Economic Evaluation of High-Concentrator Photovoltaic Systems

D.L. Talavera and G. Nofuentes

Abstract Before the installation of an high-concentrator photovoltaic (HCPV) system, any project developer or prospective owner must assess the economic and financial feasibility of the investment. This chapter has a tutorial content that is aimed at providing the reader with the necessary tools to accomplish that task. Some fundamentals and profitability indices are shown, reviewed, and adapted to the peculiarities of HCPV (i.e., net present value [NPV], benefit-to-cost ratio [BCR], internal rate of return [IRR], etc.). Both economic and financial analyses depend on a wide variety of factors that configure a specific scenario. Two scenarios are provided to illustrate the proposed tools. (1) The first scenario corresponds to the end of 2013 with a cumulative installed HCPV power that adds up to 160 MWp outlined as follows: assumed initial investment cost of 1800 €/kWp with 80 % financed by means of a loan and 20 % funded through equity, a feed-in-tariff scheme of 0.10 €/kWh with an annual direct normal irradiation of 2200 kWh/m^2, and a weighted average cost of capital (WACC) assumed equal to 6.5 %. Such an investment is feasible from an economic viewpoint since IRR = 7.2 % > 6.5 % and BCR = 1.08 > 1. However, this investment fails to be financially feasible because negative cumulative net cash balances appear during the first 15 years of the system's operation. (2) The second scenario is assumed to take place in 2020 so that forecasting both costs and the financial environment has been required. Cumulative installed HCPV power is predicted to be equal to 1400 MWp by the end of 2020. Learning curves, in which a progress ratio of 0.80 is assumed, lead to an initial investment cost of 800 €/kWp, which is also financed by external capital (80 %) and equity (20 %). HCPV-generated electricity is assumed to be entirely fed to the grid at a pool price of 0.05 €/kWh. In addition, there is an annual direct irradiation of 2200 kWh/m^2 and a WACC of 4.5 % are assumed. This investment does not only prove to be feasible from an economic point of view because IRR = 8.5 %, which is well above 4.5 %, and BCR = 1.5 > 1, it is also viewed favourably from a financial viewpoint because positive cumulative net cash balances are obtained over the whole project life cycle. Consequently, the economic and financial viability of

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HCPV is likely to take place at the turn of this decade. Last, a sensitivity analysis of IRR and BCR to each considered factor has been performed for both two scenarios. This analysis ranks these factors according to lowest to highest effect on IRR and BCR as follows: annual degradation rate, income tax rate, annual operation and maintenance cost, life cycle of the HCPV system, discount rate, annual direct normal irradiation, and initial investment cost of the HCPV. Annual final yield, performance ratio, and HCPV electricity unitary price exert the same influence on IRR and BCR. Stand out that these three factors are function of the annual direct normal irradiation.

1 Introduction

High-concentrator photovoltaics (HCPV) is an emerging and promising technology: Electricity is produced by means of harnessing an inexhaustible energy source without causing any significant environmental impact. However, project developers and prospective owners of HCPV systems need information regarding the economic and financial feasibility of such systems. This chapter is mainly addressed to provide the tools and enable the reader to carry out this economic and financial assessment. Multiple factors are involved in this analysis, so an effort has been made to take as many as possible of them into account. Just to give an example, income taxation and tax depreciation, which are considered here but often are overlooked by similar works to that presented here. However, unrealistic results might be obtained if their impact is ignored. Likewise, aspects related to financing are frequently missed. In this sense, special care should be taken because financial feasibility implies economic profitability, yet the reverse is not always true.

First, some basic concepts and fundamentals related are presented. Then some methods commonly used to assess the economic profitability analysis of investment projects in renewable energies are reviewed [8, 10, 52, 57, 60, 61]. Namely, expressions to calculate the IRR, the net present value (NPV), the benefit-to-cost ratio (BCR), and the discounted payback time (DPBT) are proposed. Some shortcomings identified in these methods lead to the introduction of the modified internal rate of return (MIRR), the modified net present value (MNPV), and the real net present value (RNPV). The financial dimension of the investment is also approached.

Two scenarios have been considered in which the previously mentioned methods and concepts are applied. One of them assumes technical and economic data corresponding to the end of 2013, whereas the other corresponds to the end of this decade. Learning curves and cumulative installed HCPV power projections, together with some factor forecasting, configure the prospective scenario assumed for 2020.

Last, the above-mentioned two scenarios are considered base cases with which to carry out an analysis of the sensitivity of IRR, NPV, and BCR to the factors on which they depend. This is especially interesting to quantitatively assess how changes in these factors influence the profitability of HCPV systems. Such an analysis may prove useful to a potential investor if estimates of future values of some factors were to make postponing his/her investment advisable.

2 Fundamentals and Concepts

In this section, some concepts used in the profitability analysis of investment projects, mainly cash inflows (CIs) and cash outflows (COs) generated by the operation and development of the project, are reviewed. In addition, a number of assumptions will be established so as to be considered in the economic evaluation of a project. In addition, the financial dimensions of an investment project will be reviewed.

2.1 Net Cash Flow

Net cash flow (NCF [in €]) over a given time period (t) is the difference between the CIs (in €) and COs (in €) generated by the operating activities of project during this time period. It may be written as:

$$\mathrm{NCF}_t = \mathrm{CI}_t - \mathrm{CO}_t \tag{1}$$

where NCF_t (€) = NCF during t, CI_t (€) = all revenue, specifically sales revenues, collected over t, and CO_t (€) = operating and maintenance cost for period t. Parameter t is usually assumed equal to 1 year.

The above expression may be broken down, according to the concepts where the resources are allocated, so that:

$$\mathrm{NCF}_t = \mathrm{RI}_t + I_t + \mathrm{di}_t + \mathrm{IT}_t + \mathrm{NCB}_t \tag{2}$$

where RI_t (€) = repayment instalments on funds borrowed (debt and/or equity capital) to fund the investment project, I_t (€) = interest charges on debt, di_t (€) = dividends, i.e., return on equity capital, paid, IT_t (€) = taxes paid on income, and NCB_t (€) = net cash balance, which represents the liquidity, i.e., the remaining money after all of these payments. All of these parameters are referred to year t. The above parameters are shown in Fig. 1.

If after-tax net the effect of taxation is taken into account in NCFs, cash flows is obtained during year t ($\mathrm{NCF}_{t(\text{after-tax})}$ [in €]) by:

$$\mathrm{NCF}_{t(\text{after}-\text{tax})} = \mathrm{NCF}_t \cdot (1 - T) + \mathrm{DEP}_t \cdot T \tag{3}$$

where DEP_t (€) = tax depreciation during year t, and T = income tax rate.

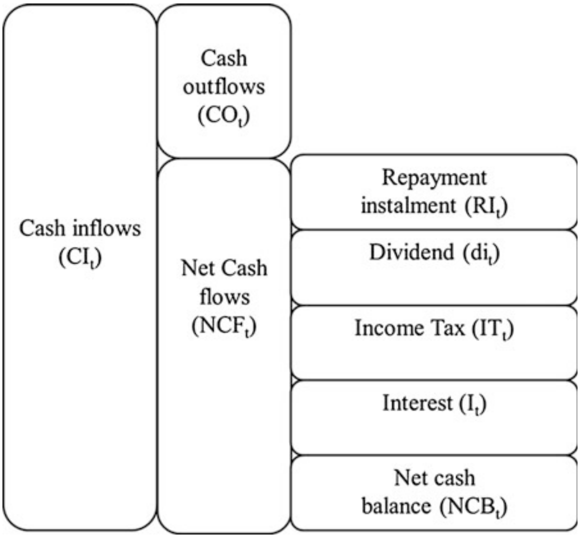

Fig. 1 Breakdown of net cash flows

As with Eq. (2), the above expression may be broken down, according to the concepts where the resources are allocated, so that:

$$\mathrm{NCF}_{t(\mathrm{after-tax})} = \mathrm{RI}_t + I_t(1 - T) + \mathrm{di}_t + \mathrm{NCB}_t \tag{4}$$

The influence of taxation on funds borrowed to finance an investment is exerted on the paid debt interest (I_t [in €]) because it is tax deductible. Accordingly, taxation leads to a decrease in the cost of capital. Hence, interests after paying taxes during year t ($I_{t(\text{after-tax})}$ [in €]) are given by:

$$I_{t(\mathrm{after-tax})} = I_t(1 - T) \tag{5}$$

2.2 *Time Value of Money: The Discount Rate*

Money has time value. The value of a certain amount of money today is more valuable than its value tomorrow. Money has time value because of the following reasons:

- Investment opportunities: An investor can profitably employ a certain amount of money received today to give him/her a higher value to be received tomorrow or after a certain period of time.
- Risk and uncertainty: Future is always uncertain and risky. Money you have now is not at risk. Money predicted to arrive in the future is less certain.

- Inflation: in an inflationary scenario, the money received today, has more purchasing power than the money to be received in future. In other words, a sum today represents a greater real purchasing power than a sum a year afterwards.

The time-value of money is the relationship between the previous factors and time. By using the present value approach and assuming an opportunity cost rate (r) and an inflation rate (i), a sum S (€) received at the present time has a future worth of $S[(1 + r)\,(1 + i)]^n$ after n years. Consequently, a sum S to be received after n years has a present worth of $S/[(1 + r)\,(1 + i)]^n$. Factor r is normally termed "real discount rate" so that the nominal discount rate, or simply discount rate, is stated as d, $1 + d = (1 + r)\,(1 + i)$. Last, parameter r is also noted as d_r. Thus, the fundamental principle behind the concept of time value of money is that a sum of money received today is worth more than the same sum received after a certain period of time.

Choosing an appropriate value of d is a controversial issue. The appropriate selection of a value of d for the analysis of a given investment project should be the rate of return for an investment of comparable risk that would be made instead. A widespread practice in organizations is to use a discount rate equal to the organization's weighted average cost of capital (WACC) [56]. WACC is the cost that the owner or investor of the project must pay for using capital sources to finance the investment. It is also common to use a discount rate equal to the opportunity cost of capital. The latter cost is based on opportunities arising from the financial market. Therefore, the value of the discount rate would be equivalent to the price of money determined by the free interplay of supply and demand. It also may represent the rate of return on the best alternative investment available.

2.3 Financial Dimensions of Projects

This section analyzes investment projects from a financial standpoint. An investment project with associated funding will be considered. This financing process implies collecting the funds needed for the investment. Despite the fact that a wide variety of instruments can be used to finance investment projects, the following two are the most widespread ones:

1. "Equity capital: Equity capital is high-risk financing that expects high returns. An equity investment can be made in support of a specific project, or equity funds can be provided to the company carrying out the project. Equity investors maintain the right to get involved in the decision-making process of the project or company to protect their investment.
2. Debt: Debt presents medium risk with modest expected returns. In contrast to equity investors, lenders who provide debt financing to a project do not own shares in the project. They provide capital for the purpose of earning interest. Because lenders must be repaid before distributions can be made to shareholders, lenders bear less risk than equity holders. For this reason, potential return to lenders is limited to risk-adjusted market interest rates" [65].

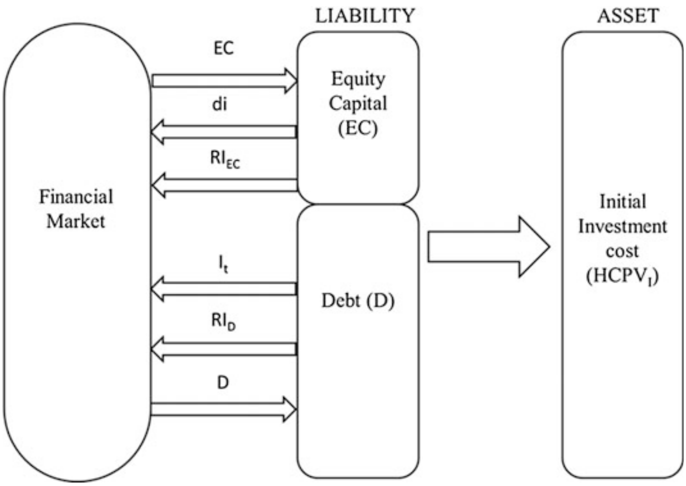

Fig. 2 Financing process of a project

Both types of investment capital are combined to finance the initial investment. The process of financing a project is shown in Fig. 2. The involved parameters are described later in the text.

The initial investment cost ($HCPV_I$ [in €]) is the initial capital expenditure that is set aside to the acquisition of assets of the investment project. It is equal to sum of the equity capital (EC [in €]), e.g., common stocks and preferred stocks, and debt (D [in €]), e.g., long-term loans, Bonds, and mortgage loans, that are used to fund the capital expenditure. The asset of the investment project equals its liability, which is formed by equity capital and debt:

$$\mathrm{HCPV}_I = \mathrm{EC} + \mathrm{D} \tag{6}$$

where $\mathrm{RI}_{\mathrm{D}t}$ (€) is the repayment instalments on debt, $\mathrm{RI}_{\mathrm{EC}t}$ (€) is the repayment installments on equity capital, I_t (€) are the interests paid on debt, and $\mathrm{di}_{\mathrm{EC}t}$ (€) are the dividends paid on equity capital. All of these parameters are referred to year t.

The result of the financing of a project can be represented as a stream of CIs and COs over time. Because CIs and COs occur at different points in time, it is easier to deal with them using a timeline. A timeline shows the timing and the amount of each CI or CO. This is shown in Fig. 3, which begins with revenue HCPV_I, followed by annual periodic costs, so that payment is made at the end of the year. Upward arrows indicate revenues, whereas downward arrows indicate payments.

The investment of the project is analyzed below according to the same criteria used for funding. Once funding is obtained, productive assets purchase market goods. The implementation of the investment will involve a trade with the market as shown in Fig. 4.

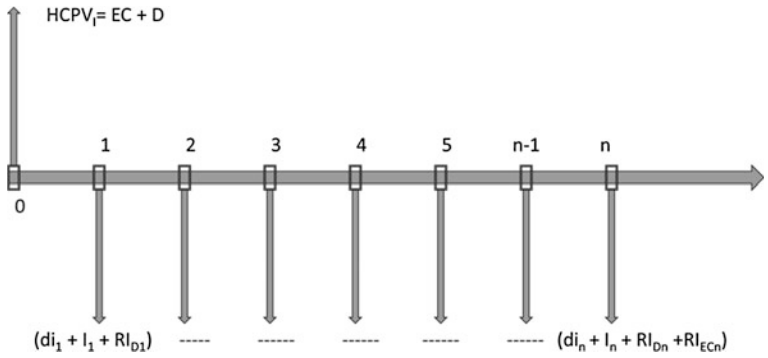

Fig. 3 Financial dimension of financing. In this figure, it has been considered that the loan duration equals the time in which the equity capital is refunded. However, in the most general case, both time periods do not coincide

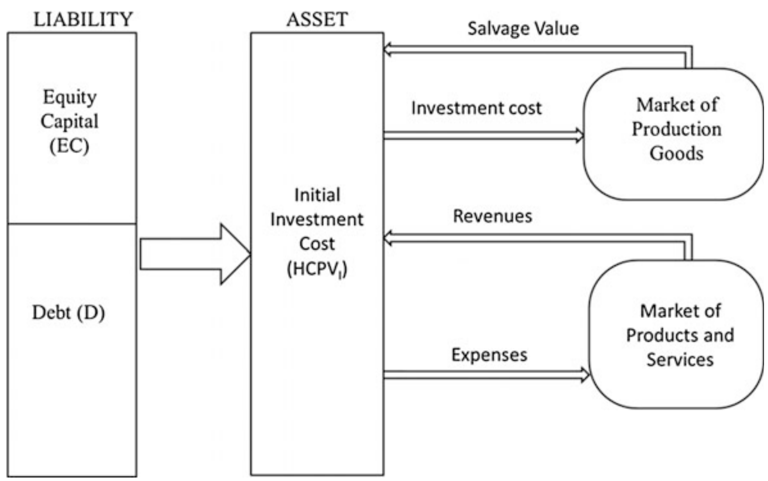

Fig. 4 Investment process of a project

Schneider [55] considers that any investment is characterized from a financial point of view in response to current revenues and payments incurred in the company. The comparison between these two monetary series is important from a practical point of view because it allows us to make an assessment of the investment, thereby obtaining a measure of profitability that it can generate for the company or investor. Consequently, from a financial point of view, i.e., money, any investment project is defined by the following variables:

- Initial investment cost or capital expediture representing an initial payment ($HCPV_I$).
- Net cash flows (NCF_t) are the result of the difference between the CIs and COs generated by the operation of the project during year *t*.

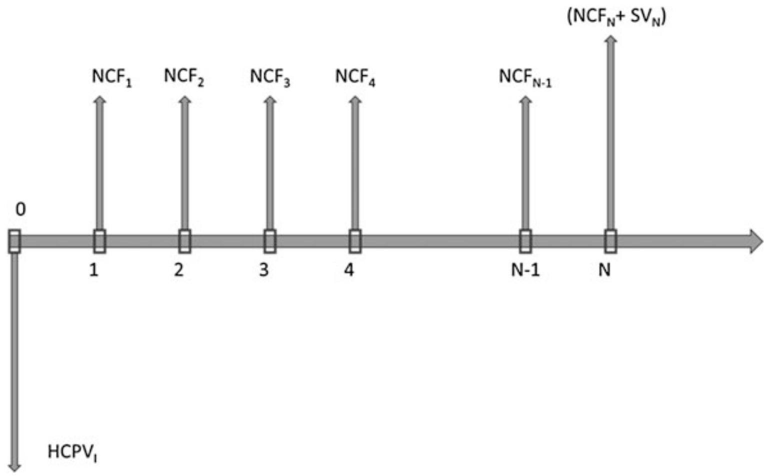

Fig. 5 Financial dimension of an investment

- Analysis period (N [in years]) is the period of time for which an evaluation is performed. N is usually equal to the lifetime of the investment project. The estimate of N is often difficult owing to the amount of variables that influence its quantification.
- Salvage value (SV_N [€]) is a salvage value received by the sale (settlement) of the assets of the investment. This inflow will be obtained by the end of the life cycle of the investment.

Finally, the investment may be represented in the same way as the study of financing of a project. This is shown in Fig. 5: It begins with an $HCPV_I$ payment, followed by a series of NCFs, being effective at the end of the year. At the end of the lifetime of the project, an amount equal to NCF_N plus the salvage value is obtained.

2.4 Evaluation of an Investment Project

The first step in the economic evaluation of a project usually comprises an investment profitability analysis together with a financial analysis. The investment profitability analysis is the measurement of the profitability of the resources allocated to a project, or, in other words, this analysis tries to ascertain the return on the capital investment. Different methods may be used as a basis on which to assess the investment profitability of a project. These methods will be studied in next section.

The financial analysis must take into consideration the financial features of a project to ensure that the disposable finances will permit the smooth implementation and operation of the project. A simple approach to this financial analysis can be performed for the sum of the CIs and COs on a year-by-year basis, i.e., the financial dimension of the financing and the financial dimension of the investment.

3 Methods for Economic Analysis of a HCPV System

The most common criteria aimed at measuring the profitability of the project, such as the NPV (€), the IRR, the BCR, the DPBT (years), the annualised value (AV [in €]), the MNPV (€), the MIRR, and the RNPV (€) are presented hereafter. Criteria based on NPV, benefdit-to-cost ratio (BCR), AV and IRR, are addressed at measuring profitability, while DPBT is aimed at measuring the liquidity of the investment.

The core idea that lies in the fact that the profitability assessment of investment projects may be broadly summarized as follows: finding a suitable parameter—or a set of them—in which all considered financial factors are taken into account so that a profitability estimation of the investment is provided.

3.1 Net Present Value

The NPV of a project is defined as the difference between the present values of the CIs and COs generated by the investment over the lifetime of the project. The NPV method discounts all of the NCFs of a project to a base year, i.e., the start of the implementation, at a predetermined discount rate. This is given by the expression:

$$\mathrm{NPV} = -\mathrm{HCPV}_I + \mathrm{PV}[\mathrm{NCF}(N)] \tag{7}$$

The present value of the NCFs (PV[NCF(N)] in €) may be written as:

$$\mathrm{PV}[\mathrm{NCF}(N)] = \mathrm{PV}[\mathrm{CI}(N)] - \mathrm{PV}[\mathrm{CO}(N)] + \mathrm{PV}[\mathrm{DEP}(N_{\mathrm{d}})] \cdot T \tag{8}$$

where PV[DEP(N_{d})] (€) is the present value of tax depreciation. The method used in the tax depreciation may be different from one country to another. Usually, the modified accelerated cost recovery system is used as the tax depreciation system in the USA [31]. In any case, readers must refer to the national taxation laws and abide by them.

PV [CO(N)] (€) is the present value of the COs over the lifetime of the project, and it may be written as:

$$\mathrm{PV}[\mathrm{CO}(N)] = \mathrm{PV}[\mathrm{HCPV}_{\mathrm{OM}}(N)] \tag{9}$$

where PV[$\mathrm{HCPV}_{\mathrm{OM}}$ (N)] (€) is the present value of the operation and maintenance cost over the system lifetime (N [in years]). It may be written as:

$$\mathrm{PV}[\mathrm{HCPV_{OM}}(N)] = \left[\mathrm{HCPV_{AOM}}(1-T)\cdot\frac{Q(1-Q^N)}{1-Q}\right] \quad (10)$$

where $\mathrm{HCPV_{AOM}}$ (€) is the annual operation and maintenance cost, assumed to be constant over the system's lifetime, while $Q(1 - Q^N)/(1 - Q)$ is the present value interest factor (PVIF[N]). Factor Q is equal to $1/(1 + d)$. Assuming an annual escalation rate of the operation and maintenance cost of the HCPV system (Δ_{OM}), PV[$\mathrm{HCPV_{OM}}$ (N)] may be rewritten as follows:

$$\mathrm{PV}[\mathrm{CO}(N)] = \left[\mathrm{HCPV_{AOM}}(1-T)\cdot\frac{Q_{\mathrm{OM}}\cdot(1-Q_{\mathrm{OM}}^N)}{1-Q_{\mathrm{OM}}}\right] \quad (11)$$

where $Q_{\mathrm{OM}} = (1+\Delta_{\mathrm{OM}})/(1+d)$.

PV [CI(N)] (€) is the present value of the CIs over the lifetime of the project. Regarding this parameter, CIs are partly obtained by means of the annual HCPV electricity generated that is used for self-consumption (E_{HCPVs} [in kWh]), and consequently saved, instead of buying it from the grid at a given price (p_s [in €/kWh]). In addition, CIs are obtained by the annual electricity generation (E_{HCPVg} [in kWh]), partly fed into the grid, that may be compensated for at a different price (p_g [in €/kWh]):

$$\mathrm{PV}[\mathrm{CI}(N)] = p_s\cdot E_{\mathrm{HCPV_s}}(1-T)\frac{Qp_s\left(1-Qp_s^N\right)}{1-Qp_s} + p_g\cdot E_{\mathrm{HCPV_g}}(1-T)\frac{Qp_g\left(1-Qp_g^N\right)}{1-Qp_g} \quad (12)$$

where the factors $Qp_s = (1 + \Delta p_s)\cdot(1 - r_d)/(1 + d)$ and $Qp_g = (1 + \Delta p_g)\cdot(1 - r_d)/(1 + d)$; Δp_s and Δp_g stand for the annual escalation rate of the electricity price that is consumed and fed from/to the grid, respectively; and factor r_d is the annual degradation rate of the efficiency of the PV modules.

As stated previously, this applies to the most general case. However, if the annual HCPV-generated electricity is used for self-consumption in its entirety, Eq. (12) is simplified:

$$\mathrm{PV}[\mathrm{CI}(N)] = p_s\cdot E_{\mathrm{HCPV_s}}(1-T)\frac{Qp_s\left(1-Qp_s^N\right)}{1-Qp_s} \quad (13)$$

Likewise, if the annual HCPV generated electricity is fed into the grid in its entirety, Eq. (12) is also simplified:

$$\mathrm{PV}[\mathrm{CI}(N)] = p_g\cdot E_{\mathrm{HCPV_g}}(1-T)\frac{Qp_s\left(1-Qp_s^N\right)}{1-Qp_s} \quad (14)$$

Regarding the present value of the tax depreciation, it can be calculated by:

$$\mathrm{PV}[\mathrm{DEP}(N_\mathrm{d})] = \sum_{t=1}^{N_\mathrm{d}} \frac{\mathrm{DEP}_t}{(1+d)^t} \tag{15}$$

where N_d (years) is the period of time over which an investment is amortized for tax purposes, and DEP_t (€) is the tax depreciation corresponding to year t. For example, if tax depreciation is assumed linear and constant over a given period of time, the present value of the tax depreciation may be estimated by:

$$\mathrm{PV}[\mathrm{DEP}(N_\mathrm{d})] = \mathrm{DEP}_y \cdot \mathrm{PVIF}(N_\mathrm{d}) \tag{16}$$

where DEP_y (€) is the annual tax depreciation for the HCPV system.

A criticism of the NPV criterion raises the lack of realism on the assumption of reinvestment of intermediate cash flows of the project. NPV assumes reinvestment of interim cash flows, in the same project or a different project, with a rate of return equal to the discount rate until the end of the life cycle of the project. Obviously, such reinvestment rate need not necessarily be equal to the discount rate assumed for the project.

The project is profitable or feasible if the calculated NPV is positive after using a sustainable discount rate. A negative NPV indicates that the project should not be considered. When selecting among alternative projects, the one with the largest NPV is chosen for implementation. The only serious limitation with this approach is that it should not be used to compare projects with unequal lifetimes.

The NPV criterion has the advantage of ease of calculation relative to the criterion of the IRR. Indeed, calculation of the IRR is a cumbersome task up to a certain extent.

3.2 Internal Rate of Return

IRR is defined as the discount rate that makes the NPV of all cash flow equal to zero. It is considered to be the most useful measure of project worth and is used by almost all of the institutions involved in the economic and financial analysis of the project. It represents the average earning power of the money used in the project over the project's lifetime. The IRR is the profitability expected from a project expressed as a percentage, whereas NPV is expressed in monetary value, as an absolute magnitude. Equally, IRR can be defined as the discount rate that makes the NPV equation equal to zero:

$$0 = -\mathrm{HCPV}_I + \mathrm{PV}[\mathrm{NCF}(N)] \tag{17}$$

This criterion also has some drawbacks. One is the lack of realism on the assumption of reinvestment of intermediate cash flows of the project as happened with the NPV criterion. The IRR criterion presupposes the immediate reinvestment of net positive cash flows until the end of the life cycle of the project, a reinvestment rate equal to the IRR of the project. In addition, it considers that any net negative cash flows are refinanced immediately until the end of the lifetime of the project with average capital of cost equal to the IRR of the project. Obviously such reinvestment or refinanced rates need not necessarily be equal to the IRR of the project.

Another drawback is the difficulty in calculating the result and possible inconsistency. Algebraically, the IRR is defined as the value of d, which satisfies Eq. (17). As can be easily noticed, this is a fairly complex equation to be solved for d. In fact, it is a polynomial of degree N, the lifetime of the project. In general, Eq. (17) can have as many as N solutions for d. The number of solutions will correspond with the number of times NCF changes sign. Fortunately, this will not typically be a problem since, for most projects, NCF will change sign only once, being negative initially while initial investment costs are being incurred, and then positive for the rest of the project life. In these circumstances, IRR will not only be uniquely defined, it will also indicate if the project looks profitable when regarding at it from different angles, e.g., exceeding a cut-off rate given by the opportunity cost, the WACC, or the minimum profitability required by the investor. Then the NPV of the project will be positive.

It should be noted that Eq. (17) leads to the calculation of a “gross” IRR. However, because most projects use financial mechanisms that required to be performed, the net internal rate of return (IRR_n) provides a more realistic assessment. Thus, IRR_n is obtained by subtracting WACC from IRR as calculated by means of Eq. (17) as follows:

$$\mathrm{IRR}_n = \mathrm{IRR} - \mathrm{WACC} \tag{18}$$

Under this criterion, a project should be accepted when the IRR is greater than the company’s cost of capital, at the least, and reject those whose IRR falls short of such cost of capital. This cost is usually set equal to WACC or the opportunity cost of capital among others.

3.3 Discounted Pay-back Time

Discounted pay-back time (DPBT, in years) is the number of years required for the sum of the NCFs generated by project to meet the initial investment cost. It is given by the expression:

$$\mathrm{HCPV}_I = \mathrm{PV}[\mathrm{NCF}(\mathrm{DPBT})] \tag{19}$$

$$\mathrm{HCPV}_I = \mathrm{PV}[\mathrm{CI}(\mathrm{DPBT})] - \mathrm{PV}[\mathrm{CO}(\mathrm{DPBT})] + \mathrm{PV}[\mathrm{DEP}(N_\mathrm{d})] \cdot T \quad (20)$$

where PV[NCF(DPBT)] (€) = the present value of the NCFs generated over DPBT, PV[CI(DPBT)] (€) = present value of the CIs generated over DPBT, and PV[CO (DPBT)] (€) = the present value of the COs generated over DPBT.

If N_d is greater than DPBT, Eq. (20) may be written as:

$$\mathrm{HCPV}_I = \mathrm{PV}[\mathrm{CI}(\mathrm{DPBT})] - \mathrm{PV}[\mathrm{CO}(\mathrm{DPBT})] + \mathrm{PV}[\mathrm{DEP}(\mathrm{DPBT})] \cdot T \quad (21)$$

where PV[DEP(DPBT)] (€) = the present value of the tax depreciation over DPBT.

Obviously, the DPBT should not exceed the serviceable life of the project (DPBT < N). Although easily understandable and straightforward, this parameter does not consider the cash flows that are produced after DPBT. Hence, it might hide sound financial opportunities for those deciding to invest in a PV system. DPBT is an indicator of liquidity and risk. The acceptability of the investment is determined by comparison with the investor's required payback period. Thus, the investment should be accepted when the DPBT is less than the investor's required payback period; otherwise, the investment should be rejected.

3.4 The BCR of an Investment

The BCR of an investment project is defined as the ratio between the present value of its CIs and the project's life-cycle cost.

$$\mathrm{BCR} = \frac{\mathrm{PV}[\mathrm{CI}(N)]}{\mathrm{HCPV}_I + \mathrm{PV}[\mathrm{CO}(N)] - \mathrm{PV}[\mathrm{DEP}(N_\mathrm{d})] \cdot T} \quad (22)$$

Using this criterion implies assuming that the project is feasible when BCR is >1 so that if some projects are to be assessed, the one with the greatest BCR should be preferred.

The BCR criterion is closely related to the NPV approach. In fact, if the NPV of a project is positive, the BCR will be >1. In contrast, if the NPV is negative, the project will have a BCR < 1. Therefore, both NPV and BCR are closely related and provide similar information to the investor/user.

3.5 Annualized Value

The annualizing process transforms a stream of cash flows into equivalent annual streams. Cash flows are discounted to their NPV and then annualized by multiplying the present value of the cash flows by $(1 - Q)/(Q(1 - Q^N))$:

$$AV = NPV \cdot \frac{1 - Q}{Q(1 - Q^N)} \tag{23}$$

where AV (€) is the annualized value. If the uniform capital recovery factor of k years is stated as UCRF(k) = $(1 - Q)/(Q(1 - Q^k))$, the annualized value of the HCPV system may rewritten as:

$$AV = NPV \cdot UCRF(N) \tag{24}$$

3.6 Modified Net Present Value

The reinvestment assumption may thus be avoided by using the MNPV. There is no reinvestment assumption associated with the MNPV because the reinvestment rate is specified. Although the simple NPV carries the baggage of the reinvestment assumption, the MNPV does not. The MPNV value considers that positive NCFs are explicitly reinvested at the company's, or an individual's, opportunity cost of capital (r) rather than implicitly reinvested at a rate equal to the discount rate (d), whereas negative NCFs are explicitly refinanced at a rate equal to the discount rate considered.

$$MNPV = -HCPV_I + \sum_{t=1}^{N} \frac{NCF_{p_t} \cdot (1 + r)^{N-t}}{(1 + d)^N} - \sum_{t=1}^{N} \frac{NCF_{n_t} \cdot (1 + d)^{N-t}}{(1 + d)^N} \tag{25}$$

where NCFp_t is a positive NCF in year t, whereas NCFn_t is a negative NCF in year t. It should be understood that NCFp_t is derived from Eq. (3) on condition that its result is positive; otherwise, NCFp_t = 0. Likewise, NCFn_t is also derived from Eq. (3) on condition that its result is negative; otherwise, NCFn_t = 0. Given that negative NCFs are explicitly refinanced at a rate equal to the discount rate considered, Eq. (25) can be simplified:

$$MNPV = \sum_{t=1}^{N} \frac{NCF_{p_t} \cdot (1 + r)^{N-t}}{(1 + d)^N} - \sum_{t=0}^{N} \frac{NCF_{n_t}}{(1 + d)^t} \tag{26}$$

The numerator of the first term in the right-hand side of Eq. (26) is the sum of all positive NCFs capitalized at the reinvestment rate until the last year (N) of the project. The second term in the right-hand side is the sum of all of the negative NCFs discounted at the financing rate—this usually equals WACC—until period zero of the project.

The decision criterion associated to the MNPV method is identical to that of the NPV: The project is profitable if the calculated MNPV is positive, whereas a negative value of MNPV means rejection. MNPV equal to zero indicates indifference.

3.7 Modified Internal Rate of Return

The reinvestment assumption can thus be avoided by using the MRR. There is no reinvestment assumption associated with the MIRR because the reinvestment rate is specified. Although the simple IRR carries the baggage of the reinvestment assumption, the MIRR does not. The MIRR is therefore probably a better way to measure the implied return from a project and gives a more reasonable measurement for comparison against other projects.

Modified IRR (MIRR) is similar to IRR, but positive NCFs are explicitly reinvested at the company's, or an individual's, opportunity cost of capital rather than implicitly reinvested at a rate equal to the system IRR, whereas negative NCFs are explicitly refinanced a rate equal to the discount rate considered.

$$0 = -\mathrm{HCPV}_I + \sum_{t=1}^{N} \frac{\mathrm{NCF}_{p_t} \cdot (1+r)^{N-t}}{(1+\mathrm{MIRR})^N} - \sum_{t=1}^{N} \frac{\mathrm{NCF}_{n_t} \cdot (1+d)^{N-t}}{(1+d)^N} \tag{27}$$

or

$$0 = -\mathrm{HCPV}_I + \sum_{t=1}^{N} \frac{\mathrm{NCF}_{p_t} \cdot (1+r)^{N-t}}{(1+\mathrm{MIRR})^N} - \sum_{t=1}^{N} \frac{\mathrm{NCF}_{n_t}}{(1+d)^t} \tag{28}$$

If HCPV_I is considered as a negative NCF corresponding to year 0, Eq. (28) may be rewritten as:

$$\sum_{t=1}^{N} \frac{\mathrm{NCF}_{p_t} \cdot (1+r)^{N-t}}{(1+\mathrm{MIRR})^N} = \sum_{t=0}^{N} \frac{\mathrm{NCF}_{n_t}}{(1+d)^t} \tag{29}$$

The numerator of the term in the left-hand side of Eq. (29) is the sum of all positive NCFs capitalized at the reinvestment rate until the last period (N) of the project. The term in the right-hand side of Eq. (29) is the sum of all of the negative NCFs discounted at the financing rate—usually WACC—until period zero of the project.

The decision criterion associated with the MIRR method is identical to that of the IRR. A project should be accepted when the IRR is greater than the company's cost of capital, at the least, and reject those in which the MIRR falls short of such cost of capital. This cost can be either WACC or the opportunity cost of capital among others.

3.8 Real Net Present Value

Section 2.1 dealt with how the NCFs of an investment project may be broken down according to the concepts where the resources are allocated by means of Eq. (4). Of all components of NCF, only the net cash balance can be actually reinvested because the remainder are obligations incurred by the company that arise from the financing of the project. If this is taken into account, a much more realistic new measurement of profitability can be proposed. This is aimed at averting the problem of the reinvestment of intermediate NCFs that becomes apparent in the NPV method. Bearing in mind Eqs. (4) and (7), the RNPV (€) is given by:

$$\mathrm{NPV} = -\mathrm{HCPV}_I + \mathrm{PV}[\mathrm{NCF}(N)] \tag{7}$$

$$\mathrm{NCF}_{t(\text{after}-\text{tax})} = \mathrm{RI}_t + I_t \cdot (1 - T) + \mathrm{di}_t + \mathrm{NCB}_t \tag{4}$$

$$\mathrm{RNPV} = -\mathrm{HCPV}_I + \sum_{t=1}^{N} \frac{\mathrm{RI}_t + I_t \cdot (1 - T) + \mathrm{di}_t}{(1 + d)^t} + \sum_{t=1}^{N} \frac{\mathrm{NCB}_t \cdot (1 + r)^{N-t}}{(1 + d)^N} \tag{30}$$

Values of NCB_t are reinvested if positive, and r is assumed equal to the reinvestment rate given by the company's, or an individual's, opportunity cost of capital. Values of NCB_t are refinanced if negative, so that r is assumed equal to WACC, whereas d equals the discount rate considered.

It should be noted that the widespread assumption of setting d equal to WACC leads to:

$$0 = -\mathrm{HCPV}_I + \sum_{t=1}^{N} \frac{\mathrm{RI}_t + I_t \cdot (1 - T) + \mathrm{di}_t}{(1 + d)^t} \tag{31}$$

Therefore, the RNPV can be simplified as:

$$\mathrm{RNPV} = \sum_{t=1}^{N} \frac{\mathrm{NCB}_t \cdot (1 + r)^{N-t}}{(1 + d)^N} \tag{32}$$

As shown above, NCB_t can be derived from Eq. (4) as:

$$\mathrm{NCB}_t = \mathrm{NCF}_{t(\text{after}-\text{tax})} - \mathrm{RI}_t - I_t \cdot (1 - T) - \mathrm{di}_t \tag{33}$$

The criterion followed to assign the value of r in Sect. 3.5 (MNPV) may also be applied to Eq. (32).

4 Economic and Financial Feasibility of a Project

An investment project is feasible from an economic point of view when the return provided by the assets exceeds the cost of its liabilities, i.e., the NPV is >0, and the IRR is greater than the cost of capital for its liability.

An investment project is feasible from a financial point of view when at all times of its life cycle it has a a positive cumulative net cash balance. Then the financial

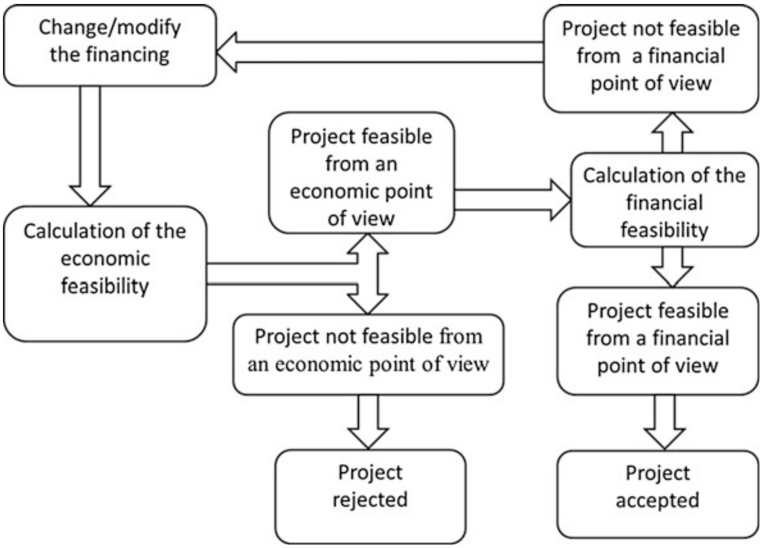

Fig. 6 Process of economic and financial feasibility

feasibility of a project is determined by the sum of the CIs and COs on a year-to-year basis. In other words, this is the financial dimension of the financing and the financial dimension of the investment.

A project might be feasible from an economic but not from a financial point of view. In this case the reverse is not possible: A possible option to turn it into a feasible one from a financial standpoint requires modifying the financing. Such modification may affect the economic feasibility of the project so that the study should be performed again as shown in Fig. 6.

5 Economic Analysis

To provide realistic results in the analysis that follows, some data were obtained from PV market surveys and reports from energy agencies. Two scenarios are proposed for the study of the economic profitability of HCPV systems. The first scenario is configured according to the information available by the end of 2013. Then, a second scenario is hypothesized to take place in 2020 by trying to predict the evolution of the HCPV market up to that year. For each scenario considered, a base case has been defined as a starting point to carry out a profitability analysis of HCPV systems.

5.1 Estimation of Parameters Involved in the Analysis

This review will lead to the identification of the value of the parameters required for a profitability analysis of the HCPV systems for a given scenario (2013) and a prospective scenario (2020). It should be noted that some of the figures presented here referring to costs and electricity yields are all normalized per kWp. The symbols used for these factors are the same for those not normalized except that they are shown in brackets and with the subscript "kWp."

5.1.1 Calculation of the HCPV Initial Investment Cost

Several market analysis [25, 30, 44] indicate that the HCPV world cumulative installed capacity in 2013 accounted for 160 MWp and that this could exceed 1400 MWp in 2020 as shown in Fig. 7. Based on the available information, different average annual growth rates (r_{HCPV} [in %]) of this capacity may be assumed. The company IHS expects an average annual growth rate equal to 36 %, whereas Globaldata expects growth to be 32 %. Bearing in mind both two values, it is assumed that r_{HCPV} 34 % in our analysis. Such an optimistic assumption implies that the installed HCPV capacity will exceed 1200 MWp in 2020.

Learning curves can be used to estimate the evolution of the initial investment cost of HCPV systems for upcoming years. These curves describe the cost reduction as a function of the accumulated experience in the manufacturing and in the use of a particular technology. The learning curve of a HCPV system can be expressed as:

$$\mathrm{HCPV}_{I\mathrm{year}} = \mathrm{HCPV}_{I2013}\left(\frac{Q_{\mathrm{HCPV\ year}}}{Q_{\mathrm{HCPV\ 2013}}}\right)^{\log_2^{(1-\mathrm{LR})}} \tag{34}$$

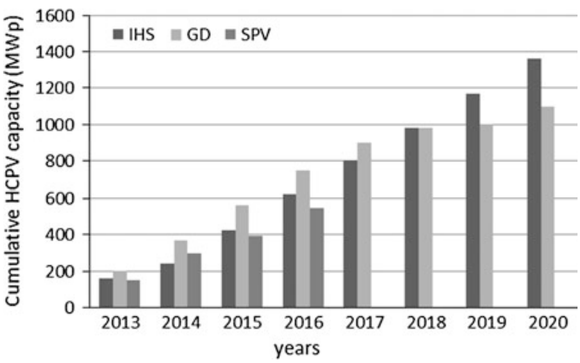

Fig. 7 Forecast of the HCPV world cumulative capacity. Market forecast performed by the private companies IHS (HIS), Globaldata (GD), and SPV Market (SPV)

Table 1 Learning ratio values of conventional PV as estimated by several authors (Poponi [49]; Parente et al. [48]; Bhandari and Stadler [4]

Author/date	Period of time analysed	Region studied	LR (%)
Poponi/2003	1976–2002	World	25
Parente/2002	1981–2000	World	23
Poponi/2003	1989–2002	World	20

where $HCPV_{I\text{year}}$ (€/kWp) is the HCPV initial investment cost in the year under study, $HCPV_I$ 2013 (€/kWp) is the HCPV initial investment cost in 2013, $Q_{HCPV\ \text{year}}$ (kWp) is the HCPV world cumulative installed capacity in the year under study, Q_{HCPV} 2013 is the HCPV world cumulative installed capacity in 2013 (kWp), LR is the learning rate, and $\log_2(1 - LR)$ is the learning elasticity parameter. In 2013, the typical initial investment cost per kWp in HCPV varied from 1400 to 2200 €/kWp [20, 21]. In this study, an HCPV initial investment cost equal to 1800 €/kWp in 2013 is assumed.

As shown in Table 1, the learning rate of conventional PV has decreased with time as more experience in this technology has been gained. This ratio has sunk from a value of 25 % in the first stage of this technology (1976–2002) to a lower value of 20 % in later stages. As commented, HCPV technology is still in its first stages, and therefore a learning ratio of 25 % may be reasonably assumed. This value configures what is referred to as the "optimistic scenario" in the following text.

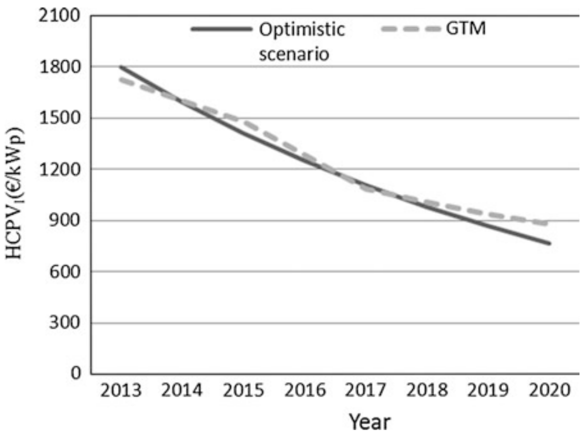

Fig. 8 Learning curve of the initial investment cost of HCPV systems in the assumed scenario (*optimistic scenario*). The initial investment cost of HCPV forecast performed by the private company GTM Research Inc [50] is also depicted

Based on the data described previously, the learning curve of the initial investment cost of HCPV systems could be estimated. Figure 8 shows the results obtained for the envisaged scenario. These results depend on multiple variables that may change over time; therefore, the data obtained might be altered. However, it is possible to expect a prospective scenario in which the initial investment cost of HCPV will fall within the interval of 700–900 €/kWp. In this study, $HCPV_I$ will be set equal to 800 €/kWp in 2020.

5.1.2 Estimation of HCPV Electricity Yield

Several methods have been proposed in the literature to calculate the energy generated by a PV grid connected system [1–3, 22, 27, 28, 37, 39–41, 47, 54, 68]. The method, based on the performance ratio (PR), is one of the most commonly used. The [32] defines that the annual generated electricity by a 1-kWp conventional PV system may be estimated using the following Eq. (35):

$$Y_{\mathrm{f}} = \mathrm{PR}\frac{H_{\mathrm{A}}}{G_{\mathrm{STC}}} \tag{35}$$

where Y_{f} [kWh/kW] is the annual final system yield in a conventional 1-kWp PV system, $\mathrm{H_A}$ [kWh/m^2] is the in-plane annual global irradiation, and G_{STC} [1 kW/m^2] is the global irradiance at standard test conditions. Values of PR in conventional PV systems usually range from 0.70 to 0.80 [9, 45, 51, 53, 59].

Likewise, the annual generated electricity by a 1-kWp HCPV system can be estimated using the following equation:

$$Y_{\mathrm{fHCPV}} = \mathrm{PR}\frac{\mathrm{DNI_A}}{\mathrm{DNI_{STC}}} \tag{36}$$

where Y_{fHCPV} [kWh/kW] is the annual final yield in a HCPV system, $\mathrm{DNI_A}$ [kWh/m^2] is the annual direct normal irradiation, and $\mathrm{DNI_{STC}}$ [1 kW/m^2] is the DNI at standard test conditions. Values of PR in HCPV systems have been reported to range from 0.75 to 0.90 [26, 29, 35, 36, 38, 46, 58, 66]. In the considered base case, an intermediate value of 0.82 has been used.

5.1.3 Estimation of the Remaining Factors

Initial investment cost of an HCPV system may be financed by means of debt or/and equity capital. Long-term loans and equity capital are chosen in this work. It has been assumed that 80 % of this initial amount is taken on loan ($\mathrm{HCPV_l}$ [in €]), i.e., debt, while the remaining investment amount (20 %) is contributed from stock issue ($HCPV_{eq}$ [in €]), i.e., equity capital. Regarding the loan, the interest rate (i_l) is considered equal to 6 %, whereas N_l is set equal to 20 years [15, 23]. Regarding equity capital, the dividend percentage d_{eq} is assumed equal to 12 % [21], and equity capital is payable in full at the end of the life cycle of the project (N [in years]). The risk related to HCPV projects perceived by investors is higher than that perceived regarding other renewable technologies, so cost of debt and equity capital, i.e., d_{eq} and i_l, take higher values.

The share of external financing and equity financing can be included in the analysis explicitly through the WACC over the discounting factor or nominal discount rate. Given that $HCPV_I = HCPV_l + HCPV_{ec}$, and taking into account taxation, Eq. (37) is obtained:

$$\begin{aligned} \mathrm{HCPV}_I = & \left(\mathrm{HCPV}_l \cdot \frac{i_l(1-T)}{1-(1+i_l(1-T))^{-N_l}} \cdot \frac{Q\cdot(1-Q^{N_l})}{1-Q} \right) \\ & + \left((d_{eq} \cdot \mathrm{HCPV}_{eq}) \cdot \frac{Q\cdot(1-Q^{N})}{1-Q} + \mathrm{HCPV}_{eq} \cdot Q^N \right) \end{aligned} \quad (37)$$

The first term of the right-hand side of Eq. (37) refers to loan: As commented previously, $HCPV_l$ is borrowed at an annual loan interest (i_l) to be repaid in N_l years. The second term refers to equity capital, with an annual payback in the form of dividends (d_{eq}), and is amortized at the end of the life cycle of the system. It is worth mentioning that the left-hand side of Eq. (37) only equals its right-hand side if the selected value of d is equal to the WACC of the investment.

The HCPV electricity unitary price, i.e., $p_{u,}$ in (€/kWh), of the HCPV-generated electricity paid to the owner, fed to the grid, or saved by the owner—in situ self-consumption—can be fixed at wholesale or retail price of the market. In the USA, the average retail price of electricity to ultimate customers by the end-use sector was equal to \$0.1/kWh (all states' data from May 2013, 2014 [13]). Values of p_u varying between 0.07 and 0.30 €/kWh comprise the value of most market prices and present generation-based incentives for PV in different countries such as Germany, Italy, France, USA, Greece, and the UK among others [6, 7, 19, 33, 67]. For example, for flat-plate PV, Germany offers a minimum of 0.1102 €/kWh for a free-standing facility and Italy from 0.106 to ≤0.176 €/kWh as a function of rated power plus a premium for personal consumption. France offers from 0.0818 to ≤0.3159 €/kWh depending on the rated power. In the USA, net metering is regulated by law in most states, but state policies vary widely [12]. The feed-in tariff values for HCPV in Italy, according to the Ministerial Decree of 05 July 2012, vary from 0.215, 0.201, and 0.174 €/kWh for rated power ranging from 1 to 200, 200.01 to 1000, and >1000 kW, respectively [6]. For an HCPV system with a rated power >1 MWp, a reasonable value for the assumed base case is given by $p_u = 0.1$ €/kWh for the scenario (2013).

The annual increase rate of the HCPV electricity unitary price (rp_u), which is linked to the evolution of electricity markets, is always difficult to forecast. In the upcoming years 2014–2020 in the EU, retail electricity prices could increase from 2 to 5 % yearly depending of the country (European Photovoltaic Industry Association [17]. In the USA, retail electricity prices are expected to grow in the coming years (2014–2040) at an annual average rate ranging from 2.2 to 2.6 % [63]. In this study, rp_u is set equal to 2.5 %.

Regarding inflation, taking into account averages of historical data related to annual inflation rates (period 2005–2014) for some countries, the obtained values are i = 1.9 % for the Euro area [14, 24]; i = 2.3 % for the USA; i = 1.8 % for Canada; and i = 3 % for China [24]. Thus, i is assumed equal to 2.2 % in the base case.

The annual HCPV electricity yield generated by the system is assumed to decrease every year. Average annual degradation rate (r_d) in the efficiency of flat PV panels is 0.5 %/year [5, 34]. The analysis period equals the lifetime of an HCPV system, which is assumed equal to 30 years; consequently, N is set equal to 30 years. This makes sense because nowadays, flat PV systems have a life cycle of ≥30 years. The salvage value of the system's life cycle (S_V) is considered equal to zero.

The nominal discount rate (d) is assumed equal to the weighted average capital of cost to calculate the profitability criteria [21]. This capital cost will vary depending on how the capital resources are chosen to finance the initial investment cost. In the base case, the after-tax WACC is equal to 6.5 % given the assumptions stated in the first paragraph of this section.

Yearly operation and maintenance cost have been reported to be equal to 28 €/kWh/y for HCPV systems [11, 20]. Other estimates consider an annual fixed percentage of the initial investment cost HCPV$_I$, which is assumed equal to 2 % for [18]. The latter approach has been chosen in this work. The annual escalation rate of the operation and maintenance costs (r_{OM}) is set equal to the value of the annual inflation rate, i.e., r_{OM} = 2.2 %.

The income tax rate (T) for the organization or taxpayer, changes depending on each country's regulations. The value income tax rate is assumed equal to 30 % for this study. The method used in the tax depreciation uses a maximum linear coefficient of 5 % with a tax life for depreciation of 20 years [42, 43, 62]. Table 2 summarises the previous analysis by showing the figures chosen and assumed for each factor that define the case base for HCPV systems in the given scenario.

In a prospective scenario (2020) as described hereafter in Sect. 5.1.1. $[\mathrm{HCPV}_I]_{\mathrm{kWp}}$ equals 800 €/kWp, whereas the perceived risk of HCPV projects is similar to that of some other renewable technologies; therefore, cost of debt and equity capital is lower—by means of dividends and loan interest rate, respectively—than those stated values of the case base analysed according to Table 2 so that d_{ec} = 8 % and i_l = 4 %. HCPV electricity unitary price is set equal to 0.05 €/kWh,

Table 2 Values of factors assumed for the profitability analysis of HCPV systems in the scenario (2013)

Factors	Base case	Units
$[HCPV_I]_{kWp}$	1800	€/kWp
DNI_{STC}	1	kW/m^2
DNI_A	2200	kWh/m^2
PR	82	%
r_d	0.5	%
p_u	0.10	€/kWh
rp_u	2.5	%
$[HCPV_{OM}]^a_{kWp}$	2.0	%
r_{OM}	2.2	%
T	30	%
d = WACC	6.5	%
i	2.2	%
i_l	6.0	%
N_l	20	Years
d_i	12	%
N	30	Years

[a]This value should be interpreted as the percentage of $[HCPV_I]_{kWp}$ that is spent on operation and maintenance tasks on an annual basis

the pool price [64]; European Commission [16] because generation-based incentives for HCPV are assumed to be unavailable by 2020. The values of the remaining factors are the same to those of the base case of Table 2. Table 3 summarises these

Table 3 Factors values assumed for the profitability analysis of HCPV systems in the prospective scenario (2020)

Factors	Base case	Units
$[HCPV_I]_{kWp}$	800	€/kWp
DNI_{STC}	1	kW/m^2
DNI_A	2200	kWh/m^2
PR	82	%
r_d	0.5	%
p_u	0.05	€/kWh
rp_u	2.5	%
$[HCPV_{OM}]^a_{kWp}$	2.0	%
r_{OM}	2.2	%
T	30	%
d = WACC	4.5	%
g	2.2	%
i_l	4.0	%
N_l	20	Years
d_i	8.0	%
N	30	Years

[a]This value should be interpreted as the percentage of $[HCPV_I]_{kWp}$ that is spent on operation and maintenance tasks on an annual basis

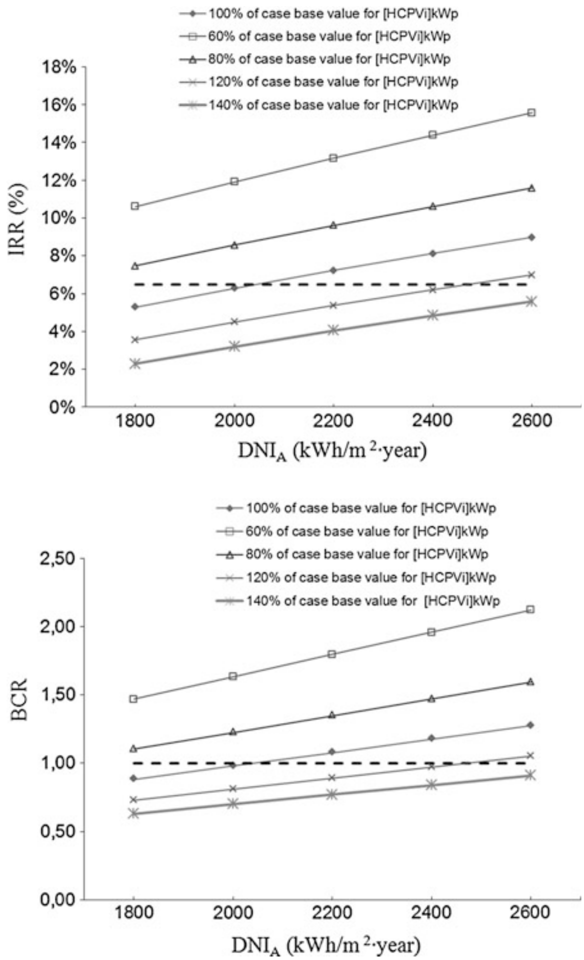

Fig. 9 IRR (*top panel*) and BCR (*bottom panel*) as a function of annual direct normal irradiation for variations of normalized-per-kWp initial investment cost. For each figure the rest of parameters are those stated for the base case in Table 2. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., *d* WACC = 6.5 % (*top panel*), and BCR = 1 (*bottom panel*)

considerations by showing the figures assumed for each factor that defines the case base for HCPV systems in the prospective scenario (2020).

5.2 Results

Solving the equations presented in Sect. 3, together with the figures shown in Tables 2 and 3, by means of using a spreadsheet, paves the way to the calculation of the profitability criteria for each base case. Thus, the following indices are obtained

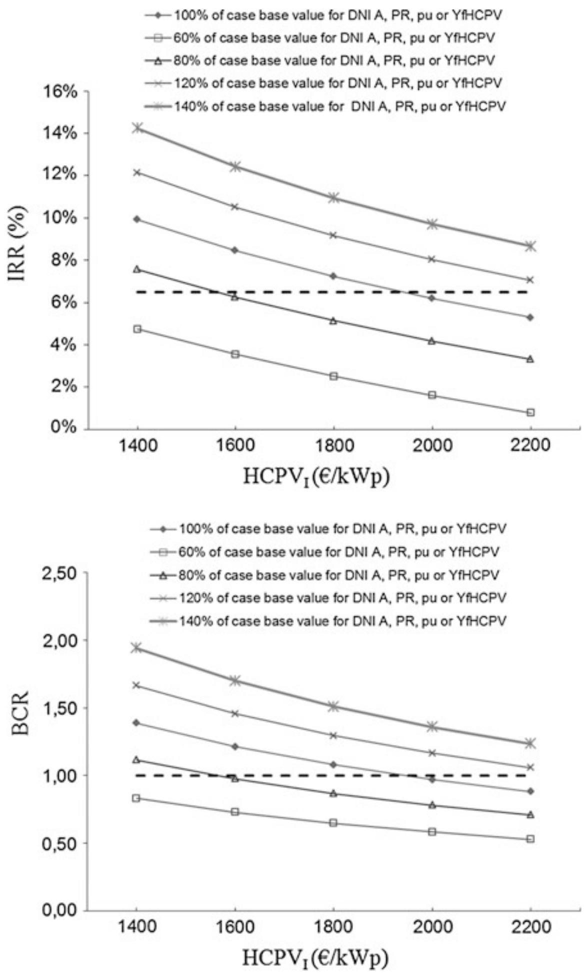

Fig. 10 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of annual direct normal irradiation, PR, electricity unitary price, and normalized-per-kWp annual energy yield. For each figure the rest of parameters are those stated for the base case in Table 2. Regarding PR, only percentage values <120 % of the base case (0.82) should be considered given that annual PR cannot exceed the ideal value of 1. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 6.5 % (*top panel*), and BCR = 1 (*bottom panel*)

for the given scenario (2013): IRR = 7.23 %, IRR_n 0.75 %, BCR = 1.08, DPBT = 25 years, NPV = 151 €/kWp, and PI = 0.08. Regarding the prospective scenario (2020), the following results are obtained: IRR = 8.45 %, IRR_n = 3.98 %, BCR = 1.5, DPBT = 15.5 years, NPV = 445 €/kWp, and PI = 0.56. Assuming a reinvestment rate equal to 7 % in Eqs. (26), (28) and (33) leads to the following values for the given scenario: MIRR = 7.05 %, MNPV = 331 €/kWp, and

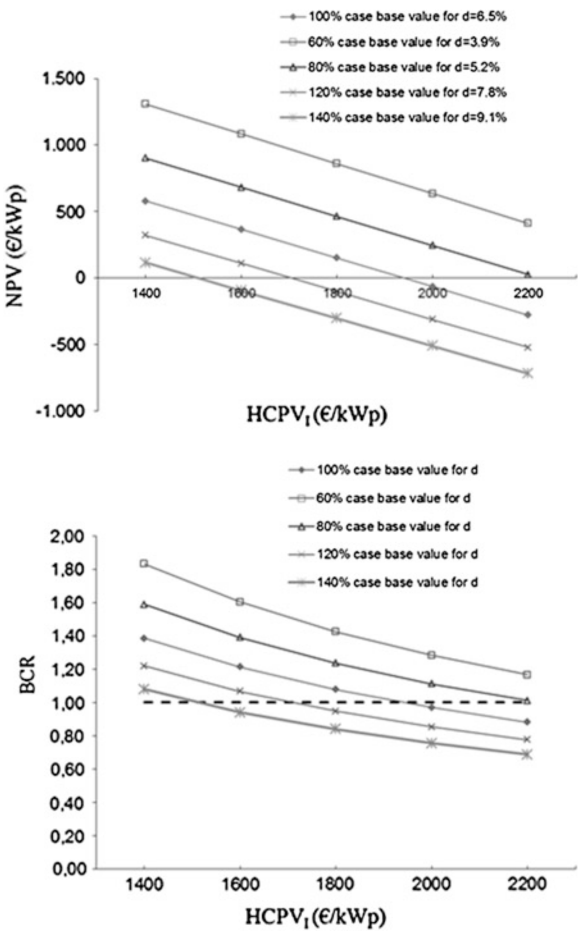

Fig. 11 NPV (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of nominal discount rate. For each figure the rest of parameters are those of base case shown in Table 2. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., NPV = 0 (*top panel*) and BCR = 1 (*bottom panel*)

RNPV = 157 €/kWp. In contrast, assuming a reinvestment rate equal to 5 % in the prospective scenario results in the following values: MIRR = 5.8 %, MNPV = 556/kWp, and RNPV = 477 €/kWp. For both base cases, and given that IRR is greater than WACC, NPV is positive, and BCR is >1, we can conclude that HCPV systems are feasible from an economic point of view.

Regarding the financial feasibility of the base case corresponding to the given scenario (2013), a negative cumulative net cash balance in the first 15 years is obtained, so it would not be feasible from a financial point of view. Therefore, in this case the funding conditions should be modified. However, when calculated in

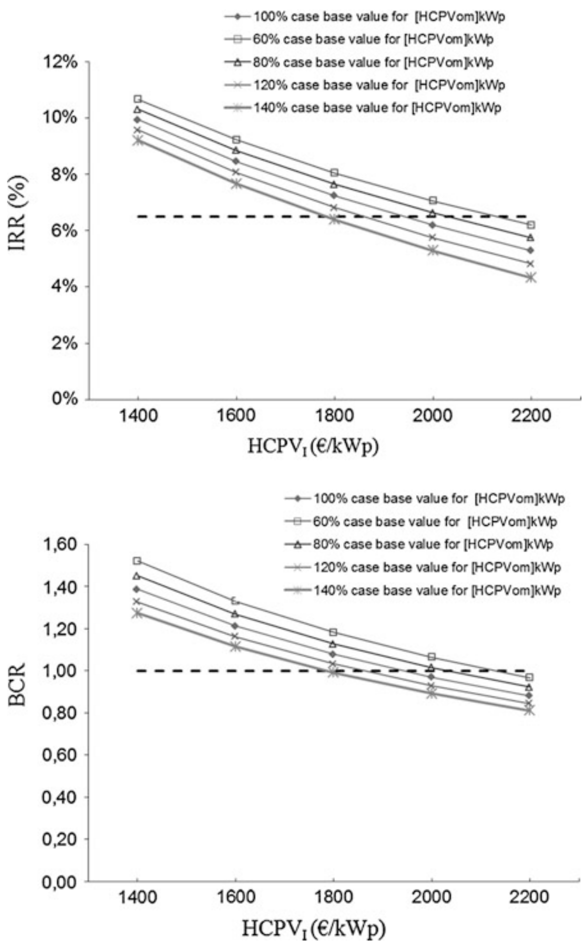

Fig. 12 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of normalized-per-kWp annual operation and maintenance cost. For each figure the rest of parameters are those of base case in Table 2. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 6.5 % (*top panel*), and BCR = 1 (*bottom panel*)

the base case for the prospective scenario, a positive cumulative net cash balance appears over the whole life cycle of the HCPV system, so it would be also feasible from a financial point of view.

6 Sensitivity Analysis

Possible changes in the value of the factors that configure both the considered given and future base case scenarios obviously influence an HCPV system's profitability criteria. Therefore, a sensitivity analysis of the latter criteria to those factors is

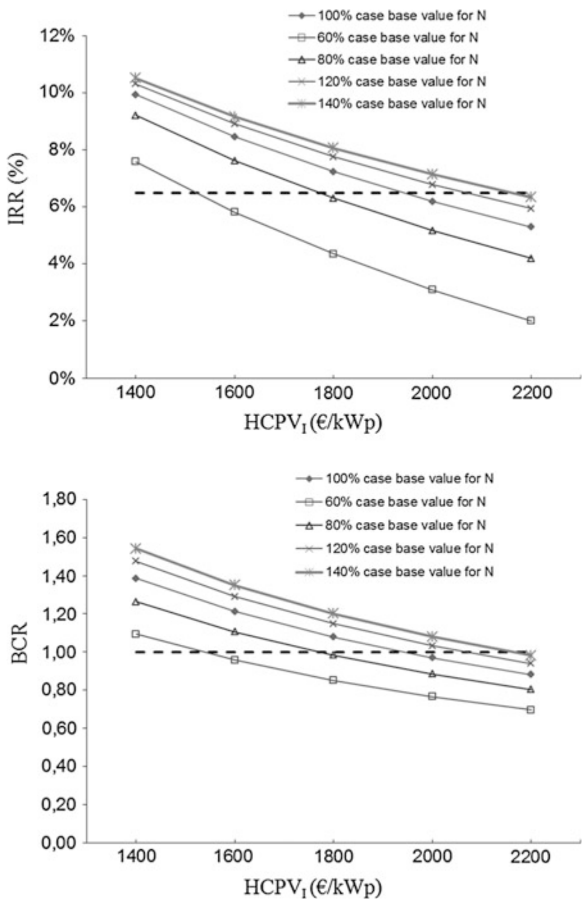

Fig. 13 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of life cycle. For each figure the rest of parameters are those of base case in Table 2. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 6.5 % (*top panel*) and BCR = 1 (*bottom panel*)

shown herein. According to Sect. 5, a base case has been defined in each scenario as a starting point to study the deviations of the studied profitability criteria as a function of the variations in the values of the factors that define this base case. Figures 9, 10, 11, 12, 13, 14 and 15 show the effect of deviations of these parameters from the figures that define each base case. Variations of factors within the range from −40 to +140 %, with 20 % increments, have been considered. Figures 9, 10, 11, 12, 13, 14 and 15 show figures of IRR (percentage units), NPV (€/kWp), and BCR (as a function of annual direct normal irradiation or initial investment cost) for deviations of the factors that define the base cases for the current scenario.

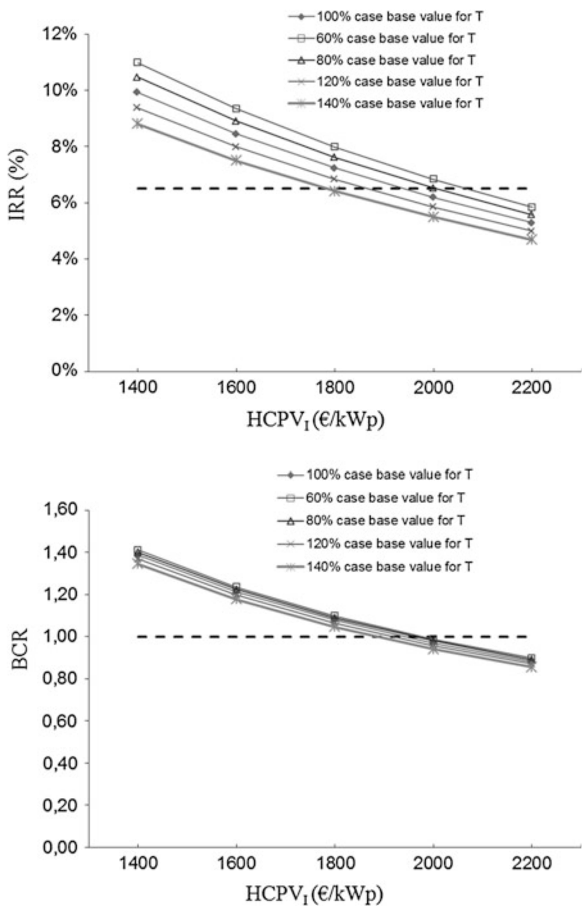

Fig. 14 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of tax. For each figure the rest of parameters are those of base case in Table 2. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 6.5 % (*top panel*) and BCR = 1 (*bottom panel*)

6.1 Given Scenario

The results of the sensitivity analysis for the given scenario (2013) are shown in Figs. 9, 10, 11, 12, 13, 14 and Table 4. As commented previously, in these figures the profitability criteria are depicted as a function of annual direct normal irradiation or initial investment cost for variations of the factors that characterize the base case.

When the values obtained for IRR, BCR, and NPV in Figs. 9, 10, 11, 12, 13, 14 and 15 are compared, some conclusions can be drawn. Variations in the annual degradation rate in the efficiency of the PV panels have little influence on IRR and BCR. Variations in certain factors, such as income tax rate and the percentage

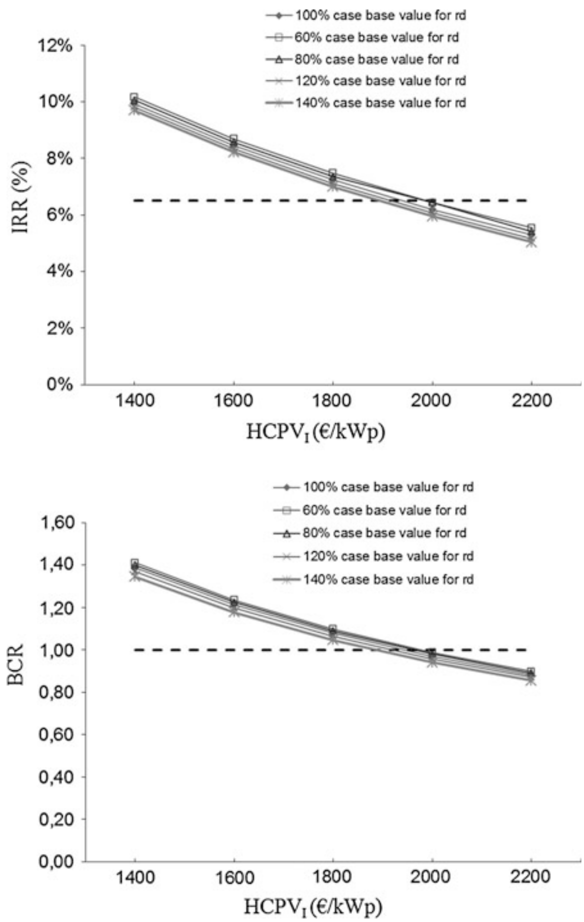

Fig. 15 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of annual degradation rate in the efficiency of the PV panels. For each figure the rest of parameters are those of base case in Table 2. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 6.5 % (*top panel*), and BCR = 1 (*bottom panel*)

annual operation and maintenance cost, exert a similar influence on the profitability criteria. Such influence turns out to be greater than that exerted by deviations of the annual degradation rate in the efficiency of the HCPV panels. Variations in the useful life cycle exert a lower impact on the profitability criteria than those of the nominal discount rate, but these criteria show more sensitivity to such variations than to those of all of the previously mentioned factors. IRR, BCR, and NPV are even more sensitive to variations in annual direct irradiation, normalised annual

Table 4 Effect of the variation of the analysed factors on base-case IRR and BCR for the given scenario (2013)

Factor	Units	Factor value range	Range of variation of IRR (%)	Range of variation of BCR
$[HCPV_I]_{kWp}$	€ kWp	1080 ÷ 2520	13.2 ÷ 4.1	1.80 ÷ 0.77
$[HCPV_{OM}]_{kWp}$	%	1.2 ÷ 2.8[a]	8.1 ÷ 6.4	1.18 ÷ 0.99
d	%	3.9 ÷ 9.1	No variation[b]	1.43 ÷ 0.84
r_d	%	0.3 ÷ 0.7	7.5 ÷ 7.0	1.11 ÷ 1.05
N	Year	18 ÷ 42	4.4 ÷ 8.1	0.85 ÷ 1.20
T	%	18 ÷ 42	8.0 ÷ 6.4	1.10 ÷ 1.05
DNI_A	kWh/m^2	1320 ÷ 3080	2.5 ÷ 10.9	0.65 ÷ 1.51
Yf_{HCPV}	kWh/kWp	1016 ÷ 3048	Same as above	
p_u	€/kWh	0.06 ÷ 0.17		
PR	–	0.49 ÷ 1.0	2.5 ÷ 9.2	0.65 ÷ 1.29

[a]These values should be interpreted as the percentage of $[HCPV_I]_{kWp}$ that is spent on operation and maintenance tasks on an annual basis

[b]It should be understood that IRR stands for "gross" IRR so that this profitability criterion remains constant irrespective of the value of d in this work, which is set equal to WACC. However, as commented in a previous section, the IRR_n is directly influenced by WACC because $IRR_n = IRR - WACC$

HCPV electricity yield, PR, and HCPV electricity unitary price. It should be borne in mind that these three factors cause the same effect. Last, the greatest impact on profitability criteria is exerted by deviations from the normalised initial investment cost related to the base case.

The variations of IRR and BCR experienced by the variations of each factor considered are listed in Table 4. In this table, columns 4 and 5 depicts the range of variation of the IRR and BCR for the specific range of the analysed factors. These values of IRR and BCR were drawn from Figs. 9, 10, 11, 12, 13, 14 and 15.

6.2 Prospective Scenario

As shown in the previous section, a short analysis on the factors that most influence the profitability criteria is performed herein. Thus, the results of this sensitivity analysis on the profitability criteria in a prospective scenario are shown in Figs. 16,

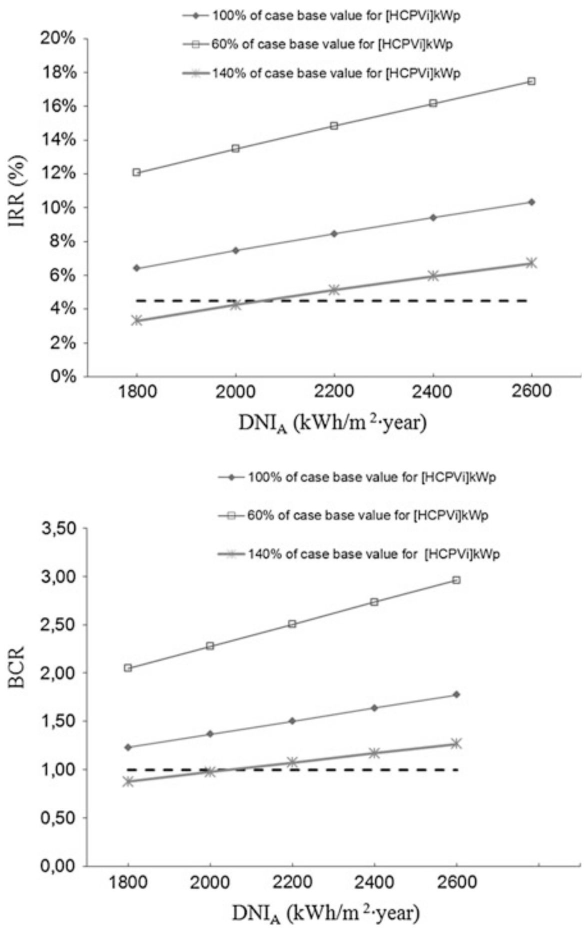

Fig. 16 IRR (*top panel*) and BCR (*bottom panel*) as a function of annual direct irradiation for variations of normalized-per-kWp initial investment cost. For each figure the rest of parameters are those of the base case presented in Table 3. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 4.5 % (*top panel*), and BCR = 1 (*bottom panel*)

17, 18, 19 and Table 5. As is the case in the given scenario, an insignificant impact on IRR, BCR, and NPV is caused by deviations of the annual degradation rate and income tax rate from the values assumed for these two factors in the base case. A similar conclusion holds for the annual operation and maintenance cost. Consequently, no figures are provided regarding the sensitivity of IRR, BCR, and NPV to the previous three factors given their scarce influence compared with that exerted by the remaining ones described with later in the text.

Some sound conclusions may be derived by comparing the values obtained for IRR, BCR, and NPV in the figures mentioned in the preceding paragraph. Variations in the life cycle and nominal discount rate exert a similar influence on the

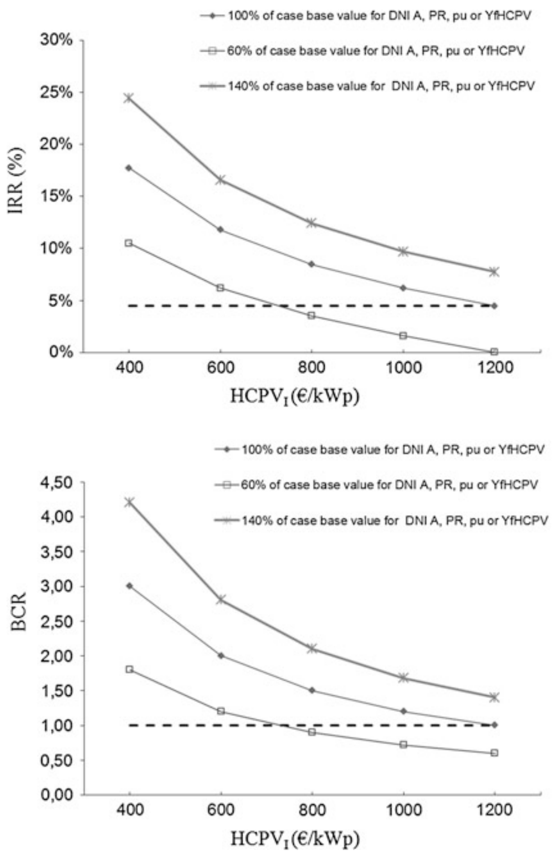

Fig. 17 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of annual direct normal irradiation, PR, electricity unitary price, and normalized-per-kWp annual energy yield. For each figure the rest of parameters are those of the base case presented in in Table 3. Regarding PR, only percentage values <120 % of the base case (0.82) should be considered given that annual PR cannot exceed the ideal value of 1. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 4.5 % (*top panel*), and BCR = 1 (*bottom panel*)

profitability criteria, but it is believed to occur a lesser extent than that exerted by the remaining factors studied. The nominal discount rate, the life cycle of the HCPV system, the annual final yield in an HCPV, the HCPV electricity unitary price, the PR, the annual direct normal irradiation, and the normalised initial investment are ordered from lowest to highest impact on profitability criteria related to the base case. As happened in Sect. 6.1, it should be noted that $Y_{f\mathrm{HCPV}}$, p_{u}, PR, and DNI_A exert the same influence.

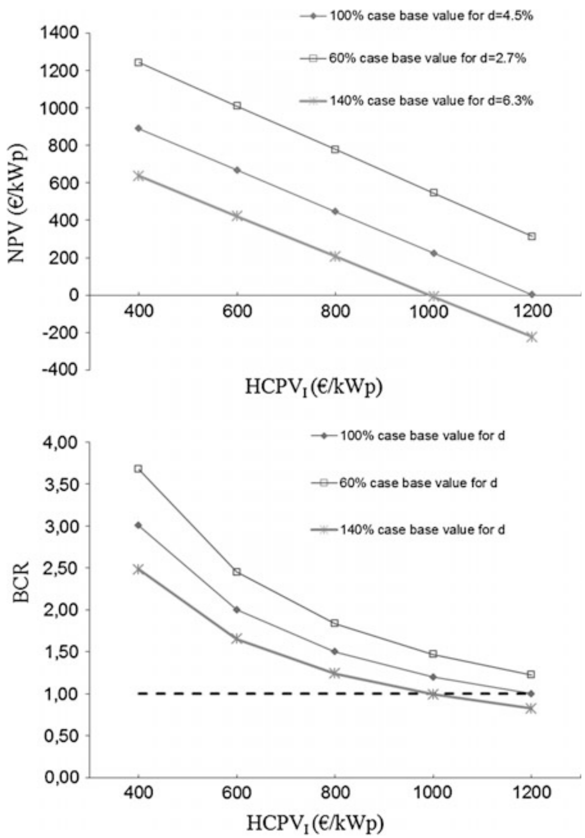

Fig. 18 NPV (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of nominal discount rate. For each figure the rest of parameters are those of the base case presented in Table 3. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., NPV = 0 (*top panel*) and BCR = 1 (*bottom panel*)

The effect of the variation of each factor considered exerted on the value of IRR and BCR are listed in Table 5. In this table, columns 4 and 5 depict the range of variation of the IRR and the BCR for the specific range of the analysed factors, respectively. These values of IRR and BCR were drawn from Figs. 16, 17, 18 and 19.

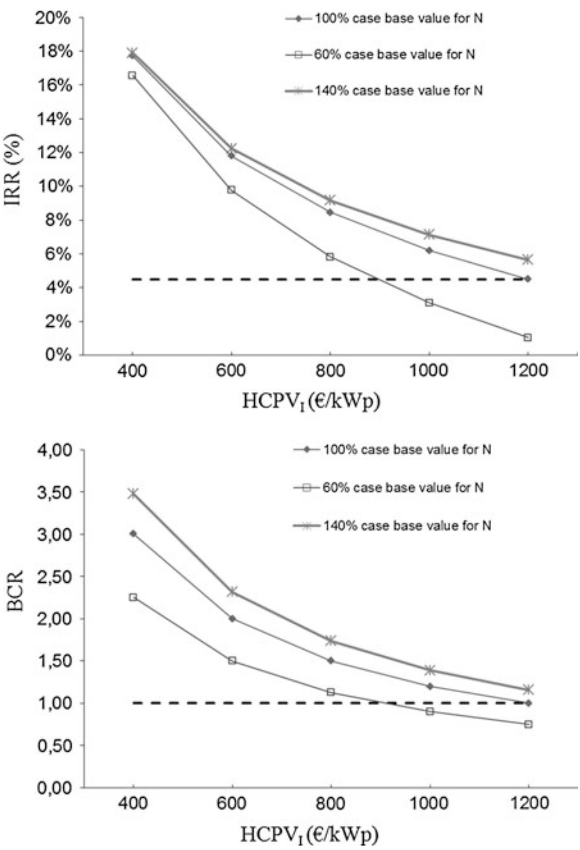

Fig. 19 IRR (*top panel*) and BCR (*bottom panel*) as a function of initial investment cost for variations of life cycle. For each figure the rest of parameters are those of the base case presented in Table 3. The *horizontal dashed line* shows the threshold of economic feasibility for both criteria, i.e., d = WACC = 4.5 % (*top panel*), and BCR = 1 (*bottom panel*)

Table 5 Effect of the variation of the analysed factors on base case IRR and BCR for the prospective scenario

Factor	Units	Factor value range	Range of variation of IRR (%)	Range of variation of BCR
$[HCPV_I]_{kWp}$	€ kWp	480 ÷ 1120	14.8 ÷ 5.1	2.50 ÷ 1.07
d	%	2.7 ÷ 6.3	No variation[b]	1.84 ÷ 1.24
N	Year	18 ÷ 42	5.8 ÷ 9.2	1.13 ÷ 1.74
DNI_A	kWh/m^2	1320 ÷ 3080	3.6 ÷ 12.4	0.90 ÷ 2.10
Y_{fHCPV}	kWh/kWp	1082 ÷ 2526	Same as above	
p_u	€/kWh	0.03 ÷ 0.07		
PR	–	0.49 ÷ 1.0	3.6 ÷ 10.5	0.90 ÷ 1.8

[a]These values should be interpreted as the percentage of $[HCPV_I]_{kWp}$ that is spent on operation and maintenance tasks on an annual basis

[b]It should be understood that IRR stands for “gross” IRR so that this profitability criterion remains constant irrespective of the value of d in this work equal to WACC. However, as commented in a previous section, the IRR_n is directly influenced by WACC because IRR_n = IRR − WACC

7 Conclusions

An introduction to the economic and financial analyses of HCPV systems has been presented throughout this chapter. The proposed mathematical expressions are aimed at taking into account most factors on which these analyses are based. To put them into practice, two different scenarios have been presented so as to provide two base cases.

The first base case corresponds to the year 2013, in which the cumulative installed HCPV power accounted for 160 MWp by the end of that year. This scenario is mainly characterized by an assumed initial investment cost of 1800 €/kWp with 80 % financed by means of a loan and 20 % funded through equity, a feed-in-tariff scheme of 0.10 €/kWh, an annual direct normal irradiation that equals 2200 kWh/m^2, and a perceived risk of the investment considered greater than that associated with other renewable techniques: This results in a WACC assumed equal to 6.5 %. The economic analysis proves that this investment as feasible from this point of view given that the IRR (7.2 %) exceeds the WACC and the BCR is >1 (1.08). However, this investment fails to be feasible from the financial viewpoint due to the negative cumulative net cash balances that are obtained during the first 15 years.

The second base case corresponds to a prospective scenario in 2020. Obviously, making some predictions regarding costs and financial environment has been necessary so that most relevant ones are commented below.

Cumulative installed HCPV power forecast, i.e., 1400 MWp by the end of 2020—together with learning curves, in which a learning ratio of 0.20 is assumed—lead to an initial investment cost of 800 €/kWp, which is also financed by external capital (80 %) and equity (20 %). HCPV-generated electricity is assumed to be sold in its entirety to the grid at a pool price of 0.05 €/kWh, the same annual direct irradiation as commented previously, and a lower perceived risk of default is considered, which decreases the WACC to 4.5 %. The results derived from the economic analysis prove this investment as feasible from this point of view given that the IRR (8.5 %) nearly doubles the WACC and the BCR equals 1.5. In addition, this investment is feasible from the financial viewpoint because positive cumulative net cash balances are obtained over the whole project life cycle. This a optimistic—but also realistic—promising scenario in which HCPV turns out to be a real alternative to conventionally generated electricity.

The sensitivity of the IRR and the BCR to each considered factor has been ascertained in both scenarios presented herein. This sensitivity analysis provides clear evidence that annual degradation rate, income tax rate, annual operation and maintenance cost, life cycle of the HCPV system, discount rate, annual direct normal irradiation, and initial investment cost of the HCPV system are ordered from lowest to highest impact. It should be noted that annual final yield, PR, and HCPV electricity unitary price exert the same influence on IRR and BCR stand out that these three factors are function of the annual direct normal irradiation.

The results of the sensitivity analysis shown above may prove useful for government bodies and prospective owners of HCPV systems. Indeed, these results shed light on how changes in existing technical and economic factors that shape a given scenario may influence the profitability of the investment on these systems.

Appendix: Terminology

$[HCPV_{AOM}]_{kWp}$	Normalized per-kWp annual operation and maintenance cost of the HCPV system (€)
$[HCPV_I]_{kWp}$	Normalized per-kWp initial investment cost of HCPV (€/kWp)
Δ_{OM}	Annual escalation rate of the operation and maintenance cost of the HCPV system (%)
Δp_g	Annual escalation rate of the electricity price that is fed to the grid
Δp_s	Annual escalation rate of the electricity price that is consumed from the grid
AV	Annualised value (€)
BCR	Benefit-to-cost ratio
CI_t	Cash inflows over *t* (€)
CO_t	Cash outflows for *t* (€)
d	Nominal discount rate (%)
D	Debt (€)
d_{ec}	Annual dividend of the equity capital or return on equity (%)
DEP	Annual tax depreciation (€)
DEP_t	Tax depreciation during *t* (€)
di_t	Dividends-return on equity capital-paid (€)
DNI_A	Annual direct normal irradiation (kWh/m^2)
DNI_{STC}	Direct normal irradiation in standard test conditions (1 kW/m^2)
DPBT	Discounted payback time (year)
d_r	Real discount rate (%)
EC	Equity capital (€)
E_{HCPVg}	Annual HCPV electricity generated which is fed to the grid (kWh)
E_{HCPVs}	Annual HCPV electricity generated that is used for self-consumption (kWh)
G_{STC}	Global irradiance in standard test conditions (1 kW/m^2)
H_A	In-plane annual global irradiation (kWh/m^2)
$HCPV_{AOM}$	Annual operation and maintenance cost of the HCPV system (€)
$HCPV_{eq}$	Equity-financed fraction of the initial investment (€)
$HCPV_I$	Initial investment cost on the HCPV system (€)
$HCPV_l$	Loan-financed fraction of the initial investment (€)
i	Annual inflation rate (%)

(continued)

(continued)

i_l	Annual loan interest (%)
IRR	Internal rate of return (%)
IRR_n	Net internal rate of return (%)
I_t	Interest charges on debt during t (€)
$I_{t(\text{after-tax})}$	Interests after paying taxes during t (€)
IT_t	Taxes paid on income during t (€)
LR	Learning rate
MIRR	Modified internal rate of return (%)
MNPV	Modified net present value (€)
N	Life cycle of the HCPV system, equal to analysis period (year)
NCB_t	Net cash balance during t (€)
$NCFn_t$	Negative net cash flow during t (€)
$NCFp_t$	Positive net cash flow during t (€)
NCF_t	Net cash flow during t (€)
$NCF_{t(\text{after-tax})}$	After-tax net cash flows obtained during t (€)
N_d	Period of time over which an investment is amortized for tax purposes (year)
N_l	Amortization of loan (years)
NPV	Net present value (€)
p_g	Price at which electricity is sold to the grid (€/kWh)
PR	Performance ratio
p_s	Price at which electricity is bought from the grid (€/kWh)
p_u	HCPV electricity unitary price (€/kWh)
PV [DEP(N_d)]	Present value of the tax depreciation (€)
PV[CI(DPBT)]	Present value of the cash inflows generated over DPBT (€)
PV[CI(N)]	Present value of the cash inflows over the lifetime of the project (€)
PV[CO(DPBT)]	Present value of the cash outflows generated over DPBT (€)
PV[CO(N)]	Present value of the cash outflows overthe lifetime of the project (€)
PV[DEP (DPBT)]	Present value of the tax depreciation over DPBT (€)
PV [$HCPV_{OM}$(N)]	Present value of the HCPV system operation and maintenance cost (€)
PV[NCF (DPBT)]	Present value of the net cash flows generated over DPBT (€)
PV[NCF(N)]	present value of net cash flows (€)
PVIF(N)	$Q(1 - Q^N)/(1 - Q)$
Q	$1/(1 + d)$
Q_A	Annual growth installed capacity (%)
Q_{HCPV}	HCPV world cumulative installed capacity
Q_{OM}	$(1 + \Delta_{OM})/(1 + d)$
Qp_g	$(1 + \Delta p_g)\cdot(1 - r_d)/(1 + d)$

(continued)

(continued)

Qp_s	$(1 + \Delta p_s)\cdot(1 - r_d)/(1 + d)$
r_d	Annual degradation rate in the efficiency of the HCPV panels (%)
r_{HCPV}	Average annual HCPV power growth rate (%)
RI_{Dt}	Repayment instalments on debt (€)
RI_{ECt}	Repayment instalments on equity capital (€)
RI_t	Repayment instalments on funds borrowed (debt and/or equity capital) to fund the investment project during t (€)
RNPV	Real net present value (€)
r_{OM}	Annual escalation rate of the operation and maintenance cost of the HCPV system (%)
S_{VN}	Salvage value of the system at the end of its life cycle (€)
t	Period of time (year)
T	Income tax rate (%)
UCRF(k)	$(1 - Q)/(Q(1 - Q^k))$
WACC	Weighted average cost of capital (%)
Y_f	Annual final yield in a conventional flat-plate PV system (kWh/kWp)
Y_{fHCPV}	Annual final yield in a HCPV system (kWh/kWp)

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