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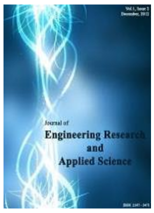

Renewable energy growth nexus for wind and solar power in Turkey

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Abstract

The energy efficiency of buildings at residential sector can be greatly improved through the use of passive solar heating strategies. These strategies are universally applicable to new buildings of small to moderate size and are also applicable to many existing buildings that are suitable for retrofit. Three types of tools are provided. First, a general discussion of the basic concepts and principles of passive solar heating is presented to familiarize the reader with this technology. Second, a set of guidelines is presented for use during schematic design or for initial screening if an evaluation is being performed. These guidelines enable the user to quickly define a building that will perform in a cost-effective manner at the intended building site. Finally, a quantitative design-analysis procedure is presented that enables the user to obtain an accurate estimate of the auxiliary heating requirements of a particular passive solar design. This procedure may be used to refine a schematic design based on the guidelines already mentioned, or may be used to compare the merits of candidate designs in a proposal evaluation. The purpose of this paper is to provide the tools needed by professionals involved in building design and/or evaluation who wish to reduce the consumption of non-renewable energy resources for space heating and cooling.

Keywords: Renewable energy, energy growth, wind power, solar energy, Turkey.

1. Introduction

Energy is used for direct consumption as well as an input of production in any economy. Hence, an increase in energy consumption has been seen as an indicator of development [1]. With known negative externalities of fossil fuel consumption, the focus has shifted to renewable energy resources to achieve greater sustainability [2]. While all countries are scaling up solar and wind installations in their territory, it is important to understand the linkages of major renewable energy sources with economic output [3]. Particularly, it is so for the emerging economies [4]. Given resource constraint, emerging economies cannot afford to over-allocate or under-allocated resources among various sources of energy renewables. However, the literature is scant on the contrast between solar and wind energy, and no literature exists that look at the growth-renewable energy nexus while contrasting solar and wind energy [5]. This article examines the nexus of major renewable energy sources, wind and solar, and the GDP of Turkish provinces and fills up this gap in the literature [6-8].

Climate change is the result of critical market failures. Addressing climate change therefore reflects the Bank's mandate to promote the transition to market-based economies and its commitment "to promote in the full range of its activities environmentally sound and sustainable development" [2]. The Paris Agreement reflects a broad-based international commitment to address climate change. The agreement commits countries to emission pathways consistent with "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels." The Agreement emphasizes the need for efforts to promote both climate change mitigation and climate change adaptation [2-6].

The paper builds upon the core theoretical underpinning of energy–growth nexus. The theoretical model presents solar and wind energy as an input in an economy-wide production function. Since there is a technological deficiency in the storage of large volume electricity, economically, it is likely that the nature and extent of intermittency issues will be different between the electricity generated from solar and wind. This study contrasts solar and wind resources and deploys different techniques to capture both the inter-state variations and the dynamics of these relationships over time.

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The latest panel data available for Turkish provinces has been used to analyze this relationship. For solar energy, the dynamic panel model has been used. For wind energy, panel co-integration techniques have been used. This paper further contributes to the energy–growth nexus literature by affirming the relationship between renewable energy and growth. Uses of recent data, the updated methodology, and policy analysis from the federal-structure perspective are additional features of this study.

2. Current energy situation in Turkey

2.1. Introduction

In Turkey, according to the Ministry of Energy and Natural Resources (MENR), renewable energy sources consist of wind, solar, biomass, and small hydropower projects with energy generation capacity less than 25 MW [1]. As of 31st October 2021, renewable energy was the second most important energy source in the country. As a source of energy, the use of renewables will gain importance in the coming years. This is because the conventional sources of energy are laden with supply-side bottlenecks in Turkey. Table 1 shows Turkey's total energy production in 2020 [1]. Table 2. Also shows renewable energy in Turkey [1].

Table 1. Turkey's total energy production in 2020 (Mtoe)

Energy Sources	Production	Consumpt.
Hard coal & Lignite	14.8	40.1
Oil	3.4	34.2
Gas	0.4	40.1
Hydropower	6.7	6.7
Geothermal	10.6	10.6
Wood and Biomass	3.4	3.4
Solar/Wind/Other	4.2	4.2
TOTAL	**43.5**	**140.1**

Source. Refs. [1-5]

Table 2. Turkey's total energy production in 2020 (Mtoe)

Energy Sources	Production	Consumpt.
Hard coal & Lignite	14.8	40.1
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Solar/Wind/Other	4.2	4.2
TOTAL	**43.5**	**140.1**

Source. Refs. [1-5]

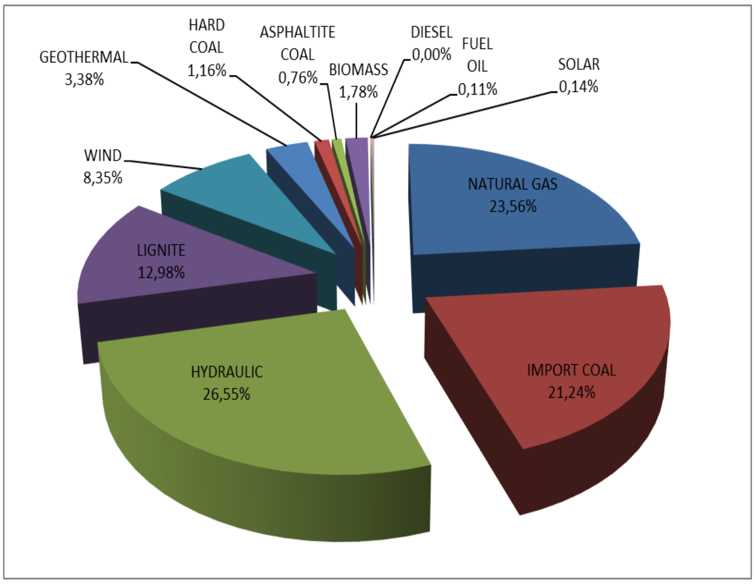
Turkey is one of the top five countries in installed renewable energy capacity in European Union [2]. In 2021, wind accounted for 11% of the installed capacity in renewable energy, the installed capacity in solar was 8%, while small-hydropower accounted for only 6% [1]. While grid-connected wind power in Turkey dates back to 2012, solar power plant installation began in 2016 only [2]. Among the states, wind energy's average cumulative installation capacity is much higher than solar. This is because the installed capacities of both of them are going up at a rapid speed in India. However, the speed of capacity installation for solar energy is much faster than that for wind energy. Further, there are wide variations among the states in the capacity installations for both, although they are evidence of sigma convergence over the years.

The Turkish government has set 55 MW renewable energy installation in 2021. Although the installed capacity in the wind is currently much higher than the solar, solar has been given much greater emphasis than the wind when setting targets. Out of the 55 MW, solar energy installation constitutes 10 MW, and wind energy installation constitutes 14 MW [1].

2.2. Electricity outlook

Turkish electricity sector has developed through the principle of supply security at its heart and with an aim to contribute to economic growth and national prosperity. For long years, power services in Turkey had been delivered by a public institution operating within a vertically integrated structure. In the 1990s, power generation and distribution operations were separated, followed by the attempts to include private sector companies in investment and operation processes and the use of various models to that end. In the early 2000s, some legal regulations were launched and resolute liberalization steps were taken, triggering an evolution in the electricity sector into the current competitive, multi-player model where operations are segregated [1-8].

Development and liberalization of the electricity market in Turkey started with the entry into force of the Electricity Market Law (EML) in 2001. Prior to this period, the market was controlled by public institution such as the MENR. In the subsequent years, the electricity sector has turned into a multi-actor sector and an environment where free market competition is predominant. Figure 1 shows Turkey's distribution of licensed electricity generation by energy sources in 2020 (%).



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- Figure 1. Turkey's distribution of licensed electricity generation [1].

An analysis of current ownership status regarding generation plants shows that the public power plants are affiliated and the public share within the installed capacity declined from 80% to 20% in years. TEİAŞ's responsibility is to operate the current system and operate the balancing power market and ancillary services market. Figure 2 also shows source-based development of licensed electricity generation (GWh) [1].

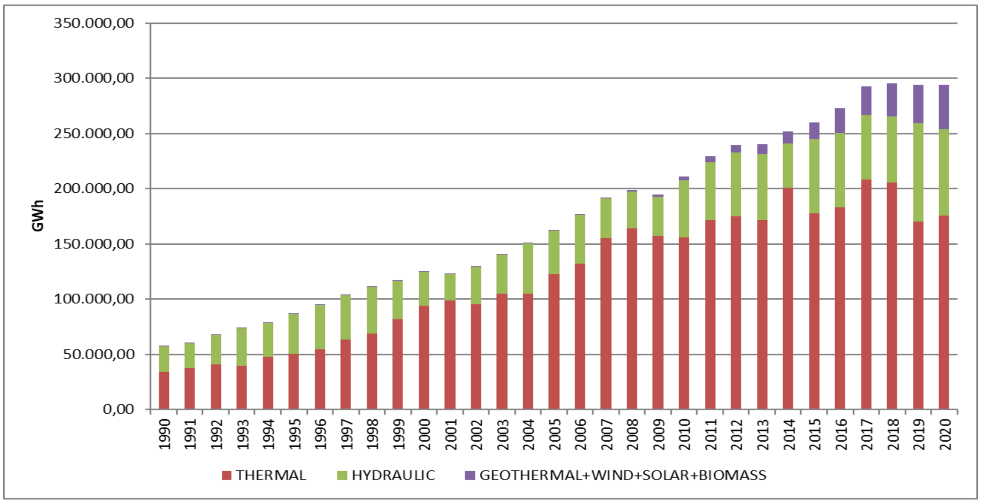

Figure 2. Source-based development of licensed electricity generation (GWh) [1].

3. Methods and data

3.1 Theoretical framework

The theoretical foundation of the models adopted in this paper follows Inglesi-Lotz [9] with some modification that suits federal structure. A Cobb–Douglas functional form is used to capture the relationship between inputs and output. So, we can write;

$$Y = AK^{\alpha} L^{\beta}$$

Y is economic output, K is capital, L is labor, A is total factor productivity, and α and β are the elasticity of labor and capital. Further, we have incorporated either wind or solar installation capacity to find their impact on economic growth. Further, we assume that this Cobb-Douglas production function is homogeneous of degree zero. Taking the natural logarithm form of the Cobb-Douglas function, we get the following:

$$\text{Log } Y/L = \text{Log}A/L + \alpha 1\log K/L + \alpha 2\log E/L \quad (1)$$

where E is either the installation capacity of solar or wind.

3.2 Variables and data

A researcher typically faces several challenges working in energy–growth nexus. In many studies, data availability is the key determinant to choose the sample period and methodologies [10-17]. For renewable energy, we have used solar and wind power capacity installations. The solar power capacity installation includes both ground-mounted and rooftop installation. These data are collected from the MENR database. For solar, we have data for large 16 Turkish provinces from 2011-12 to 2017-18. For wind, we have data for 8 Indian states from 2001-02 to 2017-18. Detailed sources of the data are given in Appendix A. For the economic output of the state, the annual GDP, measured at 2011–12 prices, has been used. The source is NITI-CSO database. Further, per capita development expenditure by the State Governments is taken as a control variable and the data for it taken from RBI report on state finances [18-30].

We have solar data for 16 provinces from 2014 onwards. Given the shorter period, the article cannot adopt panel cointegration techniques. Instead, the dynamic panel model, in particular, system generalized method of moments (GMM) has been adopted to trace the GDP-Solar relationship. Theoretically, the method here can only test whether the solar is influencing GDP or not [24-30].

3.2.1 The econometric model for GDP- solar relationship

The adopted baseline model, taking Eq. (1) into consideration, is

$$y_{it} = \beta_0 + \beta_1 x_{it} + \delta_i + u_t + v_{it} \quad (2)$$

All the equation variables are in levels. 'y_{it}' is the dependent variables –log of per capita GDP in year t for state i, 'x_{it}' is different explanatory variables expected to be relevant to determine the GDP. δ_i is state-specific and $u_t$is year-specific fixed effects. These fixed effect parameters control the unobserved factors that do not vary with time and affect the GDP for all states in the same year. To capture the dynamicity of GDP, we have adopted the dynamic panel model as follows [20-24]:

$$y_{it} = \beta_0 + \beta_1 y_{i(t-1)} + \beta_2 x_{it} + \delta_i + u_t + v_{it} \quad (3)$$

As the error term is correlated with the lagged dependent variable $y_{i(t-1)}$, the problem of endogeneity is created, and the Ordinary Least Squares (OLS) estimator will be biassed and inconsistent. Best and Burke [11] and Clo et al., [13] suggested that this problem of endogeneity cannot be addressed with Two-Stage Least Squares (2SLS) or panel fixed effects estimator. In estimating this type of models, Arellano and Bond (1991) suggested that the GMM estimator is generally used [24-30]. System GMM is considered to be superior as it uses both differences and levels simultaneously. Further, if an endogenous variable is persistent, then system GMM is more suitable. Hajko [15] argued that lagged independent variables can be poor instruments when they do not change much over time. Hence, we have adopted the system GMM estimation process. Further, instead of taking the first difference transformation, the orthogonal deviation transformation approach to system GMM. This shows the problem of magnification of difference due to gaps in data. The final form of the estimated model is;

$$y_t = \alpha + \beta\, y_{t-1} + \gamma\, SOLAR_{it} + \partial\, SOLAR_{it-1} + \varphi\, X_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

Where y is GDP per capita, solar is installed solar capacity per capita, X consists of two variables- ELCON indicating electricity consumption per capita and DEVEX indicating per capita development expenditure by the State Government. Further log transformation of all the variables was taken [12-16].

To test the validity of instruments, we have conducted the Hansen test. AR test is done to test the existence of autocorrelation in the residuals. In the absence of second-order serial correlation, the GMM estimator can be said consistently. For valid instruments, differenced residuals should not show significant second-order serial correlation. Hence, a high p-value in AR (2) test tells us the validity of the moment conditions. Payne [22] discussed the positive correlation of the error term with the lagged dependent variable biases β_1, the yi(t−1) coefficient, upward for OLS estimation and downward for fixed effects regression. Hence, a reliable estimate should lie within the two values. Therefore, we have estimated OLS, Fixed Effects and system GMM model (using a one-step GMM) [23-26].

3.2.2. Gross domestic product (GDP) and wind energy nexus

As the data for long time series is available a panel cointegration method was adopted, followed by regression estimation and a causality test. To begin with, we checked the cross-sectional dependence among the dependent and independent variables. Checking cross-sectional dependence is important for panel data study consisting of neighboring countries or sub-regions within a country, as these units are expected to depend on each other. This is because variables with cross-sectional data containing homogeneity, the specific methodology needs to be employed to prevent spurious results [20-24].

After the unit root test, the lag length selection criteria indicated two optimal lags for the GDP-wind panel. Hence, a cointegration test was done to test the existence of long-term equilibrium relationships. Further, vector error correction method (VECM) estimation, and to trace the causal relationship among these variables, the Granger causality test is conducted. If a past time series of X_t does not predict another time series Y_t, given the past Y_t, then X_t does not Granger-cause Y_t [24]. Proceeding from Eqn. (1), the following model is worked upon for the GDP-Solar relationship:

$$y_t = \alpha + \beta_1 WIND + \beta 1 ELCON + \beta_2 DEVEX + \mu_1 \quad (5)$$

Where y stands for the per capita GDP of each State, WIND stands for each state's per capita wind energy installation capacity. ELCON indicates electricity consumption per capita for each state, and DEVEX indicates each state government's per capita development expenditure. Further log transformation of all the variables was taken.

4. Results and discussions

4.1. Solar-GDP relationship

The dynamic panel estimation of Eq. (4) is reported in Table 3. It shows that the current year's growth rate of per capita solar energy does not significantly impact per capita GDP growth. However, per capita solar energy for previous year growth rate has a statistically significant (at 2% level) positive impact on per capita GDP growth. The value of the Hansen p is 0.619. test, which indicates the validity of instruments. AR test is done to test the existence of autocorrelation in the residuals. For valid instruments, differenced residuals should not show significant second-order serial correlation. Hence, a high p-value in AR (2) test tells us the validity of the moment conditions. The p-value AR (2) is 0.126, which shows the absence of a second-order serial correlation. Hence, the GMM estimator can be said consistent. In this type of dynamic panel model, it is very natural that the p-value of AR (1) shows the existence of first-order serial correlation. Initially, the p-value of AR (1) was not showing the existence of first-order serial correlation. We have introduced time dummies as explanatory variables, which has corrected this anomaly. The p-value of AR (1) is 0.029, significant at a 6% level. However, this has increased the number of instruments in the model. Further, the positive correlation of the error term with the lagged dependent variable biases β_1, the yi(t−1) coefficient, upward for OLS estimation and downward for fixed effects regression. Hence, a reliable estimate should lie within the two values. Therefore, we have estimated OLS, Fixed Effects and GMM model (using a one-step GMM). Our results show that the coefficient of y_{t-1} in the GMM model is 0.74, and it lies between 0.38 (coefficient of y_{t-1} in FE model) and 0.99 (coefficient of y_{t-1} in OLS model). Hence, the estimated GMM model of this article is a reliable one [18-24].

Table 3. Descriptive statistics on cumulative solar and wind installed capacity in high potential provinces (MW)

Time of day	Solar			Wind		
	Mean	Standard Deviation	Coefficient of variation	Mean	Standard Deviation	Coefficient of variation
25 April 08:00	18.27	34.68	3.42	546.36	1372.36	2.44
25 April 09:00	34.67	72.64	3.26	712.64	1538.64	2.38
25 April 10:00	54.86	96.34	3.12	814.24	1640.54	2.26
25 April 11:00	72.36	116.46	3.02	986.23	1812.87	2.14
25 April 12:00	96.46	134.34	2.86	1024.67	1850.23	1.94
25 April 13:00	146.34	157.36	2.76	1165.86	1992.12	1.89
25 April 14:00	188.46	167.36	2.71	1224.12	2050.87	1.82
25 April 15:00	258.64	184.24	2.64	1296.13	2122.42	1.69
25 April 16.00	396.68	198.86	2.46	1342.45	2168.12	1.58
25 April 17.00	796.56	224.65	2.32	1398.68	2224.87	1.44
25 April 18:00	**1218.24**	**286.24**	**2.16**	**1436.78**	**2262.54**	**1.36**

4.2. Wind-GDP relationship

To begin with, we have conducted a panel unit root test for all the variables GDP, SOLAR, ELCON, and DEVEX by LM unit root test. It shows all these four variables having I (1) process. The optimum lag has been selected using various information criteria and other lag selection criteria. After selecting optimum lag, we have conducted a cointegration test indicates cointegration between the log of per capita wind energy, log of per capita GDP, log of per capita electricity consumption, and log of per capita development expenditure of the state governments. Both the value of trace statistics and maximum eigenvalue shows that there is one cointegrating equation. Hence, there is a long-term relationship between the log of per capita wind energy and log of per capita GDP, log of per capita electricity consumption, and log of per capita development expenditure of the state government [14-30].

Then Granger causality test was conducted and reported in Table 4. We found bidirectional causality from the log of per capita GDP to the log of per capita wind energy. This means that economic growth in the states granger causes growth in wind energy during this analysis period. At the same time, it appears that having growth in wind energy Granger causes GDP growth. Hence, the economy's growth patterns have a nexus with growth patterns in wind energy and vice versa. Impulse response shows that the shocks in the log of per capita GDP positively impact the log of per capita wind energy and vice versa. Thus, it re-iterates the findings from the Granger causality test. Thus, we found that both growth of solar energy and wind energy positively impact the economic growth of the state economy. Hence, the economies in which government invest more or encourage more private investment in solar and wind energy should experience higher economic growth. Further, we found two-way causality between growth in per capita wind energy and growth in per capita GDP. This indicates that states with higher economic growth are also installing wind energy capacity at a faster rate. Though we cannot say about the causation of GDP growth to growth in solar energy through our dynamic panel model, we have used the scatter plot to understand the correlation between the two. In Figure 3, the scatter plot does not show that states with higher per capita GDP also have higher per capita solar energy.

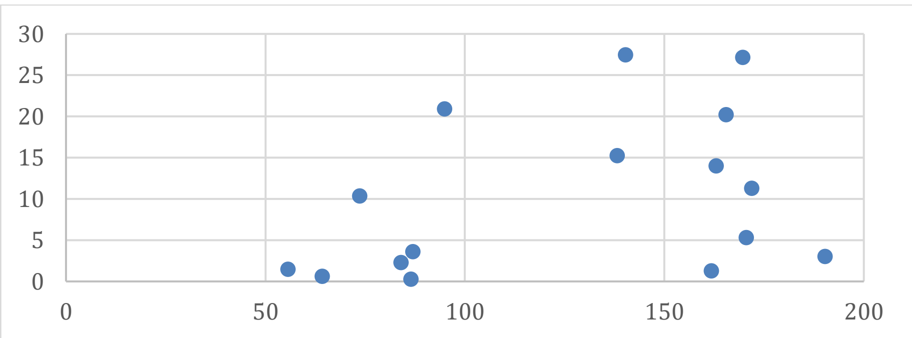

Figure 3. Scatter plot of per capita GDP and per capita solar energy capacity.

Table 4. Relationship between Solar and GDP.

	(1)	(2)	(3)
Variables	Pooled	FE	**GMM**
Levelized GDP	0.994 (0.016)	0.386 (0.120)	**0.745** **(0.253)**
ELCON	-0.0253 (0.018)	0.0522 (0.130)	**-0.213** **(0.193)**
SOLAR	-0.0045 (0.006)	-0.0049 (0.006)	**-0.0197** **(0.013)**
Levelized SOLAR	0.0067 (0.006)	0.0019 (0.006)	**0.0108** **(0.003)**
DEVEX	0.058 (0.026)	0.0292 (0.06)	**0.474** **(0.324)**
Constant	-0.349 (0.238)	6.826 (1.634)	**-1.46** **(1.53)**
AR (1)			**-2.24**
AR (2)			**1.53**
No. of Instruments			**21**
Hansen p			**0.619**
Robust standard errors in parentheses			

Table 5. Results of Granger Causality test

Pairwise Dumitresu Hurlin Panel Causality Test			
Null Hypothesis	W-Stat	Z-Bar-Stat	Prob.
LWIND does not homogeneously cause LGDP	3.361	3.311	0.001
LGDP does not homogeneously cause LWIND	4.446	4.928	0.000
LELCON does not homogenously cause LGDP	6.861	8.578	0.007
LGDP does not homogeneously cause LELCON	7.046	8.779	0.000
LDEVEX does not homogeneously cause LGDP	3.294	3.198	0.001
LGDP does not homogeneously cause LDEVEX	6.265	7.649	0.000
LELCON does not homogeneously cause LWIND	2.612	2.166	0.031
LWIND does not homogeneously cause LELCON	2.484	1.989	0.047
LDEVEX does not homogeneously cause LWIND	2.738	2.362	0.184
LWIND does not homogeneously cause LDEVEX	3.729	3.854	0.001
LDEVEX does not homogeneously cause LELCON	7.208	9.079	0.000
LELCON does not homogeneously cause LDEVEX	4.073	4.378	0.000

In Figure 4, the scatter plot of the average (over the period 2012 to 2018) growth rate of each state's per capita solar energy with its average growth rate of per capita GDP shows a positive correlation. So a richer state not necessarily adopting solar energy, but the states which are growing fast also have the faster adoption of solar energy.

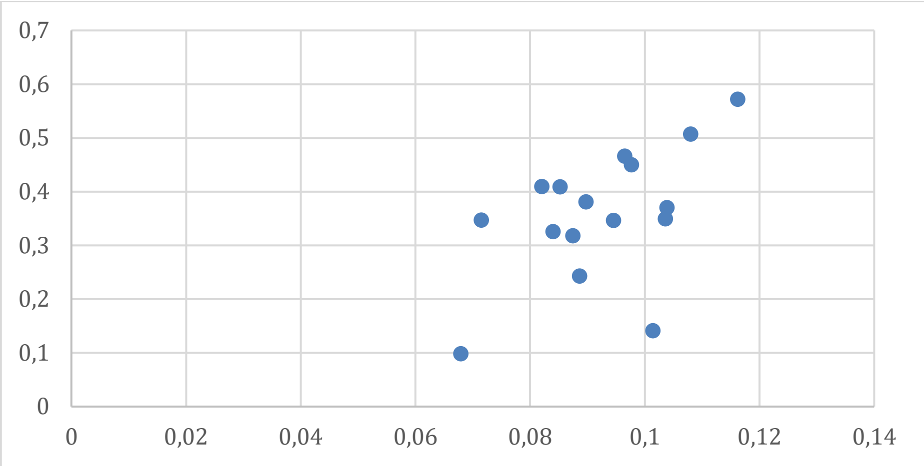

Figure 4. Plot of growth of per capita solar capacity and growth of per capita GSDP.

5. Conclusions

For a country like Turkey depend on imports for non-renewable energy sources such as hard coal, gas and petroleum becomes crucial for growth from the energy security perspective apart from being instrumental for sustainability. Moreover, renewable energy plays a vital role in achieving targets of energy access to all. States being key players in solar and wind energy proliferation, a state-level study is required for Turkey. This study examined renewable energy proliferation at the granularity of state-level, applying appropriate methodology separately for wind and solar panel dataset.

We found a long-term relationship between state economic growth and the growth of installed wind energy in Indian states. System GMM approach helped us to find that growth in solar energy impact growth in GDP significantly. The granger causality result suggests bidirectional causality from GDP growth to growth in wind energy. Though we could not econometrically test the existence of bidirectional causality between the growths of solar energy to GDP growth, the scatter plots tell us a positive correlation between these two. Hence, we may argue that economic growth and solar and wind energy positively influence each other, and it has profound policy implications.

The findings of this study indicate that higher adoption of wind and solar energy would lead to higher economic growth in states. In addition, with growth in the economy, there will be more solar and wind energy proliferation. The reason may be that high growing states are increasingly looking for renewable energy as a source for their energy requirement. In other words, increasing deployment of renewable energy capacity is relaxing the energy constraint to growth for the high-growth states. Further, given that renewables will be promoted due to positive sustainability externalities, if the deployment continues without differentiating between differently growing states, we may create greater economic inequality among the states in the long run. Since more GDP growth causes greater growth in solar and wind installations, policy treatment has to differ for different states. Low-income growing states need special encouragement to adopt renewable energy.

A special set of policies for these states is also required because of the second-order effect of constrained resources to deal with the climate change arising from non-renewable energy generation in such states. Incentive such as Feed-in Tariffs, subsidies, innovative financing and preferential treatment of renewable projects are some of the ways low-income growing states can catch up with high-income-growing high-renewable growing states. All the policy-making and regulatory bodies in Turkey: MENR, MEU, TUBITAK, SERCs and state energy departments need to synergy their efforts if the disparity between states is to be mitigated.

Further, though we have estimated the economic growth-energy nexus separately for wind and solar, we did not find a significant difference among these two major renewable energy sources regarding the nature of nexus. This may be because wind and solar energy production costs are not much different from each other in Turkey. As per the Report on ‘Projected Costs of Generating Electricity 2020’ [18], in Turkey, the cost of solar energy production is $35.60 per MWh, $35.91 per MWh for wind energy. Hence, states should specialize in that renewable energy source with they have a greater capacity to produce. However, this result may not hold for many countries, where there is a substantial difference in the cost of producing energy from solar and wind.

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