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Integrated Photovoltaic System Sizing for a Building of 40 Apartments and Economic Evaluation Using RETScreen™

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Abstract— This work describes a building integrated photovoltaic system (BIPVS) sizing for a building of 40 apartments in the city of Bogotá, Colombia. To do this, we consider the application of the Colombian Law 1715, which encourages the use of renewable energy sources and it becomes a useful tool so that our country can achieve the commitments made in the agreement COP 21. The calculation procedure of the electric load of the building is presented as well as the photovoltaic array sizing. The results indicate that the building requires a transformer of 112,5 kVA, its common areas consume 2460 kWh/month and a photovoltaic generator of 25,8 kW would be required. The economic analysis using RETScreen™ indicates that the net present value for the life period of the project (25 years) is USD$117,940 with a reduction of 27,4 tons/year of CO2.

Keywords— Photovoltaic system, distributed energy, economic analysis, RETScreen.

I. INTRODUCTION

The PV market has grown over the past decade at a remarkable rate even during a difficult economic period and is on the way to becoming a major source of power generation for the world [1]. After a record growth in 2011, the global PV market stabilized in 2012, and grew again significantly in 2013 [2].

Since the BIPV offers the possibility to replace part of the traditional building material, with a possible price reduction in comparison to a classic rooftop installation [3,4], the correct estimation of system level performances, system reliability and system availability is becoming more important and popular among installers, integrators, investors and owners; with this purpose several tools and models were developed [1, 5,6,7]. The combination of different phenomena, such as the solar radiation available on site, the presence of dust, the shadowing or UV radiation over long outdoor exposure, affect in different ways the real performance of BIPV systems and thus the related economic evaluations [8-10].

In 2015, some 60GWp of new photovoltaic (PV) systems were installed globally [11] bringing the total worldwide installed capacity to nearly 250GWp, with Asia leading the wave of new installations [12]. Information Handling Services Inc. (HIS) has raised its global solar PV forecasts for 2016–65 GWp, and over 70 GWp is expected to be installed in 2019 [13]. By 2020, the cumulative global market for solar PV is expected to triple to around 700 GWp [14].

In addition to being a renewable and pollution free energy generation technology with no moving parts, PV modules can also be integrated into buildings as BIPV systems, adding aesthetic value [15]. When installed in an optimized way, BIPV systems can reduce heat transferred through the envelope and reduce cooling load components decreasing the CO2 emissions [16]. Apart from some facade installations, the rooftop segment represented more than 23 GWp of total installations in 2015, with projections of more than 35 GWp to be installed by 2018 [12].

There are several studies about photovoltaic energy in Colombia [17-19] and this one is intended to improve the distributed energy analysis on buildings.

II. ANALYTICAL PROCEDURE

A. Calculation of the building loads

Calculating the effective impedance it is performed by the following equation:

$$Z_{ef} = R * Cos\, \emptyset + X * Sin\, \emptyset \qquad (1)$$

With:
R: resistence.
X: reactance.

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To calculate the voltage regulation is used the following equation:

$$\Delta V\% = \frac{\sqrt{3} * I * l * (R * Cos\emptyset + X * Sin\ \emptyset)}{V_0} * 100 \qquad (2)$$

Where I is the electric current, l is the cable length and Vo voltage.

In the case of single phase circuits, the following equation is used:

$$\Delta V\% = \frac{2 * I * l * (R * Cos\emptyset + X * Sin\emptyset)}{V_0} * 100 \qquad (3)$$

Equations (4), (5) y (6) allow to calculate the active, reactive and apparent power respectively:

$$P = V * I * cos\emptyset \qquad (4)$$

$$Q = V * I * sen\emptyset \qquad (5)$$

$$S = V * I \qquad (6)$$

Meanwhile, the maximum diversified demand for a building can be determined by the following expression:

$$DMD_{nUsers} = \frac{Maximum\ Demand\ 1\ User \times (Nusers)}{f\ diversity\ Nusers} \qquad (7)$$

The maximum diversified demand for n years is calculated as:

$$DMD_{year\ n} = DMD_{year\ 0} \times \left(1 + \frac{r}{100}\right)^n \qquad (8)$$

With maximum diversified demand transformer capacity is calculated:

$$S_{transf} = S_{user.res.} + S_{common\ areas} + S_{pub.lights} \qquad (9)$$

B. Residential energy demand

The cost per kW of conventional energy in Colombia, is closely linked to the hydraulic generation and is associated with the level of reservoirs as can be seen in Figure 1, which presents the average costs between 2000 and 2012, and ranging from USD $0,017 to USD $0,073 per kWh depending on the greater or lesser amount of water it is counted in reservoirs, respectively [20].

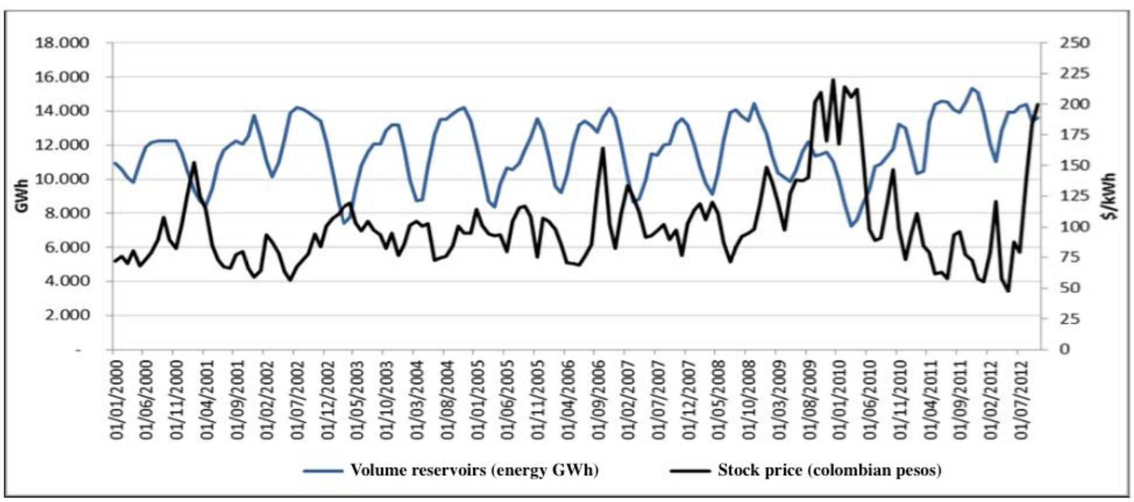

Fig. 1. Ratio of stock price with the volume of reservoirs.

As shown in Figure 1, the energy available in the reservoirs varies between 7000 GW and 15000 GW from 2000 to 2012. The availability of reservoirs has been above the stock price of energy until 2009; when it was surpassed but then it normalizes again from 2010.

Figures 2 and 3 show the residential energy consumption by social strata in Bogotá between 1998 and 2012.

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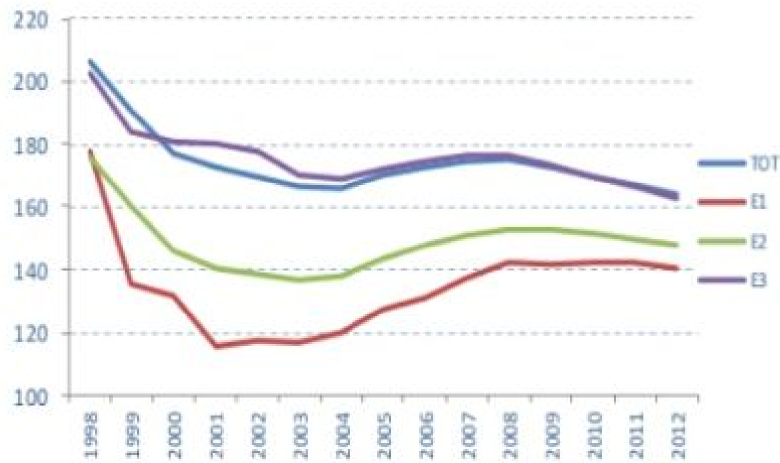

Fig. 2. Average monthly consumption (kWh). Residential strata 1, 2 and 3 [21].

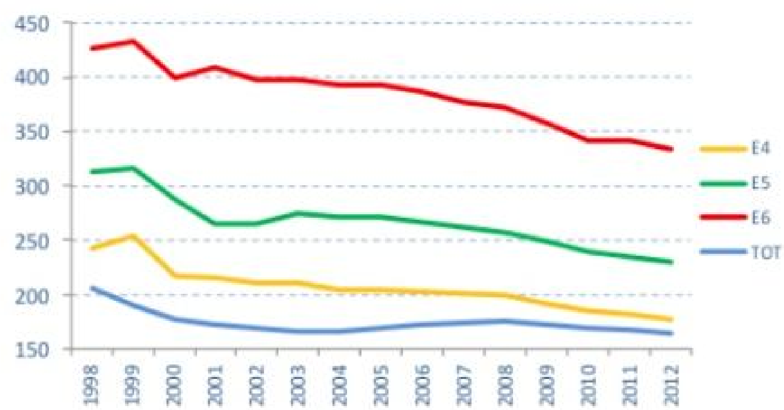

Fig. 3. Average monthly consumption (kWh). Residential strata 4, 5 and 6 [21].

It can be seen that consumption per strata for 2013 reflects its socioeconomic differences, although the strata 1 and 2 converge. Since 1998 the consumption are falling; but it starts to recover in 2004; especially strata 1, 2 and 3 [21].

Table 1 shows the projected energy demand in Bogotá and Cundinamarca until 2020.

Year	Model added		Sector model		Upme	
	GWh	Incr. %	GWh	Incr. %	GWh	Incr. %
2012	13.940		13.940		13.940	
2013	14.508	4,1	14.363	3,0	14.720	5,6
2014	15.083	4,0	14.895	3,7	15.207	3,3
2015	15.685	4,0	15.453	3,7	15.739	3,5
2016	16.297	3,9	16.031	3,7	16.801	6,7
2017	16.959	4,1	16.645	3,8	17.547	4,4
2018	17.618	3,9	17.267	3,7	18.316	4,4
2019	18.275	3,7	17.896	3,6	19.075	4,1
2020	19.024	4,1	18.583	3,8	19.674	3,1

Table 1. Results of the estimation of energy demand of Bogotá until 2020 [21].

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The added model predicts an annual growth of energy demand in the region between 3,7% and 4,1% and sector model between 3,6% and 3,8%. The total annual demand is 14 500 GWh. By 2020 it is predicted that the total energy demand will be between 18 500 GWh and 19 000 GWh. Predictions are close to those of the UPME in the low range for UCP Center with annual growth of 3,1% and 6,7%; to approach a demand of 19 600 GWh to 2020 [21].
Figure 4 shows the predictions of power demand for Bogota and Cundinamarca to 2018.

Fig. 4. Predictions of power demand for Bogota and Cundinamarca to 2018 [21].

The predictions of power demand come to apply to energy predictions with the load factor obtained from the predictions of energy and maximum power from UPME [21]. The increase in power between 2013 and 2018 is 370 MW corresponding to 16%, reaching 2679 MW in 2018.

C. Colombian Law 1715 - 2014

The Congress of Colombia created the Law 697 of October 3, 2001; with which the rational and efficient use of energy is promoted, the use of renewable energy is promoted and other provisions.

In 2014, Law 1715 (May 13th) is promulgated; with which the integration of non-conventional renewable energy to the National Energy System (SIN) is regulated.

Table 2 presents a comparison of both laws.

Aspect	Law 697 - 2001	Law 1715 - 2014
Incentives	For research: The National Government will promote research programs about Rational and Efficient Use of Energy through Colciencias.	Incentives for non-conventional energy generation: Promote research, development and investment in the field of energy generation with renewables and efficient energy management. Those forced to declare income but directly make investments in this regard, are entitled to deduct from their income annually for the 5 years following the taxable year.
	For education: Icetex benefits from lending to students who want to pursue careers or specializations about renewable.	IVA tax incentive: equipment, components, machinery and services which are intended for renewable energy, as well as for measurement and evaluation of potential resources, are excluded from IVA.

	Public recognition: The national government will create distinctions to natural or legal persons, who excel at the national level in application of rational use of energy; which are awarded annually.	Tariff incentive: natural or legal persons that from the effective date of this law are holders of new investments about renewable, will enjoy exemption from customs duties.
	General: The national government establishes incentives and impose penalties, according to the program of rational and efficient use of energy.	Accounting incentive: accelerated depreciation of assets. The generation of electricity from renewable, will enjoy accelerated depreciation scheme.

Table 2. Comparison of incentives granted by Law 697 - 2001 and Law 1715 - 2014 [22].

Incentives promulgating with Law 1715-2014 represent a significant advance and they will allow lead in promoting new unconventional energy technologies interconnected with SIN. New models of support for such projects are needed, related to the purchase the kWh exported by the company providing the electrical service; at prices that even double the cost of the kWh conventionally generated (hydro or thermal) and financing of up to 70% of the initial investment; as it is currently the case in countries like Germany, Japan and the United States.

For the reasons mentioned above, distributed photovoltaics for residential becomes very important because this type of energy can support residential energy demand in Bogotá and contribute to the reduction of greenhouse gases.

III. RESULTS AND DISCUSSION

A. Energy demand and photovoltaic generator

Our analysis is focused on the photovoltaic generation system connected to distribution network as distributed generation option. The building has 40 apartments with an area of 72 m^2 each and photovoltaic panels are used to supply 100% of the energy demand of the common areas of the building. We took into account the recommendations of the Colombian Electrical Code NTC 2050.

The maximum demand of the building is 79 389,45 kVA as shown in Table 3.

40 apartments of 72 m^2		
Load M^2 = 72M^2 X 32VA/M^2	2305	NTC 2050 SECC. 220 TABLA 220-3 -b
Load small devices APT 1	3000	NTC 2050 SECC. 220 -3 b
SUBTOTAL LOAD	5305	
First 3000VA X 100%	3000	NTC 2050 SECC. 220 TABLA 220-11
Another ones (5305-3000=2305) POR 35 %	807	NTC 2050 SECC. 220 TABLA 220-11
LOAD TOTAL	3807	DM
DMD 1 YEAR =3807X40/3,28	46423	DMD - 1 YEAR
DMD 8 YEARS= 46423X(1+3/100)^8	58807	DMD - 8 YEAR
COMMON AREAS DMD	20582	INSTALLED CAPACITY (W)
MAXIMUM DEMAND	79389,45	DMD TOTAL
TRANSFORMER CAPACITY	112,5 KVA	

Table 3. Electrical demand of the building and transformer`s capacity.

The maximum demand for the first 8 years of operation of the building is 58 807 kVA; total electric load of common areas is 20 582

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kVA and the transformer required to manage the total demand of the building must be 112,5 kVA. The total current is 313 A and cables were selected 1LXF No. 350 and 3x350A regulated protections. Table 4 shows the adjusted value of the energy demanded by the common areas of the building:

PHOTOVOLTAIC ENERGY - COMMON AREAS	
ENERGY DEMAND COMMON AREAS - KWh/mes	2460
POWER PHOTOVOLTAIC ARRAY - KW	25,6

Table 4. Total energy demand by the common areas of the building.

The total demand of the common areas is 2460 kWh/month for which a photovoltaic generator is required 25,6 kW.
The cost per kWh for common areas is USD $0,11; this represents a cost of USD $3247,2/year.

B. Economic analysis using RETScreen™

The first step in the analysis using RETScreen, is to enter the geographical location of the city in which the PV array will be installed; in order that the software determine the potential of solar energy in the region.
Bogota is located at 4.7°N latitude, -74,1ºE longitude and 2546 m above sea level.

Figure 5 shows the weather conditions of Bogota according to RETScreen.

Site reference conditions — Select climate data location

Climate data location: Bogota/Eldorado

Show data ☑

	Unit	Climate data location	Project location
Latitude	°N	4,7	4,7
Longitude	°E	-74,1	-74,1
Elevation	m	2.546	2.546
Heating design temperature	°C	4,1	
Cooling design temperature	°C	20,8	
Earth temperature amplitude	°C	8,5	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		12,9	80,6%	5,01	75,7	2,2	20,6	158	90
February		13,2	80,4%	4,66	75,7	2,2	21,4	134	90
March		13,6	81,7%	4,47	75,7	2,2	21,4	136	112
April		13,8	82,8%	3,93	75,7	2,0	21,2	126	114
May		13,8	82,6%	3,70	75,7	2,1	20,8	130	118
June		13,5	80,5%	3,79	75,8	2,5	20,2	135	105
July		13,1	78,9%	4,04	75,8	2,7	20,3	152	96
August		13,1	78,5%	4,33	75,8	2,6	21,4	152	96
September		13,1	80,0%	4,31	75,7	2,2	22,1	147	93
October		13,2	82,8%	4,33	75,7	2,0	21,4	149	99
November		13,4	84,0%	4,10	75,7	2,0	20,5	138	102
December		12,9	82,5%	4,55	75,7	2,3	20,2	158	90
Annual		13,3	81,3%	4,27	75,7	2,3	20,9	1.716	1.204
Measured at	m					10,0	0,0		

Fig. 5. Environmental data from Bogota to project implementation.

The monthly environmental data indicate that Bogota has an average of 13.3 °C/month; a relative humidity of 81.3%/month and a daily solar radiation of 4,27 kWh/m^2.
The energy model used in RETScreen has an electricity export rate that is corresponding to the projection of energy sales by our photovoltaic generation system $/MWh.
Based on the price of residential energy sector in Bogota, export rate for our electricity generation system would be USD $0,11/KWh or USD $110 MWh (USD $1 = 3000 COP, August-2016); with an ability to export power to the grid of 30.7 MWh per year.
The technical data of the PV generator are selected through a library that has the RETScreen software. 86 solar panels of 300 Wp each, were selected, Canadian Solar brand, polycrystalline type, for a total power generation capacity of 25.8 kW, with an efficiency

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of 15.6% per panel. The two inverters selected have an operating capacity of 10 KW each and an efficiency of 98%. Both devices have 10% losses. See Figure 6.

Annual solar radiation - horizontal	MWh/m²	1,56			
Annual solar radiation - tilted	MWh/m²	1,54			
Photovoltaic					
Type		poly-Si			
Power capacity	kW	25,80			
Manufacturer		Canadian Solar			
Model		poly-Si - CS6X-300P - MaxPower	86 unit(s)		
Efficiency	%	15,6%			
Nominal operating cell temperature	°C	45		°F	113,0
Temperature coefficient	% / °C	0,40%			
Solar collector area	m²	165		ft²	1.777
Miscellaneous losses	%	10,0%			
Inverter					
Efficiency	%	98,0%			
Capacity	kW	20,0			
Miscellaneous losses	%	10,0%			
Summary					
Capacity factor	%	13,6%			
Electricity exported to grid	MWh	30,694			

Fig. 6. Technical data of solar panels and selected inverters.

The costs associated with the project stages are: system design, purchasing and procurement of equipment and materials, procurement and implementation and O&M system.

The overall cost of the project implemented with 25.8 kW was USD $38203, with the following characteristics:

1) *Initial Costs:* In the initial costs are included: Feasibility, development, engineering, power system and incidentals. This value is USD $38203 corresponding to 100% of the project.
2) *Annual Costs:* They correspond to that associated with the operation and maintenance O&M cost of the system, whose annual projection was USD $258.
3) *Period cost:* It refers to the projected costs in years, where the life or replacement of parts involved in the project is determined. In this case the life of inverters is 13 years. The projection of costs for the inverters in the year 13th was USD $6609.

In our analysis of emissions of greenhouse gases, a base case is determined by using Diesel. This case generates an emission factor of 0.894 tCO2/MWh and a contribution of 27,4 tCO2/year for fuel consumption of 31 MWh.

Thanks to the use of photovoltaic panels, the emission factor greenhouse gases is 0.00 tCO2/MWh and a contribution of 0.00 TCO2 for a generation of 31 MWh.

Figure 7 shows the analysis of CO2 emissions avoided by using photovoltaic solar energy.

RETScreen Emission Reduction Analysis - Power project

☑ Emission Analysis

⦿ Method 1
○ Method 2
○ Method 3

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Colombia	Oil (#6)	0,894		0,894

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100,0%	31	0,894	27,4
Total	100,0%	31	0,894	27,4

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GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2			Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	27,4	0,0			27,4		27,4
Net annual GHG emission reduction	27,4	tCO2	is equivalent to	11.773	Litres of gasoline not consumed		

Fig. 7. Analysis of CO2 emissions avoided by the use of solar energy.

The reduction of total annual emissions of greenhouse is 27,4 TCO2, equivalent to 11,733 liters of gasoline avoided. Finally, Figure 8 shows the cumulative cash flows.

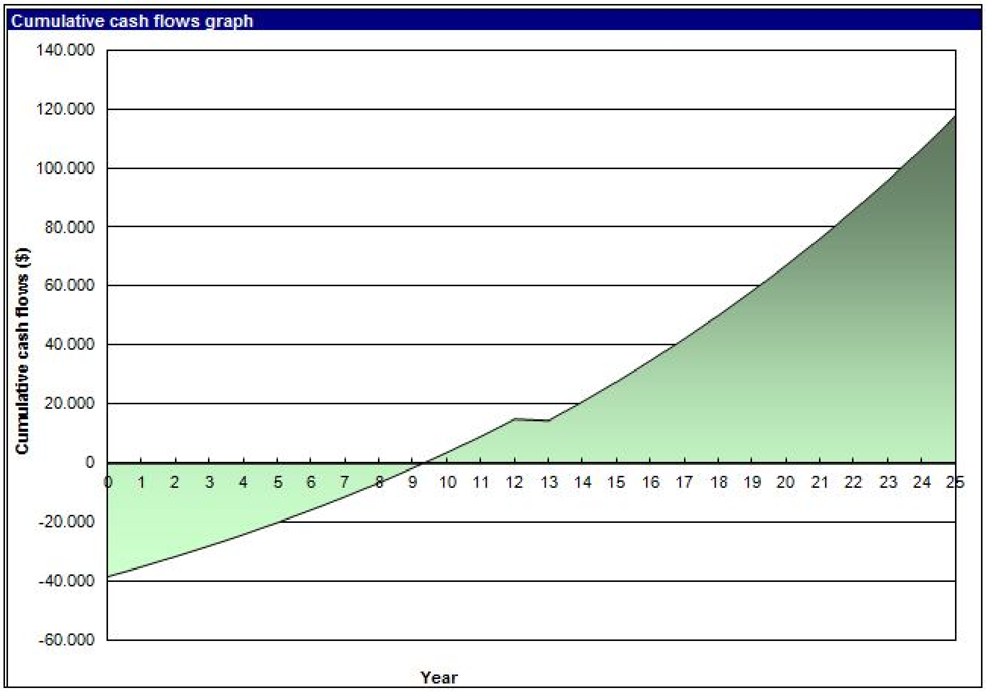

Fig. 8. Analysis of cumulative cash flows.

The initial economic investment of the project is USD $38203 and it is recovered in a time period of 9.3 years and energy savings for generation and/or sale of annual energy is 31MWh at a cost of USD $ 0,11/KWh equivalent to USD $ 3376 / year. After 9.3 years the generation or sale of power is reflected in net income, with a small valley in Figure 4 due to the replacement of inverters. The net present value (NPV) for the project to 25 years is USD $ 117940. It is important to clarify that economic analysis includes the benefits granted by Colombian Law 1715 by eliminating the payment of taxes on solar panels and inverters of the project. This reflects that investment in our generation system based in photovoltaics, is profitable with positive profit margins after 9,3 years of operation.

IV. CONCLUSIONS

In this project the feasibility of installing a photovoltaic system was studied as distributed generation, technical and economic level. As for the technical feasibility, previously it showed that this depends directly on the energy demand of the building. Due to the high energy demand of the building, we decided to use photovoltaic solar energy to supply 100% of the demand of the common areas: 86 solar panels of 300W each (25,8 kW) are required to meet demand.

The photovoltaic generator has a capacity to export power to the grid of 30,7 MWh per year; with export electricity rate of $ 0,11 / KWh.

Project implementation reduces 27,4 tCO2/year equivalent to 11 733 liters of gasoline avoided.

The economic investment of the project is USD $38203 and is recovered in a period of 9.3 years; time from which profits are obtained.

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Thanks to Colombian Law 1715, it is possible to save the cost of taxes on solar panels and inverters; making investment costs are reduced considerably. In Colombia it should be possible to pay the user per kWh exported to the grid and thus the photovoltaic generation could be competitive with hydro and thermal generation.

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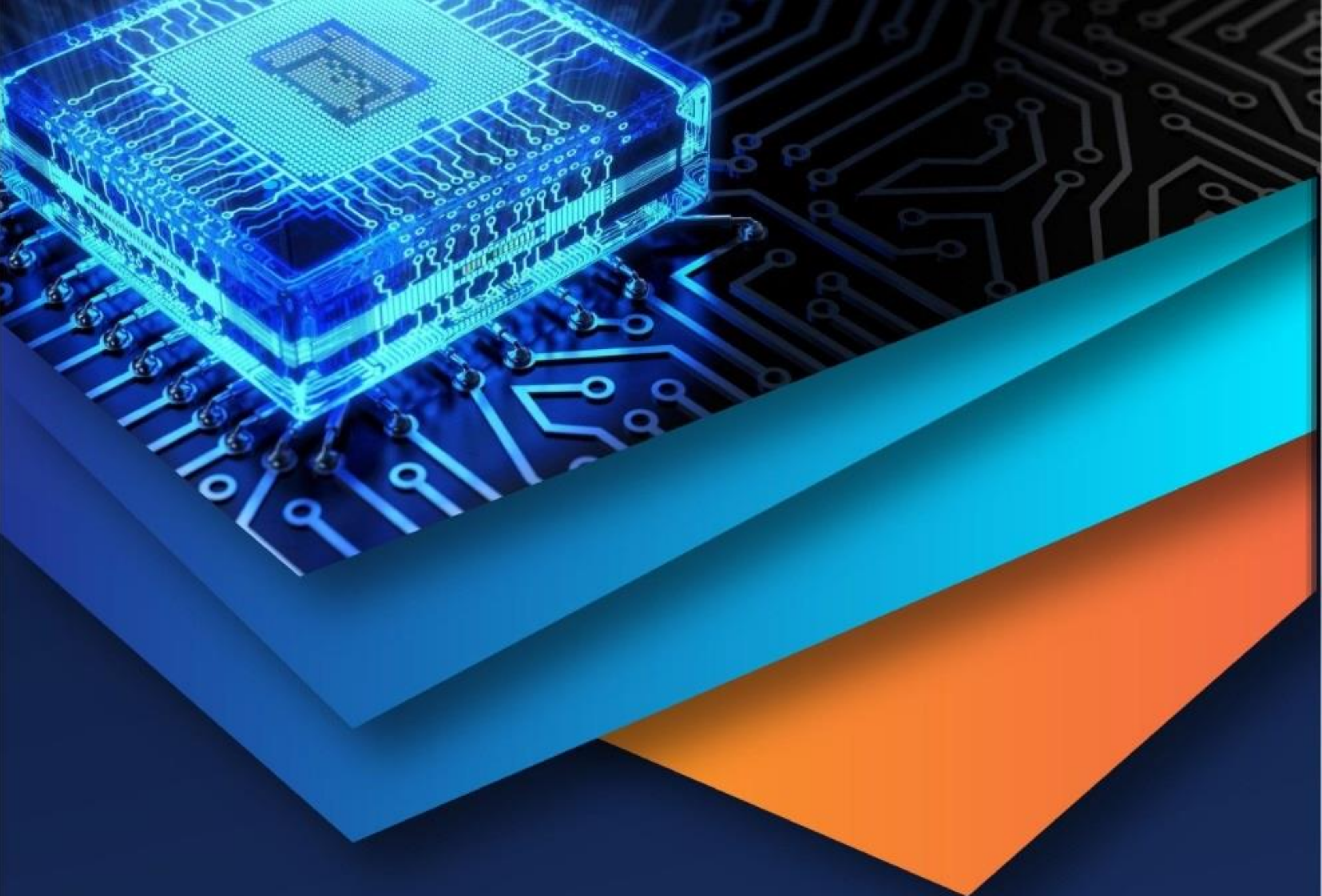

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