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Comparative Analysis of Stills: Environmental Impact and Energy Efficiency through Wood Consumption Quantity

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Abstract

Our research focuses on a comparative analysis of stills in Nosy-Be, aiming to assess their environmental impact and energy efficiency through wood consumption. To this end, three methods were employed. Firstly, a comparative approach between traditional and modern stills was conducted, revealing that they exhibit higher wood and energy consumption than their contemporary counterparts. Secondly, a predictive method based on linear regression was used to estimate wood consumption based on still capacity, demonstrating a positive correlation between still capacity and predicted wood consumption. Finally, a temporal analysis of wood consumption was conducted, considering time and wood quality, revealing significant variations in wood consumption based on these factors. This study has provided an in-depth insight into the energy efficiency of stills in Nosy-Be, highlighting key considerations for the sustainable use of forest resources in this region.

Keywords: *Stills, environmental impact, energy efficiency, wood consumption, comparative method, predictive method, temporal analysis.*

Introduction

A still is the equipment used to extract essential oils such as ylang-ylang. The main producers of ylang-ylang oil include the Comoros, Madagascar, and other countries in the Indian Ocean region. These tropical areas offer ideal conditions for growing ylang-ylang, whose flowers are used in the process of extracting this precious essential oil.

In Nosy-Be, many wood-based stills are used, but they consume a significant amount of wood. Although there are stills with steam generators, they also depend on wood. This is why we are undertaking a study on the possibility of powering these stills with renewable energy. Although the project may be initially expensive, the return on investment is quick and efficient.

In Nosy-Be, a multitude of wood-based stills, exceeding twenty in number, characterize the landscape. Large companies, once owned by coloniali22sts, now have highly sophisticated stainless-steel stills with a capacity ranging from 3000 to 5000 liters, imported to meet their needs.

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A prime example of this modernization is the SPPM (Nosy-Be). These large-scale stills operate efficiently, powered by a steam source that contributes to their distillation process [1], [2].

The results of our comparative study between the simple still (SS), the wood steam generator still (WSGS), and the electric still (ES) provide crucial insights into the energy efficiency and environmental impact of each system. With the quantity of flowers processed and the number of stills being constant, the distinction between these technologies lies in their energy approach and sustainability.

The prediction of wood consumption by stills is based on the rigorous application of the linear regression method, which allows for the analysis and modeling of relationships between different parameters. Among these parameters, the cooking duration plays a crucial role as it directly influences the amount of wood needed for each distillation process. Similarly, the amount of wood required per kilogram of oil produced is a determining factor, closely related to the efficiency of the distillation process. The yield of the still and its capacity are also essential elements, as they affect the total amount of wood consumed over a given period. Finally, the estimation of deforestation caused using wood in the stills is integrated into the analysis to assess the overall environmental impact of this activity.

Principle of Operation of an Alembic

An alembic is a device used to obtain essential oils. Initially, it was employed in the production of perfumes, essences, or pharmaceutical products. It consists of four parts:

- The body or boiler: placed in a water bath or directly on the heat source, it contains the liquid to be distilled.

- The head: covers the body and is equipped with a column where the vapor rises.

- The swan neck: a cylindrical tube that conducts vapors to the condenser.

- The condenser or coil: a coiled tube where vapors condense due to the liquid circulating around it.

Principle of Operation of a Wood-based Alembic:

The operation of the wood-based alembic starts with heating water in the boilers. Once the water is heated, the flowers are added to this hot water. The process is sustained by regularly feeding the firebox with dry wood, ensuring a constant heat necessary for distillation.

Figure 1: Simple wood-based alembic

2.3 Principle of a Modern Alembic:

The steam alembic can operate either by atmospheric distillation or by pressure distillation. The heat source used in these alembics is a steam generator, known as BABICOC, which is powered by dry wood. This system efficiently heats the materials to be distilled, ensuring optimal production of essential oils or other distilled products.

Figure 2: Steam alembic from Nosy-Be

The BABICOC is a steam generator that produces steam at a temperature ranging between 150 and 200°C, with a maximum pressure of 10 bars. This steam is then conveyed to the alembic through metal conduits. The steam generator consumes 2 cubic meters of dry wood per hour to heat the water and transform it into steam. Compared to traditional methods, this approach allows for more efficient use of dry wood, thereby reducing the amount of wood required for the distillation process. This makes the BABICOC not only more effective in terms of steam production but also more environmentally friendly due to reduced wood consumption.

Figure 3: Steam engine powered by dry wood

An atmospheric distillation alembic normally operates at a pressure of 0.65 bar with a temperature range between 150 and 200°C. It can distill 150 kg of ylang-ylang flowers over 24 hours, yielding 3.75 kg of essential oil.

In contrast, a pressure distillation column alembic operates at 2.5 bar with a temperature range also between 150 and 200°C. It can distill 400 kg of ylang-ylang flowers in just 12 hours, resulting in 10 kg of essential oil.

3. Impact and Efficiency of stills (graph)

Quantity of Energy Consumed

$$E = P_m . T \quad (1)$$
$$B_C = E_a * R \quad (2)$$

Pm: Average power of the still
T: Cooking duration
BC: Wood consumed by the still
Ea: Energy of the still
R: Wood yield

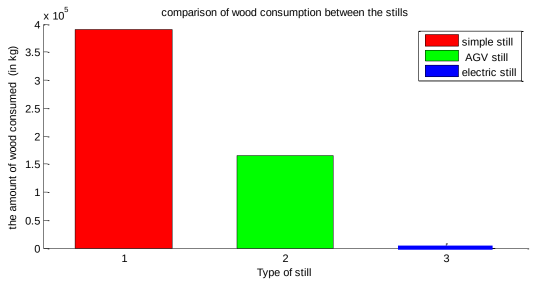

Figure 4 : Comparaison de la consommation de Bois entre les alambics

The simple stills, numbering more than twenty in Nosy-Be, are widely present but lead to significant wood consumption due to their average power of 2454 kW and their cooking duration of 36 hours. In contrast, the WSG stills, although less common, display lower wood consumption thanks to their power of 3212 kW and a reduced cooking duration of 12 hours. As for the electric still, although it is not yet used on the island, its environmental advantage lies in its zero-wood consumption, being powered by a photovoltaic source, with a power of 120 kWh and a cooking duration of 12 hours. This diversity of stills offers interesting prospects for energy efficiency and environmental impact in Nosy-Be.

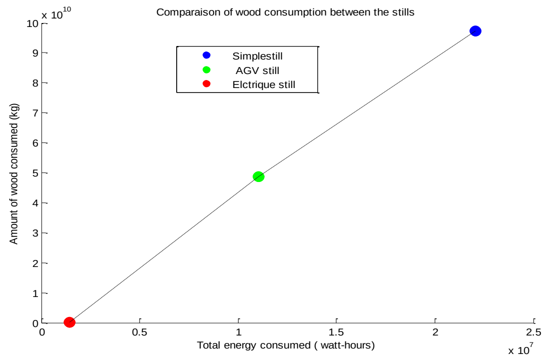

Figure 5: Comparison of Wood and Energy Consumption Between Stills

The illustrated curve eloquently demonstrates the correlation between the amount of wood consumed and the results obtained by the different types of stills. The electric still stands out clearly by reducing the total energy curve, thus highlighting its environmental advantage. This visualization underscores the remarkable efficiency of the electric still compared to its counterparts, offering a compelling perspective for a transition to more sustainable distillation methods.

Forecasting Method

Forecasting is an advance estimation or conjecture about a future event, based on the analysis of past data, trends, or other relevant information. It aims to anticipate likely developments to make informed decisions [4]. In this research, we will use the least squares method to fit a straight line to our data.

Study of Wood-Based Stills in Nosy-Be

The study of wood-based stills in Nosy-Be is essential for understanding the efficiency of these pieces of equipment in oil production. This study focuses on five stills of different capacities and examines their oil yield as well as their wood consumption. The primary objective is to evaluate the relationship between the capacity of the still, the oil yield, and the amount of wood required for each cooking operation. By understanding these relationships, we can optimize the use of the stills and minimize wood consumption, which is crucial for the environmental and economic sustainability of oil production in Nosy-Be.

Results were recorded for five stills in Nosy-Be, which differ by their capacity (C). For a 50 kg still, the oil yield (R) ranges from 1.5 to 2 kg, the cooking time is 16 to 24 hours, and the wood consumption (B) is 1.5 to 2 cubic meters. For a 100 kg still, the oil yield is 2.5 to 3 kg, the cooking time is 18 to 24 hours, and it consumes 2 to 3 cubic meters of wood. For a 200 kg still, the oil yield is 5 to 6 kg, with a cooking time of 20 to 24 hours, and a wood consumption of 5 to 6 cubic meters. For a 400 kg still, the oil yield is 10.5 to 12 kg, with a cooking time of 20 to 24 hours, and a wood consumption of 5 to 8 cubic meters. Finally, for a 1600 kg still, the oil yield is 40 to 46 kg, with a cooking time of 30 to 36 hours, and a wood consumption of 40 to 48 cubic meters.

The quality of the product depends on the quality of the wood used, but with dry wood, the yield is optimal. It also depends on the season, during the rainy season, the yield decreases, and the cooking time increases.

Lineark Regression

Linear regression is widely used in various fields to model and predict linear relationships. Linear regression is a statistical method that models the linear relationship between a dependent variable and one or more independent variables.

Principle

Principle It seeks to fit a straight line (or hyperplane in higher dimensions) that minimizes the sum of the squares of the differences between the actual observations and the predicted values.

- *Linear Regression Model*

We assume a model of the form [5]:

$$\beta = \beta_0 + \beta_1 C + \beta_2 R + \epsilon \quad (3)$$

β_0 is the intercept
β_1 and β_2 are the regression coefficients for C and R respectively
ϵ is the residual error

Calculation of Regression Coefficients

To estimate the coefficients, we use the least squares method, which solves the system of normal equations:

$$\begin{bmatrix} n & \sum C_i & \sum R_i \\ \sum C_i & \sum C_i^2 & \sum C_i R_i \\ \sum R_i & \sum C_i R_i & \sum R_i^2 \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{bmatrix} = \begin{bmatrix} \sum B_i \\ \sum C_i B_i \\ \sum R_i B_i \end{bmatrix} \quad (4)$$

To simplify, we will use the average values of the intervals:

Table 1: The table of average interval values

Capacity (C)	Efficiency (R)	Wood consumption (B)
50 kg	1.75 kg |	1.75 m³
100 kg	2.75 kg	2.5 m³
200 kg	5.5 kg	5.5 m³
400 kg	11.25 kg	6.5 m³
1600 kg	43 kg	44 m³

Solving the system of equations

$$\begin{bmatrix} 5 & 2350 & 63.25 \\ 2350 & 2665000 & 6970 \\ 63.25 & 69700 & 1949.1875 \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{bmatrix} = \begin{bmatrix} 6425 \\ 70950 \\ 1913.3125 \end{bmatrix} \quad (5)$$

Here are the steps to build the linear regression model

- Examine the relationships between the capacity of each still, the oil yield, and the wood consumption.
- Apply the least squares method to fit a straight line to our data.
- Estimate the coefficients of the model from the provided data.
- Once the coefficients are estimated, the model can be used to predict the wood consumption for the 5 stills.

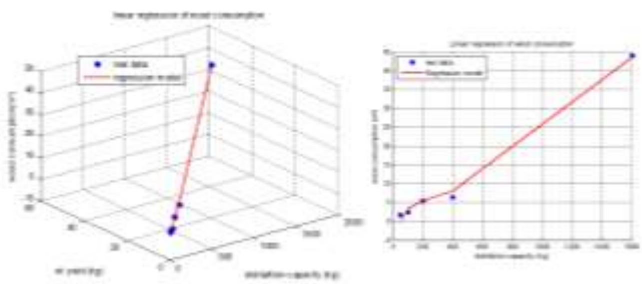

Figure 6: Prediction of wood consumption for the stills at Nosy-Be

The graph shows the results of a linear regression analysis aiming to model wood consumption as a function of still capacity and oil yield. The blue points on the graph represent the actual data collected for stills of various capacities, oil yields, and wood consumption. The red line represents the linear regression model fitted to this data, calculated using the least squares method to minimize the sum of the squares of the differences between the observed values and the values predicted by the model.

The X-axis represents still capacity in kilograms (kg), the Y-axis represents oil yield in kilograms (kg), and the Z-axis displays wood consumption in cubic meters (m³).

Predictions of wood consumption for the 5 stills

The predicted values of wood consumption vary for different still capacities. The larger the capacity of the still, the higher the predicted wood consumption, which is consistent with the coefficient associated with capacity [6].

Table 2: Table of Linear Regression Model Coefficients

Coefficient	Value	Explanation
Intercept (β_0)	1.1775	This coefficient represents the value of wood consumption (m³) when both still capacity and oil yield are equal to zero.
Coefficient for capacity (β_1)	0.2214	This coefficient indicates the increase in wood consumption (m³) for each additional kilogram of still capacity, all else being equal.
Coefficient for efficiency (β_2)	-7.2526	This coefficient indicates the decrease in wood consumption (m³) for each additional kilogram of oil yield, all else being equal.

Intercept (β_0 = 1.1775)

This coefficient represents the wood consumption in cubic meters when both the still capacity and oil yield are zero. While it's not practical to have a still with zero capacity and yield, this coefficient serves as a baseline reference point for the regression model..

Coefficient for capacity (β_1 = 0.2214)

This coefficient shows that for each additional kilogram of still capacity, wood consumption increases on average by 0.2214 cubic meters. This indicates a positive relationship between still capacity and wood consumption.

Coefficient for efficiency (β_2 = -7.2526)

This coefficient reveals that for each additional kilogram of oil yield, wood consumption decreases on average by 7.2526 cubic meters. This negative relationship suggests that higher oil yields are associated with lower wood consumption, indicating greater efficiency in wood utilization for higher yields.

Temporal Analysis of Wood Consumption in Nosy-Be

In this section, we conducted a detailed temporal analysis of wood consumption by the stills in Nosy-Be, using the PERT (Program Evaluation and Review Technique) method. This method allows us to assess the expected durations for critical activities such as oil yield, cooking time, and wood consumption, for different types of stills.

Through this analysis, our aim is to identify key factors that influence wood consumption and optimize the oil production processes in Nosy-Be.

The expected duration (TE) is calculated using the PERT formula as follows [7]:

$$TE = \frac{TP + 4 \times TO + TPe}{6} \tag{6}$$

-TP: Most Probable Time
- TO: Most Optimistic Time
- TP_e: Most Pessimistic Time

This formula is used to estimate the expected average duration for an activity, taking into account optimistic, pessimistic, and most likely estimates. It is widely used in project management to assess activity durations and determine critical paths throughout a project.

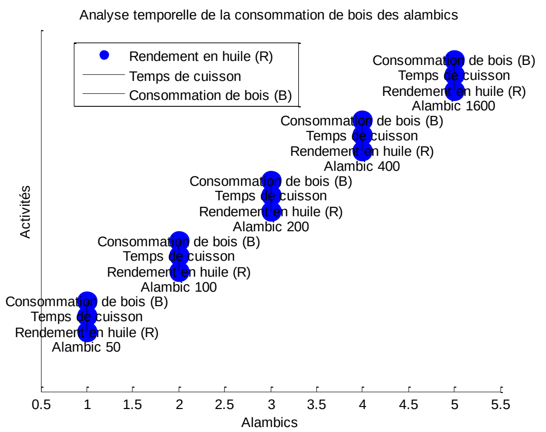

Figure 7: Temporal Analysis of Wood Consumption by Still

The figure illustrates the temporal analysis of wood consumption for different stills in Nosy-Be, based on their specific characteristics. Each still is represented by a series of activities including oil yield (R), cooking time, and wood consumption (B). Activities are connected by lines to indicate dependencies between them. The clear and orderly layout of the graph allows for easy comparison of still performance based on their capacity, showing how variations in oil yield and cooking time influence wood consumption. This visualization helps identify the most efficient stills in terms of wood consumption and oil yield, providing crucial information for the planning and optimization of oil production processes in Nosy-Be.

Conclusion

The in-depth analysis of the collected data reveals that electric still emerges as a promising solution in the context of distillation, offering an environmentally friendly and energy-efficient alternative. Compared to the simple still and the wood-fired steam generator still, the electric still stands out by minimizing environmental impact while optimizing energy efficiency. The curve of total energy consumed versus the amount of wood consumed illustrates the positive trend associated with the electric still. This technology proves to be not only economical but also in line with contemporary ecological imperatives. Considering the growing challenges related to climate change and the preservation of natural resources, widespread adoption of the electric still could constitute a significant advancement in the field of distillation. The intrinsic advantages of electric still lie in its ability to adapt to demand while minimizing energy costs and reducing dependence on fossil fuels. This transition to more sustainable technologies is crucial for the industry, contributing both to environmental preservation and more efficient production.

The best solution for improving energy efficiency and reducing the environmental impact of stills in Nosy-Be is the adoption of the electric still (ES). Although the initial installation is costly, the electric still eliminates wood consumption, significantly reducing deforestation and depletion of forest resources. Additionally, it offers superior energy efficiency compared to traditional stills and wood steam generators. By integrating renewable energy sources, such as solar power, the ES can become even more sustainable and cost-effective in the long term. Thus, despite the initial cost, the electric still represents a wise investment for a more environmentally friendly and energy-efficient future.

While the forecasting method used provides an initial estimate of future wood consumption by the still, more advanced approaches could be explored for increased accuracy. Estimating deforestation underscores the importance of sustainability in the use of natural resources, prompting consideration of alternative practices and more sustainable models to minimize environmental impact. This visual representation highlights differences in wood consumption trends among the AS, AGV, and AE stills. However, it's crucial to note that the data used are randomly generated for illustrative purposes. For more accurate forecasts, real historical data and more advanced modeling methods would be required. The electric still stands out for its consistent consumption, underscoring its environmentally friendly nature compared to other types of stills.

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