Financing of Residential Rooftop Photovoltaic Projects Under a Net Metering Policy Framework: The Case of the Colombian Caribbean Region

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ABSTRACT

The inclusion of photovoltaic energy in the Colombian energy matrix has had several difficulties due to the lack of energy policies and regulations in renewable energy projects. The lack of government support with subsidies that extend the coverage of PV energy projects in residential areas has made the collection of funds more challenging. This paper presents a techno-economic analysis for the implementation of grid-connected photovoltaic projects on the roofs of residential areas, under the net metering policy framework. For the profitability analysis, the discounted cash flow (DCF) method was used. The revenues were obtained from the forecasts of the electrical power production of the PV system, based on the characteristics of the Colombian Caribbean Region. For this purpose, the meteorological data (2013-2017) of this region were used as an input for the calculation of the economic benefits that can be achieved with the implementation of PV systems. Based on the technical sizing and economic assumptions, it was proved that the DCF method allows to accurately determine the optimal debt ratio. After evaluating the three scenarios proposed, it was demonstrated that profitability and self-sustainability, with investment from creditors, is obtained from the implementation of PV systems of at least 3 kWp.

Keywords: PV Systems, Net Metering, Discounted Cash Flow Method, Optimal Debt Ratio
JEL Classifications: Q42, G32, G5

1. INTRODUCTION

On a global level, the insertion of renewable energy sources in the energy matrix, as an alternative for the generation of electricity, brings benefits for the socioeconomic development of a country (Paez et al., 2017), promoting new energy markets, such as the self-generation and sale of surplus energy to the grid, which help mitigate the environmental impact caused by fossil fuel generation (Robles et al., 2018; Burke and Stephens, 2018).

According to the Global Status Report (REN 21, 2017), the main regulatory frameworks to promote photovoltaic technologies in many countries, focus on Feed-in Tariff and net metering. The latter, as a support for photovoltaic generation, is currently applied in Europe (Italy, Denmark, the Netherlands), USA (Adopted in 41 states), South America and other countries in the world. According to the authors, Yamaya et al. (2014) and Sajjad et al. (2018), although the Feed-in Tariff policy is the most widely used worldwide, the policy with greater application as a regulatory mechanism to promote renewable energy power generation, is the net metering.

On the application of regulatory frameworks related to the net metering energy policy, the following works are highlighted worldwide. In Schelly et al. (2017), federal and state policies in the United States were analyzed, oriented to the implementation of

residential photovoltaic energy systems, evaluating the behavior of costs, benefits and incentives. The authors Shivalkar et al. (2015) and Dellosa (2015) determined the potential impact and economic viability of investing in photovoltaic systems with the application of the net metering policy in India and the Philippines respectively.

In Ur Rehman et al. (2017), an economic analysis was performed on residential systems for net metering regulation in Pakistan. The authors in Dufo-López and Bernal-Agustín (2015), proposed a comprehensive methodology for the evaluation of the different modalities of net metering in Spain. In addition, in Abdin and Noussan (2018), the economic benefits that can be obtained with the application of the residential net metering policy in Italy were evaluated. For Latin America, in countries such as Peru (Mojonero et al., 2018), Brazil (Rocha et al., 2017), Chile (Watts et al., 2015) and Mexico (Ospino-Castro et al., 2017), are shown case studies where the viability of the net metering policy was determined, in order to encourage the implementation of photovoltaic energy for residential areas taking into account economic investment.

In Colombia, from the enactment of Law 1715/2014, the use of renewable energy sources is promoted (Eras et al., 2018). The Ministry of Mines and Energy, through the Regulatory Commission for Gas and Energy, issued resolution 030/2018, which regulates small-scale self-generation and distributed generation activities. This resolution establishes the scenarios for the delivery of surplus power generated, in the case of residential applications, that use grid-connected photovoltaic (PV) systems (García et al., 2018). In this way, self-generation is enabled through the net metering policy.

However, despite the fact that regulations exist in Colombia, there are still governmental, technical and economic barriers regarding the implementation of grid-connected photovoltaic systems in residential areas. Obtaining a loan for these projects requires a financial analysis with reliable forecasts. In that sense, this article would be a reference to implement this type of analysis without taking into account government incentives.

The main objective of this paper is to perform an economic feasibility analysis of the optimal debt radio with creditors, implementing the discounted cash flow method (DCF). This methodology is based on determining the income and costs throughout the operational life of a PV installation, based on the devaluation of money over time. This procedure is appropriate in the case of PV systems because it is possible, from the technical dimensioning, to determine the DCF accurately.

2. MATERIALS AND METHODS

2.1. Solar Energy Potential of the Colombian Caribbean Region

The Caribbean Region is one of the five regions of the Colombian territory. It produces 15% of the gross domestic product (GDP) and concentrates 21.8% of the population (10.7 million inhabitants according to DANE projections in June 2017-DANE, 2017), of which 73.9% are located in the areas urban and 26.1% in the rural area. This region is located in the extreme north of

Colombia, composed of seven departments (Atlántico, Bolívar, Cesar, Córdoba, La Guajira, Magdalena and Sucre) and one island (Archipiélago de San Andrés, Providencia y Santa Catalina), which occupy 11.6% of the country land area.

According to the Mining and Energy Planning Unit (UPME), Colombia has an average monthly solar irradiance that varies between 4.0 and 6.0 kWh/m²/day (Muñoz et al., 2014; Peña-Gallardo et al., 2020); being the departments of the Caribbean Region where the highest average irradiance values are presented, between 5.2 to 6.8 kWh/m², which exceeds the world average value of 3.9 kWh/m² (Chamorro et al., 2017). This region has between 5.0 and 6.5 sun hours daily on average (Ramírez-Cerpa et al., 2017). Table 1 shows the average hourly behavior of solar irradiance in a horizontal plane for the Caribbean Region.

Another important aspect for the design of PV systems is the operating temperature, due to the impact that PV modules have when temperature increases (Karki, 2015; Wen et al., 2008). Figure 1 shows the average temperature during the 12 months of the year in the Caribbean Region, where it is shown that the temperature varies from 24 to 32°C in the hot seasons between April and July.

2.2. Energy-Balance Modeling
In the literature, there are several mathematical models that describe the performance of a grid-connected PV system (Rekioua and Matagne, 2012; Núñez et al., 2019). A simplified model is presented in Park et al. (2014), which was used in this paper to calculate the power production of the grid-connected PV system and the average daily power consumption demand, in relation to the socioeconomic stratum for a single-family home in the Caribbean Region (SUI, 2018). Figure 2 shows the behavior of the proposed scenarios ((a) stratum 1, (b) stratum 3 and (c) stratum 5), according to the average daily consumption of each house and the average daily power supplied of each PV generator (a-1kWp, b-3kWp and c-5kWp), relating the self-consumption of each home and the surplus energy for the grid.

The balance of losses to evaluate the performance parameters of a grid-connected PV system, such as the reference yield (Kumar et al., 2017), the system efficiency (Malvoni et al., 2017), the performance ratio (PR) (Watts et al., 2015) and the capacity factor (CF) (EIA, 2018), are defined by IEC 61724 Standard and the

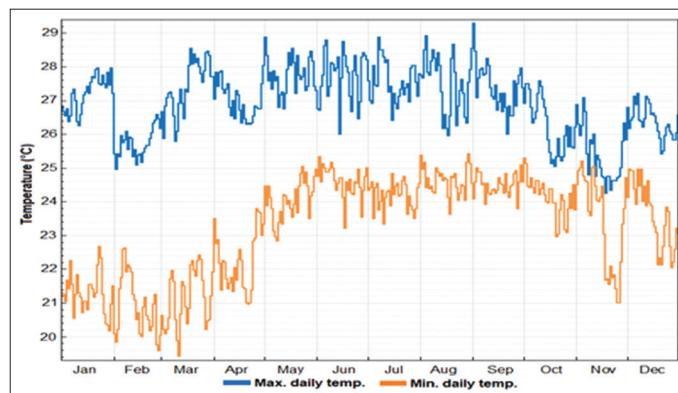**Figure 1:** Average temperature in the Caribbean region

Table 1: Hourly averages solar irradiance on a horizontal plane (W/m²)

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dic
0-5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5-6	0.0	0.0	0.0	0.5	3.1	2.9	1.1	0.6	1.5	1.2	0.5	0.0
6-7	21.2	19.8	38.0	70.4	99.7	83.9	92.2	85.7	89.7	84.7	73.2	40.8
7-8	180.2	158.7	191.8	294.4	294.9	258.1	213.8	242.7	288.2	287.8	284.5	225.4
8-9	438.7	397.7	437.0	485.7	515.1	493.8	443.0	473.0	542.2	513.7	528.9	494.7
9-10	708.6	683.2	729.8	759.3	740.8	706.8	701.2	690.0	720.9	703.8	698.2	753.6
10-11	920.6	900.1	871.5	874.4	710.3	758.4	846.5	751.5	742.9	707.9	743.5	910.0
11-12	944.5	893.7	874.4	824.8	730.4	746.7	896.0	743.1	687.3	670.6	689.7	866.1
12-13	942.9	924.5	879.9	784.1	699.1	787.8	857.5	718.3	666.5	626.3	674.4	853.4
13-14	944.9	954.7	872.6	674.6	710.6	773.6	774.9	585.7	647.3	627.8	688.7	842.1
14-15	802.4	857.6	872.0	601.0	658.8	652.4	663.3	580.6	581.6	517.5	534.3	690.3
15-16	584.8	621.7	617.0	419.5	469.5	411.3	446.6	417.3	363.6	358.0	332.6	426.3
16-17	306.4	336.5	332.0	247.0	267.9	219.1	261.2	243.1	194.0	166.8	138.0	187.9
17-18	60.2	82.6	88.0	80.9	70.2	70.5	94.2	70.4	47.8	20.9	12.5	20.5
18-19	0.2	0.5	0.2	0.6	1.2	3.6	5.8	2.0	0.1	0.0	0.2	0.0
19-0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	6855	6831	6804	6117	5971	5968	6297	5604	5573	5287	5399	6311

Between 0 and 200 (W/m²) — Between 400 and 600 (W/m²) — Greater than 800 (W/m²)
Between 200 and 400 (W/m²) — Between 600 and 800 (W/m²)

International Energy Agency (Jamil et al., 2017). Table 2 shows the annual average of energy balance and losses of the grid-connected PV system, based on the power consumption of the socioeconomic strata studied in this work.

In the case of the 1 kWp system, the daily energy generated, before the inverter, is 5.1 kWh/day on average, generating an annual average of 1,857 kWh/year. Taking into account the losses associated with the system, the energy delivered by the inverter has an annual average of 1,604 kWh/year, with an efficiency ratio of 86.4% and a CF of 18.3%.

In the 3 kWp system, the inverter losses are 88% on average. The daily energy produced before the inverter is 14 kWh/day, generating 4,962 kWh/year. In relation to the transformation losses of the inverter, there is an annual average of 4,389 kWh of generation and CF of 16.7%.

For the 5 kWp system, the daily energy produced by the PV system at the input of the inverter is 23 kWh/day, with a generation of 8,273 kWh/year and with a yield of 89% on average, generating 7,336 kWh/year delivered to the grid, with a CF of 16.7%.

2.3. Deterministic Model for Economic Analysis

This section shows the economic model used to analyze the probabilities of profitability for the grid-connected PV systems, on the roofs of urban areas. In order to identify financing that maximizes the economic return, under the net metering billing mechanism, the DCF deterministic model was used for the analysis of free cash flow in a PV plant (Rodrigues et al., 2017; Sommerfeldt and Madani, 2017a).

Table 2: Annual average of energy balance and losses

PV system	1 kWp	3 kWp	5 kWp
Edc, G (kWh/day)	5.1	14	23
Edc, G (kWh/month)	1857	4964	8273
Eac, G (kWh/day)	4.4	12	20
Eac, G (kWh/month)	1604	4389	7336
Reference yield (kWh/kWp)	5.4	5.4	5.4
Array yield (kWh/kWp)	4.5	4.5	4.5
Final yield (kWh/kWp)	3.9	4.0	4.0
System loss (kWh/kWp)	0.6	0.5	0.5
Capture loss (kWh/kWp)	0.9	0.9	0.9
Performance ratio (%)	72.4	74.1	74.3
Inverter efficiency (%)	86.4	88.4	88.7
Array efficiency (%)	12.7	12.7	12.7
System efficiency (%)	11.0	11.3	11.3

DC power generated- (Edc, G), AC power generated- (Eac, G)

$$DCF_y = \frac{SCF_y}{(1+r)^y} \quad (1)$$

Where SCF_y is the simple cash flow (See Eq. 2). $DCFy$ considers the value of money over time, where r is the interest rate.

SCF_y=cash in flow$_y$–cash out flow$_y$

$$SCF_y = \sum_{y=1}^{Y} (T_s \times E_s + T_e \times E_e)_y - \sum_{y=1}^{Y} (OM)_y \quad (2)$$

In Eq. 2, Y is the life of the project, T_s represents the self-consumption tariff and T_e is the grid injection tariff. E_s is the annual production (kWh) of the PV system used in self-consumption, E_e is the energy production of the PV system that is injected into the grid and OM is the cost of operation and maintenance.

Figure 2: Curves of the grid-connected PV systems according to the socioeconomic stratum: (a) stratum 1, (b) stratum 3 and (c) stratum 5
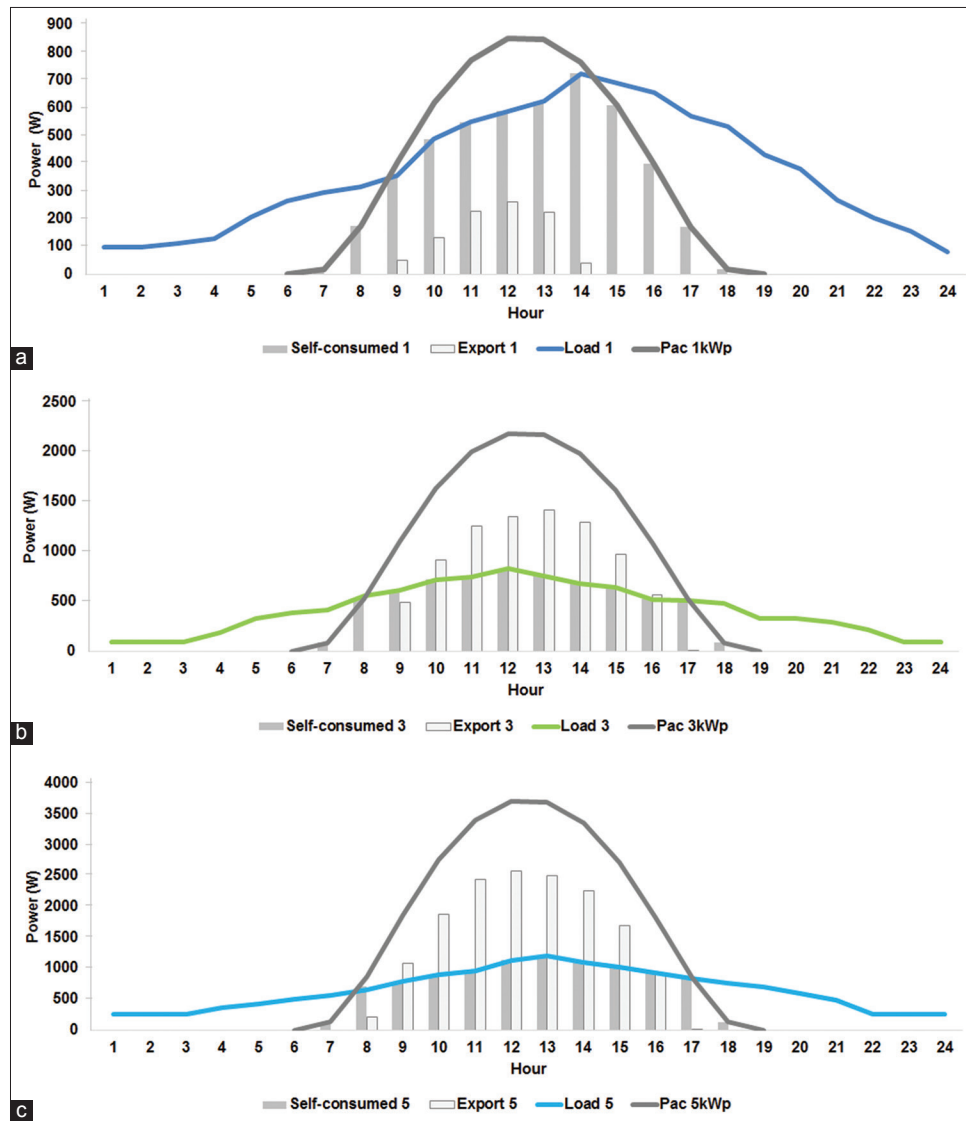
The Net Present Value (NPV), Eq. 3, it is a flexible and important evaluation indicator for the amortization analysis of PV system projects (Akter et al., 2017). A project is economically viable if the NPV is positive.

$$NPV = \sum_{y=1}^{Y} \frac{C_y}{(1+k)^y} - C_0 \qquad (3)$$

Where C_y is the annual net cash flow, k is the discount rate and C_0 is the initial investment of the PV system.

The Internal Rate of Return (IRR) is determined when the NPV is equal to zero in Eq. 4. It is an economic indicator that analyzes the profitability of a project by comparing it with the discount rate (Rodrigues et al., 2017). The size of the IRR has a direct correlation with the attractiveness of the investment, that is, a high IRR indicates that the investment opportunity is favorable.

$$IRR = \sum_{y=1}^{Y} \frac{C_y}{(1+IRR)^y} - C_0 = 0 \qquad (4)$$

The Discounted Payback Period (DPB) is the required number of years to recover the investment, considering the discount or the interest rate. It is defined as in Eq. 5, when the NPV is zero.

$$DPB = \sum_{y=1}^{Y} \frac{C_y}{(1+r)^y} - C_0 = 0 \qquad (5)$$

For the optimization of return against the criteria of the creditors, it is necessary that the operation of the PV system generates a free cash flow that exceeds the debt commitments (Lüdeke-Freund and Loock, 2011). The index that measures the capacity to assume the debt is the debt coverage ratio (DCR), which is calculated as the ratio between the net flow and the debt commitments. A value of DCR equal to one indicates that the operation generates sufficient capital to cover the costs. As a safety margin, creditors typically require a DCR greater than one during all periods of the operational life of the PV plant. A value between 1.15 and 1.35 is essential to obtain a loan from commercial banks (Pradhan et al., 2019).

2.4. Technical and Economic Assumptions
In this section, all the assumptions related to the economic feasibility analysis for decision-making in investments of grid-

connected photovoltaic systems are defined. In this case, three scenarios were considered: 1 kWp - area 7 m², 3 kWp - area 20 m² and 5 kWp - area 33 m². This division is initially due to two conditions: the socioeconomic stratum and the space availability for the installation of PV systems on the roofs of homes.

As mentioned in the previous paragraphs, all the calculations presented in this work are based on socioeconomic strata 1, 3 and 5. For social interest housing (VIS, in Spanish), stratum 1, a housing area of 35 m² was considered, which is the minimum area in Colombia for a single-family home (Decree 2060 of 2004). For strata 3 and 5, not VIS, the housing areas are on average 73 m² and 150 m² respectively, according to the Secretaría Distrital de Planeación (2012). These conditions are decisive for defining scenarios that consider different alternatives according to the space available for the installation of the PV system.

The annual production of the PV systems was calculated using the electrical characteristics of the Kyocera KD250GX-LFB2 polycrystalline module (250 Wp). Taking into account the geographical location for the study area of this work, an azimuth of 180° and an annual inclination of 12° were used. These modules, according to manufacturer data, have a lifespan of 25 to 30 years, with an output power degradation rate of 80% at 20 years and 90% at 10 years (Rodrigues et al., 2016). Therefore, this work assumes a useful life of the investment equal to 25 years. The data-sheet of the selected PV module has a degradation rate of 0.7%/year during the first 20 years.

For the grid connection, SMA Sunny boy 1300TL, 3000TL, 5000TL inverters were used, which have a high efficiency performance (Muñoz et al., 2014). The lifespan of a high quality inverter is between 15 and 20 years depending on the operating conditions (Sommerfeldt and Madani., 2017a). In the calculations, a useful life of 10 years was considered, according to the authors (Rodrigues et al., 2017). Currently, the cost of inverters is between $0.12 and $0.49/Wp (Sommerfeldt and Madani, 2017b). Therefore, a conservative replacement cost of $0.25/Wp was assumed and occurs in year 10.

In the literature, the assumptions in the cost of installation capital for residential PV systems grid-connected, in cities such as Ghana, Spain, Australia, China, Chile, Brazil, Italy, The United Arab Emirates and Sweden, consider costs in a range from $1.40 - $2.60/Wp (Table 3). In Colombia before law 1715 of 2014, incentives in renewable energy projects, such as exemption from value added tax (VAT) payments, were not considered. Consequently, the installation costs of these systems were very high, around $6.57/Wp, which did not encourage the implementation of these projects (Gaona et al., 2015).

As of the exemptions established with the approval of Law 1715, installation capital costs in Colombia have followed a dynamic similar to the international market. In the period from 2010 to 2017, technology in PV systems has decreased by 73% in capital costs according to the International Renewable Energy Agency (IRENA). In this work, an installed cost of $1.10/Wp was assumed, which considers the value of labor, engineering design, structure

Table 3: Capital cost assumptions for the installation of residential PV systems

Country	Costs USD $/Wp installed	Reference
Ghana	$2.03/Wp	(Asumadu and Owusu, 2016)
Spain	$1.73/Wp	(Dufo-López and Bernal-Agustín, 2015)
Australia	$1.40/Wp	(Akter et al., 2017)
Chile	$2.50/Wp	(Ramírez-Sagner et al., 2017)
Brazil	$1.90/Wp	(Miranda et al., 2015)
Italia	$1.67/Wp	(Abdin and Noussan, 2018)
China	$2.04/Wp	(Rodrigues et al., 2017)
Sweden	$1.81/Wp	(Sommerfeldt and Madani, 2017b)
The United Arab Emirates	$2.60/Wp	(Griffiths and Mills, 2016)

adaptation, equipment and supplies of grid-connected systems without battery banks.

For the assumptions of the average cost and annual increase in energy, the data for the 2011-2017 period, published by Electricaribe S.A. were used, which is the energy trading company for the Colombian Caribbean Region (Electrificadora del Caribe S.A. E.S.P, 2018). For the socioeconomic strata analyzed (1, 3, 5), the assumptions for the energy consumption rate were 0.059, 0.11 and $0.16/kWh respectively; observing an average annual increase in the energy price of 6.7%. For the sale of surpluses, 30% below the consumption rate was considered.

In reference to the Consumer Price Index (CPI), a percentage that directly affects operation and maintenance costs, according to the National Administrative Department of Statistics (DANE) this value was 4.09% for the period 2011-2017 (DANE, 2018). For the authors Griffiths and Mills (2016) and Sommerfeldt and Madani (2017b), the annual operation and maintenance costs of a PV system range between 0.5% and 1.9% of the capital cost, depending on the system size. Annual fixed operating and maintenance costs for this work, such as inspections, cleaning, minor repairs, were established as 0.5% of the installation cost in the first year, increasing annually in relation to the CPI. Table 4 shows the data used for sensitivity and inversion analysis.

In relation to the amortization period of grid-connected PV projects, according to Lima (2019), the amortization period is around 5 years. Other authors mention amortization periods of 10 years (Ioannou et al., 2014). In Colombia, the national government through state entities or development banks, and commercial financial entities, have credit lines with a broad portfolio that encourage investment in renewable energy and energy efficiency (Table 5). In this work, an amortization period of 7 years was used with a reference interest rate of Fixed Term Deposit (DTF) of 5.34%, plus 4% annual effective interest rate, established by the Bank of the Republic of Colombia for 2017 (Banrep, 2017).

3. RESULTS

In order to analyze the results obtained with the assumptions and the potential of generated remuneration, the economic investment

Table 4: Inputs for sensitivity and investment analysis

Input	Value	Units	Reference
PV system	1 3 5	kWp	Estimated values
PV degradation rate	0.7	%/year	(Rodrigues et al., 2016)
PV lifespan	25	Year	(Rodrigues et al., 2016)
Inverter lifespan	10	Year	(Rodrigues et al., 2017)
Inverter replacement cost	0.25	$/Wp	(Sommerfeldt and Madani, 2017b)
Capital cost of the PV system	1.10	$/Wp	(Asumadu and Owusu, 2016; Dufo-López and Bernal-Agustín, 2015; Akter et al., 2017; Ramírez-Sagner et al., 2017; Miranda et al., 2015; Abdin and Noussan, 2018; Rodrigues et al., 2017; Sommerfeldt and Madani, 2017b; Griffiths and Mills, 2016)
Energy costs (Stratum 1-3-5)	0.059 0.11 0.16	$/KWh	(Electrificadora del Caribe S.A. E.S.P, 2018)
Sale of energy surpluses	30	%	Estimated value
Consumer Price Index	4.09	%	(DANE, 2018)
Annual operating and maintenance costs	0.5	%	(Griffiths and Mills, 2016; Sommerfeldt and Madani, 2017b)
Amortization	7	Year	(Lima, 2019; Ioannou et al., 2014).
Interest rate	DTF+4%	%	(Banrep, 2017).

**Table 5: Credit lines of financial institutions in Colombia (2017)**

Type of financial entity	Name	Credit line	Interest rate	Payment term	Grace period
State Entities	Financiera del Desarrollo Territorial (Findeter)	Renewable energies and lighting	DTF+1.90% T.A	8 years	2 years
		Rediscount of infrastructure for energy development	DTF+2.10% T.A	15 years	3 years
	Banco de Comercio Exterior de Colombia (Bancóldex)	Energy efficiency and renewable energy	0-6 years. DTF + 0.70 % E.A. 6-10 years. DTF E.A. + 0.85 % E.A.	10 years	1 year
		Sustainable development	DTF+0.70% E.A.	6 years	6 months
Comercial Banks	BancoColombia	Green	DTF	5 years	2 years
		Environmental	Not available	5 years	1 year
	Davivienda	Energy efficiency	DTF + fixed points	10 years	Not available
		Renewable energy	DTF + fixed points	12 years	Not available
	Banco proCredit	ProEco Pyme	DTF + fixed points	8 years	Not available

T.A: Quarters in advance, E.A: Annual effective interest rate

modality was taken into account, based on a debt index >1, in order for creditors to consider investing their money and that the systems be financially self-sustainable. For the calculations, the tax incentives established in Decree 2143 of November 4, 2015, were used. For the optimal level of indebtedness, the impact of the evolution of the debt on the IRR and the DCR was considered. Figure 3 shows the impact obtained for this work in the scenarios considered for the 3 strata. The profitability of the project increases with indebtedness, however, in parallel, the ability to pay for the project is reduced.

The total cost of the 1 kWp PV system is $1,100 USD with a DCR greater than 1.1. Consequently, in order to have a self-sustaining system with income from the installation, it is necessary to have 70% of the investment in own funds and 30% of loans with creditors (Figure 4). From the resulting analysis for investors, an IRR of 11%, DPB of 11.7 years and NPV of $1,299 were obtained. Taking into account the premises mentioned above, the project is profitable indicating positive returns. However, in year 10, a

Figure 3: Analysis of the optimal indebtedness for the PV systems in the 3 strata
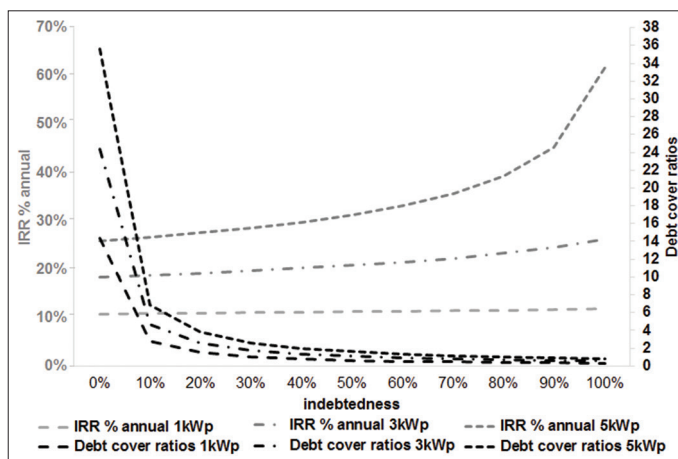
money outflow is generated, generating a DCR of 0.6, due to a possible change of the investor Table 6.

For the 3 kWp PV system, a total cost of $3,300 USD for commissioning was obtained. The indebtedness capacity of the project, reaches up to 50% of investment by the creditors, with a DCR of 1.1, generating an IRR of 20.8% and NPV of $6,764. The payback period was projected according to the DPB at 6.8 years, indicating positive returns throughout the life of the project (Figure 5). Considering investor change in year 10 and year 20, a cash flow outflow is generated, however, the

Table 6: Economic and financial feasibility indicators

Debt %		0	10	20	30	40	50	60	70	80	90	100
Discount rates %		0	0.93	1.87	2.80	3.74	4.67	5.60	6.54	7.47	8.41	9.34
1kWp	DCR	14.3	2.8	1.5	1.1	0.8	0.7	0.5	0.5	0.4	0.4	0.3
	NPV $	3128	2421	1818	1299	850	460	118	−182	−449	−685	−897
	IRR %	10.8	10.9	11.0	11.0	11.1	11.2	11.3	11.4	11.6	11.7	11.9
	DPB Years	9.6	9.8	11.6	11.7	11.9	12.1	12.2	12.4	12.6	12.7	12.9
3kWp	DCR	24.4	4.7	2.6	1.8	1.4	1.1	0.9	0.8	0.7	0.6	0.6
	NPV $	19,904	16,366	13,371	10,823	8641	6764	5140	3727	2492	1405	445
	IRR %	18.5	18.9	19.3	19.7	20.2	20.8	21.5	22.3	23.3	24.6	26.3
	DPB Years	6.1	6.3	6.4	6.5	6.6	6.8	6.9	7.0	7.2	7.3	7.4
5kWp	DCR	35.6	6.9	3.8	2.6	2.0	1.6	1.4	1.2	1.0	0.9	0.8
	NPV $	52,699	44,171	36,983	30,893	25,708	21,269	17,449	14,145	11,274	8765	6562
	IRR %	25.9	26.7	27.5	28.6	29.8	31.3	33.2	35.7	39.2	45.3	61.7
	DPB Years	4.4	4.4	4.5	4.5	4.6	4.7	4.9	5.0	5.1	5.2	5.3

Figure 4: Optimum debt point of the 1kWp PV system (70% own funds, 30% creditors)
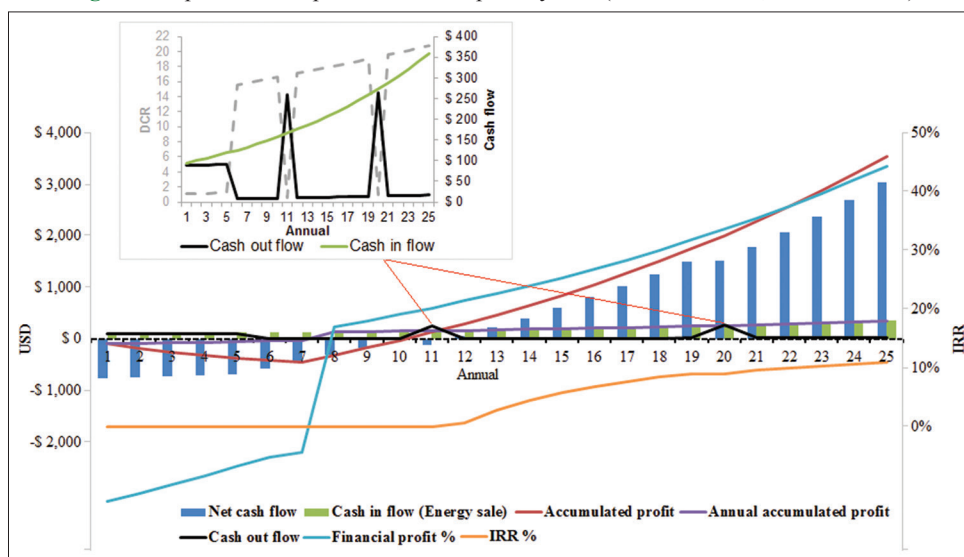

Figure 5: Optimum debt point of the 3kWp PV system (50% own funds, 50% creditors)
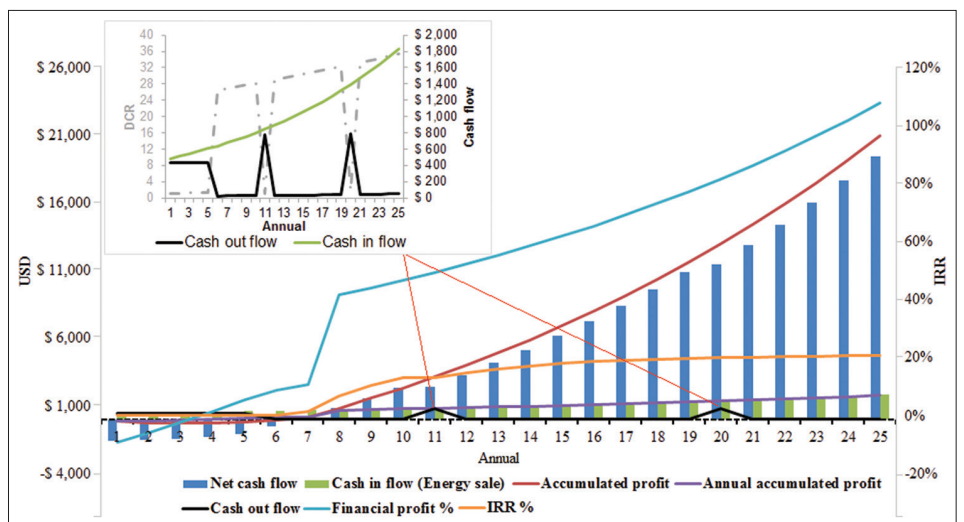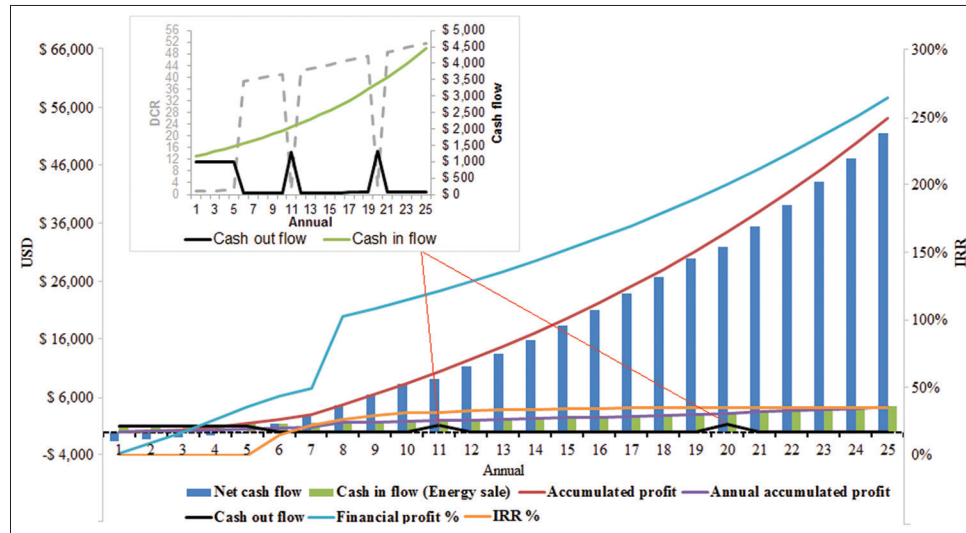
Figure 6: Optimum debt point of the 5kWp PV system (30% own funds, 70% creditors)

cash flow inflow for the sale of energy, keeps the DCR stable at 1.1 Table 6.

For the 5 kWp system (Figure 6), an investment of $5500 USD is necessary. The economic feasibility in relation to the creditors and self-sustainability of the project, reaches up to 70% of financing. With a DCR of 1.2, there is a 5-year investment recovery period, with an NPV of $14,145 and an IRR of 35%. The DCR in year 10 was 1.6, giving positive returns throughout the operation of the PV system.

Considering the socioeconomic level of each social stratum, the 1 kWp grid-connected PV systems for families of stratum 1, require an investment of 70% with their own funds, in order to generate a free cash flow that exceeds the commitments of the debt. This situation makes it difficult to implement this option, due to the socioeconomic conditions of the families that live in this stratum in the Caribbean Region.

On the contrary, in the 3 kWp and 5 kWp grid-connected PV systems for strata 3 and 5 respectively, a more flexible debt commitment can be made, taking into account the percentages of own investment required (50% and 30%). Based on the point of economic and financial feasibility of the three systems, the 5 kWp system generates greater economic profitability, with a better financial security margin normally demanded by creditors.

In the event that the initial capital in own funds is insufficient, to reach DCR greater than 1, it is necessary to consider different financing options. Within these, the use of third-party property structures is considered, whose model offers alternatives for consumers who do not assume risks associated with the property or prefer a low initial investment; adopting the contractual form of a power purchase agreement (PPA) for residential self-generation projects.

4. CONCLUSIONS

The new regulation in the net metering energy policy, which allows the sale of surplus energy from PV systems in Colombia, generates a new energy market expanding the possibility of investment for this type of systems in residential homes. However, investments in renewable energy in Colombia are still a new field that requires greater market maturity. Obtaining a loan requires a financial analysis based on reliable forecasts to make investment decisions with significant levels of uncertainty.

The proposed method is designed for easy understanding of investors. The cost-benefit equations are generic enough to cover most of the international tariff schemes. The scenarios proposed in this document are based on the energy and economic assumptions of the Colombian Caribbean Region, showing alternative financing schemes that may be useful for promoters, investors, individuals, cooperatives and associations.

After completing this work, it can be concluded that in the urban areas of the Colombian Caribbean Region, an optimal financial and economic solution, for obtaining capital with creditors, is the implementation of grid-connected PV systems on roofs (starting at 3kWp), in order to obtain flexible indebtedness points and self-sustainable systems since its installation. The initial investment cost of the PV system, the annual production of solar energy and the evolution of the self-consumption tariff have a high impact on the payback period of the investment. In this new context, it is necessary for the Colombian government to implement energy policies to grant subsidies in order to expand coverage in PV energy projects in urban areas.

5. ACKNOWLEDGMENTS

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