7-4-2019

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American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Benefit-Cost Analysis for the Supply of Renewable Electric Energy in Zones Not Interconnected Case Study Miraflores Boyacá

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Abstract

This research is carried out through a documentary and technical analysis in which, through the review of the literature, research articles and other sources of scientific and technological compilation, to economically determine the implementation of a scenario modeled at 1 cubic meter (1 m^3) only in terms of the supply of renewable electric energy with cooling purposes, a model that will be analyzed with the help of the benefit-cost ratio (B/C) for the supply of energy in areas not interconnected to the national grid, With the purposes of agriculture preservation Postharvest, for the case study Miraflores Boyacá, the objective is to generate an economic analysis for the possible implementation of the scenario and selection, taking into account that for the study of the indicators of goodness of fit in the evaluation of projects of Engineering, the indicators that are used for the project are the net present value (NPV) and the re B/C these data are presented through a cash flow, in each of the points proposed, which are composed of systems, and those systems are the possible electric sources such as the wind power, solar power and the biomass only the three most representative sources or usable in the town of Miraflores were taken, demonstrating that wind energy is the one that best represents B/C, for the future implementation in a real-scale model.

Keywords: postharvest; wind power; solar; biomass; Miraflореño collection; goodness of fit indicator; cash flow.

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1. Introduction

In this research a methodological proposal was generated, through the analysis of a multi-scenario matrix for the evaluation of the B/C ratio, the use of renewable energy systems for the supply of an underground storage room for post-harvest of horticultural products, for it was used as a case study the town of Miraflores in the state of Boyacá in Colombia. Different evaluation scenarios were proposed, combining the use of alternative energy systems, the energy consumption for a cubic meter (m^3) of cooling, thus know the amount of electric energy that each system must provide, then the implementation and the annual maintenance cost will be determinate and the as well as the benefit, and to be able to determine the indicators of the financial evaluation of the project. This analysis arises as a response to the conditions of the Miraflores peasants that are economically affected due to the loose in the post-harvest (according to the figures shown below), as they do not have the conditions suitable for the storage of their products, It is also a commercialized product at low prices and in a short time, therefore, the income is different from what was expected.

2. Methodology

The approach of the analysis methodology (B/C) of the energy supply for the underground structure, refers to the town of Miraflores which generates a high production of horticultural products; based on a bibliographic review, a multi-scenario matrix is proposed, and the varying of the percentages of use of each system.

2.1 National Context

According to the National Planning Department [DNP] [1], it is lost and wasted a total of 9.76 million tons in the country, of this total 36% are for losses, which 19.8% corresponds to post-harvest and storage; and in terms of products from this 36% the 60% is equivalent to the loss in fruits and vegetables (information estimated from the DNP report without considering the wastes) taking into account the region where the town of Miraflores is located (middle-east) it is reported a loss of food of 27,7% it is found the region with the highest percentage in Colombia **Figure 1.**

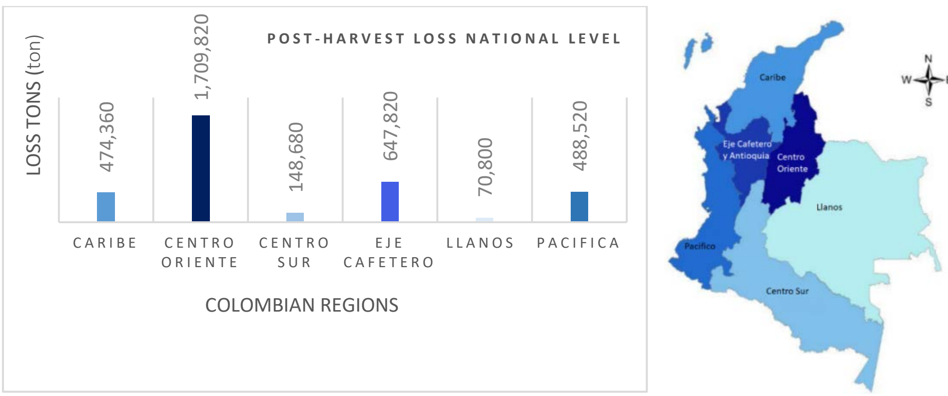

Figure 1: Tons lost at a national level. Own preparation based on the National Planning Department, [1]

2.2 Regional Context

Miraflores is located in Colombia, it is part of the state of Boyacá, which is located in the southeast. **Figure 2**, It has an area of 258 km² with an average temperature of 22 ° C, SE winds that can be used for a wind source and a relative humidity of 68% [2].

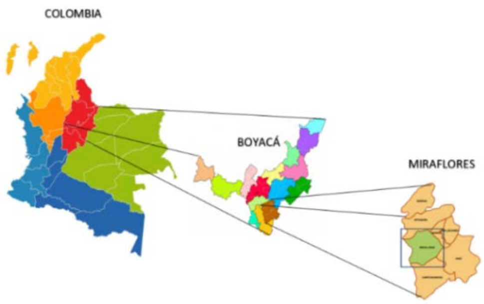

Figure 2: Location of Miraflores in Boyacá and Colombia [3].

Colombia has a fruit and vegetable production of 5.89 million tons **Figure 3,** in terms of the preservation of post-harvest, [4] it presents particular conditions regarding its infrastructure that will be subsequently evaluated [5].

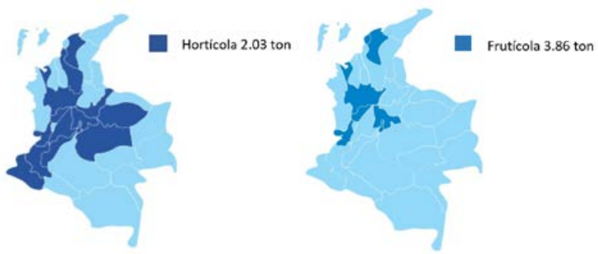

Figure 3: National Horticultural Production 2013 [6].

According to the Institute of Hydrology, Meteorology and Environmental Studies [IDEAM], the average wind speeds at 10 meters high for Miraflores are 5-6 m/s, and the average maximum speed is 27-30 m/s (**Figure 3**) [7], and the solar irradiance is 4.5 kW-h / m^2 (**Figure 4**) [8]. The residual biomass is a function of the volume of organic matter that can be collected from it, this together with the characteristics of a possibility of exploitation of wind and solar energy present the benefits for the possible implementation of the project.

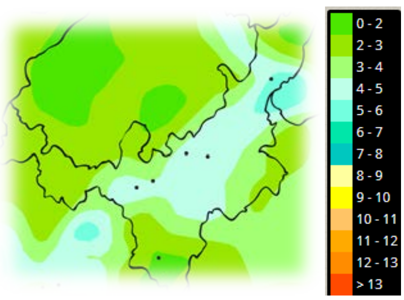

Figure 3: Wind (m/s) Boyacá [7].

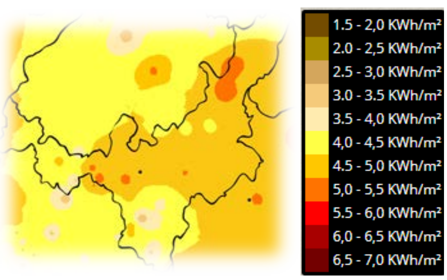

Figure 4: Solar irradiation [8].

2.3 Literature review

The literature review sought to identify the different types of alternative power generation systems, and the characteristics that Miraflores presents according to the systems that can be used for their geographical location. The most common types of renewable energies found are: hydroelectric energy, wind energy, biomass, solar energy, geothermal energy, and the energies of the sea [9], among these energies were selected those that can be exploited in Miraflores. Since Miraflores has a predominantly mountainous geomorphology, it is a usable condition for the implementation of solar energy by the radiation present in the area [2]; Wind energy will also be taken into account due to the exploitable speed of the winds present in this geographical area [8]; Biomass energy either as organic matter in decomposition [10], food or waste of these is usable given that they are approximately 1,722,940 tons. [11], this energy source is known as residual biomass [12] and is considered relevant in the analysis of this research due to the high percentages of loss in horticultural products reported previously [1]. The financial evaluation of the implementation of renewable electric power systems has been developed by González and Perales [13] [14] outstanding authors, in addition to them, there was a study developed by Fedesarrollo[1] [15], which was used as a guide in the approach of the study; the implementation of some type of renewable electric power system should be based on the financial evaluation of engineering projects [16], analyzing the indicators of goodness of fit as it is proposed by Infante [17]. The implementation at the national level of renewable energy from the financial point of view for the benefit of agriculture and non-interconnected areas has been evaluated by different authors IPSE[2] [18], [19], [20], because the alternatives are considered as possible hybrid systems [21], Fedesarrollo also provides information about the situation of Colombia in terms of carbon emissions, in which Colombia contributes 0.37% of total global emissions, therefore Colombia does not affect in terms of emissions, but could be damaged due to global warming, therefore it is another mitigating factor in the B/C ratio in favor of the use of renewable energies.

2.4 Proposal of the Multi-scenario matrix

According to the findings in the bibliographic review phase, the most viable energy systems to be employed in the municipality of Miraflores were identified, defining that only 3 alternatives of the 5 existing ones are viable; the analysis matrix is made up of energy systems and different percentages of energy supply, thus constituting six financial evaluation scenarios **Table 1**.

Table 1: Matrix Multi-scenario own elaboration.

System \ Scenario	**1**	**2**	**3**	**4**	**5**	**6**
Wind energy	100%	-	-	50%	25%	25%
Solar energy	-	100%	-	25%	50%	25%
Biomass energy	-	-	100%	25%	25%	50%

[1]Fedesarrollo: The Foundation for Higher Education and Development.
[2] IPSE: Institute of Planning and Promotion of Energy Solutions for Non-Interconnected Zones.

2.5 Analysis of the stages

Given the percentages established in each of the scenarios, the economic and financial evaluation of each of the energy systems was carried out in order to define the indicators of goodness, considering the following scope:

- The useful life of the scenario 10 years.
- Maintenance once a year (annual) for each system.
- Amount of energy that the storage place would need per cubic meter of refrigeration for a temperature of 10°C.

After evaluating the systems in scenarios 1, 2 and 3 at 100% utilization each, it is projected to hybrid scenarios 4, 5 and 6, with their respective percentages, to subsequently generate a financial proposal, in which it is desired to know the initial investment, to implement the project and the benefits both in money and in the reduction of lost tons in the post-harvest of the chosen alternative.

To define the amount of energy needed to supply the underground storage structure, the energy consumption per cubic meter of refrigeration was defined considering that the durability of fruits and vegetables can be extended in the post-harvest period with an average temperature of 15° C. [22] , and also because it is an underground structure there is a decrease in temperature thanks to the thickness and type of soil on it, according to different researches that have been developed by authors such as Tinti [23,24,25]. The geometric model to consider is presented in **figure 5**, showing the different processes of heat transfer, which is what generates that the temperature inside the underground structure does not consume so much electrical energy.

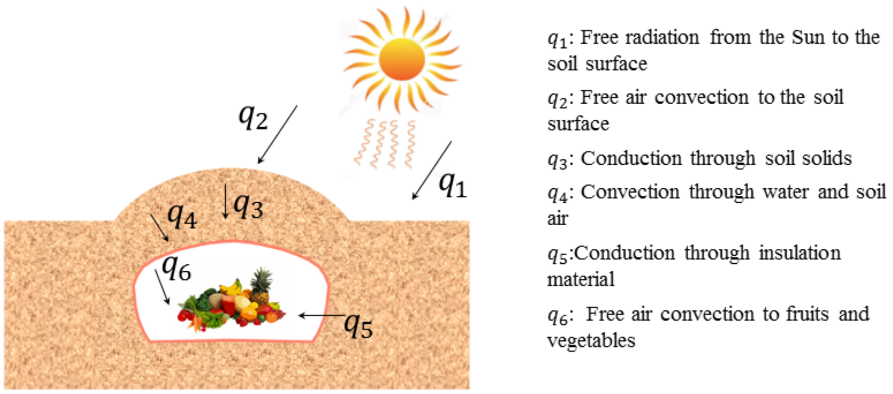

Figure 5: The incidence of solar radiation in the soil for the storage model.

3. Results

The results obtained from the evaluation of the different considerations are presented, and some variables that were not within the scope of this investigation are defined; the amount of energy required per cubic meter of refrigeration was defined, the average consumption of the electrical elements in the storage place, and the characteristics and attributes of the mechanisms in these systems capable of providing the energy demanded by the storage place.

3.1 Energy consumption for one m^3 of refrigeration

For the town of Miraflores, the possibility of implementing a hybrid system and systems that generate 100% energy are evaluated [13], hybrid refers to the possibility of a combination of photovoltaic, wind or biomass systems, which It has the purpose of supplying renewable electric energy to an idealized model per cubic meter (1 m^3 and/or 1000 L), which must maintain a constant cooling temperature.

To define what can be the energy consumption that storage needs to refrigerate, since the design phase has not yet started, and it is not the purpose of this study, it was resorted to estimating which could be this consumption as if it was of a refrigerator, an analysis was carried out with nine (9) refrigeration equipment present in the market with volumetric capacity close to 1000 L as can be seen in **Table 2.**

Table 2: Commercial domestic refrigeration equipment with capacity in liters (L) and consumption in (kW-h).

Brand	Reference	Consumption / capacity (kW-h/L)		
		Model 1	Model 2	Model 3
Mabe	[26]	25,8 / 250	28,2 / 320	34,8 / 420
Challenger	[27]	42,2 / 450	40,5 / 470	44,7 / 535
Haceb	[28]	42 / 430	42 / 447	50,7 / 656
Abba	[29]	32,55 / 295	29 / 300	28 / 400
Samsung	[30]	39,9 / 718	41,3 / 781	42,7 / 806
Lg	[31]	44,2 / 738	53,95 / 792	48,46 / 950
Electrolux	[32]	33,6 / 458	90 / 510	85 / 725
Whirlpool	[33]	37,77 / 583	42,48 / 728	46,47 / 752
General Electric	[34]	39,77 / 693	47,84 / 717	41,4 / 753

In **Figure 6** we can observe the dispersion of the data by neglecting the highest energy consumption data, thus obtaining an R^2 of 0.9535 for a linear correlation, where CE is the energy consumption in kW-h, and V is volume in L, it could be estimated that the energy consumption for a volume of 1000 L in storage is 49.26 kW-h.

The additional electrical consumption data for the storage place in Miraflores, were estimated and presented in **Table 3**, for example, the luminaires obtained from taking the dimensions of the real-scale model that has a volume of 2000 m^3 are 86 fluorescent tubes t8 2784 lumens 32w [35], and by proportionality take the luminaires needed for 1 m^3 that would be 0.0435 and a computer that needs the location consumes on average 0.01 kW-h [36], this considered as the minimum equipment for the operation.

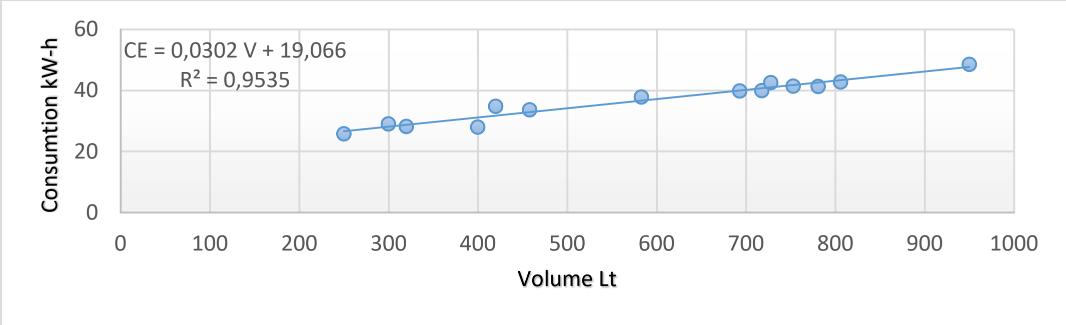

Figure 6: Linear projection graph to determine the energy consumption for 1000 L of capacity.

Table 3: Consumption of electric power collection site for 1 m^3. Own elaboration based on [35,36]

Electronic device	Potency (kW)	Daily time of use (h)	Monthly Use (h)	Total monthly consumption (kW-h)
Luminaires	0.0435	12	360	15.66
Computer equipment	0.01	8	240	2.4
Cold room (m^3)	49.26	24	720	35.47
			SUMMATION	53.53

3.2 Analysis of the bibliographic Review

From the review made and considering the geographic location and geomorphological conditions of Miraflores, of the six (6) electric energy generating systems (wind, solar, biomass, hydroelectric, geothermal and tidal), three (3) were discarded: geothermal, hydroelectric and tidal due to:

- Geothermal energy is obtained from areas with some volcanic activity and Miraflores does not have volcanic activity.
- Hydroelectric energy is discarded because to access to this type of energy it is necessary to be connected to the national grid, and for the rural area this is often very complex, although in Colombia it is one of the great generation systems, and does not generate innovation.
- The energy of the sea was discarded because Miraflores is located at a distance from the sea of approximately 450 km.

Therefore, the analysis was carried out for wind, solar and biomass energy, systems that will be analyzed in terms of their mechanism and electrical generation.

3.3 Analysis of wind, solar and biomass energy mechanisms per unit

Three different devices are presented for each of the selected systems with their characteristics, and properties in guarantee, generated energy and useful life, as shown in **Table 4**

Table 4: Some electrical generation equipment found in the market.

Mechanism	Generate energy	Guarantee	Useful life	Cost per system	
	Wind Energy				
Windmill 400W	0.4 kW-h	1 year	10 years	$802,76	[37]
Wind turbine of 600W	0.6 kW-h	1 year	10 years	$286,36	[38]
Generator Ista Breeze ®	0.5 kW-h	1 year	10 years	$410,00	[39]
	Solar Energy				
Renogy - Kit De Arranque Solar Mono-crystalline De 100W	0.1 kW-h	1 month	10 years	$1.429,99	[40]
400 W Watt 400 W Solar Panel + of 1500W Inverter 12v Rv Barco Off Grid	1.5 kW-h	25 years	10 years	$364,24	[41]
Renogy 300W 12 volts monocrystalline Solar Starter Kit	0.3 kW-h	5-25 years	10 years	$949,48	[42]
	Biomass Energy				
Biomax 25	25 kW-h	1 year	10 years	$21,850.00	[43]
FGB 20	20 kW-h	1 year	10 years	$91.712,50	

In the previous table there are some of the different equipment present in the market, of these with the help of a cost analysis one will be selected by source for the scenarios (1, 2 and 3), then proceeds to analyze the scenarios (4, 5 and 6) with the systems already selected.

3.4 Analysis of multi-scenario matrix scenarios

Table 5 shows the input data of the project, there you can see the percentages of post-harvest that are lost, amounting to 50% of production, the goal is to achieve a reduction in approximately 15% of post-harvest, the latter is assumed by the project, however, this percentage could be exceeded later on.

The data presented here is used for the entire multi-scenario matrix, the income and expenditure data of the project are taken from the statistical analysis regarding the social level in the national territory, these data were taken from the report delivered by the DANE[3] [44].

Table 5: Input data for the elaboration of the cash flow. Own elaboration based on [37,38,39,40,41,42,43,44,45]

Percentage of national post-harvest loss	50 %
The percentage decrease in the loss (taken – expected)	15 %
INCOME OF THE PROJECT	
Income – Cooperative* 20 farmers - USD /year	$ 87.791
Income - Cooperative 20 farmers USD /year without loss	$ 175.582
Increase in the expected income of 15% Over the loss of the post-harvest.	$ 26.335
OUTCOME OF THE PROJECT	
Expenses of survival	$ 71.247,56
Expenses – invoice value **/year	$ 1.986,77
Cost of the investment wind power system 1.	EFNM[4]
Cost of the investment wind power system 2.	
Cost of the investment wind power system 3.	
Cost of the investment solar energy system 1.	
Cost of the investment solar energy system 2.	
Cost of the investment solar energy system 3.	
Cost of the investment biomass energy system 1.	
Cost of the investment biomass energy system 2.	

* A cooperative is assumed in which the incomes of 20 farmers per year.

** A cost of electric bill is assumed according to the service provider company, if in some case the service is provided.

- **Scenarios 1, 2 and 3**: The wind, solar and biomass energy that are evaluated, for the power generated and demanded, the percentage is assumed to recover from post-harvest with the implementation of the project, the monetary values will be taken into account in dollars for the whole project, the costs of the machines for the electric generation systems are a function of the percentage of the number that is used of these per cubic meter.

[3] DANE: Administrative Department Statistics National
[4] EFNM: In function of machine numbers.

In table 5, it can be seen that depending on the goodness of fit indicators such as the VPN and C / B, the ones with the highest indicator for each system were taken, which were then used in scenarios 4, 5 and 6.

Table 6: Selected systems if operated with a single mechanism at 100% for 1 m3.

Scenarios	Mechanism of used system	Demanded potency per year with the model (kW-h) /m^3	Generated potency per years with the system (kW-h)	Number of machines needed /m^3	VPN > 0	B/C	Chosen Systems	Quotes
1	Windmill 400W	642.36	3456	0.19	$97.418	1.20	Wind turbine of 600W	[38]
	Wind turbine of 600W	642.36	5184	0.12	$97.503	1.20		
	Generator Ista Breeze ®	642.36	4320	0.15	$97.483	1.20		
2	Renogy – a mono-crystalline solar starter kit of 100W	642.36	432	1.49	$94.865	1.19	400 W solar panel r + 1500W Inverter 12v Rv Barco Off Grid	[41]
	400 W Watt 400 W Solar panel + 1500W Inverter 12v Rv Barco Off Grid	642.36	6480	0.10	$97.481	1.20		
	Renogy 300W 12 volts monocrystalline Solar Starter Kit	642.36	1296	0.50	$96.934	1.20		
3	Biomax 25	642.36	54000	0.01	$97.205	1.1982832	Biomax 25	[38]
	FGB 20	642.36	43200	0.01	$96.175	1.1957714		

- **Scenarios 4, 5 and 6**

Table 7: Combination of selected systems from table 5, with the variation of percentages according to the multi-scenario matrix. Own elaboration

Scenarios 4, 5 and 6	**Evaluated percentage**	**Mechanism of used system**	**Demanded potency per year with the model (kW-h)/m^3**	**Generated potency per years with the system (kW-h)**	**Number of machines needed /m^3**	**VPN > 0**	**C/B**	**Chosen system**	**Quotes**
4	Wind 50%	Wind turbine of 600W 400 W	321.18	5184	0.062	$292,42	1.198	4	[38]
	Solar 25%	Watt 400 W solar panel + 1500W Inverter 12v Rv Barco Off Grid	160.59	6480	0.025				[41]
	Biomass 25%	Biomax 25	160.59	54000	0.003				[43]
5	Eólico 25%	Turbina de viento de 600W 400 W	160.59	5184	0.031	$292,19	1.198		[38]
	Fotovoltaico 50%	Watt 400 W Panel Solar + De 1500W Inverter 12v Rv Barco Off Grid	321.18	6480	0.050				[41]
	Biomasa 25%	Biomax 25	160.59	54000	0.003				[43]
6	Wind 25%	Wind turbine of 600W 400 W	160.59	5184	0.031	$292,33	1.198		[38]
	Photovoltaic 25%	Watt 400 W solar panel + 1500W Inverter 12v Rv Barco Off Grid	160.59	6480	0.025				[41]
	Biomass 50%	Biomax 25	321.18	54000	0.006				[43]

These scenarios are hybrid systems in which a combination of the selected systems is presented, taken from **Table 5** since these were the ones that presented the greatest financial attributes. **Table 6** shows a variation in their percentages of energy utilization, which causes the machines of the system used to vary substantially and therefore the indicators of goodness, therefore the combination of scenarios with greater attributes is selected financially.

As you can see in the tables shown above, if you want to build the model with a single system that works 100% Table 5, the most favorable would be with a wind generation system, since from the investor's point of view it has a VPN greater than the other two systems and a cost-benefit ratio that shows that for every dollar of investment, $ 20.00 (twenty) dollars of income are received, the costs of maintenance, operation, installation and the wind turbine (wind system) can be seen in **Table 8**.

Table 8: Generation model 100%, discriminated in costs. Own elaboration based on [46]

WIND TURBINE OF 600W		**value per percentage of the needed system**
Cost of 1 (one) aerogenerator system	$802,76	
Percentage of the needed systems / m^3	0.19	
The real cost of the aerogenerator.	57.0%	$149,21
Planning, setting up and balancing the plant (1 time)	22.0%	$24,76
Operation and Maintenance 1/year	21.0%	$23,64
The total cost of the implementation without financing	$197,61	
The total cost of the financed implementation	$216,00	

Considering the financial analysis, for table 6, you can take scenario 4, which presents the most favorable NPV and its cost-benefit relationship shows us that for every dollar of investment $ 19.00 dollars of income are generated, this combination is discriminated in **Table 9.**

Table 9: Discrimination of the scenario 4.

Combination	**System**	**machines needed per system**	**Percentage of energy supply/ m^3**	**Cost of the generation system / m^3**	**Quotes**
4	wind	0.0619	50%	$23,50	[38]
	Solar	0.0250	25%	$82,26	[41]
	Biomass	0.0029	25%	$177,93	[43]
			Total	$283,69	

The initial investment for year zero of this combination is $ 219,702.99 according to the cash flow of the model, which takes into account both the expenditures of the farmer's cooperative and the maintenance operation and installation of all systems, data that if compared to the income of the farmers that are $ 263.37 dollars in year zero generate a balance of $ 43,670 dollars positive, that if after 10 years of project life the projection of the VPN has a positive value of $ 292.42 and a cost-benefit ratio of $ 20.00 for each dollar, which indicates that it is the best alternative for generating electricity for the town of Miraflores.

4. Discussion

The best scenario from the point of view of the financial indicators corresponds to the hybrid scenario 4 which contributes in energy percentage (50% 25% 25%); this corresponds to a potentially viable alternative due to the geographical location and predominantly agricultural activity of the town of Miraflores. The batteries used in the storage of wind energy are used for solar energy too. The biomass system is still highly speculative since its implementation implies the development of a particular generating plant for each project. In the way in which cash flows are shown, you can see that it always shows positive which is attractive to the investor. The costs of the systems are subject to the representative value of the dollar for the day in which the quotation is made for these, the renewable energy systems show that they have the potential to help mitigate the environmental impacts and that it is possible to reduce the use of energy Polluting fossils

5. Conclusions and comments of the findings

The already identified scenario can be taken to the desired volume of refrigeration, since having it per cubic meter can be dimensioned at convenience, and the number of electrical appliances needed within the post-harvest storage area can be added.

The external temperature can be reduced and maintained, which will give the farmer a place of storage with the possibility of refrigeration if it is desired to make more useful the refrigeration should have conservation tables of each fruit and vegetable product.

When calculating the machines that each scenario needs, you can see that per cubic meter only one machine exceeds the amount of energy needed, which is why it was calculated by percentage, this means that the systems have properties that contribute much more than what may be needed.

6. Recommendations

It's necessary analyze the different types of fruit in each scenario and site, this means that if the model want to be used in another country, must to have, study of temperature, air, land and solar radiation, and the politics of biomass use, because could be a high cost the implementation, and the quantity of energy is not so big like the cost of find it.

The construction of the model is the next part of the process, and the cost of civil built has another cost that aren't previously evaluated in this article.

This process must to be supervised by a professional, able of teach to the rural population the process and a head all they could to do the process by them self's

This process must be supervised by a professional, capable of teaching the rural population the process and later they can do the process themselves.

Evaluate the value of the dollar and the prices to the moment of to do the model, because it´s change frequently, and by the time this is summer or winter it´s too change the conditions.

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