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Optimizing solar dryer design: A multicriteria decision making approach for hybrid systems

Optimización del diseño de secadores solares: un enfoque de toma de decisiones multicriterio para sistemas híbridos

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Abstract

Solar dryers are a sustainable and efficient alternative for preserving agricultural products, offering numerous benefits for both the environment and the agro-industrial sector's economy. The objective is to develop a decision-making methodology based on environmental, economic, and social criteria, allowing the acquisition of data for the design of solar dryers using alternative energy sources to achieve the hybridization of one or more energy sources. The Analytic Hierarchy Process (AHP) methodology is based on breaking down a complex problem into a series of simple and manageable problems. This methodology evaluated alternatives based on different criteria and factors to consider. The AHP methodology was divided into three stages: the first was to define the problem to be solved, the second was to determine the criteria, and the third was to analyze the possible alternatives. This research provided information for the design of a solar coffee dryer in San Antonio el Porvenir, Chiapas. The solar dryer's design was based on criteria proposed by the producers, such as ease of repair, the product not being in contact with the ground, and ensuring safe operation due to the presence of children and women near the drying process.

Sustainable, Agricultural, Methods

Resumen

Los secadores solares son una alternativa sostenible y eficiente para preservar productos agrícolas, ofreciendo numerosos beneficios tanto para el medio ambiente como para la economía del sector agroindustrial. Desarrollar metodología de toma de decisiones basada en criterios ambientales, económicas y sociales que permita obtener datos para el diseño de secadores solares con fuentes alternas de energía para obtener una hibridación de una o más fuentes de energía. El análisis de procesos jerárquicos se basa en la descomposición de un problema complejo en una serie de problemas simples y manejables, esta metodología evaluó alternativas en función de diferentes criterios y factores a considerar, la metodología análisis de procesos jerárquicos (AHP) se dividió en tres etapas la primera fue cual era el problema a resolver, la segunda determinamos los criterios y la tercera analizamos las alternativas. Esta investigación permitió proveer información para el diseño de un secador solar de café en San Antonio el Porvenir Chiapas, el diseño del secador solar con base en criterios propuestos por los productores tal como de fácil reparación, producto sin contacto con el suelo y seguro de operar debido a que, niños y mujeres se encuentran cerca del proceso de secado.

Sustainable, Agricultural, Methods

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Introduction

Hybrid solar dryers have emerged as a sustainable solution for drying agricultural products and have received considerable attention in recent years. These systems harness solar energy along with other additional heat sources, such as biomass, electrical energy or waste heat, to create a more efficient and reliable method for the drying process (Goel, 2023).

Solar energy as the main source of heat in these dryers reduces dependence on fossil fuels and reduces greenhouse gas emissions. One of the challenges of conventional solar dryers is their dependence on weather conditions. During periods of low solar radiation, such as cloudy days or seasons with weaker solar intensity, drying efficiency may be affected and operation may be interrupted (Mohana, 2020).

This is where the solar hybrid dryer comes into play. By combining solar energy with other heat sources, these hybrid systems offer greater flexibility and reliability in the drying process. The integration of multiple heat sources allows the dryer to work continuously, even in conditions of low solar radiation, such as cloudy days or at night, additional heat sources come into play to maintain the drying process (Jha, 2021).

Additional heat sources used in compound dryers may vary based on local availability and feasibility. Biomass, such as firewood, agricultural residues or pellets, is often used as an additional heat source. Biomass burning not only provides heat for the dryer, but also a way to take advantage of agricultural and forestry by-products, contributing to the sustainable management of natural resources (Gorjian, 2022).

Combining multiple heat sources in a hybrid solar dryer ensures stable and reliable drying performance. Currently, for the design of solar dryers in general, it is carried out under the following steps

1. Determine Drying Requirements (Product)
2. Select the appropriate type of solar dryer
3. Solar Dryer Size
4. Design the solar collector
5. Design of the drying chamber
6. Installation of the solar dryer
7. Test and tuning

However, the growing demand for solar dryers faces not only technical issues but also economic, social and environmental situations, (Vera-Montenegro, 2014). Since although these devices tend to be friendly to the environment, operation, operation, maintenance, among other factors influence the acceptance and good use of the devices.

This research, through the use of the analytical hierarchical process (AHP) which is a multi-criteria decisión-making(MCDM), evaluates the best hybridization for solar dryers, and provides technology developers with extra information when designing the systems, such as the use of food contact materials, return of device investment, operating costs, adaptability among other criteria.

The AHP method has been used to evaluate criteria in the area of sustainability, energy, economy and others topics. a decentralized hybrid renewable energy system can go a long way to fill a power gap between generation and power demand when a single renewable energy system is neither sustainable nor reliable (Matheri, 2023).

MCDM are currently used for various applications since it allows evaluating criteria through different methods, for various applications from exergetic efficiency (Ren-E. Dong, 2023), to determining Optimization of a photovoltaic solar thermal collector (Das, 2023), or even using these methods in Selection of wastewater treatment technology analyzing the best alternatives (Ćetković, 2023).

In the introduction section, the reader into a context about hybrid solar dryers and the need for a tool to optimize their design based on a multicriteria analysis tool.

In the methodology section, the reader will appreciate the construction of the multi-criteria hierarchical analysis methodology from a conceptual way to obtaining the criteria selected for this research.

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Methodology for selection of alternative energy source for solar dryers

The AHP technique (Analytic hierarchy Process) is a multi-criteria decision-making tool that is based on the hierarchical decomposition of a complex problem into a series of simpler and more manageable elements. This technique is used to evaluate and select alternatives based on multiple criteria or factors that must be considered (Atanasova-Pacemska, 2014).

The hierarchical structure was divided in three levels: the top level is the objective, which is the general problem to be solved; The second level is the criteria, which are the dimensions or factors that must be considered to achieve the objective; and the third level are the alternatives, which are the possible solutions to be evaluated (de FSM Russo, 2015).

Next, the methodology for the multi-criteria objective hierarchization

Step 1: Define the objective and selection criteria

1. Establish the main objective of the selection of alternative energy sources in solar dryers.

2. Identify the relevant criteria for the evaluation of the different energy sources, such as efficiency, availability, costs, environmental impact and technical feasibility.

Step 2: Create a hierarchical structure

1. Design a hierarchical structure that reflects the relationship between the objective, the criteria and the alternative energy sources.

2. Put the goal at the top of the hierarchy, followed by the criteria, and finally the energy sources.

Step 3: Comparison of criteria

1. Perform pairwise criteria comparisons using preference scales.

2. Ask experts in the field to assign numerical values to criteria comparisons based on their relative importance.

Step 4: Calculate relative weights

1. Saaty eigenvalue method to calculate the relative weights of the criteria.

2. Normalize the values to obtain a final weighting of the criteria validating the consistency of the matrix through the consistency index (IC) if ($IC \leq 0.1$), it indicates a good decision (Jorge, 2015).

Step 5: Comparison of energy sources

1. Perform pairwise comparisons of energy sources using the same criteria defined above.

2. Obtain numerical values from the comparisons of energy sources by experts.

Step 6: Calculate relative weights of energy sources

1. Saaty 's eigenvalue method to calculate the relative weights of energy sources.

2. Normalize the values to obtain a final weighting of the energy sources.

Step 7: Analysis and decision making

1. Evaluate the results obtained and analyze the relative importance of energy sources according to the established criteria.

2. Make informed decisions based on relative weights and preferences for energy criteria and sources.

Step 8: Validation and sensitivity

1. Perform a sensitivity analysis to assess the stability of the results against changes in the comparisons of criteria and energy sources.

2. Validate the results obtained with experts in the field and make adjustments if necessary

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	Definition	Explanation
1	equal importance	Both values have equal contribution to the objective
3	moderate importance	one element is slightly more important than the other
5	Important	one element is more important than the other
7	Very important	One element is strongly more important than the other
9	Extremely important	One element is extremely more important than the other
2,4,6,8	intermediate values	Intermediate values between the previous ones of 1, 3, 5 and 7

Table 1 Saaty scale
Source: Own Elaboration

The hierarchy was important since it raises the central objective of decision-making as well as the criteria was evaluated

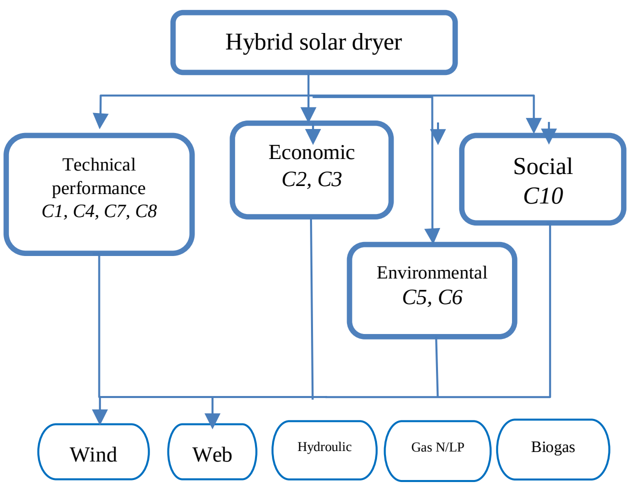

Figura 1 hierarchy AHP
Source: Own Elaboration

We select criteria that were considered important when performing solar hybridization as shown in the table.

id	Criterion	Description
C1	Energy efficiency	Capacity of the energy source to be used efficiently for the drying process
C2	installation cost	the costs associated with the acquisition and installation of the power source in the solar dryer
C3	operating cost	the recurring costs associated with the operation and maintenance of the energy source over time.
C4	Availability and access	the ease with which the power source can be accessed and its availability in the region or area where the solar dryer will be used.
C5	Environmental impact	the environmental footprint of the energy source, including greenhouse gas emissions and other pollutants.
C6	Sustainability	the ability of the energy source to be sustained in the long term without depleting natural resources and without causing significant damage to the environment
C7	Adaptability and flexibility	the ability of the power source to adapt to different climatic conditions and to the changing needs of the drying process
C8	stability and reliability	the ability of the power source to provide a stable and reliable supply of heat throughout the drying process
C9	Technical viability	The compatibility of the power source with the existing technology in the solar dryer and its ability to integrate seamlessly
C10	Social acceptance	the acceptability of the energy source by users and the community, considering factors such as risk perception, cultural acceptance and social considerations.

Table 2 Criteria to evaluate in the alternatives
Source: Own Elaboration

Once the criteria are determined, we will analyze the common alternative sources of heat that could be considered:

Biomass (firewood, agricultural residues, pellets, etc.) (Dhanuskodi, 2014).

1. Electrical energy (from the grid or generated through photovoltaic solar panels or other systems) (Amer, 2010).

2. Waste heat (for example, from industrial processes or cogeneration systems) (Arias, 2023).

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3. Geothermal energy (taking advantage of the heat from the subsoil) (Hadibi, 2021).

4. Wind power (using the kinetic energy of the wind to generate heat) (Kong, 2022).

5. Hydroelectric power (through hydraulic turbines to generate electricity and heat).

6. Gaseous biomass energy (biogas, landfill gas, biomass gasification, etc.) (Maurer, 2019).

7. Energy from liquid fuels (such as biodiesel or ethanol) (Singh, 2018).

Considering these alternative sources of heat, we can combine them in different ways to create hybrid solar drying systems. However, the exact number of combinations will depend on the specific constraints and limitations of the solar dryer design, as well as the characteristics and availability of each heat source.

It is important to note that each combination will have its own advantages, disadvantages, and technical, economic, and environmental requirements. Therefore, a detailed AHP analysis and thorough evaluation of each combination will be carried out to determine which is the most suitable for a particular hybrid solar dryer case.

The pairwise comparison technique was originally proposed (Thurstone, 1927), it is a widely used and well-established methodology in Analytical Hierarchy Procedures (AHP) and Analytical Network Processes (ANP) (Saaty, 2004)This technique is used to compare two attributes or alternatives in pairs according to a criterion specific. All pairwise comparisons are organized in a matrix called the Pairwise Comparison Matrix (PCM), also known as the positive reciprocal matrix.

The PCM, represented by the matrix

$$A = [aij] \tag{1}$$

has the following definitions and associated notations. Each element *aij* of the matrix represents the comparison between the attribute or alternative *i* and the attribute or alternative *j* in terms of the considered criterion.

The matrix is symmetric, with

$$aij = \frac{1}{aij} \tag{2}$$

and the diagonal elements [*aij*] are equal to 1. Each *aij* is rated using a numerical scale that reflects the relative importance or preference between the elements compared.

$$A = \begin{bmatrix} a_1 & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \tag{3}$$

Using a multi-criteria approach, different solar dryer design and configuration alternatives can be considered, as well as various variables related to performance and efficiency. Multi-criteria decision-making makes it possible to evaluate and compare these alternatives taking into account the different established criteria, such as energy efficiency, cost, drying quality and sustainability.

In this way, it is concluded that the methodology for the optimization of solar dryers through multicriteria decision making allows more informed and balanced decisions to be made, considering multiple aspects and relevant objectives. This can help improve the efficiency and performance of solar dryers, optimizing their design and configuration to achieve optimal results in terms of drying quality, energy efficiency, and sustainability.

Implementation the metodology propused

A group of coffee producers was selected for the design of a hybrid solar dryer to evaluate the methodology with a real case, the community is San Antonio el Porvenir, Municipality of Independencia, Chiapas, Mexico.

The average climatic conditions are reported through nearby actinometric stations and NASA data for the place report sunny with clear skies and low probability of precipitation, where favorable climates for drying occur, however, in an interview with the coffee growers they describe rainy, cold weather and excessive cloudiness during the coffee harvest season, which results in post-harvest losses.

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Figure 2 San Antonio el porvenir extremely humid climate
Source: Own Elaboration

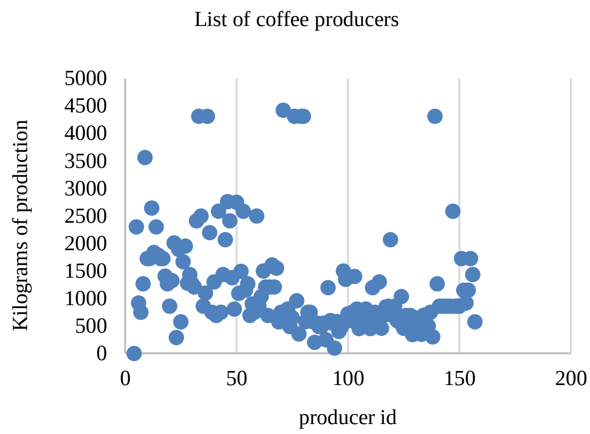
This community has access to electrical energy, however this energy is unstable and intermittent, on the other hand, the coffee growers request for the design proposal that the coffee is not in contact with the ground since their product must comply with certifications of organic product granted by the FDA among other certifications, in the interview the storage and use of pruning firewood from the coffee plantations were observed.

Figure 1 pruning coffee trees using for firewood
Source: Own Elaboration

The dryers need to be low cost and easy to maintain because the closest city to San Antonio el Porvenir is Comitan de Dominguez Chiapas, which is 2.5 hours away and which represents a considerable expense in transportation payment.

Figure 4 Red points are coffee zone far to Comitan
Source: Google Earth

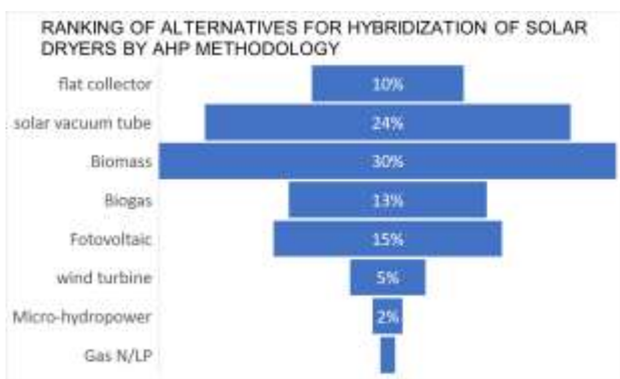
On the other hand, they request that the design proposal be modular since not all of them produce the same and they are not the same varieties of coffee.



Graphic 1 Production in kilograms of coffee from San Antonio El Porvernir
Source: Own Elaboration

Results

Once with the data obtained and evaluating the criteria with the information obtained, we proceed to qualify and analyze the criteria with the AHP model proposed below, a ranking of results for hybridizations for solar dryers is presented.



Graphic 2 AHP results for hybridization
Source: Own Elaboration

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The AHP Model ranks above the other alternatives the use of a main secondary source is biomass since we have availability and there is no deforestation as such to obtain this resource, later I pass to the vacuum tube collectors that have been used with blowers to inject cold air and extract hot air.

Hybridization alternatives considered all information provided by the user and was not limited to the study of energy potentials.

Gratitude

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Conclusions

In our opinion, AHP is a powerful method to solve complex decision-making problems with ease. The AHP is essentially a way of measuring intangibles through pairwise comparisons with judgments showing the superiority of one item over another because of the assets they share. Many examples are given by knowledgeable people without going into all the statements, but comparing only those that form a tree that encompasses all the elements, thus shortening the time of the exercise. AHP has found useful applications in decision making with respect to many intangible assets. It is a process of designing a framework that includes all the essential factors that influence the outcome of a decision. Pairwise comparative judgments are then made to demonstrate everyone's understanding of the importance, preference, or potential influence of these items on the final result by summarizing preferences derived from different sets of comparisons.

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