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A methodology for the economic evaluation of photovoltaic systems

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Abstract

This paper presents a model for the economic evaluation of electrical energy production from photovoltaic systems. The economic evaluation model takes into account all the operational incomes as well as all the expenses for the implementation, operation and maintenance of the photovoltaic system. The model uses five financial criteria and is applied for the economic evaluation of an on-grid photovoltaic station at the prefecture of Chania.

Keywords: Photovoltaic plants, Electricity production, Financing schemes, Sensitivity analysis, Cash flows, Internal rate of return, Net present value.

1. Introduction

In modern societies, energy consumption appears to be an increasingly intensive problem, while the undesired effects of the use of conventional energy sources are getting to be more severe. These facts lead the international community to take measures in order to reduce the consequences of those effects. During the last years, the interest for energy production has focused on the use of the Renewable Energy Sources (RES). RES provide an explicitly more “clean” form of energy, which is complied with the demands of international conventions for the environment protection. A type of RES is the photovoltaic (PV) system. PV systems are taking advantage of the solar energy, which they convert directly into electricity. An advantage of PV systems is that they can store the produced energy, using a suitable subsystem of batteries, in order to use it afterwards.

A summary of the experienced results of using PV systems is presented in Korokawa et al. (2001). Vallvé and Serrasolses (1997) present examples of autonomous PV systems that are used in residential territories of Spain. Haas et al. (1999) presented the experiences from the domestic usage of relatively small PV systems in Austria. A survey comparing interconnected PV systems that are installed on the roofs of buildings located in south Spain is given by Castro et al. (2004). Spiegel et al. (2000) investigate the potential for reducing the greenhouse gas emission by using PV stations in the USA. Perez et al. (2004) presented a comparison between the simple payback method and the cash flows method for the economic evaluation of a PV system.

In this paper, a methodology for the economical evaluation of PV systems is presented. This methodology covers every phase of a PV system development, from the preliminary design to the final evaluation of the plantation's performance. In order to implement this methodology, the knowledge of information concerning the site of the plantation, the cost of equipment and several financial parameters, like inflation, are needed.

The proposed methodology is complete and detailed. The methodology makes the evaluation of the PV projects for all the different types of PV applications, namely off-grid PV plants, on-grid PV plants and PV plants for water pumping. The method includes a module for the calculation of the energy delivered by the PV plant and a module for the economic evaluation of the PV plant. Five economic evaluation criteria are used: the internal rate of return, the net present value, the year-to-positive cash flow, the simple payback and the profitability index. Another feature of the proposed methodology is that it provides the possibility to calculate the total reduction of greenhouse gas emissions. This reduction is caused because of the usage of the PV system instead of a conventional power source.

Various users can use the proposed methodology: regulatory authorities (who are evaluating PV project proposals), investors, electric utilities, and policy makers. This methodology can be used worldwide, exploiting certain economical and weather characteristics of a specific location. The proposed method incorporates the current state of the art in several phases of a PV plant establishment, ranging from technical characteristics and the energy delivered by it to the economical evaluation, providing an easy way to follow step by step the development of the PV system. The proposed methodology covers all the three major categories of PV system applications, namely off-grid, on grid and water pumping PV systems. In addition, this methodology offers a direct way to compare two or more alternative options to supply with energy specific applications, including hybrid PV systems. Finally, it should be mentioned that this methodology is developed in a modular manner, providing the way to deal individually with all the parameters needed in order to implement the PV project (e.g. solar and weather data, technical data, economical data, etc).

The paper is organized as follows: Section 1 briefly describes the PV systems. In Section 3, the proposed methodology for the economic evaluation of PV systems is described in detail and special features of it are pointed out. In Section 4, the financial evaluation process of this methodology is analytically presented, underlining the mathematical framework adopted. Section 5 describes an implementation of the proposed methodology together with the obtained results. Section 6 concludes the paper.

2. Photovoltaic systems

2.1 Photovoltaic phenomenon

PV systems collect solar energy and transform it directly into electricity. The *photovoltaic phenomenon* is taking place when solar radiation reaches an appropriate material surface that is used in PV systems. Semiconductor materials, like Si, Ge, GaAs, and CdS are used to construct semiconductors' surfaces. When solar radiation reaches those surfaces, it causes the release of the external electrons of the atoms, which are free to move in every direction, producing in this way electrical current. This phenomenon is called photovoltaic phenomenon and this kind of contact between two semiconductors for electricity production is called *solar cell* [Kagkarakis, 1992].

2.2 Photovoltaic system components

The smaller structural unit in every PV system is the *solar cell*. In order to achieve the desired electricity output, a combination of many solar cells is used. This formation is called *PV module*. The number of solar cells that is used depends on the desired voltage that has to be achieved.

In cases that the electrical power demands, in several applications, is significantly big, the usage of PV panels is recommended. *PV panels* are pre-constructed units ready to be installed and are composed of several PV modules. In some applications though, the demand in electrical power requires the use of a *PV array*, which is a group of interconnected PV modules or PV panels. On the other hand, there are some applications that involve the use of a combination of several PV arrays, composing in this way a *PV park*.

It's worth mentioning that the so-called PV generator comprises the basic component of a PV system. A *PV generator* generates the electrical power in the framework of a PV system. It consists either of only one PV module or a PV panel. In larger installations, however, it consists of several groups of PV modules or PV panels.

An important component of a PV system is the *DC-AC inverter*. This inverter is used to invert the DC voltage produced by the PV system into AC voltage.

In many cases of PV systems, there is a need to store the produced energy, in order to use it afterwards (e.g. during rainy days or during nights). The storage of the produced energy is implemented by using appropriate batteries, which along with their control unit comprise the energy storage system.

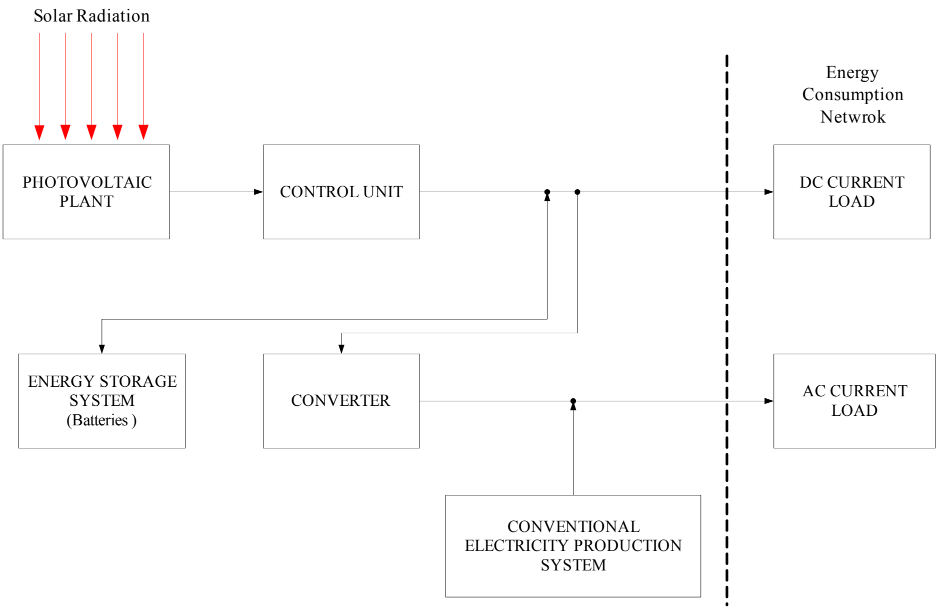

Figure 1: *General layout of a photovoltaic plant.*

It should be mentioned that in several occasions of PV systems, there might be a need for using a conventional energy production system (e.g. diesel generators, natural gas, gasoline, etc) along with the PV system, in order to cover the energy demands of the plant. These kind systems are known as hybrid PV systems.

In Figure 1, the general layout of a PV installation is shown.

2.3 Photovoltaic applications

There are four main categories in which PV technology can be implemented [IEA]:

1. *Off-grid domestic PV systems*: this category involves the off-grid PV systems that are used to supply domestic devices.
2. *Off-grid non-domestic PV systems*: PV systems that are not interconnected with the main power supply network and they are used in non-domestic applications, e.g. telecommunications, water pumping, weather data registration, etc.
3. *Grid connected distributed PV systems*: PV distributed systems that are interconnected with the main power supply network. They are used to provide energy to buildings or residential territories. The special feature of these systems is that the redundant produced electrical energy can feed the main power supply network through an inverter.

4. *Grid-connected centralized PV systems*: PV systems that are grid connected and centralized. These systems are primarily used for two reasons: as an alternative energy source against conventional centralized energy sources and to support the main power supply network.

A more analytical categorization can be found in [Tsoutsos et al. (2004)].

3. Economic evaluation methodology

3.1 General

In this paper, a methodology is proposed in order to evaluate if the investments in PV plants are profitable or not. The methodology offers the possibility for the evaluation of all types of PV plants, as they have been described in section 2.3. More analytically, this methodology deals with three main types of PV systems:

1. Off-grid PV systems.
2. Grid connected PV systems.
3. Water pumping PV systems.

In this section, all the necessary inputs for the methodology are described and the basic calculations for each type of a PV plant are given. Finally, the economic evaluation method is presented.

3.2 Inputs

The necessary inputs for the proposed methodology include technical characteristics of the equipment, weather data of the plantation site, cost data for the equipment and the activities related to the development of a PV plant. The inputs also include economical, financial and accounting data that characterize the operation of a particular PV plant.

In general, these inputs may be grouped into three main categories:

1. Technical characteristics of the PV plant.
2. Characteristics of the plantation site.
3. Economical and financial inputs.

3.2.1 Technical characteristics of the photovoltaic plant

This category includes the following input parameters: the type of the investigated PV plant, the nominal efficiency of the PV modules, the nominal total installed capacity of the PV plant, the tilt of the installed PV modules, the efficiency and the capacity of the inverter(s) and the characteristics of the energy storage system (if it exists). Other inputs are the energy consumptions of the supplied devices or the fuel consumption by a supporting conventional energy production system.

3.2.2 Characteristics of the plantation site

This category includes the following input parameters: the weather data of the plantation site, the latitude of the site, the solar radiation density that the site is exposed to and the annual average temperature of the site. These inputs will help in the calculation of the available solar radiation to the PV system, which is an important parameter in order to compute the overall efficiency of the plant.

3.2.3 Financial parameters

In this third category of inputs, the parameters regarding the economic data for the evaluation of the PV plant are given. Cost data about the equipment (e.g. cost of PV modules, cost of inverter(s), electrical equipment etc) are defined in this category. The costs of the preliminary design and the development of the PV plant are also defined in this category of inputs.

Financial parameters also include the discount rate (with which the performance of the PV plant will be compared), the debt ratio and the debt rate, the taxation rate and the governmental or other grants. Moreover, the price that the produced energy is sold, the energy escalation rate, the national inflation and the expected lifetime of the PV plant (during which the net annual cash flows are calculated) are given in this category.

3.3 Evaluation results

In every PV plant, except for the on-grid PV plants, there is a need for the load consumption to be known. Therefore, there is a need to calculate the AC and DC energy demands that have to be served by the PV plant. These AC and DC energy demands are calculated as follows:

$$E_{DC} = \sum_{m_i} \left(L_{DC} \cdot H_d \cdot \frac{N_{d/w}}{7} \cdot N_{days} \right)_{m_i} \qquad E_{AC} = \sum_{m_i} \left(L_{AC} \cdot H_d \cdot \frac{N_{d/w}}{7} \cdot N_{days} \right)_{m_i} \quad \textbf{(1)}$$

where L_{AC} and L_{DC} are the AC and DC loads respectively, H_d are the hours of use of the application in a daily basis and $N_{d/w}$ are the days of use of the application in a weekly basis for every month of use m_i.

The overall PV system efficiency is:

$$n_{PV} = n_{Tc} \cdot \left(1 - P_{PV\,losses}\right) \cdot \left(1 - array\,controler\,index\right) \cdot \left(1 - P_{losses}\right) \quad \textbf{(2)}$$

where n_{Tc} is the temperature corrected efficiency in temperature T (%), $P_{PV\,losses}$ (%) are the losses in the PV system, $array\,controler\,index$ is an index that takes the value

1 when the maximum power point tracking (MPPT) system is used in the PV system and the value 0.75 otherwise and P_{losses} (%) are the losses in the whole PV plant.

The total area of the PV plant is calculated as follows:

$$S_{array} = \frac{P_{array-nom}}{n_{array-nom}} \quad \textbf{(3)}$$

where $P_{array\text{-}nom}$ (kWp) is the installed capacity of the PV plant and $n_{array\text{-}nom}$ (%) is the nominal efficiency of each of the PV modules of the PV plant.

3.3.1 Off-grid photovoltaic plants

In off-grid PV plants, the total amount of the electrical power that is delivered can be calculated in connection with the served application. When the energy consumptions of the supplied devices are known, the total AC and DC energy demands can be calculated by equation (1). If there is one or more devices that use AC current, there is a need to use one or more inverters, the capacity and efficiency of which are calculated. The designer of the PV plant chooses the number of inverters that will be used in the PV plant. Knowing the inverter(s) efficiency, the equivalent energy demand in DC current can be calculated. In case that the produced energy by the PV plant exceeds the calculated energy demands, then the excess of energy is calculated by the difference of the total energy demands from the total produced energy by the PV plant. Finally, the capacity of the energy storage system (batteries) is calculated and proposed (when such system is used in the PV plant).

Usually, in off-grid PV plants, the use of an energy storage system is needed, in order to provide with energy while PV plants are not able to produce more energy (e.g. during the night). The capacity (Ah) of the used energy storage system is given by:

$$Batt_{m_i-capacity} = \frac{1000 \cdot \left(L_{DC} + {L_{AC}}/{n_{inv}} \right) \cdot Batt_{autonomy}}{Batt_{DOD} \cdot \left(1 - F_{capacity\,dlvd}\right)_{m_i}} \quad \textbf{(4)}$$

where $\left(1 - F_{capacity\ dlvd}\right)_{m_i}$ are the portions (%) of the nominal capacity that are not delivered for each month m_i, $Batt_{autonomy}$ is the autonomy (days) of the batteries used, $Batt_{DOD}$ is the maximum depth of discharge (%) of the batteries used and L_{AC} and L_{DC} are the AC and DC loads respectively that the application consumes.

The total energy delivered by the PV plant is:

$$RE_{dlvd-m_i} = \sum_{m_i} \left(E_{cont-met-dir-PV} + E_{matched-PV} + E_{met-batt} \right) \quad \textbf{(5)}$$

where m_i is the month of use, $E_{cont-met-dir-PV}$ is the "constant" (during day-time) part of energy demand that is achieved directly by the PV generator, $E_{matched-PV}$ is the part of energy demand that is served directly by the PV generator and $E_{met-batt}$ is the part of energy demand that is served by the energy storage system. $E_{cont-met-dir-PV}$ can be served directly either by the PV generator or by the energy storage system.

3.3.2 Grid connected photovoltaic plants

In the case of grid connected PV plants, there is a need to use one or more inverters, in order to invert the produced by the PV plant DC current into AC current, which can be supplied directly to the main power supply network. The capacity of the inverter(s) used is calculated. In such PV plants, there is no need to use an energy storage system, because the excess of the produced by the PV plant energy can be supplied directly into the main power supply network. Furthermore, any additional energy demands can be served directly by the main power supply network.

The total energy delivered by the PV plant is calculated as follows:

$$E_{AC-dlvd} = \sum_{m_i} \left(S_{array} \cdot H_{tilted} \cdot n_{PV} \cdot n_{inv} \cdot N_{days} \right)_{m_i} \quad \textbf{(6)}$$

where S_{array} is the total PV array area (m^2), H_{tilted} is the monthly average daily radiation in the PV module plane ($kWh/m^2/day$), n_{PV} is the overall PV array efficiency (%), n_{inv} is the inverter(s) efficiency (%) and N_{days} is the number of days of each month m_i.

3.3.3 Water pumping photovoltaic plants

The water pumping PV plants are a special category of PV plants that are used for water pumping. In these PV plants, the produced energy is used to supply the solar pump. The total energy demands are calculated considering the amount of water that has to be pumped. In case that the solar pump uses AC current, there is a need to use one or more inverters, because the PV plant produces directly DC current.

These PV plants may or may not use an energy storage system. The calculation of the characteristics of the energy storage system (if it exists) is the same with the respective case of off-grid PV plants.

The total energy delivered by the PV plant supplied to the solar pump is:

$$PE_{dlvd} = \sum_{m_i} \left(N_{days} \cdot MIN\left(E_{avail-pump} \cdot n_{pump},\ Eq_{pump-dmd-d} \right) \right)_{m_i} \quad \textbf{(7)}$$

where N_{days} is the number of days of each month m_i, $E_{avail-pump}$ is the available energy to the solar pump, n_{pump} is the efficiency of the used solar pump and $Eq_{pump-dmd-d}$ is the equivalent daily energy demand of the solar pump that is proportional to the water level in the pumping source.

4 Financial evaluation

In this Section, the proposed economic evaluation methodology will be presented. The initial costs of the investigated project, the potential savings resulted by the PV plant operation, the annual incomes and outcomes, the taxation and the PV plant's equipment depreciation are issues to be analyzed. The results of the economic evaluation are derived by the use of five financial evaluation criteria that are applied to the results of the annual cash flows of the project.

4.1 Initial costs

The initial costs of the project include activities such as the feasibility study, the preliminary design of the facility, the purchase of the equipment and the salary and training of the staff needed. In this methodology, several periodic costs are included, such as the maintenance of the facility, the replacement of the equipment, the operational costs, taxes and insurance costs etc.

4.2 Annual savings

The potential savings by the operation of the PV plant are taken into account in an annual basis. Such savings could be resulted by the replacement of some type of fuel used before the PV plant installation. Furthermore, they may be derived by the compensation caused by the reinforcement of the local power energy supply network or the credits granted because of the reduction of the greenhouse gas emissions.

4.3 Annual cash flows

The calculation of the annual cash flows of the PV project plays an important role in order to achieve reliable results using the proposed methodology. For this calculation, all incomes and outcomes of the project have to be taken into account, in order to calculate the total annual income and outcome cash flows during the project's lifetime. For each year that the PV plant operates, the total net annual cash flows are calculated as the difference between the annual income and outcome cash flows of the respective operating year. The lifetime of the project is defined to start at year 0.

The annual income cash flows of the project can be calculated by summing all types of income resulting by the operation of the PV plant. The proposed methodology takes into account the following types of income:

- *Energy sources savings*: this kind of savings is calculated for each operating year of the PV plant. For the year 0, it is defined to be equal to the product of the annual energy savings and the unit energy cost that is saved. The unit energy cost is considered to be zero for year 0. For each year after year 0 it is equal to the product of the annual increment factor and the amount of savings of the former year. The annual increment factor equals to $(1 + r_{E\text{-}cost})$, where $r_{E\text{-}cost}$ is the energy cost escalation rate and it is equal to 1 for year 0.
- *Capacity savings*: for the year 0, this kind of savings is equal to zero. For each one of the following years until the end of the project's lifetime it is calculated as the product of nominal installed capacity of the PV plant and the annual capacity saving (which is defined by the institutional frameworks of each country) and with the factor $(1 + f)$, where f is the national inflation. The factor $(1 + f)$ equals to 1 for year 0.
- *Credits for the renewable energy production*: for the year 0, these credits are defined to be equal to zero. For each one of the following years of the project's lifetime, they are calculated as the product of the renewable energy production credit and the annual increment factor for the renewable energy production credit. This increment factor is equals to 1 for year 0 and to $(1 + r_{RE\text{-}credit})$ for each one of the following years, where $r_{RE\text{-}credit}$ is escalation rate of the annual renewable energy production credit.
- *Incomes due to greenhouse gas emissions reduction*: this kind of income is equal to zero for year 0. For each one of the following years, until the end of the project's lifetime, these incomes are calculated by the product of the annual income due to greenhouse gas emissions reduction and the increment factor $(1 + r_{GHG})$, where r_{GHG} is the escalation rate of the annual greenhouse gas emissions reduction credit. This increment factor equals to 1 for year 0.
- *End of project's lifetime value*: this value depends on the project's characteristics. The final value that is taken into account is equal to $E_{value} \cdot (1 + f)^{PL}$, where E_{value} is the end of project's lifetime value, PL is the project's lifetime and f is the national inflation.
- *Grants*: in many cases they correspond to the state grants for the development of PV projects.

The annual outcome cash flows of the project are calculated in a similar way. The possible outcome types for the PV plant are described next:

- *Initial costs*: they are the costs for the feasibility study, the purchase of the equipment, the plant's installation, etc.
- *Energy supply costs*: they are the costs for the energy supply to the PV plant. These costs are multiplied by an annual increment factor that equals to $(1 + f)^n$ for each year n between 1 and PL, where PL is the project's lifetime and f is the national inflation.

- *Operation and maintenance costs*: for the year 0, these costs are equal to zero, while for each one of the next years of the project lifetime, these costs are calculated form the formula $C_{O\&M} \cdot (1+f)^n$, $1 \le n \le PL$, where $C_{O\&M}$ are the costs for the operation and maintenance.
- *Debt service*: these costs refer to the reimbursement of the project's debt, if there is one. The annual debt payments are calculated by:

$$d_p = \frac{-\text{Project}_{debt} \cdot r_{debt} \cdot \left(1 + r_{debt}\right)^{Debt_{term}}}{\left(1 + r_{debt}\right)^{Debt_{term}} - 1} \qquad \textbf{(8)}$$

  where r_{debt} is the debt interest rate and $Debt_{term}$ is the debt reimbursement term. For the year 0, there are no such costs for the project.
- *Periodic costs*: these costs concern periodic costs of the project, such as equipment replacement, the plant's maintenance and inspection etc. These costs are calculated at the time that they expected to be occurred. For instance, if a battery replacement is expected to occur at year n, where $1 \le n \le PL$, then the cost for this replacement is multiplied by the factor $(1 + f)^n$, where PL is the project's lifetime and f is the national inflation.

It's worth mentioning that the annual cash flows are calculated before and after taxation is applied. In general, there is the possibility to use the right of carry forward and the possible equipment depreciation in the cash flows calculation.
Finally, let us note that the first cumulative cash flow is equal to the first net cash flow (*incomes - outcomes*), while each one of the following cumulative flows, until the end of the project's lifetime, are equal to the sum of the present net cash flow with the former one. The cumulative net cash flows are calculated always including taxation, when it is applied.

4.4 Economic evaluation criteria

The economic evaluation of the PV plants is implemented with the use of five financial evaluation criteria:

1. Internal rate of return (IRR).
2. Net present value (NPV).
3. Year-to-positive cash flow.
4. Simple payback.
5. Profitability index.

Analytic information about these criteria can be found in Appendix A.

5. Application of the economical evaluation methodology

In this Section, an application of the proposed methodology is presented. This application concerns the installation of a PV station in the prefecture of Chania, Crete, for electrical power production.

5.1 Problem definition

The case of the installation of a PV station at the prefecture of Chania, Crete will be discussed in this section. The PV station will be handled as an investment plan that will be evaluated. More specifically, the parameters that characterize the installation of this PV station are defined in order to formulate several Base Cases for its analysis. Then a sensitivity analysis follows for the results of the evaluation. This analysis is taking place into two steps. In the first step, nine parameters of the project are analytically examined. In the second step, a sensitivity analysis is carried out, using financing schemes for those parameters that resulted in a significant change in the results of the analysis during the first step. The financing schemes depict the way that the project is funded and they follow the general scheme: *Capital Investment – Lending - Grants*. For instance, the financing scheme 40% - 40% - 20% shows that the project is funded by 40% from capital investment, by 40 % from lending and by 20% from state or other grants to the project.

Referring to the installation site, the territory of Chania, Crete, has a latitude of $\varphi = 35.3°$ and it has 2,808 hours of sunshine every year [National Observatory of Athens], while it is exposed at 1,7 MWh/m^2 of solar radiation, on horizontal plane, in an annual basis [Lalas et al. 1982].

The investigated PV station is interconnected to the electrical power supply network of Crete and it will provide all the produced energy to it. Therefore, there is no need to use an energy storage system. The produced energy by the PV station is sold at a feed-in tariff of 77 €/MWh [Regulatory Authority for Energy]. For the development of this PV station, it is assumed that the total costs for it should not be more than € 1,500,000.

5.2 Results

Taking into account the values of the parameters for the Base Case, it is calculated that the PV station will have a total installed capacity of 120 kWp. 750 PV modules will be used; each one of them will have a nominal capacity of 160 W and an efficiency of 12.7%. Furthermore, 8 inverters will be used; each one of them will have a nominal capacity of 15 kW and an efficiency of 94%. The tilt of the chosen PV modules will be $\beta = 30°$, which is close to the site's latitude (therefore it is considered to be optimal). The losses in the PV system are estimated to be around 5%, while the losses in the whole PV plant are estimated to be 7%. The total estimated PV array area is expected to be around 945 m^2 and the total energy delivered by the PV station is estimated to be around 161 MWh per year. The individual characteristics of the PV station are shown in Table 2.

The analysis has shown that the total costs for this PV station will be around € 1,277,350. The financing schemes that are examined for the economical evaluation are the following: 60%-0%-40%, 60%-40%-0%, 40%-20%- 40% and 100%-0%-0%. The expected lifetime of the investigated project is considered to be 25 years. The economical parameters used for the analysis of each financing scheme are shown in Table 3.

***Table 2**: Technical characteristics of the PV station (Base Case).*

Characteristic	**Value**
Total installed capacity	120 kWp
Number of PV modules	750
Efficiency of each PV module	12.7 %
Efficiency of each inverter	94 %
Expected PV array area	944.9 m^2
Delivered energy by the PV station	160.75 MWh/year

***Table 3:** Financial parameter values for each investment plan (Base Case).*

Financial parameter	**Financing schemes**			
	60%-0%-40%	60%-40%-0%	40%-20%-40%	100%-0%-0%
Discount rate	12%	12%	12%	12%
Inflation	3.5%	3.5%	3.5%	3.5%
Debt rate	8.5%	0%	8.5%	0%
Debt term	10 years	0 years	10 years	0 years

***Table 4:** Financial evaluation results for each investment plan (Base Case).*

Evaluation Criterion	**Financing schemes**			
	60%-0%-40%	60%-40%-0%	40%-20%-40%	100%-0%-0%
Internal rate of return (IRR)	22.6%	15.3%	26.6%	13.%
Simple payback period	5.0 years	8.3 years	5.0 years	8.3 years
Time to first positive cash flow	4.6 years	8.8 years	4.0 years	7.9 years
Net present value (NPV)	€ 674,489	€ 251,722	€ 708,760	€ 183,548
Profitability index	0.55	0.34	0.72	0.15

The economic evaluation results using the five economic criteria introduced in Section 4.4, for each financing scheme and for each Base Case, are shown in Table 4.

The results presented in Table 4 seem to be very encouraging. More specifically, the IRR takes values bigger than 12%, which is the value for each Base case, for each investigated financing scheme. This fact leads to the conclusion that the investment in this PV plant is attractive. In specific, the IRR takes relatively high values for the schemes that involve lending. It is also concluded that small loans improve the IRR.

The results are also attractive for the simple payback time and the year-to-positive cash flow time. More specifically, the mean simple payback time is about 5 years for the schemes that do not involve lending, while the respective time is close to 8.5 years for the rest schemes. This result could possibly be explained by taking into consideration the time needed for the loan settlement. The mean time for the occurrence of the first positive cash flow (year-to-positive cash flow) is close to 4.5 years for the schemes that involve lending and close to 8.5 years for the rest of them, in correspondence with the results for the simple payback time.

The results for the NPV calculation, concerning all the investigating financing schemes, show that the investment in this PV plant seems to be profitable. More specifically, the NPV takes positive values in all these schemes. Especially for the schemes that do not involve lending, but involve grants to the project, the NPV arises to relatively high positive values, because in these cases the amount of the invested capital by the investors is reduced.

Table 5: Sensitivity analysis parameters for comparing two scenarios with the Base Case.

No	Parameter	Symbol	Base Case	Scenario 1	Scenario 2
1)	PV array modules losses	$P_{array-loss}$	5%	7.5 %	10 %
2)	PV system losses	P_{losses}	7 %	5%	9%
3)	PV modules tilt	β	30°	45°	60°
4)	PV modules cost	$PV_{array-\cos t}$	€ 643,560	€ 617,818	€ 669,302
5)	Inverters cost	$Inv_{\cos t}$	€ 216,000	€ 207,360	€ 224,640
6)	Renewable energy production escalation rate	$r_{RE-credit}$	1 %	1.5%	2 %
7)	Inflation	f	1.4 %	2.5 %	4 %
8)	Discount rate	k	12 %	10 %	9 %
9)	Expected project lifetime	PL	25 years	20 years	30 years

Finally, the profitability index takes positive values for each one of the investigated schemes. This fact shows that the investment in this certain PV plant might be profitable. It should be noted that this index takes higher positive values for the schemes that involve grants to project, but do not involve lending at the same time.

Then, sensitivity analysis is carried out for each financing scheme, taking into account the values presented in Table 5. The results of the sensitivity analysis are presented in Table 5. This analysis has shown that the PV modules cost, the discount rate and the project lifetime have the biggest impact on the economic evaluation results. The sensitivity analysis has also shown that the state or other grants to the project significantly contribute to the project financial viability. In addition, the analysis has shown that the lending could contribute in a positive way to the project's financial viability. It's worth mentioning that the more the project lifetime, the better the economic evaluation results. Finally, the selection of the debt term period for extended periods (8 years or above) improves the economical evaluation results, compared to the results for smaller debt term periods.

The observation that the evaluation results are improved for extended lifetime periods of the project could be explained by the fact that the operational incomes of it for such lifetime periods are enough to cover a significant part of the operational and other costs of it (loan and several other costs).

6 Conclusions

The PV systems technology is a form of renewable energy production that is rapidly developing globally. The source for the PV energy production is the solar energy, therefore the impacts to the environment are considerably little. Countries around the world adopt PV systems as a reliable alternative form of energy production, even though a small portion of sunshine during the day characterizes several of these countries.

In our days, the purchase and installation of PV systems are still very expensive. The purchase of the appropriate equipment, especially the PV modules, could arise up to 50% of the total initial costs of the PV system. This fact could be balanced by the relatively high state grants to such projects, which could arise up to 40% of the total initial costs of the project in many countries around the world.

In this paper, a methodology for the economic evaluation of PV plants is presented. This methodology takes into account all the installation phases of every PV plant type. The economic evaluation is based on the individual technical parameters of every PV plant. In the evaluation process, the initial costs of the PV plant and the annual cash flows resulted by the operation of the PV plant, play a significant role. The economic evaluation is implemented with the use of five financial criteria, most of which take into account the expected PV plant lifetime and the diachronic value of money.

The proposed method is applied for the economic evaluation of an on-grid photovoltaic station at the prefecture of Chania and the main conclusions from this application are the following:

- The cost for the purchase and installation of a PV plant is still high.
- The PV project lifetime plays an important role in the financial viability of PV plants.
- The value for the discount rate could have significant impacts on the PV plant's performance. This value is important because it is the conventional rate of an alternative (and secure) investment, with which the performance of the PV plant is compared.

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Appendix A

The Internal Rate of Return (IRR) represents the profits and other benefits of the PV plant, expressed in the portion of the annual performance of the initial costs of the project. The IRR is calculated by the following equation [Apseridou (2002)]:

$$0 = \mathrm{I}_{cap} + \sum_{t=1}^{n} \frac{C_t}{(1+IRR)^t} + \frac{S_{PL}}{(1+IRR)^{PL}} \qquad \textbf{(A.1)}$$

where I_{cap} is the project's equity, S_{PL} is the remaining value of the project, C_t is the net cash flow of the project at year t and PL is the expected lifetime of the project.

Net Present Value (NPV) expresses the present value that a series of cash flows will have in the future. The NPV is calculated by [Zopounidis (2000)]:

$$NPV = \sum_{t}^{PL} C_t \cdot (1+k)^{-t} - I_{cap} \qquad \textbf{(A.2)}$$

where C_t is the net cash flow of the project at year t, *k* is the discount rate, I_{cap} are the capital investments of the project and PL is the expected lifetime of the project.

The Year-to-Positive cash flow time is the time when the first positive net cash flow occurs. In many cases, the calculation of the exact time of the first positive net cash flow occurrence is defined by using linear interpolation between those two years.

The Simple Payback method shows the time that the investors will collect back their invested capital to the PV plant. The time counts from year 0. The payback time is calculated by [Zopounidis (2000)]:

$$SP = \frac{I_{cap} - I_G}{p - d_p - E_{yr}} \qquad \textbf{(A.3)}$$

where I_{cap} are the capital investments of the project, I_G are the grants to the project, p are the annual savings of the project, d_p is the annual debt payment of the project and E_{yr} is the annual operating cost of the project.

The Profitability Index, PI, represents the comparison between the project's NPV with the capital investments of it, I_{cap} [Zopounidis (2000)]:

$$PI = NPV / I_{cap} \qquad \textbf{(A.4)}$$

Positive and bigger than 1 values of this index show a good economic performance of a project.