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The internal rate of return of photovoltaic grid-connected systems: A comprehensive sensitivity analysis

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ABSTRACT

At present, photovoltaic grid-connected systems (PVGCS) are experiencing a formidable market growth. This is mainly due to a continuous downward trend in PV cost together with some government support programmes launched by many developed countries. However, government bodies and prospective owners/investors are concerned with how changes in existing economic factors – financial incentives and main economic parameters of the PVGCS – that configure a given scenario may affect the profitability of the investment in these systems. Consequently, not only is a mere estimate of the economic profitability in a specific moment required, but also how this profitability may vary according to changes in the existing scenario. In order to enlighten decision-makers and prospective owners/investors of PVGCS, a sensitivity analysis of the internal rate of return (IRR) to some economic factors has been carried out. Three different scenarios have been assumed to represent the three top geographical markets for PV: the Euro area, the USA and Japan. The results obtained in this analysis provide clear evidence that annual loan interest, normalised initial investment subsidy, normalised annual PV electricity yield, PV electricity unitary price and normalised initial investment are ordered from the lowest to the highest impact on the IRR. A short and broad analysis concerning the taxation impact is also provided.

1. Introduction

Recently, the number of PV grid-connected systems (PVGCS) has grown sharply worldwide. This development has been brought about mainly by means of a continuous downward trend in PV costs together with a wide variety of supporting policies that different developed countries have launched. These strategies or policies are implemented with financial incentives, such as granting a subsidy per kWp of installed capacity or a payment per kWh produced and sold. In other words, these financial incentives can be broadly categorised as generation-based –feed-in tariff, net metering, green certificates and investment-focused – initial investment subsidies or rebates, low-interest loans.

First, this paper briefly reviews some policies together with main financial incentives aimed at supporting PV systems. Then, some parameters related to the profitability of an investment are also briefly discussed. By means of classical analysis of investment projects applied to PVGCS [1], some equations are proposed here for the estimation of those parameters. The internal rate of return (IRR) is emphasized, since this profitability index is probably one of the most meaningful for investors. Additionally, three different economic scenarios have been assumed for the estimation of the IRR to represent the top three geographical markets for PV: the Euro area, USA and Japan. Obviously, possible changes in the factors that are involved in the calculation of the internal rate of return – financial incentives and main economic parameters of the PVGCS – cause variations in this profitability index. In order to show the influence of those factors, a sensitivity analysis – properly adapted for each economic scenario considered – has been carried out. Decision-makers in developed countries may take advantage of this sensitivity analysis when planning grid-connected PV supporting measures that might vary over time, according to the renewable energy policy of each country. Besides, these variations of supporting measures may take place while a prospective owner is planning whether or not to invest in a PVGCS, or some time after the investment has been made. Consequently, the results of this analysis may prove useful to provide an assessment of how the IRR is to change when any of the incentives considered or economic parameters of the system is altered. The results of the proposed analysis are shown in tables and graphics in the last part of the paper.

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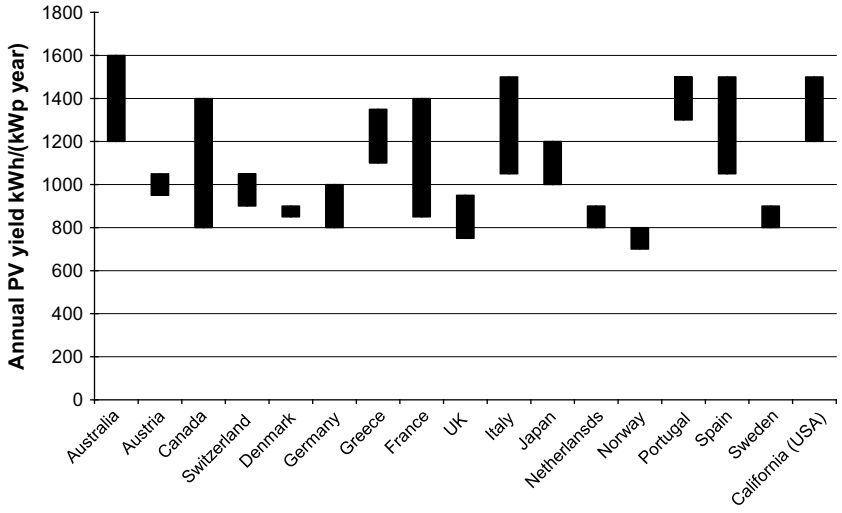

Fig. 1. Minimum and maximum annual PV electricity yields in different countries produced by a 1-kWp system (kWh year^{-1}) with optimally inclined PV modules and performance ratio equal to 0.75. (Sources: European Commission Joint Research Centre, http://re.jrc.cec.eu.int/pvgis/apps/pvest.php?lang=en&map=Europe; and National Renewable Energy Laboratory, http://www.nrel.gov/rredc/pvwatts/).

2. Policies and financial incentives

2.1. Policies

Government bodies on national and local levels together with some utilities have launched strategies or policies of support for photovoltaic systems. These policies are implemented through schemes dealing with renewable energy sources. Some of these support policies and financing incentives are explained hereafter.

An example is the European Union (EU) case, and its Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources (RES) in the internal electricity market [2]. This directive sets a target to double the share of renewable energy from 6% to 12% of gross energy consumption in Europe by 2010 and to increase the proportion of renewable electricity up to 21%. Also, indicative targets for the share of Electricity from Renewable Energy Sources were set for each Member State. This Directive contributes to the global target set by the EU White Paper, in which some goals were proposed: renewable energies would provide 12% of the total energy and 23.5% of the electric energy in the European Union by 2010 [3].

In January 2007, the European Commission has issued a Communication on a Renewable energy Road Map as a part of a comprehensive Energy Package. The new strategy includes a legally binding target of a 20% share of renewable energy in the European overall energy mix by 2020. The European Summit of March 8 and 9, 2007, has confirmed this target [4,5].

Another case is the USA, where there were no firm federal targets for renewable energy development. Recently, the Department of Energy has released details of the President's Solar America Initiative, proposing a large funding increase for solar energy research. This initiative aims to make solar competitive with existing sources of electricity by 2015 [6]. However, some states have adopted policies of renewable electricity. Thirteen states (as of August 2003) had adopted some forms of renewable electricity standards. Renewable Portfolio Standard (RPS) policies are expanding at the state/provincial level in the USA. In 2005, 20 of their states (Arizona, Connecticut, Iowa, Maine and Massachussets, among others) had RPS. Most RPS policies require renewable power shares in the range of 5–30 percent, typically from 2010 to 2020 [7,8].

The Japanese RPS market went into effect on 1 April 2003, based on the special measures law concerning the use of new energy by electric utilities. The goal is to reach 1.35 percent of the electricity from renewable energy sources by 2010 [9]. Moreover, Japan's target for the cumulative capacity of PV systems to be installed by 2010 is 4820 MW [6].

The most important development for renewable energy in China, including solar PV, was the introduction at the beginning of 2006 of the Renewable Energy Law. In China, the expected PV capacity installed by 2010 is 400 MW [6].

In Germany, the National PV plan is based on a feed-in tariff system. This is regulated by the Renewable Energy Law (Erneuerbare Energien Gesetz–EEG) [10]. Also, Spain has a renewable energy scheme for 2005–2010, which plans the installation of 363 MWp in new photovoltaic systems by 2010, from which 96% are grid-connected systems [11]. At the end of 2007, new legislation has been passed.

Table 1
Indicative installed PVGCS prices per kWp in various countries in 2005 (source: IEA, Trends in photovoltaic applications survey report of selected IEA countries between 1992 and 2005, Report 2006).

Country	PVGCS < 10 kW		PVGCS > 10 kW	
	EUR	USD	EUR	USD
Australia	6.2–8.7	7.6 –10.7	6.2	7.6
Austria	5.0–6.0	6.2 –7.4	5.0–5.5	6.2–6.8
Canada	6.7–8.3	8.3–10.3	8.4	10.4
Switzerland	5.5–7.1	6.8 –8.8	4.7–5.8	5.8–7.2
Denmark	4.5–10.8	5.5 –13.3	6.7–13.5	8.3–16.7
Germany	6·0	7·4	–	–
Greece	6.0–10.0	7.4–12.3	6.0–10.0	7.4–12.3
France	6.5	8.1	4.5	5.6
UK	6.9–22.4	8.5–27.6	5.0–15.5	6.2–19.1
Italy	6.0–8.0	7.4–9.9	5.5–7.0	6.8–8.6
Japan	4.9	6.0	5.3	6.6
Korea	7.8	9.6	7.8	9.6
The Netherlands	5.5–6.0	6.8–7.4	4.8	5.9
Norway	10.0–13.9	12.4–14.1	–	–
Portugal	6.0–8.5	7.4–10.5	5.0–6.2	6.2–7.7
Spain	6.7	8.3	6.7–5.7	8.3–7.0
Sweden	6.0	7.4	5.4	6.7
USA	5.7–8.1	7.0–10.0	5.3–7.3	6.5–9.0