific, with Australia, China, Japan, Korea Rep., New Zealand; Europe and Central Asia, with Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Luxembourg, Netherlands, Norway, Poland, Portugal, Russian Federation, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom; Latin America and Caribbean, with Chile, Mexico; Israel; North America, with United States; South Asia, with India. The sample, obtained by combining OECD and IEA economies, offers a wide range of variation across countries of RE consumption as well as degree of financial development.

Energy price data are, in general, not easily available for all countries, and this task is even more difficult if we focus only on renewable sources.[4] In order to provide a country-specific measure of renewable price, we computed a weighted average of the global levelized cost of electricity (2019 USD/KWH) deriving from different technologies of RE sources, such as solar, hydro, wind, bioenergy, and geothermal. The weights are represented by the installed global RE capacity by technology (KWH). Finally, we multiply the weighted average price by the country exchange rate to convert the price in local currency units.

Real GDP is obtained from the World Bank's World Development Indicators (WDI), while financial indicators are those collected from the World Bank's Global Financial Development Database (GFDD) and from the Financial Development Index Database (FDID) released by the International Monetary Fund. Financial variables taken from the GFDD are those that are commonly recognized to be the relevant measures for financial size and development in the finance and growth literature, i.e., credit by banks to the private sector over GDP, credit by banks and non-banks to the private sector over GDP, banks' assets to GDP, total value of all listed shares in a stock market as a share of GDP, value of domestic shares traded on domestic exchanges over GDP.[5] Henceforth we will refer to them as "traditional" financial indicators. Variables taken from FDID are newly released indexes which 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

[4] 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.

[5] Extensive surveys of the theoretical and empirical literature on finance and growth are provided, among all, by Popov (2017) and from Levine (2005).

provide efficient financial services):[6] each indicator is normalized between 0 and 1, thus, higher values indicate greater financial development.

Table 1. Data description and sources

| Variable | Definition | Source |
|---|---|---|
| Real GDP | GDP at constant 2010 US$ | World Development Indicators, The World Bank, 2020 (indicator code NY.GDP.MKTP.KD) |
| Renewable energy price | Levelized cost of RE by technology (2019 USD/KWH) weighted for installed global RE capacity by technology (KWH), and converted by official exchange rates (LCU per USD) | IRENA (2020) for LCOE and renewables capacity. World Development Indicators, The World Bank, 2020 for official exchange rates (indicator code PA.NUS.FCRF) |
| Share of renewables consumption | Share of renewables consumption in TFEC | IEA (2020) |
| Banks' assets ratio | Deposit money banks' assets to GDP | Global Financial Development Database, The World Bank (indicator code GFDD.DI.02) |
| Bank credit ratio | Credit by deposit money banks to the private sector over GDP | Global Financial Development Database, The World Bank (indicator code GFDD.DI.01) |
| FD | Financial development index, obtained through the aggregation of sub-indices FI and FM | IMF (2020) |
| FI | 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 | IMF (2020) |
| FID | Financial institutions depth index | IMF (2020) |
| FIA | Financial institutions access index | IMF (2020) |
| FIE | Financial institutions efficiency index | IMF (2020) |
| FM | Financial markets index obtained through the aggregation of sub-indices FMD, FMA, and FME; financial markets included are mainly stock and bond markets | IMF (2020) |
| FMD | Financial markets depth index | IMF (2020) |
| FMA | Financial markets access index | IMF (2020) |
| FME | Financial markets efficiency index | IMF (2020) |
| Private credit ratio | Credit by deposit money banks and other financial institutions to the private sector over GDP | Global Financial Development Database, The World Bank (indicator code GFDD.DI.12) |
| Market capitalization ratio | Total value of all listed shares in a stock market as a percentage of GDP | Global Financial Development Database, The World Bank (indicator code GFDD.DM.01) |
| Total value traded ratio | Value of domestic shares traded on domestic exchanges over GDP | Global Financial Development Database, The World Bank (indicator code GFDD.DM.02) |

Global Financial Development Database, The World Bank, 2019.

International Energy Agency (IEA), 2020. World Energy Balances (database).

International Monetary Fund (IMF), 2020. Financial Development Index Database.

International Renewable Energy Agency (IRENA), 2020. Renewable Power Generation Costs in 2019, IRENA, Abu Dhabi.

The Worldwide Development Indicators, The World Bank, 2020.

[6] Svirydzenka (2016).

The FD index captures the degree of development for both financial institutions (FI) and financial markets (FM). Financial institutions include banks, insurance companies, mutual funds, pension funds, and other types of non-bank financial institutions. Financial markets include mainly bond and stock markets. Each FI and FM index is measured according to 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, are therefore subject to a twofold process of aggregation that determines higher-level indices, respectively, FI and FM, and culminates at the highest-level, i.e., the FD index. The use of both traditional and newly released financial indicators allows also to check whether and how financial institutions can affect RE consumption compared to financial markets.

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

Table 2. Descriptive statistics

| Variables | Obs. | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| ln_rer | 666 | 1.7797 | 0.9430 | -0.9934 | 3.8379 |
| ln_gdp | 666 | 26.8221 | 1.5977 | 23.0780 | 30.4845 |
| ln_ren_price | 629 | -2.6950 | 2.3549 | -6.3344 | 4.3222 |
| ln_bank_credit | 662 | 4.3038 | 0.5817 | 2.4551 | 5.5634 |
| ln_private_credit | 662 | 4.3206 | 0.7814 | -0.3587 | 5.5634 |
| ln_bank_assets_gdp | 662 | 4.4401 | 0.6436 | 0.7025 | 5.5661 |
| ln_mkt_cap | 618 | 3.8713 | 0.8276 | 0.3814 | 5.5750 |
| ln_tvt | 611 | 3.0514 | 1.6475 | -3.5914 | 5.7485 |
| ln_FD | 666 | -0.5268 | 0.3469 | -1.7394 | 0.0000 |
| ln_FI | 666 | -0.4385 | 0.3076 | -1.5903 | 0.0000 |
| ln_FID | 666 | -0.7618 | 0.6038 | -2.5975 | 0.0000 |
| ln_FIA | 666 | -0.5498 | 0.5220 | -2.9519 | 0.0000 |
| ln_FIE | 666 | -0.3783 | 0.1915 | -1.8276 | -0.1412 |
| ln_FM | 666 | -0.7800 | 0.7622 | -3.9822 | 0.0000 |
| ln_FMD | 666 | -0.8582 | 0.8295 | -4.5006 | -0.0093 |
| ln_FMA | 666 | -0.9299 | 0.8245 | -4.6090 | 0.0000 |
| ln_FME | 612 | -0.7845 | 1.2475 | -7.4317 | 0.0000 |

## Table 3. Pairwise correlations

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) | (17) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) ln_rer | 1 | | | | | | | | | | | | | | | | |
| (2) ln_gdp | -0.2806*** | 1 | | | | | | | | | | | | | | | |
| (3) ln_ren_price | 0.0583 | -0.0480 | 1 | | | | | | | | | | | | | | |
| (4) ln_bank_credit | -0.0885** | 0.0693* | -0.1005** | 1 | | | | | | | | | | | | | |
| (5) ln_private_credit | 0.0652* | 0.1245*** | -0.1164*** | 0.7921*** | 1 | | | | | | | | | | | | |
| (6) ln_bank_assets gdp | 0.0944** | 0.0638 | -0.1239*** | 0.8328*** | 0.9227*** | 1 | | | | | | | | | | | |
| (7) ln_mkt_cap | -0.2438*** | 0.3972*** | -0.0785** | 0.4217*** | 0.3686*** | 0.2799*** | 1 | | | | | | | | | | |
| (8) ln_tvt | -0.1636*** | 0.6723*** | -0.0022 | 0.2980*** | 0.2780*** | 0.2270*** | 0.6296*** | 1 | | | | | | | | | |
| (9) ln_FD | -0.3876*** | 0.5358*** | -0.1736*** | 0.6303*** | 0.5462*** | 0.5090*** | 0.7450*** | 0.6256*** | 1 | | | | | | | | |
| (10) ln_FI | -0.3547*** | 0.1649*** | -0.2247*** | 0.7602*** | 0.6720*** | 0.6405*** | 0.5460*** | 0.2755*** | 0.7940*** | 1 | | | | | | | |
| (11) ln_FID | -0.2059*** | 0.2425*** | -0.1244*** | 0.7951*** | 0.7699*** | 0.7132*** | 0.6441*** | 0.4209*** | 0.8056*** | 0.8773*** | 1 | | | | | | |
| (12) ln_FIA | -0.4420*** | -0.0321 | -0.1916*** | 0.4107*** | 0.3098*** | 0.2935*** | 0.2317*** | 0.0209 | 0.4823*** | 0.7768*** | 0.4352*** | 1 | | | | | |
| (13) ln_FIE | 0.0582 | 0.1091*** | -0.2078*** | 0.3277*** | 0.3956*** | 0.4457*** | 0.2479*** | 0.0631 | 0.3172*** | 0.3994*** | 0.3765*** | 0.0620 | 1 | | | | |
| (14) ln_FM | -0.3034*** | 0.6413*** | -0.0392 | 0.3603*** | 0.3003*** | 0.2823*** | 0.6917*** | 0.6959*** | 0.8718*** | 0.4321*** | 0.5357*** | 0.1451*** | 0.1780*** | 1 | | | |
| (15) ln_FMD | -0.3235*** | 0.5794*** | -0.0765* | 0.5288*** | 0.4467*** | 0.4129*** | 0.8044*** | 0.6813*** | 0.9199*** | 0.6103*** | 0.7220*** | 0.2636*** | 0.2198*** | 0.9112*** | 1 | | |
| (16) ln_FMA | -0.3167*** | 0.2875*** | -0.0337 | 0.3055*** | 0.2416*** | 0.1977*** | 0.5150*** | 0.2717*** | 0.6823*** | 0.4258*** | 0.4412*** | 0.3038*** | 0.0289 | 0.7251*** | 0.6484*** | 1 | |
| (17) ln_FME | 0.0741* | 0.6124*** | 0.0150 | 0.1076*** | 0.0915** | 0.0765* | 0.1895*** | 0.8340*** | 0.3418*** | -0.0196 | 0.0988** | -0.1339*** | -0.1019** | 0.5904*** | 0.3777*** | 0.0789* | 1 |

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

# 4. Methodology and econometric specification

We first perform unit root tests to check the stationarity of the relevant variables, since non-stationarity could lead to spurious regression results. We first start with the level terms of the variables. If a time series at its level term is non-stationary, it will have a unit root, but if the first differences of the time series are stationary, it implies that the series is integrated of degree one. Only stationary data integrated of the same order can be used for the following panel regression analysis to generate meaningful results. Panel unit root tests can be performed according to two main categories: one is a unit root test assuming a common unit root process, such as the Levin-Lin-Chu (LLC) test, Breitung test and Hadri test, the other is a test under the assumption of individual unit root process, such as Im-Pesaran-Shin (IPS) test, ADF-Fisher test and PP-Fisher test. For unbalanced panel dataset, the Fisher type tests of ADF and Phillips Perron can be sufficient for testing stationarity. For balanced dataset, as in our case, LLC and Breitung tests can be preferred to Fisher type tests since the latter may lead to misleading results. We choose the LLC test to check the stationarity of our series since the properties of our dataset satisfy the asymptotics requirement $\sqrt{N}/T \to 0$ where $N$ is the cross-section dimension and $T$ is the time dimension. The null hypothesis is that each series in the panel contains a unit root, while the alternative one is that each time series in the panel is stationary. Results of the LLC test are reported in Table 4: all variables emerge to be stationary so there is no need of cointegration.

To estimate the relationship between RE demand and financial development we follow the same econometric specification of Sadorsky (2010, 2011) but we deviate from their analysis using RE price instead of energy price and including different financial indicators. We consider a reduced form dynamic panel model of RE demand, where the latter is supposed to depend on real GDP (y), RE price (p), and a financial indicator (fin).

Table 4. Levin-Lin-Chu (LLC) panel unit root test

| | Intercept | Intercept and trend |
|---|---|---|
| ln_ren | -2.891*** | -4.533*** |
| ln_gdp | -3.998*** | -5.447*** |
| ln_ren_price | -1.668** | -9.550*** |
| ln_bank_credit | -5.847*** | -5.753*** |
| ln_private_credit | -5.819*** | -5.198*** |
| ln_bank_assets_gdp | -6.937*** | -4.267*** |
| ln_mkt_cap | -5.618*** | -6.680*** |
| ln_tvt | -6.807*** | -11.022*** |
| ln_FD | -7.297*** | -7.587*** |
| ln_FI | -7.653*** | -5.869*** |
| ln_FID | -3.688*** | -4.544*** |
| ln_FIA | -2.302** | -1.736** |
| ln_FIE | -14.734*** | -9.379*** |
| ln_FM | -5.807*** | -8.410*** |
| ln_FMD | -5.798*** | -7.378*** |
| ln_FMA | -6.437*** | -8.412*** |
| ln_FME | -1.2e03*** | -1.2e03*** |

Missing values have been interpolated to perform the test

$$rer_{i,t} = \alpha\, rer_{i,t-1} + \beta_1 y_{i,t} + \beta_2 p_{i,t} + \beta_3 fin_{i,t} + \mu_i + \lambda_t + \epsilon_{i,t} \quad (1)$$

where $y_{i,t}$ denotes the real GDP (constant 2010 USD)) for country i (with i=1, …, 37) at year t (with t=2000, …, 2017), while $rer_{i,t}$ and $rer_{i,t-1}$ denote, respectively, the share of RE consumption at time t and the lagged one. $fin_{i,t}$ denotes the financial variable included one-at-a-time in the regression equation. $\mu_i$ denotes country-fixed effects used to control for unobserved heterogeneity across countries and thus account for common factors and unobservable, time-invariant, country-specific effects on RE consumption, while $\lambda_t$ denotes time-fixed effects. $\epsilon_{i,t}$ is the error term. For modeling purposes, all variables are expressed in natural logarithms to avoid problems associated with dynamic properties of data.

Eq. (1) is an example of a linear dynamic panel model as specified by Arellano and Bond (1991). Non-dynamic econometric approaches could lead to inconsistent estimates since this model contains unobserved panel-level effects (fixed or random) that are correlated with the lag(s) of the dependent variable. To obtain consistent parameter estimates, the generalized method of moments (GMM) estimator developed by Arellano and Bond (1991) can be suitable for such a model and for situations where the number of groups is larger than the number of time periods, like in our case. The authors use a first differencing transformation to remove the unobserved group-specific heterogeneity. However, a drawback of the Arellano and Bond (1991) approach is that it can perform poorly if the autoregressive parameters are too large, or if the ratio between the variance of the panel-level effect and the variance of the idiosyncratic error is too large. Therefore, 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 price, GDP, and financial variables. In Eq. (1), RE consumption, GDP, and financial indicators (one-by-one) are treated as endogenous considering lags two, three and four.

# 5. Results

System GMM estimates for regression models including traditional financial size indicators and IMF’s financial development indicators are reported, respectively, in Table 5 and 6. For each model, the share of RE consumption of a given year is influenced by its one-lag variable, since the estimated coefficient is positive, statistically significant at the 1% level, and it shows an high level of persistence. The estimated coefficients on real GDP emerge to be negative and not statistically significant in each of the five models, while the price of RE is negative and significant at least at 10% (10% in Model 1, 5% in Models 2 and 5, and 1% in Model 4), except for Model 3, denoting the existence of a traditional negative relationship between RE demand and the price of renewables.

Table 5. System GMM panel estimation results for traditional financial indicators

| | Dependent variable: share of RE consumption | | | | |
|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 |
| ln_rer (-1) | 0.953***<br>(83.89) | 0.957***<br>(103.03) | 0.953***<br>(104.64) | 0.957***<br>(81.10) | 0.954<br>(79.24) |
| ln_gdp | -0.00782<br>(-1.36) | -0.00861<br>(-1.52) | -0.00874<br>(-1.45) | -0.00570<br>(-0.87) | -0.00518<br>(-0.61) |
| ln_ren_price | -0.00843*<br>(-1.89) | -0.0114**<br>(-2.21) | -0.00801<br>(-1.57) | -0.0126***<br>(-2.61) | -0.0104**<br>(-2.23) |
| ln_bank_credit | 0.0199<br>(1.16) | | | | |
| ln_private_credit | | 0.0193**<br>(2.54) | | | |
| ln_bank_assets_gdp | | | 0.0290***<br>(2.61) | | |
| ln_mkt_cap | | | | -0.00626<br>(-0.51) | |
| ln_tvt | | | | | -0.00480<br>(-0.83) |
| Obs./Groups | 589/37 | 589/37 | 589/37 | 554/37 | 551/37 |
| AR(1) | 0.006 | 0.006 | 0.006 | 0.006 | 0.005 |
| AR(2) | 0.916 | 0.902 | 0.913 | 0.553 | 0.537 |
| Sargan test | 221.8(0.260) | 216.8(0.341) | 216.0(0.355) | 220.5(0.279) | 227.1(0.186) |

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 share of RE consumption. Standard errors are reported in parentheses. The estimated coefficients on the time dependent dummy variables and constants are not reported. 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%.

There are only two financial indicators to be statistically linked to RE demand, i.e., the private credit ratio and the banks' assets ratio whose estimated coefficients are both positive and significant at the 5% and 1% level, respectively. No stock market indicator emerges to be statistically significant, showing that banks and non-bank financial institutions can play a crucial role in financing firms working in the RE sector.

Table 6. System GMM panel estimation results for financial development indexes

| | Dependent variable: share of RE consumption | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 | Model 8 | Model 9 |
| ln_rer (-1) | 0.958*** (85.10) | 0.969*** (91.01) | 0.967*** (105.88) | 0.975*** (92.21) | 0.955*** (97.85) | 0.952*** (94.90) | 0.946*** (72.85) | 0.954*** (99.91) | 0.943*** (69.00) |
| ln_gdp | -0.0116* (-1.68) | -0.00849 (-1.52) | -0.0135** (-2.10) | -0.00367 (-0.85) | -0.00938** (-2.09) | -0.0137* (-1.66) | -0.00481 (-0.72) | -0.00967* (-1.82) | -0.0238*** (-2.68) |
| ln_ren_price | -0.00986** (-2.29) | -0.00986** (-2.34) | -0.00708* (-1.69) | -0.00737* (-1.95) | -0.0100** (-2.39) | -0.0100** (-2.03) | -0.0121** (-2.56) | -0.0117** (-2.47) | -0.0103** (-2.11) |
| ln_FD | 0.0365 (1.23) | | | | | | | | |
| ln_FI | | 0.0618** (2.16) | | | | | | | |
| ln_FID | | | 0.0311** (2.34) | | | | | | |
| ln_FIA | | | | 0.0519** (2.55) | | | | | |
| ln_FIE | | | | | 0.0397 (0.86) | | | | |
| ln_FM | | | | | | 0.00970 (0.86) | | | |
| ln_FMD | | | | | | | -0.00859 (-0.84) | | |
| ln_FMA | | | | | | | | 0.00191 (0.20) | |
| ln_FME | | | | | | | | | 0.0157* (1.80) |
| Obs./Groups | 592/37 | 592/37 | 592/37 | 592/37 | 592/37 | 592/37 | 592/37 | 592/37 | 544/34 |
| AR(1) | 0.005 | 0.006 | 0.005 | 0.006 | 0.006 | 0.006 | 0.005 | 0.006 | 0.006 |
| AR(2) | 0.953 | 0.950 | 0.979 | 0.981 | 0.934 | 0.943 | 0.933 | 0.933 | 0.868 |
| Sargan test | 232.7(0.125) | 228.3(0.172) | 227.9(0.176) | 239.3(0.074) | 226.2(0.198) | 242.4(0.056) | 270.9(0.003) | 220.7(0.276) | 226.6(0.192) |

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 share of RE consumption. Standard errors are reported in parentheses. The estimated coefficients on the time dependent dummy variables and constants are not reported. 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%.

An increase by 1% in the private credit ratio or in the banks' assets ratio increases the share of RE consumption by, respectively, 0.0193 and 0.0290. This outcome can be partially explained by the high dependence of the RE sector on external sources of financing: banks and non-bank financial institutions support investments in renewables by reducing market frictions in the renewable sector. The larger the banking sector in the economy, the better is the benefit in terms of increasing RE demand. It is well known in the literature that financial intermediaries arise to break down frictions in the credit market, mostly transaction costs, excessive risk-taking, and asymmetric information.

GMM estimates for regression models including the nine IMF financial development indexes are displayed in Table 6. The coefficient of one-lag RE consumption is still positive and significant at 1% level. Estimates for real GDP ranges between -0.00367 and -0.0238 (larger value than the GDP coefficients estimated in Table 5) and they are statistically significant at 10% in Models 1, 6 and 8, at 5% in Models 3 and 5, and at 1% in Model 10. As for Table 5, RE price coefficients are negative and significant at the 5% level, except for Models 3 and 4 (10% level). Looking at the estimated coefficients on the financial variables, the degree of development of financial institutions is positively related to RE demand. FI, FID, and FIA emerges to be positively linked to RE consumption and statistically significant at the 5% level. The largest coefficient is associated to FI (0.0618), followed by FIA (0.0519), and by FID (0.0311). No index related to the development of financial markets (mainly stocks and bonds markets) emerges to be statistically significant, except for the FME index, whose estimated coefficient is positive (0.0157) and significant at 10%. The estimates tell us the same story as Table 5: the degree of development of financial institutions (banks and non-banks financial intermediaries) affects RE consumption, in terms of i) larger depth and better quality of the financial services provided, as well as ii) larger promotion and easier access to the services provided by financial institutions. Our 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, where the latter is mostly measured by domestic credit to private sector.

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, while AR(2) tests show no second-order autocorrelation. Sargan tests reported in Table 5 show no evidence of miss-specification at conventional levels of significance. In Table 6, Models 4, 6, and 7 show potential miss-specification issues: Models 4 and 6 reject the null hypothesis that overidentifying restrictions are valid at the 10% level, while Model 7 at the 1% level.

## 6. Elasticities in the short- and long-term

Short-run and long-run elasticities can be obtained from the GMM regressions results of Table 5 and 6. The estimated coefficient on a variable represents the short-run elasticity of the share of renewable consumption with respect to that variable. The long-run elasticity is computed by dividing the short-run elasticity by one minus the estimated coefficient on the lagged RE consumption variable.

Table 7 provides short- and long-run elasticities for regression models including traditional financial variables. For instance, the short-run price elasticity denotes that an increase by a percentage point in renewable price decreases the share of RE consumption by -0.013% and -0.008%. Long-run elasticities show larger coefficients than the short-run ones: the long-run price elasticity ranges between -0.29302 and -0.17043, implying if real GDP increases by 1% the share of RE consumption decreases around -0.11% and -0.2%. 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, -0.006% or -0.005% in the short-run, and by, respectively, -0.146% or -0.104% in the long-run. Regarding banking variables, the total banks assets/GDP shows the largest values for elasticities: a 1% increase in total banks assets/GDP increases RE demand by 0.029% in the short-term, and by 0.617% in the long-term. Values for bank credit and private credit elasticities are similar (respectively 0.0199 and 0.0193 in the short-run, 0.423404 and 0.448837 in the long-term).

Table 8 reports RE demand elasticities for those regression models including synthetic financial indicators. Short- and long-run GDP elasticities show a larger variation range than those reported in Table 7: short-run ones vary from -0.0238 and -0.00481, while long-run between -0.41754 and -0.08907.

Table 7. Energy demand elasticities calculated using estimates from Table 5

| | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 |
|---|---|---|---|---|---|
| *Short-run elasticities* | | | | | |
| ln_gdp | -0.00782 | -0.00861 | -0.00874 | -0.0057 | -0.00518 |
| ln_ren_price | -0.00843 | -0.0114 | -0.00801 | -0.0126 | -0.0104 |
| ln_bank_credit | 0.0199 | | | | |
| ln_private_credit | | 0.0193 | | | |
| ln_bank_assets_gdp | | | 0.0290 | | |
| ln_mkt_cap | | | | -0.00626 | |
| ln_tvt | | | | | -0.00480 |
| *Long-run elasticities* | | | | | |
| ln_gdp | -0.16638 | -0.20023 | -0.18596 | -0.13256 | -0.11261 |
| ln_ren_price | -0.17936 | -0.26512 | -0.17043 | -0.29302 | -0.22609 |
| ln_bank_credit | 0.423404 | | | | |
| ln_private_credit | | 0.448837 | | | |
| ln_bank_assets_gdp | | | 0.617021 | | |
| ln_mkt_cap | | | | -0.14558 | |
| ln_tvt | | | | | -0.10435 |

Table 8. Energy demand 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 elasticities* | | | | | | | | | |
| ln_gdp | -0.0116 | -0.00849 | -0.0135 | -0.00367 | -0.00938 | -0.0137 | -0.00481 | -0.00967 | -0.0238 |
| ln_ren_price | -0.00986 | -0.00986 | -0.00708 | -0.00737 | -0.0100 | -0.0100 | -0.0121 | -0.0117 | -0.0103 |
| ln_FD | 0.0365 | | | | | | | | |
| ln_FI | | 0.0618 | | | | | | | |
| ln_FID | | | 0.0311 | | | | | | |
| ln_FIA | | | | 0.0519 | | | | | |
| ln_FIE | | | | | 0.0397 | | | | |
| ln_FM | | | | | | 0.00970 | | | |
| ln_FMD | | | | | | | -0.00859 | | |
| ln_FMA | | | | | | | | 0.00191 | |
| ln_FME | | | | | | | | | 0.0157 |
| *Long-run elasticities* | | | | | | | | | |
| ln_gdp | -0.27619 | -0.27387 | -0.40909 | -0.1468 | -0.20844 | -0.28542 | -0.08907 | -0.21022 | -0.41754 |
| ln_ren_price | -0.23476 | -0.31806 | -0.21455 | -0.2948 | -0.22222 | -0.20833 | -0.22407 | -0.25435 | -0.1807 |
| ln_FD | 0.869048 | | | | | | | | |
| ln_FI | | 1.993548 | | | | | | | |
| ln_FID | | | 0.942424 | | | | | | |
| ln_FIA | | | | 2.076 | | | | | |
| ln_FIE | | | | | 0.882222 | | | | |
| ln_FM | | | | | | 0.202083 | | | |
| ln_FMD | | | | | | | -0.15907 | | |
| ln_FMA | | | | | | | | 0.041522 | |
| ln_FME | | | | | | | | | 0.275439 |

Renewable price elasticities are instead similar, in sign, magnitude, and variation range, to those reported in Table 7. In line with the outcomes of Table 7, financial institutions indicators show larger values of elasticity, either in the short- or in the long-run, than financial markets indicators, implying that the degree depth, access, and efficiency of the banking sector generate larger changes to RE demand than the degree depth, access, and efficiency of both stock and bond markets. For instance, a one percent increase in one of the four financial markets indicators generates a short-term change to the share of RE consumption between -0.009% and 0.016%, while the same percentage variation in financial institutions indicators potentially increases RE consumption between 0.031% and 0.062%. The largest value of short-run elasticity is associated to FI (the one incorporating the three sub-indices FID, FIA, and FIE), i.e., 0.0618, followed by the FIA indicator with 0.0519. In the long-run perspective, a 1% increase in financial markets indicators provides a change in RE demand between -0.159% and 0.275%, while a 1% change to financial institutions indicators lead to an increase in RE demand between 0.869% and 2.076%.

The outcomes of this paper tell us that increases in the (i) private credit provided by financial intermediaries, (ii) size of the banking sector, and (iii) degree of development of financial institutions, boost RE demand in the countries belonging to our sample. The long-run elasticities of financial indicators (both "traditional" and development 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 and RE prices, but they also show larger long-run impacts on the share of RE consumption than national income and energy prices do.

These outcomes suggest policy makers consider the valuable role of the financial sector, in particular of banks and non-banks financial institutions, when modeling the RE demand, or even defining energy policies. As highlighted by 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, GFSG 2016, 2018).

Stock-market variables and other financial-market related development indicators (FM and related sub-indices) show no statistically significant link with the demand for renewables. To foster bond and stock markets financing of RE, it is important to take into consideration implications for different types of investors. The GFSG 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. Governments and other regulatory bodies should implement policies aimed to i) foster the financing of EI and, in the meantime, gradually reduce the financings 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.

## 7. Conclusions

Investigating the factors which may affect RE demand is essential to formulate energy policies aimed to achieve sustainable development goal and manage global CO2 emissions, both at global and national level. The transition towards a greener energy demand is related to RE generation. Financing RE technologies is therefore crucial to increase the availability of these energy sources and to reduce their cost. However, critical market frictions affect the financing of RE technologies, and that is why recent scholars point out that a well-functioning financial system can support the deployment of renewable sources of energy.

The main goal of this study has been to empirically examine whether financial development stimulates or not RE consumption on a global scale of 37 countries, during the 2000-2017 period. We estimated a reduced form RE demand model where we also investigated the effect that RE price and GDP may have on RE demand. As well as confirming a traditional negative relationship between RE consumption and RE price, our findings contribute to the strand of the literature which shows a positive link between RE demand and financial indicators. We show that the degree of development of financial institutions (banks and non-bank financial intermediaries) fosters RE consumption according to i) larger dimension of the banking sector, ii) larger depth and better quality of the financial services provided, and iii) larger promotion and easier access to the services offered by financial institutions.

Our results suggest that improvements in the financial sector, mostly related to banking activities, can positively influence the deployment of RE, and that country authorities should provide clearer economic policy signals to financial markets investors regarding green investment. Mobilizing private capital towards EI is indeed crucial to support the ongoing green transition, and it should be complementary to public financing to provide economic, environmental, and social benefits. Low incentives to develop clean energy technologies prevent EI from gaining a competitive advantage with respect to brown ones, and the absence of consistent policy interventions raise the financial risk attached to the profitability of EI. Policy makers should put a great effort in reducing regulatory barriers to RE investments and in designing institutional mechanisms aimed to grant an easier access to green finance instruments, to consolidate green banking activities, to increase the profitability of RE asset finance, and to reduce financial risks.

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