Original Research Article

Resource Efficiency and Economic Efficiency of Fish Farms in the Southeast of Côte d'Ivoire

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ABSTRACT

Fish farming is considered a complement to fish production in Côte d'Ivoire. Better use of resources in the production process would ensure sustainable fish production. This study analyzes the resource efficiency and economic efficiency of 32 fish farms in the southeast of Côte d'Ivoire using a data envelopment analysis (DEA) model and cost-benefit analysis. The results revealed that fish farmers showed low performance, with average technical efficiency scores of 0.738 (CRS) and 0.575 (SBM) and an average economic score of 0.553. Fish farmers using industrial feed are the most technically and economically efficient. Through DEA model scenarios, the study shows that fish farmers generated excesses in resource utilization, causing a shortfall in output. Scenario-3 based on the slack-based model minimizing resources simultaneously with a maximization of output indicated that a reduction of excesses in resources would have increased the output by 16.18%. Finally, the cost benefit analysis shows that, overall, fish farms achieved a positive gross and net profit margin. This study suggests that policy actors should play an important role in facilitating fish farmers' access to feed and quality fingerlings. In addition, fish farmers must be trained on good practices for sustainable production and pond management.

Keywords: Côte d'Ivoire, DEA, economic efficiency, fish farming, resource efficiency

1. INTRODUCTION

Aquaculture is recognized as a sub-sector in the fisheries industry that has experienced the most rapid growth in fish production in the world. This sub-sector will contribute to a large part of fish production by 2030, marked by the doubling of tilapia production from 4.3 to 7.3 million tons per year from 2010 to 2030 (World Bank, 2013). It is estimated that aquaculture will soon account for approximately half of the world fisheries production and will provide nearly 62% of fish consumption. To achieve these objectives, the aquaculture sector should be able to improve productivity while promoting sustainable practices (Waite et al., 2014). This means an increase in fish output relative to an efficient use of resources (land, water, feed, energy) and a minimization of water pollution, fish diseases and losses.

Côte d'Ivoire demonstrated its interest in aquaculture development as far back as the colonial era through aquaculture research. The natural asset of the country for the practice of aquaculture is characterized by its openness to the Atlantic Ocean and inland waters. Nearly 60% of its territory is served by a permanent water system (MIPRAH, 2003) [1]. However, the contribution of aquaculture to national fish production is still marginal. In 2000, the total production was approximately 1,200 tonnes. In recent years, it has been estimated to be 4,500 tonnes, representing 5.7% of national fisheries production (DAP, 2014)[2]. The production is dominated by tilapia (*Oreochromis niloticus),* which account for 90%, followed by African catfish (*Heterobranchus longifilis* and *Clarias gariepinus*) and catfish (*Chrysichthys nigrodigitatus*) (MIPRAH, 2009). Despite the production increase, several constraints were identified as hindering the development of aquaculture.

The Strategic Plan for Livestock Development, Fisheries and Aquaculture (2014-2020) underlined some constraints directly related to aquaculture production. These include (i) low availability of fingerlings; (ii) low availability and quality of feed; (iii) inappropriate water management; (iv) poor knowledge of aquaculture management techniques; and (v) insufficient support of aquaculture extension services.

Feed is an essential input in aquaculture production. Fish farmers use either industrial feed or reformulate feed from agricultural by-products or leftover food. Since industrial feed has a high cost and is not accessible to all fish farmers, they reformulate the fish feed themselves. The reformulated feed is sometimes of poor quality, which can affect productivity and result in significant economic losses related to low quality, low weight and high fish mortality [46,47]. This suggests the importance of measuring the productive and economic efficiency of fish farmers in Côte d'Ivoire to assess their level of performance and identify ways to improve them.

Several studies have focused on productive efficiency and profitability analysis of aquaculture in Sub-Saharan Africa at the farm level (Bukenya et al., 2013; Ougandari & Akinbogun 2010; Onumah & Acquah, 2010; Kareem et al., 2009; Brummett et al., 2004; Kaliba et al., 2006; Kaliba et al., 2007; Hyuha et al., 2011; Boateng et al., 2013; Ideba et al., 2013). These studies used stochastic frontier analysis (SFA) or data envelopment analysis (DEA) to estimate the efficiency score and its determinants. In contrast to these approaches, our study analyzes resource efficiency and economic efficiency. It aims first to identify the efficiency of the use of resources, the slacks in the resources (excesses) and output (shortfall) using DEA models. It also determines the profitability of fish farms using cost benefit analysis. We apply our methodology to 32 fish farms in the southeast of Côte d'Ivoire surveyed in 2009. Indeed, in 2005, the south of the country was still the area of high fish production with 82.34% of total aquaculture production or 713.12 tonnes, followed by the central west with 14.43% or 125 tonnes and the east with 3.28% or 28 tonnes (MIPRAH, 2009).

This study aims to contribute to the existing literature on the analysis of productive efficiency and profitability in aquaculture. In addition, knowledge of the level of productive and economic performance of fish farms in Côte d'Ivoire could be useful for policy makers to develop policies that will ensure the viability and sustainability of aquaculture.

The rest of the study is organized as follows. Section 2 focuses on the literature on efficiency measures and empirical studies related to the productive efficiency and profitability of aquaculture. Section 3 describes the methodologies of the study. Section 4 presents the data and the area of the study. Sections 5 and 6 present the results and the discussion, respectively. The final section concludes the study.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

This section has two parts. The first part discusses the concepts and measures of efficiency. The second part presents the empirical work on the technical efficiency and profitability of aquaculture in Sub-Saharan Africa.

2.1 Concepts and measures of efficiency

The efficiency measurement began with the work of Farrell (1957) inspired by those of Koopmans (1951) and Debreu (1951). It is intimately related to the estimation of the production frontier based on the distance function. Farrell (1957) distinguished between technical efficiency and allocative efficiency.

The concept of technical efficiency refers to the ability to produce maximum output from a given set of inputs. Allocative efficiency is defined as the ability of the production unit to combine the inputs in optimal proportion, given their respective prices and the technology of production. The product of technical efficiency and allocative efficiency determines the economic efficiency or overall efficiency. It can be interpreted as the potential reduction of production costs (cost efficiency) or a potential increase in revenue (economic efficiency). Economic efficiency enables one to draw conclusions on the opportunity of a production unit to operate at the optimal or suboptimal size.

In microeconomic theory, producer behaviour is generally characterized by profit maximization or cost minimization. Thus, the choice of economic efficiency measurement depends on the availability of inputs or outputs prices. Cost efficiency is defined as the ratio of observed cost to minimal cost. It is the measure of economic efficiency oriented-input proposed by Farrell (1957). Revenue efficiency is estimated as the ratio of revenue obtained and optimal revenue. It is the measure of economic efficiency-oriented outputs introduced by Färe et al. (1985). These ratios are called efficiency scores and are bounded between 0 and 1. A production unit is efficient if the calculated score is equal to 1; otherwise, the production unit is inefficient. The efficiency analysis helps one to know the best level of resources to be used to achieve a maximum level of output and the level of resource and output slacks. It also allows one to analyze resource efficiency and output efficiency. Resource efficiency is a means of sustainable production and is defined as the creation of more value with fewer resources.

In practice, two approaches can be used to measure efficiency: stochastic frontier analysis (parametric approach) and data envelopment analysis (nonparametric approach). In the presence of multiple outputs, the DEA approach proposed by Charnes et al. (1978) is the most appropriate. It allows one to calculate the efficiency scores and the input and output slack values and to identify the production units that are fully efficient. The efficiency scores are determined by optimizing the DEA model either in constant returns or in variable returns. In addition, the DEA model can be optimized following the orientation of the production unit objective. The input-oriented DEA models consider the possible (proportional) input reduction while maintaining the current levels of outputs. The output-oriented DEA models consider the possible (proportional) output augmentation while maintaining the level of inputs. However, these standard DEA models do not take into account slacks in the "objective function". Charnes et al. (1985) developed an additive DEA model that considers a possible input decrease as well as output increase simultaneously.

This model provides a measure of non-equi-proportional efficiency scores, unlike the standard models that provide equi-proportionate efficiency scores. It identifies the efficient units of those inefficient. However, it does not measure the intensity of inefficiency or standard models (Tone, 2001). In these respects, Tone (2001) proposed a slack-based model (SBM) that optimizes the input and output slacks and provides a pure measure of efficiency.

2.2 Empirical Review on productive efficiency and profitability of fish farming

2.2.1 Productive Efficiency

There is a substantial empirical literature on the economic analysis of fish farming in Sub-Saharan Africa, mainly focused on "tilapia". These studies evaluated technical, allocative and economic efficiency on the one hand and profitability on the other hand. Studies have shown that fish farms do not reach their potential level of output, yet they are still profitable. Kareem et al. (2009) estimated the technical, allocative and economic efficiencies of 85 tilapia fish farmers using concrete and earthen pond systems in Ogun State. The results of the study revealed that the economic efficiency of the concrete pond system was 76%, while the economic efficiency of the earthen pond system was as high as 84%. Both systems have almost the same level of technical efficiency, with 88% for concrete ponds and 89% for earthen ponds. The study also revealed that the allocative efficiency was 79%, while earthen ponds had 85%. Analyzing the inefficiency model, the study found that farmers' experience is the only source of efficiency.

Onumah & Acquah (2010) applied the single-stage modeling stochastic frontier approach to examine the technical efficiency and its determinants of 150 fish farming polycultures (tilapia, catfish and carp) in southern Ghana. The results of the study revealed that the technical efficiency score of fish farms ranged from 34.3% to 98.4%, with an average of 80.8%. The study found that gender and cultural system (monoculture) are the principal sources of efficiencies. By interacting variables in the inefficiency model, the study also found that older fish farmers with more experience, older fish farmers benefiting from extension service and those who received formal education and training were more technically efficient.

Ougandari & Akinbogun (2010) modelled and estimated the technical efficiency with the production risk input of 64 fish farms in Oyo State in southwestern Nigeria. The empirical findings of the study showed that mean fish output is significantly influenced by labour, fertilizer, and feed. Fertilizer and feed are found to be risk-increasing inputs, while labour is revealed to be a risk-reducing input. The study indicated that the technical efficiency is estimated to be 92.21% without risk and 79.21% with risk, showing that the efficiency score is overstated when the production technology of the fish farms is modelled without the flexible risk component. The study revealed that experience, training, and market access are the factors that decrease technical inefficiency.

Bukenya et al. (2013) used the stochastic frontier production function to examine the efficiency of resource utilization of 200 small-scale fish farms in three major districts in central Uganda. They found that small-scale farmers were inefficient in resource allocation by overutilizing labour with an allocative index of -0.94 and grossly underutilized pond size, feed and fingerlings with allocative efficient indices of 1.15, 1.64, and 3.71, respectively. Estimating the determinants of technical efficiency, the study found that access to extension service, access to credit, and possession of a farm register are the key factors to improve technical efficiency.

2.2.2 Profitability

Brummett et al. (2004) evaluated the profitability of five intensive aquaculture farms in the peri-urban area of Cameroon using cost-benefit analysis. The study showed that the profit varies considerably among farmers. Two fish farms made losses, and the other three were profitable, with an annual net profit ranging between 0.3 million FCFA (545 USD) and 3.87 million FCFA (7036 USD). The average net profit represents 34% of the total revenue. The study indicated that fish farmers could improve profitability if they adopted best practices in feeding and fish stocking.

Kaliba et al. (2006) examined the profitability of three systems of Nile tilapia culture (mixed culture of tilapia, tilapia with catfish as predatory and sexed male tilapia) of 85 fish farms in Tanzania. The study used a gross margin approach applied to two pond sizes (150 m^2 and 300 m^2) and found that all cultural systems are profitable. The systems of tilapia with catfish as predatory and sexed male tilapia showed higher profit margins estimated to be 0.27 and 0.47, respectively, with pond sizes of 150 m^2 and 0.23 and 0.30, respectively, with pond sizes of 300 m^2. However, mixed culture tilapia generated less profit and does not ensure sustainable economic viability.

Kaliba et al. (2007) performed the same analysis in Kenya based on 138 fish farmers operating in pond sizes of 200 m^2 and 634 m^2. They found that a pond size of 634 m^2 generated more profit; however, the profit margin is higher, with a pond size of 200 m^2 estimated at an average of over 50 percent. The study also revealed that sexed male tilapia showed higher profit regardless of the size of the pond; however, the profit from mixed culture of tilapia was low, and the economic viability was not sustainable. Hyuha et al. (2011) determined the profitability of 200 small aquaculture businesses in central Uganda. Through cost-benefit analysis, they showed that small aquaculture businesses are profitable, but profits remain relatively low. On average, aquaculture businesses achieved a net profit of 41 USD per pond per cycle. In addition, for each pond, 1 USD invested gives a return of 0.05 USD.

Boateng et al. (2013) evaluated the profitability of 80 fish farmers of male tilapia in the Ashanti Region of Ghana. They employed gross margin analysis. Their results showed that the average annual profit is estimated to be GH¢5282.17 (3521 USD), representing 65% of the total sales. They also found that the return on investment was 0.91, meaning that GH¢ 1 invested gives a profit of GH¢ 0.91 (0.6 USD). They also concluded that fish farming is considerably profitable in the Ashanti Region of Ghana. In addition, Ideba et al. (2013) estimated the gross margin of 36 fish farmers of tilapia and catfish in Calabar Cross Rivers State in Nigeria. The results of the study revealed that fish farmers in this region were profitable, with a gross margin ranging between 400,000 Naira and 700,000 Naira per year (2500 USD to 4375 USD). They further found that 89% of fish farmers made a profit ranging from 200,000 naira to over 3.5 million naira (1250 USD - 21875 USD).

Similar to these previous studies, the present research analyzes resource efficiency and economic efficiency by adopting a different approach. It shows in what proportions the resources should be used efficiently to increase the output level. It also evaluates the profitability of the 32 fish farms in the southeast of Côte d'Ivoire.

3. METHODOLOGY

Our methodology first used DEA approaches to estimate the technical and economic efficiency score as well as the resource efficiency through scenarios (Oriented-input, Oriented-output and slacked based Model). Afterwards, we applied a cost-benefit technique to determine the profitability of fish farms in the study area.

3.1 Data Envelopment Analysis

Suppose n Decision Making Unit $\left(DMU_j : j = 1,2,...,n\right)$ using m inputs $x_{ij}(i = 1,2,...,m)$ to produce s outputs, $y_{rj}(r = 1,2,...,s)$. y_{rj} is the output r of DMU_j, and x_{ij} is the input i of DMU_j. The relative efficiency h_{j_0} for the benchmarking DMU_{j0} is determined as follows (Charnes, et al., 1978):

Model 1: Standard Models (primal and dual)

$$Maximize \quad h_{j_0} = \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}}$$

$$\text{S/C} \left\{ \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}} \right. \qquad (1)$$

$v_i \geq 0,\ u_r \geq 0$, avec $i = 1,2,...,m$ and $r = 1,2,3,...,s$

v_i and u_r are the weights of each input and output, respectively. The relative efficiency h_{j_0} is defined as the ratio of weighted output to the weighted inputs. By introducing slack variables s^- and s^+, the maximization program (primal model) is transformed into a minimization program (dual model). The dual model is described as follows:

$$Minimize\ \ \theta \qquad (2)$$

$$\text{S/C} \begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + s_j^- \leq \theta x_{ij_0} \\ \sum_{j=1}^{n} \lambda_j y_{rj} - s_j^+ \geq y_{rj_0} \\ s^- \geq 0,\ \mathrm{s}^+ \geq 0,\ \lambda_\mathrm{j} > 0 \end{cases}$$

By adding the constraint $\sum_{j=1}^{n} \lambda_j = 1$, we obtain the BCC model developed by Banker et al. (1984), which allows one to take into account returns of scale. θ is the efficiency score to be estimated. s^- and s^+ are slack variables representing the excess in inputs and deficit in output. λ_j is a scalar positive vector. The optimal solution of the program above is to determine ($\theta^*,\ \lambda_j^*,\ \mathrm{s}_j^{-*},\ \mathrm{s}_\mathrm{j}^{+*}$). DMU_{j0} is efficient if $\theta^* = 1$, and $s_{j_0}^{-*} = 0$, $s_{j_0}^{+*} = 0$. DMU_{j0} is weakly efficient if $\theta^* = 1$ and $s_{j_0}^{-*} \neq 0$, $s_{j_0}^{+*} \neq 0$. If $\theta^* < 1$, DMU_{j0} is said to be inefficient.

Model 2: Slack-Based Model

The slack-based model (SBM) developed by Tone (2001) is based on the additive DEA model. It takes into account slacks (inputs and output) in the efficiency measure, unlike standard DEA models. The SMB DEA model is set as follows:

$$\underset{\lambda, s^-, s^+}{Min}\ \rho = \frac{1 - \frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{i0}}{1 + \frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{r0}} \qquad (3)$$

$$\text{S/C} \begin{cases} x_{ij_0} = \sum_{j=1}^{n} \lambda_j x_{ij} + s_j^- \\ y_{rj_0} = \sum_{j=1}^{n} \lambda_j y_{rj} - s_j^+ \\ s^- \geq 0,\ \mathrm{s}^+ \geq 0,\ \lambda_\mathrm{j} > 0 \end{cases}$$

ρ represents the efficiency score. The ratio ρ is defined as the mean reduction rate in inputs to the mean expansion rate to output. In other words, the SBM efficiency score is interpreted as the product of output and input inefficiencies. s^- and s^+ are slack variables representing the excess in inputs and deficit in output. DMU_{j0} is SBM-efficient if $\rho = 1$, $s^{-*} = 0$ and $s^{+*} = 0$, meaning zero slack in inputs and output.

Model 3: Economic efficiency (Revenue efficiency)

The revenue efficiency is obtained by maximizing the program below:

$$Maximize \quad \sum_{r=1}^{s} p_{rj_0} y_{rj_0} \tag{4}$$

$$\text{S/C} \begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + \le x_{ij_0} \\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rj_0} \end{cases}$$

p_{rj_0} represents the price of output r and λ_j is a positive scalar. The optimal solution of the maximization program is $\left(y_{rj}^*, \lambda_j^*\right)$. The revenue efficiency (RE) score is the ratio of the obtained revenue to the maximum revenue.

$$RE = \frac{\sum_{r=1}^{s} P_{rj_0} y_{rj_0}}{\sum_{r=1}^{s} p_{rj_0} y_{rj_0}^*} \tag{5}$$

The revenue efficiency score is contained between 0 and 1. DMU_{j0} is economically efficient if RE=1.

3.2. Resource Efficiency Analysis

The analysis of resource efficiency is based on inputs and output slacks. We estimated the slacks following three production objectives that fish farmers can set defined as scenarios:

- Scenario 1: A fish farmer minimizes the resource given a fixed level of fish output (Objective oriented-input)
- Scenario 2: Fish farmer maximizes the level of fish output given the resource (Objective oriented-output) and
- Scenario 3: The fish farmer maximizes the level of fish output while minimizing the resources [Objective oriented input-output (Slack Based Model)].

The resource efficiency analysis consists of determining the fish output surplus that can be achieved if excess was reduced.

Profitability

The budgetary technique involving cost-benefit analysis is used to determine the profitability of fish farming in the study area. The methodology is specified as follows:

Profit = TR – TC (9)
TR= P. Q (10)

Where TR=Total Revenue; TC= Total Cost; P= the average fish price; and Q= the quantity of fish output. In addition to profit, profitability can be determined with the use of ratio analysis as follows:

- *Gross Profit* = Total Revenue – Variable Cost
- *Net Profit* = Total Revenue – Total Cost
- *Gross Profit Margin* = gross profit/total revenue
- *Net Profit Margin* = net profit/total revenue
- *Return of Investment* = Net Profit / Total Cost

3.3 Study Area

The study focuses on the southeast of Côte d'Ivoire. The data used are from a survey collected as part of a veterinary study[3] financed and coordinated by the Swiss Centre for Scientific Research (CSRS) in Côte d'Ivoire. The data were collected using a survey questionnaire administered to an exhaustive sample of 38 fish famers in the southeast of Côte d'Ivoire during the period January-February 2009. This area was chosen based on its importance in fish production and concerned with six cities: Aboisso, Agboville, Adzopé, Anyama, Bingerville and Dabou. Data from six fish farmers were excluded from the analysis due to missing data. In sum, data from 32 fish farmers were selected for the study.

The information collected was on fish output, inputs, fish farmer characteristics and farm characteristics. We distinguish small and large farms. Fish farmers are concentrated in Abidjan (Bingerville and Anyama) and Agboville. Table 1 shows the distribution of fish farms, the number of ponds, their size and the level of production.

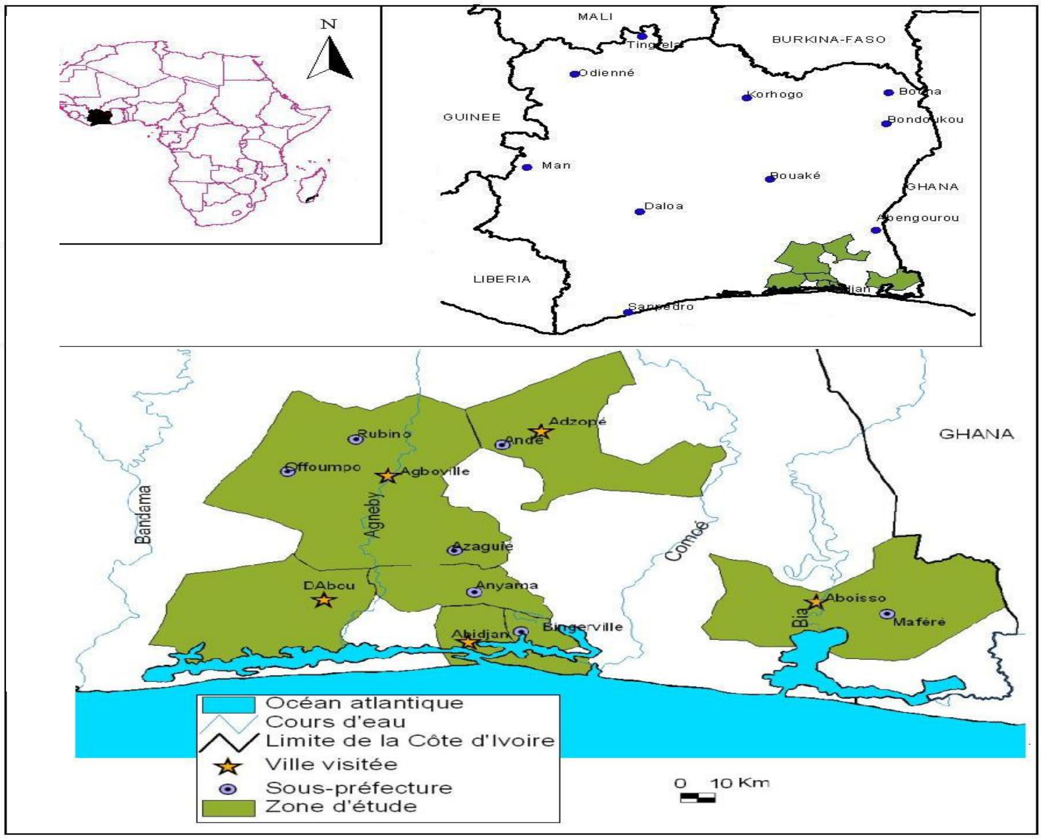

Figure 1: Area of the study

Table 1: Distribution of fish farms, pond number and size, and production

Localities	Number of Fish Farms	Pond number	Size (m^2)	Percentage (%)	Production (Kg)	Percentage (%)
Aboisso	6	88	60,535	9.50	14,304	4.00
Adzopé	4	211	437,485.7	68.10	76,139	21.12
Agboville	8	106	77,923	12.10	22,394	6.22
Bingerville	6	255	13,968	2.20	230,935	64.00
Dabou	5	184	35,917.4	5.60	8,987	2.50
Anyama	3	42	16,260	2.50	7,750	2.15
Total	**32**	**884**	**642,089.1**	**100.00**	**360,509**	**100.00**

Table 2 shows the description of the variables used in the study. Four inputs and two outputs were used to analyze the resource efficiency. *Feed,* as an essential resource in fish farming, is measured in kilograms. It was composed of industrial products (IVOIGRAIN and granulate) and reformulated feed from agricultural byproducts such as fish meal, rice flour, cottonseed, wheat bran and bread. On all the farms surveyed, 87.5% of farmers used conventional feed, 9% of farmers used conventional feed and natural feed, and 3% of farmers used leftover food. Among the fish farmers who used conventional feed, 47% of them used industrial feed, 44% of them reformulated the fish feed themselves and 9% of them used both types of feed.

The quantity of fingerling (measured in number). Land is the total pond size *(measured in* m^2*). Water* is the amount of water used in the ponds *(measured in* m^3*)*. The two outputs are the quantity of fish produced (measured in kilograms) and the average fish weight (measured in grams). The fish produced is composed of 97.6% tilapia, 1.7% catfish and 0.6% African catfish. Table 2 also shows the descriptive statistics of input costs and output price. The costs concern feed, fingerlings, labour, equipment and other costs. Costs and price are measured in FCFA[5]. Equipment costs included pond construction, cages, fishing nets (seines) and other equipment used by the fish farmers. The other costs included transportation cost, energy cost and bloodstock cost.

Table 2: Descriptive statistics of the variables used in the study

Variables	Mean	Max	Min	Std. Err
Resources				
Feed in *Kilogram (kg)*	41,170.4	407,898	14,000	89,681.3
Fingerlings *(number)*	82,282.3	960,000	1,290	17,996.6
Land in squared meter *(*m^2*)*	20,367.5	359,150	1,060	62,749.4
Water in *cube meter (*m^3*)*	17,262.8	69,362.5	795	47,424.9
Costs				
Feed in *FCFA*	66,333,388	90,000,000	0	16,300,000
Fingerlings in *FCFA*	138,437.5	1,750,000	0	440,403.8
Labour in *FCFA*	3,511,625	34,100,000	9,000	6,847,467
Equipment *in FCFA*	2,768,902	31,431,334	32,725	6,380,591
Other costs *in FCFA*	1,101,005	11,400,000	20,000	2,274,926
Outputs				
Quantity of fish *(kg)*	11,398.34	29,280.89	35	144,000
Fish weight *(g)*	341.5	450	250	51.15
Price				
Price of kg of fish in *FCFA*	1,484.6	2,000	1,100	211.9

4. RESULTS AND DISCUSSION

The results of technical and economic efficiency scores, resource efficiency and profitability are presented in this section.

4.1 Technical and Economic Efficiencies

We use Models 2, 3 and 4 to estimate the technical and economic efficiency scores. The results in Columns 1 and 2 in Table 3 are the technical efficiency scores of the CCR and SBM-DEA models obtained using feed, fingerlings, water and land as inputs and fish output and fish weight as outputs. The results indicated that the average technical efficiency scores were 0.738 and 0.575, respectively. The CCR scores are lower than SBM scores. In total, 40 percent of fish farms are CCR-efficient and SBM-efficient, with an efficiency score equal to 1. There are farms, (Number 3 of Aboisso, Numbers. 10, 11, 13 and 17 of Agboville, Number 18 of Anyama, Number 21, 22, 23 and 25 of Bingerville and Number 29, 30 and 31 of Dabou.

The results in column 3 are economic efficiency scores and are obtained from Model 4. Fish revenue is the output, and feed cost, fingerlings cost, labour cost, equipment cost and other cost are the inputs. The results show that the average economic efficiency score is estimated to be 0.553. In total, 25 percent of fish farmers are economically efficient. These are farms (Number 5) of Dabou, (Number 16 of Agboville, (Number 22, 23, 24 and 25 of Bingerville and Number 30 of Dabou. The results also show that only farms such as Muctho, Adjin, Adjin telegraph and Dabou are both technically and economically efficient.

Table 3: Technical and economic efficiency scores

	Regions	Locality	Technical Efficiency CCR (1)	Technical Efficiency SBM-DEA (2)	Economic Efficiency Revenue (3)
1.	Aboisso (6)	Aboisso	0.713	0.638	0.363
2.		Befe	0.696	0.100	0.061
3.		Aboisso	1	1	0.665
4.		Mafere	0.642	0.217	0.681
5.		Mafere	0.819	0.302	1
6.		Mafere	0.606	0.315	0.258
7.	Adzope (3)	Andé	0.049	0.041	0.118
8.		De la mé	0.329	0.011	0.795
9.		Bonauga	0.456	0.080	0.333
10.	Agboville (8)	Anyama	1	1	0.358
11.		Anyama	1	1	0.798
12.		Rubino	0.550	0.250	0.242
13.		Mutcho	1	1	0.843
14.		Offoumpu	0.687	0.152	0.597
15.		Azaguié	0.593	0.468	0.917
16.		Azaguié	0.589	0.536	1
17.		Azaguié	1	1	0.519
18.	Anyama (3)	Anyama	1	1	0.452
19.		Anyama	0.752	0.574	1
20.		Anyama	0.233	0.186	0.226
21.	Bingerville (7)	Adjin	1	1	0.527
22.		Adjin	1	1	1
23.		Adjintele	1	1	1
24.		Akakro	0.663	0.381	1
25.		Akakro	1	1	1
26.		Achokoi	0.568	0.027	0.180
27.		Achokoi	0.874	0.596	0.136
28.	Dabou (5)	Dabou	0.204	0.151	0.050
29.		Dabou	1	1	0.375
30.		Dabou	1	1	1
31.		Ira	1	1	0.534
32.		Mopoyem	0.278	0.367	0.105
		Average	**0.738**	**0.575**	**0.553**

Figure 2 examines the spatial distribution of fish farmers according their technical and economic efficiency levels. The figure shows a positive but low relationship between technical efficiency and economic efficiency. This result means that fish farms that produce efficiently are likely to earn maximum revenue.

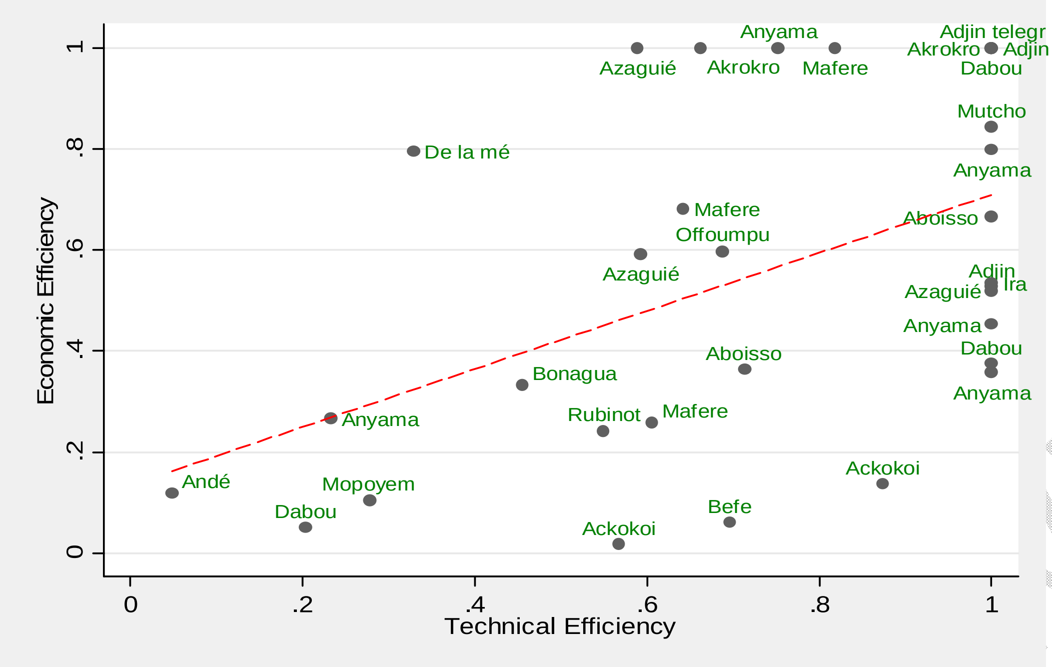

Figure 2. Relationship between Technical efficiency and Economic Efficiency

The results in Table 4 compare the average efficiency scores by type of feed used. The average technical efficiency of farmers using industrial feed is higher than that of those who use reformulated feed. They are 0.695 and 0.589, respectively. The average economic efficiency is similar for both systems. They are 0.618 and 0.605, respectively. Trained fish farmers using industrial feed have an average higher technical and economic efficiencies equal to 0.739 and 0.724, respectively, followed by experienced fish farmers who use reformulated feed with efficiency scores of 0.618 and 0.632, respectively. The less economically efficient are untrained fish farmers using industrial feed.

Table 4: Efficiency scores and experience by type of feed used and access to training

Industrial feed				**Reformulated feed**			
Training	Technical Efficiency	Economic Efficiency	Experience in year	**Training**	Technical Efficiency	Economic Efficiency	Experience in year
Access (8)	0.739	0.724	4.09	**Access (6)**	0.560	0.597	3.16
No access (7)	0.643	0.468	6.58	**No access (6)**	0.618	0.632	6.18
Average	**0.695** (0.376)	**0.605** (0.340)		**Average**	**0.589** (0.392)	**0.615** (0.334)	

4.2. Resource efficiency analysis

The optimization of DEA models following three scenarios (Oriented-input, Oriented-output and Slacked Based Model) shows the presence of slacks (excesses in inputs and shortfall in output) in the production (Table 5). The proportion of resource slacks defined as the ratio of the amount of excesses to the total resources used are the following:

- Scenario 1: Feed (7.8%); Fingerlings (0.06%); Pond Size (46.6%) and Water (30.92%)
- Scenario 2: Feed (31.7%); Fingerlings (3.92%); Pond Size (80.06%) and Water (50.93%)

- Scenario 3: Feed (1.9%); Fingerlings (10.81%); Pond Size (52.5%) and Water (50.17%)

The results indicated that excesses in inputs are lower in Scenario 1 and higher in Scenario 2. The results also show that fish output shortfall is higher in Scenario 3 than in Scenario 1 and Scenario 2. They are 54123 kg, 822 kg, and 2780 kg, respectively, equal to 16.18%, 0.77% and 0.22% of the total production.

These results indicated that the efficient management of resources leading to zero slack in resource use in different scenarios will increase the fish output by 16.18% (Scenario 3), 0.77% (Scenario 2) and 0.22% (Scenario 1). On the one hand, this analysis highlights how much excess in input and shortfall in production can be considerable depending on the objectives that a production unit can be fixed; on the other hand, it shows how a reduction of input excesses results in an increase of output.

Table 5: DEA Scenarios

All DMU	Feed s^-	Fingerling s-	Water s^-	Land s^-	Output s^+	Projection Output
Total	1,317,452	2,633,034	552,410.2	651,761.1		360,509
(Scenario 1) Oriented-inputs	102,811 **(7.80 %)**	1,646 **(0.06 %)**	257,491 **(46.60 %)**	201,556 **(30.92 %)**	822	361,331 **(0.22 %)**
(Scenario 2) Oriented-outputs	418,560 **(31.77 %)**	103,424 **(3. 92%)**	442,297 **(80.06%)**	331,958 **(50.93%)**	2,780	363,289 **(0.77 %)**
(Scenario 3) Slacked Based Model	25,797 **(1.90%)**	284,783 **(10. 81%)**	298,089 **(52. 51%)**	327,004.6 **(50.17%)**	58,361	418,870 **(16.18%)**

4.3 Profitability analysis

Table 6 presents the profitability analysis of the fish farms using the "Cost-Benefit" approach. The results show that variable costs and fixed costs represent 80.44% and 19.56% of the total production cost, respectively. The cost share of each variable input in the total cost is the following: feed (46.86%), labour (24.81%), other costs (7.8%) and fingerlings (1.21%). Similarly, the fixed inputs are pond (7%), other equipment (6.31%), cages (5.72%) and seines (0.53%). Fish farmers make average annual total revenue of 16,926,772 FCFA. On average, the variable cost amounted to 11,384,455 FCFA. By deducting the variable cost in the total revenue, fish farms obtain an average annual profit of 5,542,317 FCFA, representing 32.7% of the total revenue. Gross margins vary from a positive value of FCFA 74,507,000 FCFA to a loss of 12,392,431 FCFA. Subtracting the gross margin to a fixed cost, the average net profit margin is 2,760,050 FCFA, representing 16.38% of the total revenue. The results also indicated that the return on investment is 0.19, meaning that 100 FCFA invested make a net profit of 19 FCFA.

Table 6: Profitability Analysis

Variables	Amount (Average in FCFA) N=32	Percentage (%)	Min-Max
Output	11,398.5		35 – 144,000
Price	1,485		1,100 – 2,000
Total revenue	**16,926,772.5**		**39,900 – 187,200, 000**
Variable cost	11 ,384 ,455.1	**80.44**	
Fingerling cost	138,437.5	0.97	
Feed cost	6,633,387.6	46.86	
Labour	3,511,625	24.81	
Other cost	1,101,005	7.8	

Gross profit	**5,542,317.4**		**(-) 12,392,431 – 74,507,000**
Gross profit margin (%)	**32.7**		**0 – 67.76**
Fixed Cost	2,768,902	**19.56**	
Pond Cost	990,425.7	7	
Seines Cost	75,171.8	0.53	
Cages Cost	809,951.6	5.72	
Other Equipment	893,353	6.31	
Total Cost	14,153,358.1	**100**	
Net Profit	**2,773,414,4**		**(-) 18,727,209 – 59,667,725**
Net profit margin (%)	**16.38**		**0 – 65.42**
Return on investment	**0.19**		**0-1.89**

In Figures (3) and (4), we examine the spatial distribution of economic efficiency and return on investment and economic efficiency and net profit margin, respectively. The figures pointed out that fish farmers who are economically efficient realize a high return on investment and high net profit margin. The farms of Adjin télégraphe, Anyama, Adjin, Akakro and Dabou showed a return of investment more than 1 and a net margin profit more than 50 %. For example, the net profit of the farm Adjin télégraphe represents 65.42% of its total revenue, and 100 FCFA invested by the farm gave him a net profit of 189 FCFA.

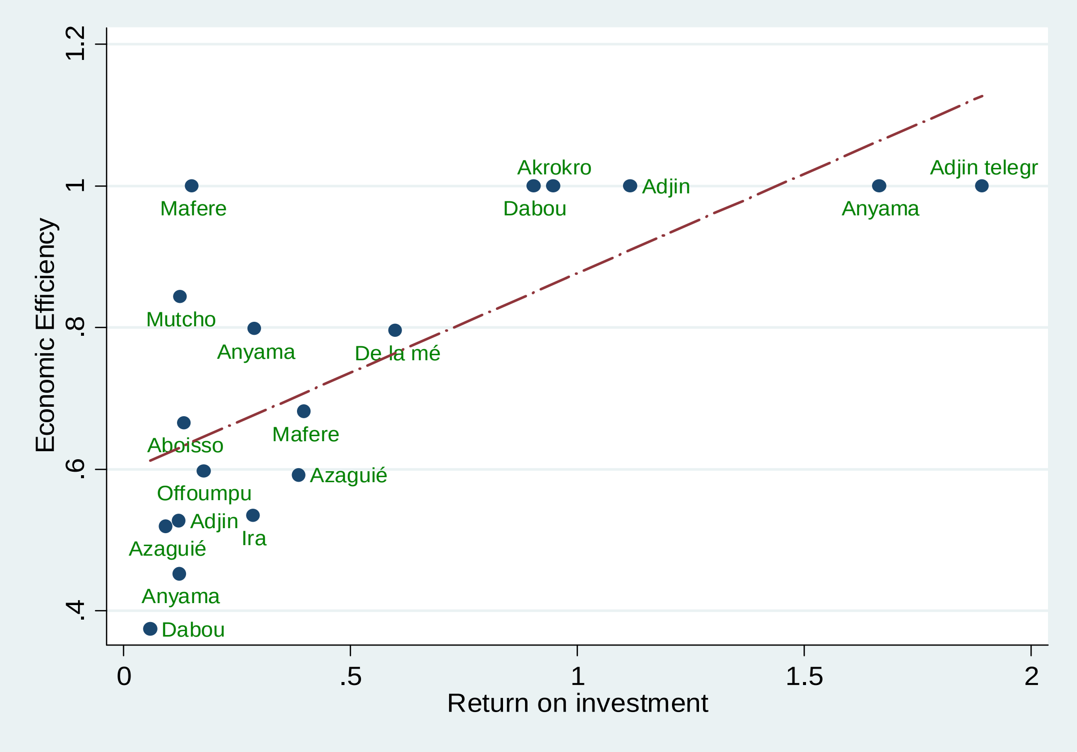

Figure 3: Economic efficiency and return on investment

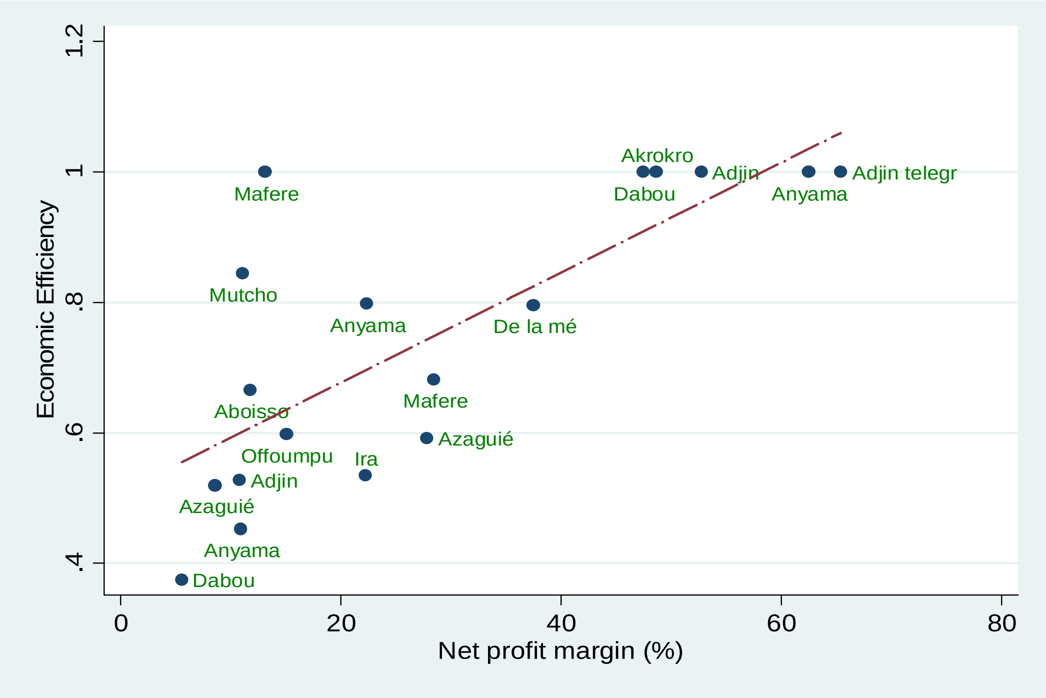

Figure 4: Economic Efficiency and Net Profit Margin

The results of the efficiency analysis indicated that the average levels of technical and economic efficiencies are low. These results implied that there is a possibility of increasing the production level and revenue if fish farmers efficiently combine the resources used (feed, fingerlings, land and water). The results also show that only four fish farmers simultaneously reach their production potential of economic potential. The average efficiency score found in this study is low compared to those found in other studies measuring the technical efficiency of tilapia (Kareem et al., 2009; Ougandari & Akinbogun2010; Onumah & Acquah 2010). Unlike those studies that have used the stochastic frontier, our study adopted the DEA approach to consider two outputs (fish output and fish weight).

Our study compared the technical and economic efficiency depending on the type of feed. The results indicated that (i) fish farms using industrial feed are more technically and economically efficient than fish farmers who use reformulated feed; (ii) the same economic performance is achieved regardless of the type of feed used; (iii) trained fish farmers using industrial feed are the most efficient; and (iv) fish farmers who reformulate their fish feed with more experience but are untrained are also efficient. These results imply that access to training and access to feed and quality fingerlings are essential to increase fish productivity and revenue.

The results of resource optimization showed the presence of waste in production. Wastes are higher when the fish farmer aims to maximize the production level given the resources (Scenario 2). However, if fish farmers wanted to minimize the excesses in the use of resources while aiming for increased production, they would have had a production surplus of 58361 kg, equivalent to 16.18% (scenario). The results imply that a production strategy aiming at a minimization of resources as well as maximization of output and with zero slacks allows for sustainable production. According to Waite et al. (2014), to improve the productivity and environmental performance of aquaculture, fish farmers must increase production in relation to the resources used and minimize water pollution, fish diseases and losses.

The findings on profitability showed that on average, fish farmers achieved gross and net profit margins of 32.7% and 16.13%, respectively, and a return on investment of 0.19. These results indicated that there is a positive profit that can be derived from fish farming in the area of the study. Some studies in Ghana and Nigeria have shown that fish farming is a profitable business. Boateng et al. (2013) found in the Ashanti Region of Ghana that fish farmers realized on average a net profit margin of 65% and a return on investment (ROI) of 0.91. Ideba et al. (2013), in Calabar Cross Rivers State in Nigeria, found an annual profit ranging from 1250 USD to 21875 USD.

4. CONCLUSION

Fish farming is considered an essential supplement to national fish production. In the production process, feed and fingerlings are combined in a water pond. To make fish farming a sustainable business, it is necessary to use these resources efficiently. The objective of this study was to analyze the resource efficiency and economic efficiency of fish farms in the southeast of Côte d'Ivoire. We used the nonparametric approach and cost-benefit analysis.

Our first results showed that, on average, the technical and economic efficiencies of fish farmers are low. However, few of them are both technically and economically efficient. There is a productive and economic potential that can be realized if resources (feed, fingerlings, water and land) are used efficiently. The results also showed that fish farmers using industrial feed are technically more efficient than those that reformulated their fish feed themselves. However, on average, the same economic performance can be achieved regardless of the type of feed used.

Second, using DEA model scenarios, we found that fish farmers generate excesses in resource utilization, causing a shortfall in fish output. The excesses are higher when the objective of the fish farmer is to obtain a maximum fish output given the resources available (Scenario 2, DEA oriented-output). Similarly, excesses are smaller when fish farmers aim to minimize resources given a fixed level of fish output (Scenraio-1, DEA oriented-input). The excesses in Scenario-3 (DEA Slacked Based Model) are smaller than those in Scenario-2 and higher than those in Scenario-1. The fish output deficit caused by these excesses was higher in Scenario-3, followed by Scenario-2 and Scenario-1. A reduction of excesses of resources in Scenario-3 would have an increased fish output of 16.18%. This result indicated that production management aiming to minimize resources simultaneously with a maximization of output is likely to ensure sustainable aquaculture production.

Third, the results of the cost-benefit analysis revealed that, on average, fish farmers achieved positive gross and net margins, but these were low. However, efficient fish farms have realized high gross and net margins.

In sum, our study suggests that policy makers should play an important role in helping fish farmers have better access to fish feed and quality fingerlings. To this end, policy actors must promote and support research in the formulation of local fish feed from agricultural by-products, which should be available in the country. In addition, fish farmers must be trained on good practices of sustainable production and pond management to reduce the slacks (excesses and shortfall) in the production process.

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