ISSN (e): 2250 – 3005 || Volume, 10 || Issue, 7|| July – 2020 ||
International Journal of Computational Engineering Research (IJCER)

Use of Photovoltaic Energy as a Means for Environmental Sustainability of an Irrigation System by Rainwater Captation

Gabriel Camargo, Valentina Ariza Chaverra and Monica R. Gómez Muñoz
[1]Faculty of Environmental Engineering, Libre University of Colombia, Bogotá, Colombia.

ABSTRACT
Irrigation activity is essential to meet the needs of plants and crops. However, this requires large amounts of water and energy. The use of photovoltaic energy helps to reduce the energy expenditure that is produces, while rainwater harvesting systems are an alternative to reduce the exploitation of the aquifers. The aim of this work is to design a rainwater irrigation system using photovoltaic energy for the Country Condominium "La Sabaneta" located in Puente Nacional, Santander, Colombia. We evaluated hydrometeorological data obtained from a literature review, for the previous definition of parameters and the design of pipes for the irrigation system, together with the determination of the photovoltaic panel system. Results suggest that the use of photovoltaic energy is feasible for the sustainability of the different crops in the study area, in addition to being environmentally friendly.
***Keywords**: Renewable energies, Irrigation, Sustainability, Photovoltaic energy, Rain water.*

Date of Submission: 28-10-2020 Date of acceptance: 10-11-2020

I. INTRODUCTION

Agriculture has brought great economic progress to most countries in the world [1], this is why, farmers seek to obtain more than one crop on the same land per year by intensifying the cultivated area or increasing irrigation. This was observed more frequently in the 1990s, where the average annual intensity was higher in irrigated areas than in rainfed areas [2], therefore, an excessive consumption of both water and energy needed in this process was and still is generated.

Irrigation systems are of utmost importance to benefit the growth of plants and crops; however, this requires large amounts of water resource and implies energy expenditure. Data from the Colombian Environmental Information System (SIAC) show that in Colombia the agricultural sector demands a higher percentage of water than other sectors, with 46.6% per year. On the other hand, in recent years there has been an increase in the population at the national level, according to figures from DANE in Puente Nacional, where the Country Condominium "La Sabaneta" is located and which is the study area, the population for 2019 was 14,740 people and in the department of Santander it was 2,237,587 inhabitants, while in 2009 the population was 1,999,999 [3], this population increase is directly proportional to the demand for basic resources for the community. An example is the deficit of water, when there is no drinking water network or the water has a very high cost, this is corrected by alternative supply systems [4]. This work seeks to design an irrigation system for coffee, banana, yucca, orange, pineapple, tangerine, lemon, lemongrass and palm tree crops, with renewable energy, in search of economic and social benefits for the Country Condominium "La Sabaneta", and thus saving energy costs and reducing the intervention in water sources. By implementing the use of renewable energy, not only does it improve environmental conditions by decreasing the impact on climate change [5], but it will also make the condominium more attractive to future customers. The implementation of photovoltaic energy in the Condominium enhances the use of clean energy in the department of Santander and in the country, in addition to being viable thanks to the high radiation in various regions of the country [6].

For this purpose, the use of autonomous photovoltaic energy is considered, selecting solar panels, a controller, an inverter and batteries, optimal for the system; as well as rainwater in the design of an irrigation system in the aforementioned location.

II. METHODOLOGY

The design of the irrigation system with renewable energies is divided into four parts. (i) In the first instance, a compilation of hydrometeorological data was carried out on official pages, of the National Administration of Aeronautics and Space (NASA), the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) and the Regional Autonomous Corporation of Santander (ACS). The foregoing in order to obtain annual data on precipitation, maximum and minimum temperature, maximum and minimum wind speed, relative humidity and maximum and minimum radiation in Puente Nacional, Santander.

(ii) In the second instance, the parameters required for the development of the system for crop diversity were evaluated, data on sea level altitude, longitude and latitude were taken with the Global Positioning System (GPS) around the study area for a subsequent selection of representative data, then, the reference evapotranspiration data for each month and an annual average were determined in the ecological zone of the Country Condominium La Sabaneta, study area, applying the Hargreaves method (1), based on maximum and minimum temperatures and radiation [7].

$$ETo=0,0023*Ra*(Tm+17,8)*\sqrt{\Delta T} \qquad (1)$$

ETo: Reference evapotranspiration (mm/day) Ra: Radiation (mm/day)
Tm: Average daily temperature (°C)
ΔT: Temperature variation (°C)

Once the reference evapotranspiration is obtained, the real evapotranspiration is calculated by multiplying the ETo and the crop coefficient (Kc) taken from the Food and Agriculture Organization of the United Nations (FAO), a dimensionless number that represents the differences in evaporation and transpiration of the previously mentioned crops (FAO).

Following the parameters, the water demand (m^3/day) was evaluated during the days after sowing, that is, the stages of the crop corresponding to: establishment, growth, flowering and maturation, against the Kc for each crop and the monthly evapotranspiration, in the same way, he required flow in m3/hour was determined, determining the month in which the crop consumes more water.

(iii) Thirdly, the total losses in the pipeline were found by dividing the pipes into two categories: the main one, pipes that run along the main paths, and the secondary one, which corresponds to the pipeline that crosses the crops and sectioning the ecological zone into five sections, for this , a total flow rate was set by adding the maximum flow rate of each crop, pipe diameter, friction factors and viscosity and flow rate (2).

$$V = \frac{Q}{A} \qquad (2)$$

V: Fluid speed (m/s)
Q: Fluid flow (m^3/s)
A: Pipe area (m^2)

After having these values, they were related in the Reynolds equation (3) to determine the type of flow.

$$Re = \frac{V*D}{\gamma} \qquad (3)$$

V= Fluid speed (m/s) D= pipe diameter (m)
γ= Fluid viscosity (m2/s)

Darcy's equation (4) was used to find the friction losses in the pipes. By relating the friction factor, pipe length, diameter, velocity and gravity.

$$hf = f*\frac{L}{D}*\frac{V^2}{2*g} \qquad (4)$$

F= friction factor
L= length (m) D= diameter (m) V= Speed (m/s)
G= Gravity (m/s2)

Once this was done, the right type of pump was determined to provide the required water flow in gallons per minute (gal/min). To obtain this result, first the number of laterals required to irrigate the surface daily (5) was determined and then the number of sprinklers needed (6).

[illegible] = [illegible] = [illegible] (5)

[illegible] ∗ [illegible]

N: Número de laterales requeridos. Srd: Superficie diaria de riego (m2) L: Longitud de los laterales (m)
Sl: Separación entre laterales (m)

[illegible] = [illegible] + 1 = [illegible] (6)

n: Number of sprinklers L: Lateral length (m)
Se: Separation between sprinklers (m)

By means of the Christiansen coefficient (F) the pressure loss is corrected considering the outlets it has (7).

$[illegible] = 0.351+1 + 0.154$ (7)

(2∗[illegible]) [illegible]2

n: Number of exits that the pipe has, in the case of lateral pipe it will be the number of sprinklers

The power requirements at the pump are calculated by equation (8) and the motor power requirements by equation (9)

[illegible] = [illegible]∗[illegible] / 76∗[illegible] (8)

HPb: Power required by the pump (HP)
Qs: Flow rate of the system or in the irrigation subunit (lps) HT: Total system load (m) Eb: Pump efficiency

[illegible] = [illegible]∗[illegible] / 76∗[illegible]∗[illegible] = [illegible] / [illegible] (9)

Finally, the photovoltaic design was carried out by first executing a load study where the daily consumption and the maximum demand were established. To determine the latter, the power of the pump is multiplied by three to increase the demand and thus protect the inverter. Then, the system voltage is determined by multiplying the daily consumption by a protection factor, which is 20% to compensate for losses in the panels.

The number of panels was found by calculating the photovoltaic power (10), then taking the result and dividing it by the power of the selected panel.

[illegible] = [illegible] / [illegible].[illegible].[illegible]

Cd: Daily consumption
(W) S.P.H: Solar peak hours

After that, through the system voltage, the controller was selected, which will allow energy to be stored and which in turn protects the batteries, the series design of the panels was carried out and the real number of solar panels to be used was determined.

The inverter power was selected based on the maximum pump demand. Finally, the number of batteries to be used was established (11).

$$BT = Bp * Bs$$

BT: Total batteries
Bp: Parallel batteries
Bs: Serial batteries

III. RESULTS AND DISCUSSION

3.1 hydrometeorological data

Table 1 shows a monthly average of precipitation data, relative humidity, maximum and minimum wind speed, maximum and minimum temperature, and the maximum and minimum radiation of Puente Nacional from 1983 to 2019. As can be seen, January is usually the most unfavorable month in terms of precipitation, while October is the most favorable; the months with the lowest and highest relative humidity are February and November, respectively; in terms of maximum and minimum wind speed, August has the maximum while July has the minimum; the maximum temperature is recorded in February and the minimum temperature in July; historically, January and December have the highest levels of radiation while April is the month with the lowest levels.

Table 1. Hydrometeorological data

PARAMETRO	UNIT	JAN.	FEB-	MAR.	APR	MAY	JUN	JUL	AGU-	SEPT.	OCT.	NOV.	DIC.	ANNUAL
PRECIPITACIÓN	mm/d	2,3	3,7	6,67	7,58	7,53	5,23	4,71	5,06	6,35	8,27	6,57	3,57	5,63
RELATIVE HUM	%	82,04	79,79	81,42	84,65	85,76	84,09	82,02	80,88	81,69	85,79	87,7	85,94	83,48
WIND MAX SPEED	m/s	1,14	1,16	1,12	1,06	1,07	1,25	1,3	1,29	1,15	1,08	1,08	1,07	1,15
WIND MIN SPEED	m/s	0,14	0,16	0,15	0,13	0,12	0,17	0,2	0,21	0,16	0,12	0,11	0,12	0,15
MAX. TEM	°C	22,21	22,99	22,85	22,32	21,83	21,73	21,85	22,3	21,27	21,26	20,9	21,43	21,91
MIN TEM	°C	13,29	13,47	14,05	14,2	13,76	12,83	12,37	12,4	12,79	13,42	13,68	13,56	13,32
MAX RAD	kW*h/ m2/dia	6,3	6,05	5,61	5,12	5,6	5,79	5,93	5,82	5,83	5,68	5,69	6,3	5,81
MIN RAD	kW*h/ m2/dia	4,9	4,35	4,53	4,22	4,28	4,53	4,76	4,47	4,53	4,44	4,46	5,03	4,54

Source: Authors, data was taken from NASA. 2020

3.2 Irrigation System Parameters

Table 2. shows the crop coefficient intervals

Table 2. Kc values and intervals

Interval between wetting events	Low 1-3 mm day-1	Moderate 3-5 mm day-1	High 5-7 mm day- 1	Very high > 7mm day-1
Weekly minor	1,2-0,8	1,1-0,6	1,0-0,4	0,9-0,3
Weekly	0,8	0,6	0,4	0,3
Greater than once in a week	0.7-0,4	0,4-0,2*	0,3-0,2*	0,2-0,1*

Source: Authors, data was taken from FAO. 2020

Table 3 contains a compilation of data previously found by crop, among which are: total days of crop growth, Kc, average evapotranspiration (ETo), water demand (m^3/day) and flow in m^3/h. The month in which the water demand and flow are highest is also included along with their respective ETo. It is possible to observe how the banana crop requires a higher water demand than other crops with 17.93 m^3/day and a flow of 0.75 m^3/h, while the pineapple crop requires the least water, with a water demand of 6.64 m^3/day and a flow of 0.28 m^3/h. A total flow of 4.42 m^3/h is obtained.

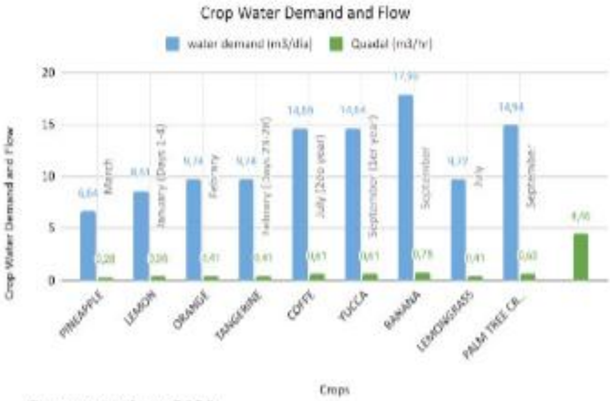
Table 3. Required parameters per crop

CROP	TOTAL GROWTH DAYS	kc INITIAL	kc MEDIUM	kc FINAL	AVARAGE ETo (mm/Dia)	AVERAGE WATER DEMAND (m3/Day)	AVERAGE FLOW (m3/hr)	MONTH WITH THE HIGHEST WATER EXPENDITURE: MONTH	ETo (mm/día)	WATER DEMAND (m^3/día)	FLOW (m^3/hr)
PINEAPPLE	540	0,5	0,3	0,3	23,06	4,84	0,2	March	24,14	6,64	0,28
LEMON	22	0,75	0,7	0,75	20,87	8,403	0,35	January (days 1-4)	20,87	8,61	0,36
ORANGE	150	0,75	0,7	0,75	22,64	9,08	0,38	February	23,61	9,74	0,41
MANDARINE	60	0,75	0,7	0,75	22,52	9,11	0,38	February (days 23-28)	23,61	9,74	0,41
COFFEE	574	0,8	0,95	1,05	23,18	12,25	0,51	July (2nd year)	25,26	14,59	0,61
YUCCA	750	0,3	1,1	0,5	23,45	10,31	0,43	September (1st year)	22,17	14,64	0,61
BANANA	390	0,65	1,2	1,15	23,33	13,5	0,56	September	27,17	17,93	0,75
LEMONCILLO	245	0,65	0,75	0,65	23,47	9,09	0,38	July	25,26	9,72	0,41
PALM TREE	2730	0,95	1	1	23,33	12,79	0,53	September	27,17	14,94	0,62
TOTAL FLOW (m3/h)											4.42
TOTAL FLOW (L/s)											1.225

Source: Authors 2020

Regarding the information provided in table 3, a diagram was made where the crops are analyzed, reflecting that the plantain crop is the one that requires the most water demand and flow (Figure 1)

Figure 1. Crop Water Demand and Flow



Source: Authors 2020

3.3 Sprinkler irrigation system

Figure 2 shows pipes' design made in AutoCad, it can be seen that the water tank feeds the main pipe and the rest of the pipes for a total of 5 sections and thus be able to cover all areas in their entirety.

Figure 2. Pipeline and Sprinkler Irrigation System Design

Source: Authors 2020

The calculations for the main pipe such as diameter, flow rate, water viscosity factor, speed, friction factor, length, pressure drops in the pipe, the absolute roughness of PVC and Reynolds with their respective value, unit and conversion are detailed in table 4.

2-inch pipe (Section 1)

Table 4. Main pipe loss calculations

DATA	VALUE	UNIT	CONVERSION	UNIT
Diameter	2	inches	0.0508	m
Flow	4.41	m3/ hr	1.225	Lt/s
Water Viscosity Factor	1.004x10−6	m2/s		
Speed	0.604	m/s		
Friction factor	0.021	Dimensionless		
Length	65	Meters		
Load losses in the pipeline	2,76x10-3	Dimensionless		
Absolute roughness of PVC	0.0015	mm		
e/d	0.0000295			
Reynolds	30.56x10^3		Turbulent flow	

Source: Authors. 2020

The advantage is that the PVC pipe is more resistant than polyethylene (PE). The pressure caused by the water as it passes through the pipes makes it a fragile material that can withstand shocks better. That is why it is usually buried to avoid accidental breakage and the effect that ultraviolet radiation has on this material that would be accelerated wear

In equation (2) the flow rate in lt/s of the total crops was used, resulting in a fluid speed of 0.604 m/s

$$V = \frac{Q}{A} = \frac{(1.225\,lt/s) * 1\,m^3}{\frac{\pi}{4}(0,0508)^2 * 1000\,lt} = 0.604\,\frac{m}{s} \quad (2)$$

Reynolds' Equation. For practical flow applications in pipelines.

Table 5. Reynolds Number Ranges

Flow type Number
Laminate <2000
Tubular >4000

Source: Authors. 2020

$$Re = \frac{V * D}{\nu} = \frac{0.604\,\frac{m}{s}(0.0508)m}{1.004 \times 10^{-6}} = 30.56 \times 10^{3}$$

.0000295

With the data Reynolds Number that was obtained, it is possible to define that it is a Turbulent Flow and for this reason it is correct to affirm that the theoretical Friction Factor should be used:

Friction Factor

$$\frac{□}{□} = \frac{0.0015\ □□}{50.8\ □□} = 2.95□10^{-5}$$

$$□ = \frac{0.25}{\left[\log\left(\frac{0.0000295}{3.71} + \frac{5.74}{□□^{0.9}}\right)\right]^2}$$

e= roughness coefficient

f=0.021

Darcy's equation is an empirical equation that relates pressure loss due to friction along a pipeline with flow velocity.

Darcy's Equation

$$h□ = 0.021 * \frac{65□}{0.0508\ □} * \frac{0.030^2}{2 * 9.8}$$

$$h□ = 1.23□10^{-3}$$

The calculations to determine the loss in the 1-inch secondary pipe, taking sections 2, 3, 4 and 5 is shown in Table 5, where the velocity, Reynolds number, friction factor and length and losses for each section are detailed.

Table 5. Secondary Pipe Loss Calculations

DATA	VALUE	UNIT	CONVERSION	UNIT
Diameter	1	inches	0.0254	m
Flow	4.41	m3/ hr	1.225	Lt/s
Kinematic Viscosity Factor	1.004x10−6	m2/s		
Speed	2.41	m/s		
Reynolds	60970		Turbulent Flow	
Friction Factor	0.09	Dimensionless		
Length section 2	70	meters		
Load losses in the pipeline	17,56x10-3	Dimensionless		
Length Section 3	70	meters		
Load losses in the pipeline	24,59x10-3	Dimensionless		
Length Section 4	60	meters		
Load losses in the pipeline	21,07x10-3	Dimensionless		

Length Section 5	80	meters
Load losses in the pipeline	28,10x10-3	Dimensionless
e/D	0.000059	
Absolute roughness of the PVC	0.0015	mm

Source: Authors. 2020

Considering that to calculate the pump were obtained the number of sprinklers in the area, the number of laterals per irrigation, the multiple output coefficients, the pump power and the engine power.
Analyzing collected data such as flow rate, pipe losses, pressure, length. It was considered the selection of the Centrifuge Pump type Jet Fix 1 HP (table 6), with the technical data of the pump it can be evidence that these are used mainly for hydropneumatics systems, for sprinkler irrigation (Figure 3).

Figure 3 Pump required

Table 6. Technical data of the pump

Brand	**Altamira Water**
Model	Suction and discharge
Pump Type	Jet Fix centrifuge type
Engine Type	IP44 protection, class F insulation
Efficiency	High efficiency

Em =Engine efficiency (0,90-0,95)

3.4 Photovoltaic design

To carry out the load study, the power of the pump to be used is taken; multiplying by the number of hours of operation per day, the energy is obtained by daily consumption, giving 899.4 W/h; the maximum demand was obtained by multiplying by 3 the power of the pump being the safety factor to protect the inverter (table 7).
The system voltage is determined by giving a protection factor to the daily consumption, in this case, it was taken the 20% resulting in 1079.28 Wh, because the daily consumption is less than 2000 Wh, the voltage to be used is 12V.
Daily consumption x protection factor 899,4 W X 20% = 1079,28 Watt
After this, the amperage is obtained resulting in 84.94 A.
To obtain the number of panels required, the power was first calculated with the peak solar hours with an optimal tilt angle of -5° for April, the most unfavorable month in terms of radiation, resulting in 228.18 W. After this, the number of photovoltaic panels to be used was estimated by previously selecting the model (figure 4).

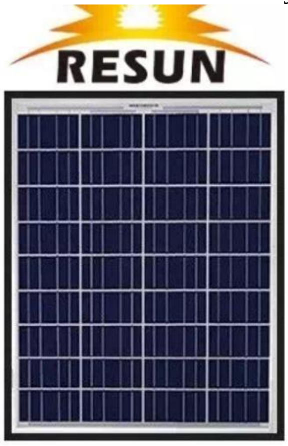
$$Power = Cd/h.s.p = 1079.28/4.73 = 228.18 \text{ Watt}$$

Cd: Daily Consumption
H.S.P: Solar peak hours: it is 4.73 with a tilt angle of -5°. Data taken from NASA

Number of paneles=Pf/Pm= 228.18 W/100W= 2.282 = 3

Pf: Photovoltaic power
Pm: Module or panel power

Figure 4. Solar Panel 100 Watts Resun Polycrystalline 12V



Source: Solartex. 2020

The controller was selected considering the voltage determined for the design of the system, this controller works with Maximum Power Point Tracker (MPPT) as they have greater capacity and is of the SNRE brand (figure 5).

Figure 5. Controller MPPT 40A ML2440 12/24V

Source: Solartex. 2020 Table 8 shows the specifications of the chosen solar panel.

Table 8. Solar panel specifications

Model	RSM100P
PotencMaximum rated power (Pmax)	100 W
Optimal operating voltage (Vmp)	17,40 V
Optimal operating current (Imp)	5,75 A
Open Circuit Voltage (Voc)	21,58 V
Short circuit current (Isc)	6,04 A
Operating Temperature	-40°C - +85°C

Source: Authors. 2020. Data was taken from Solartex.

Table 9 shows the controller specifications.

Table 9. Controller specifications

Modelo	ML2440
System voltage	12V/24V auto
Maximum power input to the PV system	550W (12V) / 1100W (24V)
Conversion efficiency	≤ 98 %

Source: Authors. 2020. Data taken from Solartex

Four solar panels are taken as the final number to make the design of 2 series of 2 panels to increase the performance of the system (table 10).

Table 10. Photovoltaic design performance

Series	**2 series of 2 panel**
Panels	**4**
Voltage (connected in parallel)	**43.16**
Amperage	**12.08**

Source: Authors. 2020. Data taken from Solartex

Voltage: Panel Voc: 21.58x2 = 43.16
2 multiplied by the number of panels in the series Amperage: Panel Isc: 6.04x2 = 12.08

The power of the inverter depends on the maximum demand of the pump, 449.7 W. We take an inverter brand POWERT pure wave as it feeds all types of load (Figure 6). The inverter specifications are shown in Table 11.

Figure 6. Inversor 500 Watts Pure Wave 12 Volts

Source: Solartex. 2020 Table 11. Inverter Specifications

Source: Authors. 2020. Data taken from Solartex

Batteries (capacity)

System voltage (v): 12V
Daily consumption (Cd): 1079,28 Inverter efficiency: 88%.

C= [Amps/hour]
= Cd/inverter efficiency= 1079.28 W/0.88=1226.45 W
=1226,45/12V=102,20 Ah
Parallel batteries

Model	SUNS-500-PS
AC output	120V DC
Frequency	60 Hz
Efficiency	> 88%

Figure 7. VRLA AGM 55Ah 12 Volt Kaise Battery
Source: Solartex. 2020

Ah/day= 102,20
Pd: Download depth: 50%

Nd: Number of days of autonomy (1) Battery capacity = 55 Ah

Parallel batteries
(Ah/day x Nd)/Pd = (102.2 x 1)/0.50 = 204.4 Ah
204.4 Ah/C. Battery = 204.4/55Ah = 3.72 = 4 batteries Serial batteries
B. in series = System V/ Battery V Bs = 12V/12V = 1 Battery

Total batteries = Bp x Bs = 4x1 = 4 BATTERIES

IV. CONCLUSIONS

As a result, a prototype was designed that can simplify the work for farmers by using an "intelligent and renewable energy" irrigation system that can supply water to plants in a uniform manner. Results were achieved according to initial expectations.

The development of the automated irrigation system represents a great advantage for users who, for different reasons, do not have the necessary resources for optimal irrigation of their long term crops and minimizing water consumption, which together with the autonomous system represents a saving in economic terms.

The project contributed significantly to identify and highlight the points to be covered, the proposed design meets the entire ecological zone and meets the needs of crops.

BIBLIOGRAPHY

[1]. J. J. Perfetti, Á. Balcázar, A. Hernández, and J. Leibovich, *Políticas para el desarrollo de la agricultura en Colombia*, vol. 1. Bogotá, Colombia: Fedesarrollo, Sociedad de Agricultores de Colombia, 2013.

[2]. P. Bifani, *Medio ambiente y desarrollo sostenible* , Cuarta Edición., vol. 1. Madrid: IEPALA Editorial, 1999.

[3]. DANE, “Demografía y población,” 2020. [Online]. Available: https://www.dane.gov.co/index.php/estadisticas-por-tema/demografia-y-poblacion. [Accessed: 22-Jun-2020].

[4]. J. A. Ballén Suarez, M. Á. Galarza García, and R. Ortiz Mosquera, “HISTORIA DE LOS SISTEMAS DE APROVECHAMIENTO DE AGUA LLUVIA,” *Univ. Nac. Colomb.*, 2006.

[5]. FAO, *El estado mundial de la agricultura y la alimentación*, FAO. Roma, 2016.

[6]. J. Gómez-Ramírez, J. D. Murcia-Murcia, and I. Cabeza-Rojas, “LA ENERGÍA SOLAR FOTOVOLTAICA EN COLOMBIA: POTENCIALES, ANTECEDENTES Y PERSPECTIVAS,” Bogotá, Colombia, 2017.

[7]. J. A. Gómez and M. Cadena, V*alidación de las fórmulas de evapotranspiración de referencia (eto) para colombia*, Nota Técnica del IDEAM, Instituto de Hidrología, Meteorología y Estudios Ambientales – IDEAM, 2017.