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# A system dynamics approach for the photovoltaic energy market in Spain[☆]

Santiago Movilla [a], Luis J. Miguel [b], L. Felipe Blázquez [c,*]

[a] Department of Geography, University of Bergen, Faculty of Social Sciences, PO Box 7802, 5020 Bergen, Norway
[b] Department of Automatic Control and Systems Engineering, University of Valladolid, E.I.I., Paseo del Cauce s/n, 47011 Valladolid, Spain
[c] Department of Electrical and Automatic Control and Systems Engineering, University of León, E.II.I.I., Campus de Vegazana s/n, 24071 León, Spain

## HIGHLIGHTS

- The paper describes a simulation model of the photovoltaic energy sector in Spain.
- The model allows to analyse dynamic behaviour of PV sector under different scenarios.
- The work is directed to assist policymakers in designing energy policies.
- Results show that PV energy could start to be competitive in the short-medium term.
- Model structure could be applied to other countries with other parameters.

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## ABSTRACT

The goal of this paper is to contribute to understanding the behaviour of the photovoltaic (PV) sector in Spain and its expectations under possible scenarios. Currently, PV solar energy is not a profitable sector by itself. Therefore, the Spanish government, like the governments of other countries, has stimulated investment with subsidies. The spectacular increase of PV facilities exceeded all forecasts and the government decided to curb the trend. The present hypothesis is that continuing with this support to PV energy, the technological advances and the economy generated from the production of panels would be able to make the sector profitable in the future without the necessity of subventions. Based on this hypothesis, a computer simulation model was built using the system dynamics methodology. To test its utility, the model was challenged to fit the historical data and to explore several futures over the next few years. The model allows an understanding of the sector's behaviour under the latest policies of the Spanish government, thus helping to design future public policies. The simulation results are different depending on the adopted policy and the scenario. Therefore, these factors will determine the success or failure of the investments in this type of energy.



## 1. Introduction

Green energy policies have experienced continually accelerating growth in the past several years. In the framework of these green energy policies, PV electricity generation is receiving increasing support worldwide from public authorities due to its environmental benefits in comparison with fossil energy sources. However, this emergence of public support has been subject of a relatively small number of research works focused on the analysis and assessment of these widespread and varied policies (Avril et al., 2012; Carvalho et al., 2011; Zhang et al., 2011; Zhao et al., 2011). This work analyses the sensitivity of different variables on the development of the PV market in Spain, with special emphasis on policy decisions. The method allows an understanding of the dynamic relation between the different variables, such as public subsidies or electricity price, and the number of installed PV panels. The understanding of these dynamic relations is a powerful tool to design PV energy policies under different scenarios.

PV energy consists of the direct conversion of sunlight into electricity through an electronic device called "solar cell". The solar radiation is captured in the PV panels to generate electricity (PV effect) in the form of direct current. The performance of the panels is the fraction of the solar radiation which is converted into electricity. In facilities connected to the grid, this energy is transformed into alternating current by an electronic device known as an inverter, and discharged to the grid distribution at the point of connection. At present, the performance of these

* Corresponding author. Tel.: +34 987 293 471; fax: +34 987 291 790.
*E-mail address:* diefbq@unileon.es (L.F. Blázquez).

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panels is very low (around 15%), which means that energy obtained in this way is not cost-effective as the cost of producing the panels is far greater than the value of their energy production throughout their useful lives.

With the idea of developing this technology so that in the future it can be profitable, the Spanish government, like those of other nations, is betting strongly on this type of energy. The government is making it artificially profitable through the use of large subsidies paid according to the energy they produce and through encouraging the research and development of the sector in ways that someday, whether through the yield being higher or the costs of the components being lower, the sector can be competitive. Furthermore, the use of PV energy avoids the discharge of greenhouse gases to the atmosphere. As is well known, greenhouse gases can cause global warming and a rise of the planet's temperature with possible catastrophic consequences for human beings. In this respect, the Kyoto Protocol, in which Spain participates, sets emission limits for some member countries, which must pay fines for emitting excess tonnes. As for the emission of such gases, the energy sector occupies a very important place, because in Spain this sector is primarily responsible for emissions into the atmosphere, mainly due to the plants producing from thermal energy, such as coal, oil or natural gas. However, to account for the uncertainty and variability from solar energy, it is necessary to have additional flexible conventional generation capacity available in a power system with solar energy, to provide fast ramping capability. Hence, the production of electricity from PV panels not only does not pollute, but it also replaces some thermal energy, thus mitigating the discharge of $CO_2$ to the atmosphere and avoiding the payments or fines for such emissions, since Spain is one of the countries that exceed emissions agreed by the Kyoto Protocol (Martínez et al., 2009).

It is necessary to bear in mind that the energy required to construct a PV panel is very large because they are made of pure silicon, which is produced in ovens at high temperatures. However, a silicon solar panel with a regular purity can produce nearly ten times more energy than the energy used in its manufacture. This is because the energy needed to obtain silicon of regular purity is much lower with respect to that needed for a silicon cell of high purity, but the differences in PV energy production are not very significant. As estimated, a silicon solar cell has to be functioning between two and three years in order to “return” the energy used for its manufacture. This is assuming that the panel is installed in a relatively sunlit country.

The research method to be used in this context is a computer simulation model of the main variables that have an influence on the PV market. The simulation model is based on the system dynamics approach (Forrester, 1961; Sterman, 2000). The method has been previously used to model other energy systems with the purpose of being used for decision-making tools (Castro et al., 2009; Mediavilla et al., 2013). The main idea consists of building a computer simulation model to reproduce the behaviour of such variables as the PV panel price, the evolution of the panel efficiency, the PV power installed, the subsidy value, the electricity price, the investments in PV energy, the payback period on investments, or the costs and yield of panels in general, over the last few years. The structure of the model is built according to the observed relations between the involved variables. The model has to replicate the historical data, explain the causes of the behaviour and how it is reproduced.

The article is organised as follows: In Section 2 a literature review and the problem description are presented, where necessary background information to understand this problem is given. Section 3 describes the research method used in this work, where the process of using system dynamics is shown. Section 4 explains the conceptual model description. In Section 5 the simulation results are presented. Finally, Section 6 shows the conclusions of the work and some references are presented.

## 2. Renewable energy policy in Spain: The photovoltaic sector

The key points of the energy policy of the Spanish government are written in the Renewable Energy Plans (IDAE, 1999, 2005, 2011). The subsidy value and the conditions of every new PV installation are collected in a Royal Decree (RD) that can be updated and reviewed depending on the fulfilled goals or new situations. This subsidy value, which is also called a feed-in tariff, is the price per unit of electricity that a utility or supplier has to pay for PV electricity from private generators. Once an installation is hosted in a decree, the grants received during the whole life of the installation are the subsidies associated to this decree, even after its expiration. From 1998 up to the present, there have been four Royal Decrees in total (ME, 2004; MIE, 1998; MITC, 2007, 2008).

The Renewable Energy Furtherance Plan, PFER, 2000–2010 (IDAE, 1999) included a program of financial aids for renewable energies, including photovoltaic. From 1998, Spain began to support PV energy and, until the year 2000, PV energy in Spain was limited to a few experimental facilities (IDAE, 2007). In 2002 the degree of fulfilment was only 19.2% with respect to the energetic goal of the PFER.

The PER 2005–2010 was designed with the following two main objectives: 12% of primary energy consumption would be supplied in 2010 by renewable energy; and for PV energy, a goal of 371 MW in 2010 was set. In September 2007, 85% of the second target was reached, and the government established a new temporal decree of one year before its deadline to allow the construction of PV facilities according to the conditions of the previous subsidy program. That decree expired in September 2008. At the beginning of 2008 the accumulated electric power was higher than 506 MW (IDAE, 2008), surpassing the total forecasts for 2010. Spain's photovoltaic capacity rose to 3404.8 MW, amounting to a newly installed capacity of 2670.9 MW in 2008 (including 1 MW off-grid). This dizzy growth (352% up on 2007) is explained by the reduction in the photovoltaic energy feed-in tariff from the end of September 2008, which prompted a rush for installations. One installation hosted in RD 661/2007 can receive 0.44€/kW h, when the electricity price (TMR: Mean reference tariff) was around 0.075 €/kW h, but a similar new installation hosted in the RD 1578/2008 receives only 0.32€/kW h. Moreover, this RD 1578/2008 has limited the construction of new PV facilities with a ceiling of 500 MW installed in 2009 (including 233 MW from ground-based power plants), 502 MW in 2010 (including 207 MW from ground-based power plants) and 488 MW in 2011 (including 162 MW from ground-based power plants). This new legislation effectively curbed the growth of Spain's capacity in 2009. However, the additional PV capacity was still increasing over the following years, because with the subsidies of the RD 1578/2008, the PV energy was still a profitable sector in Spain, even though less profitable than with the subsidies of the RD 661/2007. These additional PV capacities were 145 MW in 2009, 370 MW in 2010 and 400 MW in 2011 (EPIA, 2012; REN21, 2011).

Once a policy has been established by the government, it should be known if this policy is suitable for the purpose for which it was designed. If we were capable of seeing all the factors involved in the development and evolution in the implementation of solar energy, it would be possible to assess the decision of the rulers who justify it, by means of a dynamic model to monitor whether the policy has taken advantage of the chances of success or is only a failure and a waste of money that serves only good intentions or vested interests.

On the one hand, the development of cheaper PV generators in the near future is a good line of research to invest in. But on the other hand, it is also good to look at creating a PV market by increasing the amount of PV installations, because this growth is