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### Comparative analysis of three economic scenarios for a solar pineapple dehydration plant Análisis comparativo de tres escenarios económicos para una planta deshidratadora solar de piñas

Vázquez, A.<sup>a</sup>, Nolasco, J.C.<sup>a</sup>, Guido-Arroyo, O.I.<sup>a</sup>, Domínguez-Marquez, J.<sup>b</sup>, Ortiz-Martínez, F.<sup>b</sup>, Campos-Domínguez, A.<sup>b</sup>, Vidal, A.<sup>b\*</sup>

<sup>a</sup> Micro and Nanotechnology Research Centre MICRONA, Veracruz University, 94294, Veracruz, Mexico.

<sup>b</sup> Mechanical Engineering and Naval Sciences Faculty, Veracruz University, Veracruz, Mexico.

[zs19026220@estudiantes.uv.mx](mailto:zs19026220@estudiantes.uv.mx); [janolasco@uv.mx](mailto:janolasco@uv.mx); [zs20022556@estudiantes.uv.mx](mailto:zs20022556@estudiantes.uv.mx); [jdominguez@uv.mx](mailto:jdominguez@uv.mx);

[franortiz@uv.mx](mailto:franortiz@uv.mx); [acampos@uv.mx](mailto:acampos@uv.mx); [avidal@uv.mx](mailto:avidal@uv.mx)\*

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### Resumen

A nivel mundial, aproximadamente un tercio de la producción alimentaria anual se desperdicia, y la piña es un ejemplo destacado, enfrentando desafíos debido a su bajo costo y vida útil limitada. Una solución prometedora para reducir este desperdicio es la deshidratación de las piñas, un método probado para prolongar su vida útil y aumentar su valor. Sin embargo, los deshidratadores convencionales elevan los costos de producción, afectando la viabilidad económica para los productores. Para superar esta barrera, se propone una alternativa innovadora basada en el uso de energía solar para el proceso de deshidratación. Este estudio evalúa la viabilidad técnica y económica de implementar una planta de deshidratación de piñas con energía solar en Alvarado, Veracruz. La metodología incluye un análisis exhaustivo de la producción y una evaluación de tres escenarios económicos diferentes, diseñados para medir el rendimiento financiero de la inversión. Los escenarios incluyen un escenario base, con una inversión inicial completa, y dos escenarios alternativos con estrategias de inversión dividida en etapas, con el fin de facilitar la implementación gradual del proyecto. Los análisis económicos se realizaron utilizando parámetros como el valor

presente neto, el periodo de recuperación de la inversión y la tasa interna de retorno, basados en dólares USD de 2019, asegurando la comparabilidad con datos de 2024. Los resultados muestran que el escenario base ofrece el mayor retorno, con un 175%, superando al escenario 2 (162%) y al escenario 3 (121%). A pesar de que los costos iniciales elevados pueden ser una barrera para la adopción generalizada, los escenarios 2 y 3 representan opciones más accesibles para pequeñas y medianas empresas. Este enfoque no solo aborda la sostenibilidad, sino que también presenta una oportunidad viable para el crecimiento económico en el sector agrícola. La investigación destaca el potencial de la energía solar para reducir el desperdicio de alimentos y mejorar la viabilidad económica de los productores, contribuyendo a un futuro más resiliente y sostenible para la industria agrícola.

**Palabras clave:** Piña, Deshidratado solar, Alimentos orgánicos, Viabilidad financiera, Negocio familiar, Veracruz.

### Abstracts

Worldwide, approximately one-third of annual food production is wasted, and pineapple is a prominent example, facing challenges due to its low cost and limited shelf life. A promising solution to reduce this waste is pineapple dehydration, a proven method to extend shelf life and increase their value. However, conventional dehydrators raise production costs, impacting the economic viability for producers. To overcome this barrier, an innovative alternative based on the use of solar energy for the dehydration process is proposed. This study assesses the technical and economic feasibility of implementing a solar-powered pineapple dehydration plant in Alvarado, Veracruz. The methodology includes a comprehensive production analysis and an evaluation of three different economic scenarios, designed to measure the financial performance of the investment. The scenarios include a baseline case scenario, with a full initial investment, and two alternative scenarios with staged investment strategies to facilitate the project's gradual implementation. The economic analyses were conducted using parameters such as Net Present Value (NPV), payback period, and Internal Rate of Return (IRR), based on 2019 USD, ensuring comparability with 2024 data. The results show that the baseline scenario offers the highest return, at 175%, surpassing scenario 2 (162%) and scenario 3 (121%). Although high initial costs may be a barrier to widespread adoption, scenarios 2 and 3 represent more accessible options for small and medium-sized enterprises. This approach not only addresses sustainability, but also presents a viable economic growth opportunity in the agricultural sector. The research highlights the potential of solar energy to reduce food waste and improve the economic viability of producers, contributing to a more resilient and sustainable future for the agricultural industry.

**Keywords:** Pineapple, Solar dehydration, Organic food, Financial viability, Family business, Veracruz.

### INTRODUCTION

At the global level, approximately one-third of the annual food production goes to waste (FAO, 2019). Taking pineapple as an

example, its loss in the supply chain can be attributed to a low level of technology usage from planting to harvest. (Ghazi et al., 2023). In turn, this limits the possibility of applying

edge technology to the post-harvesting stage increasing final production costs and limiting the shelf life of the fruit. Thus, this results in undervalued production by small-scale farmers who face constraints due to the nature of the product and fluctuations in market prices.

One solution to this problem is pineapple preservation through the dehydration process, which prevents losses during harvesting, storage, and distribution (Abraham et al., 2023). Dehydrated pineapple has an extended shelf life of up to 40 days under ambient storage temperature (Saxena et al., 2009) allowing producers to store unsold harvests in their fresh state. Furthermore, this process adds value to the product, increasing profit margins and making it a more profitable venture (Deep & Harsh, 2017).

However, the challenge lies in dehydrating devices, which traditionally operate with conventional heat sources such as electricity or gas, increasing production costs and generating environmental impacts, such as the greenhouse effect (Chauhan et al., 2021). A viable solution is the adoption of solar energy, reducing investment costs by eliminating expenditure on energy sources. An additional advantage of a solar drying plant is its ability to operate autonomously, independent of the national electrical grid. This makes it suitable for installation in remote communities near cultivation areas, thanks to the low electrical consumption of fans powered by isolated photovoltaic systems.

The second parameter analyzed, Simple Payback Period (SPP), measures the time it takes for an investment to generate enough cash flows to recover its initial cost. It's a

The objective of this work is to evaluate the technical and economic feasibility of implementing a solar drying plant near pineapple production areas to reduce the amount of unsold fresh pineapple. The operational time of the plant is analyzed to determine its economic viability using financial indicators such as Net Present Value (NPV), the payback period, and the Internal Rate of Return (IRR). The analysis compares three economic scenarios: a single-stage complete investment, a two-stage investment, and a three-stage investment, with the first scenario serving as the reference. Additionally, the study examines which of these financial indicators has the greatest impact on decision-making.

## METHODS

The economic evaluation methodology aims to enhance the clarity of the investment for a pineapple drying plant by analyzing the project profitability parameters. The following economic parameters were taken from Sreekumar et al. (2009). The first parameter analyzed is the Net Present Value (NPV) which evaluates the profitability of an investment by calculating the difference between the present value of cash inflows and outflows over a period of time. This can be calculated by Eq. 1 where  $t$  is the number of periods,  $R$  is the net cash inflow-outflows during a single period, and  $r$  is the discount rate.

$$NPV = -\text{Cost of investment} + \sum_0^t \frac{R_t}{(1+r)^t} \quad \text{Eq. 1}$$

simple way to evaluate the risk and liquidity of an investment. This can be calculated by Eq. 2.

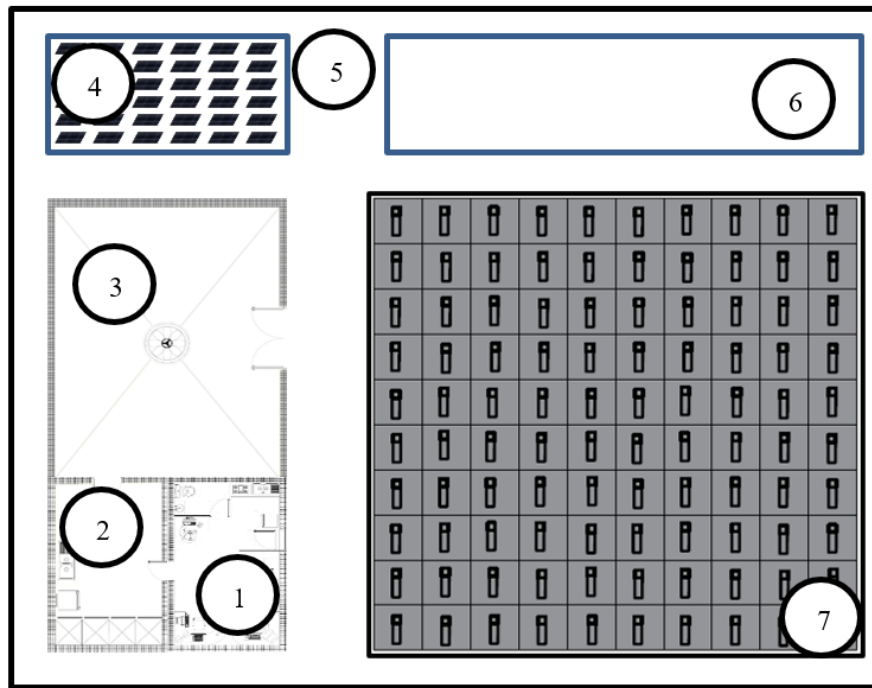
$$SPP = \frac{\text{Initial investment}}{\text{Annual cash inflows}} \quad \text{Eq. 2}$$

The third parameter analyzed is the investment rate of return which measures the gain or loss of an investment over a specific period, expressed as a percentage of the initial investment cost. This is presented in Eq. 3.

$$IRR = \left( \frac{\text{Current value of Investment} - \text{Cost of investment}}{\text{Cost of investment}} \right) \times 100 \quad \text{Eq. 3}$$

The investment involves setting up a processing plant capable of handling one ton per production cycle. To achieve this, the project is divided into stages in order to facilitate production and commercialization

while gradually raising the necessary capital for full construction. The general distribution of the solar drying production plant is shown in Fig. 1.



**Figure 1.** General distribution of the solar drying plant with 7 areas: Office (1), processing room (2), store (3), solar panel area (4), supply water well (5), zone for compost (6), and dryers' area (7).

The study strategically divides the initial investment cost into stages, aiming to improve the economic feasibility of the plant compared to a single-stage investment. This approach results in a lower overall cost. The objective of analyzing the economic viability in one, two, and three stages is to enhance the feasibility of implementation.

However, it's important to note that production expenses play a crucial role in all three scenarios, constituting a significant portion of expenditures. Consequently, these production expenses are separated from the scenario methodology to prevent redundancy in expense presentation. Table 1 in the supplementary material provides a breakdown of the expenses associated with processing fresh pineapples.

**First scenario**

The first scenario states that it has its own resources to implement a solar pineapple drying plant with the capacity to process one ton every five days. This is through expenditure of investment in the areas of solar dryer devices, civil infrastructure, isolated photovoltaic system, and furniture and

equipment expenses (see tables S1, S2, S3 and S4 in supporting information). The result of this scenario will be a standard for rating performance if the investment process is carried out in two stages (second scenario) and in three stages (third scenario). The diagram in Figure 2 presents the description of the investment.

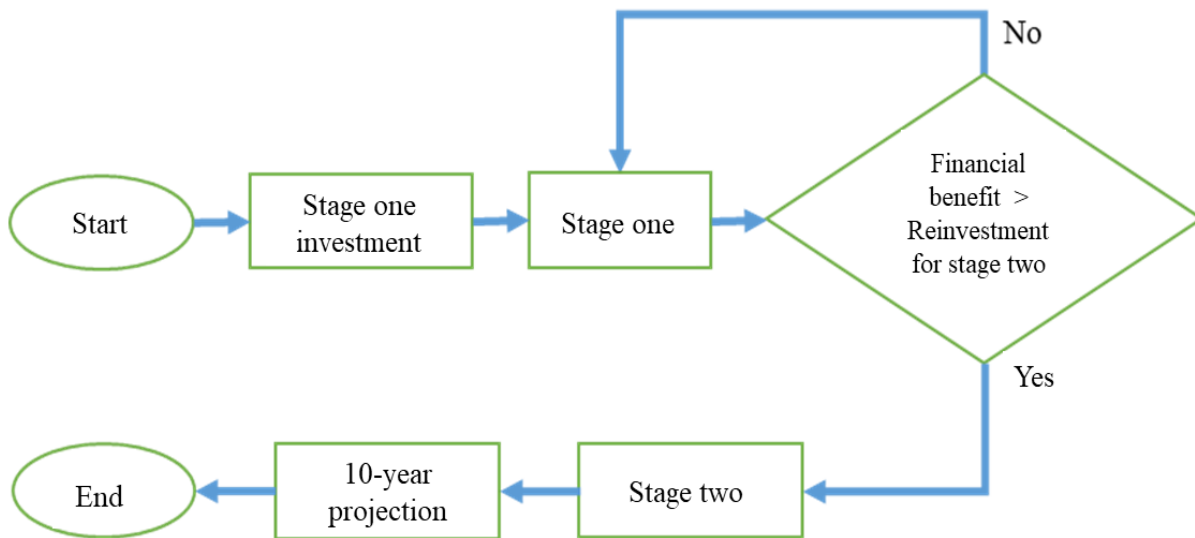


**Figure 2.** Flow diagram of the economic development of the drying plant in one stage.

**Second scenario**

This proposal consists of separating the investment into two parts, dividing the investment into a first stage of 45,370 USD and a second stage of 47,480 USD (see Table 1 and Table 2). The diagram in Figure 3 presents the description of the two investments. It is noted that, in order to carry

out the reinvestment of the second stage, the economic benefits must be greater than the reinvestment. This verifies that it does not require external resources to implement this project. Below, the destination of each expenditure is specifically described, which allows development while production is taking place.



**Figure 3.** Two-stage drying plant economic development flow diagram.

**First stage:** Within the expenses of the first stage, the following expenses are considered: the construction of 20 dryers, 191 m<sup>2</sup> of foundation slab, the construction of the process room and the toilet of the office, the

supply water well and the installation of 4 photovoltaic solar panels of 325W, with 4 batteries, as well as the furniture of the processing room. Table 1 details the amounts of this set of expenditures.

**Table 1.** Expenditure for the first stage, scenario 2.

Type	Costs (USD)
Dryers' construction	\$20,743
Furniture and setups	\$1,779
Photovoltaic system	\$2,835
Infraestructure	\$20,572
<b>Total</b>	<b>\$45,929</b>

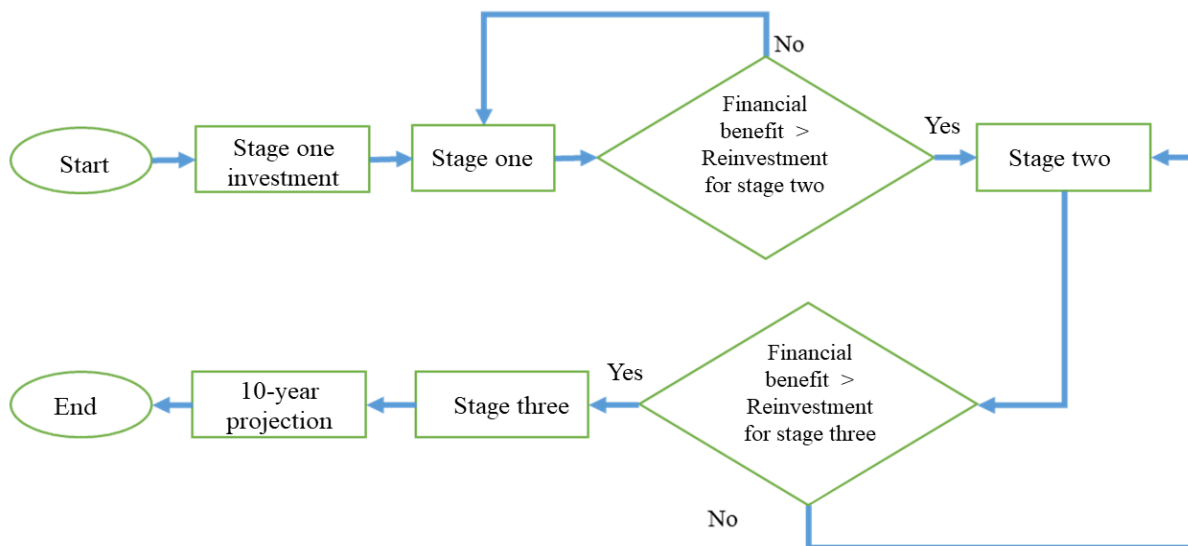
**Table 2.** Expenditure for the second phase, scenario 2.

Type	Costs (USD)
Dryers' construction	\$20,743
Furniture and setups	\$1,421
Photovoltaic system	\$6,826
Infraestructure	\$18,008
<b>Total</b>	<b>\$46,998</b>

**Second stage:** the expenses of the second stage are considered to be the following: the construction of 80 dryers, 250 m<sup>2</sup> of foundation slab, the construction of the process room and the office toilet, the supply water well, and the installation of 24 photovoltaic panels of 325W, with 18 batteries, as well as the furniture of the process room. At this stage, the cost of the total conditioning of the office is considered, including the furniture and the cost of 30 more dryers with the 120 m<sup>2</sup> foundation slab. Table 2 details the amounts of this set of expenditures.

**Third scenario**

This economic scenario is carried out in three stages of construction so that the disbursement of the initial investment occurs gradually, that is, it adapts to the process of evolution of a newly created company. In the same way, gradual development favors personal administration, and it is possible to reduce losses due to the learning curve. However, it is probably the scenario with the most construction and production logistics. The process is developed through the following three stages, which are shown in Figure 4. The destination of each expenditure is specifically described below, allowing development in the first stage and in the second stage.



**Figure 4.** Flow diagram of the three-stage economic development of the drying plant.

**First stage:** In the first stage of the project, it is estimated the construction and commissioning of what is essential to produce, considering 20 dryers with 81 m<sup>2</sup> of foundation slab, the construction of the process room and the office; the latter will not be fully conditioned, considering only the toilet, the water supply well and the installation of 4 photovoltaic panels of 325W that will feed the load of the first stage. This will be used to start processing 200 kg of pineapple per drying cycle. Table 3 details the amounts of this set of expenditures.

**Table 3.** Expenditures for the first stage, scenario 3.

Type	Costs (USD)
Dryers' construction	\$8,297
Furniture and setups	\$1,034
Photovoltaic system	\$2,835
Infrastructure	\$12,608
<b>Total</b>	<b>\$24,775</b>

**Second stage:** in this stage, the total conditioning of the office is considered, including the furniture, as well as 30 solar dryers and 110 m<sup>2</sup> of construction area. With this reinvestment, an increase in processing capacity is expected from 200kg per cycle to 500kg of pineapple. Table 4 details the amounts of this set of expenditures.

**Table 4.** Expenditure for the second stage, scenario 3.

Type	Costo (USD)
Dryers' construction	\$12,446
Furniture & Equipment	\$745
Infrastructure	\$7,965
<b>Total</b>	<b>\$21,155</b>

**Third stage:** considering the necessary outdoor lighting, the construction of a granary and the installation of 20 more photovoltaic panels with the same capacity to finish feeding the rest of the equipment such as air conditioning and electric dryers, this equipment was described in table 1. In the same way, 50 more dryers are added, making a total of 100 devices and the construction of the foundation slab for them with a total of 250 m<sup>2</sup>. At full production capacity, it is expected to process one ton of pineapple per drying cycle. Table 5 details the amounts of this set of expenditures.

**Table 5.** Expenditures for the third phase, scenario 3.

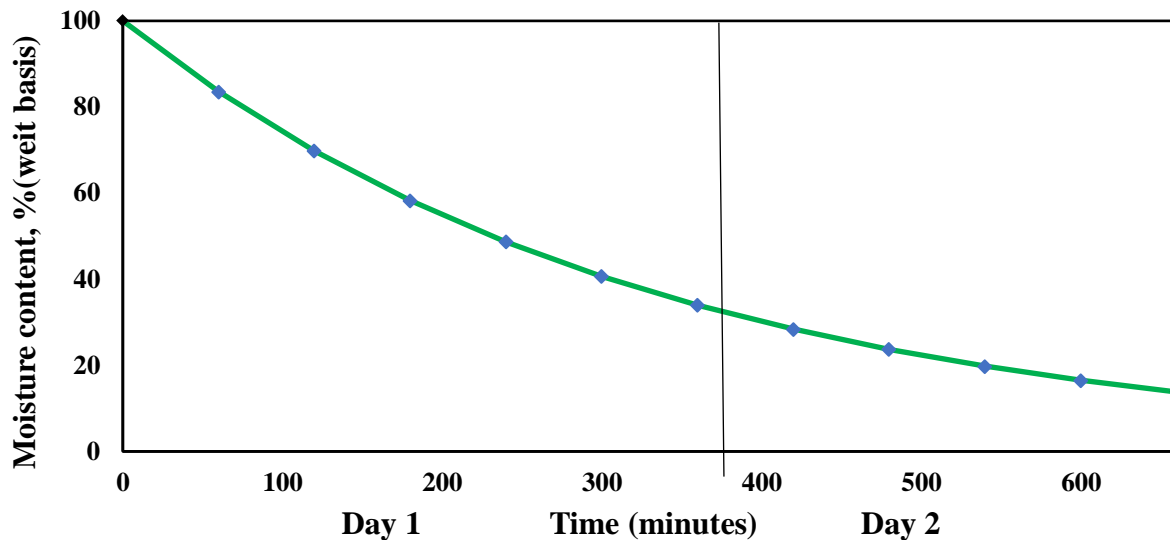
Type	Costo (USD)
Dryers' construction	\$20,743
Furniture and setups	\$1,421
Photovoltaic system	\$5,584
Infrastructure	\$18,008
<b>Total</b>	<b>\$45,755</b>

## RESULTS

The duration of solar dehydration is closely linked to solar irradiation levels and the specific type of dryer employed. Solar irradiation refers to the amount of solar energy or sunlight, measured in watts per square meter (around 1 kW/m<sup>2</sup>), received at a particular location and time on the surface of Earth. In the context of this study, it means the intensity and availability of sunlight that directly impacts the efficiency of the solar drying process (Vidal et al., 2012, 2013). In the case of the solar drying facility utilizing active indirect solar dryer devices, the processing time spanned approximately 12 hours over two days in June. To visually illustrate the pineapple drying kinetics and its dependency on the amount of solar irradiation, refer to Figure 5. Notably, the

operational hours extended from 10:00 a.m. to 4:00 p.m. Similar behavior of Reduction of moisture content over time has been reported

in the literature (Malakar et al., 2023; Rani & Tripathy, 2021).



**Figure 5.** Reduction of moisture content over time.

The drying kinetics reveal a progressive reduction in the humidity of pineapples for two days, ending in the desired drying level at approximately 13° Brix (Gilago et al., 2023; Ramallo & Mascheroni, 2012). However, the efficiency of this process is susceptible to external factors, notably weather conditions. The presence of clouds can limit the mass transfer by diminishing the sunlight received by the dryer, thereby reducing collector irradiation. This phenomenon results in a drop in air temperature, impacting the efficiency of moisture absorption by the air. Consequently, the mass transfer dynamics during the dehydration process may extend from the initially projected two days to a prolonged duration of three days.

Furthermore, the proposal to extend the processing time by an additional two days serves a dual purpose. Firstly, it allows for a prudent evaluation of economic viability, culminating in a finalized processing period of five days. Secondly, it facilitates the implementation of enhanced quality control

measures designed to mitigate the risk of pathogens. As part of this strategic approach, the plant envisages operating for 300 days per year, employing these five-day cycles. This operational model results in a total of 60 drying cycles annually. It is important to note that this calculation is intentionally conservative, providing a baseline estimate for the anticipated production output.

Other authors (Gilago & Chandramohan, 2023; Sreekumar, 2010; Sreekumar et al., 2008) also calculate an annual operating time of 300 days for dehydrating pineapple, as well as a time for each dehydration cycle of five days. Based on this, it is possible to perform financial feasibility calculations to determine the monetary benefits and, subsequently, the economic viability parameters.

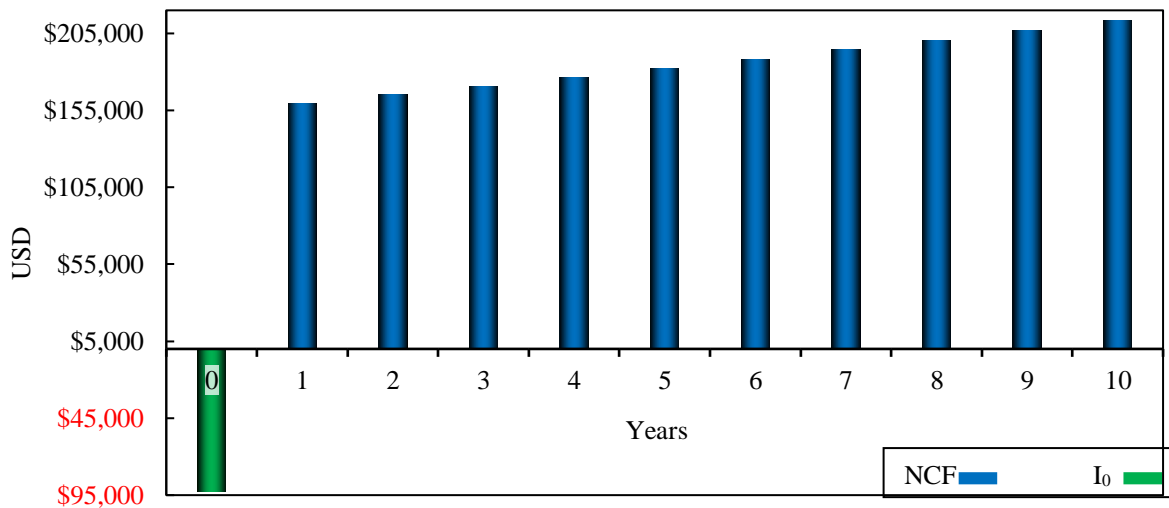
### **First Scenario**

For the first scenario, the economic criteria of return on investment, Net Present Value (NPV) and investment return rate (IRR) were obtained. In addition, cash flow was

developed to graphically understand the effect of money change over time. This can be seen in Figure 6, which estimates the return on investment over a period of less than one year, as well as an annual increase in net cash flow (NCF). This result is obtained by means of the payback period criterion, reaching, exactly, a time of 7 months ( $I_0$ ) for the return of capital. This dependent variable revealed that the plant will have financial benefits for the remainder of the 9 years and 5 months. Likewise, the life of the plant can be extended from 10 years since the dryer

devices are modular, replaceable, and low cost per unit.

The second parameter is the NPV, bringing to present value the benefit of the investment in the solar drying plant. This dependent variable shows the maximum return on investment, reaching a 10-year NPV of \$1,036,539 (USD). This amount, being positive, reflects the viability of the economic scenario. In addition, this parameter, being affected by inflation and national taxes, exposes the financial feasibility of the current implementation in Mexico.



**Figure 6.** Cash flow from the first economic scenario.

The third parameter is the IRR, which was obtained with the value of the 10-year NPV; achieving a return on investment of 175%. This dependent variable can be compared with the annual interest rate of a bank loan and with the rate of return offered by CETES in Mexico; This is to understand the potential of investing in a solar drying plant. In the former, the minimum annual interest rate is 39%, this rate being a fraction of the annual return offered by the plant. While, in the second, the annual return is 11%; This is the minimum return on an investment. Therefore, it is feasible to use our own resources as well

as external resources to invest in this economic scenario.

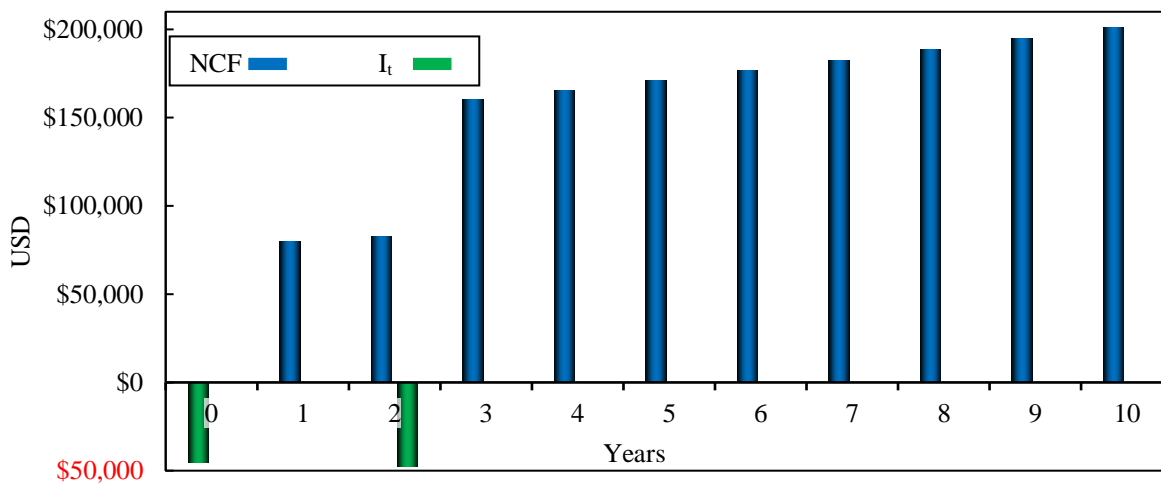
### Second Scenario

Scenario two applied the two-point investment methods to calculate the economic parameters of feasibility. These variables are presented in the graph in Figure 7, which shows cash flow, plant profitability, and payback time. This time was calculated from 7 months ( $I_t$ ) for each disbursement, investing in year zero and year two. The investment dynamic is to disburse the initial

investment ( $I_0$ ) and after 14 months apply the second investment ( $I_1$ ).

On the other hand, the NPV reached a value of \$1,013,946 (USD). This amount, being positive, reflects the viability of the second economic scenario, taking into consideration that it has its own resources to invest. Likewise, this parameter was affected by the increase in the profits of the second investment, causing a higher value of the NPV.

Finally, the IRR, which was obtained with the NPV value of the second 10-year scenario, achieved a return on investment of 162%. In the same way, this dependent variable can be compared with the annual interest rate of a bank loan and with the rate of return offered by CETES. With this criterion, it is feasible to use own and external resources to invest in this scenario.



**Figure 7.** Cash flow of the second economic scenario.

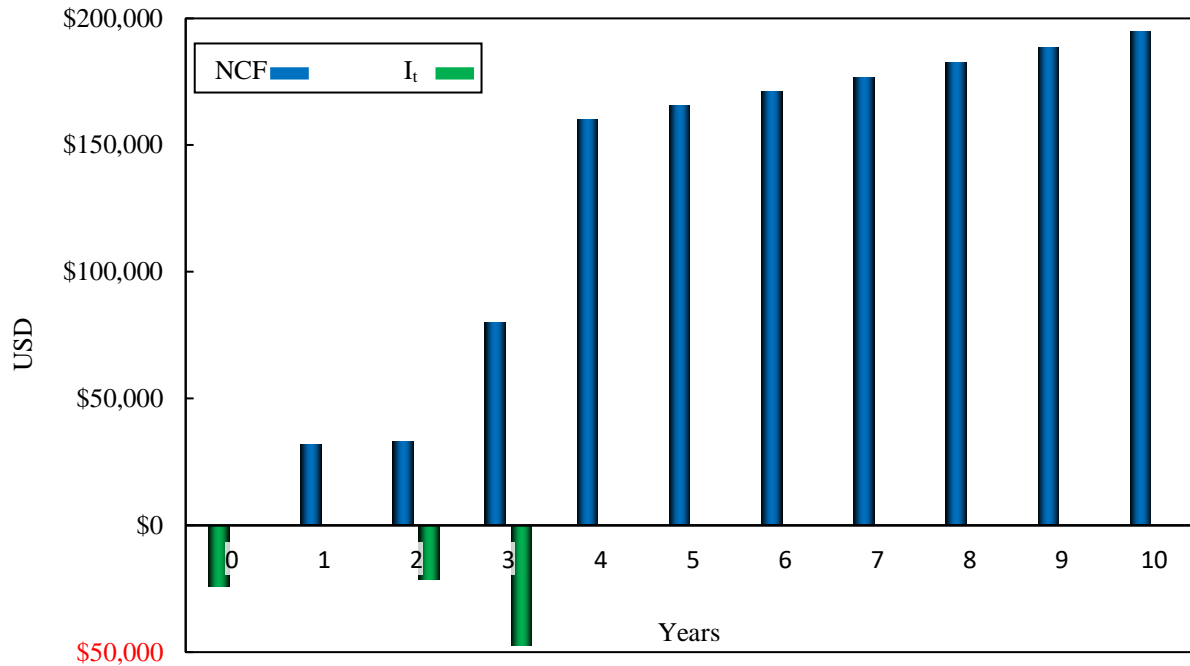
### Third Scenario

Scenario three applied the investment methods at three points to calculate the economic parameters of feasibility. These variables are presented in the graph in Figure 8, which shows cash flow, plant profitability and payback time. This time was calculated from nine, five, and four months ( $I_t$ ), investing in year zero, year two, and year three, respectively. The investment dynamic is to disburse the initial investment ( $I_0$ ), after 14 months apply the second investment ( $I_1$ ) and after four months plus the last disbursement.

On the other hand, the NPV reached a value of \$840,072 (USD). This amount, being

positive, reflects the viability of the second economic scenario, taking into consideration that it has its own resources to invest. Likewise, this parameter was affected by the increase in the profits of the second and third investments, causing a higher value of the NPV.

Finally, the IRR, which was obtained with the NPV value of the third scenario at 10 years; achieving a return on investment of 121%. In the same way, this dependent variable can be compared with the annual interest rate of a bank loan and with the rate of return offered by CETES. With this criterion, it is feasible to use own and external resources to invest in this scenario.



**Figure 8.** Cash flow of the third economic scenario.

### Comparison of economic profitability parameters

The differences in the economic scenarios applied to the solar drying plant are products of the ways in which investments are spent. These changes are reflected in the economic profitability parameters presented in Table 6, which compares the payback period, the 10-year NPV, and the IRR. In the analysis of these variables, the three scenarios coincide in the positive economic feasibility at different rates of return. Comparing the IRR, our result agrees with the literature (Gilago et al., 2022; Mohammed et al., 2020).

However, there are wide differences in the recovery periods, NPV, and IRR of the three scenarios. This is due to the size of each investment, as well as the profit obtained in each of them. For example, scenario one, the ideal scenario of a single outlay on the initial

investment, shows the shortest payback time caused by the higher amount invested. It is also the scenario with the NPV and, consequently, the highest IRR; outperforming scenario two by 13%.

On the other hand, scenario two has the advantage of investing in two parts at the same time as producing. This allows a producer to start with a lower investment cost, obtaining profitability close to the ideal of scenario one. Also, the VPN of this scenario is remarkably close to scenario one. However, the payback period is doubled to get the resources from the second investment. Finally, scenario three has the lowest economic parameters but has the advantage of starting the investment with a lower outlay. This is more in line with the reality of a producer who has limited resources to invest in a solar drying plant.

**Table 6.** Comparison of profitability parameters.

Scenario	1	2	3
Simple Payback Period	7 months	1 year and 2 months	1 year and 6 months
10-Year NPV (USD)	\$1,036,510	\$1,013,927	\$840,072
IRR	175%	162%	121%
Initial Investment (USD)	\$92,928	\$45,930	\$24,775

This study was conducted in 2019, and it is important to acknowledge that certain costs may exhibit variability based on the economic stability of Mexico. However, it is noteworthy that the exchange rate between the USD dollar and the Mexican peso has remained stable, as evidenced by data from 2024 (Exchange-rate, 2024). Consequently, the analysis conducted in this study can be deemed both relevant and reliable.

## CONCLUSIONS

The study assessed the technical and economic feasibility of establishing a solar-powered pineapple drying facility in Alvarado, Veracruz, through an experimental evaluation of the production process and a comparative analysis of three economic scenarios. The duration of the active indirect solar drying process was determined using the minimum average solar irradiance, suggesting the possibility of conducting up to 60 drying cycles per year. A comparison of three investment scenarios revealed distinct implications for potential investors. Scenario 1, offering a profitability rate of 175%, demonstrated the highest returns but also required a significant initial investment, which could put a barrier for some stakeholders. In contrast, Scenarios 2 and 3, with profitability rates of 162% and 121%, respectively, represent more accessible options due to their lower capital requirements, making them particularly suitable for small and medium-sized

enterprises. All scenarios surpassed Mexico's minimum bank interest rate of 39%, thereby confirming the economic viability of a solar-powered pineapple drying plant. It is recommended that further sensitivity analyses be conducted to account for fluctuations in production costs and potential incentives for renewable energy adoption. Additionally, diversification strategies involving other regional crops should be explored to strengthen the facility's economic resilience and sustainability.

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