García, M.T.; Cabeza, L.; Soares, I. (2018): "Assessment of energy policies to promote photovoltaic generation in the European Union". ***Energy***, vol. 151, nº 15, 864-874.

Title

Assessment of energy policies to promote photovoltaic generation in the European Union

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ASSESSMENT OF ENERGY POLICIES TO PROMOTE PHOTOVOLTAIC GENERATION IN THE EUROPEAN UNION

Abstract

Renewable energy is a focal point of discussion in the European Union as clean production technologies contribute to all three aims of energy policy (security, competitiveness and sustainability). This paper focuses on an empirical assessment of feed-in tariff and quota obligation policies as well as their policy design elements applied to solar photovoltaic energy in the European Union over the period 2000-2014. The results indicate that only feed-in tariff policy has significant impacts in terms of installed photovoltaic capacity. However, its main policy design elements (tariff size and contract duration) have a positive but not significant influence on the development of this clean production technology. Policy-makers should consider the importance of reducing regulatory uncertainty about these parameters.

Keywords: Solar photovoltaic, energy policy, feed-in tariff, quota obligation, empirical assessment.

1. Introduction

The World Commission on Environment and Development, established by the Resolution 38/161 of the United Nations General Assembly in autumn 1983, introduced the concept of sustainable development in its Report *Our Common Future* (better known as Brundtland Report). It is defined as "*development that meets the needs of the present generation without compromising the needs of future generations*" (World Commission on Environment and Development [1], chapter 2, paragraph I). From the point view of the needs of society, it is obvious that energy generation is an aspect of major importance as it is necessary for the development of any human activity. Therefore, how energy is produced and used, in terms of efficiency, are vital issues as the existing resources are limited and the necessities are increasing due to the growth of world population and the development of the societies.

Thermal technologies, based on the use of fossil fuels, have traditionally been the support of electricity energy generation with the consequent negative effects on greenhouse gas emissions. Nowadays, actions to combat climate change are especially relevant as they are set in one of the seventeen objectives of sustainable development of the Agenda 2030, adopted by world leaders in September 2015, which formally entered into force on 1 January 2016. In particular, the seventh objective of the Agenda 2030 for Sustainable Development establishes the obtaining of affordable and clean energy with the aim of "*encouraging the transition to an affordable, reliable and sustainable energy system, in which it is necessary to invest in renewable energy (RES-E) resources, to give priority to practices of high energy performance and to adopt clean technologies and infrastructures*" (United Nations [2], p.2).

In this context, the European Union (EU) has adopted, since the beginning of the discussion, a role based on promoting the change of the energy model, such as it is shown in the Directive 2011/77/CE of 27 September 2001 [3], which is modified later by the Directive 2009/28/CE of 23 April 2009 [4]. Both of them make reference to the promotion of the use of energy from renewable sources. Likewise, the conclusions of the European Council 7224/1/07 [5] establish that the 20% of the final gross energy consumption has to be supplied from renewable sources as aim for 2020. More recently, an EU-wide binding target for RES-E of at least 27% for 2030 is set in the EU [6]. These objectives involve important challenges that can only be reached by developing effective RES-E support policies and with specific actions to get an improvement of energy efficiency of these sources [7,8].

In this context, solar source "*is one of the cleanest energy resources that does not compromise or add to the global warming*" (Solangi *et al*. [9], p. 2149) and it is characterized by having a great future potential [10]. In particular, in the field of electricity generation, solar photovoltaic (PV) emerges as a resource with tremendous potential in all countries and as the most prominent energy. In the EU-28, electricity energy from renewable sources on the total gross electricity energy consumption was 27.5% in 2014 [11]. More specifically, in the period 2004-2014, the contribution of solar PV on total electricity generated from renewable sources increased from 0.1% to 11.0%, which allowed this technology to position itself as the third most important renewable technology. Likewise, in this period, solar PV energy, together with wind and biomass, have been the technologies that have experienced greater relative growth [11].

Despite the importance of this production technology, there is scarce empirical evidence about the effects of RES-E support policies on installed solar PV capacity. Most of the literature is based on case studies and, therefore, it is necessary to improve our understanding in this field with the aim to know which specific policies (based on prices or on quotas) are more effective in the development of solar PV energy. Furthermore, literature hardly considers the design elements of these policies (except the case of Jenner *et al*. [12] but it analyses only the case of feed-in tariff policies). This issue is essential in order to policy-makers can know the main strengths and/or weaknesses of each policy and thus can establish, if it is the case, suggested improvements.

Therefore, in this context, the objective of this paper is to analyse the effects of the two main RES-E support policies in the EU: feed-in tariff (FIT) and quota obligation as well as their main policy design elements on the installed solar PV capacity in the EU-28 in the period 2000-2014.

The remainder of this paper is structured as follows. Section 2 presents the theoretical framework. Section 3 discusses the sample, the variables and proposes the methodology. Section 4 shows the main results. Section 5 provides a discussion of the results. Finally, Section 6 presents the main conclusions.

2. Theoretical framework

RES-E support policies can be considered as a key concept to promote the development of clean production technologies and, thus, to achieve international environmental targets [13]. In this context, there is a certain unanimity about the importance of FIT and green certificates with quota systems as main RES-E energy support policies [14,15,16].

FIT are based on a fixed-price contract which is determined by the public authorities for a certain period of time. It represents the full price received by a solar PV energy producer for any KWh of electricity from solar PV system. Alternatively, this system can be paid in the form of an additional premium, on top of the electricity market price (feed-in premium). On the other hand, the functioning of green certificates with quota systems is based on the obligation of producers, distributors or consumers to maintain a specific quota of RES-E in their energy consumption, which is set previously by governments. In this system, energy price is established by the agents that participate in the program. The quota system is known as quota obligation (or renewable portfolio standard) and it is mainly implemented by tradable green certificates that represent the environmental benefit of the electricity generated from RES-E.

Despite the importance of solar PV energy to promote sustainable development, in the present EU's Sustainable Development Strategy framework, there is scarce literature that analyses the specific effects of the different support policies to promote this clean production technology in the EU (see Table 1).

[Insert Table 1. Literature review about RES-E support policies and solar PV energy deployment in the EU. Source: Own elaboration]

The methodology of case study has been amply used in this topic. Campoccia *et al*. [17] found the importance of FIT policies in order to promote solar PV energy in the EU by analysing the cases of the main four member states that have got the best results in the promotion of solar PV and wind energy (France, Germany, Italy and Spain). They emphasized the case of Italy as the country that developed a more effective support policy based on a FIT policy, in which the owner of the solar PV system obtained a FIT for the whole produced electric energy and a payment for the part of electric energy sold to the utility.

Dusonchet and Telaretti [18] studied the RES-E support policies to solar PV in various western European countries whose results showed that the same support policy could have different results as a consequence of its different implementation in various member states. So, the impact is very limited when tariff does not cover expenses and even it could derive in limitations, such as a low cap, the establishment of reduced number of guaranteed years regarding FIT value and/or the implementation of complicated administrative procedures. Similar results are obtained by Dusonchet and Telaretti [19] for the cases of 10 eastern member states (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic and Slovenia), in which only countries with enough support actions to recover the investment costs, in a reasonable time, have been characterized by a suitable development of solar PV energy.

Sarasa-Maestro *et al*. [14] studied the development of solar PV systems in ten countries of the EU. Their results showed that financial crisis created retroactive lows with the consequent negative impact on investor confidence. Regarding green certificates, they suggested that this type of certificates were well accepted by consumers who do not want to absorb costs in their electricity bills.

Campoccia *et al*. [20] analysed the main differences in the establishment of FIT policies of six member states (France, Germany, Greece, Italy, Spain and the UK) which have been characterized by achieving the best results in this clean production technology. They concluded that: a) ground-mounted solar PV systems were not profitable in these member states -except for the case of Greece-, b) Italy has established the most profitable solar PV support for building integrated solar PV systems and c) the greatest profitability indexes have been obtained for member states with active net-metering and self-consumption. However, in the case of Italy, Orioli and Di Gangi [25] highlighted that solar PV support policy should be complemented with higher increases in tax credit rates in order to promote invest as a consequence of the reduction of electricity prices.

On the other hand, Sener and Fthenakis [21] found the importance of establishing energy-policy mixes, by analysing the cases of United States, Germany, China and Japan, in order to obtain an effective and efficient development of solar PV energy. The combination of both policies result in reductions of both solar technology and grid integration costs. Similarly, Sahu [22] analysed the effectiveness of support policies of solar energy in the top ten global producers of this clean production technology (Germany, Italy, Japan, Spain, USA, China, France, Belgium, Czech Republic and Australia). They found that both FIT and quota obligation have been essential to fulfil the solar projections of these countries.

Nevertheless, a more exhaustive empirical assessment has been hardly used in the assessment of solar PV support policies. As exceptions, Jenner *et al*. [12] employed a panel data methodology from 1992-2008 to study the effectiveness of FIT policies on onshore wind and solar PV energy in 26 European countries. Their method considered tariff size, contract duration as well as electricity price and production cost to estimate the resulting return on investment. They found that FIT policies have resulted in solar PV energy development. However, this study analysed only solar PV support policies based on prices and not on quantities.

Dusonchet and Telaretti [23] developed comparisons based on economic indexes (net present value and the internal rate of return) in France, Germany, Greece, Italy and the UK. Their results suggested that the future development of RES-E in the EU would be given by the establishment of self-consumption regulatory systems. Bono and Giacomarra [24] proposed a dynamic model to measure the technical efficiency of solar PV sector in the EU in the period 1996-2010. Their results indicated that technical efficiency was a consequence of the economic and political contexts as well as the specific adopted political support policy. Therefore, they concluded the necessity of strengthening the monitoring tools in order to assess, in a suitable way, the different faces of the political arrangements.

As conclusion, we can establish that only some studies have been centred in the case of a specific policy (FIT) (for example, [12] or [20]) and although some research has studied both solar PV energy support policies -based on prices and quantities-, it does not consider policy design features (for example, [22,21,14]). Likewise, the majority of literature has been based on case study (for example, [17,21,18,19], among others).

Therefore, it is necessary to deepen in this research topic in order to identify which specific policy has resulted in more installed solar PV capacity as well as to know the impact of policy design in the development of such a clean production technology. It is essential to fulfil the targets related to sustainable development as its potential contribution to a major share of RES-E in the future of the EU [26].

Once literature has been reviewed in this research topic, we proceed to the formulation of the hypotheses. Firstly, it is necessary to consider that, with the aim of reducing the difference between solar PV energy cost and the cost of energy for conventional production technologies, the development of solar PV sector has been promoted by the establishment of both support policies -FIT and quota system- in the last decade in the EU.

FIT has been the most used RES-E energy support policy for all sizes of solar PV systems in the EU. Experience shows that FIT policies have been effective at stimulating the development of solar PV energy. Thus, the establishment of guaranteed prices for fixed periods of time can significantly reduce the risks of investing in that production technology [20,12]. Likewise, quota obligation based on tradable green certificates allows solar PV energy plants to sell certificates in addition to the revenues from selling electricity which provide an incentive for the deployment of solar PV energy [23,22].

Taking into consideration these arguments, both energy support policies (FIT and quota system) would offer enough incentives to develop solar PV energy. Thus, the first hypothesis is proposed as follows:

H1 FIT and quota obligation policies will positively affect the installation of solar PV energy capacity.

Nevertheless, policy design elements are essential to maintain investor confidence and therefore to obtain a well-functioning of each RES-E energy support policy. A suitable design of both policies would derive in enough investment security and therefore in a reasonable return on investment which is especially relevant to leverage significant capital amounts for solar PV energy deployment [27].

In order to reduce the risk of investing in solar PV energy plants, FIT policies should establish enough payments to recover project costs as well as guarantee them for the lifetime of the technology [28]. Therefore, tariff size and contract duration are essential design elements in this support policy [29,30]. A positive relationship between tariff size and contract duration on installed solar PV capacity is expected as these variables can positively influence investor confidence [31,12].

Taking into account the above mentioned arguments, the following hypotheses are proposed:

H2 The higher the tariff size in FIT, the greater the installed solar PV capacity.

H3 The longer the contract duration in FIT, the greater the installed solar PV capacity.

Regarding quota systems, this policy should offer enough incentive in terms of remuneration and certainty to ensure solar PV energy expansion [27]. De Jager *et al*. (2008) [30] identify certificate prices as main policy design element in quota obligation. This variable should be sufficiently high to increase security of investments in case of fluctuations of prices. Likewise, certificate award rate is considered as a relevant policy design element in this RES-E support policy as it can positively influence investor confidence [32]. Finally, time horizon is essential to guarantee future demand for solar PV energy as quota obligation should be ensured to be in place for an enough long period of time in the future. A positive impact of all these variables on solar PV energy is expected [31,29].

Considering the arguments posed in the previous paragraphs, the following hypotheses are proposed:

H4 The higher the certificate prices and electricity prices in quota obligation, the greater installed solar PV capacity.

H5 The higher the award rates in quota obligation, the greater the installed solar PV capacity.

H6 The longer the time horizon of the quota obligation, the greater the installed solar PV capacity.

3. Sample, variables and methodology

3.1. Sample

To test the hypotheses presented above, we examined Eurostat database as well as reports about the state of RES-E support policies in the EU over the period 2002-2014 (28 countries, 281 observations). The analysis starts in 2000 as most RES-E energy support policies were implemented in the EU in the early of that decade. Those cases for which there was not information on any of the variables were not considered in the study in order to avoid missing values in the estimates and to have the same sample size in all models. As a result, we ended up with an unbalanced panel of 27 countries and 256 observations.

3.2. Measuring variables

3.2.1. Dependent variable

In this study, installed solar PV capacity is considered as the dependent variable [22,14]. The explanation is that policymakers should know if solar PV energy support policies have actually increased solar PV capacity beyond what would have happened in their absence [12]. In this context, this variable is measured as the electricity capacity of solar PV energy generators (in MW) (PV_CAPACITY).

3.2.2. Explanatory variables

As RES-E energy support policies may influence the installed capacity of this clean production technology [24,20,12], this effect is taken into account in the model by creating three dummy variables:

- RES-E energy promotion policy1 that makes reference to the non-existence of a specific promotion policy in solar PV energy (RES-E_POL1).

- RES-E energy promotion policy2, this is the existence of a quota obligation in solar PV energy (RES-E_POL2).

- RES-E energy promotion policy3 which refers to the existence of FIT in solar PV energy (RES-E_POL3).

Besides, in order to assess the impact of different policy design elements, the main constituent terms of FIT and quota obligation are included in the model.

More specifically, in FIT, tariff size and contract duration are considered as the main design elements [12]. Tariff size makes reference to the price obtained by a solar PV energy producer for electricity sold to the grid (in Euros/MWh) in FIT observations and 0 otherwise (TARIFF_SIZE). In the case of premium tariffs, it is the electricity market price plus the bonus. For fixed-price tariffs, it is the amount of the tariff. As solar PV energy schemes are diverse due to tariff amount differs with the size of the installations, the mean value of the each solar PV tariff across all size is considered in the model [12]. With regard to contract duration, it is the duration of a FIT contract in years and 0 otherwise (TARIFF_DURATION).

Regarding quota obligation, certificate prices variable consider the prices obtained generally through a market mechanism (in Euros/MWh) together electricity market prices (in Euros/MWh) in quota obligation in solar PV energy and 0 otherwise (QUOTA_PRICE). Electricity market prices are included in certificate prices in order to consider all remuneration to be able to analyse the expansion of solar PV energy [26]. Award rate makes reference to the number of awarded certificates for solar PV energy generators (in MWh) (QUOTA_AR). With regard to time horizon of the quota obligation, it is the duration of a quota contract in years and 0 otherwise (QUOTA_HORIZON).

3.2.3. Control variables

Control variables refer to five categories: (i) state trends of security of energy supply, (ii) environmental concern, (iii) conventional energy trends, (iv) electricity price trends, and (v) economic situation.

(i) State trends of security of energy supply. Dependency on energy imports and electricity energy consumption variables are introduced in this category.

Dependency on energy imports makes reference to extent to which an economy relies upon imports in order to meet its energy needs (information obtained from Eurostat). This variable is obtained from net imports divided by gross inland energy consumption (in %) (IMPORTS). A positive relationship between this variable and investment on renewable sources could be expected in order to substitute energy imports by local resources [33,34].

Secondly, electricity energy consumption per capita (MWh per capita) was considered (ELECT_CONSUMPTION) which was obtained from Eurostat. Electricity energy consumption makes reference to the energy needs of a country. Electricity energy consumption could have a positive or a negative impact on the RES-E and particularly on solar PV energy development as energy needs can be satisfied by either RES-E or by traditional fossil fuel sources or a mix of them [35,36].

(ii) Environmental concern. In this context, government commitment to environmental policy and carbon dioxide emissions variables are included.

Regarding government commitment toward environmental policy, this variable is defined as the environmental protection expenditure that considers not only environmental investments but also environmental current expenditure and subsidies (in Euros per capita) (GOV_POLICY). According to [37,38], a positive impact of this variable on RES-E and particularly on solar PV energy development is expected.

Besides, carbon dioxide emissions per capita include total emissions related to Kyoto Protocol divided by population (tonnes of CO2 equivalent per capita) EMISSIONS). A positive relationship between this variable and RES-E investment incentives could be expected as these emissions are largely responsible for climate change, with consequent positive impact on RES-E and particularly on solar PV energy development [39,40].

(iii) Conventional energy trends. In this category, price of gas and contribution of gas to electricity generation were introduced.

Price of gas is the average import border price in Europe obtained from the BP Statistical Review of World Energy (Euros/million BTU) (GAS_ PRICE). A positive relationship between prices of conventional production technologies, such as gas, and RES-E use and therefore RES-E and particularly on solar PV energy development would be expected [41,42].

The variable contribution of gas to electricity generation shows the percentage of gas in total gross electricity supply (in %) from Eurostat (GAS_CONTRIBUTION). The expected impact of this variable on RES-E (and particularly solar PV energy) development could be associated to the power of interest groups associated with fossil energy. They may be an obstacle for the development of clean production technologies [35].

(iv) As a proxy of electricity price trends, household electricity prices were considered, which make reference to electricity prices charged to final consumers (in Euro/MWh) (ELECT RETAIL_PRICES). This variable may have a positive impact on RES-E and particularly on solar PV energy development as higher electricity prices would make RES-E more economically feasible [38].

(v) Related to the economic situation, we focused on gross domestic product (GDP) (introduced in the analysis in logarithms). A positive relationship is expected between this variable and RES-E and particularly on solar PV energy development [43].

3.3. Model

A pooled OLS regressions clustered on the firm level is developed with STATA12 program[1]. Besides, explanatory and control variables are lagged by one year in order to control for endogeneity problems in the models proposed. Although we considered the possibility of employing a panel data methodology, for example, a dynamic panel data model, the two-step difference GMM model drawn up for dynamic panel data models by [44] as our number of countries is not so large, this methodology was not applied because the results would not be reliable as the number of instruments would be larger than the number of countries.

The pool OLS we run is as follows:

$$\text{PV\_Capacity}_i = a_0 + \beta X_i + \sum_{t=2000}^{2014} D_t + \varepsilon_i$$

Where:

PV_CAPACITY is the dependent variable.

X denotes the explanatory and control variables,

$\sum_{t=2000}^{2014} D_t$ is a set of time dummy variables and

ε_i is the error term.

4. Results

Descriptive statistics and the correlation coefficients of the variables used in the regression analyses are listed in Tables 2 and 3, respectively. Despite some of the variables show a statistically significant correlation, analysis of the variance inflation factors (VIF) revealed no evidence of multicollinearity as none of them remained above 10 [45].

[Insert Table 2. Descriptive statistics. Source: Own elaboration]

[Insert Table 3. Correlation matrix. Source: Own elaboration]

The results of the regression analyses are summarised in Table 4. Model 1 focuses on the effect of RES-E energy support policies on the contribution of solar PV energy to electricity supply, while Model 2 considers the effect of different policy design elements.

As in the variables section was described, RES-E_POL is a qualitative variable that puts the RES-E energy support polices into three possible categories; thus, to make it operative we define three dummy variables. Nevertheless, it is only possible to add k-1 dummies (in our case 2) in the regression models as the parameters cannot be estimated in the other case. Thus, we present our results combining the dummies into pairs to understand what their coefficients really mean. It is enough to state the results of the

[1] Besides, cluster option also implies the estimation of standard robust errors.

combination of dummy RES-E_POL2 (quota obligation in solar PV energy) and RES-E_POL3 (FIT in solar PV energy) as the results of the remaining combinations may be inferred from the previous one.

The results of Model 1 show that FIT (RES-E_POL3) significantly increases solar PV energy capacity in comparison to the non-existence of a specific RES-E energy support policy (RES-E_POL1). These results are in line with [12,20] that suggest greater development of solar PV energy with FIT policies. However, the pair wise comparisons show that there are no significant differences between quota obligation (RES-E_POL2) and the non-existence of a specific RES-E energy support policy (RES-E_POL1). Quota obligation (RES-E_POL2) increases solar PV energy capacity, although no statistically significantly, in comparison to the non-existence of a specific solar PV energy support policy (RES-E_POL1). The explanation can be given by greater risk for investors as they have to face not only risk related to policy parameters but market design parameters also which could limit investment [46,30]. Therefore, the first hypothesis proposed can be only confirmed partially.

Hypothesis 2 must be rejected because a greater tariff size obtained by a solar PV energy generator when power is sold to the grid (TARIFF_SIZE) influences solar PV energy capacity positively but non-significantly. The regulatory uncertainty that has characterized this policy design element might explain the results obtained. Thus, tariff size has been frequently changed in the legislation of member states with the consequent uncertainty for investors about the maintenance of the initial tariff size over time [47,48].

Our results neither support Hypothesis 3 as higher duration of a FIT contract (TARIFF_DURATION) does not influence significantly onshore photovoltaic solar capacity. This policy design element is essential in FIT policies as the longer the period of guaranteed prices, the lower the cost of capital [30]. However, again the regulatory uncertainty about the maintenance of the contract duration could limit investment decisions [49].

Nevertheless, Hypotheses 4 is supported as certificate prices (QUOTA_PRICE) are statistically significant ($\beta= 0.122$ $p = 0.000$). The results suggest that certificate prices, together with electricity market prices, seem to be sufficiently high to increase security of investment in solar PV energy. This finding is in line with [22,50].

Regarding Hypothesis 5 is rejected as award rate (QUOTA_AR) does not turn out to be significant. Once again the regulatory uncertainty about this policy design element in quota obligation might explain the obtained result [51]. Likewise, contrary to the proposed in Hypothesis 6, the results suggest that a greater time horizon of the quota obligation (QUOTA_HORIZON) reduces solar PV energy capacity ($\beta= -0.144$; $p = 0.000$). An explanation might lie in that quota obligation would not be ensured to be in place for an enough long period of time in the future to secure solar PV energy investment. It is required that quota systems ensure an enough level of RES-E demand over a long sufficient time horizon in order to be effective [52,51]).

Regarding control variables, the results support a positive and significant influence of GAS_PRICE on the dependent variable in both models (in Model 1 and Model 2, respectively, $\beta= 0.183$ $p = 0.006$; $\beta= 0.120$ $p = 0.025$) in line with other studies [42,36]. This seems to suggest that greater gas prices provide incentives to substitute this source of traditional energy with solar PV energy.

[Insert Table 4. Linear regression analysis. Source: Own elaboration]

In addition, our analyses revealed that dependency on energy imports (IMPORTS) and the country economic situation (GDP) have a positive impact on installed solar PV capacity (in Model 1, $\beta= 0.010$ $p = 0.064$; $\beta= 0.315$ $p = 0.056$, respectively). Therefore, greater dependency on energy imports might favour the investment on solar PV resources to substitute energy imports by local resources [33,34]. In addition, countries with better economic situation might have more resources to invest in clean production technologies with the consequent positive effect on solar PV energy development [43].

With the aim of establishing the robustness of the results obtained, our estimations employing additional measures, considering the FIT and quota obligation sub samples separately, and additional estimations were repeated.

First, the Hypotheses 1 and 2 were tested considering individually the FIT and quota obligation, respectively. We stress that the number of observations in both sub samples is not large and consequently we must be cautious when interpreting the results. More specifically, in FIT subsample, TARIFF_SIZE and TARIF_DURATION result in a statistically significant increase of installed solar PV capacity. Regarding quota obligation subsample, QUOTA_ HORIZON and QUOTA_ AR have a negative and positive impact respectively, both statistically significant, on installed solar PV capacity.

Second, the models proposed (summarised in Table 4) were estimated considering contribution of PV energy to electricity supply as a percentage of total gross electricity supply (PV_CONTRIBUTION) as dependent variable, instead of capacity of solar PV energy to electricity supply. The results were similar.

Third, when the estimations (summarized in Table 4) are repeated considering only as endogenous variables (those in which the endogeneity problem is more clear) IMPORTS, CONTRIBUTION_GAS, and EMISSIONS and the results did not vary significantly.

Fourth, the initial models are repeated considering alternatively different proxies for the control variables and in all cases regarding the main explanatory variables the results remain be the same. More specifically, GDP was substituted by GDP per capita. Besides, regarding government commitment toward environmental policy, GOV_POLICY variable was changed by environmental investment made by government (in Euros per capita) (GOV_POLICY2).

5. Discussion

RES-E has been characterized by being a focal point of discussion in energy policy of the EU as these clean production technologies contribute to mitigation of climate change by reducing greenhouse gas emissions, achieving sustainable development and protecting the environment [53]. In this sense, the Directive 2009/28/EC [4] sets a binding target of 20% final energy consumption from RES-E by 2020. More recently, a new target of at least 27% of final energy consumption from RES-E by 2030 in the EU has been implemented as part of the 2030 Energy Strategy [54]. These regulations establish national targets for each member state but give them enough flexibility to implement the RES-E support policy that consider more suitable in function of their particular national circumstances.

The relative effectiveness of the two main RES-E support policies (FIT and quota obligation) for promoting solar PV energy in the EU is compared in this paper. The results suggest that FIT policies would give better results than quota obligation systems in terms of installed solar PV capacity in the EU.

Nevertheless, the specific design of any RES-E support policy can be essential to obtain an efficient and well-functioning of these policies as well as to maintain investor confidence. In this sense, the relative effectiveness of the main design elements is studied in both policies. The results indicate that design elements of FIT policies are not significant for solar PV energy deployment in terms of installed capacity. Uncertainty about the maintenance of tariff size and contract duration might reduce investor confidence with the consequent negative impact on their investment decisions [28].

Regarding quota obligations, the results of this paper suggest the importance of both certificate prices and time horizon in quota obligations to develop solar PV energy capacity. The governmental commitment in the long term with these design elements is essential to get a successful solar PV energy deployment [55,56]. More specifically, the results suggest the necessity of introducing changes in both time horizon and award rate of certificates in quota obligations in order to obtain better results in terms of solar PV installed capacity.

The European Commission [53] establishes that RES-E support schemes used in the EU have been, in many cases, changed or revoked retroactively. It resulted in a negative impact on investor confidence. With the aim of reducing this problem, and in order to ensure that the 2030 target is met, the European Commission published on 30 November 2016 a proposal for a revised renewable energy Directive [53]. This regulation considers the introduction of a set of principles for RES-E support schemes, which favour the deployment of clean production technologies, which are mainly based on:

- The development of a partial opening of RES-E support schemes to cross-border participation mandatory. It would ensure that investments can be implemented where potential and other conditions are more favourable with the consequent reduction of overall system costs and support costs.
- The establishment of cost-effective RES-E support schemes to facilitate a market-oriented and Europeanised approach.
- The design of RES-E support schemes in a form that does not distort the functioning of electricity markets. This might be achieved when support is granted in addition to market incomes.
- The deployment of RES-E should involve the lowest possible cost for consumers. For it, member states should minimise the overall system costs of RES-E deployment by considering grid and

system development needs, the resulting energy mix and the potential of technologies in the long term.

- RES-E support policies should be stable and avoid frequent changes. In this sense, the introduction of changes affects capital financing costs and project development costs. Therefore, it is essential to promote cost-effective support policies and to ensure their financial sustainability.
- Cooperation at all levels, bilaterally or multilaterally, between member states in relation to RES-E target is encouraged.

Therefore, the application of these characteristics in both solar PV energy support policies (FIT and quota obligations) would reduce regulatory risks and have a great impact on solar PV project financing cost and therefore on propensity to invest [47].

6. Conclusions

RES-E seems to be an efficient and effective solution for sustainable development as these resources can mitigate environmental impacts from energy systems by reducing greenhouse gas emissions. In this context, a suitable design of RES-E support policies is essential to create enough investor confidence that promotes the investment in these clean production technologies.

This paper provides an empirical evaluation of FIT and quota obligation applied to solar PV energy in the EU. The results suggest that FIT policies gave better results in terms of installed solar PV capacity in the EU over the period 2000-2014. However, its main design elements (tariff size and contract duration) do not seem to have a significant impact on the deployment of this clean production technology. Policy-makers should consider the importance of not changing or revoking retroactively these design elements in order not to increase regulatory uncertainty.

Regarding quota obligation, outstanding results are obtained for certificate prices as this variable, together with electricity prices, seem to have significant impacts on the deployment of solar PV energy. In this policy, a revision of both award rates and time horizon might be essential when enacting this policy to obtain a suitable development of this clean production technology.

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