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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Silva, Palloma/Amaral, Roberta et. al. (2024). Understanding the influence of wind and solar PV on socioeconomic and environmental trends : a non-causality perspective. In: International Journal of Energy Economics and Policy 14 (5), S. 1 - 9.
https://www.econjournals.com/index.php/ijeep/article/download/15999/8112/39306.
doi:10.32479/ijeep.15999.

This Version is available at:
http://hdl.handle.net/11159/701573

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International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(5), 1-9.

Understanding the Influence of Wind and Solar PV on Socioeconomic and Environmental Trends: A Non-causality Perspective

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Received: 13 February 2024 **Accepted:** 05 July 2024 **DOI:** https://doi.org/10.32479/ijeep.15999

ABSTRACT

This paper investigates the non-causality perspective of economic growth, investment, social well-being, employment, GHG emissions on renewable energy sources (RES) (wind and solar PV), providing a comprehensive overview of renewable technologies that effect on socio-economic and environmental drivers. The analysis and enhancing linear regression techniques, addressing cross-country RES installed capacity heterogeneity, and applying time-lags techniques to better understand the temporal effect of RES´s investment. The study tested: (I) economic growth in a country is related to the development of RESs, employment, investment. (II) Increased RESs share positively impacts social well-being. (III) RESs implementation reduces GHG emissions. Our findings suggest that RES positively influenced economic growth over time for countries with higher installed capacity. However, this statistically significant is not observed across countries with lower installed capacity nor across all indicators, like social well-being, employment, investment, which show modest growth trend over time. GHG emissions also showed an inverse trend, suggesting the needs the renewable electricity´s expansion accompanied by additional mitigation measures to reduce emissions. One limitation is the temporal restriction, which limits the assessment of long-run trends. Future research should focus on gathering a larger dataset for long-run trends analysis.

Keywords: Renewable Energy, Investment, Economic Growth, Social, Employment, Greenhouse Gas Emissions
JEL Classifications: C8, C18, C19, C23, O13, Q2, Q43

1. INTRODUCTION

Renewable energy sources (RES) are pinpoint as a pivotal strategy to decarbonize the energy system and mitigate change. Keeping global average surface temperature below 2°C above pre-industrial levels and pursuing efforts to limit it to 1.5°C as set in the Paris Agreement is crucial (UNFCCC, 2015) By 2030, increasing RES capacity to over 90% and achieving 85% of electricity generation from RES is pivotal (IEA, 2022). By 2030, renewable energy capacity is projected to triple to over 11,000 GW, led by solar and wind, which will play a crucial role in economic growth new job creation, and achieving Net Zero Emissions by 2050 (IEA, 2023). The International Energy Agency´s (IEA) revealed that global renewable energy capacity increased by 50% in 2023, based on 2022, led mainly by China which more than doubled its solar capacity and increased its wind capacity by 66% in 2023 (IEA, 2024). This growth in renewable capacity tends to be positively reflected in the creation of new jobs, particularly in countries such as China, Brazil, India, USA and EU, which boast (IRENA, 2020) the highest concentration of jobs in renewable energy, leading industry transformation, engineering and installations (IRENA, 2016). By 2050, however, we verified that there will be a major concentration of RES global jobs, mainly drive by Asia countries for about 64% of global renewable energy jobs, Americas for 15% and Europe for 10%. Regarding this percents, solar energy will for over 50% in Asian countries, 34% in the Americas and 30% in Europe. The rise wind energy for above 15% in Asian countries, around 10% in Americas and Europe (IRENA, 2020). The growth in investment driven by capital-intensive RES technologies, leads to multiplier effects in the economic growth, significantly impacting GDP (Bhuiyan et al., 2022; Charfeddine and Kahia, 2019; Chien and Hu, 2008; Ntanos et al., 2018; Sharma et al., 2021).

Welfare, including health and education, is vital alternative to GDP for assessing the impact of rise renewable energy, serving as a broader perspective beyond the purely economic aspects captured by GDP. Policies should thus consider integrated approaches for successful transition, considering energy, economy, social well-being and environment for decision making (IRENA, 2016). In fact, although material living conditions, or economic well-being, are a critical factor for overall societal well-being, this concept recognized as multi-dimensional (OECD, 2011; Stiglitz, 2009). Understanding (and measuring) well-being requires considering three aspects, not only economic well-being (material living conditions) which determine consumption possibilities and people´s command over resources, but also quality of life, described as the collection of non-monetary characteristics of individuals, and the sustainability of the socio-economic and natural systems where people live and work, which depends on how current human activities impact the stocks of various types of capital (natural, economic, human and social) (OECD, 2011). The literature extensively explores the relationship between renewable energy, economic growth, jobs creation, and climate mitigation, using various analysis methods (Adams et al., 2018; Alkasasbeh et al., 2023; Bhuiyan et al., 2022; Chen et al., 2019; Chien and Hu, 2008; Ferhi and Helali, 2023; Grijó and Soares, 2016; Inglesi-Lotz, 2016; Meyer and Sommer, 2016; Ntanos et al., 2018; Proença and Fortes, 2020; Shahbaz et al., 2020; Sharma et al., 2021; Xiaosan et al., 2021; Yildirim et al., 2012). Multiple studies reveal a causal link between renewable energy and these drivers, in different contexts such as energy consumption and renewable electricity generation and countries/regions (Adams et al., 2018; Alkasasbeh et al., 2023; Bhuiyan et al., 2022; Charfeddine and Kahia, 2019; Grijó and Soares, 2016; Inglesi-Lotz, 2016; Ntanos et al., 2018; Shahbaz et al., 2020; Sharma et al., 2021; Xiaosan et al., 2021). Adams et al. (2018), Shahbaz et al. (2020), and Ntanos et al. (2018), for instance, concluded that both renewable energy sources (RES) and non- renewable energy sources (NRES) contribute to economic growth.

Adams et al. (2018), focused on 30 Sub- Saharan-African (SSA) countries between the 1980 and 2012 period, founding that RES had a lower impact on economic growth compared with non-RES. This could be attributed to the fact that many countries in the region as still in the early stages of investing in renewable energy technologies, have yet to fully reap the benefit from these investments.

Ntanos et al. (2018), conducted a close analysis for 25 European countries over the period 2007-2016. The authors observed that the correlation between renewable energy sources and GDP was higher in countries with higher GDP levels, compared to the correlation with non-renewable energy sources in countries with lower GDP levels that rely more heavily on fossil fuels.

Shahbaz et al. (2020) observed that 38 Organization for Economic Cooperation and Development (OECD) countries, 58% have a stronger link between RES and economic growth link to non-RES.

Grijó and Soares (2016) examined a sample of 18 European countries compared with other regions of the world, analyzing the relationship between Solar PV and GDP from 2000 to 2012. Their research revealed various patterns: a one-way relationship between RES consumption and economic growth in Hungary, India, Japan, Netherlands and Sweden; an inverse one-way relationship between GDP and RES consumption in Argentina, Spain and Switzerland; and a two-way relationship in Belgium, Bulgaria, Canada, France, Pakistan and USA. Additionally, non-causality was observed in Brazil, Finland and Switzerland. Inglesi-Lotz analyzed all the OECD countries for the period from 1990 to 2010. The author concluded that renewable energy consumption or total energy mix impact statistically significant on economic growth, However, this finding is not unanimous, as other (Bhuiyan et al., 2022; Charfeddine and Kahia, 2019; Chien and Hu, 2008; Sharma et al., 2021), have presented contrasting results. Charfeddine and Kahia (2019) studied 24 countries of the Middle East and North Africa (MENA) region in 1980-2015 period. The authors found that renewable energy consumption has a slightly effect on economic growth, due to MENA´s countries still be in development financial sector, thus, having weak contribution to economic growth. Sharma et al. (2021) conducted the study on 27 European Union countries from 1990 to 2016. Their research showed a negative correlation between RES and economic growth. In terms of renewable consumption, its impact on economic growth was negative due to the weak performance of European countries climate action and clean energy in the short-term, but it seems to change in the long-term. Bhuiyan et al. (2022) analyzed 46 articles focusing on primarily G7 and N-11 countries from 2010 to 2021. Their findings indicated that, while RES do not significantly hinder economic growth for developing and developed countries, is slightly influence of RES on economic growth for developed countries.

Chien and Hu (2008) employed Structural Equation Modeling (SEM) to examine the impact of RES on GDP across 116 countries (2003). Their study focused analyzing causal relationship between RES, GDP, capital formation, trade balance, consumption, and energy imports. Their findings suggest that RES contributes to capital formation due to business expansion and capital accumulation. However, the final SEM model could not increase sample size, and X^2 test reliability and conclusions may be affected by the sample size. Several studies have also been exploring impacts of RES on employment (Bhuiyan et al., 2022; Charfeddine and Kahia, 2019; Chien and Hu, 2008; Ntanos et al., 2018; Sharma et al., 2021), with many authors agreeing that RES are the main driver in promoting employment (direct or indirect) (Hanna et al., 2024; Hillebrand et al., 2006; Llera Sastresa et al., 2010; Meyer and Sommer, 2016; Proença and Fortes, 2020). The studies conducted by Proença and Fortes (2020), Meyer and Sommer (2016) and Hanna et al. (2024) revealed positive net employment effects of RESs. However, it is not a consensual argument for all (Almutairi et al., 2018; Böhringer et al., 2013; Lambert and Silva, 2012; Mu et al., 2018). Bohringer et al. (2013) and Mu et al. (2018), for instance, found limited potential for employment gains in Germany and China, respectively, which depend on factors like subsidy rates and financing mechanisms. Other authors have been assessing the effect of RES on greenhouse gas emissions. Xiaosan et al. (2021) focused on China (1990-2018), to examine the causal relationship hydropower and renewable electricity generation, and carbon dioxide (CO_2e) emissions. They used the ARDL model and concluded that both technologies significantly reduced CO_2e in the short-term and long-term (Xiaosan et al., 2021). While Charfeddine and Kahia (2019) used panel vector autoregressive (PVAR) model. The Primary limitation of this study is not considering the heterogeneity between MENA´s countries. Also, the authors found that renewable consumption has a limited effect on reducing CO_2 emissions, due to MENA´s countries energy sector having weak contribution to improving environmental quality. Although PVAR model enables the incorporation of country fixed effects, including country fixed effects poses an estimation challenge, especially when integrating lags of dependent variables. The presence of fixed effects can lead to potential biases in coefficients when using mean-differencing methods to address them (Charfeddine and Kahia, 2019).

Despite these studies, few have been examining the effect of RES on social well-being aspects (Ahn et al., 2021; Sugiawan et al., 2019) and even fewer addressing all the necessary dimensions of their impact, including climate mitigation, economic development, and jobs creation, thus not providing a comprehensive hydropower and biomass, which may lead to sustainability concerns and potentially result in the over or underestimation of the significance of key RES technologies, such as solar and wind. While Structural Equation Modelling (SEM) provides valuable insights into complex relationships, researchers must be cautions of its limitations when applied to smaller sample sizes, for instance (Chien and Hu, 2008). In contrast, the ARDL model is suitable for smaller sample sizes, but not capture real dynamics if there is a stochastic trend in the data (Alkasasbeh et al., 2023; Xiaosan et al., 2021). Panel data analysis also has some limitations of design and data collection issues, short time-series dimension, and statistical problems, requiring further diagnostic and specification tests (Baltagi, 2005; Hsiao, 2007; Proença and Fortes, 2020).

Thus, our paper aims to investigate to which extended for RESs technologies deployment (wind and solar), key mitigation levers, have been associated with a broader economic growth and social development, as well as climate mitigation, filling up a gap in the existing literature, establishing non-causality perspective on indicators and having more holistic understanding of RESs influence in the indicators such as economic growth, investment, social well-being, employment, and GHG emission, providing a comprehensive insight into the RES influence within the scope of 32 countries with good levels of economy development, industrialization, and education from 2000 to 2022. Our study enhances and expanding method by (Amaral and Froner, 2010) approach adapting linear regression for large databases with others techniques, focusing on evolution of R^2 over time, without needs of the beta coefficient calculation for concentrating solely on the R^2. By introducing a time-lagged component to the method proposed by (Amaral and Froner, 2010), our approach addresses the possible delayed effects of RES investment. Additionally, we employ cluster analysis for countries grouping, and fixed effects panel data analysis to facilitate precise comparative analysis and enhancing the robustness of the results.

The rest of this paper is organized as follows: Section 2 presents the methodology and data used; Section 3 shows the results and discussions; and the study conclusion are presented in Section 4.

2. METHODS AND DATA

In order to obtain the final outcome of this work, we examine the evolution of coefficient of determination R^2 over time, introducing a novel approach to the existing literature in economics and energy by applying "Amaral and Froner´s technique" trough simulating a linear regression. This technique effectively reduces the quantity of equations, avoiding the needs of beta coefficient calculation for, concentrating solely on the R^2.

2.1. Data Sources and Variables

This subsection presents the steps that defined the elaboration of this work, containing all the methodology applied to answer the equations about relationship between the growth of RES capacity as independent variable under the indicators such as gross domestic product per capita (GDPC), represented by economic growth, Gross fixed capital formation (% of GDP) or GFCF/% GDP, represented by investment, the employment rate represented by employment, the Gini Index represented by social well-being and Greenhouse gas emission per capita represented by GHG emissions, as dependent variables. We also categorized the group of countries by the applying cluster analysis technique based on the total of onshore and offshore wind and solar electricity power capacity in MW (2022), according to rules of the presented in Table 1, and a fixed effects panel data analysis, providing empirical evidence of this relationship, within the scope of the countries of the European Union (EU), United States of America (USA), Canada, United Kingdom (UK), Japan and Republic of Korea. And to gain a better understanding of the effects of investments in RESs, we examined the databases without a time lag, as well as with a 1-year and 2-year time lag. This allowed us to observe that the impacts of RESs investments may not manifest immediately.

The sources of data of GFCF/% GDP, GDPC, Gini Index, employment rate and GHG emissions per capita collected from the World Bank database, OECD. Stat and IRENA. Stat for technologies Solar and wind from 2000 to 2022, as depicted in Table 2. This period was chosen due to data availability in IRENA statistics dataset. To cover missing data at country level, we used interpolation statistic technique for all variables. There are countries with missing employment data in the period analyzed, such as Bulgaria, Croatia, Cyprus, Romania and Malta due to the lack of comparability of information in relation to other available

Table 1: Cluster distribution

Regional scope	(*) USA, UK, Japan, Germany, France, Italy, Spain (**) Netherlands, Korea, Canada, Poland, Belgium, Sweden, Greece, Denmark, Portugal, Austria, Finland, Ireland, Romania, Hungary, Czechia Republic, Bulgaria, Lithuania, Croatia (***) Estonia, Slovenia, Cyprus, Slovakia, Luxembourg. Malta, Latvia

Clusters	Numbers of countries	Group of dummies	Wind and solar total electricity capacity (measured as MW in 2022)
I*	7	d1=1; d2=1	Above 35.000
II**	18	d1=1; d2=0	Above 1.000 and below 35.000
III***	7	d1=0; d2=0	Below 1.000

Table 2: Summary of the annual data collected and the respective sources

<table>
<tr><th colspan="6">Temporal scope: 2000-2022</th></tr>
<tr><th colspan="6">Regional scope: EU 27 (data for each member state), USA, UK, Canada, Japan and Republic of Korea</th></tr>
<tr><th>Variables[a]</th><th>Unit of measure</th><th>Description</th><th>Source</th><th>Period</th><th>References</th></tr>
<tr><td>GFCF per GDP</td><td>Percentage of GDP</td><td>It includes land improvements, plant, machinery, and equipment purchases, roads, railways, schools, offices, hospitals, and commercial and industrial buildings, including net acquisitions of valuables</td><td>World Bank</td><td>Annual</td><td>World Bank, 2023</td></tr>
<tr><td>GDP/per capita</td><td>GDP at constant prices (US Dollar, base 2015) per capita</td><td>It is presented in national currency, both in current prices and constant prices. The constant prices are based on (national base year, previous year prices and OECD base year i.e., 2015). For the Euro area countries, are calculated through of the fixed conversion rates against the euro</td><td>OECD. Stat</td><td>Annual</td><td>OECD, 2023b</td></tr>
<tr><td>Gini index %</td><td>Dimensional value from 0 to 100, where 0 indicates perfect equality, while 100 represents perfect inequality</td><td>The Gini index measures income or consumption distribution within an economy</td><td>World Bank</td><td>Annual</td><td>World Bank, 2023</td></tr>
<tr><td>GHG emissions</td><td>Thousands of metric tons per capita</td><td>The measure is expressed as Kilograms per capita, in thousands and represents the total GHG, excluding LULUCF per capita</td><td>OECD. Stat</td><td>Annual</td><td>OECD, 2023a</td></tr>
<tr><td>Employment rate*</td><td>Percentage of total working age population</td><td>The calculation is based on as the ratio of the employed individuals to the working age population (15–64 years old). It is measured in thousands and expressed as a percentage</td><td>OECD. Stat</td><td>Annual</td><td>OECD, 2023c</td></tr>
<tr><td>Wind and solar PV electricity capacity</td><td>MW of total electricity capacity</td><td>Selected technologies: Total onshore wind energy; offshore wind energy; and Solar photovoltaic</td><td>IRENA statistics</td><td>Annual</td><td>IRENA, 2023</td></tr>
</table>

*There are countries with missing data in the period analyzed as informed above, [a]Electricity capacity is considered as the independent variable, all the others are dependent variables. GHG: Greenhouse gas, GDP: Gross domestic product, GFCF: Gross fixed capital formation, LULUCF: Land-use, land-use change, and forestry, OECD: Organization for economic cooperation and development

database platforms. The data collected resulted in 704 observations for the entire sample, covering 22 annual data and 32 nations.

2.2. Econometric Approach

This study applies techniques developed by (Amaral and Froner, 2010), for analyzing large databases through simple linear regression combined with: (i) time-lagged technique, (ii) cluster analysis, and (iii) a fixed effects panel data analysis. To accomplish this, we will simulate the equations using data from 2011 to 2022, with 60 equations for each lag, resulting in a total of 180 estimations. The work aims to simulate the simple linear regressions represented as:

$$Y_{it} = \alpha + \beta_1 RE_{it-j} + \beta_2 D_1 + \beta_3 D_2 + u_i \tag{1}$$

Where, i denotes the number of sample observations from which calculations are made. j denotes time lags years and t denotes the time period. For first equation, the dependent variables (Y_{it}) is expressed by investment, for second equation by economic growth, for third equation by social well-being, for forth equation by GHG emissions and fifth equation by employment in observations i. Among the independent variable (RE_{it-j}) is expressed by total electricity capacity of onshore wind, offshore wind and solar. The dummies are measured in MW of renewable technologies and expressed by Table 1. We categorized countries into clusters based on Table 1, measured in MW of renewable technologies (2022). α is the linear coefficient and β_i is the angular coefficient of the model. The $u_{i:}$ are random disturbances. Following Table 3 provides a summary of the calculation for "g." By (Amaral and Froner, 2010)

Table 3: g value results

Time lags	Number of observations per lags	Estimation of g
Without time lag	738.1616	0.00564
Time lag 1	706.1616	0.00589
Time lag 2	674.1616	0.00617

technique we introduced an alternative approach that replaces the traditional beta estimation Equation (2) above with the use of R^2 and we introduce the estimations of the amount for "g" in all time lags.

Well then want to find the significant regressions, where

$$\frac{MQ_{REG}}{MQ_{ERROR}} > 4.1616 \leftrightarrow$$

$$R^2 > (4{,}1616 / (n + 2{,}1616)) = g \qquad (2)$$

Estimations for g have been conducted for all time lags (Table 3).

In the upcoming section, we will track the progression of beta estimation over time and simulate the coefficient of determination R^2 annually, through of the technique inspired by (Amaral and Froner, 2010).

3. RESULTS AND DISCUSSIONS

This section presents and discusses the progression of beta estimation and the coefficient of determination R^2 over time.

3.1. Empirical Results and Discussions

In this study, we observed the evolution of R^2 over time to better understand the impacts of total electricity capacity of renewable energy under the indicators selected (e.g., economic growth, investment, social well-being, employment, and GHG emissions). According to (Amaral and Froner, 2010) technique and considering g value results (Table 3). For cluster I, (outlined in Table 1), most of the results were statistically significant for all variables and time lags (Table 4). In the absence of time lag (W/lag), only 5% of outcomes is statistically non-significant, corresponding to the investment; social well-being; and employment. To the same lag of 1 year, only 7% of them were non-significant, corresponding to the investment; social well-being; and employment. While for time lag 2 years, 10% of them were non-significant, applied to the social well-being, employment and the investment. More details, will be discussed next subsection (3.1.1).

For Cluster II, the R^2 estimates were statistically significant in most of variables and time lags (Table 5). Only for investment is observed some statistically non-significant values, mostly in 2020 and for all time lags. This can be justified by COVID-19 pandemic, that starting in 2020, where renewable energy projects saw a drop in investment (IEA, 2020).

Unlike clusters I and II, in cluster III, the majority of the results were statistically non-significant (Table 6). In fact, 42%, 40% and 37% of the outcomes were statistically non-significant, for W/Lag, Lag of 1 year and Lag of 2 years, respectively. Apparently, these results can be justified by the low RES capacity in countries from central and eastern European (CEE) in cluster III, which may influence the economic and social development and the reduction of GHG emissions. Underutilized RES and inefficient infrastructures in these countries hinder economic growth and industry development (Fedajev et al., 2023). Energy dependence degree exposes vulnerabilities in energy and industrial policies, highlighting the need for increased renewable´s share in their energy mix (Marinaş et al., 2018). Malta, Cyprus and Luxembourg were highly dependent in 2021, with over 90% imported energy, except Estonia (1%) (Eurostat, 2021).

The summary depicted in Figure 1 shows that RES technologies (wind and solar) are linked to economic growth, social development and climate mitigation. Notably, the correlation with economic growth is particularly strong, highlighting RES´s role in driving economic growth regardless of time lag.

After analyzing R^2 evolution over time variables and all-time lags, our focus was on Cluster I with the most significant performance, as shown in Table 1. This group, referred to as Cluster I, consists of countries with high electricity capacity of wind and solar energy, which correlates with most of higher values of economic growth.

3.1.1. Cluster I evaluation

This subsection examines results obtained for Cluster I, which comprises the countries with higher RESs power capacity and the highest statistical significance. Independently of the time lag considered (Figures 2-4) or even in its absence (Figure 4), our findings suggest that wind and solar electricity capacity demonstrates a truly significant influence on economic growth.

Table 4: Evolution of R^2 the respective with cluster I

Years/ time lags	R2 for investment			R2 for economic growth			R2 for social well-being			R2 for GHG emissions			R2 for employment		
	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	lag 1	Lag 2
2011	0.032	0.029	0.028	0.192	0.168	0.142	0.003	0.003	0.002	0.062	0.062	0.056	0.007	0.007	0.007
2012	0.045	0.042	0.038	0.212	0.184	0.164	0.009	0.008	0.007	0.059	0.057	0.057	0.006	0.005	0.006
2013	0.056	0.055	0.052	0.230	0.201	0.176	0.015	0.017	0.016	0.060	0.058	0.056	0.006	0.004	0.004
2014	0.058	0.059	0.056	0.257	0.226	0.200	0.021	0.024	0.025	0.061	0.059	0.057	0.010	0.006	0.004
2015	0.054	0.056	0.056	0.290	0.258	0.230	0.027	0.031	0.034	0.062	0.060	0.057	0.018	0.012	0.008
2016	0.047	0.050	0.051	0.328	0.295	0.265	0.034	0.036	0.039	0.064	0.060	0.058	0.031	0.023	0.016
2017	0.038	0.040	0.042	0.369	0.338	0.308	0.042	0.045	0.046	0.065	0.062	0.059	0.047	0.039	0.031
2018	0.028	0.028	0.029	0.411	0.382	0.353	0.051	0.053	0.055	0.069	0.065	0.062	0.066	0.059	0.050
2019	0.019	0.019	0.018	0.449	0.423	0.394	0.059	0.061	0.062	0.069	0.066	0.063	0.087	0.080	0.073
2020	0.012	0.011	0.010	0.447	0.421	0.395	0.060	0.060	0.060	0.064	0.060	0.057	0.088	0.084	0.079
2021	0.007	0.006	0.005	0.471	0.447	0.422	0.062	0.062	0.060	0.065	0.061	0.058	0.092	0.092	0.089
2022	0.004	0.003	0.002	0.498	0.477	0.453	0.065	0.064	0.062	0.066	0.064	0.061	0.103	0.104	0.104

Source: IRENA, World Bank, OECD. The areas that have been painted represent values statistically non-significant. OECD: Organization for economic cooperation and development, GHG: Greenhouse gas

Table 5: Evolution of R^2 the respective with cluster II

Years/ time lags	R2 for investment			R2 for economic growth			R2 for social well-being			R2 for GHG emissions			R2 for employment		
	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2
2011	0.070	0.088	0.104	0.211	0.224	0.229	0.057	0.069	0.077	0.052	0.049	0.044	0.132	0.143	0.144
2012	0.076	0.091	0.107	0.181	0.196	0.209	0.040	0.051	0.062	0.042	0.043	0.039	0.108	0.126	0.136
2013	0.083	0.099	0.111	0.151	0.168	0.183	0.023	0.032	0.041	0.034	0.034	0.035	0.085	0.104	0.121
2014	0.076	0.095	0.108	0.134	0.143	0.159	0.015	0.020	0.028	0.029	0.027	0.028	0.069	0.082	0.101
2015	0.061	0.077	0.092	0.125	0.128	0.137	0.010	0.012	0.017	0.028	0.024	0.023	0.062	0.068	0.082
2016	0.050	0.060	0.072	0.123	0.119	0.122	0.009	0.010	0.012	0.027	0.024	0.021	0.060	0.062	0.069
2017	0.039	0.047	0.055	0.127	0.119	0.117	0.009	0.009	0.010	0.029	0.025	0.022	0.061	0.061	0.064
2018	0.030	0.038	0.044	0.133	0.124	0.118	0.011	0.010	0.010	0.030	0.026	0.024	0.064	0.063	0.064
2019	0.016	0.022	0.026	0.139	0.131	0.122	0.013	0.012	0.012	0.028	0.026	0.024	0.067	0.066	0.065
2020	0.008	0.011	0.015	0.132	0.126	0.119	0.018	0.016	0.015	0.019	0.020	0.019	0.068	0.066	0.065
2021	0.004	0.006	0.008	0.128	0.126	0.121	0.024	0.021	0.018	0.014	0.015	0.016	0.069	0.069	0.068
2022	0.002	0.003	0.004	0.123	0.124	0.122	0.030	0.026	0.023	0.009	0.011	0.013	0.072	0.072	0.072

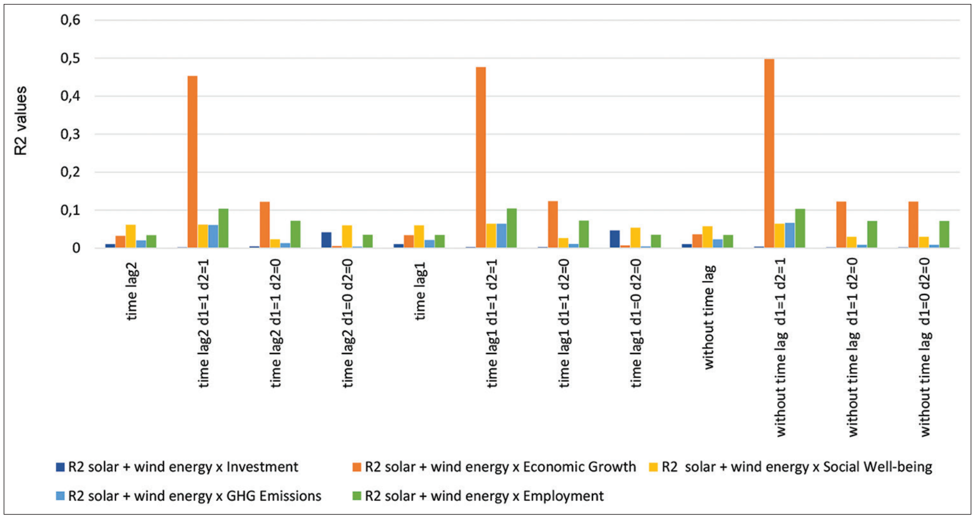
Source: IRENA, World Bank, OECD. The areas that have been painted represent values statistically non-significant. GHG: Greenhouse gas, OECD: Organization for economic cooperation and development

Table 6: Evolution of R^2 the respective with cluster III

Years/ time lags	R2 for investment			R2 for economic growth			R2 for social well-being			R2 for GHG emissions			R2 for employment		
	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2	W/Lag	Lag 1	Lag 2
2011	0.022	0.086	0.052	0.015	0.222	0.084	0.001	0.069	0.057	0.031	0.050	0.132	0.002	0.000	0.064
2012	0.029	0.037	0.041	0.006	0.014	0.082	0.000	0.003	0.082	0.012	0.024	0.139	0.001	0.002	0.044
2013	0.039	0.040	0.031	0.003	0.005	0.012	0.000	0.003	0.022	0.006	0.009	0.022	0.005	0.001	0.002
2014	0.051	0.050	0.037	0.002	0.002	0.004	0.001	0.000	0.005	0.002	0.003	0.007	0.009	0.005	0.001
2015	0.055	0.052	0.038	0.001	0.001	0.002	0.003	0.001	0.000	0.001	0.001	0.002	0.014	0.010	0.006
2016	0.064	0.052	0.046	0.002	0.001	0.001	0.008	0.001	0.002	0.000	0.001	0.000	0.018	0.010	0.012
2017	0.066	0.061	0.046	0.003	0.002	0.001	0.018	0.015	0.013	0.000	0.000	0.000	0.023	0.021	0.018
2018	0.069	0.063	0.047	0.003	0.002	0.002	0.023	0.021	0.020	0.000	0.000	0.000	0.026	0.025	0.023
2019	0.068	0.065	0.049	0.005	0.003	0.002	0.033	0.030	0.031	0.000	0.000	0.000	0.030	0.028	0.028
2020	0.059	0.057	0.045	0.005	0.004	0.003	0.041	0.041	0.041	0.001	0.001	0.001	0.032	0.031	0.030
2021	0.052	0.054	0.044	0.007	0.005	0.004	0.046	0.049	0.052	0.002	0.003	0.002	0.033	0.033	0.033
2022	0.044	0.047	0.042	0.009	0.007	0.005	0.047	0.054	0.060	0.004	0.004	0.004	0.035	0.035	0.035

Source: IRENA, World Bank, OECD. The areas that have been painted represent values statistically non-significant. GHG: Greenhouse gas, OECD: Organization for economic cooperation and development

Figure 1: R^2 estimates, considering the respective time lags according to the clusters



Additionally, we highlight employment, with the analysis indicating that the most significant growth trend of R^2 occurred across all time lags from 2015 to 2019, with a slightly more pronounced growth in 1 year lag (Figure 2). However, outcomes show low statistically significant, suggesting a limited influence of RESs on employment. We believe this must change due to efforts in increasing solar and wind power capacity by 2050. Similar conclusions were obtained by (Ragwitz et al., 2009), concluding that the distribution and budget effects of renewables growth can diminish a large gross employment effect, which

Figure 2: Evolution of R^2 considering the respective time lag 1 with cluster I

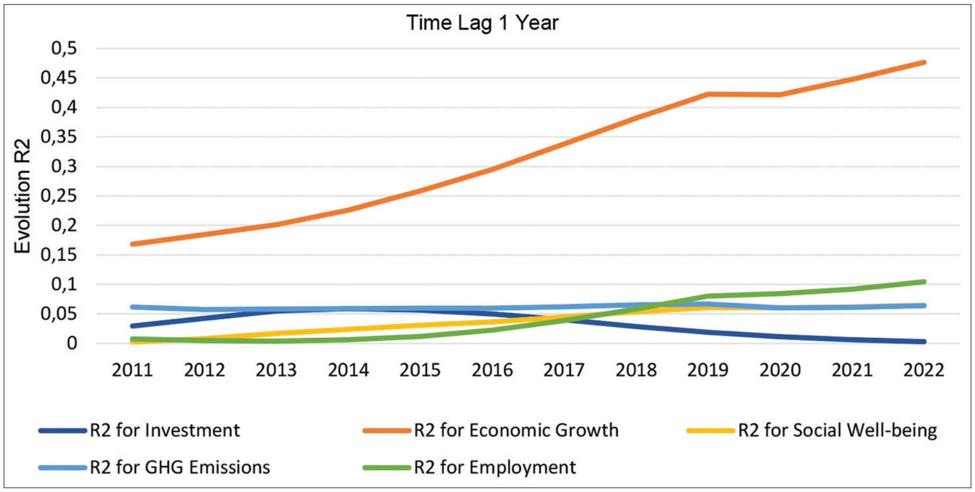


Figure 3: Evolution of R^2 considering the respective time lag 2 with cluster I

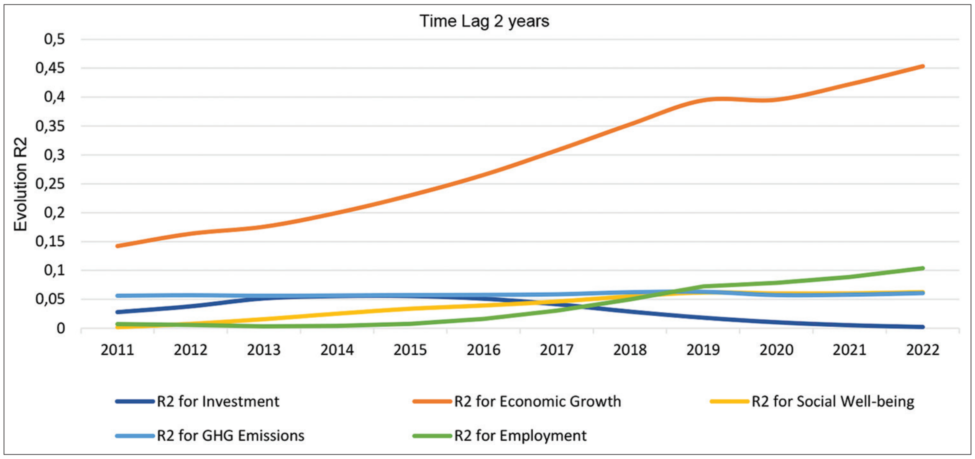
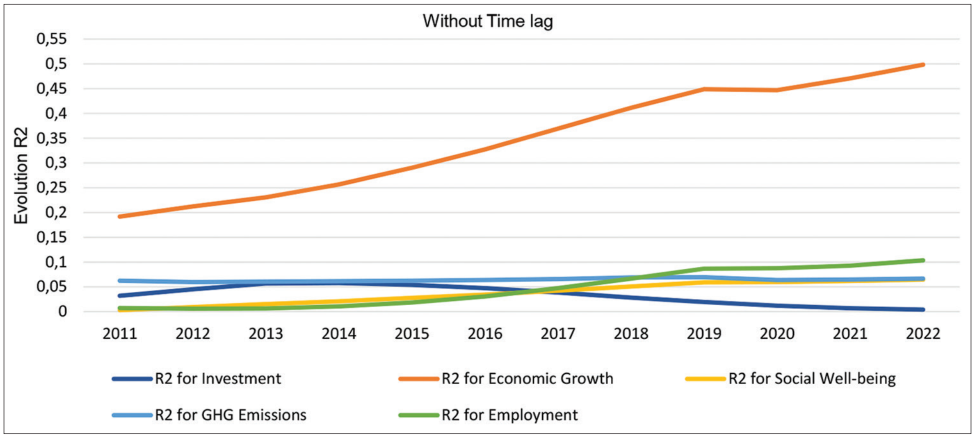


Figure 4: Evolution of R^2 considering the respective absence time lag with cluster I



may limit net employment potential. Cai et al. (2017), also found similar outcomes in their study on employment analysis in Italy. Job creation per unit of installed capacity was not significant, possibly due to overly optimistic assumptions about import and the domestic RES industry´s ability to rapidly expand in response to increased demand (Cai et al., 2017). The investment is the only indicator that demonstrates a downward trend, independent on the time lag, in 2020, can be justified by COVID-19 pandemic, where renewable energy projects saw a drop in investment (IEA, 2020). However, these socio-economic and environmental indicators, like investment and GHG emissions presented lower statistical significance. Solar and wind are crucial for mitigation efforts, reducing 4 Gt of CO_2 emissions by 2030 and being primary to reduction Net Zero Emissions by 2050 (IEA, 2023). Based on our findings, GHG emissions showed a slight upward trend of the R^2 value for all time lags, up until 2019, reinforces pivotal concerning climate action and renewable electricity. Burck et al. (2024), highlights pivotal concerns on climate action and renewable electricity. Countries' targets and policies ambitious may not effectively reduce emissions. Austria aims for 100% renewable electricity by 2030, but per capita emissions since 1990 only decreased by 15%. Global urgency to reduce reliance on fossil fuels highlights the need for strong expansion of renewable energy by governments. The authors suggest attention to decarbonizing sectors like agriculture, transport and industrial, but these sectors beyond our study´s scope (Burck et al., 2024). According to Climatewatchdata (2020), the USA emitted 16.61 tons of carbon dioxide equivalent (tCO_2e), Germany 8.33tCO_2e, Japan 8.67 tCO_2e, UK 5.94 tCO_2e, Italy 5.92 tCO_2e, Spain 5.71 tCO_2e and France 5.58 tCO_2e (Climatewatchdata, 2020). Ahn et al. (2021) found that renewable energy´s share in the energy mix reduces social welfare. This is due to reduced cost-efficiency outweighs the positive climate effect energy policy uncertainty also decreases social welfare by increasing uncertainty in return on capital, lead rational agents to postpone investments (Ahn et al., 2021). By its hand our findings indicate that the evolution of social well-being R^2 is low, but statistically significant, social well-being depict a smooth risen pattern up to 2019 for all the analyzed lags, but more pronounced in time lag 1 year (Figure 2). This suggests a delayed impact of RES on social well-being over time.

Our findings suggest that only economic growth demonstrates a truly significant influence of wind and solar electricity capacity. Based on current data, the difference between time lags is not very significant. Longer periods needed to observe RES effects on socio-economic and environmental. Decarbonize electricity sectors is pivotal, but not only, also agriculture, transport and industry.

4. CONCLUSION

This study aims to analyze the effect of solar and wind power capacity on socio-economic and environmental indicators including economic growth, investment, social well-being, employment and GHG emissions, providing a comprehensive evaluation of RES effect on them. We utilized and enhanced the simple linear regression technique introduced by (Amaral and Froner, 2010) for a smaller set of data and incorporated additional techniques in the methodology such as time-lags, to better understand of effects of RES investment over time; cluster analysis categorizing countries based on total onshore and offshore wind and solar electricity capacity in 2022; and fixed effects panel data analysis, providing empirical evidence for 32 industrialized nations. By employing this technique, we are able understand the non-causal relationship, for instance, like social well-being variable on RES, reducing effectively the necessary volume of data. Unlike most of previous studies, focused on total renewable energy including biomass and hydropower, our research exclusively focuses on solar PV and wind, given their crucial role in meeting the global production capacity needed to achieve Net Zero Emissions targets by 2050 (IEA, 2023). The regressions analysis revealed a clear upward trend of R^2 values observed for the cluster I, comprising countries such as USA, United Kingdom, Japan, Germany, Italy, France and Spain, with higher RES power capacity. Addressing the query of the study, the findings suggest that in these countries, the expansion of renewable capacity has a positive and significant impact on economic growth, whereas for other variables such as social well-being, investment and employment the positive effect of RES, while present, is statistically low. Conversely, RES have not yielded a positive trend in GHG emissions, which may be attributed to the relevance of other sectoral emissions, such as those from transport and industry, suggesting that mitigation efforts should not solely focus on power sector decarbonization.

The lower significance of RES on most of socio-economic indicators, particularly in countries with lower installed capacity, may be attributed to the longer maturation time and scale of investments in RESs to significantly influence them. However, it is essential to acknowledge that only time can definitively validate or refute these hypotheses. This highlights the temporal dynamics of power capacity as a potentially influential factor, including the need for further research, which hinders the assess the trend of influence of RES on the indicators studied. From a policy perspective, the impact of increasing renewable electricity capacity, particularly solar PV and wind, on socio-economic development is still uncertainty although our analysis suggests it may be positive. It is crucial to prioritize investments and implement effective mechanisms existing to simulate the growth of these technologies. This will create a sustainable virtuous circle of growth and enable the economy to fully benefit from the advantages of RESs.

5. ACKNOWLEDGMENT

The authors also acknowledge FCT/MCTES for funding CENSE (UID/04085/2020) and Patricia Fortes research (2020.00038. CEECIND). Center for Economics and Finance at UPorto has been financed by Portuguese Public Funds through FCT (Portuguese Foundation for Science and Technology) and by the European Regional Development Fund through COMPETE 2020-Programa Operacional Competitividade e Internacionalização (POCI)-in the framework of the project POCI-01-0145-FEDER-006890"- Isabel Soares.

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