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**ECONOMIC AND RISK ANALYSIS FOR IMPLEMENTATION OF A  
SAVONIUS WIND TURBINE FOR AERATION PROCESS IN FISH  
FARMING**

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*In Brazil, consumers can generate their own electricity from renewable sources, also known as Distributed Generation (DG). Besides contributing to the diversification of the energy matrix, distributed generation brings benefits to the economy as well as self-sustainability. The use of unconventional wind devices such as the Savonius turbine can be a low-cost solution, reducing environmental impacts for decentralization of energy production. The Brazilian aquaculture sector is growing quickly and, therefore, presents great potential for improving existing technologies aiming at sustainability. This paper analyzes the risks of the aeration process powered by a Savonius wind turbine, an alternative mechanical energy source, as a substitute to electrical energy normally used for this purpose in a fish farm. The conceptual and mechanical design of the Wind Aerator - as this system for the aeration of ponds in fish farming, powered by a Savonius wind turbine, has been called - is complete. The economic feasibility analysis of the implantation considers a capital recovery time metrics (Payback), Net Present Value (NPV) and Internal Rate of Return (IRR). The risks are analyzed under two aspects: qualitative analysis method and quantitative analysis method, considering the internal rate of return, discounting the effects of inflation (Net IRR) and the payback by months. The best-and worst-case scenarios are compared to the base case. The connection between the wind turbine and the air compressor is made through a spiral bevel gear and the study is carried out using the theoretical reference values of the torque supplied on the turbine shaft to calculate the air compressor flow. The aeration process for the oxygenation of ponds in aquaculture, since it's powered by a Savonius wind turbine, contributes as an alternative, renewable, and clean energy source without the use of electricity.*

**Keywords:** Savonius wind turbine, Aeration, Fish farming, Dissolved oxygen, Renewable energy, Economic analysis, Risk analysis, Sensitivity analysis.

## 1. INTRODUCTION

In Brazil, the Distributed generation (DG) has grown over the years, reaching 5.297 megawatts of installed power in march 2021 (ABGD, 2021). The Distributed Generation has the benefits of financial savings, environmental awareness, self-sustainability and reduction losses, contributing to the diversification of the energy matrix (Aneel, 2012). Unconventional devices for electric energy generation can be a solution for power generation. The use of Savonius wind turbines in DG fits in this context, being a solution for decentralized generation of energy with low cost and reduced environmental impacts (Akwa, 2010).

Brazilian Fisheries and Aquaculture Sector is projected to register a Compound Annual Growth Rate - CAGR of 3.5% during the forecast period of 2021 until 2026. The Brazil is focusing on the fisheries and aquaculture sector, due to the rising interest among investors, both at domestic and global levels (Mordor, 2021). Furthermore, innovation and technology are being implemented in this market to assist producers in the decision-making process and in the automation of facilities. Fish farming and aquaculture 4.0 is already a reality at the facilities in the State of Paraná (Aquaculture, 2021).

The Savonius turbine is vertical axis wind turbine (VAWT). These turbines are characterized by their rotation axis being perpendicular to the wind speed and to the ground, and by providing high torque at low angular speed. The Savonius turbine was developed and patented by Sigurd J. Savonius in 1929, is regarded as one of the simplest models among vertical axis wind turbines and operates due to the aerodynamic drag forces (Akwa *et al.*, 2012a). This model of wind machine has its geometry defined in a “S” shape, being composed by two blades. This configuration reduces the resistance to the opposite movement for the blade going against the wind direction (Menet, 2004). The torque is generated by means of drag force on the blades, instead of lift, as in the large commercial wind turbines.

The turbine’s technical features are: (i) simple construction at low cost; (ii) operates with wind coming from any direction; (iii) low noise and low angular velocity in operation; (iv) reduced wear on moving parts; (v) various rotor configuration options; and (vi) high static and dynamic moment (Akwa *et al.*, 2012b).

To perform an economic analysis, a few metrics must be considered as comparison parameters. The Payback, Net Present Value (NPV) and Internal Rate of Return (IRR) were the metrics used for economic feasibility analysis (Grant; Ireson, 1970). Payback metric is a financial indicator that represents the time it takes to recoup the cost of an investment, it is used to analyze the feasibility of an investment according to its payback period (Samanez, 2007). The Net Present Value (NPV), is calculated by bringing all project cash flows to the date zero and adds them to the initial investment. This analysis enables the evaluation of the present through future data comparisons applying a discount rate called the Minimum Rate of Return – TMA (Samanez, 2007). On the other hand, the Internal Rate of Return (IRR) method defined as the percentage of profitability of the project analyzed and the closer to the value of the TMA, the greater the investment risks (Galesne *et al.*, 1999).

The risk management is a systematic process of defining, analyzing and responding to risk in order to maximize positive events and minimize the consequences of negative events (Damodaran, 2009). Assuming that the input data for the analysis are known, that is, they are information without variability, sensitivity analyzes and scenario analyzes are constructed (Saul, 1995).

Risk analysis is widely used in several segments to assess the feasibility of implementing a new product. For example, Almeida *et al* (2016) analyzed the economic viability of a photovoltaic plant and verified that the simulation results showed that caution is needed when evaluating investments in photovoltaic solar nature. The case study was careful about the operating expenses, maintenance and administration, as well as take into account the loss of gradual efficiency of the modules. At the end, it was verified that this type of project is highly sensitive to current and applicable rates in the country. On the other hand, Rech *et al.* (2020) made the analysis to assess the economic feasibility of implementing a digital densimeter in a microbrewery and carry out a risk analysis of this implementation and observed that, even in a very pessimistic scenario, the project is economically viable. Specifically applied to Savonius turbines used in fishing farm, was not found in the literature an economic viability analysis

From this perspective, the objective of this paper is to present a preliminary economic feasibility analysis of the implantation of a Savonius wind turbine as a propulsive for an aeration of ponds in aquaculture. In addition, risk and scenarios analyses are also performed. The following sections describe the methodology used in the analyses and the results obtained.

## 2. METHODOLOGY

The turbine power was defined based on the study of water oxygenation necessary for fish farming. A turbine with a capacity of 250 W, was designed, meeting the demand for 0.5 kg O<sub>2</sub>/h (Table 2). The average wind speed of 10 m/s was adopted according to the Climatological Table of the Salgado Filho International Airport (SBPA) - Porto Alegre/RS, where historical measurements between 2001 and 2010 show winds with an average annual speed of approximately 4.3 m/s and gusts of around 14 m/ s. (Redemet 2020). With these data, the turbine was sized and submitted to a specialized company to make a budget for manufacturing costs to be used as a parameter in the economic analysis (Projelmec,

2021). The dimensions of the proposed turbine are shown in Figure 1 and Table 1. The turbine is manufactured using 1020 steel and then galvanized (Balafa, 2020).

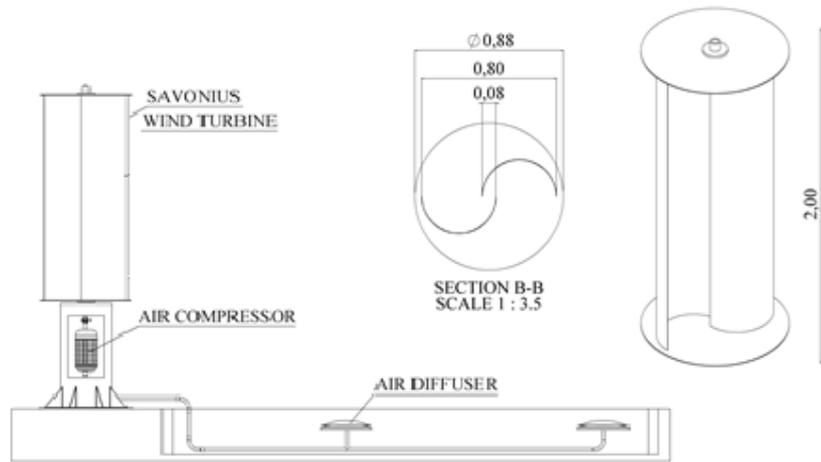


Figure 1. Savonius wind turbine geometry design and disposition (dimensions in meters).

Table 1. Savonius wind turbine dimensions.

Turbine area, m <sup>2</sup>	1.60
Diameter, m	0.80
Height, m	2.00
End plate, m	0,88
Radius, m	0.40
Number of blades	2

## 2.1 Physical conditions of water

In aquaculture, dissolved oxygen is the main parameter that determines the quality of the water. If its level is low, or does not exist, there is a total loss of production. The greater the biomass, the greater the demand for oxygen by the cultivation unit. Supplying oxygen to water can be done in many forms, the simplest method being the exchange of water and the most sophisticated being the application of oxygen at high pressure. This work considers the aerator that injects air into the water.

Aeration in aquaculture is determined by the Total Oxygen Demand (TOD) and the Standard Oxygen Transfer Rate (SOTR). The TOD depends on the total respiration in the water from the plants at the bottom and from the animals and the SOTR depends on the efficiency of the aerator considering the amount of oxygen mass that the device transfers to the water over time. By dividing the SOTR by the consumption of electrical energy consumed, the SAE (Standard Aerator Efficiency) is obtained, usually expressed in kg O<sub>2</sub>/kWh.

This work evaluates the condition in which there is oxygen demand SOTR of 0.475 kg/h for 430 m<sup>2</sup> of water with 30% salinity. It is considered 8 hours of operation per day of an aerator driven by a Savonius turbine with an average power of 250W per hour. The SAE is 1.85 kg O<sub>2</sub>/kWh and the electricity price of US\$ 0.196 per kW was considered, what results in US\$ 140.96 p.a. (per annum).

Table 2. Physical conditions of water inside the pond (adapted from Arana (2017)).

Approximate area, m <sup>2</sup>	$A_T$	430.0
Approximate depth, m	$P$	2.0
Water temperature, °C	$T$	20.0
Salinity, %	$S_{AL}$	35.0
Total Oxygen Demand, kg O <sub>2</sub> /h	$TOD$	0.50
Standard Oxygen Transfer Rate, kg O <sub>2</sub> /h	$SOTR$	0.88
Standard Aerator Efficiency, O <sub>2</sub> /kWh	$SAE$	1.85

## 2.2 Compressor characteristics

Considering the 250 W power average availability of the turbine, an Aeromack industrial aerator commonly applied for diffused air aeration and powered by an electric motor was proposed as a reference device. The Aeromack model CRE-MINI industrial aerator has a nominal power of 248 W, and an air flow rate of 1.1 m<sup>3</sup>/min (Aeromack, 2021).

## 2.3 Economic analysis

Data were collected to obtain economic, financial and technical information. Economic data were researched on open channels of government agencies (IBGE, 2021). The technical data were collected through budget with a businessman. Other information was collected in bibliographic research. Based on this information, economic modeling and identification of the risks inherent to the implementation of the Savonius wind turbine were carried out. Capital recovery time metrics (Payback), net present value (NPV) and Internal Rate of Return (IRR) were used.

In this work, the risk was analyzed under two methods: qualitative analysis and quantitative analysis. The qualitative method prioritizes risks and estimates the probability of occurrence and impact. The measure of the risk impact probability and the estimation of its implications for the project objectives are evaluated by the quantitative method, characterized as deterministic or probabilistic. In the deterministic case, it is assumed that the input data for the analysis are known without variability in the information. From this information sensitivity analyzes and scenario analyzes can be constructed (Saul, 1995).

Regarding maintenance and replacement, the only mechanical components of the turbine that need attention are the bearings. However, they are subject to very low rotation and loads, and thus their expected service life (20 years) is shorter than their physical life. The structure as a whole is analyzed under the philosophy of extreme loads, what is only generated by gusts, and thus the structural safety is guaranteed by design (Balafa, 2020), and no replacements are necessary.

## 3. RESULTS

The investment values considered for modeling the installation of the Savonius wind turbine were based on the budget estimated (Projelmec, 2021) and the cost of the industrial aerator was obtained from market research (Aeromack, 2021). Table 3 presents the results for expected investment.

Table 3. Project investment.

Description	Value (US\$)	Source
Savonius Turbine	933.44	Projelmec, 2021
Mechanical Installation	78.08	
Industrial Aerator	93.70	Aeromack, 2021
Total	1,105.21	

Savings in Electricity bill was considered as project revenues. The inflation considered in the modeling was 8,06% per year, according to the IBGE (2021). The life cycle considered for the equipment was 20 years (EPE, 2019) and the minimum acceptable rate of return (MARR) was 15%, according to Garbeet *al.* (2011). The modeling of the project is shown in Figure 2. The net present value (NPV) calculated for the project was US\$ 457.63. The internal rate of return, discounting the effects of inflation (Net IRR) was 11.20% and the payback was 11.26 years.

P (year)	Investment (US\$)	Revenue (US\$)	Cash Flow (US\$)
0	-1,105.21		-1105,21
1		152.33	152,33
2		164.60	164,60
3		177.87	177,87
4		192.21	192,21
5		207.70	207,70
6		224.44	224,44
7		242.53	242,53
8		262.08	262,08
9		283.20	283,20
10		306.03	306,03

Continued on next page.

P (year)	Investment (US\$)	Revenue (US\$)	Cash Flow (US\$)
11		330.69	330,69
12		357.35	357,35
13		386.15	386,15
14		417.27	417,27
15		450.90	450,90
16		487.25	487,25
17		526.52	526,52
18		568.96	568,96
19		614.81	614,81
20		664.37	664,37
		NPV	457.63
		IRR	20.20%
		Net IRR	11.20%
		PAYBACK (year)	11.26

Figure 2. Economic modeling of the project.

After the modeling economic, the project's risks were mapped. The identified risks were classified into three dimensions and linked to the model variable impacted by its effect. Table 4 presents the risks raised.

Table 4. Savonius wind turbine implementation risk.

Risk classification	Risk	Impacted model variable
Technological	Life cycle shorter than expected	Life cycle
Operational	Intermittence of winds	Power
Systemic	Inflation variation over the analysis period	Inflation
	Electricity Price variation over the analysis period	Electricity Price

The variables impacted by the identified risks were subjected to a sensitivity analysis. The output variable chosen for analysis was the NPV. A variation of 20% more and less for each variable was considered. The 10% plus and minus points were also collected. The Sensitivity Analysis of the variables considering the NPV is shown in Figure 3:

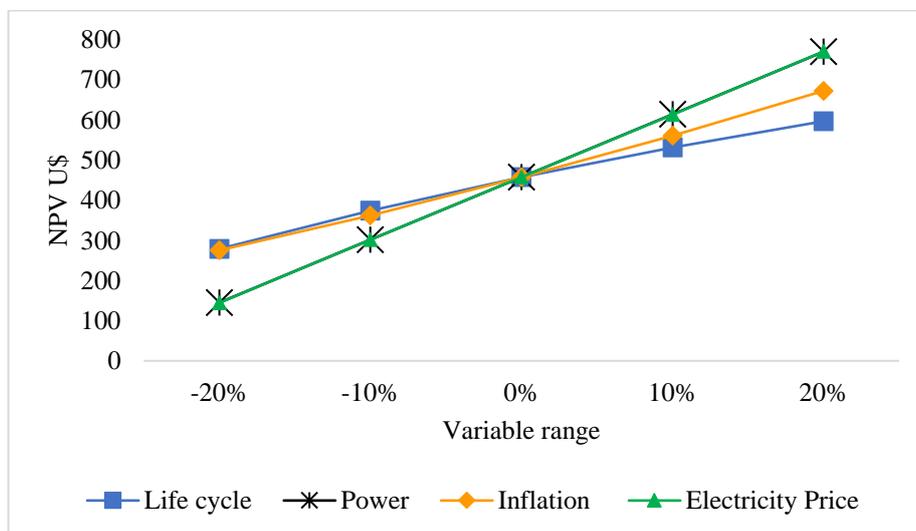


Figure 3. Sensitivity analysis.

The sensitivity analysis of the project showed that the variables power and electricity price of the Savonius wind turbine are representative considering the NPV as the output variable. The inflation and life cycle variables have little impact. The determining variables for the project, that is, power and electricity price were subjected to scenario analysis. In the analysis of scenarios, 3 contexts were considered: pessimistic, probable and optimistic.

Scenario summary				
	Current values:	PESSIMISTIC	PROBABLE	OPTIMISTIC
<b>Variablecells:</b>				
<b>Power [W]</b>	250	200	250	300
<b>ElectricityPrice [R\$/kW)</b>	1.003	0.176	0.196	0.215
<b>Results:</b>				
<b>NPV (US\$)</b>	457.63	20.41	457.63	957.18
<b>Net IRR</b>	11.24%	15.25%	11.24%	15.96%
<b>PAYBACK (years)</b>	11.26	17.68	11.26	7.25

Figure 4. Scenario analysis.

In the pessimistic scenario, was considered that the power generated and the electricity price was reduced, was obtain NPV of US\$ 20.41 and a payback of 17.68 years. In the optimistic scenario, was obtain NPV of US\$ 947.18 and a payback of 7.25 years. This considers a favorable wind condition and the turbine works for more than 8 h with an average power of 250 W per day.

#### 4. CONCLUSIONS

The aim of this work was to perform an economic analysis of the implementation of a Savonius wind turbine and perform a risk analysis of this implementation. An economic modeling was performed based on data collected from the literature, budgets and market indexes. The new technology showed to be economically viable. Based on this scenario, the project's risk was surveyed and the model variable impacted by each risk. The variables identified were submitted to a sensitivity analysis. It was found that the most impactful variables for NPV were power of Savonius turbine and electricity price. These variables were submitted to a scenario analysis. It was observed that, in probable and optimistic scenario, the project is economically viable.

For future studies, given the economic feasibility of the project, it is suggested to study the use of excess energy generated, since energy saving is one of the system constraints of the activity (Aquaculture, 2021).

Exploring pisciculture and aquaculture 4.0 with process automation, it is possible to optimize the use of the turbine, i.e., to direct the compressor air by measuring the oxygen concentration.

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