

Article

# Climate-Smart Agriculture in the Northeast of Brazil: An Integrated Assessment of the Aquaponics Technology

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**Abstract:** The purpose of this study is to determine if aquaponic systems can reduce food insecurity in the semi-arid regions of Brazil and generate income for the beneficiaries. Aquaponics is a potentially sustainable way to produce food based on gardening, hydroponics and aquaculture. A case study, based on a project called Aquaponova, was developed. The aquaponic systems currently used in the project are non-commercial and designed for households with limited resources. The data based on six existing systems within this project were used to compare the costs and the benefits. The cost–benefit analysis covers four scenarios and three financing options. The results show that aquaponic systems have a large potential and can reduce food insecurity in semi-arid regions while generating income for the beneficiaries. Even if the system only produces 40% of the total estimated production, the system will still be feasible. However, the low opportunity cost of labour is an essential factor for obtaining these positive results. Moreover, the social benefits, such as a community spirit and the health benefits of the system, should not be underestimated.

**Keywords:** aquaponics; Aquaponova; Brazil; semi-arid region; food insecurity; cost–benefit analysis; socio-economic approach; climate-smart agriculture

## 1. Introduction

The 2018 Food and Agriculture Organisation’s (FAO) report states that there is “evidence of a continuous rise in world hunger [ ... ]. In 2017, the number of undernourished people is estimated to have reached 821 million—this means about one person out of every nine in the world. Undernourishment and severe food insecurity appear to be increasing in almost all sub-regions of Africa, as well as in South America” [1]. This does not only refer to agriculture but also to fisheries. Worldwide, 1.4 billion people get their essential micronutrients from fish. Ever since the wild fish catch peaked in 1996, it has been diminishing by 1.22 million tons per year. This is more or less 1% less per year [2]. Furthermore, the FAO report emphasized the alarming signs of increasing food insecurity and different forms of malnutrition. This is a clear warning that nations need to act to make sure everybody gets the help she/he deserves on the road towards achieving the Sustainable Development Goals (SDG) on food security and improved nutrition [1].

Climate-smart agriculture (CSA) is a way to transform and reorient agricultural systems to support food security in this new reality of climate change [3]. The three major pillars of CSA according to Totin et al. [3] are “(a) increasing agricultural productivity; (b) increasing adaptive capacity at multiple scales [ ... ] and (c) reducing greenhouse gas emissions” [3]. The FAO recognizes the potential of aquaponics as an important CSA alternative. “Aquaponics is one type of integrated agriculture/aquaculture technique that meets the criteria of climate-smart agriculture. It sustainably

increases food security by increasing agricultural productivity and income” [4]. Forecasts show that agricultural production must increase by 60% worldwide by 2050 in order to meet the increased demand. The majority of this increase will have to come from higher agricultural productivity [5].

The main objective of this study is to explore the idea that aquaponics could help diminish food insecurity and generate income for poor families in arid regions. This CSA application can be a viable and important production strategy because the system is based on the interconnectedness of an ecosystem and adapts well to a semi-arid climate. Aquaponics uses the basics of gardening, farming and sustainable living in combination with hydroponics and aquaculture, which, according to some experts and researchers [5,6], is vital for the future of agriculture.

More specifically, this study will focus on the economic feasibility of an aquaponic system when applied at the individual-household level. Additionally, this study will estimate the potential cost and benefits of this system for a demarcated area in the northeast of Brazil. The objective of the system is to feed families in small communities and sell the surplus of vegetables and fish generated by the aquaponic system. The case study “Aquaponova” in the semi-arid northeast of Brazil will illustrate the social and economic impact of an aquaponic system. The project started in 2018 and is still in its early stages; yet, it is very relevant to follow-up on the developments, adaptations and challenges from the beginning onwards. The unique data from the project will be used to conduct a cost-benefit analysis, demonstrating the strengths and weaknesses of the system when addressing poverty and undernourishment. The project incorporates the aquaponics principles in the agriculture of arid areas in order to increase the amount and variety of family production. In 2018, the Federal Institute of Paraíba started a trial to grow vegetables and to breed chickens and fish using aquaponic techniques. The results of the trial can be used by the government to improve the sustainability of agriculture in arid regions in the future. This paper shows that the Aquaponova system has a large potential to diminish food insecurity and generate income for families while contributing to achieve the international SDGs.

### 1.1. Semi-Arid Northeast of Brazil

The semi-arid regions of Brazil, roughly 982,500 km<sup>2</sup>, is known as a very dry region. The average annual rainfall is approximately 750 mm, although—in some regions—the amount of water does not exceed 400 mm [7,8]. The water evaporates rapidly due to an average annual temperature above 20 °C. A total of 92% of all the rainwater falling in this territory is “consumed” by evaporation and only 8% is utilized to feed rivers, lakes, dams and drainage systems in this region [7]. This results in a continuous water deficit, associated with malnutrition, poverty and economic, social and environmental losses [9].

Additional problems—besides water scarcity—are salty groundwater and desertification. The available water in the ground in semi-arid regions is very salty and as such not appropriate for human consumption and irrigation. Therefore, a production method that utilizes salty water can have great potential in the semi-arid region. Furthermore, the region has to deal with the degradation of land. This desertification is mostly a consequence of human activities and climatic variations, mainly affecting regions in South-America and Sub-Saharan Africa [10,11].

The Brazilian Institute of Geography and Statistics (IBGE) shows that nearly 25% of the Brazilian population lives in poverty, which corresponds to more than 50 million people. The World Bank suggest a Brazilian poverty threshold of USD5.50 a day, which corresponds to a family income of R\$638 (or USD165 using the exchange rate of R\$3.87) a month. The northeast of Brazil has the highest poverty rate of the country, namely 43.5% [12]. As a result, 50% of the national anti-poverty cash transfer program—called Bolsa Família—goes to that region (2011), despite representing only 30% of the population [13].

The high poverty rates are inextricably linked to the famine in the region. Monteiro, Conde and Konno [14] conducted a survey in the semi-arid region of Brazil, indicating a chronic infant malnutrition rate of 6.6%, while the average malnutrition rate was 2.5%. Since 1975, the annual malnutrition rates kept rising from 3.06% to 7% between 1996 and 2005. Since then, the situation has barely improved. However, it should be noted that since the involvement of federal income transfer programs, the frequency of

malnutrition is decreasing. Another study of Saldiva, Silva and Saldiva [15] four years later in the same region shows that “4.3% of the children were underweight, 9.9% were stunted and 14% were overweight”.

## 1.2. Aquaponics

Aquaponics has its origins back in the 1970s. However, the research concerning this climate-smart agricultural system only took off from 2010 onwards. Aquaponics mimics the natural balance and relationship between plants, animals and water. It represents the natural cycle where plants need fish waste as nutrients to grow while the fish benefit from the cleaner, oxygenated water obtained by algae and, in so doing, live longer [16].

The aquaponic system is using fairly simple technology but, nevertheless, potentially has numerous benefits for poor and undernourished families in arid regions. In order to understand the strengths of the aquaponic system, the basic technological principles are explained briefly. The most basic aquaponic system consists of minimal two fish tanks so that fish can be separated in terms of size or age. This is important for two reasons: first to avoid cannibalism and secondly if all the fish were the same size, they needed all to be harvested at the same time [6].

The fish are fed with fish feed or animal material, which they convert into protein. The waste material of the fish sinks to the bottom of the water tank. By installing a small engine and a pipe, the dirty water can be pumped through a bio-filter. According to Nicolas and Savidov [6], the bio-filter is “an essential component between the fish and the plants which essentially comprises bacteria which convert the waste products from the fish into soluble nutrients for the plants”. More specific, the ammonia (excreted by the fish) is converted into nitrite and then nitrate by the bacteria in the bio-filter. High levels of ammonia in the water are toxic to fish.

In the next step the filtered water passes through a tube where the plants grow. Similar to the situation of the fish, it is important to have vegetables of different sizes so that they do not all have to be harvested at the same time. The remaining water, which is not absorbed by the plants, tumbles back into the water tank. In a nutshell, the water carrying waste material from the fish is pumped through a bio-filter where bacteria neutralize the ammonia and nitrite toxicity. The water leaving the bio-filter contains nitrate, which is neither toxic for the fish nor the plants. The filtered water then seeps through the tubes where it is used by plants as a nutrient source. Finally, the filtered residual water, without ammonia, which is not absorbed by the plants, is re-circulated back into the fish tank. This is how the aquaponic system produces valued fish protein with a minimal squander of water or pollution, while producing vegetables at the same time [6].

Inherently water is lost through evaporation and absorption by plants. However, the precise amount of water that is lost depends on various factors; for example, the temperature, the volume of the water tanks, if the surface area of the tank is exposed to the sun, the type and amount of vegetables, etc. On average, water loss would result in 5% to 10% per week, which is about 150 L of water if the tanks would contain 2000 L of water in total. Therefore, the aquaponic owners have to intervene: Besides keeping all of the components in the system operational, the owner needs to add water, to feed the fish and to harvest the grown vegetables and fish on a regular basis. Especially in arid areas it is important that this system is shielded from the sun to minimize the evaporation. Furthermore, a small solar panel could be installed on the roof and connected onto the system to keep a battery continuously charged to provide the filters with power at night [17].

In previous studies, the economic costs and benefits were only considered if the purpose of the system was commercial. The findings of these case studies should not be generalised due to essential differences in the climate of countries, economic structures and the objective of the system. Bosma et al. [18] made a cost–benefit analysis for an aquaponic system in the Philippines, with the aim of identifying the elements that have the greatest impact on costs and benefits. It is important to indicate some crucial differences in the design of the Bosma et al. paper and this paper. First of all, in the application of Bosma et al., the system is installed in a tropical climate and where water is more

easily accessible. Secondly, the system is installed in a coastal area, which makes the access to fish easier. Ultimately, the aquaponic system does not aim to feed the family but rather to sell vegetables and fish on local markets. Developing aquaponics as a business requires much more space and time. For example, the aquaponic system in the Philippines has 15 fish tanks and an area to cultivate vegetables of 96 m<sup>2</sup>, producing 1250 kg of fish, 8320 kg of lettuce and 1985 kg of tomato per year once the system was operational. Maintaining all environmental factors in balance is much more demanding on a large scale than on a household scale. The system is sustainable but not equally profitable in all countries and/or for all purposes [19].

The study of Bosma et al. [18] corresponds to Buysens and Gobin's [20] research indicating that the economic feasibility of a small aquaponic system—aiming at selling the production on a market—is not always feasible. Buysens and Gobin [20] conclude that the return of the system mainly depends on the fish component. More specifically, the choice of the fish species and the amount and size of the fish. Tokunaga et al. [21] also revealed a number of important variables that can influence the economic benefits of the system. They conclude that the systems are less beneficial than what the experiments promise. The main reason for this is the choice of fish species and the geographical location of the project. Other variables that need to be taken into account are government subsidies and taxes, having a nearby market with a high demand for vegetables and fish and low transport costs [20]. The FAO [4] stated recently that “commercial aquaponics is not appropriate in all locations, and that many aquaponic businesses have not been successful. Large-scale systems require careful consideration before financial investment, especially regarding the availability and affordability of inputs (i.e., fish feed, building and plumbing supplies), the cost and reliability of electricity, and the access to a significant market willing to pay premium prices for local, pesticide-free vegetables”.

These findings are interesting but not applicable when the purpose of the system is not commercial but rather to provide the producing families with food and to only sell the surplus. First, the system could be much smaller and simpler than a system with commercial purposes. Secondly, only fish and vegetables that could easily survive in the system would be cultivated. Thirdly, there is no need for employees to be paid, the family can maintain the system herself, even in combination with a job. Our analysis will contribute to the literature by assessing a non-commercial aquaponics system in a semi-arid region.

## 2. Materials and Methods

This case study evaluates an aquaponic project called Aquaponova. Even though it is difficult to incorporate the social costs and benefits in a cost–benefit analysis (CBA), a CBA seems to be the appropriate method since it allows researchers to consider and compare different financial options in different scenarios. However, a CBA of a new technology is a complicated exercise because several factors have to be taken into account. This section will estimate the potential costs and benefits of this system for a demarcated area in the northeast of Brazil. It is important, however, to remember that a “benefit assessment is typically a mixture of potential outcomes rather than a pure black or white answer, i.e., the use of the technology under different developmental, human, and climatic conditions will lead to different benefit scenarios” [19].

To assemble the CBA, unique data from an ongoing project called Aquaponova is used. The project is conducted by the Federal Institute of Paraíba and includes creating an industrialized model of low costs and letting families benefit from the output provided by the aquaponic system. The data used in this case study were collected between mid-2018 and early 2019 and was obtained by calculating the average quantity of food produced by the first six systems installed. Based on these data, this article will discuss the result of a cost–benefit analysis to decide whether this project could potentially reduce the food insecurity in the region. To assess the economic feasibility of the Aquaponova project in four different scenarios and three different financial situations, the Net Present Value (NPV) was calculated. The NPV is the present value of the net benefit stream. The net benefit is defined as the benefits minus the costs during a specific period.

The objective of the Aquaponova project is installing the system, with the participation and training of the beneficiaries, to meet the food needs of those families and to generate a small surplus, which then could be sold to generate income. Aquaponova could be a sustainable, low cost and easy operational solution, in line with most of the Sustainable Development Goals (SDGs).

### 2.1. Social Aspects

The families using the aquaponic system were selected by the researchers of the Instituto Federal da Paraíba. The first families to participate were contacted by the researchers; others applied when they learned about the project from people in the community. Upon completing a workshop, the beneficiaries must be able to maintain an aquaponic system autonomously. In addition, the farmers will receive technical assistance during the first six months as from the implementation of the system, in order to guarantee the correct operation and maintenance of the system. In this way, new farming practices can be spread through the aquaponic system and the entire community involved can benefit from this technology.

Aquaponova can contribute to 11 of the 17 SDGs (excluding Goals 5, 8, 9, 11, 16 and 17). In fact, most of the sustainable technological solutions (e.g., aquaculture, hydroponics, etc.) that make up the Aquaponova system are already known, tested and validated in relation to the SDGs [22,23]. Although not all of the social benefits can be incorporated in the CBA, it is important to mention them. Therefore, this article will give some examples how the Aquaponova program can contribute to the SDGs:

Goal 1: “End poverty in all its forms everywhere” [24]. The Aquaponova project contributes to this SDG by allowing families to produce their own food and sell the surplus of vegetables, fish and eggs on the market. A small amount of additional income it could lift some families out of poverty.

Goal 2: “End hunger, achieve food security and improved nutrition and promote sustainable agriculture” [24]. With an Aquaponova module it is possible to produce food for a family in the semi-arid region, contributing to ending hunger and achieving food security and improved nutrition.

Goal 3: “Ensure healthy lives and promote well-being for all at all ages” [24]. By producing healthy food, in addition to promoting opportunities for decent work, Aquaponova can contribute to a healthy life and more well-being for all, at all ages.

Goal 4: “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” [24]. Aquaponova is composed of several social technologies of which the knowledge contributes to lifelong learning and to inclusive and equitable quality education, bringing new horizons to the families of farmers, who can improve the system or specialize in some specific subsystem.

Goal 6: “Ensure availability and sustainable management of water and sanitation for all” [24]. Aquaponova is directly related to this SDG by promoting sustainable management of the little water available in the semi-arid region. The system re-circulates the available water.

Goal 7: “Ensure access to affordable, reliable, sustainable and modern energy for all” [25]. The Aquaponova can be fed by a solar energy system. Therefore, there is no need to pay for conventional electric energy.

Goal 10: “Reduce inequality within and among countries” [24]. Aquaponova can potentially contribute to the reduction of inequalities, since it enables decent employment, access to new technologies and income generation in rural areas.

Goal 12: “Ensure sustainable consumption and production patterns” [24]. Aquaponova contributes to this SDG by enabling sustainable production and consumption patterns, in the very environment of the small rural property, by reusing water and producing organic and healthy food.

Goal 13: “Take urgent action to combat climate change and its impacts” [24]. Aquaponova optimizes the use of natural resources, especially water, physical space and solar energy, reducing the emissions produced by traditional rural production systems, thus combating climate change and its impacts.

Goal 14: “Conserve and sustainably use the oceans, seas and marine resources for sustainable development” [24]. Aquaponova contributes to the conservation and sustainable use of marine resources for sustainable development because the families will breed their own fish.

Goal 15: “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss” [24]. Aquaponova is a productive ecosystem that helps family farmers to stop degrading the environment for their own survival. The system minimizes desertification and helps the environment to recover.

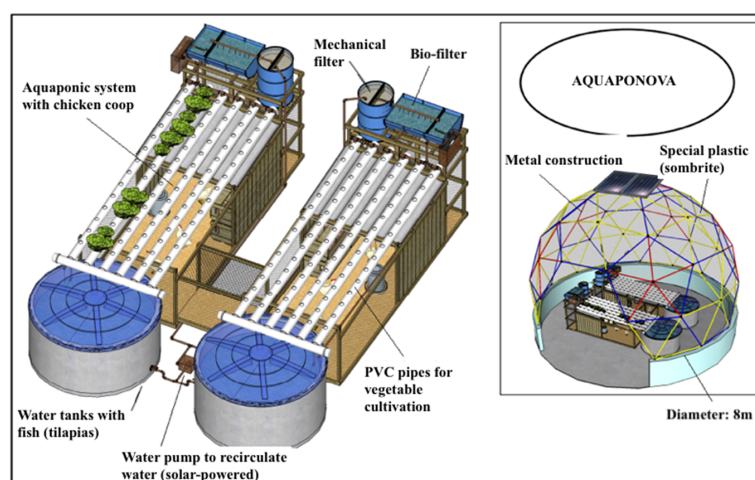
## 2.2. Economic Aspects

The Aquaponova system—as shown in Figure 1—contains 12 PVC pipes and 2 water tanks of 1000 L. The oxygenation of the water in the tanks is partly done by the water recirculation itself. The water that goes down the PVC pipes falls back into the fish tank from a height of about 30 to 40 cm, causing some oxygenation. The other part of the oxygenation is done by an aquarium oxygenation pump (powered by 12V). Each PVC pipe contains 14 holes to plant the vegetables. The space below the pipes is enclosed and used as a chicken coop (see Figure 2). To protect the vegetables, fish and chickens from the sun, the system is covered with a shade screen, preferably a plastic mesh netted cloth. On top of the construction is a solar panel that produces energy to pump the recirculating water. The scale of the system makes it possible to obtain a production capable of meeting the needs of a family of up to five people with fish, eggs and vegetables (see Figure 3). In addition, there is a surplus which can be sold on the market to generate income. The capital and operational expenditure are shown in Table 1.

**Table 1.** Capital and operational expenditure. Source: Aquaponova project.

	Description	Total (USD)
Capex	Materials	1603.00
	Installation services	2190.00
	Chicks, fry (tilapia), seeds (start package)	104.00
	Maintenance (10% of materials) (per year)	160.30
Opex	Technical support (per time)	22.70
	Fry (tilapia) and seeds (every 2 months)	4.00
	Labour cost (per hour)	1.25
	Emergency electricity (per month)	0.60

Note: The costs used in this table are based on the exchange rate of R\$3.87 per dollar as on 9 March 2019.



**Figure 1.** Aquaponova design.

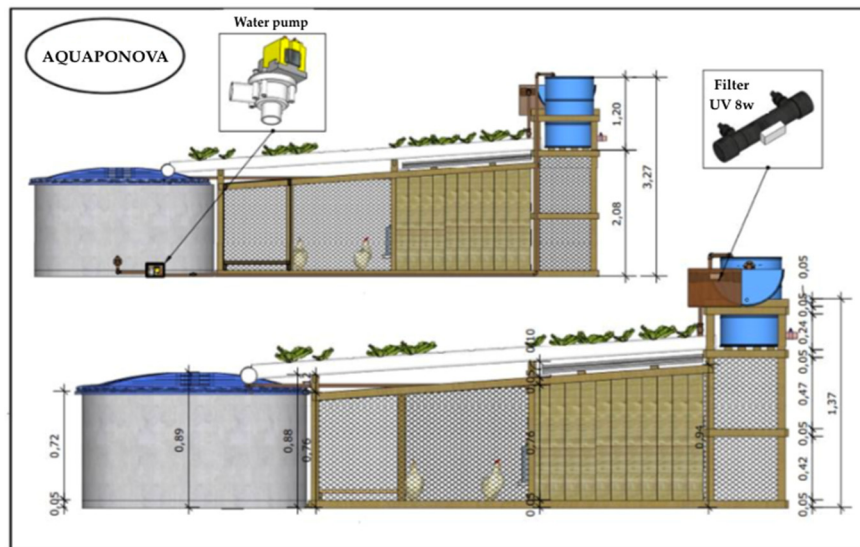
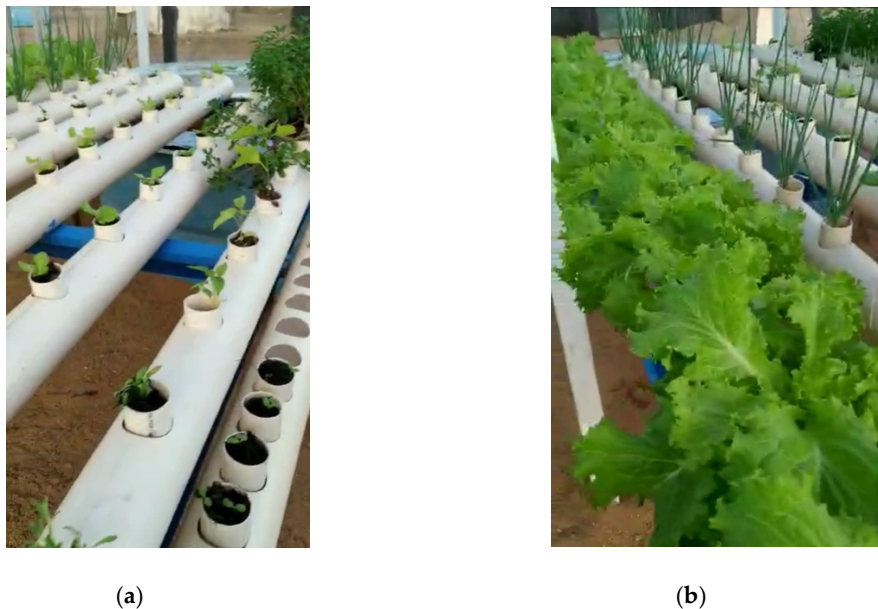


Figure 2. Aquaponova design side view.



(a)

(b)

Figure 3. (a) shows the growing vegetables in an aquaponic system and (b) shows lettuce ready to be harvested.

### 2.2.1. Capital Expenditures (CAPEX)

These are the cost of developing or supplying non-consumable parts of a product or system. In the Aquaponova project it covers:

- The materials to build the Aquaponova: two water tanks of 1000 L, iron pipes to build a roof, a plastic shading screen, PVC tubes, canvas for the chicken coop, electric pump, ultraviolet filter, filtering elements for the biological filter and the solar panel.
- The installation services: construction and installation of the system, including logistics and transport and the workshops the beneficiaries can follow to understand how to use and maintain the system.
- Ten chickens and one rooster, 200 units tilapia fry and vegetable seeds.

### 2.2.2. Operational Expenditure (OPEX)

These are the recurring costs for a product, system or company. The main operational cost is the maintenance, technical support and the opportunity cost of labour. Other costs are the purchase of fry, seeds, a small weekly supplementation of the water—due to evaporation—and back-up electricity, which are almost negligible. The opportunity cost of labour is based on the estimated time of daily labour spent to manage the system, which is maximum of 30 min a day. In addition, one day a week the produced surplus must be sold on the market. These expenses will all be included in the CBA as costs.

Maintenance is assumed to be 10% of the value of the materials used to build the Aquaponova system as indicated by the project developers of the Aquaponova. This includes only the annual cost of repairing or replacing broken components. The technical support is the expert assistance and advise the beneficiaries can receive when confronted with problems they cannot solve themselves. Assuming the beneficiaries would ask for assistance once a month for the first six months and then two times the next year, the cost would be USD22.70 every time they ask for assistance.

Opportunity cost of labour is the value of the best possible alternative use of the labour and time that is lost by using the labour and time for something else. Estimating the opportunity cost of labour per hour is a difficult exercise. In this paper this cost will be based on the minimum income in the region, which is USD1.25 (R\$4.54) per hour [25]. The choice to base the opportunity cost of labour on the minimum wage has to do with the fact that the target group of this project are poor and low-income families, who are often not or poorly educated.

Electricity is required to keep the systems properly working (filtering, oxygenation, water pumping, ultra-violet light, etc.). The basic electricity supply comes from the solar panel that is included in the case. The solar panel is connected to a battery so that energy can be stored to keep the system running during the night and cloudy days. However, to cope with unexpected lack of electricity from the solar system, the case assumes that electricity from the utility provider can be used as back-up. This paper considered the need of electricity from the grid for 24 h per month. The total cost for 24 h of electricity would be USD0.60 a month.

Water is needed to fill the two tanks. Each tank has a capacity of 1000 L. The standard tariff in Brazil for water is USD13 per month for up to 10 m<sup>3</sup>. Considering the low monthly water consumption of the Aquaponova system, around 1 m<sup>3</sup> a month, this analysis does not consider this in the cost structure. Taking into account the warm climate, maximum 10% of the water will evaporate each week, equivalent to 200 L (depending on climate, location, etc.). The water can be replenished by household water or by (salt) groundwater.

### 2.2.3. Food Insecurity and Nutritional Impact

The Aquaponova production depends on the climate (e.g., temperature, sunlight, humidity, rain patterns, etc.), the produced vegetables and the people managing the system. Families are free to choose what they want to produce. In theory, the vegetables can be harvested throughout the year if sufficient water is available. Furthermore, the production can increase as the families gain a better understanding of the system's functioning. Both the income generated by selling vegetables, fish and eggs as the money that the family "saves" by producing its own food, will be included in the CBA as revenues. Food prices are estimated based on the average market price in the region. The value of the food consumed by the family is increased by 5% to compensate for the time the family economized by not going to the supermarket or community market. An overview of the food production can be found in Table 2.



**Table 2.** Revenues from vegetables, fish and eggs. Source: Aquaponova project.

	Average Weight 1 Unit (kg)	Average Weekly Production	Average Monthly Production	Average Market Price (USD)	Market Value (USD) Monthly
Tomatoes (kg)	0.15	1.50	6.50	1.33	8.65
Cabbage (kg)	1.00	2.00	8.66	0.64	5.54
Peppers (kg)	0.14	0.85	3.68	3.05	11.22
Lettuce and coriander (units)		34	146	0.65	94.90
Tilapia (units)	0.80	5.76	25	2.70	67.50
Eggs (12 units)		3.50	15	2.00	30.00
Total sum					217.81

#### 2.2.4. Financing Options

The initial cost of the Aquaponova is the main obstacle to make the project affordable to low income families. This paper will discuss how the existing Aquaponova systems have been financed. Furthermore, this paper will explore two alternative models of government participation to provide the necessary funds to deploy the system in the semi-arid regions.

- Own financing: The six Aquaponova systems that have been installed, were all financed by the beneficiaries. However, the researchers are aware that this cost is making it difficult to find poor families to participate in the project. Hence the researchers are currently looking for other funding options. Therefore, this paper will explore two alternative funding options.
- Government financing of the infrastructure: In this model the producer can get access to government financing, for example Inovagro, which is a program in Brazil designed to encourage sustainable projects in rural areas. The Inovagro program was launched in 2014 by the National Bank of Development to offer financing for the incorporation of sustainable technological innovations in rural properties, aimed at increasing productivity and improving agricultural management. The program gives Aquaponova users the opportunity to borrow money to install the system at a fixed interest rate of 6% a year. In the CBA, the entire amount of USD4500 to support the project for ten years, will be borrowed. The repayment can be started after three years but within 10 years the entire borrowed amount must be repaid [26,27].
- Brazilian government or external agencies support: In this case the government or other organizations—for example the World Bank or FAO—would provide funds for the installation and technical support of the Aquaponova project. Most of the costs for the families would be eliminated. Although this option is interesting to analyse, it is less likely to become a reality.

#### 2.2.5. Investment Cost-Benefit Analysis

This paper will discuss the conducted CBA for the present case with a project length of 10 years. The costs and benefits will not be calculated per month as they can vary each month. To estimate the profitability of the project, the net present value (NPV) for four different scenarios was estimated. The NPV is the present value of the net benefit stream. The net benefit is defined as the benefits minus the costs during a specific period, in this case 10 years. The net benefit must be discounted by using a discount rate. If the discount rate is high, then one prefers the money now, rather than later. Furthermore, the inflation rate must be taken into account. When the NPV is larger than zero, then it is wise to start the project. To calculate the NPV the following formula is used:

$$NPV = \sum_{n=0}^N \left[ \frac{(B_n - C_n)}{(1+r)^n} \right] \quad (1)$$

in which  $B_n$  is the benefits in year  $n$ ,  $C_n$  is the costs in year  $n$ ,  $r$  is the discount rate and  $N$  is the total project period (= 10 years).

To determine the appropriate discount rate, similar projects were considered. It became apparent that researchers usually choose a discount rate between 6% and 9% [18]. Thus, in the calculations of this project, a discount rate of 6% will be used. By applying a discount rate, the costs and benefits in the future will have a relatively lower value than today. For the inflation rate, 5% will be applied, based on the average inflation in Brazil the last years.

Since a CBA depends on the used data and the assumptions made, four different scenarios are discussed. Each of these scenarios also include three different financing options. The four scenarios are as follows:

- The opportunity cost of labour and the revenue from own food production and consumption cancel each other out.
- The opportunity cost of labour is different from the revenue from own food production and consumption.
- Fluctuating food production.
- Fluctuating opportunity cost of labour.

The tree financing options include:

- (a) own financing;
- (b) Inovagro (provision);
- (c) government or external support (subsidies).

### 3. Results

Based on the data of the already existing Aquaponova systems, this paper gathered information about the costs and the revenues of the system. Considering the total food production, a part will be consumed by the family (on average five members) and the other part will be sold on a market. Both the income from selling vegetables and the income saved by families by producing their own food will be incorporated in the CBA. The cost of installing and maintaining the Aquaponova system for ten years is USD4500 (Capex and Opex over a 10-year period, discounted to today's value), and will be the same in each scenario.

The CBA considers three different cases of financing in four different scenarios. In general, each scenario will be evaluated on the basis of the NPV in ten years' time. Each scenario will consider an inflation rate of 5% a year, a discount rate of 6% a year and an interest rate of 6% a year (if the Inovagro program were to be used).

Because social benefits are difficult to quantify, they are not included in the CBA. The most important social benefits are mentioned in Section 2.1.

#### 3.1. Scenario 1: The Opportunity Cost of Labour and the Revenue from Own Food Production Cancel Each Other Out

In this scenario, the assumption is made that the food produced and consumed by the beneficiaries is worth as much as the opportunity cost of labour. Therefore, these costs and revenues are being disregarded in the CBA. Only the revenues from the eggs sold, Tilapia, coriander and lettuce are taken into account, as well as the costs regarding the installation, maintenance, seeds, fry and chicks. To evaluate the system, three different financial options will be commented and summarized in Table 3.

**Table 3.** Net present value (NPV) in Scenario 1, 2, 3 and 4. Source: Cost–benefit analysis (CBA) based on the Aquaponova project.

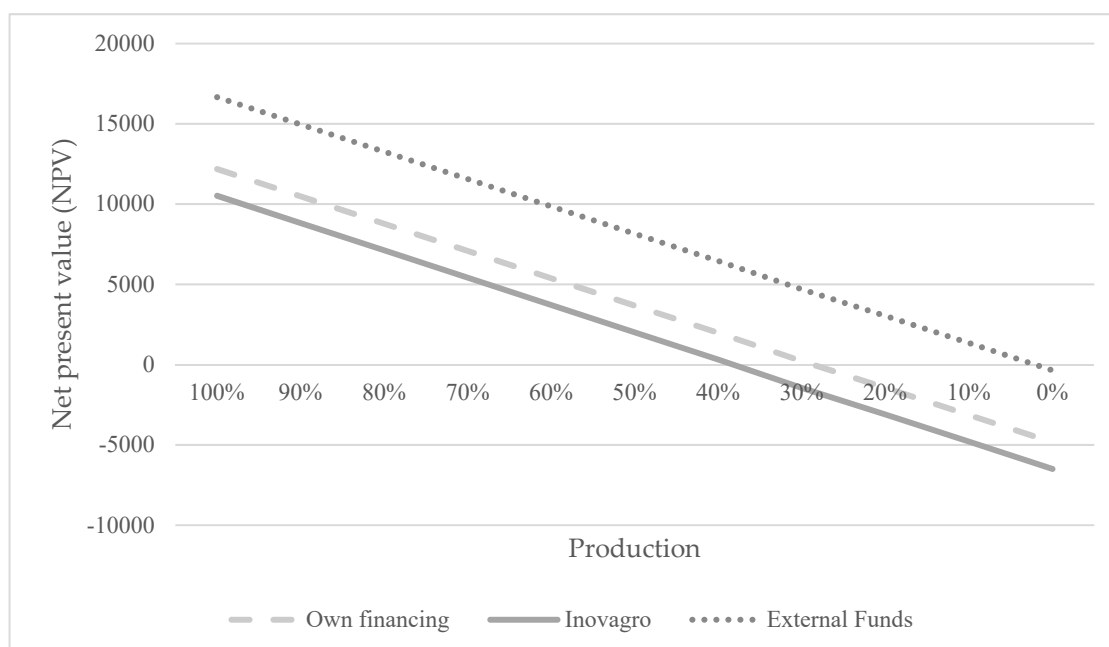
NPV (10 Years) USD	Scenario 1	Scenario 2	Scenario 3 (50% Production)	Scenario 4 (2.5USD Labour/Hour)
Own financing	10,735	12,181	3676	5469
Inovagro	9072	10,518	2013	3805
External funds	15,213	16,660	8154	9947

### 3.2. Scenario 2: The Opportunity Cost Of Labour Is Different From The Revenue From Own Food Production

This is an interesting—and more economically correct—scenario than the previous one. In this scenario the opportunity cost of labour and the revenue from consuming home-grown food are considered in the CBA. The first difference is that the opportunity cost of labour is taken into account, although it is possible to combine a paid job with managing the Aquaponova system. Due to the high unemployment and poverty rate in the region, the opportunity cost of labour per hour is based on the minimum hourly wage of USD1.25 (R\$4.54) [25]. The second difference is that the home-grown food consumed by the beneficiaries is valued 5% more than the food sold on the market. To evaluate the system, three different financial options will be commented on and are summarized in Table 3.

### 3.3. Scenario 3: Fluctuating Food Production

In the previous scenarios the assumption was made that the Aquaponova system always produces the same amount of food. This paper considers this situation as the maximum production or production at 100%. This means that during the project period of ten years the system would always work impeccably. In reality, there will be days that the system does not work, there will be harvests that fail, fish that die, and so on. Therefore, it is necessary to estimate the NPV in case of decreasing food production from full production (100%) to zero production (0%) (see Figure 4).

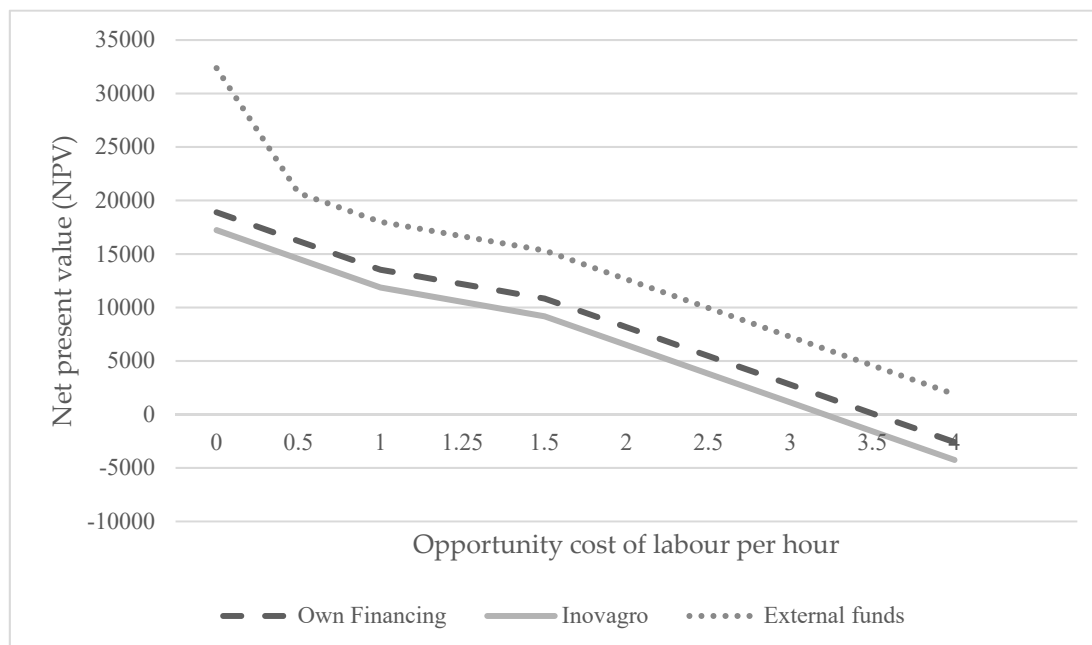


**Figure 4.** A graph of the fluctuating food production. Source: CBA based on the Aquaponova project.

### 3.4. Scenario 4: Fluctuating Opportunity Cost of Labour

The opportunity cost of labour is the highest monthly cost in the analysis even though the minimum wage in Brazil—USD1.25—is very low. It is possible that the minimum wage will increase

in the coming years as a result of the country's fast-growing economy. This scenario will show what would happen to the NPV if the minimum wage was to rise or fall. In Scenario 2 and 3, the opportunity cost of labour was set at USD1.25 an hour; in this scenario the NPV will be evaluated at an opportunity cost of labour per hour of between USD0 and 4 (see Figure 5).



**Figure 5.** A graph of the fluctuating opportunity cost of labour. Source: CBA based on the Aquaponova project.

#### 4. Discussion and Conclusions

The main advantages of the aquaponic system are the growth of vegetables (in this case tomatoes, cabbage, peppers, lettuce and coriander, but other vegetables can also be grown in the system), the significant reduction in the usage of water, a larger production of vegetables than when grown in soil and less need for artificial fertilizer. However, there are some disadvantages as well: The system is expensive for poor families, some technical knowledge is required, as is the monitoring of water to make sure the water quality is liveable for the fish, electric energy is needed to maintain and recycle the water within the system and the components must not fail as it could lead to the loss of fish and or plants. The literature already points out the most important advantages and disadvantages of the aquaponic system. Nevertheless, it can be very useful to evaluate the system under a number of specific circumstances, as shown in the different scenarios.

As was mentioned before, this is not the first study on aquaponic systems. However, the aim of previous experiments was to commercialize the production of vegetables. That requires much more time, space and knowledge than when developing an aquaponic system to primarily feed the family and sell the surplus on local markets [18]. The Aquaponova initiative is the first project to implement aquaponic systems in an arid region and focus on developing a sustainable solution for the rising undernourishment. Yet, the Aquaponova project is still in its start-up phase, resulting in limited available data. Nevertheless, it is important to monitor and evaluate the project from the start, so emerging challenges can be addressed and the aquaponic system can be optimized.

This study shows that the Aquaponova project has great potential to reduce malnutrition and generate income for the beneficiaries. In the first scenario, without taking household consumption and the opportunity cost of labour into account, the NPV for a period of 10 years of one aquaponic system is between USD9100 and 15,200, depending on the financial situation. In the second scenario, taking household consumption and the opportunity cost of labour into account, the NPV for a period of 10

years of one aquaponic system is situated between USD10,500 and 16,600. This income can make a huge difference for poor families. However, these scenarios assume a constant production with no setbacks or problems. The third scenario shows the NPV under different production capacities. Even when the system would only produce 40% instead of 100% production, the NPV for a period of 10 years would be situated between USD5400 and 11,500, which can still make a difference in the lives of poor families. The fourth scenario shows the NPV for a period of 10 years under different opportunity costs of labour. The research shows that the results are very dependent on the low opportunity cost of labour. This is the reason why these positive results can only be obtained in developing countries or less developed regions in growing countries, such as Brazil.

The literature review indicated that 43.5% of the population in the northeast region of Brazil lives in poverty. This means that these families have a daily income of USD5.5 or just over USD2000 a year [12]. Given a period of ten years, these families have to make ends meet with an average of USD20,000. The Aquaponova project gives them the opportunity to earn on average an extra USD10,000 in the same period in combination with more food security and other social benefits.

These are positive and promising results. However, some critical side-notes must be made. First, this paper assumes that after following a workshop the beneficiaries have enough knowledge to maintain and manage the system (with limited expert help in the first few months). Since the fish and plants depend on the same water, it is not easy to optimize the situation for both fish and plants. Both need water with a specific temperature, nutrient level and pH level. The technical side of the system is also not self-evident. The beneficiaries need to know how to repair and/or replace the different components such as the solar panels or filters, otherwise an imbalance is created that can be damaging to the fish and the plants. If the beneficiaries do not know how to manage and maintain the system properly the food production and the lifespan of the aquaponic system will decrease substantially. Secondly, the system needs daily attention, which means that it is impossible for the family to be absent even for more than one day. Visiting relatives for a weekend could already trigger an imbalance in the aquaponic system, causing harvesting losses. Nevertheless, since the families in question are usually poor or have low incomes, this paper assumed that the beneficiaries will mostly stay at home. Thirdly, the CBA is based on the average market price of vegetables, fish and eggs in the region and not on the average price of food on local markets. This research assumes the local market prices and regional prices are fairly similar. However, vegetables on local markets are often cheaper than imported food in supermarkets, but as the region suffers from desertification and water scarcity, the food supply is limited, and the prices may be higher than in the supermarkets. Therefore, it is difficult to estimate the exact revenues, in reality the prices of fish, eggs and vegetables could be higher or lower than anticipated in this paper. Fourthly, this paper assumes that all the vegetables and fish offered by the beneficiaries on the market are sold. Lastly, the calculations were made under a non-tax assumption. If taxes had to be paid on the income of the family, derived from the aquaponic system, the revenues would be less. These are all assumptions that can influence the results of the assessment.

Two important limitations must be taken into account. First, the CBA is based on data from six existing Aquaponova systems. If the data came from more systems, they would be more reliable. Moreover, the project has only just started, which means that we do not have a notion of the additional costs and setbacks in the coming years, which, as a consequence, could not evidently be taken into account in the CBA. Secondly, there are several (social) benefits that are not quantified; for example, the fact that families can consume healthier (and more) food, that families can learn new things, that communities and individuals are brought together, that more healthy food is brought to local markets to the benefit of others, etc.

#### *Further Research and Policy Recommendations*

There are many options for future research. A first possibility is to carry out similar research in a few years when the Aquaponova project is more widely spread and more data has been collected. In this way, researchers will have a better view of unexpected costs or new opportunities. A second possibility

is to quantify the social benefits, for example, are the beneficiaries/is the community healthier? Is the community spirit better? Since quantifying these benefits is very difficult the researcher could opt to interview beneficiaries about their experience with the system. Is the system easy to use? Are they satisfied with the production? A third possibility is to analyse the costs and benefits when producing different vegetables and fish species. A fourth possibility is to analyse how small producers can organise themselves around cooperatives to improve the income of the small producers. Cooperatives can be very important in organizing, distributing and stocking the production. Furthermore, cooperatives have the possibility to innovate and implement technical developments faster than families and small producers. Lastly, it could be interesting to explore some opportunities and possibilities the project creates. For example, what would be the effect of expanding the system to increase the production? Could the system be installed in schools, so children could benefit from healthy school lunches while learning about the system? Could neighbouring families work together and install one larger system and share the costs and benefits?

This paper would recommend policy makers to encourage the development of aquaponics by offering free workshops and free technical assistance. Furthermore, governments can support the communities eligible to take such initiatives by providing subsidies or tax deductions.

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