Analysis of Aerators for Shrimp Farming: Cost Optimization and the Real Cost of "Cheap"

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Abstract

Aerator selection is a critical economic decision in shrimp farming, often complicated by the trade-off between initial cost and long-term operational efficiency. This paper presents an analysis comparing two aerator options within the context of a specific shrimp farm, integrating Léon Walras's General Equilibrium Theory and Friedrich von Wieser's concept of Opportunity Cost. The study evaluates aerators based on updated technical performance metrics (including Temperature-Adjusted Oxygen Transfer Rate - OTRT and Standard Aeration Efficiency - SAE) derived from the farm's Total Oxygen Demand (TOD) and detailed, adapted financial indicators (Net Present Value - NPV, Internal Rate of Return - IRR, Payback Period, Return on Investment - ROI, Profitability Index - k, Opportunity Cost, and Equilibrium Price) tailored for equipment comparison. Results from the specific case study demonstrate that prioritizing higher efficiency (Aerator 2) over lower initial unitary cost (Aerator 1) leads to substantial long-term savings, a significantly positive NPV, high interpreted ROI and IRR, rapid payback, and a considerable opportunity cost associated with choosing the less efficient option. The analysis underscores the importance of applying robust economic principles and adapted technical-financial assessments for optimizing operational costs and ensuring financial sustainability in shrimp aquaculture (Boyd & Hanson, 2021; The Fish Site, 2021).

Keywords: Shrimp Farming, Aquaculture Economics, Aerator Efficiency, Opportunity Cost, Cost Optimization, Mathematical Modeling, Financial Analysis, Equipment Comparison Metrics

Highlights

- Higher efficiency aerators reduce long-term costs in shrimp farming.
- Adapted financial metrics reveal flaws in traditional equations.
- Opportunity cost of low-efficiency aerators exceeds $14M in NPV.
- In-loco data confirms poor performance of low-durability aerators.

1. Introduction

The economic analysis of optimal aerator choice in shrimp farming benefits from the General Equilibrium Theorem developed by Léon Walras in the 19th century, complemented by Friedrich von Wieser's concept of opportunity cost, introduced in 1914. Walras proposed a framework to understand how interconnected markets reach simultaneous equilibrium, where supply equals demand through relative prices (Walras, 1874). This approach is useful for analyzing complex systems like shrimp farms, where multiple "markets" (oxygen, energy, shrimp, operating costs) interact to maximize profitability (Asche et al., 2021). Opportunity cost measures the value of the best alternative forgone, evaluating aerator options (Boyd & Hanson, 2021).

1.1 Analogy with the Oxygen Market and Opportunity Cost

In shrimp farming, dissolved oxygen is a critical input. An "internal oxygen market" can be conceptualized where demand (Total Oxygen Demand, TOD) is driven by shrimp and microbial needs, and supply depends on aerators' Temperature-Adjusted Oxygen Transfer Rate (OTRT). Aerators interact with energy, maintenance, and replacement markets, connecting to the external shrimp market. Walras's Theorem suggests equilibrium when these markets adjust simultaneously. Choosing a cheaper, less efficient aerator incurs an opportunity cost equal to the net present value of savings forgone by not selecting the more efficient option (Boyd & Hanson, 2021; Susilowati et al., 2021).

1.2 The Cake Recipe: Why Assuming HP per Pound of Shrimp is Incorrect

Assuming a fixed horsepower (HP)-per-production ratio is erroneous. Shrimp production depends on multiple factors (dissolved oxygen, temperature, salinity, density). Aerator HP does not directly equate to oxygen supply; OTR_T is critical. Fixed HP ratios ignore interdependencies, leading to inefficient investments in low-OTR_T aerators and significant opportunity costs (Boyd, 2015; Responsible Seafood Advocate, 2022).

1.3 Original Equation of Léon Walras's General Equilibrium

Walras formalized general equilibrium with supply/demand equations, subject to Walras's Law (excess demands sum to zero). Equilibrium prices are found via

"tâtonnement" (Walras, 1874). In shrimp farming, equilibrium involves optimizing aerator costs, meeting TOD, maximizing profits, and accounting for opportunity cost (Asche et al., 2021; Valderrama et al., 2023).

1.3 Context Overview

This paper analyzes several aerators in a specific shrimp farm context, integrating updated technical performance metrics and adapted financial indicators. The study evaluates aerators based on Standard Oxygen Transfer Rate (SOTR), to fulfill a 1000 hectares Shrimp Farm for a given Total Oxygen Demand (TOD), and derives financial indicators tailored for equipment comparison. Results demonstrate that prioritizing higher efficiency leads to substantial long-term savings, a significantly positive NPV, high interpreted ROI and IRR, rapid payback, and a considerable opportunity cost associated with choosing the less efficient option.

1.4 Aerator Market in Ecuador

The Ecuadorian aerator market is characterized by a wide range of options, from low-cost, low-efficiency models to high-performance, high-cost alternatives. The choice of aerator significantly impacts operational costs and shrimp yield. The market is influenced by factors such as energy prices, shrimp prices, and technological advancements in aeration systems. Understanding the trade-offs between initial investment and long-term operational efficiency is crucial for shrimp farmers aiming to optimize their production systems (Boyd & Hanson, 2021; The Fish Site, 2021).

By analysing aerator imports from Ecuador's customs database, in the period of 2021 to 2024, we can gain insights on market trends, pricing strategies, and the competitive landscape of aerator suppliers in the region.

After performing data manipulation techniques, we can observe the following patterns:

Aerator Imports in Ecuador (2021-2024)

The dashboard on aerator imports (2021-2024) reveals some insights across multiple dimensions. China dominates as the top country of origin with 15.5M USD (FOB), followed by Taiwan at 4.1M USD, while generic brands lead at 17.9M USD (CIF), far ahead of Wangfa at 3.2M USD. In terms of importers, Area Andina S.A. handles the highest volume at 647K units, with Crustáceos y Peces de Sudamérica as the second-largest at 137K units. Product descriptions show aerators of 12-16 pallet units leading at 548K kg (net weight), indicating a focus on bulk shipments. Ningbo is the top embarkation city with 398K units (ad valorem), and Agencia Maritima Global moves 708K units (freight value), highlighting their logistical prominence. Consignee directions peak with La Puntilla (Satellite) at 211K units (insured value), and the generic

model category tops brokered models at 154K units, reflecting market preferences for cost savings.

Aerator Unitary Prices in Ecuador (2021-2024)

The aerator prices chart (2021-2024) shows a highly skewed distribution of FOB unit prices, with a mean of 812.96 USD, indicating that most brands have prices below this value, but a long tail extends to 1200 USD+. Acquaeco has the highest average unit price at 1258.27 USD, followed by Walker at 1108.55 USD, suggesting they cater to a premium segment. In contrast, Zuma offers the lowest average at 500.80 USD, followed by WangFa at 546.36 USD, positioning them as budget options. Other brands like Hongteng (673.33 USD), and Aerex (802.14 USD) cluster closer to the mean, while Wenling (961.32 USD) and Annex (1021.79 USD) sit between the mid-range and high-end, reflecting a diverse pricing landscape in the aerator market.

2. Case Study: Comparing Different Aerator Options for an Ecuadorian Shrimp Farm

2.1 Case Study Overview and Parameters

This case study examines an intensive shrimp farm in Ecuador with 1,000 hectares of production area. The farm operates at a tropical water temperature of 31.5°C, which significantly affects oxygen transfer efficiency through the established temperature correction factor ($\theta = 1.024$). The farm's Total Oxygen Demand (TOD) is calculated at 5.47 kg O_2/hr/hectare, resulting in a substantial total requirement of 5,470 kg O_2/hr across the entire operation.

For this analysis, we compare seven different paddlewheel aerator models (Aerator 0 through Aerator 6), all operating at the standard power rating of 3 HP (2.238 kW). These aerators exhibit varying performance characteristics:

Farm Parameters

Parameter	Value
Farm area	1000 hectares
Operating temperature	31.5°C
Energy cost	$0.05/kWh
Daily aeration	8 hours
Total Oxygen Demand (TOD)	5,470 kg O_2/day
Annual shrimp production	18,250,000 kg

Analysis period	10 years
Discount rate	10%
Annual inflation rate	3%

2.2 Aerator Investment Options

The aerators under consideration present a classic economic dilemma: less expensive models with lower efficiency versus higher-priced models with superior oxygen transfer rates. While Aerator 0 has the lowest initial cost (500 USD), it does not offer the lowest operational cost. Aerator 1, despite being more expensive (600 USD), delivers lower SOTR (1.0 kg O_2/hr vs. 1.2 kg O_2/hr). The most efficient option, Aerator 6, transfers 6.0 kg O_2/hr but costs 1,500 USD per unit.

The economic challenge is compounded by differences in durability (ranging from 2.0 to 6.0 years) and maintenance costs (from 20 USD to 90 USD per unit annually). This creates complex trade-offs between initial investment and long-term operational expenses. The total number of aerators required varies dramatically between options due to their different oxygen transfer capacities, directly impacting both initial investment and ongoing operational costs.

Aerator Model	Power (HP)	SOTR (kg O_2/hr)	Purchase Price (USD)	Maintenance Cost (USD/year)	Durability (years)
Aerator 1	2	1.5	600	85	2.5
Aerator 2	2	2.9	800	95	4.5
Aerator 3	3	3.8	900	125	3.0
Aerator 4	3	3.0	1000	140	6.0
Aerator 5	4	3.0	1200	160	5.0

2.3. Standard Oxygen Transfer Rate (SOTR)
The baseline oxygen transfer capacity under standard conditions (20°C, 0 DO, 1 atm), measured in kg O_2/hr (Kumar et al., 2020).
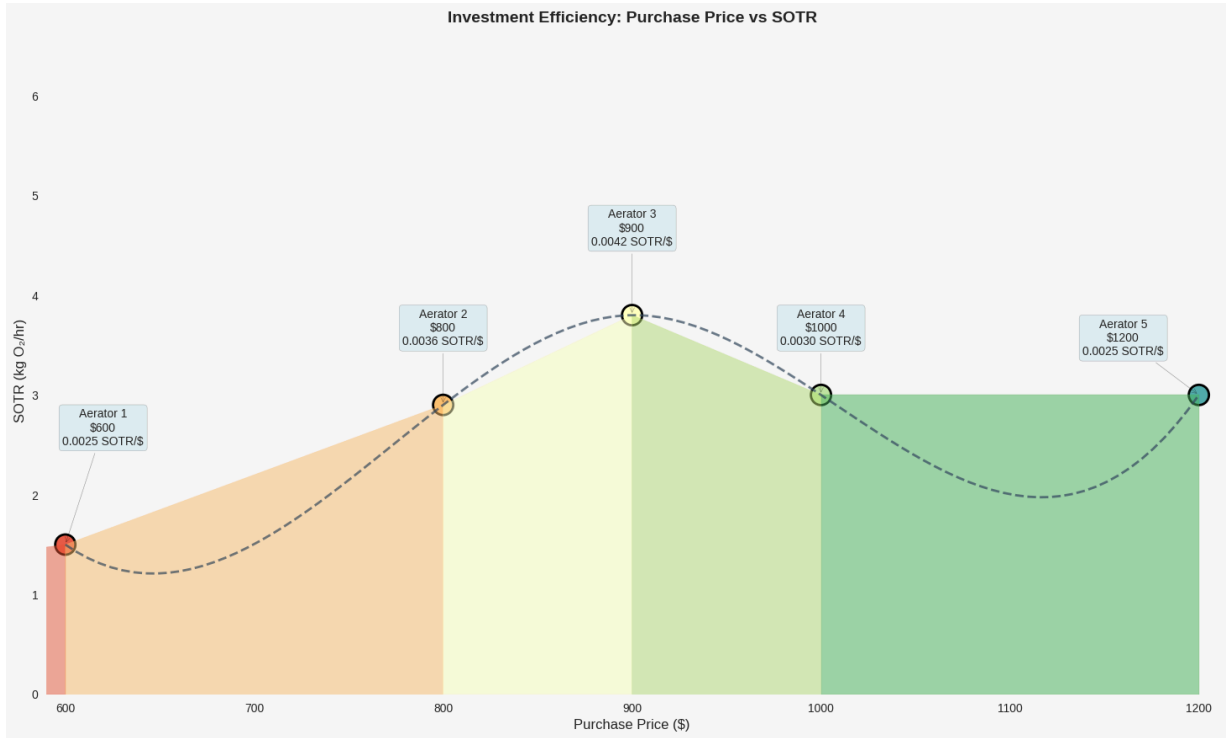
2.3.1.2 Temperature-Adjusted Oxygen Transfer Rate (OTRT)

$$OTR_T = (\text{SOTR} \times 0.5) \times \theta^{(T-20)}$$

Where $\theta = 1.024$ (temperature correction factor) (Boyd, 2015).
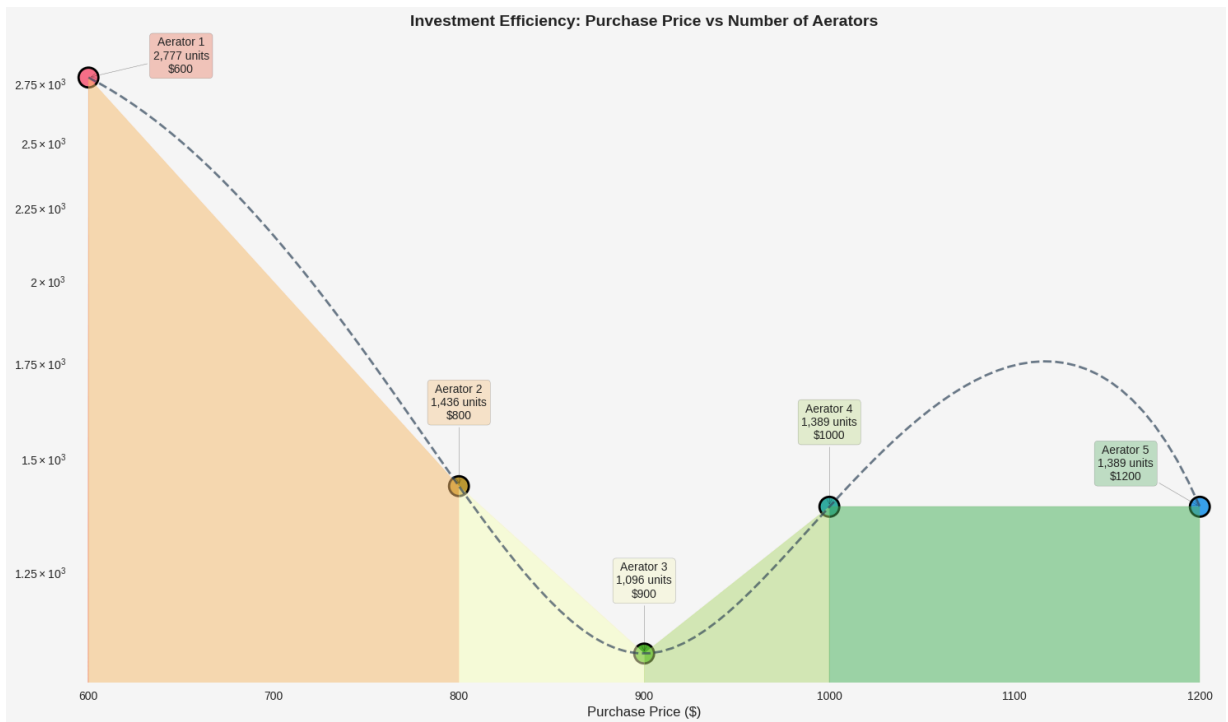
2.3.1.3 Standard Aeration Efficiency (SAE)

$$\text{SAE} = \frac{\text{SOTR}}{\text{Power (kW)}} \quad (kg\, O_2/\text{kWh})$$

Where Power $(\mathrm{kW}) = \mathrm{Power}\ (\mathrm{HP}) \times 0.746$ (Kumar et al., 2020).

2.3.1.4 Aerator Quantity Calculation

$$\text{Number of Aerators} = \left\lceil \frac{TOD}{OTR_T} \right\rceil$$

2.3.2 Annual Revenue

$$\text{Annual Revenue} = \text{Total Annual Production (kg)} \times \text{Shrimp Price (\$/kg)}$$

Production depends on density, depth, area, and culture cycles (Engle, 2010).

2.3.3 Initial Investment

$$\text{Total Initial Cost} = \text{Number of Aerators} \times \text{Cost per Aerator}$$

2.3.4 Annual Operating Costs

1. **Energy Cost:**

$$\text{Power (kW)} \times \text{Energy Cost (\$/kWh)} \times \text{Operating Hours per Year} \times \text{Number}$$

2. **Maintenance Cost:**

$$\text{Maintenance Cost per Unit per Year} \times \text{Number of Aerators}$$

3. **Replacement Cost (Annualized):**

$$(\text{Number of Aerators} \times \text{Cost per Aerator})/\text{Durability (years)}$$
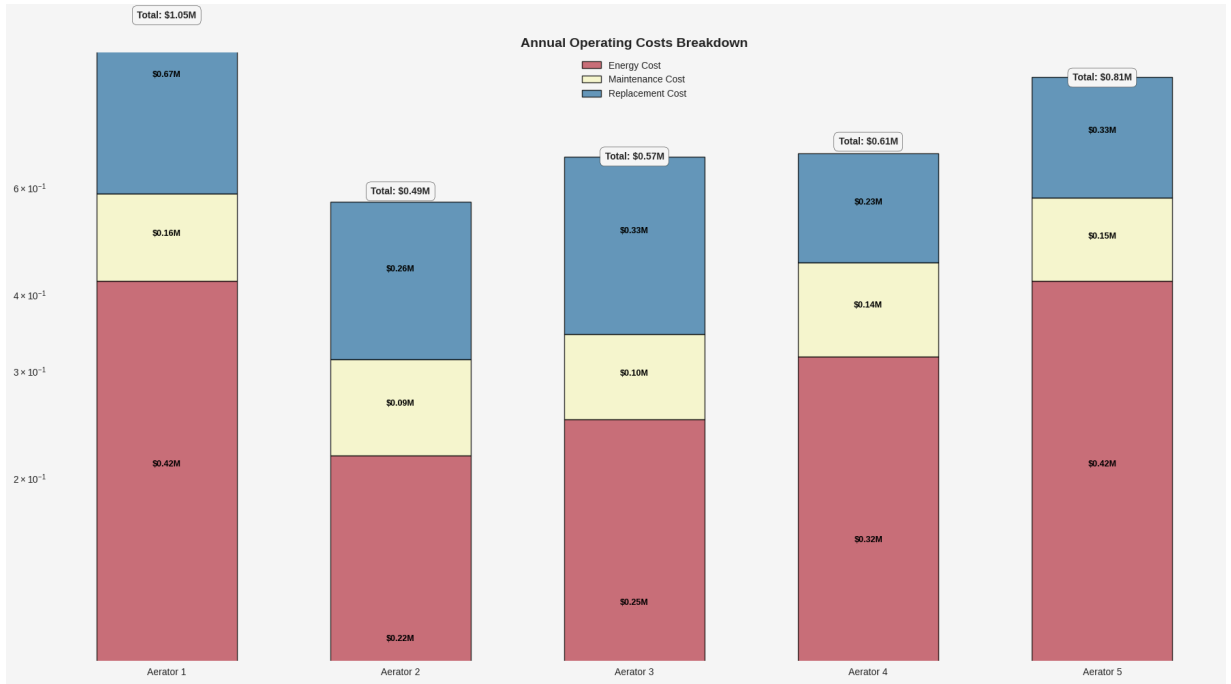
2.3.6 Net Present Value (NPV) of Savings

$$\text{NPV}_{\text{Savings}} = \sum_{i=1}^{n} \frac{\text{Annual Saving}_{\text{Year 1}} \times (1 + r_{\text{inflation}})^{i-1}}{(1 + r_{real})^i}$$

Where $r_{real} = \frac{1 + r_{nominal}}{1 + r_{inflation}} - 1$ (Intelligon, 2022; Susilowati et al., 2021).

2.3.7 Adapted Financial Metrics

Standard metrics (IRR, Payback, ROI, k) were adapted due to violations of positive incremental investment assumptions in aquaculture equipment comparison (Engle, 2010; Kumar et al., 2020).

2.3.7.1 Internal Rate of Return (IRR)

$$0 = -\Delta I + \sum_{i=1}^{n} \frac{S_{yr1} \times (1 + r_{\text{inflation}})^{i-1}}{(1 + \text{IRR})^{i}}$$

If $\Delta I \leq 0$, standard IRR is undefined; adapted IRR anchors against baseline cost, scaled by SOTR ratio, capped at 100% (Kumar et al., 2020).
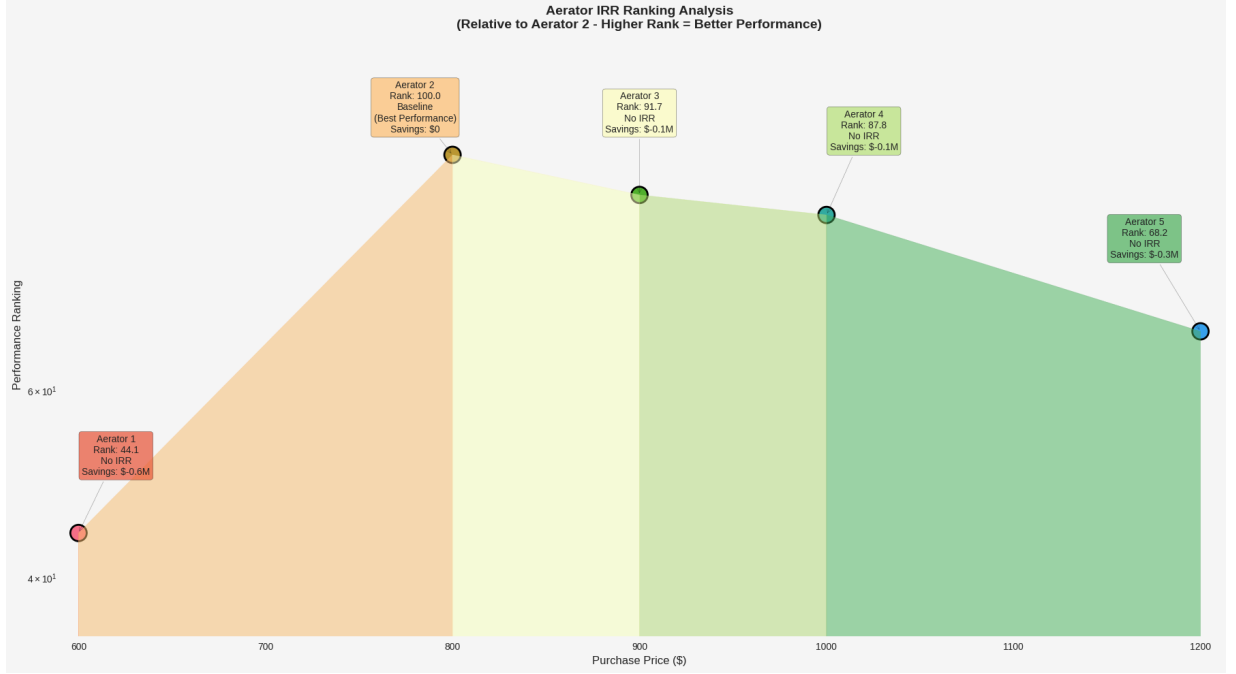
2.4.2.1 Payback Period

Payback period calculation depends on investment difference (ΔI) and annual savings:

Case 1: When $\Delta I < 0$ and $S_{\text{yr1}} > 0$ (cost savings with positive annual savings)

$$\text{Payback Period} = \frac{0.01}{R_{\text{SOTR}}}$$

Case 2: When $\Delta I \geq 0$ and $S_{\text{yr1}} > 0$ (additional investment with positive annual savings)

$$\text{Payback Period} = \frac{\Delta I}{S_{\text{yr1}}}$$

Case 3: When $S_{\text{yr1}} \leq 0$ (no annual savings)

$$\text{Payback Period} = \infty$$

Where: • $R_{\text{SOTR}} = \frac{S_{\text{yr1}}}{C_{\text{base}}} \times R_{\text{SOTR}}$ (SOTR ratio factor) • C_{base} is the baseline cost (Engle, 2010)

2.4.2.2 Relative Return on Investment (ROI)

ROI calculation depends on investment difference (ΔI) between candidate and baseline aerators:

Case 1: When $\Delta I < 0$ (cost savings)

$$\text{ROI}_{\text{relative}} = \min\left(\left(\frac{S_{\text{yr1}}}{C_{\text{base}}} \times R_{\text{SOTR}} \times (1 + F_{\text{cost\_sav}})\right) \times 100, R_{\text{SOTR}} \times 100\right)$$

Case 2: When $\Delta I = 0$ (equal investment)

$$\text{ROI}_{\text{relative}} = \min\left(\left(\frac{S_{\text{yr1}}}{C_{\text{base}}} \times R_{\text{SOTR}}\right) \times 100, R_{\text{SOTR}} \times 100\right)$$

Case 3: When $\Delta I > 0$ (additional investment)

$$\text{ROI}_{\text{relative}} = \min\left(\left(\frac{S_{\text{yr1}}}{\Delta I}\right) \times 100, R_{\text{SOTR}} \times 100\right)$$

Case 4: When $S_{\text{yr1}} \leq 0$ (no savings)

$$\text{ROI}_{\text{relative}} = 0$$

Where:

- $F_{\text{cost\_sav}} = \dfrac{|\Delta I|}{C_{\text{base}}}$ (cost savings factor)
- $S_{\text{yr1}} > 0$ and $C_{\text{base}} > 0$ (required conditions)
- For $\Delta I \leq 0$: ROI based on savings relative to baseline cost, scaled by SOTR ratio

2.4.2.3 Profitability Index (k)

Profitability Index calculation depends on investment difference (ΔI) and NPV of savings:

Case 1: When $\Delta I < 0$ (cost savings)

$$k_{\text{relative}} = k_{\text{base}} \times (1 + F_{\text{cost\_sav}})$$

Case 2: When $\Delta I = 0$ (equal investment)

$$k_{\text{relative}} = k_{\text{base}}$$

Case 3: When $\Delta I > 0$ (additional investment)

$$k_{\text{relative}} = k_{\text{base}} \times F_{\text{cost}}$$

Case 4: When $\text{NPV}_{\text{sav}} \leq 0$ (no positive NPV)

$$k_{\text{relative}} = 0$$

Where:

- $k_{\text{base}} = \dfrac{\text{NPV}_{\text{sav}}}{C_{\text{base}}} \times R_{\text{SOTR}}$ (base profitability index)
- $F_{\text{cost\_sav}} = \dfrac{|\Delta I|}{C_{\text{base}}}$ (cost savings factor)
- $F_{\text{cost}} = \dfrac{C_{\text{base}}}{C_{\text{base}} + \Delta I}$ (cost adjustment factor)
- Condition: $C_{\text{base}} > 0$ (Engle, 2010)

2.4.2.4 Equilibrium Price (P_{eq})

Equilibrium price calculation based on market conditions and cost structure:

Case 1: When $C_{\text{base}} > 0$ (normal baseline cost)

$$P_{\text{eq}} = \max\left(0, P_{\text{base}} \times R_{\text{SOTR}} \times \left(\frac{1}{1 + F_{\text{cost, eq}}}\right)\right)$$

Case 2: When $C_{\text{base}} \leq 0$ (zero or negative baseline cost)

$$P_{\text{eq}} = \max\left(0, P_{\text{base}} \times R_{\text{SOTR}}\right)$$

Case 3: Otherwise (invalid conditions)

$$P_{\text{eq}} = 0$$

Where:

- $P_{\text{base}} = \dfrac{(C_{\text{annual, non-winner}} - (C_{E,\text{winner}} + C_{M,\text{winner}})) \times D_{\text{winner}}}{N_{\text{winner}}}$ (baseline price)
- $F_{\text{cost, eq}} = \dfrac{P_{\text{base}}}{C_{\text{base}}}$ (cost equilibrium factor)
- Condition: $P_{\text{base}} > 0$ (Asche et al., 2021)

Performance and Cost Analysis Summary

	Aerator 1	Aerator 2	Aerator 3	Aerator 4	Aerator 5
Unit Price	$600	$800	$900	$1,000	$1,200
Power Rating	2 HP	2 HP	3 HP	3 HP	4 HP
SOTR (kg O2/hr)	1.5	2.9	3.8	3.0	3.0
OTRT (kg O2/hr)	1.97	3.81	4.99	3.94	3.94
Units Needed	2777	1436	1096	1389	1389
Initial Investment	$1,160,231.82	$799,948.58	$686,863.92	$967,208.02	$1,160,649.62
Annual Energy Cost	$421,057	$217,730	$249,268	$315,906	$421,208
Annual Maintenance	$164,366	$94,994	$95,398	$135,409	$154,753
Total Annual Cost	$1,049,515	$490,491	$573,620	$612,517	$808,091
Cost per kg O2	$0.066	$0.031	$0.036	$0.038	$0.051
Energy per kg O2	0.76	0.39	0.45	0.57	0.76
Annual Savings vs Baseline	$-559,025	$0	$-83,130	$-122,026	$-317,601

Enhanced Financial Analysis

	Aerator 1	Aerator 2	Aerator 3	Aerator 4	Aerator 5
Initial Investment	$1,160,231.82	$799,948.58	$686,863.92	$967,208.02	$1,160,649.62
Annual Savings vs Baseline	$-559,025	$0	$-83,130	$-122,026	$-317,601
Net Present Value	$-4,323,913	$0	$-476,326	$-1,032,455	$-2,612,572
Internal Rate of Return	Loss-making	0.0% (Baseline)	Loss-making	Loss-making	Loss-making
Payback Period	N/A	0.0 years	N/A	N/A	N/A
SOTR Performance Ratio	0.52x	1.00x	1.31x	1.03x	1.03x
Profitability Index	0.00	1.00	0.00	0.00	0.00
Return on Investment	-1651.6%	0.0%	0.0%	-829.6%	-980.5%

🏆 Best Options Summary

Criteria	Best Option
🏆 Best Initial Cost	**Aerator 3**
💰 Best Operating Cost	**Aerator 2**
📈 Best NPV	**Aerator 2**
🚀 Best IRR	**Aerator 2**
📊 Best Profitability Index	**Aerator 2**
📈 Best ROI	**Aerator 2**
⏳ Best Payback Period	**Aerator 2**
⭐ Baseline (Most Efficient)	**Aerator 2**

📊 Key Business Insights

🎯 **Total Oxygen Demand:** 5,470.0 kg/day

🦐 **Annual Shrimp Production:** 18,250,000 kg

⏰ **Operation Schedule:** 8 hours/day, 365 days/year

💡 **Key Finding:** Aerator 2 dominates across most financial metrics, demonstrating superior cost-efficiency despite higher initial investment.