Solar Photovoltaic Energy and Its Spatial Dependence

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Abstract

In the last decade, solar photovoltaic has started to play a significant role in the energy mix consumption. Although this growth has involved almost all the western countries, marked differences in the regional distribution of photovoltaic generation capacity have been observed. These differences appear to be weakly related to climate conditions in general, and to solar radiation specifically. The literature has started to investigate the other underlying determinants, suggesting to consider the occurrence of spatial proximity effects. Accordingly, this study aims to analyze whether and to what extent the photovoltaic energy production depends on local factors, such as climate, demand, income, innovative and responsible behavior, and so forth. Through a spatial autoregressive model, we find that the regional distribution of photovoltaic production capacity is affected by strong spatial dependence. We show that the availability of photovoltaic energy may be explained by peer effects, such as diffusion of habits and emulation of neighbors.

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Keywords: solar photovoltaic; spatial energy; spatial data; peer effects; neighborhood effects

1. Introduction and background literature

The energy production and consumption models have experienced significant changes during the last decades [1]. On the supply side, although fossil fuels are still the most prominent sources, the transition to renewables is underway. Many countries have massively developed photovoltaic (PV) power generation systems. As a case in point, the share of electricity consumption met by solar energy is now more than 5% in Germany and up to 7% in Italy [2].
Worldwide, the installed capacity has grown to over ten times the level in 2007 [2]. According to IEA’s Outlook, solar energy is expected to play an increasing role in the years to come [3]. The above framework suggests investigating the PV deployment at regional and local scale and its determinants, the knowledge of which is rather limited. Balcombe et al. [4] have reviewed the motivations and barriers to the adoption of microgeneration technologies. Besides the local climate characteristics - especially the level of solar radiation [5] - several socioeconomic factors - such as age, income, investment cost, expected and actual return on investment - have been found to explain the consumers’ propensity to use renewable energy systems [6-11]. Balta-Ozkan et al. [12] show that also electricity demand, population density, pollution, and education are significant drivers.

Spatial dependence characterizes many ecological and social phenomena. It means that the behavior of a unit is affected by what happens in the surrounding areas, due to the so-called peer interaction effects, such as the diffusion of habits and the emulation of neighbors. A devoted research branch has stressed that proximity, neighborhood effects, and peer effects are important in shaping the spatial deployment of PV installations [11-17]. These effects turn out to play a prominent role, more than climate conditions [18]. A comprehensive review of the literature mentioned above can be found in Balta-Ozkan et al. [12].

2. Models, data, and method

We are interested in analyzing the dynamic relationship between the per capita PV production (Pp), the share of electricity consumption met by PV energy (Ps), and other explanatory covariates, in order to understand the behavior of the solar energy market. Our data are not simple cross-sectional because a spatial order characterizes the observations in the sample, which thus are not interchangeable. The spatial contiguity of the units raises a problem of serial correlation that seriously affects the statistical properties of the estimates. Analogous to the time series analysis, the issue can be solved by using spatial autoregressive (SAR) systems that include lagged terms [19,20,21]. SAR systems are useful to express the bivariate relationship between energy production and consumption.

Let us define the spatial index s=[latitude, longitude]. The first-order lagged dependent variables Pp_{s-1} and Ps_{s-1} are represented by the average values of Pp_s and Ps_s in the surrounding areas. Besides these lagged dependent variables, the other explanatory variables we consider are as follows: Ec_s represents the per capita electricity consumption; Ir_s is the vector of variables assumed as proxy of innovative and responsible behavior; Ef_s is the vector of exogenous factors. The three following variables approximate innovative and responsible behavior: creativity index (Ci_s); technology index; waste recycling rate. The vector of exogenous factors include several variables: latitude; solar radiation (Sr_s); surface area; residential buildings; housing density (Hd_s); population density; households; average number of members per household (Hm_s); per capita gross domestic product (Gdp_s), manufacturing firms, share of Plc and Ltd companies.

If the errors ε_s are mutually independent, then the estimation of the SAR system can be performed by separate equations. Accordingly, the two regression models, with parameters α, β, γ, δ, and ω are as follows:

\[ Pp_s = \alpha + \beta Pp_{s-1} + \gamma Ec_s + \delta'Ir_s + \omega'Ef_s + \varepsilon_s \]  \hspace{1cm} (1)

\[ Ps_s = \alpha + \beta Ps_{s-1} + \gamma Ec_s + \delta'Ir_s + \omega'Ef_s + \varepsilon_s \]  \hspace{1cm} (2)
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