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Feasibility evaluation of residential photovoltaic self-consumption projects in Peru

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ABSTRACT

The promotion of large photovoltaics projects is a trendy reality in South America, but the potential to be a solution for distributed generation through small-medium systems connected to the grid is an under-exploited reality. In this paper, a techno-economic analysis of three small PV systems located in different cities of Peru is undertaken. Based on real measured energy data, two different scenarios are going to be economically evaluated: one that resembles a lease contract and another in which a residential owner promotes its installation. Levelised Cost of Electricity results vary from 0.10 USD/kWh to 0.20 USD/kWh, showing that only in the city of Arequipa a cost-competitive result is achieved, whereas in Tacna and Lima it depends on the financing mechanism chosen. Underline that in the city of Lima grid-parity may not be achieved until 2027. In addition, companies selling PV energy within the homeowner facilities, despite resulting in LCOE values lower than the electricity tariffs, they may face non-profitable situations. Therefore, only if banks incorporate the financing of small-scale grid-connected photovoltaic projects into their product portfolio and there is a government policy to promote this technology, small PV projects may be a feasible solution for all residential users in Peru.

1. Introduction

Nowadays, photovoltaic (PV) has become a mature technology. The latest installation figures confirm its consolidation not only in the renewable energy sector, but also in the field of electricity generation. Moreover, the projected outlook not only ensures this trend, but also improves the current tendency for installed power ratios and penetration levels. Within this pattern, South American countries are playing a major role in the adoption of this technology within their energy generation mix [1–3].

Among the Latin American countries, the Peruvian economic growth rates stand out, which implicitly implies an increase in energy demand [4–6] and the need to undertake important changes in the electricity distribution system and the origin of their sources [7,8]. The total consumption of grid electricity in Peru reached a new record in 2017 (48,993.25 GWh) where approximately 73% of the energy sources in Peru came from fossil fuels such as oil and natural gas [9].

In this scenario, photovoltaic technology could be positioned as a promising alternative for the country's energy supply that may help the sustainable energy transition of the country [10]. Recent publications expose the advantages of implementing policies that encourage the use of photovoltaic technology in Peruvian cities. For example, in Ref. [11] there is a study carried out in different locations in the country which states that the promotion of roof-integrated photovoltaic systems would significantly reduce conventional energy consumption and greenhouse gas emissions by 10–24% over a period of 10 years.

However, based on the state of the art concerning the feasibility of PV projects and also the contextualization of the Peruvian PV market, it is necessary to assess about the feasibility evaluation of residential photovoltaic self-consumption projects, as it is a market yet to be exploited in the country.

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1.1. State of the art: economic feasibility of PV projects

In the literature there is an enormous availability of different studies concerning the economic feasibility of on-ground grid-connected large PV projects [12–16] or medium sized ones [17–19].

In addition, there is also abundant literature in relation to the economic analysis of photovoltaic systems integrated in buildings or small commercial businesses [20–23], and recently, a multitude of publications have emerged analyzing the economic viability of small residential photovoltaic systems connected to the grid, where the self-consumption paradigm is considered [24–30].

There are also manuscripts where different remuneration mechanisms are analysed depending on the management of the photovoltaic energy generated and the applicable retribution scheme [20,25,31,32].

Moreover, a proper economic analysis may also influence on improvements in the design strategies of either residential PV systems or large PV installations in order to have a balance between the maximization of the energy generated, the cost-competitiveness of the electricity generated and the profitability of the investment [33–36].

Also worthy of attention are those articles that deal with the influence of policies and legislation on the profitability of photovoltaic plants [37–40]. Of note are the studies published for Spain, where the retroactive application of certain laws affecting the remuneration of the energy generated by photovoltaic installations has had a major impact on the sector [41–44]. Moreover, some of these measures influenced not only on the profitability, but also on the energy performance, where in some cases, the owner of the plant might find it more profitable to leave the preventive maintenance of its PV plant that to maximize its production [18,45].

The previous studies are scattered throughout the world, and one can deduce how photovoltaic technology has matured to such an extent that over the years it has become an economically viable energy alternative, both for large photovoltaic plants and for residential use. However, it is noteworthy that only few economic residential PV studies are published referred to South America [46,47] and there is no document, to the best of the authors' knowledge, analysing in-depth the economic viability of photovoltaic systems in Peru.

1.2. Peruvian PV market

The renewable energies in Peru have not had a complete acceptance and development in the country. The main reason comes from several barriers in the regulatory framework and the public auctions that may have a negative impact in the electricity bills paid by the standard users [48].

In the case of the photovoltaic market, it has always been linked to the development of small home systems for areas isolated from the grid. The first PV rural electrification project in Peru was a German technical cooperation project which took place in the period ranging from 1986 to 1996 in the Department of Puno, where circa of 500 solar home systems where installed in a "pre-commercial" framework, i.e. subsidized [49].

This rural electrification is usually based on small stand-alone PV systems or micro-grids [50–52]. In any case, the promotion of these installations are either subsidized [53] or included in the electricity bill [54].

Among these actions, the implementation of the National Rural Electrification Plan [55] stands out in Peru. This program, which aims to achieve 100% electrification in the country, is focused especially at the populations that are in the most remote places, which have high poverty rates, and where it is known that the conventional electricity grid will not arrive in the next ten years [56]. It is estimated that approximately 500,000 homes can be electrified using PV technology in the following years [57].

In addition to the rural electrification reality, the promotion of large grid-connected PV systems in the south of the country is happening at the same.

Within the total consumption of electricity from the grid in Peru previously identified, only 0.51% had a photovoltaic origin [58], which mostly comes from this mentioned large systems recently installed in the South.

The most common remuneration mechanism for these large PV plants is that of long-term power purchase agreements (PPA) as a result of public auctions promoted by national Governments, which have been very frequent in Central and South America recently [6,59,60]. The latest auctions promoted by the Peruvian Government have been assigned to an average PPA of 49 USD/MWh for the installations of two systems with a total power of 185 of MW [3,61]. After the fourth renewable energy auction resolved in February 2016, with which the contribution to the national energy mix of non-traditional renewable energies is expected to be close to 5% during 2018, approximately 300 MW of photovoltaic energy are plugged to the National Interconnected Electric System (SEIN), as large production plants. These systems, seven in total, operate in the southern part of the country (regions of Arequipa [62,63], Tacna [64] and mainly Moquegua [65–68]). Unfortunately, there is no known article describing the operation and performance of these systems, although some of these plants have been integrated into the SEIN for more than 5 years.

Therefore, it can be said that in the Peruvian market coexists two different realities in terms of photovoltaic technology, where a total of 797 million dollars has been invested in solar projects until 2017, of which 75% comes from large-scale projects and the remaining 25% belongs to rural electrification [69]. It is estimated that by 2020 there will be an accumulated PV power of 540 MW installed in the country, where the investment potential could amount to 1350–1610 million USD [70]. On the other hand, other reports estimate that by 2020, the investment amount will be around 524 million USD, whereas this quantity will increase in 241 million USD and 96 million USD for the periods 2021–2030 and 2031–2040 respectively [71].

However, besides these two existing realities in the Peruvian PV market and their potential, the implementation of small-medium sized PV systems connected to the grid is a missing gap within the country, as there is still no specific legal framework and no financing solutions are available [72]. Nonetheless, a notable increase in the number of photovoltaic systems integrated into the small- to medium-sized grid is expected following the approval by the Peruvian government of the Supreme Decree on the Regulation of Distributed Generation (Ministerial Resolution No. 292-2018-MEM/DM). The deadline for the submission of comments was October 30th, 2018.

Although the high potential for the installation of such systems has been extensively documented [73] and the performance of PV systems and even an economic evaluation has been studied elsewhere in the Latin American context [74,75], there is a general shortage of scientific documents analyzing the energy and economic viability of this type of systems for the case of Peru. Only in Ref. [76] there is an assessment for residential PV in Peru but whose economic analysis is incomplete in the number of economic criteria used and in the selected locations.

Despite the promotion of large photovoltaics engineering projects is a trendy reality in South American countries, the potential to be a solution for distributed electricity generation through small (1–10 kW) and medium (10–100 kW) sized systems connected to the grid is an under-exploited reality in Peru from the market point of view. This manuscript attempts to fill the gap in the economic assessment in Peru between large and stand-alone PV systems.

1.3. Layout of the manuscript

According to the scenario glimpsed previously, an economic analysis will be carried out of a small PV system, typically dimensioned for its residential integration. To this end, different financing scenarios will be proposed for three locations, with the objective of evaluating the economic feasibility of integrating these systems into the residential segment, as it is currently happening in many parts of the world, where the self-consumption is a tendency.

Firstly, the performance of the three PV systems proposed will be described in chapter 2, with the added value that the data shown are based on real measurements and can therefore provide valuable insights to prospective owners or small energy companies. Chapter 3 explains the methodology for estimating the unitary generation price of these systems and their economic assessment, assuming different financing scenarios, depending on whether the systems are promoted by a private residential owner or a small-medium company (SME) whose objective may be the leasing of the system. In chapter 4, the Levelised Electricity Cost (LCOE) results will be compared with the electricity tariff applicable to a standard domestic user to assess the cost-competitiveness of the technology, uncovering some uncertain profitable scenarios, but also showing that the trend of previous years has been reversed in some cases [77]. In addition, the results of conventional methods for the economic analysis will be shown, i.e. Net Present Value (NPV) and Internal Rate of Return (IRR), where the allocation of the sales price of the generated PV electricity will be crucial. Finally, a sensitivity analysis is proposed to assess the extent to which the loan interest rate or the cost of capital should be reduced in order to revert the non-grid-parity scenarios detected.

2. Description and performance of the PV systems

Under the framework of the international cooperation project “Emerging with the Sun”, led by the University of Jaen (Spain), three different PV test facilities have been installed and monitored. In April 2015, two monocrystalline silicon PV systems were commissioned in Tacna and Arequipa, located in southern Peru, whereas the third PV installation, located in the city of Lima, has been in operation since May 2016 and is made of Sharp thin-film modules (see Fig. 1).

Fig. 1. PV testing facilities (from left to right: Arequipa, Tacna, Lima).

The location of these PV plants is not arbitrary. The criteria were established based on the availability of solar resource and the population distribution, so the concept of self-consumption could mean a real alternative to electricity generation from other energy sources. The main characteristics of the sites are summarized in the Table 1, where radiation data from the National Renewable Energy Laboratory (NREL) and the European Photovoltaic Geographical Information System (PVGIS) has been used as reference [78–80] and compared to the real measured values during the experimental campaign.

The PV systems of Arequipa and Tacna match a criterion of solar resource availability, since the levels of radiation are high. In addition, these installations are located on the roof of a building and a research centre, respectively, in order to reliably resemble the type of installations commonly used in the self-consumption configuration.

In the case of Lima, where insolation levels are significantly lower due to a high component of diffuse radiation, the selection criterion has been due to the fact that almost one third of Peruvians live there, therefore a small distributed PV system could relieve the grid by testing self-consumption solutions, although its integration into the city's urban distribution may be a challenge.

Table 2 describes the characteristics of the PV modules and inverters of the operating installations in the selected locations. In addition, the system configuration is summarized which will be used as input for the economic methodology. It can be observed that the power size of such PV installation is small, therefore, is an appropriate design for a residential use that includes the option of self-consumption.

2.1. Performance indicators of the testing facilities

The test facilities have been monitored since their start-up using commercial measuring hardware, although the data analysed in this paper are collected since their official commission, which took place months after the installation. The monitoring system for the PV plants located in Arequipa and Tacna (silicon-based) consists of Carlo Gavazzi® hardware. EOS-Array® devices are used for the measurement of string variables and the energy monitoring is measured with the EM24® energy meter and analyser.

In both locations, two thermocouples have been used for the PV module and ambient temperature measurements. The insolation data of the locations were obtained by means of a small module of the same technology, attached to the structure with the same inclination angle. This module was calibrated to obtain, by means of a shunt resistance, a voltage proportional to the incident irradiance. A diagram of the monitoring configuration is shown in Fig. 2.

In the case of the PV Thin Film facility, the SMA's own monitoring system was used, where a sensor of similar technology has been considered for irradiance measurement.

With the inclusion of irradiance sensors of the same technology

Table 1
Characteristics of the locations.

Characteristics	Arequipa	Tacna	Lima
Coordinates	−16.40S, −71.53W	−18.02S, −70.25W	−12.02S, −77.05W
Altitude	2369 m	563 m	110 m
Mean horizontal daily Irradiation (NREL)	6.50 kWh/m^2/day	6.26 kWh/m^2/day	4.85 kWh/m^2/day
Mean horizontal daily Irradiation (PVGIS)	6.55 kWh/m^2/day	6.18 kWh/m^2/day	4.60 kWh/m^2/day
Mean tilted daily Irradiation (PVGIS)	(15°) 6.86 kWh/m^2/day	(15°) 6.46 kWh/m^2/day	(15°) 4.66 kWh/m^2/day
Mean tilted daily Irradiation (measured)	(15°) 5.82 kWh/m^2/day	(15°) 5.08 kWh/m^2/day	(15°) 4.05 kWh/m^2/day
Mean Ambient temperature (NREL)	12.8 °C	16.4 °C	19.6 °C
Mean Ambient temperature (PVGIS)	13.3 °C	17.7 °C	19.7 °C
Mean Ambient temperature (measured)	18.1 °C	19.4 °C	22.3 °C

Table 2
Description of the PV plants.

	Arequipa (UNSA)	Tacna (UJBG)	Lima (UNI)
PV module characteristics	Solarworld Silicon Mono SW 275		Sharp Thin Film NA-F135GK
Maximum Power (Pm, W)	275		128
Open-Circuit Voltage (Voc, V)	39.4		59.8
Voltage at the maximum power point – (Vm, V)	31		45.4
Short-circuit current (Isc, A)	9.58		3.45
Current at the maximum power point – (Im, A)	8.94		2.82
Temperature coefficient power (γPm, %/ºC)	−0.41		−0.24
Inverter characteristics	Stecca Coolcept 3010x		Sunny Boy SMA 3.0 US
Inverter's power (Pinv, W)	3000		3000
Maximum input voltage (V)	600		600
Operating input voltage range (V)	125–500		155–480
Maximum input current (A)	11.5		10
Max. efficiency (%)	98.0		97.6
CEC efficiency (%)	97.8		96.5
System Configuration			
Tilt	15°		15°
Azimuth	0° (North)		0° (North)
Strings	1		3
Modules per string	12		9
W_p (W)	**3300**		**3456**
V_{OC} (V)	469.2		538.2
V_{MPP} (V)	372		408.6
I_{SC} (A)	9.58		10.35
I_{MPP} (A)	8.94		8.46

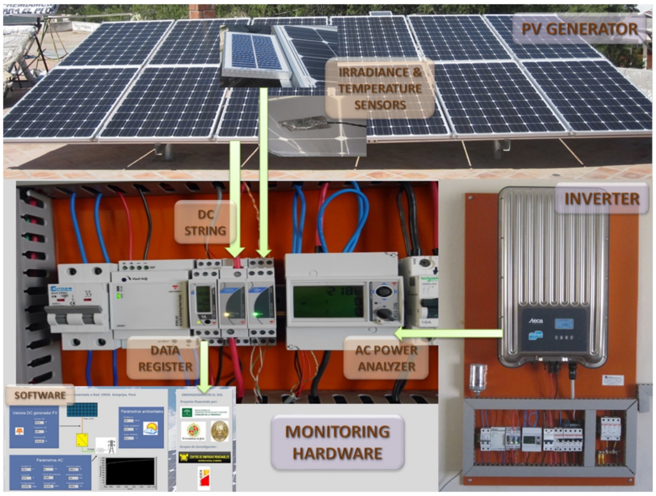

Fig. 2. Monitoring system of the Silicon PV installations.

as the PV modules, all spectral and reflection losses are inherently taken into account in the measurements. Therefore, the uncertainties and measurement errors of irradiance are mitigated as the climatic and soil effects are considered [81–83].

After more than 3 years of operation of the silicon-based PV systems, and more than 2 years of the thin-film installation, the main key performance indicators, based on real data, of the different PV plants are summarized in Table 3 [84], where the final yield of the PV system installed in Arequipa is remarkable. Considering that it is the second most inhabited city in Peru, the potential for the installation of these residential self-consumption PV systems is enormous.

Another noteworthy aspect is the low final yield of the test facility in Lima compared to the other test plants. This perceived underperformance is mainly due to the low levels of solar irradiation available in the city of Lima, which is explained by a large number of cloudy days. On the contrary, although its results in a lower final yield, the capture losses are less severe in Lima than in the Arequipa and Tacna.

This near-permanent cloudy weather, although apparently resulting in lower performance figures, is more favourable for thin-

Table 3
Performance Results of the PV plants.

	Arequipa (UNSA)	Tacna (UJBG)	Lima (UNI)
Annual Irradiation (H) (kWh/m^2/year)	2220	1859	1477
DC Energy Output (E_{DC}) (kWh/year)	6425	5326	4793
AC Energy Output E_{AC} (kWh/year)	6155	5107	4507
Reference Yield (Yr) (kWh/kWp/year)	2220	1859	1477
PV Array Energy Yield (Ya) (kWh/kWp/year)	1983	1644	1387
Final System Yield (Yf) (kWh/kWp/year)	**1900**	**1576**	**1304**
Array Capture Losses (Lc) (kWh/kWp/year)	237	212	87
BOS losses (L_{BOS}) (kWh/kWp/year)	83	68	83
Array (DC) Efficiency	14.4%	14.2%	8.5%
BOS Efficiency	95.8%	95.9%	94.0%
System (AC) Efficiency	13.7%	13.7%	8.0%
Annual Performance Ratio (PR_{annual})	85.5%	84.9%	88.5%

film technology, as the spectral content of the sun is better suited to the response of these modules [85–87]. Therefore, one question that may arise for a future investor is whether it is more appropriate to install thin-film technologies in the city of Lima for the promotion of self-consumption rather than silicon modules.

A detailed monthly distribution of the final yield and losses (capture and BOS) for each location is shown in Figs. 3–5. It can be observed that the performance (and losses) of the Arequipa PV system is approximately constant within a certain range, while in Tacna and Lima the differences between summer and winter are noticeable. This behaviour, especially for the case of Lima, may endanger the coupling of generation and consumption profiles for self-consumption in these cities, while Arequipa seems to be in an advantageous position for the promotion of PV technology under the premises of self-consumption.

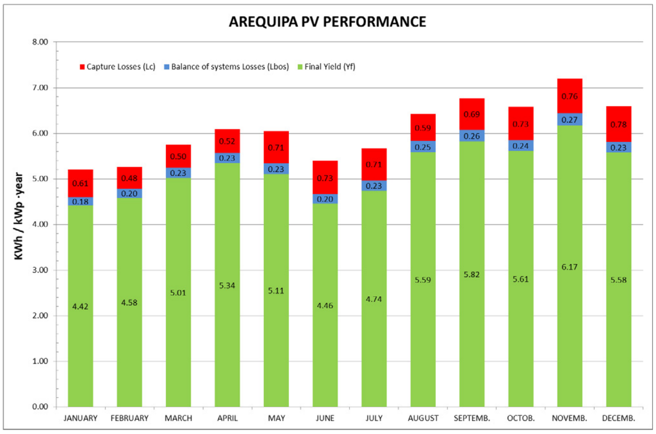

Fig. 3. Monthly Final Yield and losses of Arequipa testing facility.

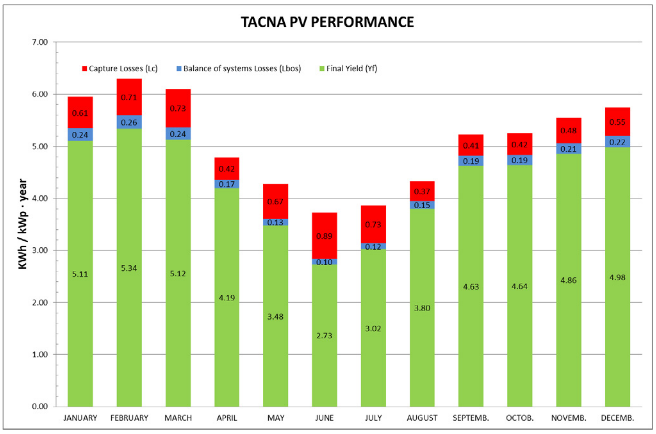

Fig. 4. Monthly Final Yield and losses of Tacna testing facility.

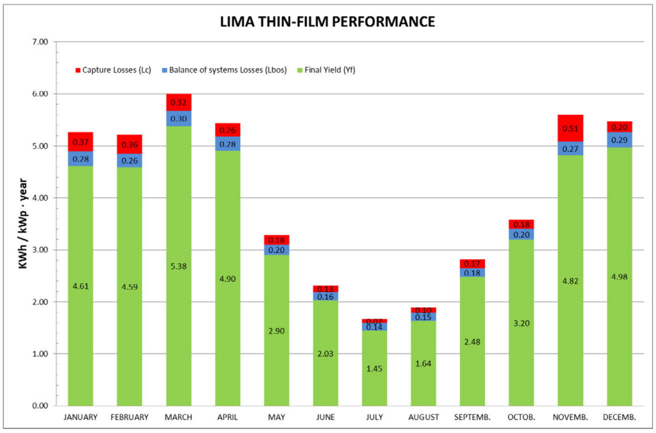

Fig. 5. Monthly Final Yield and losses of Lima testing facility.

3. Methodology of the economic and cost-competitiveness analysis

Once the performance analysis of the testing facilities has been described, an economic study is proposed in order to assess the cost competitiveness of these plants with regards to the local electricity tariffs and the economic feasibility of these investments according to the characteristics of the country and the selected locations.

In many reports and scientific papers where an economic analysis of a PV system is carried out, it is common practice to include the Net Present Value (NPV, in USD) and the Internal Rate of Return (IRR, in %) as criteria for the evaluation of the profitability of a PV investment [43,88,89]. However, different NPV and IRR results will be obtained depending on the consumption profiles, level of self-consumption, tariffs allocated to the sale of surplus PV electricity in case there is a net-balance scenario, and economic savings for the electricity not consumed from the grid. Moreover, these indicators can sometimes conceal information on the viability of such investment, as some liquidity shortfalls may arise [90].

From the end user's point of view and in order to evaluate the feasibility of such an investment, it is clearer to carry out an analysis based on the Levelised Cost of Electricity (LCOE), whose results can be compared with the standard electricity tariff paid by an average household consumer in Peru, so that the potential investor can have a tangible decision tool.

3.1. Levelised Cost of Electricity, Net Present Value and Internal Rate of Return definitions

LCOE, which has been sufficiently covered in the literature, is defined as the constant cost of generating a unit of PV electricity levelled throughout its entire life cycle and referenced to the year in which the investment is made [31,91–93]. For its calculation we need to provide information on the system's lifetime cost and the annual energy (E_{PV}) it is expected to generate until decommissioning the project, considering a certain annual degradation rate (E_{deg}). The economic expression used for the LCOE calculation is described below:

$$LCOE(USD/kWh) = \frac{LCC}{E_{PV} \cdot \sum_{n=1}^{25} \left(\frac{1-E_{deg}}{1+d}\right)^{n}} \tag{1}$$

The life-cycle cost (LCC) includes not only the cost of installing a PV plant (PV_{cost}), which it is the initial investment (PV_{INV}), but also the annual operation expenditures (OPEX) and the annual tax depreciation (DEP) in those countries in which a tax depreciation of the investment could be considered.

LCOE refers to the initial time at which the investment is made, so all the future annual expenses have to be translated to their present value (worth). By defining N_{PV} the life cycle of a PV project, N_{dep} as the time period for the tax amortization, and T the tax rate applicable (either residential or SME taxes) which can be deduced from expenses, the numerator of equation (1) can be rewritten as follows in equation (2):

$$LCC = PV_{INV} + PW[PV_{OPEX}(N_{PV})] - PW\left[DEP\left(N_{dep}\right)\right] \cdot T \tag{2}$$

There are many sources of financing a PV project that depend on the complexity and associated risk [94,95]. According to the scope of this research and the scenarios considered, only two financial mechanisms will be taken into account: long-term debt (PV_{loan}) and equity capital (PV_{eq}) contributed by either a standard home-owner or a small enterprise which may offer PV projects as a leasing product. The cost of a photovoltaic project of the dimension considered in this study can be expressed according to the following equation, where a subsidy term has been included only for the explanation of the methodology, but it will not be considered in this work.

$$PV_{INV} = PV_{loan} + PV_{eq} + PV_{sub} \tag{3}$$

The share of the investment relating to the bank loan (long-term debt) will be financed over a period of N_{loan} years and at an i_{loan} interest rate. In addition, tax deductions will be considered in accordance with the country's regulations. The proportion of investment financed by equity capital should be remunerated annually in the form of dividends (d_{eq}) to compensate for the opportunity cost lost. As with any similar investment, the equity share must be returned at the end of the selected period (N_{eq}), in this case, the N_{PV} years of life cycle of the PV project. Finally, if any subsidy is applied and linked to the initial investment, through a non-refundable quantity, although it reduces the amount of money to be financed, is also taxable for a defined period of time (N_{sub}).

Therefore, the investment to be made is summarized in the following financial equation, where the discount rate (d), unless other specification is mentioned as it happens in one of the scenarios considered in this study, is equal to the weighted average cost of capital (WACC), which represents the cost that has to be paid for the availability of capital resources.

$$\begin{aligned} PV_{INV} = & \left(PV_{loan} \cdot \frac{i_{loan} \cdot (1-T)}{1-\left(1+i_{loan} \cdot (1-T)\right)^{-N_{loan}}} \cdot PVIF(N_{loan}) \right) \\ & + \left((d_{eq} \cdot PV_{eq}) \cdot PVIF(N_{eq}) + PV_{eq} \cdot q^{Neq} \right) \\ & + \left(\frac{PV_{sub}}{N_{sub}} \cdot T \cdot PVIF(N_{sub}) \right) \end{aligned} \tag{4}$$

In the previous equation, PVIF is the Present Value Interest Factor, which it is related to the nominal discount rate during the Nx period considered depending on the duration of the loan (N_{loan}), equity (N_{eq}) or applicable subsidy (N_{sub}).

$$PVIF(Nx) = q \cdot \frac{1-q^{Nx}}{1-q} \tag{5}$$

$$q = \frac{1}{1+d} \tag{6}$$

Prospective owners should be aware that increasing the leverage of a renewable energy project provides tax advantages and it also helps to reduce the WACC when the opportunity cost of the equity capital is higher than the bank's interest rate [96]. In the case of small PV projects, such as the ones considered in this study, the previous statement is usually not complied.

In addition to the initial investment and the debt-equity share chosen, annual operation expenditures (OPEX), during the lifecycle of the PV plant (N_{PV}) also influence the calculation of LCC. This term is becoming increasingly important in the PV industry, as it influences not only the energy yield but also the profitability of a PV plant [45], and should therefore be included in this study. If this term is translated to its present worth, assuming that the annual OPEX (PV_{OPEX}) is assigned an annual percentage increase $\mathcal{E}_{OPEX}$, we obtain the following expression:

$$PW[PV_{OPEX}(N_{PV})] = \left(PV_{OPEX} \cdot \frac{K_{OPEX} \cdot \left(1-K_{OPEX}{}^{N_{PV}}\right)}{1-K_{OPEX}} \right) \tag{7}$$

Where $K_{OPEX} = (1+\mathcal{E}_{OPEX})/(1+d)$.

In some country-specific fiscal scenarios, a certain percentage of the PV investment may be legible for tax depreciation over a certain period of time (N_{dep}). This term means a reduction in the LCC and the calculation of its present worth can be expressed as follows:

$$PW\left[DEP\left(N_{dep}\right)\right] = DEP \cdot PV_{cost} \cdot PVIF\left(N_{dep}\right) \tag{8}$$

In the previous formula, *DEP* is the annual tax depreciation for the PV system and *PVIF(N_{dep})* is calculated as the previous Interest Factors (equation (5)) with $N_x = N_{dep}$

In relation to the most common economic methodologies conventionally used for the evaluation of an investment, the following expressions (equations (9)–(11)) define the Net Present Value (NPV) and the Internal Rate of Return (IRR) criteria.

$$NPV = PW[CIF(N_{PV})] - LCC \tag{9}$$

$$NPV = -PV_{INV} + \sum_{n=1}^{n=N_{PV}} \frac{Q_n}{(1+d)^n} \tag{10}$$

$$O = PW[CIF(N_{PV})] - LCC \tag{11}$$

The Net Present Value is the difference between the present worth of the cash inflows and the life cycle cost of the investment during the duration of the PV project (N_{PV}) as equation (9) describes. Another formula for expressing the NPV is shown in equation (10), where in this case, for a project to be economically feasible, the initial investment cost (PV_{INV}) has to be overcome by the summation of the annual cash flows generated during the lifetime of the project. The cash inflows (CIF) are obtained through the sale of the PV energy generated or the electricity saved for not consuming it from the grid in the case of self-consumption projects.

The IRR of an investment defines the value of the discount rate that makes $NPV = 0$. Therefore, in order for a project to be feasible, the IRR has to be greater than the discount rate used for the economic calculations.

Once the LCOE, NPV and IRR definitions have been described, the following sections will propose different financing scenarios, taking into account the economic characteristics of the country and the real data measured of the photovoltaic systems installed.

3.2. Definition of financing scenarios

In this research, for a proper identification of the LCOE, NPV and IRR in Peru, referred to the year of study (2018), different financing scenarios are proposed in order to cover several funding schemes currently available internationally for this type of projects, which may be not necessarily common in the Peruvian context. Therefore, the results could be very valuable for funding organisms and policy makers which are willing to identify financial schemes for this technology and take a stance in the market.

In all scenarios, the energy-related parameters of the PV systems that affect the economic and cost-competitiveness evaluation are the ones described in Section 2, which are based on real measurement.

The capital expenditures (CAPEX) of the installed PV systems are described in Table 4, where the cost of the systems, fully installed,

Table 4
Identification of CAPEX and OPEX of the PV systems installed.

CAPEX			**Arequipa and Tacna**	**Thin Film Lima**
	PV system Cost (USD/kW)		2180	2030
	Taxes (18% VAT) (USD/kW)		392.4	365.4
	Connection fee (USD)		102.27	
	Certification Costs (USD)		151.52	
	Administrative Costs (USD)		60.61	
	Total CAPEX (USD)	**With VAT**	**8803.32**	**8592.90**
	Unitary CAPEX (USD/kW)		2667.67	2486.37
	Total CAPEX (USD)	**Without VAT**	**7508.40**	**7330.08**
	Unitary CAPEX (USD/kW)		2275.27	2120.97
OPEX (USD/kW/year)			19	22

are based on real data provided by local suppliers. A slight difference between silicon-based photovoltaic plants and the Thin Film system installed in Lima is highlighted. A conservative scenario has been chosen for the PV system cost, since the implementation of small PV grid connected installations is not yet a widespread reality in Peru and therefore, the price decrease experienced in other countries cannot be transferred to the Peruvian reality.

The Value Added Tax (VAT) of 18% applicable in Peru has also been included and some fees have been considered based on national regulations.

In this Table 4, instead of using the national currency (PEN - Peruvian Sol) for the definition of the monetary units, USD has been chosen, for a better comparison with international reports and similar scientific papers. An exchange value of 3.3 PEN per USD has been assumed [97].

Although in similar papers, annual operation and maintenance expenditures (OPEX) are in the range of 0.5–1.5% of the initial investment [98–100], it is advisable to express this expenditure per unit of power (USD/kW), thus reflecting the current trend of asset management companies. Recent data available establish an average OPEX value in the range of 9–19 USD/kWp [101,102]. For the purposes of this paper, 19 USD/kWp, which is the worst scenario, has been considered for the Arequipa and Tacna facilities, while in Lima, as a result of higher levels of soiling and pollution particles, this amount has been increased to 22 USD/kWp, as cleaning tasks are scheduled more frequently.

In the economic methodology already explained, there are a series of economic parameters which are independent of the scenarios proposed whose values, adapted to the particularities of Peru, are summarized in the Table 5.

Inflation (g) and the Consumer Price Index (CPI) data have been adjusted according to the information available and the expected growth for the next years in the country [97,103,104]. The taxes applicable to both private individuals and Small-Medium Enterprises (SME) are based on the information provided by the National Superintendence of Customs and Tax Administration [105] and an annual linear depreciation (DEP) of 10% has been assumed for the first 10 years of operation of the systems.

Regarding the annual percentage increase of the operation and maintenance expenditures (ε_{OPEX}), it is going to match the inflation rate. Just as similar documents [106], in this analysis no residual value of the PV system is left at the end of its lifecycle and the equity share will be reimbursed at the end of the system's lifecycle (25 years).

Table 5
General financial, economic and energy parameters.

Inflation (g, %)	2
Consumer Price Index (CPI, %)	3.5
Residential Taxes (T, %)	15
Non-residential taxes (SME) (T, %)	28
Depreciation Tax (DEP, %)	10
Depreciation Years for tax purposes (N_{dep}, years)	10
Residual value of PV system at $N_{PV} = 25$ years (€)	0
Lifetime of the PV system (N_{PV}, years)	25
Annual energy degradation (E_{deg}, %/year)	0.5

In addition to the economic parameters and the energy information defined in Tables 3 and 4, it is necessary to define some general parameters, such as the annual degradation rate or the expected lifetime of the installation. Based on the information available in the literature, a linear annual power degradation rate of 0.5%/year is assumed in Table 5 [107–109].

3.2.1. *Scenario 1: enterprise point of view. Fixed discount rate according to the Peruvian law for energy investment projects*

The Peruvian electricity concession law D.L N.25844, and it subsequent amendments, establishes that any energy investment project must have a minimum profitability of 12%, so this requirement will define this first scenario of our analysis, setting the discount rate to this value ($d = 12\%$) [110]. For this study, it has been assumed that this requirement is only applied to companies that want to commercialize the energy generated by a PV system, while a particular user that wants to install a domestic system would not be subject to this restriction, since its objective is not to do business.

The traditional approach considered for medium-large PV projects makes them a mere financial product, but the objective of distributed small self-consumption PV systems differs from this conception. Firstly, the sponsors and users of these systems are not profit-driven companies, but regular homeowners seeking to save on their electricity bills while contributing to the environment. In this context, the aforementioned law and its profitability requirement are outdated.

However, a new business niche can emerge in this self-consumption paradigm, where electricity utilities can offer their residential customers the installation and maintenance of a PV energy product in exchange for a monthly fee (lease) or a unit price for the self-consumed PV electricity, without the need for the user to face the large upfront capital of these systems [111].

Under this premise, the application of this minimum profitability requirement is justified, but some assumptions must be made to define a scenario that is of interest and applicability for the business world and also for domestic users.

In this first scenario proposed a company is supposed to own the photovoltaic system like the ones under test. The PV installation will be offered as an energy product to potential homeowners, who will pay for the self-consumed electricity a flat rate, which may correspond to the LCOE calculated (USD/kWh) during the time set for the lease contract, which in this first scenario is $N_{PV} = 25$ years, matching the useful life of the PV system. This flat rate can be different in the case the companies look for greater revenues, but in any case, if companies want to offer a cost competitive service, should be lower than the electricity tariffs that users pay.

For the $LCOE_{2018}$ calculation, we have assumed that the company does not need to borrow money from the bank, so all the photovoltaic assets come from its own resources which are financed with the equity share from their stakeholder portfolio. The required annual dividends are set according to the standard rate that any similar investment project should have ($d_{eq} = 6\%$) and no VAT is applied to the PV cost, i.e. the initial investment (PV_{IN}), because we are dealing with the purchase of a good from a company which will be used to offer a service. Therefore, VAT will be applied to the LCOE result, so it will be charged to the PV customers. This amount has to be reimbursed by the company to the national treasury. In addition, the company will also charge the final customer the corporation tax (in Peru, $T_{SME} = 28\%$), because it must be paid to the treasury and would mean a loss if it is not taken into account in the company's finances.

Table 6 presents a summary of the parameters considered in this first scenario, where the forced 12% discount rate (d) will be used, instead of using the resulting WACC value of the financing mechanism chosen.

3.2.2. Scenario 2: debt and equity financing under Peruvian financing data

In this second scenario, a classic financial scheme is proposed for this type of projects. The investment is made through loans granted by banks (debt) and equity capital. In this case no subsidy is considered. Although this scenario is widely used to finance these types of PV projects, it is not a common tool available in Peru, so the results could be valuable for both banks and customers.

The investment in the PV project is financed 80% with debt and the rest (20%) with equity capital, which is contributed from the owner's own resources. Although there are no data available for the Peruvian context related to specific loans for PV systems, because banks do not have in their portfolio the financing of PV products, for this study we have compiled data on the characteristics of the credit portfolio offered by Peruvian banks to standard users, from mortgage loans, to the acquisition of vehicle or personal loans.

The median value obtained makes us to suppose that banks will probably finance this investment with an interest rate (i_{loan}) of 14% during a term of $N_{loan} = 10$ years [97,112,113].

The fraction representing the equity share has been associated with the loss of opportunity cost of a similar investment. According to the savings product portfolio offered by banks in Peru, an optimistic scenario will be to consider a similar profitability of these bank deposits as an annual retribution in form of dividends. Therefore, the equity share is defined with a dividend rate of $d_{eq} = 1\%$ during an equity term of $N_{eq} = 25$ years [113,114]. The equity share is assumed to be repayable at the end of this period.

The cost of the photovoltaic system, as acquired by a natural person, is subject to VAT. Additionally, it will be considered a rate similar to the personal income tax payable to the treasury ($T = 15\%$). Table 7 shows a summary of the parameters considered for the scenario 2.

In contrast to standard financing schemes for photovoltaic systems, in this case, taking into account the size and target market, the cost of debt is higher than equity capital.

4. Results and discussion

On the basis of the proposed scenarios different $LCOE_{2018}$ results have been obtained. The first scenario is focused on a company that offers PV energy services in exchange for a unitary price for the PV electricity generated, and sold to the customers, by a PV system installed at the customer's facilities but owned by the company. The second scenario analysed corresponds to a homeowner who installs his own PV system and replaces the power purchased from the grid with power produced by its PV installation.

Table 8 shows the $LCOE_{2018}$ results for the different PV test facilities analysed, ranging from the lowest 0.1038 USD/kWh obtained in Arequipa for the scenario 1 up to 0.2049 USD/kWh in the scenario 2 for Lima. In any case, although the PV cost in Lima is lower than in Arequipa and Tacna, the LCOE results, within the same scenario, are mainly influence by the energy yield, therefore better data will always be obtained in Arequipa, then in Tacna and ultimately in Lima.

The first analysis is derived from the lowest LCOE data obtained in all scenario 1 cases regarding the results from scenario 2. One of the reasons comes from the lowest financial effort of the company in scenario 1, since the dividend percentage required by the stakeholders is 6% and no loan is required, whereas in the homeowner case, the WACC, that is, the cost of financing the investment, is larger, mainly due to the high bank interest rates (14%). Because these types of systems, in their self-consumption application, are not integrated in the Peruvian energy market and are not yet common to be installed as distributed systems of small power in the residential sector, banks do not offer the possibility of financing their investment in their portfolio. Therefore, at present, prospective owners only have a scenario of financing with high interest rates offered by banks, which increases the result of LCOE.

Nevertheless, although the differences in the results may originally indicate the suitability of investing in such photovoltaic self-consumption systems depending solely on the location within the country, where radiation and yield differences may appear, no proper discussion can be made unless the $LCOE_{2018}$ is compared to the 2018 electricity rate of each placement. According to the available data, the electricity tariff applicable in 2018 is shown in

Table 8
$LCOE_{2018}$ results and electricity tariffs.

	Electricity tariffs 2018	$LCOE_{2018}$ Scenario 1	$LCOE_{2018}$ Scenario 2
Arequipa	0.1686 USD/kWh	0.1038 USD/kWh	0.1479 USD/kWh
Tacna	0.1716 USD/kWh	0.1252 USD/kWh	0.1783 USD/kWh
Lima	0.1537 USD/kWh	0.1469 USD/kWh	0.2049 USD/kWh

Table 6
Parameters considered for the scenario 1.

EQUITY ($PV_{eq} = 100\%$)									
d	12%	**PV_{INV}**	No VAT applicable	**d_{eq}**	6%	**N_{eq}**	25 years	**$LCOE_{SC1, 2018}$**	LCOE + VAT + T (USD/kWh)

Table 7
Parameters considered for the scenario 2.

LOAN ($PV_{loan} = 80\%$)				EQUITY ($PV_{eq} = 20\%$)			
I_{loan}	14%	**N_{loan}**	10 years	**d_{eq}**	1%	N_{eq}	25 years

Table 8 [54], which allows us to identify cost-competitiveness scenarios, i.e. grid parity realities based on the location and financial scheme applicable.

In Arequipa, regardless of the scenario chosen, there is always a grid-parity situation, therefore, from the user's standpoint, it could be more profitable to consume the PV electricity generated in a home with such system installed than to buy electricity from the grid. In the case of Tacna, only in the first scenario, i.e. an external company installs (and owns) a photovoltaic system at the owner's property and sells the electricity produced to the owner, is cost-competitive. In the city of Lima, within the assumptions made and the real data measured, it may be only profitable in the scenario 1, where grid parity was recently achieved. However, if a particular wants to promote its own system (scenario 2), the LCOE results show a non-cost-competitive situation when compared to the electricity tariff applicable in Lima.

In the light of the results, unless the bank interest rates change, the financial conditions are more favourable in the scenario of an external company that charges the user a lease or a price for the electricity produced by the PV system installed in the customer's home, but which is owned by the company.

Figs. 6 and 7 provide the information considering that the electricity tariffs will follow, during the forthcoming 25 years of operation of the PV plant, an upward trend established by the CPI mentioned in Table 5 (3.5%), which could even be considered a conservative scenario.

Fig. 6 shows that grid-parity has been achieved in all the cities analysed under the assumptions made in the scenario 1. In the case of Lima it was recently achieved in 2018, therefore if some input parameters differs from the proposed in this study, there could still be some cases where a non-competitive scenario may exist. This figure could also be useful to analyse the possible revenues variations of the companies offering such PV services, provided that they change some input data, including the electricity increase perspectives.

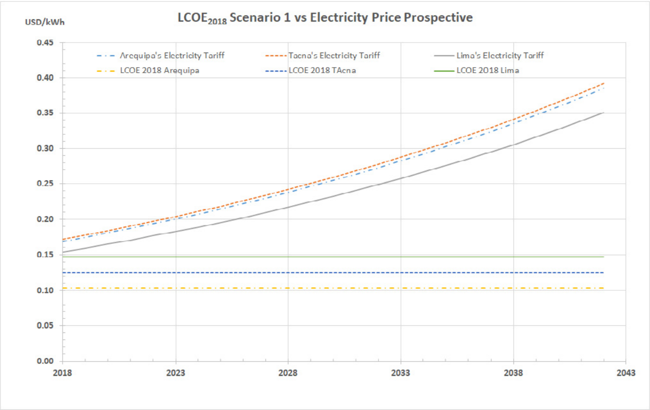

Fig. 6. LCOE_{2018} results vs electricity tariff prospective increase under the scenario 1 (leasing).

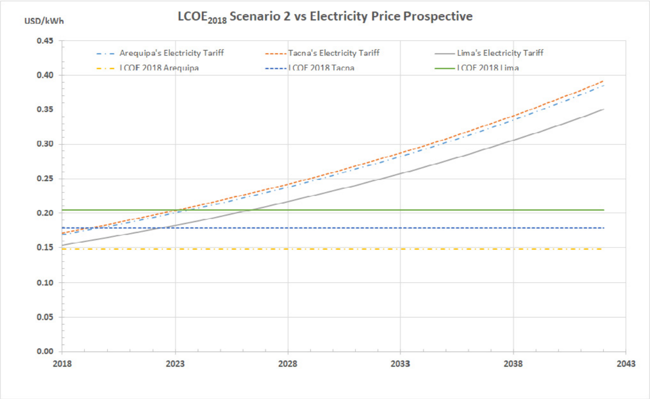

Fig. 7. LCOE_{2018} results vs electricity tariff prospective increase under the scenario 2 (loan + debt).

On the other hand, if a standard homeowner attempts to install its own PV system with the support of the bank and its own capital resources (Fig. 7), this parity could be delayed in Lima at least until 2027 with the assumptions made to install a PV system in 2018and maintaining the increase trend in the electricity tariffs. In case this increment is lower than 3.5%, this non-cost-competitive scenario could be dramatically delayed.

In the Tacna study case, where only under the scenario 2 circumstances there was a non-grid-parity situation, by 2020 this situation could be reversed, as shown in Fig. 7, provided that the local electricity tariffs increase at least 3.5% annually.

Under this circumstances, it is interesting to predict when the non-grid-parity situations, i.e. Tacna and Lima in the scenario 2, will be reversed and a cost-competitive scenario appears Besides, in those already achieved grid-parity scenarios, analysing whether homeowners will increase their savings in relation to the electricity tariffs or whether companies can apply for more profits by slightly increasing the lease tariff charged to their clients (provided that it is considered in the lease contract) is also an interesting further discussion.

Completing the cost competitiveness analysis of these facilities in Peru, it becomes necessary to discuss the level of economic profitability of the investments through an analysis of the NPV and IRR results of the proposed cases.

In Table 9 the values obtained for the different scenarios considered under the locations chosen are shown. In the locations under the scenario 2, i.e. a homeowner who wants to install its own PV system with an equity-loan share, there is a profitable result in the city of Arequipa. This result is expected, as a cost-competitive scenario was detected because the LCOE was lower than the electricity tariffs in that city.

On the other hand, due to the LCOE results from Lima discouraged the installations of such systems under the premises considered in this scenario 2, the NPV and IRR results obtained reinforce this rejection, as the NPV is negative and the IRR is lower than the WACC.

Nevertheless, in Tacna, although a non-grid-parity scenario was obtained in the scenario 2, the profitability results are positive. The main reason is that the cost-competitive situation is expected to be reached in just a couple of years, therefore, accounting for the lifetime of the system and the increase trend of the electricity tariffs, the negative cash flows are soon overpassed by the energy savings, thus the investment in this city could be feasible.

The results of the scenario 1 are always profitable from the user's standpoint, as the homeowners do not need to make the investment, with its consequent risks, and the PV tariffs are lower than the electricity bought from the grid.

However, the company providing the energy services must carefully define the selling prices of the photovoltaic energy generated to its customers.

If they decide to apply the LCOE price to the electricity produced, which could be the most advantageous and attractive for the end user, it turns out that in none of the cities analysed would have profitability in their investments. It is necessary to clarify that at this price of the LCOE, it is necessary to deduct the expenses of the VAT and the tax applicable to the company, then the real LCOE is excessively small so that the income by sale of energy cannot surpass the expenses of exploitation.

Table 9
NPV and IRR results for the scenario 1 and 2.

		Scenario 1		Scenario 2
		LCOE$_{2018}$ Scenario 1	Electricity tariffs 2018	LCOE$_{2018}$ Scenario 2
Arequipa	NPV (USD)	−2548.87	3398.27	2165.14
	IRR (%)	6.9	17.67	14.38
Tacna	NPV (USD)	−2548.87	1796.16	483.31
	IRR (%)	6.9	15.09	12.09
Lima	NPV (USD)	−2446.16	−118.03	−1491.30
	IRR (%)	7	11.78	9.11

On the contrary, if the company decides to apply the current price of electricity in each city, in a similar way to what was done for the scenario 2, despite obtaining beneficial results for the company, i.e. positive NPV and IRR greater than WACC, the end customer would not see any advantage in outsourcing the installation service of a PV system, since it would be more competitive if he himself were the promoter of his installation.

4.1. Sensitivity analysis of the financial parameters

Among the proposed scenarios, the most critical is that of a small private promoter under a classic PV financial scheme. Prospective homeowners want to know which variables most influence the reduction of LCOE, or in other words, allows them to faster achieve grid-parity or increasing their revenues.

If we take as a reference the electricity tariff from 2018, which could be assumed as the worst scenario possible for the grid-parity achievement (the lowest price means that it is harder to beat from PV unitary generation price), we can deduct from Fig. 8 the point at which a decrease in the interest rate, under the characteristics of scenario 2, makes a grid parity scenario possible in the case of Lima and Tacna. In these figures, contrary to what happens in Figs. 6 and 7, the constant values correspond to the 2018 electricity tariffs applicable in these Peruvian cities, whereas the variable values are the resulting LCOE, which will vary depending on the influence of the interest rate of the requested loan.

If the 80-20 share (loan-debt) is maintained and the dividends from the equity remains in a 1%, to achieve the grid-parity scenario in the city of Lima the interest rate need to be lower than 8.6%, whereas in Tacna it needs to be no higher than 13%.

Interest rate variation is a factor in which the final PV promoter (scenario 2) has little influence, but what can be modified is the loan-equity share, which means he can change the cost of financing his PV investment (WACC). Therefore, if the interest loan is maintained at 14% and the dividends at 1%, the results are shown in Fig. 9.

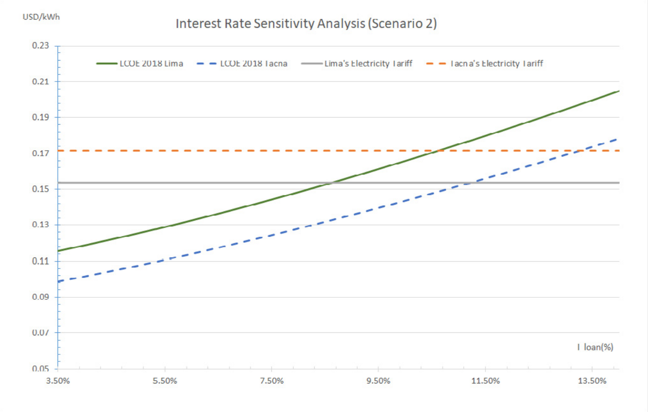

Fig. 8. Influence of the interest rate on the achievement of grid-parity.

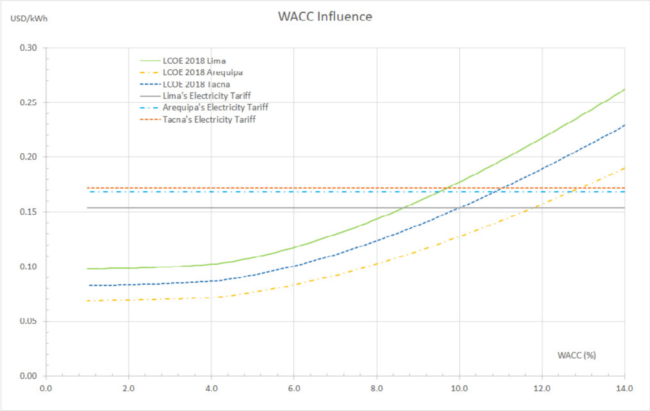

Fig. 9. Influence of the debt-equity share on the LCOE results.

Under the premises of scenario 2, a variation of WACC may jeopardise the already achieved grid-parity in Arequipa if the WACC is above 12.7%, that is, if the loan-equity share is modified from 80 to 20% to a higher leverage of 90—10%. In the case of Tacna, where there was no grid-parity in scenario 2, WACC needs to be lower than 11%, meaning a 77-23% loan-equity share. Finally, Lima's financing has the worst prospect, as WACC needs to be lower than 8.7%, so the owner of the plant needs to have savings up to 41% of the cost of the PV plant and finance the remaining 59%, so the level of leverage is much lower. This trend is contrary to what usually happens in large PV projects.

5. Conclusions

The maturity that PV technology has reached in recent years means that the installation of these systems represents a real alternative in the power generation mix of any country. In the case of Peru, the promotion of large PV plants in the South of the country through public auctions, demonstrates the acceptance of this technology as a reliable source of energy capable of contributing to the country's electricity needs. However, the installation of small sized PV systems, ranging from 1kw to 10 kW, for self-consumption is not implemented in the country's energy reality, therefore, further energy performance and economic studies are needed in order to foster a sustainable energy transition in Peru.

Prior to any economic evaluation, it is necessary to analyse the energy performance of these systems by testing different PV technologies located in distinct cities. After more than three years of operation of two silicon-based photovoltaic systems located in the cities of Arequipa and Tacna, the final annual yield is 1900 kWh/kWp and 1576 kWh/kWp respectively, which result in a high performance data very suitable for its installation in private residences.

Additionally, a tandem structure with amorphous and microcrystalline silicon PV module has been tested for more than two years in the city of Lima, which may be the first of these characteristics ever tested in Peru, resulting in a final yield of 1304 kWh/kWp. Although the special climatic conditions of the city of Lima, which advise us to install PV systems based on Thin-Film technology over Silicon one, the city's urban distribution, the large amount of consumers and only an acceptable level of final yield, may jeopardise the use of PV systems as a self-consumption product.

Based on the absence of financial support for the implementation of such systems and considering the economic parameters available in the country, two scenarios have been proposed, which are the most probable to occur in the near future. In any situation, when compared to the electricity tariffs, the good performance of the Arequipa PV test facility may advise us to install such systems as an alternative to the traditional electrical grid consumption, since the grid-parity has been reached and they are cost-competitive However, in the case of a company offering energy services, an unprofitable result is obtained if the company sells the photovoltaic electricity at the LCOE price. On the other hand, if they decide to assign an equal price to the conventional electricity, customers may find no advantage in installing photovoltaics using this formula, as it would be more profitable to promote their own systems.

On the other hand, in the city of Tacna, only under the assumption of a lease contract with an energy company is when the grid parity is reached, while a standard private promoter will have to wait until 2020. However, despite the cost-competitive scenario glimpsed, the results from the company's point of view may be either non-profitable or not economically attractive to their potential customers.

The worst scenario occurs in the city of Lima, where under no circumstances a PV system will be profitable. Although energy SMEs may find cost-competitive to incorporate this product by this year of 2018, the results of the economic profitability analysis discourage it. In the case of private domestic users, it is not advisable to install them before 2027 unless no further positive changes are applied in the country to promote such systems.

The LCOE values obtained, based on real energy and economic data, are very valuable for a wide range of stakeholders, from banks to small SMEs which want to incorporate these systems in the energy portfolio and also to residential owners who want to obtain some savings in the consumption of electricity from the grid.

Among them, companies may find these data interesting to sign any PPA agreement, as according to the NPV and IRR values obtained, the assigning a price to photovoltaic electricity produced and sold to their customers is critical to their business plans. On the other hand, residential users can discuss whether it is cost-effective and feasible to install such systems under the self-consumption framework.

Government policymakers and public actors in Peru may also find these results useful, as examples like this may encourage policies to promote the installation of small and distributed photovoltaic systems that take into account population distribution and urban planning in the country. In this regard, and in the light of these results, legislation should be introduced to promote this type of system, on the one hand to promote tax incentives that reduce the weighted average cost of capital and, on the other hand, to design net-balance strategies that make use of the energy discharged into the grid that could not be used at the time.

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Appendix. Terminology

BOS	Balance of System
CAPEX	capital expenditures
CPI	Consumer Price Index (%)
d	Discount rate (%)
DEP	Depreciation Tax (%)
d_{eq}	Remuneration in form of dividends (%)
$\mathrm{E_{deg}}$	Annual degradation rate in the PV energy generated (%)
$\mathrm{E_{PV}}$	Annual PV energy generated (kWh)
ε_{OPEX}	Annual increase of the operation and maintenance cost of the PV system (%)
g	Inflation (%)
i_l	Annual loan interest (%)
Lbos	Balance of System Losses
Lc	Array Capture losses
LCC	Life - cycle cost of the PV system (USD)
LCOE	Levelised Cost of Electricity (USD/kWh)
$\mathrm{N_{dep}}$	Period of time for tax amortization (years)
N_{eq}	Time duration of the equity investment (years)
N_{loan}	Time duration of loan (years)
$\mathrm{N_{PV}}$	Life cycle of a PV project (years)
N_{sub}	Time duration of the subsidy for taxes purposes (years)
OPEX	Operation and Maintenance Expenditures (USD)
PEN	Peruvian Sol
PPA	Power Purchase Agreements
PV	Photovoltaic
$\mathrm{PV_{eq}}$	Proportion of the initial investment financed with equity (USD)
PVIF	Present value interest factor
$\mathrm{PV_{cost}}$	Cost of a PV plant completely installed (USD)
$\mathrm{PV_{INV}}$	Initial investment of the PV system (PV cost) (USD)
$\mathrm{PV_{loan}}$	Proportion of the initial investment financed with loan (USD)
$\mathrm{PV_{OPEX}}$	Annual Operation and Maintenance Expenditures (USD)
$\mathrm{PV_{sub}}$	Proportion of the initial investment subsidized (USD)
$\mathrm{PW}[CIF(\mathrm{N_{PV}})]$	Present worth of the cash inflows (USD)
$\mathrm{PW}[DEP(\mathrm{N_{dep}})]$	Present worth of the PV system depreciation for tax purposes (USD)
$\mathrm{PW}[PV_{OPEX}\,(\mathrm{N_{PV}})]$	Present worth of the PV system operation and maintenance cost (USD)
Q	Annual Cash flows of an investment (USD)
SCI	Self-consumption index (%)
T	Residential Tax rate applicable (%)
$\mathrm{T_{SME}}$	Non-residential tax rate (corporative) (%)
USD	US Dollar
VAT	Value Added Tax (%)
WACC	Weighted average cost of capital (%)
Yf	Final Yield (kWh/kWp)

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