# *ARE BOTH RENEWABLE AND CARBON POLICIES EFFECTIVE ON THE SOLAR PHOTOVOLTAIC GROWTH IN OECD COUNTRIES? AN ECONOMETRIC ANALYSIS*

Saiful Arefeen, Graduate School of Economics, Ritsumeikan University, gr0252eh@ed.ritsumei.ac.jp
Koji Shimada, College of Economics, Ritsumeikan University, shimada@ec.ritsumei.ac.jp

## Overview

The use of solar photovoltaic (PV) in electric power systems has been increasing as a result of the negative impact of carbon emissions produced by traditional power sources throughout the world. Solar PV penetration is aided by taxes (such as carbon and energy taxes), different subsidies (such as direct financial assistance, feed-in tariffs, and feed-in premiums), and regulations (such as renewable portfolio standards and carbon emission trading). Carbon taxes, energy taxes, and carbon trading systems are vulnerable to market failures, resulting in lower emission reductions than expected. Subsidies, on the other hand, have an influence on solar PV penetration, although they may be a burden for governments. Furthermore, policy overlap may have a significant influence on the effectiveness of regulatory measures in terms of uncertainty, risk, profitability, and social welfare. As a result of the policy interactions, policy instruments such as feed-in tariffs and feed-in premiums may be switched. Furthermore, the EU ETS was recently amended into a Market Stability Reserve (MSR), which would limit the price of permits to a specific range, decreasing price swings. As a result, the ETS is transitioning from a pure quantity instrument to a hybrid of a price (i.e., a tax) and a quantity instrument. Thus, it's critical to assess whether and to what extent policies (feed-in premium, feed-in tariff and renewable portfolio standard) are effective at increasing solar capacity penetration. Understanding how different policy mechanisms interact with one another is also crucial in order to avoid potential trade-offs or take advantage of potential synergies in terms of policy objectives toward a global zero-carbon target. Furthermore, the climate policy (such as carbon tax and emission trading system) effect can give novel insights into solar PV penetration.

## Methods

The solar PV capacity is the dependent variable in this study, and the policy variables examined include the feed-in tariff, Renewable portfolio standard (RPS), Feed-in premium (FIP), carbon tax, and European Union emission trading system (EU ETS). Household electricity prices, hydropower (percent), nuclear energy (percent), energy import, GDP, and population density were all investigated as control variables. As solar PV capacity grows exponentially over the research period, the empirical model incorporates a natural logarithm in solar PV growth (2000-2020). The following is a proposed empirical model:

$$ln\Delta Solar\ PV_{jk} = \beta_0 + \sum_{i=1}^{i} \beta_i\, PI_{ijk} + C_{jk} + \epsilon_{jk} \quad (1)$$

where $\Delta Solar\ PV_{jk}$ is the solar PV capacity growth per country j and year k; $PI_{ijk}$ is a vector of i explanatory variables representing policy instruments; $C_{jk}$ consists of several control variables; and $\epsilon_{jk}$ refers to the error term.

Several econometric models such as the fixed-effect model and instrumental variable method were employed, following studies such as Alolo et al., 2020 and Bersalli et al., 2020 to investigate the impact of policies on the development of solar PV. The study addresses the unit root test, multicollinearity, heteroscedasticity, and Hausman test to get reliable estimates. We identified several conflicting points and gaps in the econometric literature. We then developed a model for this study. The control variables such as retail electricity price, hydro generation, nuclear generation, and energy imports in the eq.-1 are mechanically related to the amount of solar PV capacity—the main outcome of the analysis. As solar PV capacity increases, this can reduce generation from other sources and change energy import patterns as a result. Similarly, adding solar PV capacity will change the marginal cost of electricity and therefore impact residential electricity prices. Thus, this set of control variables are holding fixed a part of the outcome of the FIT policy. Instead, we are controlling for lags in retail electricity price, hydro generation, nuclear generation, and energy imports.

Moreover, policy instruments are usually endogenous—a correlation between policies and solar PV renewable growth does not mean the policies alone are causing solar PV growth. Moreover, solar PV growth can impact the choice of policy instruments and their design. Thus, estimating policy effects on solar development requires an identification strategy that exploits exogenous variation. We have considered the lag of policies as valid instruments because the lagged policies strongly predict the current policies.

The research uses data from various sources, including the OECD, World Bank's World Development Indicators (WDI), International Renewable Energy Agency (IRENA), European Union Statistics Database (Eurostat), and country-specific reports to conduct empirical estimations.

## Results

Table-1 summarizes the preliminary findings on solar photovoltaic capacity growth. The fixed-effect model and the instrumental variable technique results (Table 1, columns a and b) show that the FIT, RPS, FIP, and carbon tax policies have a considerable beneficial influence on the growth of solar PV in OECD nations. According to the findings, increasing the FIT price by 0.01 USD per KWh will raise solar PV capacity growth from 2.9 percent in fixed-effect models to 5.3 percent in instrumental variable models. Countries that have implemented FIT policy, on the other hand, have struggled to find appropriate FIT pricing, contract lengths, and power generation management. As a result of the FIT subsidies, which disproportionately affect low-income individuals, consumers are concerned about rising power bills and increased government liabilities. On the other hand, FIP policy gives investment certainty, which RPS does not, as well as enhanced economic reasoning, which FIT policy generally does not. The EU carbon trading scheme, on the other hand, had no significant influence on fixed-effect or instrumental variable models.

Table-1: Panel data estimation results on solar photovoltaic capacity

| Variable | Ln $\Delta$ solar PV capacity growth (MW) | |
|---|---|---|
| | Fixed-effect model (a) | Instrumental variable model (b) |
| Feed-in tariff | 2.90*** | 5.28*** |
| (USD/KWh) | (0.54) | (0.88) |
| Renewable portfolio standard | 0.80** | 1.31** |
| dummy | (0.40) | (0.65) |
| Feed-in premium dummy | 1.17*** | 1.66*** |
| | (0.41) | (0.58) |
| Carbon tax dummy | 1.38*** | 1.50** |
| | (0.50) | (0.65) |
| EU Emission trading system | 0.60 | 0.47 |
| dummy | (0.42) | (0.67) |
| L.(Residential electricity price) | 6.99*** | 6.77*** |
| (USD/KWh) | (1.40) | (1.65) |
| L. (hydroelectricity) | 0.03 | 0.05 |
| (%) | (0.04) | (0.05) |
| L. (Nuclear electricity) | 0.02 | 0.007 |
| (%) | (0.03) | (0.03) |
| L. (Energy import dummy) | -0.75 | -1.11 |
| | (0.67) | (0.72) |
| GDP (in billion USD) | 0.002*** | 0.002*** |
| | (0.0002) | (0.0002) |
| Population density | 0.16*** | 0.15*** |
| (per sq. km.) | (0.02) | (0.02) |
| Constant | -34.23*** | -33.37*** |
| | (2.93) | (3.15) |
| Observations | 303 | 303 |
| R-squared-within | 0.65 | 0.62 |
| R-squared-between | 0.12 | 0.12 |
| R-squared-overall | 0.06 | 0.06 |
| Number of country | 22 | 22 |
| Hausman's statistics | 143.9*** | |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

## Conclusions

Despite the fact that carbon taxes and emission trading systems are believed to be the best options for climate mitigation, instruments like RPS, FIT, and FIP have been popular in OECD nations to boost solar PV renewable energy. Our preliminary findings are consistent with the general impact of promotion policies: public policies had a positive and statistically significant impact on renewable investment. The finding that FIT and FIP policy have a significant positive impact on solar PV penetration is consistent with the existing study of Alolo et al. (2020). Furthermore, the study found the novel results that the carbon tax significantly influences solar PV uptake among climate policies, but the emission trading system policy has no significant impact. The study findings might aid in the critical evaluation of policy effects and overlapping rules in the power market. Policymakers may justify the implementation of numerous policy instruments with diverse aims, and regulation design must be based on a systematic and consistent trade-off analysis.

## References

Alolo, M., Azevedo, A., & El Kalak, I. (2020). The effect of the feed-in-system policy on renewable energy investments: Evidence from the EU countries. *Energy Economics*, 92, 104998.

Bersalli, G., Menanteau, P., & El-Methni, J. (2020). Renewable energy policy effectiveness: A panel data analysis across Europe and Latin America. *Renewable and Sustainable Energy Reviews*, *133*, 110351.