# ESTUDIO DE LA VIABILIDAD TECNICA FINANCIERA DEL USO DE PLANTAS SOLARES FLUCTUANTES EN EL SUMINISTRO DE ENERGIA ELECTRICA PARA UNA BOMBA ELECTROSUMERGIBLE EN UNA PLATAFORMA FLOTANTE

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**Resumen - Este Proyecto consiste en presentar nuevas formas de combinar energías alternativas con la industria petrolera utilizando plantas solares fluctuantes a un sistema de bombeo electro-sumergible en una plataforma flotante. Se propone el uso de células fotovoltaicas propuesto para reducir el consumo de energía de la generación eléctrica de los módulos de generación eléctrica en una plataforma flotante.**[1]

**PALABRAS CLAVE: energía solar, planta solar fluctuante, bomba electro-sumergible, plataforma flotante, costa afuera.**

## 1. Introduction

"The objective of this review is to highlight the potential contributions that solar energy can make to energy resources are present in the oil and gas industry. It seems certain that oil will remain a major pillar of world energy demand for about two decades. energy demand for about two decades, energy consumption in the oil industry is almost 10% of its total energy production and is expected to increase significantly with the incursion of the oil and gas industry. expected to increase significantly with the incursion of new technologies" [2]

Atmospheric pollution is one of the main problems existing today, being one of those responsible for the climate change that the planet earth is suffering. Nowadays, research and development of technologies work to avoid, reduce, compensate, or mitigate atmospheric pollution. To combine two major industries such as alternative energies and the oil industry.

The generation of energy from new technologies in the world, in which the energy demand is increasing every day, for this reason, the oil industry is looking for new methods to take advantage of clean energy, without leaving behind the extraction of natural resources, in our case hydrocarbons.[3]

This study focuses on the use of solar energy, through photovoltaic solar panels, for the transformation of electrical energy, to power systems that generate energy in an electro submersible pump, on a floating platform in the Brazilian Recóncavo, for this reason, they need to study the feasibility of using solar panels in this new mechanism of harnessing the impact of the sun's energy is born.

This study counts with the SAM simulator tool, where results of some parameters will be shown, such as design, investors, financial study, among others. To conclude how is the behavior of solar energy to energize an electro submersible pump.

## 2. Methods

### 2.1 Requirements

The optimum operating power of the electro-submersible pump in the offshore reservoir must be determined using the Baker Hughes methodology. To do so, certain steps must be followed:

The search for primary information is based on BAKER HUGHES literature.

literature in which CENTRILIFT has established a nine-step procedure, the first six of which are necessary to design the submersible pumping system
CENTRILIFT has established a nine-step procedure, the first six of which are necessary to design the submersible pumping system [4]

necessary to design the submersible pumping for a particular well. Each of the steps is explained in the following sections, which include gas calculations and variable speed operation as Step 1.

Step 1 - Basic data collection and analysis of all good data to be used in the design of the submersible pumping system.

Step 2 - Production capability.
Determine the productivity of the well at the desired level. Pump setting depth or determine the pump setting depth at the desired production level.

Step 3 - Gas calculations.
Calculate fluid volumes, including gas, at pump inlet conditions.

Determine pump inlet conditions.
Step 4 - Total dynamic head.
Determine pump discharge requirements.

Step 5 - Pump type
For a given capacity and head, select the pump type that has the highest efficiency for the desired flow rate.

Step 6 - Optimum size of components
Select the optimum size of the pump, motor, and sealing section and verify equipment limitations.

**Step 1. Basic Data**

**Table 1.**

| PROPERTIES | | UNITS |
|---|---|---|
| **PRODUCTION RATE** | 431,6 | (SBT/D) |
| **DEPTH** | 22765 | (ft) |
| **CASING** | 7 | (Pulg) |
| **DESVIATION** | 0 | ----- |
| **DESVIATION DOG LEG** | 0 | ----- |
| **TEMPERATURE** | 175,05 | (°F) |
| **COMPLETION TYPE** | Simple | ----- |
| **RECOVERY TYPE** | Primary | ----- |
| **BOTTOM FLOWING PRESSURE** | 6849 | Pwf |
| **PERMEABILITY** | 7,8 | K (md) |
| **HEIGHT** | 10,05 | h ft) |
| **VISCOSITY** | 2,49 | $\mu_o$ |
| **VOLUMETRIC FACTOR** | 1,2 | Bo |
| **RESERVOIR PRESSURE** | 8345 | Pr |
| **BOTTOM FLOWING PRESSURE** | 6849 | Pwf |
| **GRAVITY API** | 32 | API |
| **CUT WATER** | 75% | CUT WATER |
| **GAS OIL RELATION** | 106,5 | GOR (SCF/STB) |
| **SPECIFIC GRAVITY GAS** | 0,7 | SGg |
| **SPECIFIC GRAVITY OIL** | 0,865 | SGo |
| **SPECIFIC GRAVITY WATER** | 1,085 | SGw |

**Note.** *General Characteristics*

**Step 2. Production Capacity**

**Table 2.**

| Nª | Variable | Equation |
|---|---|---|
| **1** | Productivity Index | $Pi = \frac{Q}{Pr - Pwf}$ |
| **2** | Find the bubble point | $Pb = 18{,}2 * \left[\left(\frac{Rs}{SGg}\right)^{0{,}83} * \frac{10^{0{,}00091*(tr-460)}}{10^{0{,}0125*Api}} - 1{,}4\right]$ |
| **3** | Composition Gr sp | $Gr.Sp = Cw \times SGw + Co \times SGo$ |
| **4** | Pressure difference between borehole and pump depths | $head\ (ft) = perforated\ depth - pump\ depth$ |
| **5** | Pump Pressure | $Pump\ Pressure = \frac{head\ (ft) * Specific\ Gravity}{2{,}31\ \frac{ft}{PSI}}$ |
| **6** | Pump intake pressure | $PIP = pwf - pump\ pressure$ |

**Note.** *Production Capacity*

**(1)** $Pi = \frac{Q}{Pr-Pwf}$

$$Pi = \frac{431{,}61bpd}{8345 - 6845\ psi} = 0{,}2883\ bpd/psi$$

**(2)** $Pb = 18{,}2 * \left[\left(\frac{Rs}{SGg}\right)^{0{,}83} * \frac{10^{0{,}00091*(tr-460)}}{10^{0{,}0125*Api}} - 1{,}4\right]$

$$Pb = 18{,}2 * \left[\left(\frac{106{,}5}{0{,}7}\right)^{0{,}83} * \frac{10^{0{,}00091*(175{,}05+460)}}{10^{0{,}0125*32}} - 1{,}4\right] = 1749{,}68$$

$$Pr \quad Pb$$

$$8345 > 1749{,}68$$

Corte de agua = 75%

0,75 x 1,085 =0,81375

Corte de aceite = 25%

0,25 x 0,865 = 0,2163

**(3)** $Gr.Sp = Cw \times SGw + Co \times SGo$

Composición Gr sp= 0,81375+ 0,2163 = 1,03

**(4)** $head\ (ft) = perforated\ depth - pump\ depth$

$$head\ (ft) = 22765 - 21000 = 1765\ ft$$

**(5)** $Pump\ Pressure = \frac{head\ (ft) * Specific\ Gravity}{2{,}31 \frac{ft}{PSI}}$

$$Pump\ Pressure = \frac{1765 * 1{,}03}{2{,}31} = 787\ psi$$

**(6)** $PIP = pwf - pump\ pressure$

$$PIP = 6845 - 787 = 6058\ PSI$$

The calculation of production capacity is performed by the following steps: In equation (1), find the productivity index (J) or (PI), where it is generally expressed as the volume produced per unit time, per psi of pressure drop in the formation.

In equation (2), find the bubble point, where it is known as the temperature and pressure at which the first gas bubble appears.

In equation (3), we need the water and oil cut-off data, with their respective specific gravities, and then find the specific gravity composition.
In equation (4), determine the pressure difference between good depth and pump depth.

**Step 3 Gas Calculations**

**Table3.**

| Nª | Variable | Equation |
|---|---|---|
| 7 | Solution Gas/Oil Ratio | $Rs = SGg\left(\frac{Pb}{18} * \frac{10^{0,0125*Api}}{10^{0,00091*T(°F)}}\right)$^1,2048 |
| 8 | Formation Volume Factor | $F = 180\left(\frac{SGg}{SGo}\right)^{0,5} + 1{,}25T$ |
| 9 | Volume factor (Bo) | $Bo = 0{,}972 + 0{,}000147F^{1,175}$ |
| 10 | Formation Volume Factor (Bg) | $Bg = \frac{5{,}04 \times z \times T}{P}$ |
| 11 | Total volume of gas (Tg) | $Tg = \frac{BOPD \times GOR}{1000}$ |
| 12 | Solution gas (Sg) | $Sg = \frac{BOPD \times Rs}{1000}$ |
| 13 | Volume of free gas (FG) | $Fg = Sg - Tg$ |
| 14 | Volume of oil (Vo) | $Vo = BOPD \times Bo$ |
| 15 | Volume of free gas (Vg) | $Vg = Free\ Gas\ \times Bg$ |
| 16 | Volume of water (Vw) | $Vw = Total\ Fluid\ Volume \times \%\ agua$ |
| 17 | Total volume (Vt) | $Vt = Vo + Vg + Vw$ |
| 18 | Percentage of free gas | $\%\ free\ gas = \frac{Vg}{Vt} \times 100$ |
| 19 | Total mass of produced fluid (TMPF) | $TMPF = \{(BOPD \times Sp.Gr\ O + BWPD \times Sp.Gr.W \times 62{,}4 \times 5{,}6146\} + (GOR \times BOPD \times Sp.Gas \times 0{,}0752)$ |
| 20 | Composite Sp. Gr | $Sp.Gr = \frac{TMPF}{BFPD \times 5{,}6146 \times 62{,}4}$ |

**Note.** *Gas Calculations*

**(7)** $Rs = SGg\left(\frac{Pb}{18} * \frac{10^{0,0125*Api}}{10^{0,00091*T(°F)}}\right)$^1,2048

$$Rs = 0{,}7\left(\frac{1749{,}68}{18} * \frac{10^{0,0125*32}}{10^{0,00091*175,05}}\right)\text{^}1{,}2048 = 338{,}74{,}74\ scf/stb$$

**(8)** $F = 180\left(\frac{SGg}{SGo}\right)^{0,5} + 1{,}25T$

$$F = 338{,}74\left(\frac{0{,}7}{0{,}865}\right)^{0,5} + 1{,}25 * 175{,}05 = 523{,}54$$

**(9)** $Bo = 0{,}972 + 0{,}000147F^{1,175}$

$$Bo = 0{,}972 + 0{,}000147 * 523{,}54^{1,175} = 1{,}20$$

**(10)** $Bg = \frac{5{,}04 \times z \times T}{P}$

Z= 0,85; P= 14,7+1000=1014,7 Psia

$$Bg = \frac{5{,}04 \times 0{,}85 \times (175{,}05 + 460)}{1014{,}7} = 2{,}68$$

$$\textbf{(11)} \qquad Tg = \frac{BOPD \times GOR}{1000}$$

$$Tg = \frac{(431{,}61 * 0{,}25) \times 106{,}5}{1000} = 11{,}49 mcf$$

$$\textbf{(12)} \qquad Sg = \frac{BOPD \times Rs}{1000}$$

$$Sg = \frac{(431{,}61 * 0{,}25) \times 338{,}74}{1000} = 36{,}55 mcf$$

**(13)** Fg= Sg-Tg

Fg= 36,55-11,49= 25,06 mcf

$$\textbf{(14)} \qquad Vo = BOPD \times Bo$$

$$Vo = 107{,}90 \times 1{,}20 = 129{,}48\ bopd$$

$$\textbf{(15)} \qquad Vg = Gas\ libre \times Bg$$

$$Vg = 25{,}06 \times 2{,}68 = 67{,}16\ bgpd$$

$$\textbf{(16)} \qquad Vw = producción \times \%\ agua$$

$$Vw = 431{,}61 \times 0{,}75 = 323{,}71\ bwpd$$

$$\textbf{(17)} \qquad Vt = Vo + Vg + Vw$$

$$vt = 129{,}48 + 67{,}16 + 323{,}71 = 520{,}35\ BFPD$$

$$\textbf{(18)} \qquad \%\ Gas\ Libre = \frac{Vg}{Vt} \times 100$$

$$\%\ Gas\ Libre = \frac{67{,}16}{520{,}35} \times 100 = 13\%$$

$$\textbf{(19)} \qquad TMPF = \{(BOPD \times Sp.Gr.Oil + BWPD \times Sp.Gr.Water) \times 62{,}4 \times 5{,}6146\} + (GOR \times BOPD \times Sp.Gas \times 0{,}0752)$$

$$[(107.91 \times 0{,}865 + 323{,}71 \times 1{,}085) \times 62{,}4 \times 5{,}6146)] + (106{,}5 \times 107{,}91 \times 0{,}7 \times 0{,}0752) = 15$$

$$\textbf{(20)} \qquad Sp.Gr = \frac{TMPF}{BFPD \times 5{,}6146 \times 62{,}4}$$

$$Sp.Gr = \frac{156359{,}65\ lbs/d}{520{,}35 \times 5{,}6146 \times 62{,}4} = 0{,}86$$

It is essential to determine the effect of the gas on the fluid volume to select the pump and separator. The following calculations produce the percentage of free gas by volume.

In equation (7), the gas/oil ratio is determined. In equation (9), the oil volume factor, which represents the increase in barrel volume occupied by the formation, is determined. In equation (10), the gas volumetric factor is determined, which is a parameter that relates the volume occupied by a gas at reservoir pressure and temperature conditions to the volume occupied by the same mass of gas at the surface at standard conditions (14.7 psia and 60ºF).
In equations (11) and (12), the total volume of the fluids is determined and the percentages of each are calculated using Rs and GOR.

Equation (13), is to determine the free gas volume, where it is the difference of the total fluid volume result of Rs and GOR,
In equation (14), determine the oil volume. In equation (15), determine the free gas volume and in equation (16), determine the water volume. After having the values of the volumes of the fluids, proceed to find the total volume corresponding to equation (17).

In equation (19), determine the total mass produced by the fluid (TMPF). In equation (20), determine the specific gravity composition, following the corresponding equation.

**Step 4 Total Dynamic Head**

**Table 4.**

| Nª | Variable | Equation |
|---|---|---|
| **21** | Vertical distance | $Hd = Pump\ depth - \frac{PIP * 2{,}31\ ft/psi}{Specific\ Gravity}$ |
| **22** | Tubing friction los | $Ft = \frac{Pump\ depth * 49\ ft}{1000\ ft}$ |
| **23** | Discharge pressure head | $Pd = \frac{Discharge\ Pressure * 2{,}31\ ft/psi}{Specific\ Gravity}$ |
| **24** | Total, Dynamic Head | $TDH = Hd + Ft + Pd$ |

**Note.** *Total Dynamic Head*

$$\textbf{(21)} \qquad Hd = profundida\ de\ la\ bomba - \frac{PIP * 2{,}31\ ft/psi}{Specific\ Gravity}$$

$$Hd = 21000 - \frac{6058 * 2{,}31\ ft/psi}{0{,}86} = 4728\ ft$$

$$\textbf{(22)} \qquad Ft = \frac{profundida\ de\ la\ bomba * 49\ ft}{1000\ ft}$$

$$Ft = \frac{21000 * 49\ ft}{1000\ ft} = 1029\ ft$$

**(23)** $$Pd = \frac{presion\ de\ descarga * 2{,}31\ ft/psi}{Specific\ Gravity}$$

$$Pd = \frac{100 * 2{,}31\ ft/psi}{0{,}86} = 267\ ft$$

**(24)** $$TDH = Hd + Ft + Pd$$

$$TDH = 4728 + 1029 + 267 = 6024\ ft$$

**Step 5 Pump Type Selection**

Selection of pumps from the engineering catalog and selection of calculated efficiency

**Table 5.**

| Nª | Variable | Equation |
|---|---|---|
| **25** | Total number of stages | $No\ stage = \dfrac{TDH}{head/stege}$ |
| **26** | Total brake horsepower | $BHP = \dfrac{BHP}{stage} * No\ stage * Sp.Gr$ |
| **27** | Required power | $BHP = 35{,}49$ <br> $P = v * A$ |

**Note.** *Pump Type Selection Equation*

**(25)** $$numero\ de\ estaciones = \frac{TDH}{head/stege}$$

$$numero\ de\ estaciones = \frac{6024}{20} = 301{,}2$$

**(26)** $$BHP = \frac{BHP}{stage} * No\ stage * Sp.Gr$$

$$BHP = 0{,}137 * 301{,}2 * 0{,}86 = 35{,}49$$

BHP = 35,49

$$P = V \times A$$

**(27)** $$P = 418 \times 62{,}5/1000 = 26{,}12\ Kw$$

**Step 4**

The calculation of the total dynamic head (TDH) is calculated using equation (24), where their respective variables are determined as the vertical distance (Hd) between the wellhead and the producing fluid using the depth of the pump at which the calculation is located. (PIP) equation (6) and the specific weight from equation (20), following with the calculation of the tubing friction factor (Tf) equation (22), considering the depth of the pump and the friction constant per 1000 ft. It ends with the calculation of the discharge pressure, being the pressure necessary to overcome the friction of the surface fittings.

In equation (23) the pressure to overcome must be considered, as well as it's constant and the specific weight.

The sum of the variables calculated with equation (24) is performed, where the total dynamic head TDH is determined.
Step 5
The selection of the pump is made through submersible pump suppliers' catalogs, in which the WSP (western submersible pump) catalog was used, considering the flow rate at which it will operate.

A search is carried out to determine which is the optimum pump for the job, by means of the operating flow rate. From the graph, data such as feet per station, power, and efficiency at (60) HZ are extracted.

To determine the number of stations required, the calculation using equation (25) is used and the braking power of the pump is determined using equation (26).

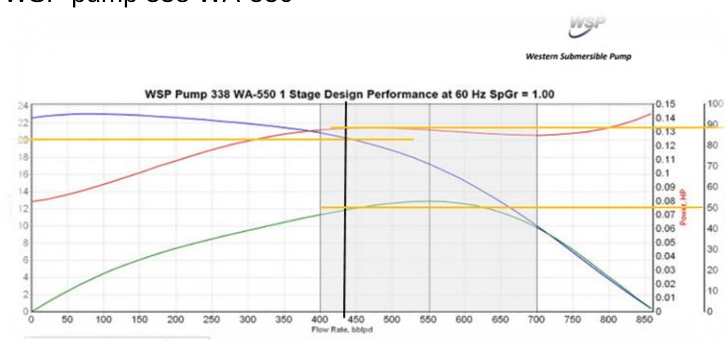
**(25)** $$numero\ de\ estaciones = \frac{TDH}{head/stege}$$

$$numero\ de\ estaciones = \frac{6024}{20} = 301{,}2$$

**(26)** $$BHP = \frac{BHP}{stage} * No\ stage * Sp.Gr$$

$$BHP = 0{,}137 * 301{,}2 * 0{,}86 = 35{,}49$$

**Figure 1.**
WSP pump 338 WA-550




**Note:** *Pump type selection by WSP pump 338 WA-550*

**Step 6**

The selection of the motor is made through the catalogs of the companies that supply submersible electric pumps, in which certain parameters are taken into accounts, such as the braking power of the pump and the fact that it performs efficient work, with which we can determine what the energy consumption is, by means of equation (27).

BHP = 35,49

$$P = V \times A$$

**(27)** $$P = 418 \times 62{,}5/1000 = 26{,}12\ Kw$$

**Figure 2.**
Schlumberger motor catalog.

Schlumberger

375 Series Motor

| 375 Series REDA* Maximus* ESP System Motor—RA Type | | | | | | | |
|---|---|---|---|---|---|---|---|
| Frequency 60 Hz | | Frequency 50 Hz | | | | | |
| Power Rating, hp | Voltage, V | Power Rating, hp | Voltage, V | Current, A | Type | Length, ft [m] | Weight, lbm [kg] |
| 14.3 | 386 | 11.9 | 322 | 27.1 | UT | 5.7 [1.7] | 195 [89] |
| 21.4 | 447 | 17.8 | 372 | 35.1 | UT | 7.6 [2.3] | 260 [118] |
| | 578 | | 482 | 49.6 | UT | 7.6 [2.3] | 260 [118] |
| 28.6 | 422 | 23.8 | 352 | 49.6 | UT | 9.5 [2.9] | 325 [148] |
| | 596 | | 497 | 35.1 | UT | 9.5 [2.9] | 325 [148] |
| 35.7 | 418 | 29.7 | 348 | 62.5 | UT | 11.4 [3.5] | 388 [176] |
| | 418 | | 348 | 62.5 | CT | 11.6 [3.5] | 388 [176] |
| | 745 | | 621 | 35.1 | UT | 11.4 [3.5] | 388 [176] |
| | 745 | | 621 | 35.1 | CT | 11.6 [3.5] | 388 [176] |

**Note**. *Selection the Schlumberger motor catalog.*

### 2.2 Simulation in SAM

The System Advisor Model (SAM) is a simulator where predictions and estimates of the cost of energy are made for the analysis of the study of obtaining energy, taking advantage of a natural and inexhaustible source, such as the sun.

From the System Advisor Model (SAM) software with the calculation of the Levelized cost of energy (LCOE) for the generation of energy by means of fluctuating photovoltaic solar panels, which consists of the conversion of light into electricity. This process is achieved with materials that have the property of absorbing photons and emitting electrons.

The simulation in SAM has a location, where the data of the field is introduced, the study of the search for the coordinates of the area, such as latitude and longitude where the feasibility study will be done.
Due to the location of the study field, the state of Bahia (Brazil) is selected, where the Recóncavo basin is located, near the coastal area of Salvador de Bahia, figure (3).

A design is considered that consists of the installation of a mesh of fluctuating solar panels in the sea next to the offshore platform, which will be supplied with energy, the panels have characteristics that are required as the azimuth and inclination, for them a calculation is made to determine its value[5].

The study area being in the southern hemisphere, the orientation will be towards the north of 0° and the tilt is determined by the following equation (28), taking into account its latitude is 12° and the result is 11.98°, so it is advisable in the simulation to use the value of 15° for being close to the equator line and thus have an inclination of the greater impact of the sun's radiation.

$$(\mathbf{28})\beta opt = 3.7 + 0{,}69 x\varphi$$

$$\varphi = 12° : corresponds\ to\ the\ latitude\ of\ the\ area$$

$$(\mathbf{28})\beta opt = 3.7 + 0{,}69x12 = 11{,}98°$$

Being in the sea, it occupies a number of 323 modules, with a total area of 642.8 m2 and a capacity to generate 122.821 kW.

For the study, the reference panels of United Renewable Energy Co._ LTDA. were used, evaluating the D6L380L4A-P panel with an area of 1.99 m2, with 72 cells of Mono-Crystalline silicon material, with a maximum operating temperature of 50ºc and a maximum voltage generation of 39 and 9.8 Amperes.

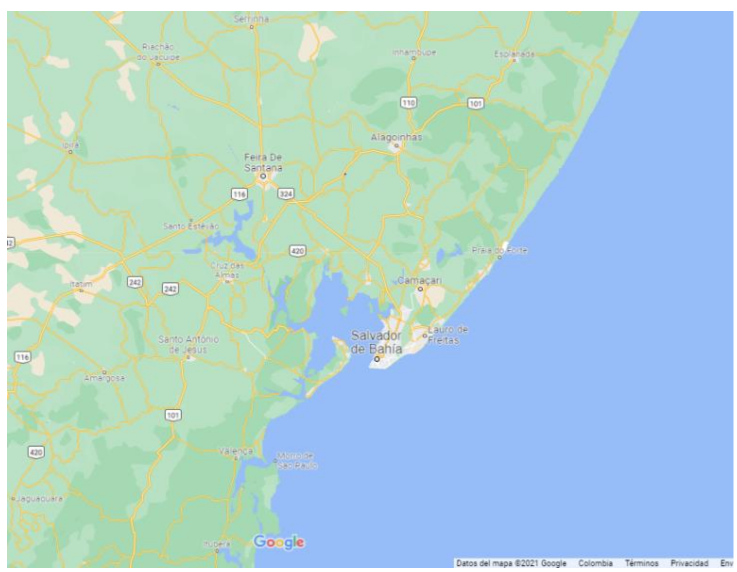
For power, 3 inverters manufactured by Huawei Technologies company of reference SUN 2000-36 KTL-US will be used. With a weighted efficiency specification of 98.416%, a maximum power of 36000 Wac at 36592.8 Wdc, specified by the manufacturer Huawei. This type of panel was chosen as it conforms to the efficiency curve specifications.

Finally, the financial parameters were proposed which are configured at a capacity of 122,821 kW with a capital cost of 587750 USD and an operating cost of 27900 USD for the calculation of the LCOE (Levelized Cost of Energy) for a time of 20 years with an inflation rate of 2.5% and an internal rate of return of 13% nominal per annum.

#### 2.2.1 Location

The following work is proposed to be designed in the Brazilian Recóncavo in the northeast zone in the coastal area near Salvador de Bahia, as shown in figure (3).

**Figure 3.**
The Brazilian Recóncavo




**Note.** Location *of the Brazilian Recóncavo*

### 2.2.2 Solar energy

"Solar energy today represents the second most penetrated advanced renewable energy source in the world, after wind, with an output equivalent to between 0.85% and 1% of global electricity demand. In 2013, this technology surpassed wind power in terms of growth for the first time, with an increase in installed capacity of 39 GW (compared to 35 GW for wind), showing an average annual growth of 55% over the last 5 years. Countries such as Germany, China, and Italy lead the solar energy markets with installed capacities of 36, 19 and 18 GW, respectively" [6].

Energizing an electro submersible pump on a floating platform, which, by not relying on the generation of electrical generation modules, is expected to result in the same efficiency in terms of hourly intensity and power output as the electro submersible pump on the offshore platform.

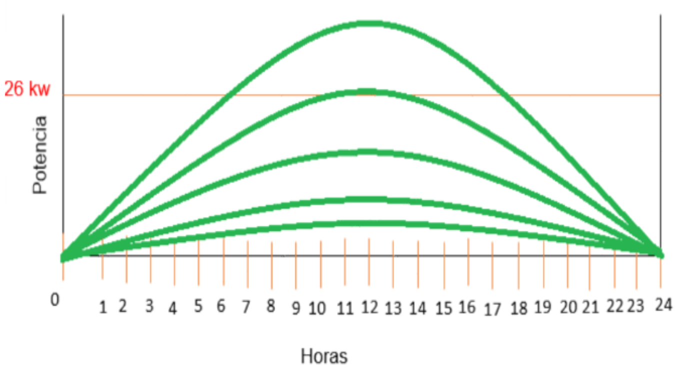
It is expected to have positive profitability and great environmental benefits for industrial innovation.

**Energy demand**

26 kw corresponds to the power of the pump, for 24 hours. Therefore, the energy required during the day corresponds to

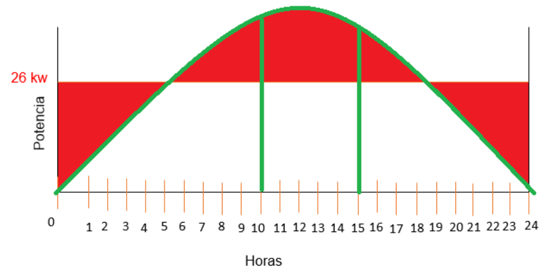
$$(\mathbf{29})\ 26\ kwx\ 24hrs = 624\ kwh$$

**Figure 4.**
Energy demand at 24 hours




**Note.** *Energy demand curve at 24 hours*
**Stored energy**

**Figure 5.**
Energy demand of hours worked




**Note**. *Energy demand curve of hours worked*

$$(\mathbf{30}) Power\ \#\ hours = 624\ kwh$$

$$Power\ x\ 5\ hours = 624\ kwh$$

$$(\mathbf{30})\ Power = 124{,}8\ kw$$

What corresponds to the power of 124.8 kW is the average energy that will supply the need of the fluctuating solar panels in 24 hours.

When the power is 124.8 kW to energize 24 hours and there is 26 kW of the pump power, there is 100 kw more, for this, there is a battery storage system for the 19 hours in which the incidence of light is low or null.

### 2.2.3 Radiation of the Brazilian Recóncavo

In the Brazilian meteorological page (INMET), it was possible to obtain data on the study area, such as radiation, temperature, climate, among others in the Brazilian Recóncavo area[7].

**Figure 6.**
Radiation of the Brazilian Recóncavo

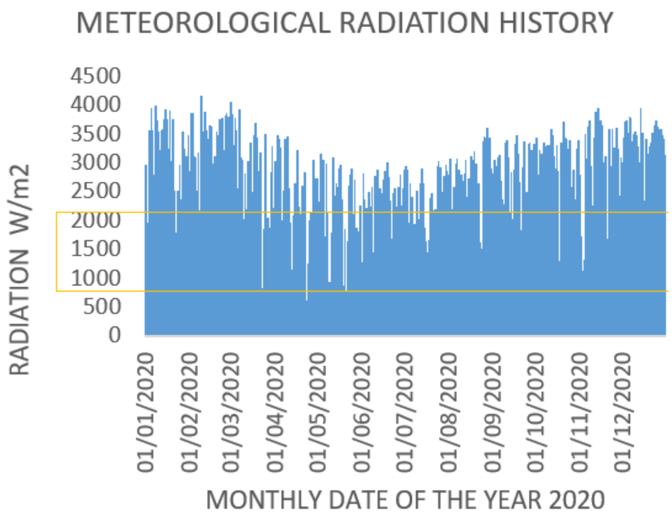

**Note** *Location and radiation of the Brazilian Recóncavo, Taken from: https://portal.inmet.gov.br/.*

When analyzing image (6), it is possible to observe the radiation in which the Brazilian Recóncavo area is located, according to the Brazilian meteorology page

(INMET), it has radiation of 1135.8 w/m2, being a value that is located at 13:00 in El Salvador (radio Farol).

**Figure 7.**

Meteorological radiation history

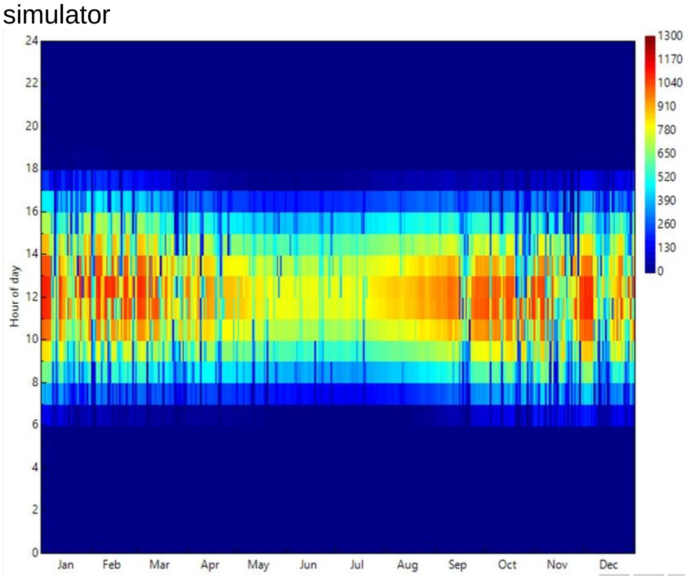



**Note.** *Historical hourly radiation of the Brazilian Recóncavo, from: https://portal.inmet.gov.br/dadoshistoricos and modified by the authors*.

This value corresponds to the daily radiation by weighted hours, from January 2020 to December 31, 2021, where the high incidence of the sun in the study area is obtained with a range of 1000 - 2000 w/m2.

**Figure 8***.*

The radiation of the Brazilian Recóncavo, using the SAM simulator




**Note.***The figure shows the radiation of the Brazilian Recóncavo, using the SAM simulator.*

From the SAM simulator (System advisor model), with coordinates of the Brazilian Recóncavo basin, information was obtained on the radiation parameters, where the energy power graphs are shown, in which the radiation is parameterized between 700 - 1200 w/m2, in the hours of 8 am and 4 pm, in the first and last months of the year.

It is concluded that the data obtained from the SAM simulator and compared with the meteorological page (INMET), is determined that the data are in a range of 700 - 1200 w/m2. And it shows no deviation from the data obtained by the two methods of analysis to determine the solar radiation in the Recóncavo basin.

## 3. Financial study

The analysis of the financial statements, through the relationships of the economic indicators, to establish useful information throughout the planning of the project, financial studies of other similar projects are considered. Factors are created for the realization of the financial study, such as making an investment plan of the project, where the cash flow period is projected, in our case it is 20 years, a working capital, where the investment that is given to the project is represented and is 587750 USD and an operating cost of 27900 USD.

**Table 6.**

| Element | TOTAL, USD$ |
|---|---|
| Solar panels | 48750 |
| Inverter | 15000 |
| Installed floats | 180000 |
| Electric installation | 26000 |
| Mounts and fasteners | 18000 |
| Energy storage | 20000 |
| construction | 280000 |
| **TOTAL** | **587750** |

**Note.** *Investment cost Taken from Estudio de prefactibilidad de la implementacion de un parquet fotovoltaico flotante en depositos de relave en la zona centro-norte de chile and edited by authors*.

**Table 7.**

| Ítem | USD/KW-AÑO | TOTAL, USD$ |
|---|---|---|
| General maintenance | 0,8 | 100 |
| Wiring inspection | 5 | 620 |
| Honeycomb washing | 4 | 500 |
| Spare parts | 2 | 250 |
| Total | -- | 1470 |
| Inverter maintenance | | 430 |
| Plant operators | | 10000 |
| Monitoring | | 1000 |
| Administrative costs | | 15000 |
| Total | | 26430 |

| | |
|---|---|
| **TOTAL** | **27900** |

**Note.** *Operating costs taken from Estudio de determinación de Costos de Operación, Mantenimiento y Administración Fijos de Generación con base en Energías Alternativas and edited by authors*.

For the cost of income, we considered the fuel prices in the Brazilian area, where diesel has had a 60% increase in refineries, due to the change of the US dollar and the international oil price[8]. As project income, the fuel consumption in gallons is taken and its value put on the platform that is no longer made for these modules that energize an electro submersible pump, where the energy that is no longer taken from these modules is 1,080,000 kWh/year, being this a fuel saving of 2,6188, 29 gallons. Considering the sale price of fuel in that period, a 20-year cash flow is made to determine the profitability of the project.

**Table 8.**

| | Year 0 | Year 1 | Year 2 | Year 3 |
|---|---|---|---|---|
| **Income earnings recordable** | | 117847,3222 | 123739,6884 | 129926,6728 |
| **Expenses operating costs** | | 27900,00 | 29.295 | 30.760 |
| **Net Flow / Profit** | -587.750 | 89947,32225 | 94444,68836 | 99166,92278 |

| Year 4 | Year 5 | Year 6 | Year 7 | Year 8 |
|---|---|---|---|---|
| **136423,0064** | 143244,1567 | 150406,3646 | 157926,683 | 165823,017 |
| **32.298** | 33.913 | 35.608 | 37.389 | 39.258 |
| **104125,2689** | 109331,5324 | 114798,109 | 120538,014 | 126564,915 |

| Year 9 | Year 10 | Year 11 | Year 12 | Year 13 | Year 14 |
|---|---|---|---|---|---|
| **174114,168** | 182819,876 | 191960,87 | 201558,913 | 211636,859 | 222218,702 |
| **41.221** | 43.282 | 43.282 | 43.282 | 43.282 | 43.282 |
| **132893,161** | 139537,819 | 148678,813 | 158276,856 | 168354,802 | 178936,645 |

| Year 15 | Year 16 | Year 17 | Year 18 | Year 19 | Year 20 |
|---|---|---|---|---|---|
| **233329,637** | 244996,119 | 257245,925 | 270108,221 | 283613,632 | 297794,314 |
| **43.282** | 43.282 | 43.282 | 43.282 | 43.282 | 43.282 |
| **190047,58** | 201714,062 | 213963,868 | 226826,164 | 240331,575 | 254512,257 |

**Note.** *Project projection exercise in 20 years*

**Table 9.**

| Nª | Variable | Equation |
|---|---|---|
| 28 | VPN | $-Costs\ of\ the\ investment + D/((1+r)) + D/(1+r)^{\wedge}2 + D/(1+r)^{\wedge}3 + D/(1+r)^{\wedge}n$ <br> D: period Flow; Net flow; x: Tio |
| 29 | TIR | $-Costs\ of\ the\ investment + D/((1+TIR)) + D/(1+TIR)^{\wedge}2 + D/(1+TIRr)^{\wedge}3 + D/(1+TIR)^{\wedge}n$ |
| 30 | Cost-benefit ratio | $(Present\ value\ of\ income)/(Present\ value\ of\ expense)$ |

**Note.** Economic indicators equation

In the project of the fluctuating solar panels, the economic indicators to be considered are net present value (VPN), internal rate of return (TIR), opportunity interest rate (TIO), the present value of income, present value of expenses and the benefit-cost ratio (RB/C).

**Table 10.**

| **TIO** | **15%** |
|---|---|
| **VNA** | 767.064 |
| **VPN** | 179.314 |
| **TIR** | 19% |
| **Present value of income** | 903.568 |
| **Present value of expenses** | 794.903 |
| **Cost – Benefit ratio** | 1,13670 |

**Note.** *Economic indicator results*

## 4. Results and Discussions

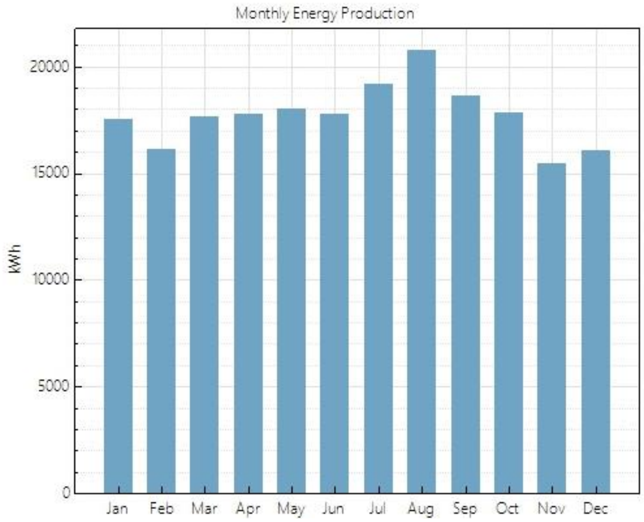
When performing the simulation in SAM, in the Brazilian Recóncavo area, a levelized cost of energy (LCOE) of 39.63 cents/kWh is obtained, as can be seen in (Fig. 9), which means that it is equivalent to approximately 4/10 of a dollar per kilowatt-hour consumed.

**Figure 9.**
General characteristics

| Metric | Value |
|---|---|
| Annual energy (year 1) | 212,879 kWh |
| Capacity factor (year 1) | 19.8% |
| Energy yield (year 1) | 1,733 kWh/kW |
| Performance ratio (year 1) | 0.76 |
| Levelized cost of energy | 39.63¢/kWh |

**Note.** *Abstract general characteristics of the SAM simulator*

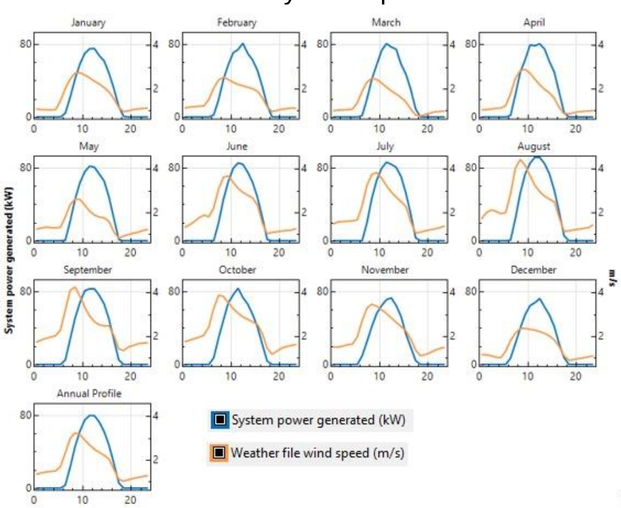
**Figure 10.**
Energy production by month




**Note***. Accumulation of energy production by month in the SAM simulator*.

As shown in (Fig. 10), the energy production is higher in the months of July, August, and September, with an energy production of more than 18000 kWh, which means that these months are of sunlight incidence and have an optimization of the annual production of 212,879 kWh.

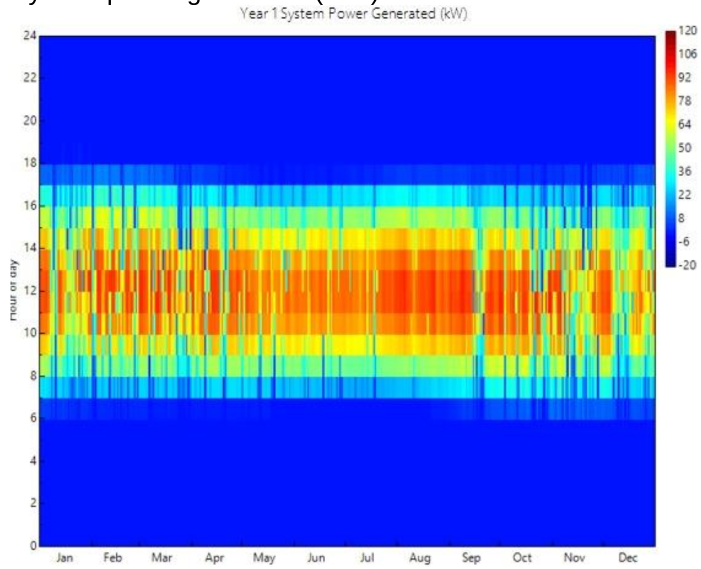
**Figure 11.**
Generation of kilowatts by wind speed




**Note**. Generation curve of kilowatts by wind speed

In (Fig. 11), it is detailed that the months January, February, November, and December, are the months that represent a slight drop in energy production, because they are areas of high humidity, since the Brazilian Recóncavo is an area that is close to the Amazon, and its winds are higher than 3 m/s.

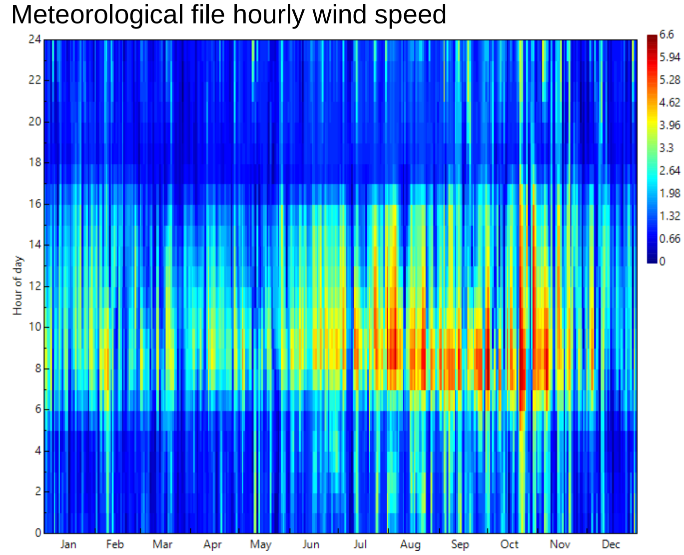
**Figure 12.**
System power generated (kwh)




**Note**. *System power generated (kwh) by the SAM simulator.*

In (fig. 12), the heat map by hours, in the months of the year, more working hours are obtained, where the absorption of sunlight and the presence of wind is between 8:00 and 16:00, where the optimal work is from 10:00 to 15:00, working a total of 5 optimal hours.

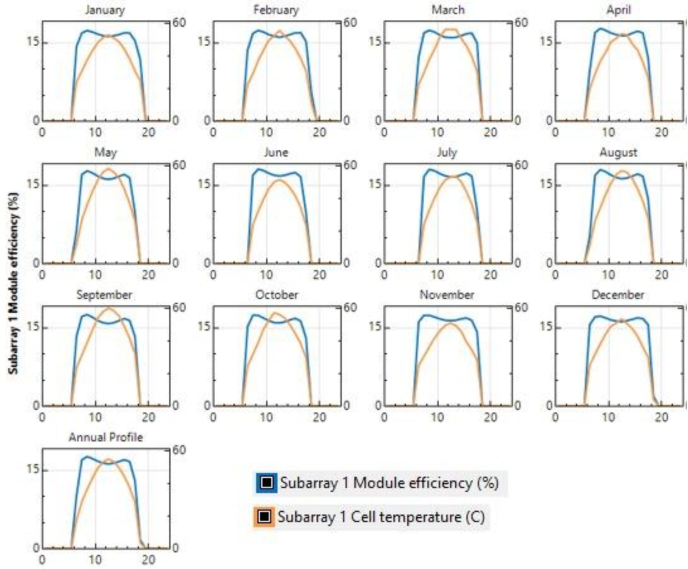
**Figure 13**.
Meteorological file hourly wind speed




**Note**. *Meteorological file hourly wind speed by the SAM simulator*

As shown in (fig. 13), we can detail a little more the wind speed that are June, July, August, and part of September, as mentioned above, where these energy levels do not vary concerning the winter season that occurs in the Brazilian Recóncavo area.

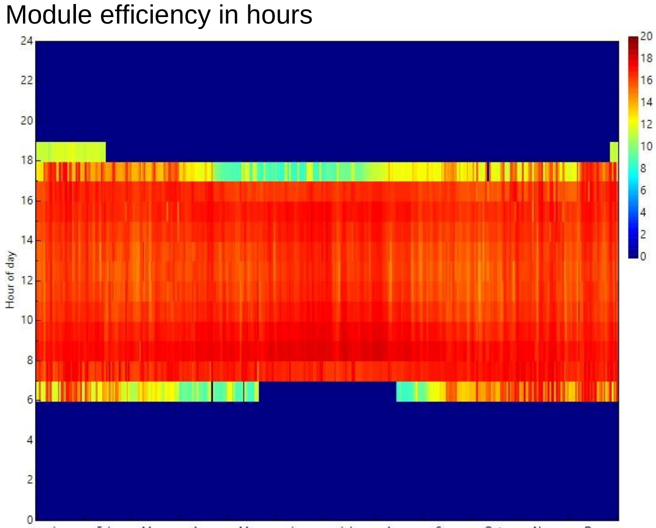
**Figure 14.**
Module efficiency




**Note**. *Module efficiency as a function of temperature in hours.*

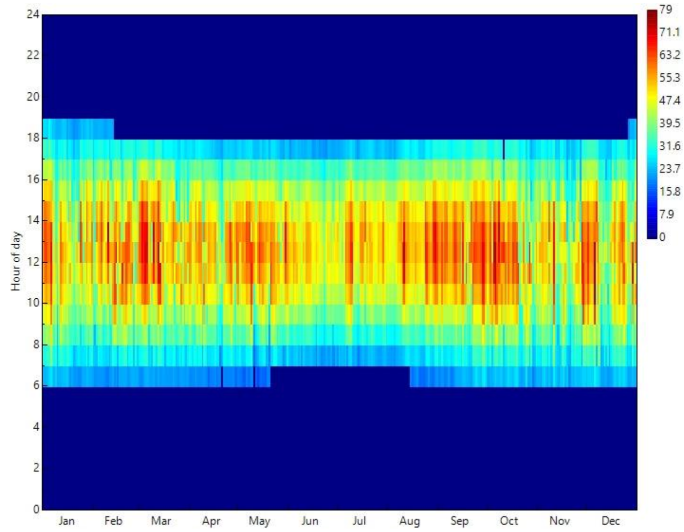
In (Fig. 14), the efficiency of the modules concerning temperature is shown, in the months with the highest energy production, such as June, July, and August, where the modules are subjected to high temperatures between the range of 12:00 to 14:00, being the most critical hours of the day, this causes the modules to strain and can produce an overheating in the equipment, so it will decrease our efficiency between 1% and 2%. In the worst case, it will cause a slight decrease in energy production. It is therefore advisable to let the equipment rest for these two hours.
Therefore, it is important to insist that a higher temperature does not always generate more energy from the modules.

**Figure 15.**
Module efficiency in hours




**Note**. *Module efficiency in hours by SAM simulator.*

**Figure 16.**
Module temperature efficiency in hours




**Note.** *Module temperature efficiency in hours by SAM simulator*

In (Fig. 15) and (Fig. 16), the thermal maps show that the efficiency of the modules remains approximately constant since the temperature is a factor affecting energy generation. As mentioned above, January, February, November, and December, due to the high humidity season in the area.

## 5. Conclusions

1. It was concluded that, in the selection of the motor, using the catalogs of the electro submersible pump suppliers, certain parameters were taken into account such as; the braking power of the pump and its efficiency, therefore the Schlumberger motor was selected when making the calculations using the Baker Hughes literature, the BHP resulted in 35.5 hp and the selection of the Schlumberger motor is the most adequate for the study since it handles power of 26 Kw, being this of low energy consumption.

2. It was determined that the system has a range of incidence of light from 8:00 to 16:00, for it was determined a minimum of hours in which it will have greater obtainment of the incidence of light, analyzing the behavior, it is recommended a minimum of 5 hours between 10:00 to 15:00. It is taken into account that the 26 kW of power required to energize the 24 hours, the calculation of the product of these variables results in 624 kwh and is the energy required, this value is divided by the number of hours of light, which is 5 hours, and this gives us the result124.8 kw of power to supply the need to energize the 24 hours and where there is 100 kw more, for this reason, these are stored in a battery system.

3. It was concluded that, with the simulation in SAM, the solar plant is an effective proposal for the generation of clean energy, capable of energizing an electro submersible pump on the offshore platform and helps to make the use of conventional generators independent of consumption.
4. With the simulation of the SAM programmer, it was possible to conclude that for the Brazilian Recóncavo area, the installation of fluctuating solar panels in the area is feasible, since they are an alternative for the generation of clean energy and where the months where the radiation is low, 323 total modules will be used, with the capacity to generate 122. 821 kW, where they work 5 hours and accumulate the energy necessary to operate the 19 hours in which the lifting system will work 24 hours a day, with an annual production of 212,879 kWh and a capacity factor of 19.8%.

5. With the financial study, it was concluded that, for the 20-year projection, the investment of 587,750 USD is recovered, taking into account factors such as the TIO (opportunity interest rate) and observing the internal rate of return (IRR), shows that the project is more than 19% profitable, one of the factors taken into account is the value of the benefit-cost ratio of the project, which indicates that the income is 1.13 times more than the expenses for a period of 20 years.

6. When performing the simulation in SAM, in the Brazilian Recóncavo area, a Levelized cost of energy (LCOE) of 39.63 cents/kWh is obtained, which means that it is equivalent to approximately 4/10 of a dollar per kilowatt-hour consumed.

## 6. Recommendations

1. Perform different changes of production flow rate increasing and decreasing and thus obtaining a range determining and knowing what the energy consumption of the electro submersible pump.

2. Study different locations in which this type of method is required in different offshore platforms and determine how feasible is its implementation.

3. When executing the project, consider the type of material, anchorage, and type of platform, considering sea erosion due to corrosion or other changes in the solar panel and structure.

4. To vary in the simulation of SAM (system advisor Model), the different materials of solar panels that are found, such as Monocrystalline, Polycrystalline, and Amorphous, and to make a comparison of the characteristics and the implementation of solar panels offshore.

5. Conduct the study to energize other equipment of the offshore platform, to determine what is the energy efficiency of the entire platform.

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