Technical Performance of Fish Farms in Cameroon: Measurements and Key Factors

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ABSTRACT

This study analyzes the techno-economic and socio-economic factors determining the choice of fish farming systems and their technical efficiency in 300 randomly sampled farms across the Littoral, Central, and Western regions of Cameroon. Using a Tobit model, the results reveal a significant correlation between socio-economic variables, the choice of farming systems, and the technical performance of operations. Four farming systems were identified: pond, Fastank, cubitainer, and concrete tank. The activity is predominantly male-driven across all systems, with a focus on *Clarias* and *Tilapia* species. Factors influencing the choice of farming systems include the level of education, membership in associations, access to training, and the species cultivated. The technical efficiency analysis shows that farms exhibit overall low or inefficient performance, with an average efficiency score of 54% (based on VRS/CRS models). However, efficiency could be optimized by adopting intensive systems (Fastank), selecting high-yield species (*Tilapia*, *Clarias*), and providing fish farmers with training in aquaculture techniques for better resource management.

Keywords: Technical performance, fish farming operations, Cameroon

INTRODUCTION

Cameroon, a Central African country, boasts a rich diversity of fisheries resources. The central, littoral, and western regions are particularly favorable for fish farming and aquaculture in general, producing over 100,000 tons of fish annually (Tchouankam, 2022). This vital sector contributes 2% to the national GDP (Ngoufo, 2021). Despite its potential, national fish production remains around 335,000 tons annually, with 96% derived from capture fisheries, while demand is estimated at approximately 500,000 tons. To bridge this production gap, Cameroon imports nearly 181,000 tons of frozen fish annually, often of questionable quality, at a foreign exchange cost of 182.5 billion CFA francs (Fonkwa et al., 2024). Fish farming operations in these regions face significant economic challenges, including high production costs, inadequate infrastructure, and the impacts of climate change (Nguendo, 2022). The sector is characterized by small-scale production, low mechanization, and heavy reliance on chemical inputs. These factors collectively reduce the competitiveness of Cameroonian aquaculture products in international markets (Keumdjio, 2021). Additionally, fish farming enterprises contend with increased market competition (Mbouh, 2022).

Moreover, recent studies suggest that fish farming enterprises can enhance their competitiveness by investing in modern technologies and innovations, as well as by developing effective marketing strategies to boost their market presence in these regions (Ngoua et al., 2022). Additionally, the implementation of policies and support programs for fish farmers could further contribute to improving their economic viability

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(Tchoumboue et al., 2023).

Despite the promotion of various modern fish farming systems and techniques, farmers continue to face challenges in maximizing their technical efficiency, as noted by several authors. It is essential for any innovation to combine financial performance with technical performance to ensure its effective adoption. Numerous studies have examined the technical efficiency of fish farming globally, particularly in Africa. Researchers typically employ two methods to assess technical efficiency: the parametric approach, using the stochastic production function, and the non-parametric approach, employing the DEA (Data Envelopment Analysis) model (Long, 2022). However, these studies often fail to provide sufficient information about efficiency levels across different farming systems. To address this empirical gap, this study aims to investigate the factors influencing the adoption of various fish farming systems in the Central, Littoral, and Western regions of Cameroon, evaluate the technical efficiency of fish farmers using the DEA approach and the estimate the impact of fish farming systems on technical efficiency through a Tobit regression model. The findings of this study will be valuable for policymakers, investors, and practitioners in the aquaculture sector, contributing to the formulation of more effective strategies to enhance the competitiveness and sustainability of fish farming in Cameroon.

MATERIALS AND METHODS

Study area

The study was conducted from February to May and then from June to September 2024 in three regions of Cameroon (Central, Littoral, and Western), selected for their high aquaculture potential due to favorable resources and climatic conditions (FAO, 2022). These areas offer a diversity of aquatic ecosystems, fish farming practices, and regional challenges, providing an opportunity to explore innovative solutions to optimize production, improve resource management, and strengthen food security.

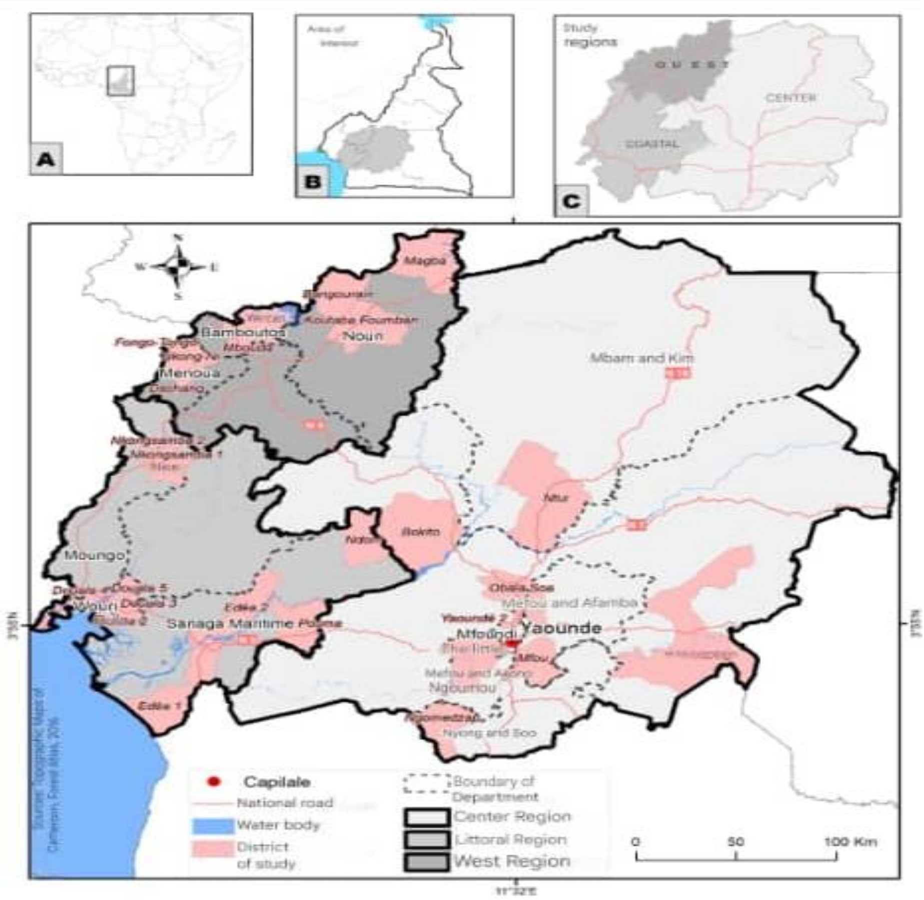

Figure 1: Map Showing the Location of the Study Regions

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Study data collection

This study employed a rigorous methodology combining primary data collection and diverse sampling techniques. Data were gathered from February to September 2024 using a questionnaire pretested with 10 fish farmers during a pilot survey and subsequently refined to include emerging elements. The final questionnaire, comprising open- and closed-ended questions, explored various aspects of fish farming operations. Sampling combined a purposive approach (using institutional lists) with the snowball technique, resulting in a sample of 300 fish farmers meeting strict inclusion criteria. Data were cross-verified through direct observation and analyzed using SPSS, Excel, and Win4Deap2 software, ensuring the robustness of subsequent analyses on technical efficiency and farming system choices.

This comprehensive methodology enabled the collection of reliable and representative data on fish farming practices in the study regions.

Table 1: Number of fish farmers to be surveyed

Regions	**Number of fish farmers surveyed**
Center	
Mefou	14
Mefou and Akono	20
Mfoundi	27
Nyong and so'o	21
Mbam and kim	18
Littoral	
Moungo	32
Sanaga maritime	22
Wouri	46
West	
Menoua	29
Noun	46
Bamboutos	25
Total number of respondents	**300**

The study determined a sample size of 300 farms to ensure an adequate representation of the diverse characteristics of fish farming operations in the three regions under investigation. This includes farm size, production type (e.g., farmed fish), and management practices. A sufficiently large sample size helps reduce sampling error and ensures that the study's findings can be generalized to the broader fish farming population in these regions.

Estimation methods

The methods used in this study to analyze the data include linear programming (the DEA model) to determine the efficiency score and nonlinear regression (the Tobit model) to analyze the determinants of technical efficiency.

Assessing technical efficiency

This study utilizes Data Envelopment Analysis (DEA), a non-parametric approach based on linear programming, to evaluate the technical efficiency of fish farmers. Unlike parametric methods, which require assumptions about error distribution, DEA assumes no predefined functional form or inefficiency distribution, although it does not account for random errors. Its ability to handle multiple inputs and outputs simultaneously makes it particularly suitable for this research.

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DEA constructs an efficiency frontier by linking the most efficient units using linear programming. It evaluates technical efficiency by comparing observed outputs to the theoretical maximums defined by this frontier. Two main models are employed:

- The CCR model (Charnes, Cooper, and Rhodes, 1978) assumes constant returns to scale (CRS).
- The BCC model (Banker, Charnes, and Cooper, 1984) allows for variable returns to scale (VRS).

For NNN farms using KKK inputs to produce MMM outputs, the data are organized into matrices XXX (inputs) and YYY (outputs). Each farm iii is represented by its input vector (xix_ixi) and output vector (yiy_iyi). DEA calculates an efficiency ratio (≤1\leq 1≤1) under constraints that ensure all units are located below or on the efficiency frontier.

This approach provides an intuitive evaluation of relative performance without imposing any specific functional form, making it a robust tool for assessing technical efficiency in fish farming operations.

Hugueni (2013) identifies two fundamental models used in DEA, each leading to the identification of a different efficiency frontier. These models are the CCR Model (Charnes, Cooper, and Rhodes) or the "Constant Returns to Scale" model : This model assumes constant returns to scale (CRS) and is appropriate when organizations are operating at their optimal size. It calculates an efficiency score known as the "Constant Returns to Scale Technical Efficiency" (CRSTE) and the BCC Model (Banker, Charnes, and Cooper) or the "Variable Returns to Scale" model : This model assumes variable returns to scale (VRS) and is suitable when organizations are not operating at their optimal size. It calculates an efficiency score referred to as the "Variable Returns to Scale Technical Efficiency" (VRSTE). These models provide complementary insights into efficiency, allowing for the differentiation between inefficiencies due to scale and inefficiencies due to other operational factors.

Furthermore, the DEA model can be input-oriented or output-oriented, according to Hugueni (2013). In an input-oriented approach, the DEA model minimizes inputs for a given level of outputs, while in an output-oriented approach, it maximizes outputs for a given level of inputs. In this study, the Variable Returns to Scale (VRS) model was used with an input orientation to optimize the use of existing resources. This choice is based on the premise that fish farmers have more control over inputs than outputs. The goal is to identify ways to reduce input usage while maintaining the same production level. It is noteworthy that while the efficiency frontier differs between the CRS and VRS models, within each model, the frontier remains unaffected by whether the orientation is input- or output-focused (Coelli and Perelman, 1999).

Problem formulation

To assess the technical efficiency of the three groups of fish farmers—those using soil-based structures (ponds, concrete tanks) and those using above-ground structures (Fastank, Cubitainer)—the study evaluates their production of two outputs: the total quantity of fish and the average fish weight. These outputs are produced using six inputs: area, quantity of fingerlings, total feed quantity, labor quantity, depreciated value of infrastructure, and quantity of fertilizers and disinfectants.

Each group uses KKK inputs (k=1,2,...,6k = 1, 2, ..., 6k=1,2,...,6) to produce one output (m=1m = 1m=1). The study aims to determine the technical efficiency levels of these producer groups using an **input-oriented** approach, minimizing inputs to achieve the same level of outputs.

Mathematical Formulation

Let n decision-making units (DMUs) be denoted as DMUjDMU_jDMUj (j=1,2,...,nj = 1, 2, ..., nj=1,2,...,n), using mmm inputs XijX_{ij}Xij (i=1,2,...,mi = 1, 2, ..., mi=1,2,...,m) to produce sss outputs YrjY_{rj}Yrj (r=1,2,...,sr = 1, 2, ..., sr=1,2,...,s). Here, YrjY_{rj}Yrj is the rrr-th output of DMU jjj, and XijX_{ij}Xij is the iii-th input of DMU jjj.

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According to Charnes, Cooper, and Rhodes (CCR), the relative efficiency hj0h_{j0}hj0 for a reference unit j0j_0j0 is determined by the following model (Charnes et al., 1978):

$$\text{Max}_{u,v}\ h_o = \frac{\sum_s^{r=1} U_r\ Y_{ro}}{\sum_m^{i=1} V_i X_{ij}} \leq 1, j = 1 \text{ à } n$$

S/C

$$\frac{\sum_s^{r=1} U_r Y_{rj}}{\sum_m^{i=1} V_i\, X_{ij}} \leq 1\ , j = 1 \text{ à n}$$

$$U_r,\ V_{(i)} \geq 0 \forall\ r = 1 \text{ to } s; \quad i = 1 \text{ to } n$$

This linear programming problem can be solved in two ways. In this case, it will be solved according to the output-oriented VRS model (the weighted sum of outputs is maximized while keeping inputs constant).

Following the output-oriented VRS model, the primal equation is written :

Minimize $\sum_{i=1}^{m} V_i\, X_{ij} - C_k$

Constraints : $\sum_{i=1}^{m} V_i\, X_{ij} - \sum_{r=1}^{s} U_r Y_{ij} - C_k$

$$\sum_{r=1}^{s} U_r\, Y_{rk} = 1$$

$U_r V_i > 0 \forall\ r = 1$ to s; i = 1 to

The dual version of this linear programming problem is as follows:

Maximize

Constraints :

$$\begin{cases} \theta_k Y_{rk} - \sum_{j=1}^{n} \lambda_j Y_{rj} \leq 0 \\ X_{ik} - \sum_{i=1}^{n} \lambda_j X_{ij} \geq 0, i = 1 \text{ à } n \\ \sum_{j=1}^{n} \lambda_j = 1 \\ \lambda_j \geq 0\ \forall\ j = 1 \text{ à } n \end{cases}$$

Finally, the inclusion of slacks in the model modifies the dual equations as follows:

Maximize $\theta_k + \varepsilon \sum_{r=1}^{s} S_r + \varepsilon \sum_{i=1}^{n} S_i$

Constraints

$$\begin{cases} \theta_k Y_{rk} - \sum_{j=1}^{n} \lambda_i\, Y_{ij} + S_r = 0, \quad r = 1 \text{ à } s \\ X_{ik} - \sum_{j=1}^{n} \lambda_j\, X_{ij} - S_i = 0, i = 1 \text{ à m} \\ \sum_{j=1}^{n} \lambda_1 = 1 \\ \lambda_j, S_r, S_i \geq 0 \\ \forall\ r = 1 \text{ à s};\ i = 1 \text{ à m}; \text{j} = 1 \text{ à n} \end{cases}$$

Tobit model specification

To identify the determinants of technical performance, a model is specified where the dependent variable is a performance score that is continuous within a closed interval. Thus, the standard Tobit censored model is not suitable because the dependent variable does not take zero values (Maddala, 1983; Greene, 1997).

Similarly, the generalized Poisson model cannot be used since the dependent variable does not consist of natural integers (Kobou et al., 2009). To overcome such difficulties, the literature often resorts to the censored Tobit model when explaining the environmental performance of firms, given that the performance levels of production units can take zero, positive, and continuous values within a closed interval.

The Tobit model (Tobin, 1958) is commonly used when there are observations where the endogenous variable takes the value zero, such as when the inefficiency level lies in the interval [0;1[[0; 1[[0;1[. The dependent variable is censored by keeping zero values in the sample.

The censored Tobit model used to explain inefficiency is specified as follows:

ET = a0+Σai Xi + i □

with :

Xi, the explanatory variable,

i = 1,2,...n a0 the constant term ;

ai, the regression coefficient and

□i, the error term

□i = Vi-Ui

The empirical form of the TOBIT model given by $Y_i = f(X_i)$ and the equation will be in the form

$Y_i = \beta_0 + \beta_1 X_i + \beta_n X_n + □_i$

With :

Y_i which represents the dependent variable "Fish farmers' technical efficiency index" (efficiency score in VRS); $X_n$is the vector of variables of interest (farm structure, feed type, fish species produced); $X_i$is the vector of control variables (gender, age, education level, marital status, main activity, secondary activity and membership of a producer organization); and$□_i$is the residual.

RESULTS

Socio-economic characteristics of fish farmers

The following table shows the characteristics of the farmers surveyed according to their fish farming system.

Table 2: Summary characteristics of fish farmers by production system.

Variables	**Pond (n= 171)**	**Fastank (n= 53)**	**Cubitainer (n= 164)**	**Concrete bin (n= 22)**
Sex of respondents				
Men	80,1	84,9	83,5	72,7
Woman	19,9	15,1	16,5	27,3

Age of respondents				
[15-30[	15,8	9,4	18,3	31,8
[30-45[	35,1	62,3	45,7	36,4
[45-60[	33,9	18,9	21,3	18,2
[60-75[	13,5	9,4	9,1	9,1
[75 ; plus[	1,8	/	4,5	4,5
Marital status				
Single	28,7	37,7	38,4	54,5
Married	63,2	60,4	52,4	22,7
Separate	5,8	1,9	0,6	22,7
Divorced	1,8	/	6,1	/
Widowed	0,6	/	2,4	/
Education level				
Didn't go to school	13,5	9,4	5,5	13,6
Primary	17,5	3,8	12,8	13,6
Secondary	34,5	24,5	32,3	18,2
Superior	34,5	62,3	49,4	54,5
Membership to an association				
Yes	19,9	54,7	16,5	22,7
No	80,1	45,3	83,5	77,3
Fish farming training				
Yes	81,9	96,2	94,5	100
No	18,1	3,8	5,5	/
Main activities				
Agriculture	66,1	62,3	57,3	36,4
Trade	56,1	62,3	64	59,1
Civil servant	15,8	11,3	16,5	9,1
Private company agent	5,3	7,5	4,9	22,7
Crafts	5,3	3,8	2,4	/
Fish farm	100	100	100	100
Breeding	24,6	49,1	28	4,5
Household size				
[0-5[	69,6	90,5	80,4	95,4
[5-10[	24,7	9,5	18,2	4,5
[10-15[	3,5	/	1,2	/
[15-plus [	2,4	/	/	/
Experience in <u>Fish farming (year)</u>				
[0-5[	70,2	69,8	76,9	90,9
[5-10[	28,1	30,2	20,7	9,1
[10-15[	1,8	/	1,8	/
[15-plus [	/	/	0,6	/

P values in parentheses

** p < 0.01, * * p < 0.05, * p < 0.1

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This table shows the characteristics of fish farmers surveyed according to the aquaculture system used. The data reveal that men outnumber women in all fish farming systems. Specifically, men represent 80.1%, 84.9%, 83.5%, and 72.7% of operators in pond, Fastank, Cubitainer, and concrete tank systems, respectively, confirming their majority across all systems. However, women also participate, either directly or indirectly, by supporting tasks such as maintenance, daily feeding, and sales. These findings align with Fonkwa et al. (2024), who highlight the low representation of women (32%) compared to men (68%) in fish farming in the Centre region of Cameroon, mainly due to socioeconomic barriers like limited land access.

Fish farming is primarily practiced by individuals aged 30 to 45 years. This age group accounts for 35.1% of pond farmers, 62.5% of Fastank users, 45.7% of Cubitainer operators, and 36.4% of concrete tank farmers, indicating a relatively young workforce. Younger fish farmers appear more willing to adopt and try new techniques. Regarding education, 34.5% of pond farmers have a higher education level, while this proportion increases to 62.3% for Fastank, 49.4% for Cubitainer, and 54.5% for concrete tanks. The results also indicate that household size influences the choice of production system, with about 70% of farmers across all systems having households with fewer than five members. These results are consistent with the observations of Dongué (2021), who found that fish farmers in the Centre region are mostly young, aged between 30 and 45.

Moreover, the results in Table 2 show that approximately 28% (on average) of the fish farmers surveyed (pond, Fastank, Cubitainer, and concrete tank) belong to producer organizations. This percentage varies depending on the production system used. The results also indicate that the majority of fish farmers using both in-ground systems (pond) and off-ground systems (Fastank, Cubitainer) have received training in fish farming, while 100% of those using concrete tank systems have undergone training in aquaculture. Experience in fish farming also varies according to the farming system employed.

Characteristics of production units and farmed areas

Table 3: Characteristics of production units by study region

Structures operated						
Regions		**Average**	**Standard deviation**	**Minimum**	**Maximum**	**Sum**
Center	Pond	2,35	1,184	1	6	167
	Fastank	2,52	1,768	1	8	78
	Cubitainer	1,92	1,038	1	4	25
	Concrete tub	3,7	0,823	2	5	37
Littoral	Pond	3,03	1,636	1	8	106
	Fastank	2	1,732	1	4	6
	Cubitainer	4,07	2,794	1	14	354
	Concrete tub	6	3,098	4	10	36
West	Pond	2,29	1,111	1	6	96
	Fastank	2,2	1,74	1	8	33
	Cubitainer	3,02	2,385	1	10	148
	Concrete tub	3,8	0,447	3	4	19
Surface area (m^2))						
Center	Pond	920,43	622,881	20	2400	63510
	Fastank	3,39	2,486	1	8	105
	Cubitainer	1,75	0,866	1	4	21
	Concrete tub	4,5	2,014	2	8	45
Littoral	Pond	256,37	289,478	4	1200	8973
	Fastank	3,33	4,041	1	8	10

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	Cubitainer	3,8	2,675	1	14	334
	Concrete tub	6	3,098	4	10	36
West	Pond	878,78	590,623	30	2400	36030
	Fastank	2,87	2,232	1	8	43
	Cubitainer	2,55	1,98	1	10	125
	Concrete tub	5,4	2,408	3	8	27

According to the table, the number of ponds exploited in the Centre region varies between 1 (minimum) and 6 (maximum), with an average of 2 ± 1.2 ponds per farm. In the other regions, it is rather the number of cubitainers (above-ground tanks) that varies : from 1 (minimum) to 14 (maximum) with an average of 4 ± 2.7 per farm in the Littoral region, and from 1 (minimum) to 10 (maximum) with an average of 3 ± 2.3 per farm in the West region. The low use of Fastanks can be explained by their high cost on the Cameroonian market. Very few fish farmers use these structures, and those who do often adapt them differently. Regarding the total surface area of ponds exploited in the Centre region, it amounts to 63,450 m², ranging from 20 m² (minimum) to 2,400 m² (maximum), with an average of 920.4 ± 622.8 m² per farm. The total surface area of cubitainers exploited is 354 m² in the Littoral region, ranging from 1 to 14 m², with an average of 4 ± 2.7 m², and 148 m² in the West region, ranging from 1 to 10 m², with an average of 3 ± 2.3 m².

Finally, for concrete tanks, the total surface area exploited is 37 m² in the Centre region, ranging from 2 m² (minimum) to 5 m² (maximum), with an average of 3.7 ± 0.8 m² per farm. In the Littoral region, it is 36 m², with a minimum of 4 m² and a maximum of 5 m², and an average of 6 ± 3 m². In the West region, the total surface area is 27 m², ranging from 3 m² to 8 m², with an average of 5.4 ± 2.4 m².



Photo 1: Bins **Photo 2**: Cubitainers **Photo 3**: Concrete tub

Fish species produced

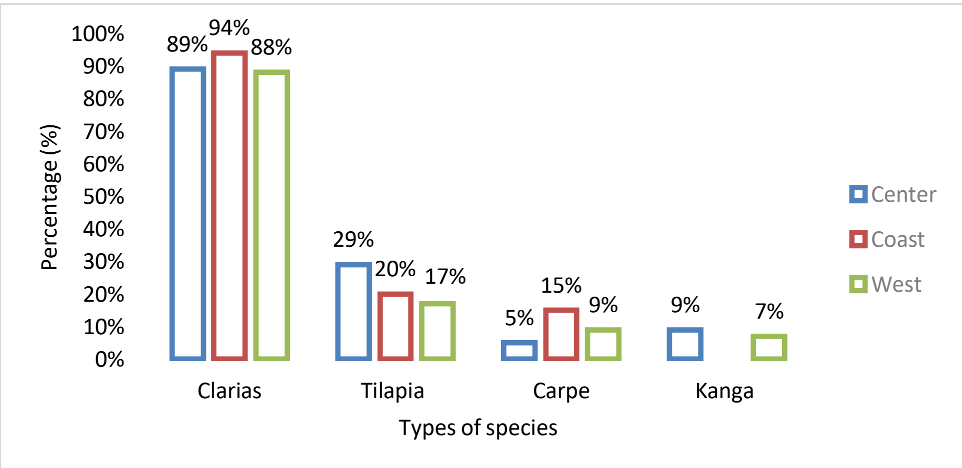

Figure 2: Distribution of fish farmers according to species recorded

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This figure shows that Clarias is the most produced species in the three studied regions of Cameroon. In the Centre region, 89% of farms exclusively raise Clarias, with an average production of 1,995.5 ± 1,588.91 fish per farm. In the Littoral region, this proportion reaches 94%, with an average of 3,352.02 ± 2,807.96 fish, while in the West region, 88% of farms produce Clarias, with an average of 2,101.02 ± 1,466.18 fish. Tilapia is also present but in smaller proportions: 29% in the Centre, 20% in the Littoral, and 17% in the West. Finally, a small but not negligible proportion of carp and kanga production is observed in each region.

This situation can be explained by several factors. On one hand, the high market demand for Clarias favors its production. On the other hand, its morphological characteristics play a key role: Clarias grows quickly and gains weight in a short time, making it an attractive species for fish farmers. Additionally, although produced less, Tilapia has the advantage of spontaneous reproduction in captivity, thus reducing the cost of purchasing fingerlings each production cycle and meeting household food needs. According to respondents, the cost of Clarias fingerlings is also more affordable (100 to 150 FCFA) compared to other species such as Tilapia or Carp, whose fingerlings cost on average 200 FCFA and are sometimes of lower quality.

Regarding the low productivity of kanga, it can be explained by several constraints. Kanga is a freshwater fish that depends on specific ecosystems, such as fast-flowing rivers or basins of the Congo River, which are scarce in Cameroon. Additionally, this species is poorly suited for captive breeding due to its carnivorous diet and particular environmental requirements. Aquaculture techniques for kanga are also underdeveloped or even nonexistent in the country. Finally, its low commercial popularity discourages investment in its production. These observations are supported by the work of Moustapha Soumahoro (2021) in the Centre region, where the majority of kanga fingerlings come from wild captures. Wikondji et al. (2023) also confirm this trend, noting that 87.50% of kanga fingerlings are collected from rivers and sold at an average price of 130 FCFA in the Centre and South regions.

Technical efficiency of fish production

The analysis of technical performance allows us to evaluate the efficiency thresholds of different farms within their respective farming systems. The variables used for estimating the DEA model, such as area, fish quantity, number of fingerlings, amount of feed, labor, and quantities of disinfectants and fertilizers, are presented in the table. Table 4 shows the characteristics of the variables used in the DEA model for the overall sample. Among the 300 surveyed fish farms, the average total area used per farm is 759.95 ± 621.9 m², with the smallest area being 8 m² (corresponding to off-ground infrastructures) and the largest area being 2432 m² (corresponding to ponds). The average number of fingerlings used is 118,793 units, with a minimum of 600 and a maximum of 260,000, and the average production per cycle is 2665.65 ± 2988.98 kg of fish. The amount of feed ranges from 5 to 1050 bags of 15 kg each, with an average of 38.16 ± 68.18.

Table 4: Descriptive statistics for DEA model variables

Variables	Units	Average	Standard deviations	Min	Max
Area	M2	759,95	621,95	8	2432
Quantity of fish	Kg	2665,65	2988,98	200	27000
Average weight	Gr	614,83	125,329	300	800
Number of fry	U	118793,1	90254,16	600	26000
Feed quantity	Bags	38,16	68,18	5	1050
Workforce	Men/years	96851,61	178113,45	6000	1500000
Quantity of disinfectants	Kg	8889,61	5310,16	400	30000
Quantity of fertilizer	Bags	10482,33	9346,03	1500	80000

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Technical efficiency of fish farms according to farm structure

Table 5: Technical efficiency estimates for fish farms

	Pond (n=171)		**Fastank (n=53)**		**Cubitainer (n=164)**		**Concrete tub (n=19)**		**Total (average)**		**Chi2 (χ^2)**
	Efficiency	%	Efficiency	%	Efficiency	%	Efficiency	%	Efficiency	%	
VRS	67	39%	50	94%	49	30%	13	64%	45	56%	30,54* (0,091)
CRS	47	27%	40	40%	33	20%	6	31%	36	30%	36,11** (0,012)
Estimated efficiencies											**ANOVA**
Mean VRS score	0,828		0,991		0,754		0,932		0,876		13,59*** (0,000)
Mean CRS score	0,693		0,951		0,634		0,897		0,793		20,93*** (0,000)

P-values in brackets

** p < 0.01, * * p < 0.05, * p < 0.1

The descriptive statistics of pure technical efficiency scores, measured under the variable returns to scale (VRS) assumption, reveal that the average technical efficiency score of fish farmers is 0.876. This indicates that, on average, they could reduce the use of production factors by 12.4% (1 – 0.876) to achieve optimal production. Among the production systems, fish farmers using Fastank and concrete tank systems show the highest efficiency scores, with respective averages of 0.991 and 0.932. Next come pond systems, with an average score of 0.828, followed by cubitainer systems, with an average score of 0.754. These results highlight significant differences in technical efficiency depending on the production systems used.

Under the constant returns to scale (CRS) assumption, the average overall technical efficiency score of the fish farms is 0.793. This implies that fish farmers could reduce input use by 20.7% (1 – 0.793) to reach optimal production, indicating a moderate level of technical efficiency in these production units. Among the production systems, Fastank and concrete tank systems display the highest efficiency scores, with respective averages of 0.951 and 0.897. They are followed by pond systems (average score of 0.693) and cubitainer systems (average score of 0.634), confirming significant efficiency disparities according to the production methods employed.

Table 5 shows that, according to the VRS model, 56% of the studied fish farms are technically efficient, with a VRS efficiency score of 1, while 44% are technically inefficient. This indicates suboptimal input use and the need for fish farmers to reduce their consumption. In the CRS model, 36% of fish farmers have an efficiency score of 1, and 64% are technically inefficient. Efficient fish farmers, whether according to the VRS or CRS model, are mainly those producing with Fastank and concrete tank systems, with respective efficiencies of 94% and 64% according to the VRS and CRS models.

The results show that fish farms are generally technically inefficient, with efficiency levels varying according to the production system. Inefficiency is particularly pronounced among producers using pond and cubitainer systems. The technical excellence of Fastank systems (VRS score 0.991) and concrete tanks (0.932) corroborates the findings of Yempabou et al. (2023) in Burkina Faso, where efficiency scores were 0.94, surpassing traditional ponds (0.82), and is slightly higher than Aboua (2016), who estimated that only 40% of fish farms are technically efficient under the VRS assumption. Moreover, our conclusions contrast with those of Ajonina et al. (2024), who demonstrate that in Nigeria, clay soil ponds achieve an efficiency of 0.95 (VRS) due to traditional water management, as well as with Oluwatayo and Adedeji (2019), who

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highlight that efficiency estimates vary according to production technologies, with producers using earthen ponds being the most efficient.

Determinants of technical efficiency

We used the Tobit model to identify the factors influencing the technical efficiency of fish farms. The analysis considered five explanatory variables grouped into two categories: socioeconomic variables (training and farming experience) and technical variables (farming system, fish species raised, and type of feed). Table 6 presents the results, with the efficiency score under both VRS and CRS assumptions serving as the dependent variables.

Table 6: Characteristics of the influence of fish farming systems on technical efficiency using Tobit model estimates

Variables	Efficiency score	
	VRS	CRS
Production system (Ref= Pond structure)		
In Fastang	0,091$^{(***)}$ (0,002)	0,105$^{(***)}$ (0,000)
In a Cubitainer	-0,1*** (0,000)	-0,066$^{(**)}$ (0,011)
E Concrete pan	0,006 (0,88)	-0,019 (0,6)
Fish farming training (Yes)	0,057$^{(*)}$ (0,072)	0,025 (0,421)
Type of feed (Ref=local)		
Imported food	-0,01 (0,779)	0,029 (0,406)
Imported feed +waste	-0,016 (0,438)	0,007 (0,738)
Imported + local food	0,061$^{(***)}$ (0,006)	-0,032 (0,149)
Local food + waste	-0,011 (0,715)	0,086$^{(***)}$ (0,005)
Year of experience (Ref= <5 years)		
5-10 years	-0,007$^{(*)}$ (0,076)	0,008 (0,046)**
Over 10 years	0,318	0,278***
	(0,129)	(0,087)
Fish species produced (Ref=Clarias)		
Tilapia	0,007 (0,787)	0,002 (0,948)
Carpe	0,034 (0,333)	-0,01 (0,767)
Kanga	0,027 (0,481)	-0,034 (0,373)
Var(e.vrste)	0,717$^{(***)}$ (0,000)	
Var(e.crste)		0,695$^{(***)}$ (0,000)
Constant	0,086 (0,611)	-0,029 (0,86)
Comments	300	300

P-values in brackets

** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$

Table 6 outlines the determinants of technical efficiency in fish farming production, demonstrating that the farming system significantly influences technical efficiency. Compared to pond systems, the off-ground system (Fastank) is associated with a significant increase in technical efficiency. Specifically, it raises the VRS efficiency score by 0.091 and the CRS score by 0.105. Conversely, the cubitainer system reduces technical efficiency by 0.1 (VRS) and 0.066 (CRS) compared to the pond system. Compared to the concrete tank system, it leads to a 0.006 increase in VRS efficiency and a 0.019 decrease in CRS efficiency. The cubitainer system is less efficient than the pond system under both CRS and VRS assumptions.

Oluwatayo and Adedeji (2019) support these findings by showing that efficiency estimates under VRS and CRS assumptions vary depending on the production technologies used, with pond systems being the most efficient production structure.

In addition to the production system, technical efficiency scores are influenced by the species of fish raised. Table 6 indicates that, under the VRS assumption, tilapia farming is associated with a higher technical efficiency score of 0.007 compared to clarias. This suggests that tilapia farming could be more efficient under variable returns to scale, although the effect is not significant under the CRS assumption.

This finding aligns with the conclusions of Iliyasu, Mohamed, and Ismail et al. (2016), who reported that tilapia farms are the most technically efficient in Malaysia. Similarly, Kariyawasam et al. (2021), in their study on efficiency differences between tilapia and catfish (clarias) farming using DEA methods in Sri Lanka, found that tilapia farming is more efficient than clarias farming.

The estimates also show that access to fish farming training has a positive impact on efficiency under VRS. Specifically, under the VRS assumption, fish farming training is associated with a significant increase in technical efficiency by 0.057. However, this effect is not statistically significant under the CRS assumption. The fact that trained fish farmers better understand production cycles, resource use, and overall farm management may explain the positive impact of training.

Experience in fish farming also impacts technical efficiency. Under the VRS assumption, 5 to 10 years of experience in fish farming is associated with a slight decrease in efficiency (0.007). However, more than 10 years of experience leads to an increase in technical efficiency scores by 0.318 (VRS) and 0.278 (CRS). This suggests that intermediate experience levels might be less efficient, potentially due to an incomplete mastery of advanced production techniques. These findings are consistent with those of Radhakrishnan et al. (2021), who reported that more years of experience improve shrimp production efficiency. Experienced fish farmers are more likely to optimize input use, have better training opportunities, and learn from past mistakes, supporting these results.

However, the variances of the error terms in our models are significant under both the VRS and CRS assumptions. This suggests that there remains unexplained variability in efficiency scores under both assumptions. While the model accounts for a substantial portion of the variation in technical efficiency, it does not consider other unobserved factors likely to influence efficiency, such as access to financing, support, and skilled labor.

DISCUSSION

The main objective of this study was to determine the current level of technical efficiency of fish farmers in Cameroon. This study was conducted on a random sample representative of the population, with a sampling rate of 56%. The results obtained from the sample can therefore be generalized to the population of fish farmers in Cameroon.

The findings reveal that fish farmers in Cameroon are technically inefficient. This implies that they could increase their current production levels by optimizing the combination of available productive resources, as indicated by the analyses.

The results also highlight significant trends in demographics, fish farming practices, and technical performance, while bringing attention to structural challenges and opportunities for improvement.

There is a male dominance in fish farming, with more than 70% of fish farmers being men across all production systems. This trend reflects socio-economic constraints, particularly women’s limited access to land and financial resources, as noted by Fonkwa et al. (2024). However, women play an important indirect role in maintenance and marketing, suggesting the need for inclusive policies to enhance their active participation. The average age of fish farmers ranges between 30 and 45 years, indicating a relatively young and dynamic population, open to adopting new techniques. This observation aligns with the findings of Dongué (2021), which emphasize that younger farmers are more likely to innovate. Moreover, the level of education influences the choice of production systems. Farmers utilizing soilless systems (Fastank, concrete troughs) generally possess higher levels of education, which may facilitate the adoption of advanced technologies. Membership in Associations and Training in Fish Farming: Belonging to associations and receiving training in fish farming are also key factors. Trained fish farmers organized into cooperatives demonstrate better technical efficiency, highlighting the importance of training and capacity building in improving aquaculture practices.

Production system characteristics and technical performance

The analysis of production systems reveals a predominance of traditional ponds, although soilless systems (Fastank, cubitainer, concrete tanks) are gaining popularity, particularly in urban areas where access to land is limited. However, the high costs of soilless infrastructure (notably Fastank) remain a barrier to their widespread adoption.

Technical efficiency, evaluated using DEA analysis, shows that Fastank and concrete tank systems are the most efficient, with average efficiency scores exceeding 0.90 under the VRS assumption. These systems enable better management of inputs (feed, water, disinfectants) and optimized production. In contrast, ponds and cubitainers exhibit lower efficiency scores, mainly due to less controlled resource management and increased losses (predation, diseases).

These results corroborate the findings of Yempabou et al. (2023) in Burkina Faso, where efficiency scores under the VRS assumption were 0.94, but they differ from those of Oluwatayo and Adedeji (2019), who observed higher efficiency in earthen ponds. This difference could be explained by distinct agroecological conditions and cultural practices between the studied regions. Our results suggest that adopting intensive systems (Fastank, concrete tanks) could improve productivity but requires significant initial investments and easier access to quality inputs.

Influence of reared species and feeding practices

Clarias overwhelmingly dominates fish production in the three regions due to its rapid growth, resilience to farming conditions, and strong market demand. Tilapia, although less widespread, shows promising potential thanks to its spontaneous reproduction, which reduces the costs of fingerlings. The analysis of the determinants of technical efficiency (Tobit model) confirms that tilapia farming is associated with a slight improvement in efficiency (VRS), supporting the findings of Iliyasu et al. (2016) in Malaysia. Training in fish farming significantly improves technical efficiency, highlighting the importance of capacity-building programs, and experience in fish farming has a positive impact, but only after 10 years of activity, suggesting a gradual learning curve.

The results of this study raise several issues for the development of aquaculture in Cameroon, including the promotion of intensive systems (Fastank, concrete troughs) through subsidies or tailored credit schemes, while strengthening access to quality inputs. It is also important to reinforce training and technical support, particularly for farmers using ponds and cubitainers, to optimize resource use. Encouraging species diversification by supporting tilapia production—which is less dependent on commercial fingerlings—and developing adapted techniques for other species such as kanga are also key. Finally, promoting the inclusion of women in the aquaculture sector by facilitating their access to land and financing is essential.

Ultimately, this study highlights the potential of Cameroonian aquaculture, as well as the challenges related to technical efficiency and the adoption of good practices. An integrated approach, combining technological innovation, capacity building, and incentive policies, could significantly improve the productivity and sustainability of the sector. Further research could explore the impact of external factors (climate, market) on

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technical efficiency, as well as the possibilities for integrating aquaculture with other agricultural activities (agro-aquaculture).

CONCLUSION

The present study aimed to identify the factors influencing the choice of production system, the technical efficiency of fish farms, and to measure the impact of production systems on this efficiency. We found that pond culture is the most widespread system, influenced by factors such as the farmer's gender, household size, access to training, education level, and fish farming experience. The average technical efficiency scores are 0.876 (VRS) and 0.793 (CRS), indicating room for improvement. Fastank and concrete trough systems are more efficient than others, with access to training, experience, and the diversity of species raised being key determinants of efficiency.

These results provide valuable insights for policymakers and both current and future fish farmers by identifying key parameters to improve technical efficiency and economic gains. Despite the emergence of modern systems, ponds remain the most commonly used and effective. Training programs should be developed to strengthen fish farmers' skills and optimize resource use. Finally, diversification towards tilapia farming and the optimization of practices are recommended.

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