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Economic feasibility analysis of small scale PV systems in different countries

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Abstract

Over the last few years, feed-in tariff for PV Systems in many countries have been significantly reduced and new regulations are being placed to promote the development of renewable energy and support self-consumption by paying lower grid-injected electricity tariffs compared to regular electricity price. The purpose of this paper is to analyze a representative set of countries, including Australia, Brazil, China, Germany, India, Iran, Italy, Japan, Portugal, South Africa, Spain, United Kingdom, and the United States of America, to identify the ones with the best investment opportunities considering the new regulations. Two case studies are included in this paper with different sizes of solar photovoltaic systems (1 kW and 5 kW). Each case study includes four different consumption scenarios ranging from 100% self-consumption to 30%. Overall, the results show that the most profit can be made in Australia, Germany, and Italy. In these countries, it is possible to quadruple the investment during the 25-year period with a 5 kW PV system which is roughly 13% higher than most European countries. Furthermore, this study explores the current policies and conditions of small-scale solar PV industry in the selected countries, providing enormous benefit to various entities namely policy makers, investors, and researchers who are working under the solar energy domain.

Keywords: Discounted payback; Economic assessment; Energy policy; Grid-tied rooftop PV system

1. Introduction

In recent years, small-scale rooftop PV systems have become closer to be a cost-competitive alternative to conventional power plants due to the continuous decrease of the PV system cost. Some new markets, have emerged outside Europe and the United States of America (USA) and are now releasing regulations to develop this area. Furthermore, environmental thinking is not the only driver to deploy the renewable energies worldwide, but the cost effective power production also plays a key role. This effective solar production can be achieved by considering certain elements that are both directly and indirectly involved with the end-user energy cost generated by the rooftop PV systems. These elements include the economic state of the region and country, the electricity tariff, the tax rates, the energy policies and programs (incentives, plans, and other investment options), the PV system efficiency, technology and market, and also the solar radiation value.

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Feed-in tariff schemes have been used to introduce new energy producing technologies into the market, such as solar based electricity generation (Campoccia et al., 2009), but they are coming to an end all around the world, particularly in the developed countries (Campoccia et al., 2014). Measures such as net-metering, self-consumption and lower grid injection tariffs are becoming increasingly popular (Yamamoto, 2012).

The PV system can be looked at as an investment and various studies have explored the economic assessment of PV systems of either isolated countries such as Australia (Oliva et al., 2014), or groups of countries such as Brazil, Germany, China, France, and Qatar (Lang et al., 2015), Germany, Spain and Greece (Lüthi, 2010), and France, Germany, Greece, Italy, Spain and the U.K (Campoccia et al., 2014).

The goal of this paper is to determine which country, out of a selection of thirteen countries, presents the most attractive PV system investment at the present moment from the investor's perspective. In order to achieve this goal, an economic assessment is employed in which two case studies are considered in this paper namely a 1 kW and a 5 kW grid-tied rooftop PV system, with four self-consumption scenarios (100%, 70%, 50% and 30%). The selected countries for this analysis are: Australia, Brazil, China, Germany, India, Italy, Iran, Japan, Portugal, South Africa, Spain, United Kingdom (UK), and the USA. These thirteen countries were chosen to help cover a wide range of influential geographic and economic factors that contribute greatly to influence the results, as shown in the literature (Kumar, 2015).

The overall organization of the paper is as follows: after the introduction, Section 2 explains the current solar policies in the selected countries. Section 3 describes the methodology used to make the economic assessment of the PV Systems. In Section 4, the results and the main findings of the data analysis are reported and discussed. Finally, the main conclusions are described in Section 5.

2. Current solar policies in the selected countries

In this section, the solar policies that are currently being practiced in each of the selected countries are briefly described. The location of the cities is pinpointed in Fig. 1.

Countries like Australia, China, Germany, Italy, Japan, the UK, Spain, and the USA were included due to the fact that they are among the ones that have the most installed PV power (Kumar, 2015; Wheeland, 2014). Table 1 presents the cumulative PV installed capacity as well as the average installed power per capita for the selected countries for this work (The International Energy Agency (IEA), 2015; Wikipedia, 2015).

Germany, Italy, Portugal, UK and Spain are inside the European Community where clear objectives were issued in terms of integrating renewable energy in the production (The Initiative of the European Commission, 2014).

Brazil, Russia, India, China and South Africa are the five major emerging national economies that compose BRICS and are interested in developing in the renewable energies area (Zhang et al., 2011). Considering that in Russia the produced energy cannot be sold, the radiation level is lower than in most countries and the low prices per kW h, therefore it was decided not to include Russia in this analysis.

Australia and Iran were chosen because they have a large solar potential as is shown in Fig. 1 and Australia has been doing a big investment in this area.

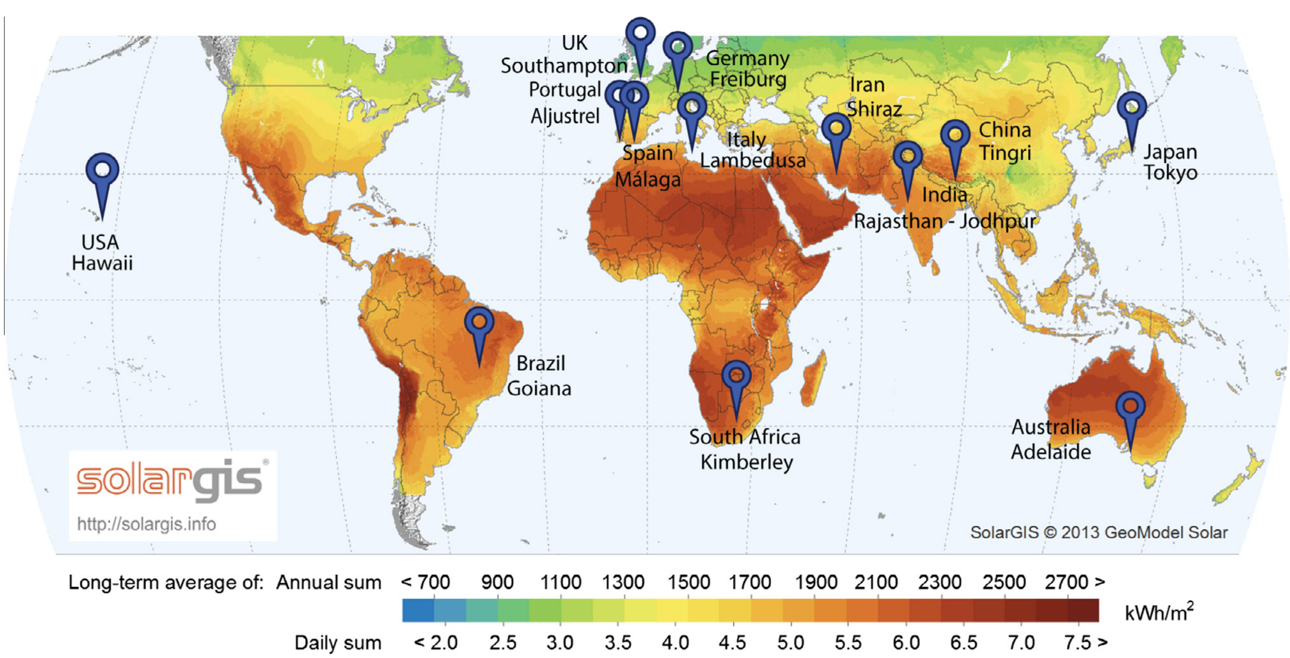

Fig. 1. Pinpointing the selected countries and respective city (SolarGIS, 2013).

Table 1
Cumulative PV installed capacity.

Country	Cumulative PV installed capacity in 2014 (MW)	Average installed power per capita (Watt per person)
Australia	4136	175.0
Brazil	11,233	0.1
China	28,199	20.2
Germany	38,200	462.2
India	2936	2.3
Iran	N/A	N/A
Italy	18,460	302.3
Japan	23,300	183.5
Portugal	391	36.9
South Africa	922	17.4
Spain	5358	113.8
UK	5104	80.4
USA	18,280	156.7

Japan is among the leading installers of PV systems, right after China (Wikipedia, 2015). Moreover, Japan has decided to change their policy about nuclear power plants and is doing a major investment in the renewable energy sector, including PV systems(Japan's Ministry of Economy Trade and Industry – Agency for Natural Resources and Energy, 2014).

Australia's Renewable Energy Target (RET) scheme, aims to produce 20% of its power from renewable energy resources by 2020 (Department of the Environment. Australia Government, 2013). More than one feed-in tariff scheme is used in Australia due to its vast geographical territory and varied climate. These schemes differ from state to state according to the Gross and Net feed-In tariff that is applied (The Australian Energy Regulator, 2014). The Net feed-in tariff is the most common scheme used in most states. The surplus solar energy is injected into the grid and sold at a lower price than the electricity tariff. Some states have adopted the Net feed-in tariff and set a minimum rate of export power to the grid, such as, Queensland, South Australia, Australia Capital of Territory, Victoria, Tasmania and Western Australia (in some cities) (Australian Government Department of Industry and Science, 2014). In New South Wales the rate is set by the electricity retailers. The Gross feed-In scheme is based on the annual payment of the total generated energy by the photovoltaic system, and is used in the Northern Territory and in some cities of Western Australia. In the Northern Territory the grid injection tariff is equal to the tariff from the retailer. In Western Australia the tariffs may range up to 0.34 €/kW h (Australian Government Department of Industry and Science, 2014). Furthermore, in most Australian territories there are financial incentives (rebate credits) related to the installation of a photovoltaic system. The Small-scale Renewable Energy Scheme was introduced to encourage photovoltaic system installations and the refund of the investment is done through Small-scale Technology Certificates (STCs). The STCs are certificates that can be redeemed for discounts with installers of photovoltaic systems or sell the surplus solar energy to the power distribution companies (Australian Government (Clean Energy Regulator), 2015).

Brazil has a vast number of energy resources, and the total installed generation capacity of the country was about 130 GW in 2013. The photovoltaic generation has played a minor role in the energy mix for the country but recently Brazil has made efforts to increase the photovoltaic distributed generation by introducing profitable measures. The biggest improvement was due to the mini and micro-production normative decree regulation that was published in 2012 (Agencia Nacional de Energia Electrica, 2012a), which was updated by the normative decree regulation published later that year (Agencia Nacional de Energia Electrica, 2012b) by The National Agency of Electric Energy. Under this normative decree law, Brazil adopted a net-metering scheme for the solar energy production. This regulation allows the consumers to install small generators and inject the surplus power into the grid in exchange for credits, which can be used for a period of 36 months. These credits cannot be exchanged for money and are canceled after the 36-month period if they are not used. In the same normative micro-production is associated to installations that are less than or equal to 100 kW of installed power.

China's new regulation for self-consumption came out in the second half of 2013 and was followed by local regulation for individual provinces. The national level regulation includes a subsidy for all energy generated of 0.056 € on top of the energy price for consumers, which seems to be a very favorable situation. The regulations for some of the provinces can add a subsidy of different forms: per kW h produced, per kW h injected in the grid or per installed kW and it can include a phase out stage, have fixed or undefined duration. In general, the values of energy at the consumer level are low but on the other hand the prices of installed kW are also lower than in most other countries since China is the biggest manufacturer of PV panels (de la Tour et al., 2011). In terms of location, the feed-in tariffs tend to compensate for the lower levels of radiation that is present mostly in the southeast part of the country. On the other hand, the highest radiation levels are obtained in the southwest part where the installation costs are higher.

Germany has been the world's top PV installer for several years. The target of 66 GW of installed PV capacity has been set by the federal government to be reached by 2030 (Property Wire, 2010) and a goal of 80% of electricity generated from renewable sources by 2050. Since 2006, the prices of PV systems in the German market have been decreasing and in the last 5 years they reduced more than 50% (BSW-Solar, 2011). Due to the high electricity tariffs and PV system price reduction, the solar power production in Germany has been growing significantly. However, since 2001 the feed-in tariff (FIT) values on the renewable productions have been gradually decreasing.

Renewable energy has been an important component of **India's** energy planning process. The total grid-connected renewable power generation capacity of 26,920 GW was achieved in 31 January 2013, which is about 12% of the total installed power generating capacity in the country (Sood and Sharma, 2014). The Ministry of New and Renewable Energy (MNRE) was set up back in 1982 to develop new and renewable energy to supplement the energy requirements of the country. In order to promote electricity generation using solar energy, the government of India launched the Jawaharlal Nehru National Solar Mission (JNNSM) in January 2010. As part of this mission, the government initiated a subsidy scheme to help individuals and organizations to seek these solar energy systems at reduced costs. The scheme is being implemented by IREDA (Indian Renewable Energy Development Agency Ltd.) through NABARD (National Bank for Agriculture and Rural Development). The JNNSM, a major initiative of the government of India, has set itself a goal of creating an enabling policy framework for deploying 100 GW of solar power by 2022 (Clover, 2015a). MNRE provides 30% capital subsidy on expenditures related to rooftop solar PV systems for both commercial and residential entities for systems up to 100 kW. The government also provides loans at 5% annual rate which covers 50% of the capital expenditure for 5 years tenure for both commercial and residential entities (The India's Ministry of New and Renewable Energy, 2013).

Recently in **Iran**, renewable energy strategy employment, has received a lot of attention, particularly concerning photovoltaic electricity productions. According to Article 133 (Paragraph B) of the law for the Five-Year Development Plan (Renewable Energy Organization of Iran (SUNA), 2014), about renewable energy development and productions, approved by the Iranian Ministry of Energy, in small scales (mini-generations), every Iranian household is allowed to install a photovoltaic electricity generation system on their rooftop. The solar production can be used as self-consumption, and the surplus generated electricity can be injected into the grid. Producers are granted, by the Iranian Ministry of Energy, up to 50% of the upfront cost for each kW installed capacity. Furthermore, the price of energy in comparison with western countries is relatively low for the end-users even though the billing system in Iran works under a slab based pricing scheme (Tavanir Co., 2014) (i.e. by consuming more than a certain threshold, the bill will have a higher value).

Renewable energy resources in **Italy**, are promoted through several kinds of national incentives such as feed-in and premium tariffs, tendering schemes and tax deduction mechanisms (reduction in VAT and income taxes). Residential PV installations are promoted through a guaranteed payment and tax deduction. At the moment, clients who plan to install a photovoltaic system, can take advantage of the following: (i) VAT reduced to 10% (instead of 22%) in solar PV system purchases; (ii) income tax deduction to cover 50% of the investment cost during the first ten years of production of up to 96,000 € (until December, 2015). This deduction can be used not only by the owners of the real estate, but also by the tenants (Alexander, 2014).

The electricity market in **Japan** is divided into ten regional areas and each regional power utility controls its own generation, transmission and distribution (International Energy Agency, 2014). After the Fukushima disaster, Japan's power generating energy mix changed significantly, by reducing the total number of operating nuclear power plants from 50 to two that are currently operating in Japan. Regarding the renewable energy mix share of the country, Japan set in July 2008 a national target of increasing the installed PV capacity to 28 GW and 53 GW by 2020 and 2030, respectively (Yamamoto and Ikki, 2010). In addition, 10% of total domestic primary energy demand is set to meet with the solar PV by 2050. Japan has a good solar insolation value (4.3–4.8 kW h/m^2 day) and is a leading manufacturer of solar panels, in which most of the PV systems are grid-connected, ranking at 4th place in the world for the cumulative solar PV installed capacity (Earth Policy Institute, 2014). In 2003, the Renewable Portfolio Standards (RPS) program, was introduced by the Agency for Natural Resources and Energy, aiming at furthering the use of renewable energies by annually imposing an obligation on electricity retailers to use a certain amount of electricity from renewable energy resources (International Energy Agency (IEA) Joint Policies and Measures Database, 2014). The RPS scheme ended in June 2012, and then was replaced by the FIT program, started in July 2012 (Japan's Ministry of Economy Trade and Industry – Agency for Natural Resources and Energy, 2014), in which the latest regulation under the FIT scheme came out in March, 2015 (Japan's Ministry of Economy Trade and Industry – Agency for Natural Resources and Energy, 2015).

The number of new PV system installations in **Portugal** has been decreasing since 2012 due to the continuous cuts made to the FIT. Portugal has a target of 670 MW of solar PV system installed capacity by 2020. In January 2015, the FIT for the small-scale solar productions were cut and a new tariff based on the Iberian Market value is attributed to the producers who inject the surplus energy into the grid (OMIE, 2015). Up to this point, self-consumption was not recognized in Portugal, and now solar producers are able to self-consume as well as inject the excess energy into the grid (Ministry of Environment/Planning Territory and Energy, 2014). Portugal practices an instantaneous net-metering scheme, meaning that the energy generated by the PV system has to be consumed at the same instant as it is produced to be considered self-consumption. The grid injection tariff is four times lower than the consumption tariff, therefore forcing the solar producers to self-consume and not inject any solar power into the grid since the grid injection extends the payback time.

South Africa has set an installation target of 22.5 GW by 2030. Rooftop PV system installations are becoming very popular among the South African electricity customers as a means to reduce the electricity bill. Net-metering schemes are being developed but have not been put in place, where the self-consumption is being practiced (Clover, 2015b). The electricity costs mentioned in this paper are the same for all the regions of South Africa throughout the year and are associated to a contracted power of up to 16 kVA. The injection of the surplus electricity into the grid is illegal in South Africa for small-scale PV systems. At the moment, there are no incentives or FIT associated to the small-scale rooftop grid-tied solutions but self-consumption solutions are allowed as long as the solar energy is not injected into the grid (Sinetech, 2015).

The PV industry in **Spain** has had some setbacks in the past few years, due to the economic situation of the country since 2012 when the energy policies were first affected because of the government going back and forth on the new regulations influenced by the big electric producers. After the FIT cuts, the renewable energy expansion came to a halt and only self-consumption for installed power bellow 100 kW is allowed with certain conditions such as the payment of fee called "backup toll" (PV Grid Consortium, 2013). The self-consumption PV installation owners have a legal obligation to register the self-consumption PV system and pay the backup toll that may go up to 0.09 €/kW h. This fee is to make up for the costs in grid usage and does not apply for off-grid solutions (Bloomberg New Energy Finance, 2014). More recently there are discussions about introducing a partial net-metering scheme based on an annual payment of the total solar production, but this law as well as the backup toll fee is still under discussion (European Photovoltaic Industry Association, 2013).

Current legislation in the **UK**, associated to PV system units is divided into three levels, less than 4 kW, from 4 to 10 kW and between 10 and 50 kW. A D grade (or higher) in the energy efficiency certificate is required to have access to the FIT. If eligible to receive a FIT the benefit can be received in three ways, namely by receiving a generation tariff, an export tariff and the savings made by the self-consumption. For the generation tariff, the energy supplier will pay a fixed rate for each unit (or kW h) of electricity generated. Once the system has been registered, the tariff levels are guaranteed for the period of the contract (up to 20 years) and are index-linked. For the export tariff, additional 0.06 €/kW h from energy supplier are available. The amount of the savings depend on how much electricity is used on site (Energy Saving Trust 2014, 2014).

The market for solar PV is growing rapidly in the **USA** both in terms of the number of new installations and in the total installed electricity generating capacity. The growth of the USA solar PV market has been largely facilitated by the support mechanisms provided by the federal and state governments. The government introduced a production tax credit (PTC) and an investment tax credit for PV development. The government has also offered federal tax credits for solar PV, which all residential building owners are eligible to receive, worth 30% of the cost of the PV system. The incentives have worked since a huge increment in PV installation capacity was achieved: 6.2 GW of new installed capacity in 2014 and approximately 18.3 GW total installed capacity by the end of 2014. Since electrical energy companies in the USA operate at a state or regional level, they have different financial incentives to promote the use of renewable energies (DSIRE, 2015). Utilities are obliged to fulfil the state's target in the form of the Renewable Portfolio Standards (RPS) which means utilities have to produce a certain percentage of the electricity from renewable sources. If these targets are not met, the energy companies have to pay high fines. Utilities usually try to meet these RPS targets by creating solar incentives for their own customers in the form of tax credits with different percentages in the different states. A net-metering scheme is associated to the solar energy production in the USA. Under this scheme, the consumer is billed by the utility company for the net consumption of electricity during a billing period. Additionally, in order to be eligible for net-metering, a system must be sized so that it will not produce more electricity than is needed to meet the on-site demand over the course of a year. The Hawaii Energy Tax Credits offers an income tax credit of 35% of the total PV system of the equipment and installation cost (DSIRE, 2015).

3. Methodology

In this section, all the methods used to calculate the return of the investment are described. In the cost-effectiveness analysis of PV systems, it is essential to take into account several indicators. The most common methods to determine the profitability and economic aspects of this type of project are: Net Present Value (NPV), Internal Rate of Return (IRR), Simple Payback Period (SPBP), Discounted Payback Period (DPBP) and the Profitability Index (PI). These methods are used in this work to evaluate the economic feasibility of the 1 kW and 5 kW roof-top PV systems in different countries. Each one has advantages and drawbacks. A brief description of all the economic methods used in this work is presented in the following section. The nomenclature of all the formulas of the economic methods are presented in the table below: (see Table 2).

Table 2
The nomenclature of the economic method formulas.

Nomenclature	
C_y	Yearly net cash flow (€)
C_0	Initial investment (€)
Y	System lifetime
r	Interest rate (%)
T_s	Self-consumption tariff (€/kW h)
T_e	Grid injection tariff (€/kW h)
E_c	The amount of electricity as self-consumption (kW h)
E_e	The amount of electricity exported into grid (kW h)
M	Maintenance cost (€)
E	Energy output (kW h)
d	Degradation rate (%)

3.1. NPV, IRR, SPBP, DPBP, Profitability Index and Score

NPV and IRR are commonly used to evaluate the profitability of an investment by calculating the difference between the discounted values of cash flows over the lifetime of projects, for example (Focacci, 2009; Ong, 2013; Rehman et al., 2007). Both allow for an intuitive performance comparison across regions and technologies for different projects. The NPV compares the present value of all cash inflows with the present value of all cash outflows associated with an investment project according to Eq. (1):

$$\mathrm{NPV} = \sum_{y=1}^{Y} \frac{C_y}{(1+r)^y} - C_0 \tag{1}$$

The NPV takes the present value of the money into consideration. It is the most accepted standard method used in financial assessments for long-term projects. However, its main drawback lies in the need for assuming an interest rate which can change the result significantly.

The IRR is an indicator that should be compared to a discount or interest rate and can override the NPV validity (Campoccia et al., 2014). The size of IRR presents a direct correlation with the investment attractiveness in percentage, in other words, a high IRR indicates that the investment opportunity is favorable. Eq. (2) shows the IRR formula. Additionally, the time value of money is considered and it allows a comparison across locations without considering the regional interest rates, which are typically very difficult to forecast (Lang et al., 2015).

$$0 = \sum_{y=1}^{Y} \frac{C_y}{(1+IRR)^y} - C_0 \tag{2}$$

For the calculations of SPBP, DPBP, NPV and IRR it is necessary to first calculate the annual Simple Cash Flow (SCF), which is the subtraction of the cash inflow with the cash outflow, as shown in Eq. (3) (Bernal-Agustín and Dufo-López, 2006).

$$\mathrm{SCF}_y = \text{Cash inflow}_y - \text{Cash outflow}_y$$

$$\mathrm{SCF}_y = \sum_{y=1}^{Y} (T_s \times E_c + T_e \times E_e)_y - \sum_{y=1}^{Y} (M + C)_y \tag{3}$$

where T_s and T_e are the self-consumption tariff and the grid injection tariff, E_c is the annual electricity generated (kW h) by the PV System which is used for self-consumption (not purchased from the distributor), and E_e is the electricity exported into the grid. M is the maintenance cost and C is the cost charged by the distributor for the availability of the power grid[1] to inject the electricity produced by the PV system into the grid.

The amount of time required to repay the up-front cost is called Simple Payback Period (SPBP). The SPBP does not incorporate the time value of money, thus assumptions on discount or interest rates are not required. It is easy to understand, but on the other hand introduces an overly optimistic bias for long term investments, overestimating the value of future returns (Lang et al., 2015). The Simple Payback Period formula is shown on Eq. (4).

$$\mathrm{SPBP} = \frac{\text{Initial Investment €}}{\text{Annual Saving €}/y} = \text{Years} \tag{4}$$

The Discounted Cash Flow (DCF) contains the time value of money and represents the SCF value in the future. The DCF value is updated with the interest rate and it´s formula is shown on Eq. (5).

$$\mathrm{DCF}_y = \frac{\mathrm{SCF}_y}{(1+r)^y} \tag{5}$$

The DPBP considers the value of money over time since it uses the DCF values to calculate the number of years needed to achieve breakeven.

The Profitability Index (PI) indicates how much profit or loss the project makes in a certain amount of time. It is calculated by dividing the NPV value by the initial investment and adding 1, as shown in Eq. (6). There is a breakeven when PI is equal to 1. When PI is equal to 2 the profit is doubled on the investment. The time of the investment assumed for this work is 25 years (Obaidullah Jan, ACA, 2013).

$$\mathrm{PI} = \frac{\mathrm{NPV}}{\text{Initial Investment}} + 1 \tag{6}$$

In order to analyze all the calculations obtained from the different economic methods in a single value, a formula to calculate a score was assumed and is shown in Eq. (7). This formula is used in each of the scenarios and in both case studies (1 kW and 5 kW PV systems). The IRR, NPV, DPBP and the initial investment are taken into account to calculate the Score. First, each element is normalized by scaling between zero and one. Then, to conclude the score of each country, a weight (0.25) is assigned to each number and all added up. The Score is a number between 0 and 1 and is used to compare countries that use the same scenario.

$$\mathrm{Score} = C_0(0.25) + \mathrm{NPV}(0.25) + \mathrm{IRR}(0.25) + \mathrm{DPBP}(0.25) \tag{7}$$

3.2. Assumptions

In this section, all the assumptions are defined and for both case studies (1 kW and 5 kW PV systems), four scenarios were considered and each of them is associated with the amount of solar production that is used for self-consumption and the amount that is used for grid injection. The scenarios are as follows:

- *Scenario 1* – 100% of the solar production is used for self-consumption;

[1] C is equal to zero in all countries except for Brazil which it is calculated as $C = 30\ \text{kW h} \times T_e$.

- *Scenario 2* – 70% is used for self-consumption and 30% is used to inject into the grid;
- *Scenario 3* – 50% is used for self-consumption and 50% is used to inject into the grid;
- *Scenario 4* – 30% is used for self-consumption and 70% is used to inject into the grid.

These scenarios were formulated to represent the real situation, since for most locations due to the load and production mismatch in time 100% self-consumption is not possible.

Retscreen software, version 4 (Retscreen International, 2014), is a tool used to analyze energy projects and in this work it is used to calculate the solar production of the PV systems in each of the countries. First, the type of solar module and inverter are selected, secondly, the slope and azimuth values according to the country are inserted and finally, the city or state with the highest solar radiation is chosen. The following sections explain these steps.

3.2.1. PV module and inverter selection

For this work, the SolarWorld 245 W Polycrystalline PV modules were selected since they are very efficient and obtained a perfect score in the PV + Test2.0 in 2013 according to available information in (PV Magazine, 2013). This test evaluates the durability, electrical safety, workmanship, performance, documentation and guarantee of the PV modules (Bailyes, 2013). The chosen PV module type is crystalline silicon, and the lifecycle is usually assumed to be within 25–30 years (Ito et al., 2003; Sánchez-Friera et al., 2011). Thus, in this work the lifetime of the investment is assumed to be equal to 25 years. In addition, among all the components of a roof-top PV system, only the inverter is expected to be replaced, at least once, within the lifetime of the investment. Commonly, 10 years is considered as the inverter´s lifecycle (Zweibel, 2010; Heacox, 2010). However, the overall lifetime of the current inverter products are difficult to predict, as these products have not been available long enough to obtain their lifetime results (Deline et al., 2011). According to the literature (Barbose et al., 2010; Branker et al., 2011; Zweibel, 2010) the replacement cost is assumed to be 9% of the initial investment of the system. The inverters selected for this work are the SMA – Sunny boy 1300TL and 5000TL since they present the best efficiency values (SMA, 2012) with efficiency values of 94.6% and 97.5% respectively. It is assumed that the inverter replacement takes place in year 10 and 20 and its cost rate for the 1 kW PV system is 15% on the initial investment and 10% of the initial investment for the 5 kW PV system.

3.2.2. Performance ratio (PV system losses)

A performance ratio (PR) between 75% and 90% is commonly considered for PV systems, since losses generated in the inverter, wiring (length, diameter and material), and module soiling (i.e. dust, snow and others) (Mani and Pillai, 2010; Peng et al., 2013) are considered. Much research has been done on the PR of PV systems, and different values found: 0.75 (Alsema and de Wild-Scholten, 2006), 0.835 (Jahn and Nasse, 2004) for well-planned PV systems and 0.75 for roof-top installations (Fthenakis et al., 2011) according to the methodology guidelines on life cycle assessment of PV systems. Thus, in this work a PR value of 0.80 is assumed.

3.2.3. Annual energy production

Retscreen software calculates the annual solar production based on the PV system parameters and its location. The cities and states were chosen based on the solar radiation values as well as electricity tariffs. Some countries presented higher tariffs in the locations with the lowest solar radiation values making these places more profitable even though the solar radiation values are low.

Two methods were used to choose the most profitable city of a given country. In the first method the choice of the city was only based on the solar radiation value and for the second method the choice of the city was based on a ratio between the electricity price and solar radiation. The countries that used the first method include Germany, India, Iran, Italy, Japan, South Africa and UK. The countries that used the second method are namely Australia, Brazil, China, Portugal, Spain, UK and the USA since all the cities can practice different electricity tariffs and normally in these situations the location with the highest solar radiation value would have the lowest electricity tariff.

In order to apply these economic methods it was essential to have, for every country, the following parameters:

- Annual solar production value;
- Average electricity escalation rate;
- Interest rate;
- Electricity tariff;
- Grid injection tariff;
- Solar subsidies;
- Currency exchange rate (as of January 9th, 2015);
- PV system cost;
- Maintenance and operations cost rate;
- Inverter substitution cost rate;
- Degradation rate of the PV modules.

The steps taken to obtain all these parameters are explained in the following subsections and are presented in the results section.

3.2.4. Economic parameters

In order to roughly predict the electricity price during the next 25 years an average evolution rate of the electricity price is calculated based on the past 25 years. The grid injection tariffs and electricity tariffs that are considered for this work are the ones that are practiced in every country at the present moment. Table 3 presents all the values mentioned above.

Table 3
Related information of all countries.

	Solar production (kW h)		Electricity tariff (€/kW h) and evolutionrate	Grid injection tariff (€/kW h)	Initial investment		Interest rate (IECONOMICS, 2015) (%)	Subsidies
	1 kW PV System	5 kW PV System			1 kW PV System	5 kW PV System		
Australia (AU) Adelaide	1467	6940	0.29 0.25%[a]	0.04 €[a]	1,559.34 € (1.60 €/W)	4,997.93 € (1.00 €/W)	6.39	Net feed-in tariff provided by the utility company
Brazil (BR) Goiana	1465	7291	0.23[b] 4.41%[c]	0.15 €[c]	2,551.27 € (2.55 €/W)	9818.09 € (1.96 €/W)	14.70	–
China (CN) Tingri	1892	9417	0.12 5.53%[d]	0.11 €[e]	1,661.00 € (1.66 €/W)	6867.00 € (1.37 €/W)	6.40	National subsidy 0.0573 €/kW h on top of the electricity price
Germany (DE) Freiburg	965	4824	0.29 3.62% [f]	0.13 €[g]	2,015.50 € (2.02 €/W)	8122.50 € (1.62 €/W)	2.40	–
India (IN) Rajasthan – Jodhpur	1587	7896	0.07 €/kW h 5.00%[h]	0.10 €	626.41 € (0.63 €/W)	3132.03 € (0.63 €/W)	6.69	30% capital subsidy PV systems up to 100 kW
Iran (IR) Shiraz	1417	7845	0.05[i] 8.73%[j]	0.14 €	1,702.84 € (1.70 €/W)	6694.73 € (1.38 €/W)	15.40	50% deduction on initial investment and feed-in tariff for the first 5 years
Italy (IT) Lampedusa Island	1576	7845	0.13 € (1 kW) 0.31 € (5 kW) 0.88%[g]	0.04 €[k]	2,408.67 € (2.41 €/W)	9445.00 € (1.89 €/W)	2.40	50% tax rebate on initial investment over 10 years
Japan (JP) Tokyo	1417	7051	0.14 3.20%[l]	0.23 €[m]	2,890.42 € (2.89 €/W)	13,209.29 € (2.74 €/W)	3.03	–
Portugal (PT) Aljustrel	1529	7610	0.20[n] 2.43%[g]	0.05 €[o]	2,449.45 € (2.45 €/W)	12,458.82 € (2.49 €/W)	2.40	–
South Africa (ZA) Kimberley	1725	8587	0.06 € (1 kW) 0.07 € (5 kW)[p] 10.73%[q]	– €	2,540.75 € (2.54 €/W)	8919.46 € (1.78 €/W)	8.70	–
Spain (ES) Las Palmas	1768	5159	0.15 2.57%[g]	– €	2,985.88 € (2.99 €/W)	13134.55 € (2.63 €/W)	2.35	–
United Kingdom (UK) Southampton	1037	5159	0.22 2.96%[g]	0.19 €[r]	2,747.14 € (2.75 €/W)	9782.24 € (1.96 €/W)	5.25	Receives a generation tariff and an export tariff
United States (USA) Hawaii	1642	8171	0.26[s] 2.29%[t]	0.26 €	3851.69 € (3.85 €/W)	9311.78 € (1.86 €/W)	3.45	30% + 35% tax rebate on initial investment over 5 years

[a] Australian Energy Regulator (AER) (2015).
[b] Companhia Hidroelétrica São Patrício (CHESP) (2015).
[c] Agência Nacional de Energia Elétrica (ANEEL) (2015).
[d] China Energy Group at Lawrence Berkeley National Laboratory (2014).
[e] National Development and Reform Commission on the Price Lever of Photovoltaic Industry (2013).
[f] Eurostat (2015).
[g] The Initiative of the European Commission (2014).
[h] Rajasthan Rajya Vidyut Utpadan Nigam Limited (2015).
[i] Tavanir Co. (2014).
[j] Tavanir Holding Company (2014).
[k] The Initiative of the European Commission (2014).
[l] Tokyo Electric Power Company (2014).
[m] Japan's Ministry of Economy Trade and Industry (2015).
[n] ERSE (2015).
[o] Ministerio do Ambiente – Ordenamento do Territorio e Energia (2014).
[p] ESKOM (2015).
[q] COSATU (n.d.).
[r] The Initiative of the European Commission (2014).
[s] The U.S. Energy Information Administration (EIA) (2015).
[t] YCharts (2015).

In Italy, Iran, China, Germany and UK the feed-in tariffs have a contract for 20 years. In Italy, Germany and the UK it was assumed that after the 20th year, injecting into the grid would not be permitted and only self-consumption would be considered. In China after the 20th year the subsidies would be taken away from the grid injection tariff.

To predict the interest rate for the next 25 years an average is calculated based on the past 25 years just as was done to calculate the electricity evolution rate. It was not possible to find the interest rate data from the past 25 years for all the countries. Data for Iran, UK and the USA is since 1990, for China since 1996, for Germany and Australia since 1998, for Portugal, Spain and Italy since 1999, for Brazil, Japan, India and South Africa since the year 2000 (IECONOMICS, 2015).

The PV system prices used in this work also include delivery, mounting and installation costs. All countries have quotes from at least three different companies. The PV system investment is an average of all the quotes of a given country.

3.2.5. Operating and maintenance cost

In order to accurately calculate the profit of the investment it is necessary to consider the inverter replacement costs as well as the costs associated with the operations and maintenance (O&M) during the lifecycle of the system. According to literature (Campoccia et al., 2009; Koner et al., 2000; Sick and Erge, 1996), the maintenance cost is estimated between 1% and 3% of the initial investment per year. In this paper, it is assumed that the O&M costs for the 1 kW PV system is 2.5% of the initial cost, and for the 5 kW it is 1.5% of the initial cost for all the countries.

3.2.6. Degradation rate

Since PV modules have a relatively long lifecycle, the power output of the system can be significantly influenced by the degradation phenomena. The degradation of the modules reduces the efficiency of the system over time (Fthenakis et al., 2011). Consequently, the predicted generation of the PV system and its economic payback period analysis can be affected by this issue. Jordan et al. (2010) obtained continuous data from more than 40 different modules from more than 10 manufacturers and compared their long-term output stability. It was concluded that the average degradation number was 0.7%/year. This is in accordance with the methodology guidelines on the lifecycle assessment of PV systems statements, where it is recommended to consider a linear degradation, reaching 80% of the initial efficiency at the end of a 30 years lifetime (i.e., 0.7% per year) (Fthenakis et al., 2011; Retscreen developers, 2014; SMA Solar Technology Group, 2012). It is assumed that the PV degradation value for this paper would be 0.7% in all of the countries. The VAT (value-added tax) is also included in all the calculations.

4. Results and discussion

In this section, all the results obtained from the proposed methodology are presented in the tables that follow.

The values presented in Table 3 are used to calculate all the economic methods of the 1 kW and 5 kW PV systems for each country in each of the four different scenarios. The maintenance and operations cost as well as the inverter replacement costs are considered in year 10 and 20 for both PV systems and the expenses are higher in percentage for the smaller PV systems. Table 3 presents all the economic parameters related to each country and all the prices include the VAT tax. The country that presents the highest solar production is China according to the results presented in Table 3, followed by Spain, South Africa, and the USA. The highest electricity tariffs are practiced in Italy, Australia and Germany followed by the USA, UK, Brazil and Portugal. USA presents the highest grid injection tariff, since net-metering is practiced, followed by Japan and Iran that practice a feed-in tariff scheme. Between the countries that do not practice net-metering nor feed-in tariff schemes, UK has the highest grid injection tariff followed by Brazil, Germany, China and India. The rest of the countries (Australia and Portugal), practice grid injection tariffs below 0.05 €/kW h. Finally, for South Africa it is illegal to inject energy into the grid.

The initial investment prices presented in Table 3 include the incentives and due to the incentives practiced in India, this is the country that presents the lowest initial investment for both 1 kW and 5 kW PV systems. The country that follows is Australia also for both 1 kW and 5 kW PV systems. The country that has the third lowest initial investment price for the 1 kW is China and Iran for the 5 kW. The countries that present the highest investment costs for the 1 kW PV system are the USA, Japan and UK and for the 5 kW PV system include Japan, Portugal and Brazil.

Brazil and Iran present the highest interest rates while Spain, Germany, Italy and Portugal present the lowest interest rates.

As previously stated, the Profitability Index (PI) indicates the amount of profit a certain investment can make during a certain amount of time (in this case during a 25 year period). When the Profitability Index is equal to one there is a breakeven, this happens on the year of the Discounted Payback Period. In this work, if the investment is recovered (PI = 1.00) and a profit with the similar amount is reached, which means PI equals 2.00, then the investment is considered viable.

Fig. 2 demonstrates the calculated PI value of the selected countries for 5 kW PV system (ordered from the best to worst of scenario 1) for all the four scenarios. As it shows Italy has the highest PI followed by Australia, Germany and USA, where Iran, Japan, Brazil and South Africa present the worst PI respectively, in all of the cases. It is worth mentioning that USA shows the same PI value,

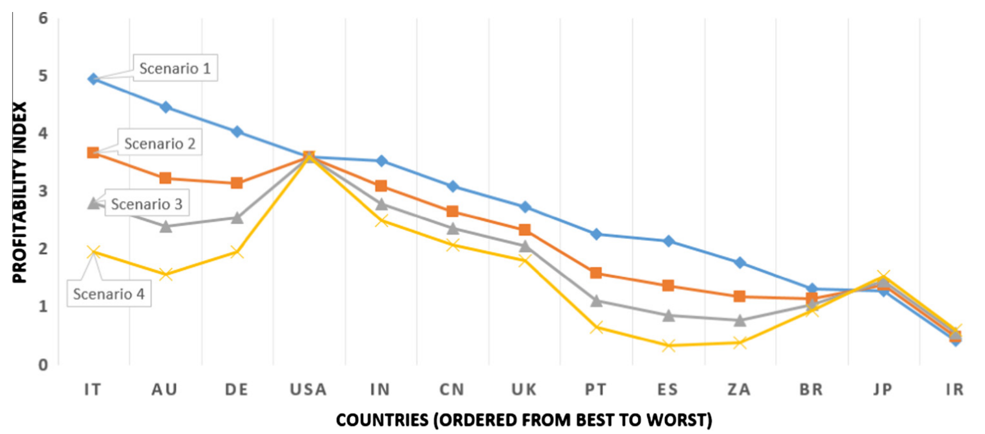

Fig. 2. The Profitability Index (PI) value of the selected countries, ordered from best to worst (5 kW PV system).

1.238, in all the scenarios, due to practicing true net-metering.

Table 4, presents the IRR, the PI and the DPBP of the 1 kW PV System for each of the countries according to the different scenarios. It is possible to double the investment before the 25th year in Australia, China, Germany, India and Portugal practicing scenario 1. It is curious to see how in Australia the DPBP is 5 years while in Germany it is 9 years and there is a possibility to make more profit in Germany. This is due to the fact that Germany has a higher electricity tariff than Australia. The IRR value in Australia is also much higher than in Germany however the interest rate in Australia is three times higher than in Germany, therefore it is more viable to invest in Germany than in Australia. In scenario 2, Germany and India are the only countries that present the possibility to double the investment before the 25th year. In scenario 3, the only country that doubles the investment is India. Iran and Japan present better results in scenario 4 when compared to scenario 1 however, the results of the investment are not considered viable. All the other results are considered not viable, since the Profitability Index is below 2.00. For the majority of the countries, the 100% self-consumption scenario is the most viable option to adopt.

Table 5, presents the Internal Rate of Return, the Profitability Index as well as the Discounted Payback Period of the 5 kW PV system for each of the countries according to the different scenarios. The 5 kW PV System scenarios present better results compared to the 1 kW PV System scenarios because the larger systems are cheaper than the smaller ones when comparing price per Watt (€/W). For example in China a 1 kW PV system costs 1.66 €/W and a 5 kW PV system costs 1.37€/W. All the scenarios using a 5 kW PV system have at least three countries that can more than double the investment. In scenario 1, eight out of thirteen countries present viable results and the countries that can quadruple the investment are Australia, Germany and Italy with a DPBP between 3 and 6 years. Italy presents the highest profit even though it has the highest investment cost and this can be due to the 50% tax rebate over the 10 year period. The countries that can at least triple the investment include China, India

Table 4
Internal Rate of Return, Profitability Index and Discounted Payback Period of a 1 kW PV System.

	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	IRR (%)	PI	DPBP	IRR (%)	PI	DPBP	IRR (%)	PI	DPBP	IRR (%)	PI	DPBP
AU	23	2.689	5	15	1.872	8	10	1.326	14	4	**0.781**	>25
BR	13	**0.902**	>25	12	**0.781**	>25	10	**0.701**	>25	9	**0.621**	>25
CN	16	2.353	10	14	1.995	11	13	1.757	12	11	1.518	13
DE	13	2.917	9	10	2.200	12	7	1.722	15	4	1.244	22
IN	17	2.496	8	17	2.271	8	16	2.120	8	16	1.969	8
IR	4	**0.234**	>25	4	**0.298**	>25	5	**0.341**	>25	5	**0.384**	>25
IT	7	1.412	13	3	1.070	23	0	**0.842**	>25	−3	**0.615**	>25
JP	3	**0.978**	>25	4	1.072	23	4	1.135	22	5	1.198	19
PT	9	2.071	12	5	1.368	17	2	**0.899**	>25	−4	**0.431**	>25
ZA	8	**0.913**	>25	5	**0.536**	>25	2	**0.284**	>25	−3	**0.032**	>25
ES	6	1.584	16	2	**0.904**	>25	−3	**0.451**	>25	−13	**−0.002**	>25
UK	12	1.770	11	10	1.484	14	8	1.294	17	6	1.103	23
USA	5	1.238	18	5	1.238	18	5	1.238	18	5	1.238	18

Dark grey is PI ⩾ 2; light grey is 1 ⩽ PI < 2; bold is PI < 1.

Table 5
Internal Rate of Return, Profitability Index and Discounted Payback Period of a 5 kW PV System.

	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	IRR	PI	DPBP	IRR	PI	DPBP	IRR	PI	DPBP	IRR	PI	DPBP
AU	38	4.458	3	27	3.220	4	20	2.395	6	12	1.570	11
BR	19	1.310	12	17	1.154	16	15	1.051	21	14	**0.947**	>25
CN	20	3.085	7	18	2.655	8	17	2.368	8	16	2.081	8
DE	18	4.038	6	14	3.148	8	12	2.555	10	9	1.963	13
IN	23	3.530	6	22	3.086	6	21	2.789	6	20	2.493	6
IR	7	**0.414**	>25	8	**0.496**	>25	9	**0.550**	>25	9	**0.605**	>25
IT	29	4.950	4	22	3.665	5	16	2.809	6	11	1.952	8
JP	5	1.288	19	6	1.391	17	7	1.460	15	7	1.529	14
PT	11	2.269	11	7	1.581	15	3	1.122	22	−1	**0.664**	>25
ZA	14	1.772	16	10	1.176	22	7	**0.779**	>25	3	**0.382**	>25
ES	10	2.139	12	5	1.371	18	1	**0.858**	>25	−5	**0.346**	>25
UK	19	2.731	6	16	2.332	8	14	2.066	9	12	1.800	11
USA	20	3.598	6	20	3.598	6	20	3.598	6	20	3.598	6

Dark grey is PI ⩾ 2; light grey is 1 ⩽ PI < 2; bold is PI < 1.

and the USA. Even though USA has the highest investment cost, it manages to have the highest profit out of the three because of the high electricity tariff. India has the lowest investment out of all the countries but does not make the highest profit because the electricity tariff is quite low. Finally, Portugal and the UK can double the investment. The USA has the same values in all the scenarios because the net-metering scheme is based on a monthly balance between the consumption and the production. Brazil also practices a net-metering scheme very similar to the USA but the taxes are not added to the grid injected units making the grid injection tariff lower than the electricity tariff and consequently making scenario 1 more profitable than any other scenario. India can make more than double the investment on all four scenarios with the breakeven happening before the 7th year due to the high solar radiation values and due to the very good investment incentives that are practiced.

In scenario 2, none of the countries make quadruple the investment but the countries that make triple the investment are Australia, Germany, India, Italy and USA. Germany always presents the longest payback period but is able to make almost as much profit by the end of the 25-year period mainly due to the high electricity tariff. China, India, and the UK can double the investment in less than 8 years.

Scenario 3 is still viable for seven countries with USA presenting the highest profit where the investment is tripled and Australia, China, Germany, India and Italy where the investment is doubled.

In scenario 4 only China, India and USA make more than double the investment, with USA presenting the highest results.

The countries that did not present viable results in any scenario are Brazil, Iran, Japan, South Africa and Spain. In the case of Iran and South Africa, this is due to the very low electricity tariff that is practiced. In the case of Brazil, Japan and Spain the unviable results are due to the high investment cost. Furthermore, for South Africa and Spain the investment is less attractive since grid injection is not permitted. In Fig. 3, the box plots graphically represent all the values obtained in all the scenarios of a given economic method (Score, DBPB, NPV and IRR) for each of the countries associated to a 1 kW PV system.

The countries that present the greatest scores are Australia, China, Germany and India since the median values are above the 0.50 mark. All the other countries present a median score value of less than 0.4, which indicates that the overall values of economic methods in all the scenarios of these countries are not very attractive.

The Discounted Payback Period graph in Fig. 3 indicates that India is the only country that can maintain the payback period in less than 10 year in all of the scenarios. The DPBP is superior to 25 year in all of the scenarios for Brazil, Iran, and South Africa making these countries not viable at all to invest in. The inferior whiskers of Australia, Germany and India indicate that in one of the scenarios the payback time is less than 10 years. The USA line indicates that in all the scenarios the payback is always the same since they practice true net-metering.

The NPV graph indicates that India, Japan and the USA make a profit superior to 0 € in all scenarios. Australia, China, Germany, Portugal and the UK make the most profit since the superior whiskers are over the 2000 € mark which means that in scenario 1 the NPV value over 2000 €. Brazil, Iran and South Africa present negative NPV values in all scenarios.

The IRR does not consider the interest rate so the values that are presented by the IRR box plots are not discounted from the cost of capital. In this case, we are comparing the countries by their simple cash-flow. India presents an IRR value superior to 10% in all scenarios. Brazil, China and India present IRR medians higher than 10%. The IRR should be compared to the interest rate of the country in order to evaluate it. The interest rate used for Brazil in this work is 14.7% and is higher than the Brazil IRR value in

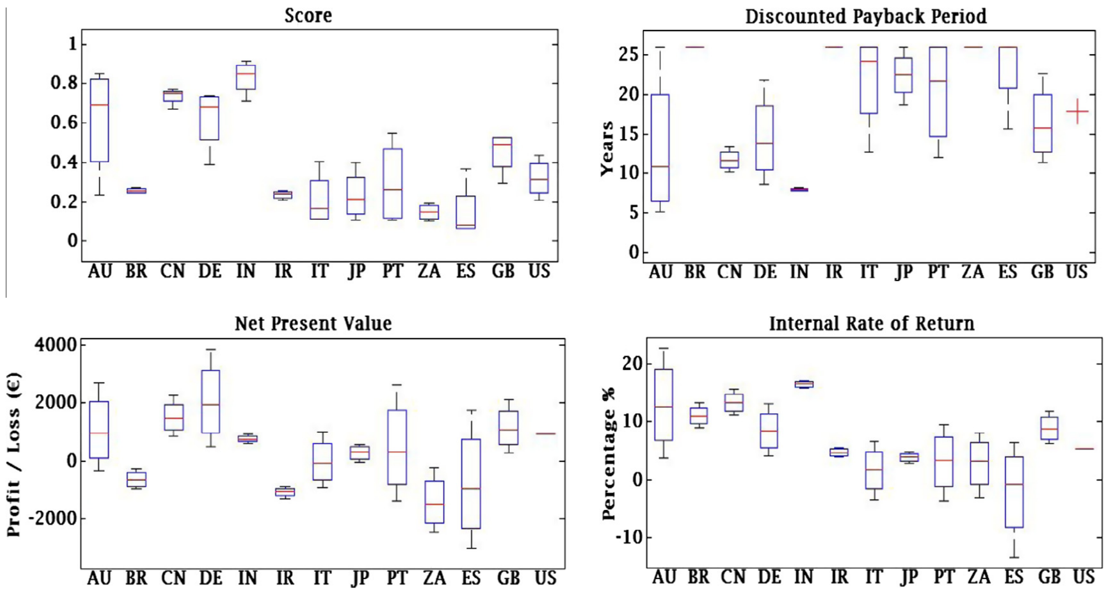

Fig. 3. The Score, DPBP, the NPV and IRR for the 1 kW PV System over the four scenarios for each country.

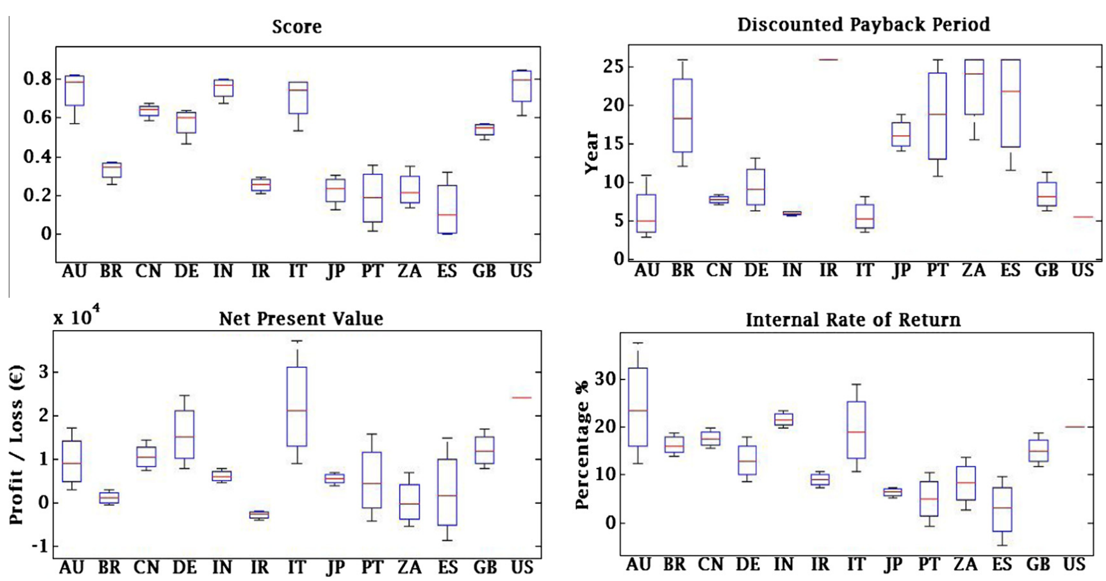

Fig. 4. The Score, DPBP, the NPV and IRR for the 5 kW PV System over the four scenarios for each country.

any of the scenarios, therefore making the PV system investment not viable. On the other hand, for China and India the IRR median value is higher than the interest rate of the countries which is 6.40% and 6.69% respectively. If the interest rate was the same in all the countries than the most profitable ones are the ones mentioned above. India, Iran, Japan, the UK and the USA present IRR values higher than 0% in all the scenarios.

Fig. 4 considers the results of a 5 kW PV System. The results are very similar to the ones shown in Fig. 3 only that in this case study the values are better in general. This is due to the fact that the investment is lower in all the countries as can be seen in Table 3. The top countries with the highest median scores do not only include Australia, China, Germany but also Italy, UK and the USA since the median values are above the 0.50 mark.

The results of the DPBP, for this case study, are better since there are more countries that have a lower median payback time than the 10-year mark. These countries are Australia, China, India, Italy, the UK and the USA.

The NPV graph shows that Germany, Italy and the USA can make a profit of over 10000.00 € in most scenarios, while USA is able to make a NPV value of over 20000.00 € in all the scenarios. India and Japan have very similar NPV values in all scenarios. All the countries manage to have a NPV value superior to 0 € except for Iran which presents negative NPV values in all the scenarios.

The countries that present the IRR median values higher than 10% are Australia, Brazil, China, Germany, India, Italy, the UK and the USA. All the other countries present IRR median values lower than 10%.

It should nevertheless be considered that a high rate of self-consumption is more difficult to achieve for a 5 kW PV system than for a 1 kW one.

5. Conclusion

This paper presents a comparative economic analysis of the main supporting policies for promoting PV systems in various countries around the world, namely Australia, Brazil, China, Germany, India, Iran, Italy, Japan, Portugal, South Africa, Spain, the UK and the USA. The goal is to determine which country presents the most viable results when investing in a PV system. This work considers two case studies based on 1 kW and 5 kW PV systems.

The economic analysis was calculated for each of the four types of scenarios on both case studies. In conclusion the best country to invest in a 1 kW PV system for scenario 1 is Germany and for scenarios 2 and 3 is India and scenario 4 does not present viable investment values for any country. The best country to invest in for the 5 kW PV system on both scenarios 1 and 2 is Italy since it presents the highest profit on the investment and for all the other scenarios is the USA since it presented the highest profit on the investment.

The 5 kW PV systems presented better results than the 1 kW PV systems mainly due to the higher investment costs per installed Watt in the latter PV systems. For these systems, the countries that can make more than double the investment on all four scenarios are India and the USA. The countries that can make more than double the investment on the first four scenarios for the 5 kW PV systems are China, India and the USA. Six out of thirteen countries can make more than double the investment with a 5 kW PV system and they are Australia, China, Germany, India, Italy and the USA. All the countries (Australia, China, Germany, India, Italy, Portugal, UK and USA) that can make more than double the investment using the 5 kW PV system in both scenarios 1 and 2 are the same except for Portugal that is only viable in scenario 1.

When using a 5 kW PV system, the countries that present the possibility to quadruple the investment include Australia, Germany and Italy. Furthermore, the countries that can offer to triple the investment include China, India and the USA.

The worst results belong to Brazil, Iran, Japan, South Africa and Spain.

The viability of the PV system project depends on the combination between the investment cost, electricity tariff, government incentives, and solar radiation.

The study conducted in this work allows drawing important conclusions that can assist governments in the studied countries to fine tune their incentive programs in order to increase the uptake of this benign energy generation technology.

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