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Economic analysis of photovoltaic projects: The Argentinian renewable generation policy for residential sectors

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The Province of San Juan-Argentina has a considerable amount of solar radiation which encourages taking advantage of a photovoltaic system. In addition, a net billing remuneration mechanism for renewable and distributed energy generation has been established by recent Argentinian Law (Dec-2017). This work presents a profitability analysis of solar photovoltaic projects connected to the grid in the residential sector, considering the Net Billing structure adopted by the Law, and also the Feed-in-Tariff structure that has been used in other countries in order to make comparisons. The valuations are performed for three different projects, taking into account the measured energy data for a year. The well-known Net Present Value method is used as the valuation index. Results show that renewable distributed generation is not profitable for the residential sector at this time, with the current technology costs, national financial conditions and tariffs, combined with some estimations regarding future electric tariffs. Considering this information, the manuscript details a sensitivity analysis of the capital cost, consumed and injected energy prices. Finally, some discussions on incentive mechanisms are introduced in order to aid national decision-makers in energy policies so as to ensure profitable projects.

1. Introduction

In the last decades, the global electric power industry has faced large and paradigmatic structural changes. Clean energy sources have increasingly-captured the attention of researchers, governments, policymakers, companies and the general public. Photovoltaic (PV) generation is a safe and mature technology, along with other renewable generations. Currently, it represents a considerable part of the total energy demand in many countries, primarily in Europe.

In Argentina, the situation is different from that of European countries since in December 2017 renewable electricity generation represented only 2% of the total electricity generation of the country, as is shown in Fig. 1. Thermal generation is the main source of electricity, reaching 62%, followed by hydroelectric generation at 31%. With the goal of increasing generation through renewable energy, Law 26.190 [1] was passed. This law states that, by December 2017, eight percent (8%) of the national energy matrix should come from renewable sources (not accomplished). The second stage of this law has the objective of achieving a 20% contribution from renewable energy sources by December 2025. To achieve these objectives, it is necessary to develop incentive mechanisms, mainly for PV energy since it is one of the most promising renewable energy sources in Argentina, particularly in the province of San Juan, due to its high levels of radiation (see Fig. 2) and the simplicity of installation, maintenance and facilities required. In addition, recent Argentinian Law 27.424 ([2], December 2017) allows for a residential user to become a user/generator and also establishes at remuneration structure. This is so recent that the electrical distribution company in Buenos Aires (Edenor) just installed its first bi-directional electric meter in January 2018 in order to connect the first client to the grid as a residential distributed generator [3]. However, a pilot project for distributed energy in the residential sector was started some years ago in San Juan by the authors in Ref. [4]. Previous (before the current law) research on solar distributed generation in Argentina can be found, such as the work in Ref. [5] which conducts a financial and technical valuation for the Province of Salta using a Net Metering scheme, and also the work in Ref. [6] where a grid parity analysis using a Feed-in-Tariff scheme for the Province of Santa Fe is introduced. Both

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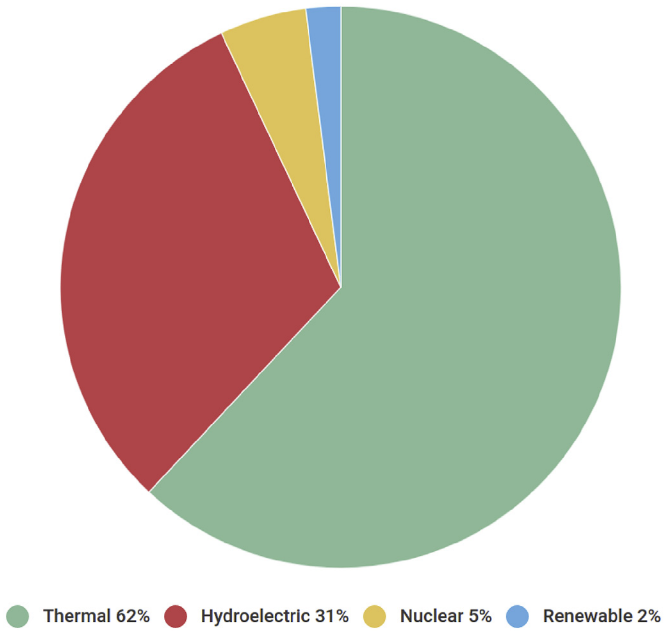


Fig. 1. Electric power generation in Argentina (CAMMESA Dic 2017).

researches do not address a project valuation with a Net Billing scheme since the papers are based on local Laws instead of the new national Law. In addition, neither of them considers the tariff model in the valuation methodology; they only use a residential consumer energy price. Moreover, the case studies are based only on PV energy estimations.

The experience of countries that currently have a strong presence of photovoltaic energy (Germany and Spain, among others) indicates that one of the largest obstacles to this type of energy is the high cost of the solar panels. Although this cost has decreased significantly, as is shown in the US solar photovoltaic system cost benchmark [8], it still remains high. Therefore, incentive policies and regulatory mechanisms have been introduced to encourage the expansion of this technology. The most widely known mechanisms are Feed-in Tariff (FiT), Net Metering (NM) and Net Billing (NB).

Although research on market policies for photovoltaic generation on the residential sector has not yet been carried out in Argentina, seeing as Law 27424 [2] is quite recent (at the time of this work), several publications around the world have studied the economic competitiveness of photovoltaic systems installed on roofs of houses connected to the distribution network. We can cite [9], in which the authors evaluate the financial performance of an investment on a PV system for the residential sector in Thailand using the FiT framework. The investment evaluation metrics used are the net present value (NPV) and the internal rate (IRR) of return. The results show that the present FiT is not enough to promote investment in PV systems on roofs in the residential sector considering the current market situation and, therefore, appropriate additional stimulus measures are proposed to encourage investment for households. Unfortunately, this work does not consider real measured data since the PV energy generated is simulated using RETscreen software [10]. In addition, authors in Ref. [11] analyze the economic profitability of photovoltaic systems of 1 kW, 3 kW and 5 kW located in different regions of China, considering the net present value (NPV), the internal rate of return (IRR) and the discounted payback period (DPBP). The analysis carried out in this work considers solar radiation levels, savings in self-consumption, cash flows of injected power and local prices of the facilities in order to demonstrate that the best performance is obtained in places with better solar radiation or where the price of electricity is higher. The annual production of PV energy is simulated with the use of software. Moreover, in Latin America, an economic analysis of two photovoltaic energy distributed generation projects which are part of the government program "Minha

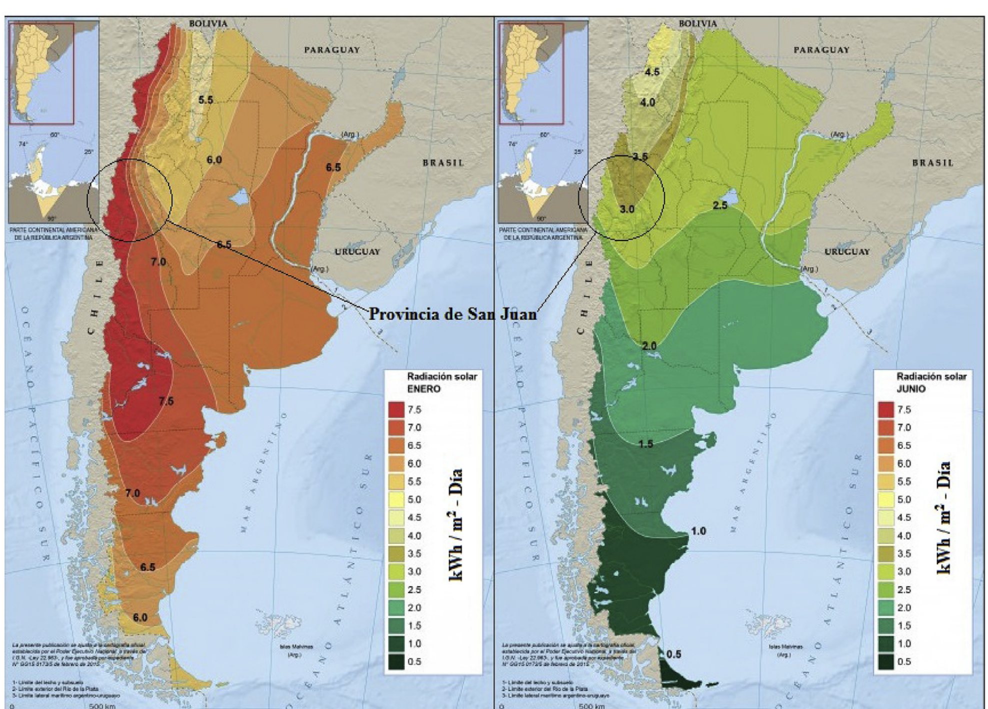


Fig. 2. Argentinian map of global irradiation [7].

Casa Minha Vida" is conducted in Ref. [12]. The authors' objective is to determine if the installation of photovoltaic systems is economically feasible. This analysis was conducted using the NPV and the IRR, taking into account an attractive minimum rate of return and varying the annual growth of energy tariffs over 25 years of operation. It is important to note that the PV energy generated is calculated based on an estimate of solar radiation (using the SunData software). Based on the results obtained, solar energy is not an accessible technology for a large part of the Brazilian population. The study also concludes that a more actively involved government is required in order to promote this type of renewable energy. In addition, authors in Ref. [13] suggest four principles to guide the creation of a FIT credit system, among other conclusions and recommendations for developing photovoltaics in Brazil for low-income housing.

Additionally [14], investigates the historical development and implementation of FiT policies in China from 2011 to 2016. The PV energy was estimated considering PV systems with a capacity superior to 20 MW. The NPV and IRR tools are used in order to show the economic impact of the FiT policy. Finally, it is concluded that in the short term, tariff levels should be adjusted more frequently to maintain the IRR values inside a proper range for this type of investment. Although this work considers large PV systems, it was significant for the field since the profitability metrics (NPV and IRR) are the same as those used in small systems.

Moreover, a profitability evaluation of a photovoltaic system for residential houses in Italy was introduced in Ref. [15], in which three metrics are used: net present value, discounted amortization time and levelized cost of energy. The analysis is applied to several cases studies of residential households and distinguishes three critical variables: (i) size of the plant; (ii) level of solar irradiation and (iii) percentage of PV energy used as self-consumption. In addition, purchase electricity price and sale electricity price are considered. The case studies proposed in this paper show that profitability can reach tempting levels and that consumers also play a key role. In fact, NPV is significant when an alignment is obtained between consumption and energy production, considering also the reduction of photovoltaic investment costs. Other interesting work is presented in Ref. [16], which introduced an economic model for evaluating the profitability of PV systems. It considers FIT and NM schemes and three projects (different generation capacity) located in European countries. The results obtained show not only the circumstances under which solar energy is economically profitable, but also the type of PV systems to be used, their locations, the minimum levels of prices and a specific combination of support schemes that should be promoted. After analyzing the results, the authors determine that this type of system is not profitable for most of the cases without an electricity compensation support plan. Therefore, a combination of FIT and NM schemes seems to be a possible option. Also, in Ref. [17], a comparison of these mechanisms is conducted for residential photovoltaic systems. Additionally [18], calculates a regulated tariff level that should support the development of the solar-energy market in China, considering residential photovoltaic installations with power that varies between 1 kW and 5 kW. Considering the costs of photovoltaic energy determined from the analysis of the NPV, and using forecasts of solar system prices, a FiT optimum for encouraging investment in photovoltaic energy is obtained. Finally [19], explores policies of the small-scale solar PV industry, taking into account the reality in many countries.

Besides this information, other researchers have considered NB schemes for their economic analysis of PV distributed generation systems, including the authors in Ref. [20] who propose a method for the evaluation of PV systems in Spain. Additionally, Watts ([21]) applied a valuation in 10 cities in Chile in order to estimate the generation potential of PV systems in that country. Moreover, authors in Ref. [22] analyze the effects of Spain's energy policy on investments in PV systems in the residential, commercial and industrial sectors. Other interesting work is presented in Ref. [23], where the profitability of PV projects is evaluated considering different schemes (NB, NM, and FiT) and based on simulated values, similar to the works cited in this paragraph.

The present work introduces a financial analysis of the framework policy established in recent Argentinian Law 27424 mentioned above ([2]) regarding photovoltaic generation in the residential sector. Evaluation of financial returns was based on the Net Present Value method, comparing FiT and Net Billing remuneration mechanisms. The methodology presented considers the tariff structure that a residential user pays for the electricity consumed from the grid. This tariff model includes taxes and fixed costs, therefore, the methodology highlights the advantages of NB schemes in countries where electricity tax rates are high. In addition, the paper is based on real measurements of solar generation obtained during the first year for three PV systems located in the Province of San Juan-Argentina, in the residential sector. A sensitivity analysis was performed in order to aid government decision-makers who are concerned with encouraging renewable and distributed generation. Consequently, some policy suggestions are introduced.

The rest of this article is organized as follows. In the following section, the general background is summarized. In Section 3, the framework for evaluating solar generation investments in residential rooftop is introduced. Section 3.6 presents a case study of residential projects in San Juan, Argentina. Both financial valuation and sensitivity analysis for the example cases are provided in section 4. Finally, Section 5 presents our conclusions.

2. Background

2.1. Investment valuation index

Net present value (NPV) is a well-known method for valuing an investment project and is determined by calculating the costs (negative cash flows) and benefits (positive cash flows) for each period of an investment and discounting its future value (see eq. (19)). A positive NPV means that the project is profitable, whereas a negative one means the opposite is true. The author of [24] present an explanation of NPV.

2.2. Remuneration mechanisms

2.2.1. Feed-in Tariff

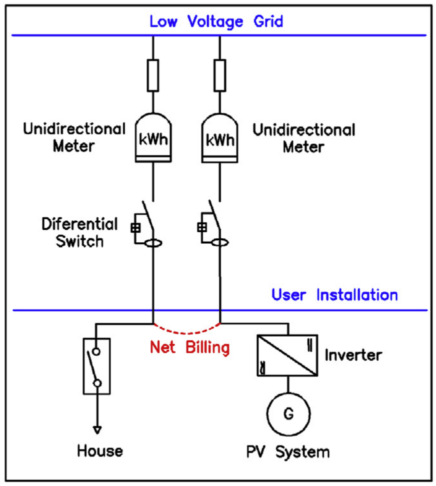
The Feed-in-Tariff (FiT) is a source of tariffs that implies the obligation on the part of a distribution company to buy the electricity generated by renewable energy (RE) producers in their service area (see Fig. 3a for the electric schematic diagram). The user will receive a payment for the energy generated. The price of this energy is set by energy policy and will be guaranteed for a determined period of time. Feed-in tariff remuneration models are introduced and analyzed in Refs. [25] and [26].

FiT is a widely used support mechanism for the promotion of renewable energies, with examples in: Europe [27,28], New Zealand [29], China [30], Japan [31], and Thailand [32].

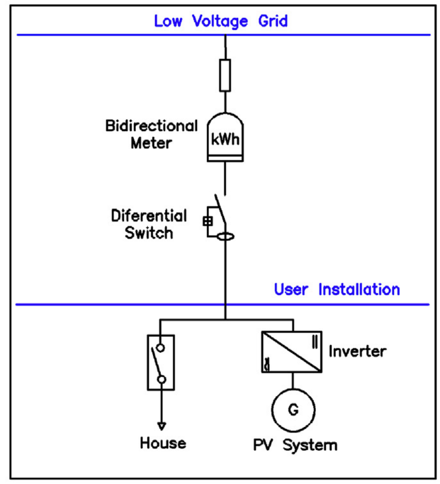
2.2.2. Net metering

This mechanism is a compensation system for energy balances, and calculates the difference between the electric energy generated by the installation, and the electric energy consumed by the user through the supply of the distribution network (see Fig. 3b).

Currently, net metering is a mechanism used in many countries,



(a) *FiT* and *Net Billing* (red dotted line)



(b) *Net Metering*

Fig. 3. Electric schematic diagram for each remuneration mechanism.

such as the US [33], Australia [34,35], and Denmark [36,37].

2.2.3. Net billing

In the case of Argentina, Law 27.424 [2] established that the Net Billing model would be adopted as the remuneration scheme. Under a net billing policy, customers may self-consume energy from their systems, effectively saving money for this energy consumed directly on-site, behind the meter. Any energy not consumed directly on-site is exported to the electric grid and credited at a specific rate.

In this way, the final value to be paid or collected by the user will be the difference between the monetary values of the demanded and injected energy (generated energy is not equal to injected energy due to the demanded energy). If there is a monetary surplus in favor of the user, a credit will be set up for the billing of the following periods. If this credit persists, the user may request from the distribution company the remuneration of the favorable balance that may have been accumulated over a period not to exceed 6 months. Fig. 3a shows the electric schematic diagram, where the dotted red line makes it possible to self-consume the generated energy. If a generation surplus exits, the energy not consumed is exported to the electric grid.

3. Methodology

3.1. Tariff model

In the Province of San Juan-Argentina, the tariff structure is formed by different tariff bands according to the energy demanded and its purpose. The bands differentiate between residential, commercial, industrial and large users, among others. The residential sector (which this work is interested in) has the following bands: **T1-R1**, **T1-R2**, and **T1-R3** (see Table 1). A user is included in the T1 band when his maximum average demand for 15 min is inferior to 10 kW. Additionally, T1-R corresponds to those whose use of energy is exclusively residential. The table shows the consumption bands for residential users.

Table 1
Residential electricity tariff in San Juan, Argentina.

Tariff-band (t_b)	Bimonthly demand
T1-R1	< 220 kWh
T1-R2	220 < and < 580 kWh
T1-R3	> 580 kWh

For the rest of the manuscript, the following variables will be used:

- Q_c is the PV energy consumed/demanded by the household,
- Q_g is the PV energy generated,
- P_c is the value that the user pays for each *kWh* consumed from the energy grid at *t before taxes*, and could change during the project lifetime, and
- P_e is the tariff that the company pays to the user for each *kWh* exported to the electric grid.

The **final** price of consumed/demanded energy that the user pays to the distribution company can be expressed as:

$$T_{tariff}(t, t_b) = C_f(t_b) + C_v(t, t_b) + T_{tax}(t, t_b) \tag{1}$$

where $C_f(t_b)$ is the fixed cost that depends on the tariff-band t_b. Additionally,

$$C_v(t, t_b) = Q_c\, P_c(t, t_b) \tag{2}$$

is the variable cost and T_{tax} is the tax applied, depending on the percentage rate (T_{rate}) estimated from several taxes (according to the tariff band) applied to the total cost (fixed and variable) and which can be expressed as:

$$T_{tax}(t, t_b) = T_{rate}(t_b)\left[C_f(t_b) + C_v(t, t_b)\right] \tag{3}$$

3.2. Demanded and generated energy

It is a local assumption that demanded energy will increase 1% per year and that this rate should be set for each particular case by the decision-maker. The demanded energy can be defined as:

$$Q_c(t) = Q_c(0)\left(1 + t\frac{1}{100}\right) \tag{4}$$

On the contrary, the performance of the photovoltaic panel decreases 1% (d_p) per year according to the works in Refs. [21,38]. Therefore, generated energy can be described as

$$Q_g(t) = Q_g(0)\left(1 - t\frac{d_p}{100}\right) \quad (5)$$

where $Qg(t)$ is the annual generation capacity of the PV project (estimated for $t > 1$) and $Q_g(0)$ is the *measured* PV generation.

3.3. Incomes

Incomes are given according to the policy tariff, either selling the total electricity generated (FiT) or consuming what is necessary and selling the surplus (Net Billing).

The Net Metering scheme will not be analyzed in this work.

3.3.1. Incomes with a FiT scheme

$$R_{FiT}(t) = Q_g(t)P_e(t) \quad (6)$$

P_e values in other countries with a FiT scheme are shown in Table 2, as well as the years supported.

3.3.2. Incomes with a net billing scheme

Fig. 4 presents a graphic representation of cumulative generated and consumed energy (30 samples). On the plot, three different samples can be noted, marked as Ts_1, Ts_2 and Ts_3. If the sample period ends at Ts_1 or Ts_2, user revenues will be generated by a savings in the electricity bill (reduction in the variable cost and taxes). The user will not receive extra money. If the sample period ends at Ts_3, user revenues will be generated not only for saving but also for selling the exported energy (reduction in the variable cost and taxes and charge of injected energy).

This scheme presents two equations depending on the sign of the term $(Qc - Qg)$. On the one hand, positive values (sample at Ts_1 of Fig. 4) mean that the user will save energy (region 1 of Fig. 4) and therefore will see a reduction in the billed amount before taxes (region 2 of Fig. 4, and also after taxes as an obvious consequence due to a reduction in the tax base). On the other hand, negative values (sample at Ts_3 of Fig. 4) mean that the user will not only reduce the billed amount (region 3 of Fig. 4) but will also receive a payment for the energy injected into the electric grid (region 4 of Fig. 4).

For the case at Ts_1 (regions 1 and 2), before the installation of the PV project, the variable cost C_v that the user pays is

$$C_v|_{beforePV} = (Qc\ Pc) \quad (7)$$

while with the PV project, the variable cost is

Table 2
Comparative FiT rate for residential PV projects in other countries. Table introduced in Ref. [9], citing [27,31,39,40].

Country	FiT rate [USD/kWh]	Years supported
China	0.059	20
Denmark	0.086 (year 1–10) and 0.058 (year 10–20)	20
France	0.263	20
United Kingdom	0.052	20
Italy	0.182	20
Germany	0.131	20
Japan	0.297	21
Malaysia	0.185	25
Thailand	0.211	25

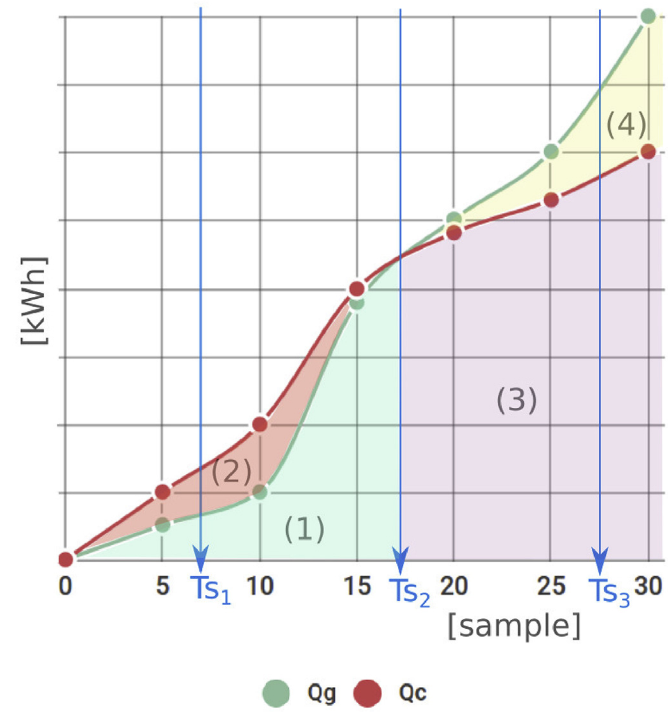


Fig. 4. Cumulative Energy Generated and Demanded, highlighting different sample times.

$$C_v|_{afterPV} = \left(\left(Q_c - Q_g\right) P_c\right) \quad (8)$$

, both before taxes. For this case of simply saving, we can say that incomes are generated by the differences between both variable costs (eq. (7) and eq. (8)):

$$R_1 = Q_c\,P_c - \left(\left(Q_c - Q_g\right) P_c\right) \quad (9)$$

which leads to:

$$R_1(t) = Q_g(t)\,P_c(t) + \psi \quad (10)$$

where ψ is a portion of saved taxes due to a reduction of the tax base (see eq. (14)).

For the case at Ts_3 (regions 3 and 4), incomes from the exported energy should be added to eq. (10),

$$R_2(t) = Q_c(t)\,P_c(t) + \psi + (Qg - Qc)Pe \quad (11)$$

Finally, joining Eq. (10) and Eq. (11), we obtain:

$$R_{NB}(t) = \begin{cases} Q_g(t)P_c(t) + \psi & ,if \quad Q_c \geq Qg \\ Q_c(t)P_c(t) + \psi + (Qg - Qc)Pe & ,if \quad Q_c < Qg \end{cases} \quad (12)$$

where the portion of taxes saved (see eq. (14)) can be expressed as:

$$\psi(t) = \begin{cases} Trate\left(Q_g(t)P_c(t)\right) & ,if \quad Q_c \geq Qg \\ Trate\left(Q_c(t)P_c(t)\right) & ,if \quad Q_c < Qg \end{cases} \quad (13)$$

since

$$\psi = T_{tax}|_{(beforePV)} - T_{tax}|_{(afterPV)} \quad (14)$$

Additionally, considering eqs. (2) and (3), each term of eq. (14) can be expressed as:

$$T_{tax}|_{(beforePV)} = T_{rate}\left[C_f + (Q_c P_c)\right] \tag{15}$$

$$T_{tax}|_{(afterPV)} = \begin{cases} T_{rate}\left[C_f + P_c(Q_c - Qg)\right] & ,if \quad Q_c \geq Qg \\ T_{rate}\left[C_f + 0\right] & ,if \quad Q_c < Qg \end{cases} \tag{16}$$

taking into account the expression of the variable cost C_v that the user pays for the energy consumed from the grid. Moreover, eq. (13) is obtained after substituting eqs. (15) and (16) into eq. (14).

Remark: In this work, the savings that a user could achieve after the installation of the PV project, due to a jump from T1-R3 to T1-R2 or from T1-R2 to T1-R1, are not considered due to its low impact on the valuation.

3.4. Operating and maintenance costs

Not only are the investment costs important to take into account for valuation, but also operating and maintenance costs (OMC). In this case, OMC is modeled as a unique annual amount represented by $C_1(t)$ which is present each year during the lifetime of the project [41], plus an inverter replacement in the 15th year. Investment cost is a one-time outlay (I_0). Both of these costs are defined in Eqs. (17) and (18).

$$C_1(t) = 0.005\, I_0 \tag{17}$$

$$C_2(t) = \begin{cases} InverterCost & \forall \quad t = \{15\} \\ 0 & \forall \quad t \neq \{15\} \end{cases} \tag{18}$$

3.5. Valuation method

The classical investment assessment method consists of calculating the net present value of the project without flexibility ($NPV_{classic}$), which for this case is calculated using eq. (19).

$$NPV_{classic} = \sum_{t=1}^{n} \frac{R(t) - C(t)}{(1-k)^t} - I_0 \tag{19}$$

where $R(t) - C(t)$ represents the annual income, with $0 < t < T_{life}$ and T_{life} being the lifetime of the project. Additionally, k is the discount rate or capital cost.

3.6. Case study

The Electrical Energy Institute at the *National University of San Juan* (UNSJ), together with *Argentina's National Scientific and Technical Research Council* (CONICET), conducted a research project with the cooperation of the electrical company *Electric Distribution of Caucete* (DECSA) and *San Juan's Provincial Energy Society* (EPSE) ([4,42,43]). This project considered photovoltaic generation in the residential sector as distributed generation (scaled between $1.6kWp$ and $4kWp$) and included the installation of pilot facilities in three household, metering and the formulation of tech-administrative procedures.

The PV projects are placed on a rooftop of three houses, located in the Province of San Juan, Argentina. Three houses belonging to each residential tariff band were selected. Based on the demanded energy, house 1 corresponds to T1-R1, house 2 to T1-R2 and house 3 to T1-R3. Location coordinates are shown in Table 3 with scale project parameters.

Table 4 shows the main measurements gathered during the first year of the project, with information regarding PV energy generated, energy consumed by each household and surplus energy. The values shown correspond to the cumulative monthly measurements over a year.

Furthermore, Fig. 5 shows the curves of consumed and generated energy, measured monthly during the first year of the project. Also, the difference between Q_c and Q_g is noted monthly, where generated energy is greater than consumed energy during some parts of the year.

In addition, Table 5 gives a detailed account of investment costs and totals for each household involved in the project.

Table 6 shows each residential tariff band in force from 01/11/2017 to 31/01/2018 [44] in San Juan, Argentina for the residential sector, *without distinguishing between different hours of the day*. For the table, the exchange rate in November 2017 (1 USD = 17.3 ARS) was applied. Tax rates are estimated since some taxes are different for different locations, and others change over time. Main taxes include the value-added tax, the public lighting tax, gross revenue and power system expansion funds, among others.

Additionally, Table 7 introduces an expected tariff structure for 2019 (extrapolating from recent historical values), as the last published tariff structure (Table 6 tariff bands from 01/11/2017 to 31/01/2018) will increase during 2018 and therefore will affect the project valuation (next 25 years). The tariff has been rising since 2016 due to a significant reduction in government subsidies.

Moreover, 113 USD for each MWh was considered as remuneration for PV energy exported ($P_e = 113$), based on the wholesale price set in Argentinian Law 27.191 [45]. Although this price was set for wholesale users, we have used this value as a minimum since there is currently no set price for residential users.

Finally, a monthly period was considered for the sample measurement/compensation of the energy consumption/injection.

4. Results and discussions

The risk-adjusted discount rate or capital cost used to calculate the classic NPV is chosen as 10% per year. This value is commonly used to represent the cost of equity for electricity market investments or projects with similar risk profiles. Moreover, the risk-free discount rate is considered as 5% and represents the return on risk-free investments. United States treasury bonds of similar maturity are regarded as a risk-free investments.

Remark: In addition, a break-even rate was considered. Therefore, prices are expressed in constant USD (US Dollar), assuming that the inflation rate affects both tariffs and investment costs equally. Besides this, the "real" discount rate from the "Fisher hypothesis" was used ([46]). This rate does not take into account the inflation rate and only considers the risk-free rate plus extra points due to the risk premium of the project. Moreover, valuation was performed before taxes.

4.1. Case-base valuation

Figs. 6 and 7 are obtained using the costs and tariffs introduced in Tables 5 and 7, respectively. Although Argentinian law [2] establishes Net Billing as the remunerative mechanism for residential users, FiT was also taken into account in this section in order to compare with foreign users and to achieve a deeper analysis.

Firstly, Fig. 6 shows the expected incomes for each year of the project (3 households) under both remuneration schemes (FiT and Net Billing). A negative slope can be seen for every curve along the project lifetime because of a decrease in the generation capacity (see eq. (5)). This figure allows us to compare the incomes generated by each scheme for a defined user, and it can be seen that incomes under NB are higher than those under FiT. This situation

Table 3
Main parameters of the PV project.

System	Nick	Coordinates	Inverter	PV module
House 1	H1	Lat: −31.627426, Lon: −68.302701	1.6 kW without transformer	$7 \times 235 = 1645$ Wp
House 2	H2	Lat: −31.666320, Lon: −68.272737	3.0 kW without transformer	$9 \times 295 = 2655$ Wp
House 3	H3	Lat: −31.661363, Lon: −68.269721	3.8 kW with transformer	$10 \times 295 = 2950$ Wp

Table 4
Measured annual energy.

Household	Consumed by House	Generated by PV	PV energy to the grid [kWh-year]	PV energy to Household	Grid energy to Household
H1	2290	2240	1497	743	1547
H2	4779	4828	3505	1323	3456
H3	6968	5434	3055	2379	4589

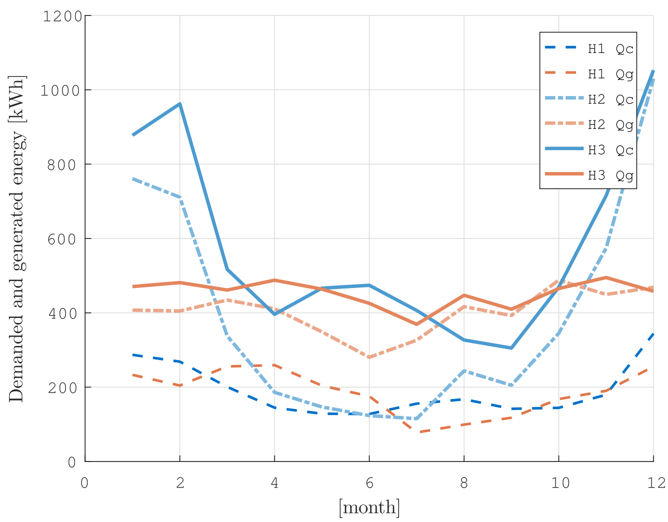


Fig. 5. Monthly measurement of consumed energy and generated energy for each household during the first year of the project.

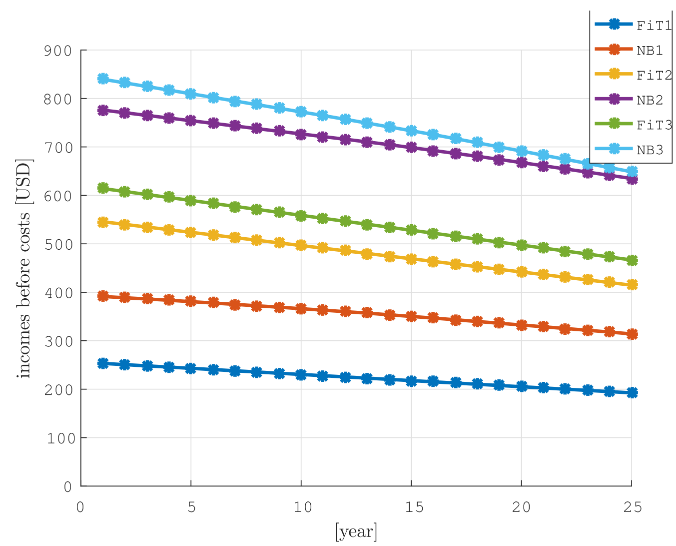


Fig. 6. Incomes for each year of project.

Table 5
Investment costs.

Household	Inverter	PV panels	Labor	Structure [USD]	Electric materials	Sunny Bean-BT-11	TOTAL
H1	1069	1809	325	1292	223	301	5021
H2	1725	2920	325	1661	223	301	7158
H3	1917	3245	325	1846	223	301	7859

Table 6
Tariff bands **(01/11/2017 to 31/01/2018)**.

Tariff-band	Fixed Cost	Variable Cost	Taxes
t_b	C_f [USD monthly]	P_c [USD/kWh]	T_{rate} [%]
T1-R1	0.5315	0.0888	27
T1-R2	2.4650	0.0741	48
T1-R3	5.8578	0.0683	40

Table 7
Tariff bands **(expected to 2019)**.

Tariff-band	Fixed Cost	Variable Cost	Taxes
t_b	C_f [USD monthly]	P_c [USD/kWh]	T_{rate} [%]
T1-R1	0.6452	0.1458	27
T1-R2	2.9922	0.1217	48
T1-R3	7.1106	0.1122	40

can be inferred by comparing Eqs. (6) and (12), where if $Pc \approx Pg$ then, $R_{NB} > R_{FiT}$ due to the tax term ψ.

Additionally, Fig. 7 was introduced in order to compare projects profitability. It shows the NPV values for each of the three households, considering the NB and FiT schemes. As can be seen, the NPV is negative for all cases under analysis, which means that distributed renewable generation in the residential sector is not profitable with the current conditions and energy prices (those considered in this work) in the province of San Juan-Argentina. Moreover, NB is more convenient than FiT, since a higher NPV was obtained from this type of remuneration mechanism, with the prices previously mentioned, for the three houses analyzed.

4.2. Sensitivity analysis

In this work, a sensitivity analysis of the capital cost, panel performance rate, exported/injected energy and consumed energy

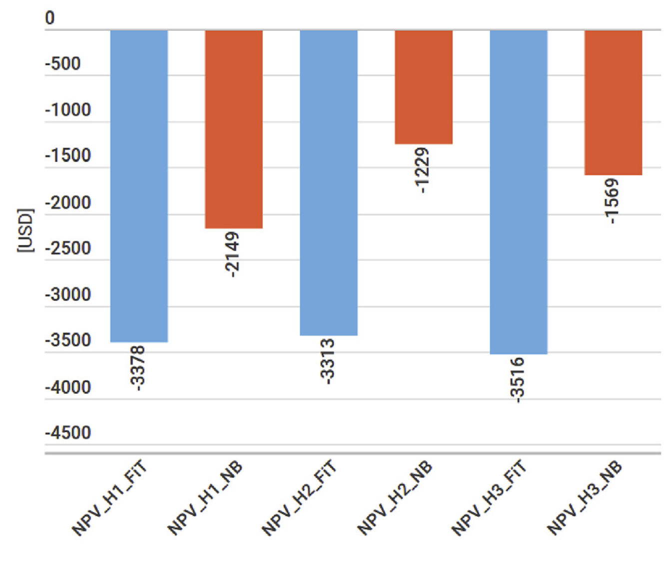


Fig. 7. NPV for each project, with FiT and NB schemes.

price is presented. Additionally, a two-dimensional sensitivity analysis is introduced with the goal of finding decision regions and allowing for an easier definition of energy policy. Moreover, the analysis was performed only for household 3 in order to simplify, since the behavior of variables for valuation is the same for all projects.

Relative variations were equally set for each mentioned variables by varying from −50% to + 50%.

4.2.1. *Unidimensional sensitivity*

In order to aid decision-makers with the design of incentive structures, it is necessary to analyze the influence of variables that can be changed through political action. Some parameters considered in the case base should be modified for the purpose of making profitable PV projects in the residential sector. Fig. 8 shows the NPV for a variation of k, P_c, P_g, and d_p according to the data presented in the Table 8 for each variable. In can be noted that NPV is positive with $k < 7\%$. This figure also presents NPV variation after an increase

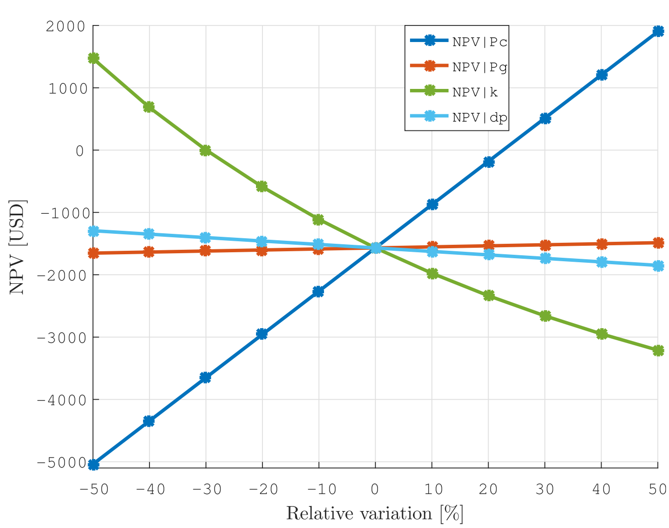


Fig. 8. Sensitivity with NB: consumed and exported energy price, capital cost, and module degradation.

in the exported energy price. Even after doubling the price used in the case base, NPV is negative, which means that this price should rise considerably in order to make the photovoltaic project profitable. This is reasonable because in the projects under analysis, exported energy is low as the installed PV power is lower than the demanded power. The figure also introduces NPV for variations of the consumed energy price, where an increase of 24% ($P_c > 0.14$) should be achieved in order to make the investment profitable ($NPV > 0$).

Fig. 9 presents NPV under a FiT scheme after increasing the exported price (P_g). It also shows marks over the curve which correspond to tariffs in other countries (see Table 2). It can be noted that if the project under analysis was remunerated with FiT schemes in Thailand, Japan or France, the project would be profitable.

4.2.2. *Discussions*

Going deeper into the methodology and analysis of results, some discussions and policy proposals can be achieved. From eqs. (6) and (12), it can be seen that when the exported energy price (P_g) is similar to the consumed energy price before taxes (P_c), the remuneration achieved by a FiT scheme is equal to that obtained by an NB scheme. But in many countries, tax rates (ψ) are high, so there exists a savings advantage for the user under NB. Additionally, FiT is more convenient when the exported energy price is higher than the consumed energy price plus taxes.

In Argentina, NB was established as the remuneration structure. Although residential users are not able to change or choose the structure with which they will be remunerated, they can determine the size of the project. This leads us to think that one incentive mechanism for the Argentinian case could be to set a very high P_g. On the one hand, this signal could motivate users to install a project that generates more than the demanded energy of the household and also to reduce energy consumption, in order to achieve a higher income by incrementing the zone (4) in Fig. 4. On the other hand, a user with scarce resources will not be able to afford such a big FV project and it would make no sense to invest in a small project.

Moreover, the government should look for ways to offer renewable energy loans with lower interest rates than commercial loans (to reduce the capital cost) since residential users are unable to obtain competitive rates.

Furthermore, an increase of P_c (price determined in liberalized electricity market) through the total reduction of electricity subsidies will encourage investment in photovoltaic generation and a reduction in demanded energy, but it also would damage the access to electricity of low income users.

Finally, if $P_g > P_c + \psi$, changing the sample time of the energy measurement from monthly to daily could give the user some flexibility. Due to the nature of solar generation, users could reduce their consumption during peak hours of solar generation in order to inject more energy into the grid. Of course this kind of measurement requires a smart electric meter which would increase the investment cost. In future work, a more complex analysis could be applied to hourly tariffs P_c and P_g, which would be interesting for countries where the electric market and infrastructure already operates in that way. This complexity involves uncertainty and flexibility in the decision-making process, which could require a real options approach in order to achieve a more realistic evaluation.

5. Conclusion and policy implications

High levels of solar radiation, the recent possibility for users to become user/generators and government targets for renewable energy coverage encourage investment in PV projects. Therefore,

Table 8
Values of variables for sensibility analysis.

Relative Variation [%]	−50	−40	−30	−20	−10	0	10	20	30	40	50
k	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
P_c	0.056	0.067	0.078	0.089	0.101	0.112	0.123	0.134	0.145	0.157	0.168
P_g	0.056	0.068	0.079	0.090	0.102	0.113	0.123	0.136	0.147	0.158	0.169
d_p	−0.5	−0.6	−0.7	−0.8	−0.9	−1	−1.1	−1.2	−1.3	−1.4	−1.5

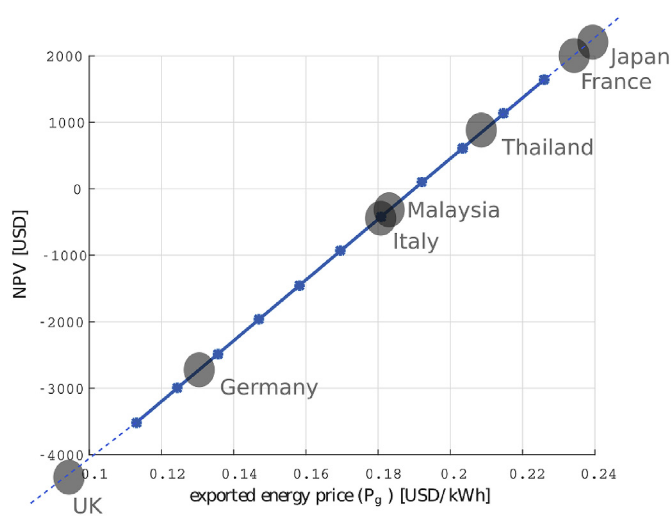


Fig. 9. Sensitivity to *exported energy price* under FiT.

this work has presented a profitability analysis of a photovoltaic project connected to the grid in the residential sector, considering the Net Billing remuneration scheme established by local law and comparing it with the FiT scheme adopted by other countries. Initial valuation data corresponded to measurements performed during the first year of three projects installed in San Juan - Argentina.

Results have shown that the investment is not feasible with the current technology costs, national financial conditions and tariffs, but do not imply that it could not be profitable in the near future with liberalized tariff prices and perhaps some promotional mechanism for the distributed solar generation. The base case also shows that the NB scheme is better than FiT for the users/generators analyzed under similar tariffs (consumed and injected energy) as taxes are high in Argentina and therefore, reducing the amount of purchased energy (NB) is more profitable than selling it to the grid (FiT).

In addition, a sensitivity analysis of the variables able to be influenced by energy policies (*Pc*, *Pg*, *k*, consumed and exported energy price and capital cost) was performed in order to find positive NPV regions. It was concluded that for the cases under analysis, increasing the injected energy price does not make the investment profitable, while the opposite occurs if the consumed energy price is increased or the capital cost is reduced. It is difficult to raise Pc within the current inflationary context since it would negatively impact vulnerable sectors and would also raise the inflation rate. Additionally, as a FiT scheme is not adopted by the law, it is difficult to use Pg as an incentive for small residential projects due to the fact that the amount of exported energy is considerably less.

Besides, due to the fact that the capital cost is very high for the average citizen, the government should contribute with low interest rate loans for investment in renewable energy, at least for the first projects until an annual quota is established.

Moreover, the methodology utilized could be applied to other regions of the country after properly setting the parameters. However, if the tariff equation changes its structure, the income equation should be adjusted to represent that particular situation. Due to the fact that this work has considered real data (PV generated and consumed energy) and has performed an investment valuation from a user point of view, subsequent work should design incentive mechanisms following the policy implications discussed above and should evaluate the effects of their application. A quantitative analysis should help to design an effective policy mechanism for each particular region.

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Appendix. Two-dimensional sensitivity

Firstly, Fig. 10 introduces the NPV against a two-dimensional sensitivity analysis with respect to the consumed and demanded energy price. Additionally, the colored contour plane is shown in Fig. 11, considering only the NPV positive region in order to aid decision-making ($P_c > 0.14$). From these two figures it can be noted that while P_c has a significant influence on the NPV in a NB scheme, P_g has a negligible influence on the NPV (the amount of exported energy is tiny as the PV power installed is not very great). This leads us to combine another sensitivity analysis on the capital cost and the consumed energy price (see Figs. 12 and 13).

As is evident from the cited figures, both variables have a significant impact on the NPV. A positive NPV region is found where a better profit is obtained for lower capital cost and higher consumed energy price (since the savings are higher). For example, some limiting points are $(P_c; k) = \{(0.11;\ 0.07),\ (0.14;\ 0.10),\ (0.19;\ 0.15)\}$. It is important to highlight the fact that taxes paid by

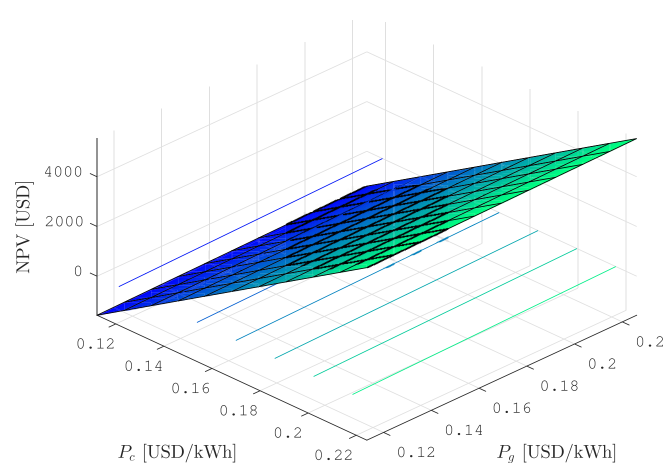

Fig. 10. Surface of the NPV two-dimensional sensitivity, to the consumed and exported energy price.

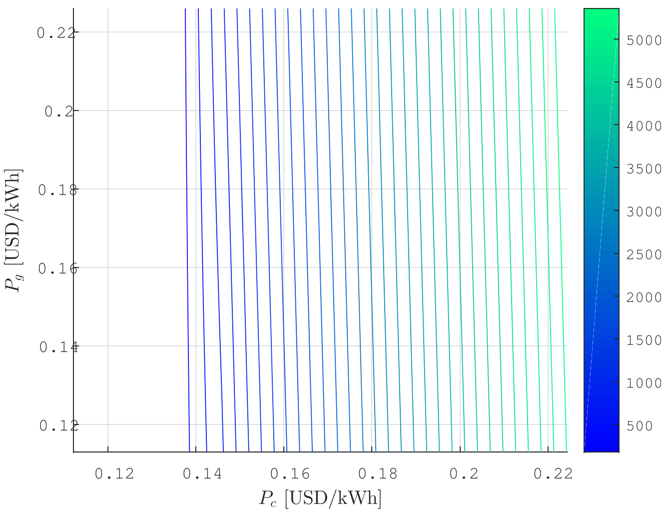

Fig. 11. Contour of the positive NPV two-dimensional sensitivity, to the consumed and exported energy price.

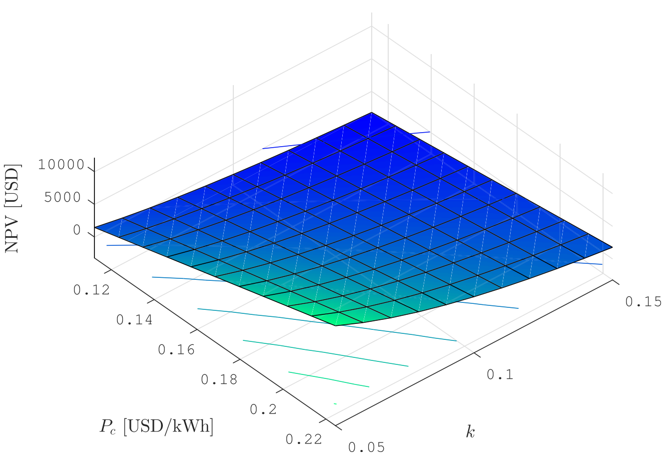

Fig. 12. Surface of the NPV two-dimensional sensitivity, to the consumed energy price and capital cost.

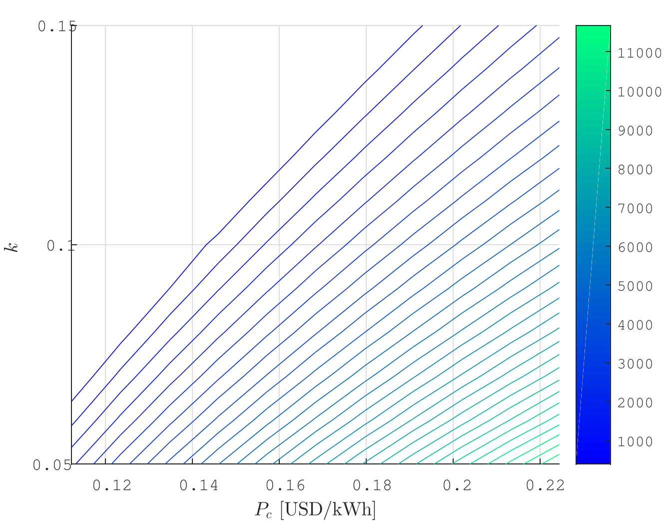

Fig. 13. Contour of the positive NPV two-dimensional sensitivity, to the consumed energy price and capital cost.

the users are high in the Argentinian cases presented, which leads to higher savings under an NB scheme.

References

[1] Ley 26.190: Régimen de fomento nacional para el uso de fuentes renovables de energía destinada a la producción de energía eléctrica. objeto. alcance. ambito de aplicación. autoridad de aplicación. políticas. régimen de inversiones. beneficiarios. beneficios. sanciones. fondo fiduciario de energías renovables. (Law 26.190: National Programme for the Promotion of the Use of Renewable Energy Destinated for Producing Energy. Objective. Scope. Field of Application. Authority of Application. Investment Scheme. Beneficiaries, El Senado y Cámara de Diputados de la Nación Argentina (Argentinian Chamber of Deputies and the Senate), December 2016. http://servicios.infoleg.gob.ar/infolegInternet/anexos/120000-124999/123565/texact.htm.

[2] Ley 27.424: Régimen de fomento a la generación distribuida de energía renovable integrada a la red eléctrica pública (Law 27.424:national Programme for the Promotion of the Distribuited Generation of Renewable Energy Integrated to the Public Electric Infrastructure, El Senado y Cámara de Diputados de la Nación Argentina (Argentinian Chamber of Deputies and the Senate), November 2017. http://servicios.infoleg.gob.ar/infolegInternet/anexos/305000-309999/305179/norma.htm.

[3] Edenor instala su primer medidor bidireccional para un usuario residencial (Edenor Installs its First Bi-directional Electrical Meter in a Residential User in Buenos Aires, January 2018. https://revistapetroquimica.com/edenor-instala-primer-medidor-bidireccional-usuario-residencial/.

[4] M. Facchini, V. Doña, D. Pontoriero, F. Morán, W. Gómez, Pilot Testing Facility for Photovoltaic Energy Feed to the Grid as Distributed Energy in Residential Sector of San Juan Province (Instalación piloto de inserción de energía solar fotovoltaica conectada a red como generación distribuida en el sector residencial de la provincia de san juan), HYFUSEN, 2011. http://www.cab.cnea.gov.ar/ieds/images/2011/hyfusen_2011/trabajos/18-128.pdf.

[5] L. Ramirez Camargo, J. Franco, N.M. Sarmiento Babieri, S. Belmonte, K. Escalante, R. Pagany, W. Dorner, Technical, economical and social assessment of photovoltaics in the frame of the net-metering law for the province of salta, Argentina, Energies 9 (3) (2016) 133.

[6] E. Sangoi, J.R. Vega, M.E. Samper, Grid parity analysis for low power photovoltaic systems in santa fe (Argentina), in: Innovative Smart Grid Technologies Conference-latin America (ISGT Latin America), 2017 IEEE PES, IEEE, 2017, pp. 1–6.

[7] Energías de mi país: Mapa de radiación solar (solar radiation map). http://energiasdemipais.educ.ar/fuentes-de-energia-potencial/mapa-de-radiacion-solar/.

[8] R. Fu, D.J. Feldman, R.M. Margolis, M.A. Woodhouse, K.B. Ardani, Us Solar Photovoltaic System Cost Benchmark: Q1 2017, Tech. rep., National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2017.

[9] T. Tantisattayakul, P. Kanchanapiya, Financial measures for promoting residential rooftop photovoltaics under a feed-in tariff framework in Thailand, Energy Pol. 109 (Supplement C) (2017) 260–269. https://doi.org/10.1016/j.enpol.2017.06.061. http://www.sciencedirect.com/science/article/pii/S0301421517304159.

[10] Retscreen. http://www.nrcan.gc.ca/energy/software-tools/7465.

[11] S. Rodrigues, X. Chen, Morgado-Dias, Economic analysis of photovoltaic systems for the residential market under China's new regulation, Energy Pol. 101 (2017) 467–472.

[12] A. Vale, D. Felix, M. Fortes, B. Borba, B. Dias, B. Santelli, Analysis of the economic viability of a photovoltaic generation project applied to the brazilian housing program minha casa minha vida, Energy Pol. 108 (2017) 292–298.

[13] J.T. Pinto, K.J. Amaral, P.R. Janissek, Deployment of photovoltaics in Brazil: scenarios, perspectives and policies for low-income housing, Sol. Energy 133 (2016) 73–84.

[14] L.-C. Ye, J.F. Rodrigues, H.X. Lin, Analysis of feed-in tariff policies for solar photovoltaic in China 2011–2016, Appl. Energy 203 (2017) 496–505.

[15] F. Cucchiella, I. DAdamo, M. Gastaldi, Economic analysis of a photovoltaic system: a resource for residential households, Energies 10 (6) (2017) 814.

[16] F.J. Ramírez, A. Honrubia-Escribano, E. Gómez-Lázaro, D.T. Pham, Combining feed-in tariffs and net-metering schemes to balance development in adoption of photovoltaic energy: comparative economic assessment and policy implications for european countries, Energy Pol. 102 (2017) 440–452.

[17] Y. Yamamoto, Pricing electricity from residential photovoltaic systems: a comparison of feed-in tariffs, net metering, and net purchase and sale, Sol. Energy 86 (9) (2012) 2678–2685.

[18] J. Rigter, G. Vidican, Cost and optimal feed-in tariff for small scale photovoltaic systems in China, Energy Pol. 38 (11) (2010) 6989–7000.

[19] S. Rodrigues, R. Torabikalaki, F. Faria, N. Cafôfo, X. Chen, A.R. Ivaki, H. Mata-Lima, F. Morgado-Dias, Economic feasibility analysis of small scale pv systems in different countries, Sol. Energy 131 (2016) 81–95.

[20] R. Dufo-López, J.L. Bernal-Agustín, A comparative assessment of net metering and net billing policies. study cases for Spain, Energy 84 (2015) 684–694.

[21] D. Watts, M.F. Valdés, D. Jara, A. Watson, Potential residential pv development in Chile: the effect of net metering and net billing schemes for grid-connected pv systems, Renew. Sustain. Energy Rev. 41 (2015) 1037–1051.

[22] J.L. Prol, K.W. Steininger, Photovoltaic self-consumption regulation in Spain:

profitability analysis and alternative regulation schemes, Energy Pol. 108 (2017) 742–754.
[23] R. Pacudan, Feed-in tariff vs incentivized self-consumption: options for residential solar pv policy in Brunei Darussalam, Renew. Energy 122 (2018) 362–374.
[24] A. Gallo, A Refresher on Net Present Value. Harvard Business Review, November 2014. https://hbr.org/2014/11/a-refresher-on-net-present-value.
[25] K.-K. Kim, C.-G. Lee, Evaluation and optimization of feed-in tariffs, Energy Pol. 49 (2012) 192–203.
[26] T. Couture, Y. Gagnon, An analysis of feed-in tariff remuneration models: implications for renewable energy investment, Energy Pol. 38 (2) (2010) 955–965. https://doi.org/10.1016/j.enpol.2009.10.047. http://www.sciencedirect.com/science/article/pii/S0301421509007940.
[27] A. Pyrgou, A. Kylili, P.A. Fokaides, The future of the feed-in tariff (fit) scheme in europe: the case of photovoltaics, Energy Pol. 95 (Supplement C) (2016) 94–102. https://doi.org/10.1016/j.enpol.2016.04.048. http://www.sciencedirect.com/science/article/pii/S0301421516302257.
[28] A. Campoccia, L. Dusonchet, E. Telaretti, G. Zizzo, An analysis of feedin tariffs for solar pv in six representative countries of the european union, Sol. Energy 107 (2014) 530–542.
[29] L.V. White, B. Lloyd, S.J. Wakes, Are feed-in tariffs suitable for promoting solar pv in New Zealand cities? Energy Pol. 60 (2013) 167–178.
[30] H. Wang, S. Zheng, Y. Zhang, K. Zhang, Analysis of the policy effects of downstream feed-in tariff on chinas solar photovoltaic industry, Energy Pol. 95 (2016) 479–488.
[31] F. Muhammad-Sukki, S.H. Abu-Bakar, A.B. Munir, S.H.M. Yasin, R. Ramirez-Iniguez, S.G. McMeekin, B.G. Stewart, N. Sarmah, T.K. Mallick, R.A. Rahim, M.E. Karim, S. Ahmad, R.M. Tahar, Feed-in tariff for solar photovoltaic: the rise of Japan, Renew. Energy 68 (Supplement C) (2014) 636–643. https://doi.org/10.1016/j.renene.2014.03.012. http://www.sciencedirect.com/science/article/pii/S0960148114001554.
[32] S. Tongsopit, C. Greacen, An assessment of Thailand's feed-in tariff program, Renew. Energy 60 (2013) 439–445.
[33] C. Schelly, E.P. Louie, J.M. Pearce, Examining interconnection and net metering policy for distributed generation in the United States, Renew. Energy Focus 22 (2017) 10–19.
[34] N. Martin, J. Rice, The solar photovoltaic feed-in tariff scheme in new south wales, Australia, Energy Pol. 61 (2013) 697–706.
[35] A. Zahedi, A review on feed-in tariff in Australia, what it is now and what it should be, Renew. Sustain. Energy Rev. 14 (9) (2010) 3252–3255.
[36] A. Poullikkas, G. Kourtis, I. Hadjipaschalis, An overview of the eu member states support schemes for the promotion of renewable energy sources, Int. J. Energy Environ. 3 (4) (2012) 553–566.
[37] A. Poullikkas, A comparative assessment of net metering and feed in tariff schemes for residential pv systems, Sustain. Energy Technol. Assess. 3 (2013) 1–8.
[38] A. Orioli, A. Di Gangi, The recent change in the Italian policies for photovoltaics: effects on the payback period and levelized cost of electricity of grid-connected photovoltaic systems installed in urban contexts, Energy 93 (2015) 1989–2005.
[39] S. Chowdhury, U. Sumita, A. Islam, I. Bedja, Importance of policy for energy system transformation: diffusion of pv technology in Japan and Germany, Energy Pol. 68 (Supplement C) (2014) 285–293. https://doi.org/10.1016/j.enpol.2014.01.023. http://www.sciencedirect.com/science/article/pii/S0301421514000287.
[40] F. In Tariffs Ltd, Feed-in Tariffs - Information on Payments for Renewable Electricity in the uk.
[41] C. Holdermann, J. Kissel, J. Beigel, Distributed photovoltaic generation in Brazil: an economic viability analysis of small-scale photovoltaic systems in the residential and commercial sectors, Energy Pol. 67 (2014) 612–617.
[42] Energía solar, desde las viviendas a la red eléctrica de caucete.
[43] Pruebas piloto generación distribuida (pilot testing on distributed). http://epsesanjuan.com.ar/web/proyecto/pruebas-piloto-generacion-distribuida/4.
[44] Cuadro Tarifario (Tariff Structures), 2017.
[45] Ley 27.191: Modificaciones a la ley 26.190: “régimen de fomento nacional para el uso de fuentes renovables de energía destinada a la produccin de energa eléctrica ”(Law 27.191: Changes to the Law 26.190, National Programme for the Promotion of the Use of Renewable Energy Destinated for Producing Energy, El Senado y Cámara de Diputados de la Nación Argentina (Argentinian Chamber of Deputies and the Senate), Octubre 2015. http://servicios.infoleg.gob.ar/infolegInternet/anexos/250000-254999/253626/norma.htm.
[46] I. Fisher, Appreciation and Interest: a Study of the Influence of Monetary Appreciation and Depreciation on the Rate of Interest with Applications to the Bimetallic Controversy and the Theory of Interest, vol. 11, American economic association, 1896.