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Influence of solar technology in the economic performance of PV power plants in Europe. A comprehensive analysis

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ABSTRACT

Solar technology development in recent years has facilitated access to solar PV systems at increasingly competitive costs. This paper analyses the influence of solar technology on the economic performance of different topologies of PV power plants. An economic model is proposed and used to identify the most suitable type of installation for a wide range of input parameters. One of the main input parameters of the model developed is the location of the power plant in one of the seven EU countries with the largest PV growth. Location affects not only the solar irradiation received by the solar modules but also the costs associated with both the installation and the operation of the power plants. A detailed review of the costs related to PV power plants is presented. The size of the power plant as well as the PV technology and tracking system implemented are additional inputs of the economic model. This paper reviews the technological evolution of the PV sector, focusing not only on improvements in solar cell efficiency but also on the types of installed technology around the world. The three most widespread specific PV technologies are further analysed to find the type of installation most suited to a given country. In addition to the traditional financial indices commonly used to evaluate the economic performance of a project, the minimum feed-in tariff remuneration indicator is proposed and estimated in this work. Results are thus of great interest to investors, policy makers, and other stakeholders interested in the development of PV power plants.

1. Introduction

Solar photovoltaic (PV) power is already the most widely owned electricity source in the world in terms of number of installations [1]. As a result of the continuous decrease in the cost of PV panels and the increase in solar cell efficiency [2], solar PV accounted for 20% of all new power generation capacity in 2015 [1]. The global PV market grew significantly in 2015 [3] —50 GW in comparison with 40 GW in 2014—, which was led by Asia for the third consecutive year. The EU market rallied in 2015 with 8.5 GW added after three years of decline, restrained by a shift away from feed-in tariffs (FiTs) and by general policy uncertainty [4]. Although Europe represents around 42.3% of the current worldwide installed capacity [5], from 2002 to 2011 Europe accounted for 75% of the total PV installed capacity in the world [6].

Fig. 1 shows the evolution of the solar PV installed capacity in the European countries with the fastest PV growth, in terms of both yearly contributions (left vertical axis, with lines) and total cumulative amounts (right vertical axis, in columns). It can be seen that although solar PV in Europe was already an emerging option in 2000, it was not until 2005 that policy decisions resulted in substantially increased installed capacity, a change led mainly by Germany. Although Spain was the driving force in 2008, new investments are almost negligible due to retroactive policy changes and a new tax on self-consumption (SC). The United Kingdom, Germany and France were the main leaders in 2015, bringing the total PV capacity installed in the EU close to 100 GW. As can be observed from Fig. 1, seven countries —Germany, Italy, UK,

Abbreviation: a-Si, Amorphous silicon; BNetzA, Federal Network Agency for Electricity; CdTe, Cadmium telluride; CF, Cash Flow; CIS, Copper indium diselenide; CNT, Carbon nanotubes; CPV, Concentrating photovoltaics; c-Si, Crystalline silicon; EU, European Union; Eurostat, Statistical office of the European Union; FiT, Feed-in Tariff; HC, Hot carrier; HICP, Harmonised Indices of Consumer Prices; IEA, International Energy Agency; IRR, Internal Rate of Return; mc-Si, Multi-crystalline silicon; NPV, Net Present Value; NREL, National Renewable Energy Laboratory; O & M, Operation and Maintenance; PBP, Payback Period; PV, Photovoltaic Energy; PVGIS, Photovoltaic Geographical Information System; QDs, Quantum dots; RES, Renewable Energy Sources; R & D, Research and Development; US, United States; SC, Self-consumption; sc-Si, Single-crystalline silicon; STC, Standard Test or Reporting Conditions; UNEF, Spanish Photovoltaic Union; VAT, Valued Added Tax; WACC, Weighted Average Cost of Capital

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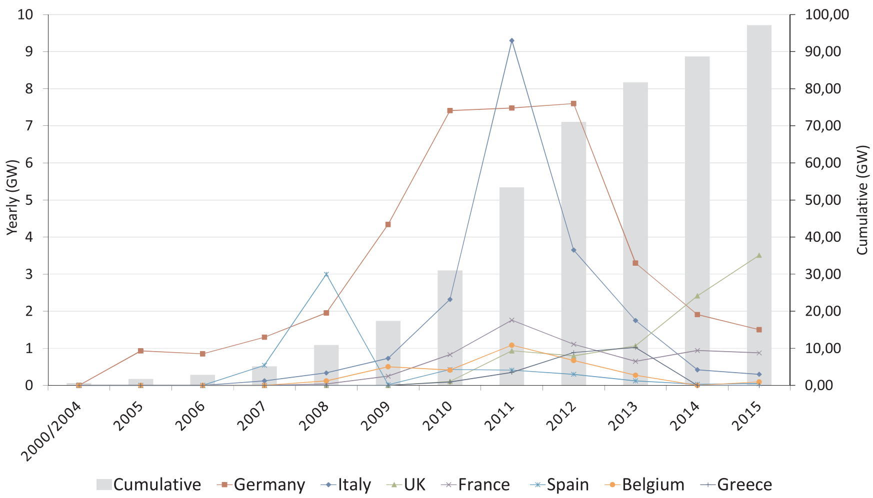

Fig. 1. Yearly and cumulative solar PV installed capacity in Europe between 2000 and 2015, in GW.

France, Spain, Belgium and Greece— represent 85.7% of the current total installed capacity in Europe. For this reason, the main focus of the present work lies in these European countries. It is worth noting that except for the United Kingdom, the other countries have experienced a similar pattern of behaviour in annual installed capacity, where a period of rapid growth is maintained for two or three years and is then followed by a sharp decline. In addition to the PV capacity installed, the contribution of PV to the electricity demand coverage is constantly increasing. In this line, solar PV currently covers more than 7% of the electricity demand in three European countries [5]: Italy, Germany and Greece.

The PV sector in Europe has experienced highly rapid growth, from 0.13 GW installed in 2000–97.14 GW installed in 2015, giving a growth factor of 750. Nevertheless, significant imbalances in electricity systems and distortion of electricity market prices have been detected due to the diversity of support policies applied to promote the use of solar PV in the different countries. Furthermore, due to the stagnation in electricity demand, electricity market design is increasingly important, and there is currently a need for new business models [7]. In this sense, one of the main concern of governments is the definition of the optimal energy support schemes to be implemented. Several public support mechanisms —including FiTs, investments subsidies, loans and others— are analysed in [8,6,9–13,7,14] to evaluate their sustainability, feasibility conditions and effect on electricity prices. A number of authors have focused on the economic analysis of these support policies for solar PV by using different economic key performance indicators. Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PBP) are the traditional indices used in previous works [15–22]. Broadly speaking, these studies found that FiT remains the most popular support scheme for all sizes of grid-connected PV systems in Europe. Other works have analysed solar PV cell technologies, environmental impact, prospects and progress in relation to other energy sources [23–39].

Our review of the literature reveals a lack of research on the impact of solar technology in the financial project of a PV power plant. The present paper comprehensively evaluates the influence of the solar PV technology in the economic performance of a PV power plant. The current technology trends are reviewed and different topologies of PV systems are proposed to consider not only residential, commercial and industrial customers but also utility owned plants. The work examines the seven EU countries with the fastest developing PV markets over the last fifteen years, as summarised in Fig. 1. A detailed comparative assessment across these countries is carried out, aiming to identify their potential future PV development. Different combinations of FiT remuneration mechanisms and self-consumption are evaluated to identify the minimum FiT value required in each country according to the technology implemented. The three PV technologies with the largest development as well as different solar tracking systems are considered. In addition, the minimum FiT parameter has not yet been found in the scientific literature and this represents a novel contribution of the present work. This paper thus fills the existing gap between solar PV technology, PV power plant costs and profitability concerns. Furthermore, due to the rapid advances of solar technology and associated costs, stakeholders in the solar sector need to know the current state of play.

After this short introduction, the paper is structured as follows: Section 2 reviews the current status of solar PV technologies. Section 3 focuses on the corresponding solar cell efficiency findings and the industry implications. Based on these initial observations, Section 4 details the economic model developed and provides both the input parameters required and the description of the specific PV power plant topologies analysed. Section 5 presents the results according to the economic performance indicators defined. Finally, Section 6 summarises the main conclusions.

2. Solar PV technology: current status

All RES are generated from solar radiation, which can be converted directly or indirectly to energy using several technologies. This section describes the present status of these solar PV technologies. All technologies related to capturing solar energy for a direct electricity generator are described as solar PV [32,22]. The history of solar PV started in 1839 [23,26,38], when the French physicist Alexandre-Edmond Becquerel observed that electrical currents arose from certain light induced chemical reactions. During the late 1940s, after one hundred years of research, the development of the first solid state devices paved the way in the industry for the first silicon solar cell developed with an efficiency of 6% in direct sunlight [29,31]. In essence, the greater the efficiency of a solar cell, the more electricity it generates for a given area of exposure to the sunlight. In short, the photovoltaic effect is explained by the quantum theory, which describes the different bands found in a particular material (conductor, semiconductor and insulator). There are two energy bands in the structure of a material, which are separated by a forbidden region known as energy gap or band gap: the valence band and the conduction band. The valence band of a semiconductor material, such as silicon, is filled with electrons, while its conduction band is empty. By contrast, in a conductor material the conduction band is partially filled. A certain amount of energy has to be reached before an electron can be transferred from the valence band to the conduction band, which is equal to the band gap energy and depends on the type of material. Therefore, according to the material used, PV technology is subdivided into crystalline, thin film, compound semiconductor and nanotechnology.