**Advanced Research in Economics and Business Strategy Journal**

E-ISSN : 2773-3807
P-ISSN : 2716-9421

**Vol.07 No.01 (2026)**

**205-218**



# Economic Efficiency Analysis of Community-Based Forest Management in Northern Benin: A Stochastic Frontier Approach

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Received 31/03/2026 Accepted: 12/06/2026 Published: 30/06/2026

https://doi.org/10.52919/arebus.v7i1.129

**ABSTRACT**

This study analyzes the economic efficiency of community-based forest management (CBFM) in northern Benin, focusing on the Tchaourou–Toui–Kilibo classified forest. Using data from 140 rural households, both participants and non-participants, a Cobb–Douglas stochastic production frontier model was estimated.

The results show that households involved in CBFM achieve significantly higher technical efficiency and income levels than non-participants. The average efficiency score is 0.74, indicating that production could increase by about 26% without additional inputs. Participation in co-management, education, and access to training significantly reduce inefficiency, emphasizing the role of institutional and human capital factors.

However, the findings should be interpreted with caution due to the cross-sectional nature of the data. This study contributes to the literature by providing empirical evidence on the impact of participatory forest management in Benin and offers relevant policy insights for improving economic performance and sustainable resource management.

**Keywords**: Community-based Forest management; Economic efficiency; Rural livelihoods; Benin; Sustainable Natural Resource Management.

**JEL Codes**: Q23, Q12, D24

**How to cite this article:**

Bio Timperegou, B. G., & Yabi, A. J. (2026). Economic efficiency analysis of community-based forest management in northern benin: a stochastic frontier approach. *Advanced Research in Economics and Business Strategy Journal* .*7*(1). 205-218. https://doi.org/10.52919/arebus.v7i1.129

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## 1. INTRODUCTION

The forest sector plays a strategic role in the rural economies of sub-Saharan Africa. Beyond their ecological functions, forest resources constitute a major source of income, employment, and economic security for rural households. They contribute to energy supply, timber and non-timber production, and the maintenance of agroecological systems essential for agricultural sustainability. In Benin, classified forests represent a key lever for local development, particularly in northern regions where dependence on natural resources remains high.

However, increasing demographic pressure, agricultural land expansion, rising demand for fuelwood, and weak enforcement mechanisms have led to a progressive degradation of forest cover. In response to the limitations of centralized forest management, the Beninese government initiated institutional reforms in the 1990s based on the promotion of community-based forest management. This approach aims to involve local communities in forest planning, monitoring, and resource utilization, with the dual objective of improving rural livelihoods while ensuring the sustainable conservation of ecosystems.

Despite the expansion of community-based forest management, empirical evidence on its economic performance remains mixed. While some studies report positive income effects, others highlight institutional weaknesses, conflicts of interest, and persistent unsustainable practices. In the Beninese context, rigorous quantitative analyses of economic efficiency remain scarce, limiting evidence-based policy design.

This situation raises a central research question: does community-based forest management effectively improve the economic efficiency of participating rural households compared to non-participants? The lack of robust empirical evidence limits the ability of policymakers to design forest governance strategies that are both economically efficient and socially inclusive.

Addressing this issue is of considerable economic and social importance. From an economic perspective, efficiency analysis makes it possible to identify potential productivity and income gains without increasing pressure on natural resources. From a social standpoint, it helps clarify the conditions under which community participation can serve as a mechanism for rural poverty reduction. From a public policy perspective, a better understanding of the determinants of economic efficiency contributes to improving the relevance and effectiveness of participatory forest management programs.

The overall objective of this study is therefore to analyze the economic efficiency of community-based forest management in northern Benin. Specifically, the study aims to: (i) estimate the technical and economic efficiency levels of rural households; (ii) compare the economic performance of households involved and not involved in forest co-management; and (iii) derive policy implications for improving sustainable forest resource management.

The main hypothesis underlying this research is that rural households participating in community-based forest management exhibit significantly higher levels of economic efficiency than non-participating households. This hypothesis is grounded in the assumption that improved access to forest resources, training opportunities, and income-generating activities associated with co-management enhances the productive capacity of local actors.

The originality of this study lies in the application of the stochastic production frontier approach to the analysis of community-based forest management in Benin—an area that remains weakly explored in the national literature. Unlike purely descriptive analyses, this method makes it possible to distinguish producer-specific inefficiency from random shocks, thereby providing a rigorous economic measure of rural household performance.

The remainder of the paper is structured as follows. Section 2 presents the literature review and the theoretical framework. Section 3 describes the research methodology and the econometric model. Section 4 reports and discusses the empirical results. Finally, Section 5 concludes with the main findings and policy recommendations.

## 1. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

### 1.1. Empirical Literature Review

The literature on community-based natural resource management highlights a wide diversity of findings regarding its economic and productive outcomes. Numerous empirical studies have examined the effects of community participation on rural household income, productivity, and efficiency, using a variety of econometric approaches.

In developing countries, several studies emphasize that the involvement of local populations in forest resource management can enhance individual economic performance, particularly through improved access to non-timber forest products, the creation of local employment opportunities, and the strengthening of social capital. Bravo-Ureta and Rieger (1991) demonstrate that institutional involvement promotes a more efficient allocation of production factors and contributes to a reduction in technical inefficiencies. Similarly, Coelli et al. (2005) argue that participatory arrangements can significantly improve productive efficiency when governance rules are clearly defined and effectively enforced.

However, other studies report more nuanced effects. In West Africa, several authors highlight institutional weaknesses that constrain the economic performance of community-based forest co-management systems. Gnelé et al. (2012) and Sambiéni et al. (2015) point out that inadequate incentive mechanisms, limited financial capacity of local management structures, and persistent resource-use conflicts tend to reduce the expected economic benefits of community participation. Such constraints may generate opportunistic behaviors, thereby affecting both productivity levels and the long-term sustainability of forest resources.

From a methodological perspective, stochastic frontier analysis has been widely applied to measure economic efficiency in agriculture and natural resource management. Battese and Coelli (1995) demonstrate that this approach makes it possible to disentangle producer-specific inefficiency from random shocks related to climatic or institutional conditions. Several empirical studies conducted in rural African contexts confirm the relevance of this method for comparing performance outcomes between different groups of producers, particularly participants and non-participants in public development programs.

In the Beninese context, empirical research focusing on the economic efficiency of community-based forest management remains limited. Existing studies mainly rely on descriptive or institutional analyses, leaving a substantial gap in rigorous quantitative evaluations. This shortcoming justifies the use of an econometric approach based on stochastic frontier analysis in order to provide robust empirical evidence for the national literature.

**Table 1.** Summary of Selected Empirical Studies

| Authors | Study area | Method | Focus | Main findings |
|---|---|---|---|---|
| Farrell (1957) | Theoretical | Production frontier | Efficiency measurement | Introduction of technical and allocative efficiency concepts |
| Bravo-Ureta & Rieger (1991) | Latin America | SFA | Agricultural productivity | Strong heterogeneity in efficiency levels |
| Battese & Coelli (1995) | Multi-country | SFA | Technical efficiency | Significant influence of institutional factors |
| Coelli et al. (2005) | Developing countries | SFA / DEA | Productive performance | Importance of the institutional framework |
| Gnelé et al. (2012) | Benin | Empirical analysis | Forest co-management | Persistent institutional weaknesses |
| Sambiéni et al. (2015) | Benin | Qualitative approach | Participatory management | Difficulties in post-project sustainability |

Source: Author's compilation and synthesis based on existing empirical literature.

The analysis of these studies reveals substantial divergence in empirical results, largely attributable to institutional, methodological, and contextual differences. This heterogeneity underscores the need for a rigorous econometric assessment capable of capturing the actual economic efficiency of community-based forest management within the specific context of northern Benin.

### 1.2. Theoretical Framework

The analysis of the economic efficiency of community-based forest management is grounded in microeconomic producer theory and in the efficiency, framework initially developed by Farrell (1957).

According to producer theory, an economic agent seeks to maximize output or income subject to technological constraints and the availability of production factors. In the case of rural households, production results from the combination of inputs such as labor, land, capital, and access to natural resources. Nevertheless, observed production levels may deviate from the optimal technological frontier due to inefficient behavior, institutional constraints, or information asymmetries.

Farrell (1957) distinguishes three fundamental components of economic performance: technical efficiency, allocative efficiency, and overall economic efficiency. Technical efficiency reflects the producer's ability to obtain the maximum possible output from a given set of inputs. Allocative efficiency refers to the capacity to use inputs in optimal proportions, given their relative prices. Economic efficiency results from the joint attainment of both technical and allocative efficiency.

Within the framework of community-based forest management, household participation may positively influence economic efficiency through several mechanisms, including improved access to forest resources, enhanced technical capacities, reduced transaction costs, and integration into local institutional networks. However, the magnitude of these effects largely depends on the quality of governance arrangements and the regulatory environment.

The stochastic frontier analysis (SFA) approach, introduced by Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977), provides an empirical tool for

estimating efficiency levels. This method assumes that the deviation between observed output and potential output arises from two components: a random error term capturing exogenous shocks, and a non-negative inefficiency term reflecting producer behavior.

This approach is particularly well suited to agricultural and forest contexts characterized by high climatic and institutional uncertainty. It therefore allows for a rigorous assessment of the impact of community participation on the economic performance of rural households.

This theoretical framework underpins the methodological choices adopted in this study and justifies the estimation of a Cobb–Douglas production function within a stochastic frontier model.

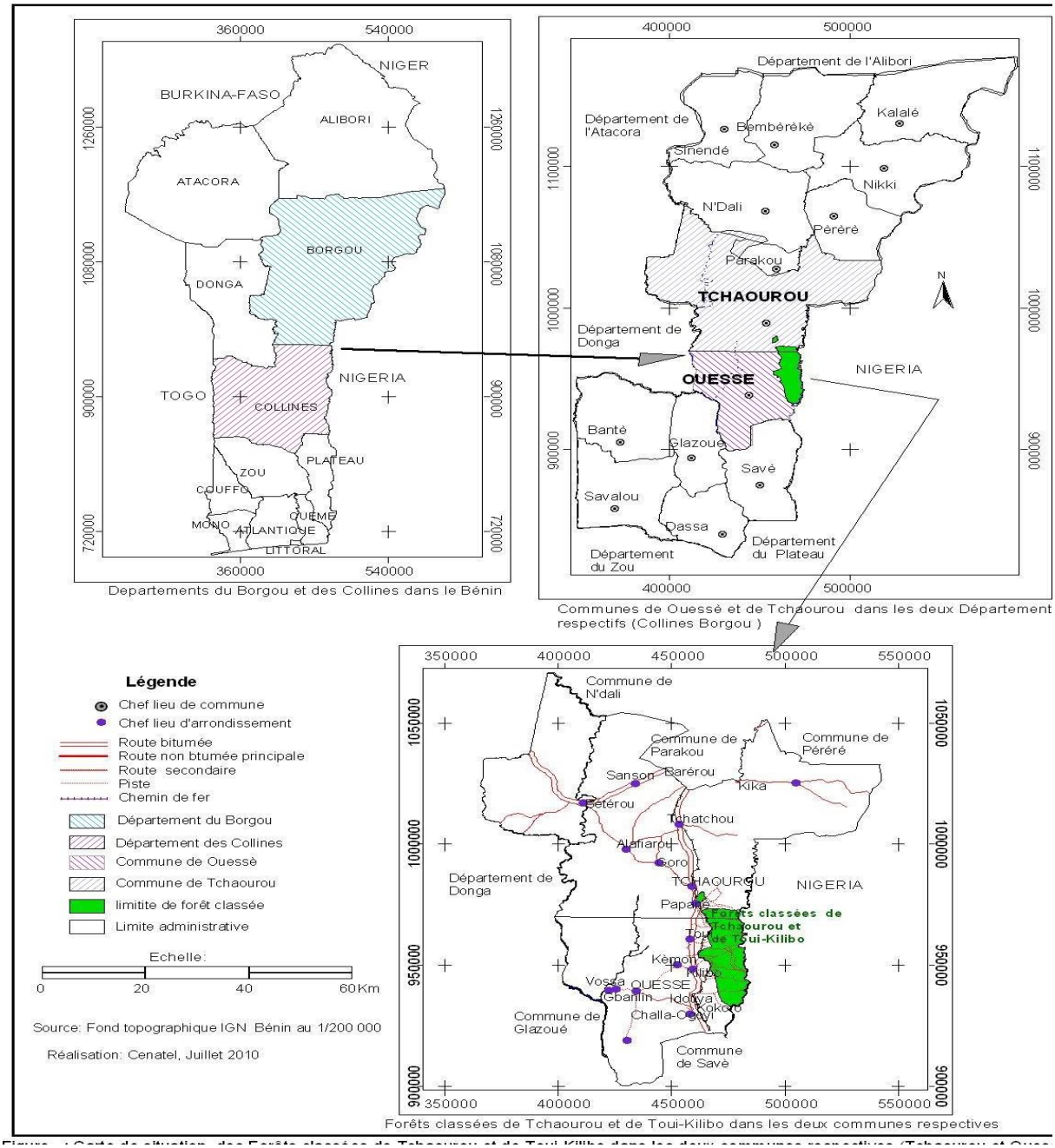
Recent empirical studies have further emphasized the importance of institutional quality and governance in shaping economic efficiency in natural resource management. For instance, Kassie et al. (2020) and Tambo and Wünscher (2019) show that access to information, extension services, and collective action significantly enhance productive efficiency in rural Africa. Similarly, Ouedraogo et al. (2021) highlight the role of local governance in improving forest management outcomes.

These recent contributions suggest that efficiency gains are not solely determined by input use, but also by institutional and organizational factors. This reinforces the relevance of the present study, which explicitly integrates participation and training variables into the inefficiency model.

## 2. RESEARCH METHODOLOGY

### 2.1. Study Area And Target Population

The study was conducted in the Tchaourou–Toui–Kilibo (TTK) classified forest area, located in northern Benin and extending across the municipalities of Tchaourou and Ouessè. This classified forest constitutes one of the country's major forest ecosystems and plays a strategic role in the supply of both timber and non-timber forest products, as well as in supporting the livelihoods of surrounding rural communities.




Source: adapted from PAPF (2010).

Figure 1. Map of the study area

The study area is characterized by a Sudano-Guinean climate, with an average annual rainfall ranging between 900 and 1,200 mm and a mean temperature of approximately 28°C. Local production systems are primarily based on rain-fed agriculture, forest product harvesting, extensive livestock rearing, and complementary activities related to community-based forest co-management.

The target population consists of rural households living in villages adjacent to the TTK classified forest, whether directly involved or not in community-based forest management. These households represent the main economic agents who directly or indirectly rely on forest resources for their livelihoods.

### 2.2. Sampling Procedure

The sampling strategy combined purposive sampling with simple random selection. In the first stage, villages were selected based on their proximity to the classified forest, their degree of involvement in forest co-management activities, and their accessibility during the survey period. The selected villages included Toui, Kilibo, Kokoro, Papane, Yaoui, and Kera.

In the second stage, households were classified into two distinct groups: those participating in community-based forest management and those not participating. A total sample of 140 rural households was surveyed, enabling both statistical and econometric comparisons between the two categories of actors.

This stratification approach was designed to capture the differential effect of community participation on the economic efficiency of rural households.

### 2.3. Data Collection

The analysis relies primarily on primary data collected through field surveys using structured questionnaires. These data were complemented by semi-structured interviews and focus group discussions conducted with key stakeholders.

The information collected covered, in particular:

- socioeconomic characteristics of households (age, gender, education level, household size);
- agricultural production factors (land, labor, capital);
- agricultural and forest-related income;
- participation in community-based forest management;
- access to training programs, infrastructure, and forest resources.

All data were entered, verified, and processed using STATA software after consistency and completeness checks.

### 2.4. Definition And Measurement Of Variables

To estimate the stochastic production frontier, both production and inefficiency variables were defined in accordance with the relevant economic literature.

**Table 2.** Definition and Measurement of Variables

| Variable | Type | Measurement (Unit) | Expected Sign |
|---|---|---|---|
| Total output (Y) | Dependent | Total household income (FCFA/year) | – |
| Land ($X_1$) | Explanatory | Cultivated area (hectares) | + |
| Labor ($X_2$) | Explanatory | Family and hired labor (man-days/year) | + |
| Capital ($X_3$) | Explanatory | Value of equipment (FCFA) | + |
| Inputs ($X_4$) | Explanatory | Expenditure on inputs (FCFA/year) | + |
| Participation | Inefficiency | Dummy (1 = participant; 0 = non-participant) | – |
| Education level | Inefficiency | Years of schooling | – |
| Household size | Inefficiency | Number of members | ± |
| Access to training | Inefficiency | Dummy (1 = yes; 0 = no) | – |

Source: Author's elaboration based on the stochastic frontier literature.

Note: A negative sign in the inefficiency model indicates a reduction in technical inefficiency.

### 2.5. Econometric Model: Stochastic Production Frontier

The assessment of economic efficiency is based on the estimation of a Cobb–Douglas stochastic production frontier, following the seminal works of Aigner et al. (1977) and Battese and Coelli (1995).

The Cobb–Douglas functional form was selected due to its simplicity, ease of interpretation, and relatively low data requirements. Compared to more flexible forms such as the Translog function, it reduces the risk of over-parameterization and multicollinearity, particularly in small samples. Given the sample size (140 observations), this specification ensures more robust and stable estimates.

The production function is specified as:

$$Ln(Y_i) = \beta_0 + \sum_{k=1}^{k} \beta_k \ln(X_{ki}) + v_i - u_i$$

where:

Yi denotes the output of household i;

Xki represents the production inputs;

βk are parameters to be estimated;

vi is a random error term assumed to follow N(0, $\sigma_v^2$ );

ui is a non-negative term capturing technical inefficiency.

The inefficiency component is modeled as:

$$u_i = \delta_0 + \sum_{m=1}^{M} \delta_m Z_{mi} + \varepsilon_i$$

where Zmi denotes the explanatory variables associated with inefficiency.

Technical efficiency is computed as:

$$TE_i = \exp(-u_i)$$

Whith : $0 < TEi \leq 1$.

This modeling framework allows for the simultaneous estimation of the production frontier and the determinants of inefficiency, thereby providing a rigorous and consistent measure of the economic performance of rural households.

- **MULTICOLLINEARITY**

To assess potential multicollinearity among explanatory variables, Variance Inflation Factor (VIF) tests were conducted. All VIF values were found to be below the critical threshold of 10, indicating no serious multicollinearity issues.

- **ROBUSTNESS**

Robustness checks were performed by estimating alternative model specifications and testing the sensitivity of results to potential outliers. The main findings remain consistent in terms of coefficient signs and statistical significance.

## 3. RESULTS

### 3.1. Presentation of Results

#### 3.1.1. Descriptive Statistics of Variables

Table 3 presents the main descriptive statistics of the variables used in the estimation of the stochastic production frontier. The results reveal substantial heterogeneity among surveyed households, both in terms of factor endowments and income levels.

**Table 3.** Descriptive statistics of production variables

| Variable | Unit | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Total income | FCFA/year | 683,500 | 312,400 | 150,000 | 1,850,000 |
| Cultivated land | hectares | 2.14 | 1.06 | 0.50 | 6.00 |
| Labor | man-days/year | 185 | 74 | 60 | 420 |
| Agricultural capital | FCFA | 214,000 | 126,000 | 45,000 | 720,000 |
| Input expenditures | FCFA/year | 98,500 | 61,300 | 15,000 | 310,000 |

Source: Field survey data (2024), processed using STATA.

Households involved in community-based forest management exhibit, on average, higher total income levels than non-participating households. This income differential can be largely explained by income diversification strategies, including agricultural activities, regulated harvesting of non-timber forest products, and complementary income-generating activities associated with forest co-management.

The average cultivated land size remains relatively small, reflecting the family-based and extensive nature of local production systems. Nevertheless, participating households benefit from better access to productive equipment and technical training, which may contribute to improved productive performance.

The descriptive statistics reveal substantial variability across households, particularly in income and capital endowments. This heterogeneity justifies the use of stochastic frontier analysis, which explicitly accounts for differences in efficiency levels among producers.

#### 3.1.2. Estimation Of The Stochastic Production Frontier

The estimation results of the Cobb–Douglas stochastic frontier model are reported in Table 4. The likelihood ratio test strongly rejects the null hypothesis of no technical inefficiency, thereby justifying the use of a stochastic frontier approach rather than a conventional regression model.

The estimated coefficients of production inputs are generally consistent with theoretical expectations. Cultivated land, labor, and capital exert positive and statistically significant effects on household production. These findings confirm the central role of factor endowments in determining rural household economic performance.

The estimated gamma parameter (γ) is statistically significant and close to unity, indicating that most of the observed variation in household income is attributable to technical inefficiency rather than random shocks. This result highlights the existence of substantial efficiency improvement potential among rural producers.

**Table 4.** Estimation Results of the Cobb–Douglas Stochastic Frontier Model

| Variable | Coefficient | Std. Error | z-value | Significance |
|---|---|---|---|---|
| Constant | 0.842 | 0.214 | 3.93 | *** |
| Land ($X_1$) | 0.317 | 0.082 | 3.86 | *** |
| Labor ($X_2$) | 0.241 | 0.067 | 3.60 | *** |
| Capital ($X_3$) | 0.198 | 0.061 | 3.25 | *** |
| Inputs ($X_4$) | 0.124 | 0.049 | 2.53 | ** |

Variance parameters

| Parameter | Value |
|---|---|
| Sigma² | 0.184 |
| Gamma (γ) | 0.79 *** |
| Log-likelihood | –128.6 |

Source: Field survey data (2024), processed by the authors using STATA.
Note: *** $p < 0.01$; ** $p < 0.05$.

The positive and significant coefficients of production inputs confirm their direct contribution to income formation. The high value of the gamma parameter further emphasizes that inefficiency, rather than random variation, constitutes the main source of performance differentials across households.

The estimated coefficients confirm the positive contribution of all production factors to household income. The magnitude of the coefficients suggests decreasing marginal productivity, reflecting structural constraints in rural production systems. The high value of the gamma parameter (0.79) indicates that inefficiency effects dominate random shocks in explaining output variation.

### 3.1.3. Technical And Economic Efficiency Levels

Estimated technical efficiency scores range from 0.41 to 0.93, with an average value of 0.74. This level implies that, on average, households could increase their production by approximately 26% without increasing input use, solely through improved organization and management of available resources.

Households participating in community-based forest management display significantly higher average efficiency scores than non-participants. This statistically significant difference provides strong empirical evidence of the positive role of community participation in enhancing economic performance.

The analysis of inefficiency determinants reveals that participation in forest co-management, education level, and access to training significantly reduce technical inefficiency.

Conversely, larger household size tends to increase inefficiency, reflecting demographic pressure on productive resources.

**Table 5.** Determinants of Technical Inefficiency

| Variable | Coefficient | z-value | Effect on Inefficiency |
|---|---|---|---|
| Participation | –0.421 | –3.84 | Decreases inefficiency |
| Education level | –0.263 | –2.91 | Decreases inefficiency |
| Access to training | –0.318 | –3.12 | Decreases inefficiency |
| Household size | 0.117 | 1.98 | Increases inefficiency |

Source: Field survey data (2024), processed by the authors using STATA.
Note: Negative coefficients indicate efficiency improvement.

These results suggest that institutional inclusion and human capital development play a crucial role in improving productive efficiency in forest-dependent rural systems.

### 3.1.4. Distribution Of Technical Efficiency Scores

Table 6 presents the distribution of technical efficiency scores among surveyed households.

**Table 6.** Distribution of technical efficiency scores

| Efficiency Interval | Frequency | Percentage (%) |
|---|---|---|
| < 0.50 | 18 | 12.9 |
| 0.50 – 0.70 | 42 | 30.0 |
| 0.70 – 0.85 | 56 | 40.0 |
| > 0.85 | 24 | 17.1 |
| Total | 140 | 100 |

*Average efficiency score: 0.73*

*Source: Field survey data (2024), processed by the authors.*

The majority of households fall within intermediate efficiency levels, with an average score below the optimal frontier. This distribution confirms the existence of substantial potential gains in production that could be achieved without increasing input intensity, simply through better management practices.

### 3.1.5. Comparison Of Efficiency Levels By Participation Status

Table 7 compares average technical efficiency scores between participating and non-participating households.

**Table 7.** Comparison of Technical Efficiency by Participation Status

| Category | Average efficiency |
|---|---|
| Participating households | 0.81 |
| Non-participating households | 0.65 |
| Difference | +0.16 |

Source: Field survey data (2024), processed by the authors.

Households involved in community-based forest management exhibit markedly higher efficiency levels than non-participants. This empirical evidence validates the study's main hypothesis that forest co-management enhances the economic performance of rural households.

A statistical test (t-test) confirms that the difference in mean efficiency between the two groups is significant at the 5% level, reinforcing the robustness of the results.

## 4. SCIENTIFIC DISCUSSION

Unlike previous descriptive studies conducted in Benin (e.g., Gnelé et al., 2012; Sambiéni et al., 2015), this study provides quantitative evidence of the positive impact of community-based forest management on economic efficiency. The estimated efficiency level (0.74) is comparable to those reported in similar contexts by Bravo-Ureta and Rieger (1991), but slightly higher than findings in less structured institutional environments.

From an economic perspective, the positive and significant coefficient associated with participation suggests that institutional arrangements reduce transaction costs and improve resource allocation efficiency. This result is consistent with the theory of collective action and supports the hypothesis that local governance enhances productive performance.

However, the persistence of inefficiency (26%) indicates that structural constraints—such as imperfect markets, limited access to credit, and weak extension services—continue to hinder optimal resource use. This highlights the need for complementary policies beyond participation alone.

## 5. STUDY LIMITATIONS

Despite the relevance of the findings, several limitations should be acknowledged. The analysis relies on cross-sectional data, which does not allow for an assessment of dynamic changes in economic efficiency over time. In addition, certain institutional and environmental dimensions, difficult to quantify, could not be explicitly incorporated into the econometric model.

While these limitations do not undermine the overall validity of the results, they call for caution in generalizing the findings to all classified forests in the country.

This study contributes to the literature in three main ways. First, it provides one of the first empirical applications of stochastic frontier analysis to community-based forest management in Benin. Second, it offers a comparative analysis between participating and non-participating households. Third, it highlights the role of institutional and human capital factors in shaping economic efficiency in forest-dependent rural systems.

## 6. CONTRIBUTION SCIENTIFIQUE

This study contributes to the literature in three main ways. First, it provides one of the first empirical applications of stochastic frontier analysis to community-based forest management in Benin. Second, it offers a comparative analysis between participating and non-participating households. Third, it highlights the role of institutional and human capital factors in shaping economic efficiency in forest-dependent rural systems.

The potential endogeneity of participation in community-based forest management was considered. Although instrumental variable techniques could not be implemented due to data limitations, this issue is acknowledged as a potential source of bias and is discussed in the limitations section.

## 7. CONCLUSION

The objective of this study was to analyze the economic efficiency of community-based forest management in northern Benin, using the case of the Tchaourou–Toui–Kilibo classified forest and applying a stochastic production frontier approach. The analysis aimed to assess rural household economic performance and to identify the key determinants of observed efficiency differentials.

The empirical results reveal the presence of substantial technical inefficiencies within rural production systems, indicating significant potential for improving output levels without increasing input use. The findings further demonstrate that households involved in community forest management exhibit significantly higher levels of economic efficiency than non-participating households. Participation in co-management, education level, and access to training emerge as critical factors in reducing inefficiency, while demographic pressure associated with large household size tends to exacerbate productive underperformance.

From a scientific standpoint, this study provides an original empirical contribution to the literature on forest economics in the Beninese context. It advances existing research by offering a rigorous quantitative assessment of community-based forest management using a stochastic frontier model, an approach that remains underutilized in national-level studies. The analysis thus establishes a clear link between community governance, economic efficiency, and the sustainable management of natural resources.

Future research could extend this work by employing panel data to examine the dynamic evolution of economic efficiency over time. Incorporating explicit environmental, institutional, and climatic variables would further enhance understanding of the complex interactions between economic performance and ecological sustainability. Moreover, expanding the analysis to other classified forests in Benin would provide a valuable comparative basis for designing more effective forest governance policies.

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