Analysis of Aquaponic Production Systems - Economic and environmental comparison with other production techniques

João Mirão Eusébio

j.meusebio85@gmail.com

Instituto Superior Técnico, Universidade de Lisboa, Portugal

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Abstract: In the last decades, associated to new consumption and production patterns, to environmental degradation and the fragility of Ecosystems, new productive concepts and resource management have been developed in order to guarantee a sustainable development. Associated with the eventual scarcity of consumable water, new agricultural systems and techniques that claim greater sustainability have been developed. However, this characteristic still remains with relatively undefined contours. In the present work four cases, three real and one virtual, were compared, based on three agricultural techniques, in the expectation of evaluating and comparing their sustainability. The analysis was based on the application of several methodologies, where in the first phase an environmental impact assessment was carried out, followed by an economic assessment.

KeyWords: Aquaponics, Hydroponics, Conventional Farming, Life Cycle Assessment, Life Cycle Cost, Net Present Value

1. Introduction

In recent centuries, as a reflection of growing industrialization, technological development and consequent environmental degradation, new challenges and strategies related to environmental protection have arisen. Concepts as sustainability have been developed, as so, several assessing methodologies, such as Life Cycle Assessment (LCA) and Life Cycle Cost (LCC).

Related to the increasing scarcity of consumable water, new techniques and agricultural production systems, such as soil-free crops, which seek greater water savings, and also mixed techniques of simultaneous production of plant and animal species seeking greater sustainability of the sector have been developed.

The present work objective is to evaluate and compare the environmental and economical sustainability of three different agricultural techniques. In order to do that four agricultural production systems were analysed - three real and one virtual. The analysis consists on the direct application of three assess methodologies of:

1) Conventional farming system
2) Hydroponic system
3) Aquaponic system
4) HidroFood -Virtual simplified aquaponic system

2. Proposed methodology for sustainability assessment

For each case analysed environmental sustainability was assessed according to the Life Cycle Assessment (LCA) methodology through which the possible environmental impacts inherent to each case were computed. To the evaluation of the economic sustainability each case was analyzed on the basis of a Life Cycle Cost (LCC) assessment by surveying all the costs inherent to the processes, and then by considering production revenues, based on the productivity of each system and an economic viability assessment of processes over time, based on the Net Present Value (NPV) method in a six year project.

2.1 Environmental Sustainability - Life Cycle Assessment

Life cycle assessment (LCA) is a methodology used to evaluate and quantify possible environmental impacts of products and processes from origin to end-of-life; Cradle to the grave. According to the standard EN ISO 14040 - Environmental Management, a methodology with an application of four distinct steps [1]:

i) Definition of the objective / object of study - functional unit (FU)

ii) Formulation of the inventory, data collection for all inputs and outputs of the process - life cycle inventory (LCI)

iii) Inventory conversion and environmental impact indexes - life cycle impact assessment (LCIA)

iv) Interpretation of results

Due to the large amount of information needed to perform an LCA as well as the complexity of its synthesis and analysis, several software's and methods have been developed, thus making these studies simpler and more efficient [2].

In the present work, the LCA of each of the process - Conventional, Hydroponic and Aquaponic production system was carried out through the Software (SimaPro, 2011) and the Eco Invent 3 database. The environmental impacts were computed using the ReCiPe Midpoint (H) V1.11 and ReCiPe Endpoint (H) V1.11 methods.

The main goal of the method is to turn the long list of indicator inventory results into a limited number of punctuation indicators. These indicators express the relative severity in an environmental impact category and are divided into two indicator levels [lcia-recipe.net]:

- 18 Midpoint
- 3 Endpoit

The purpose for calculating Endpoint indicators is that the large number of Midpoint indicators are more difficult to interpret, on the one hand because they are many, on the other because they have a relatively abstract meaning [3]. Endpoint indicators are intended to facilitate the interpretation of results as they are only three and have a more understandable meaning

2.2. Functional Unit

The functional unit considered in the present work is 1 kg of food produced, being 0,5 kg of Lettuce and 0,5 kg of Watercress

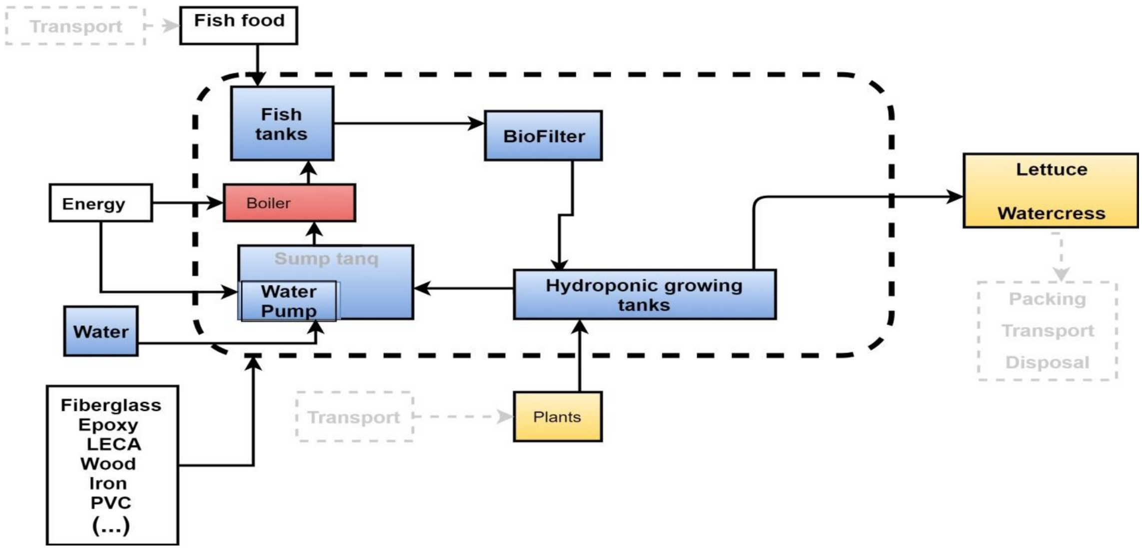

Figure 1 – Aquaponic system boundary

2.3 System Boundaries

In the present work, given that the objective of study is only the analysis of productive systems, the analysis performed only considered the production mechanisms of each agricultural system studied. As shown on figure 1, activities as transport of the systems' inputs, such as fertilizers, nutrients, fish, fish food and plants as well as post-harvest processes such as packaging, transport, sale and waste management stayed out of analysis. It should be noted that in the vast majority of agricultural systems only the growth of the plants is processed, since these are normally bought in already germinated nurseries.

2.4 Economic Sustainability

The assessment of economic sustainability - Investment analysis, aims to determine the economic sustainability of the different case studies and consequently the success or economic failure of the same. To do this, an analysis based on a Life Cycle Cost Assessment (LCC) was conducted, followed by an additional analysis of the economic viability of each case study was done in a business perspective, using a evaluation method for a given time period - NPV.

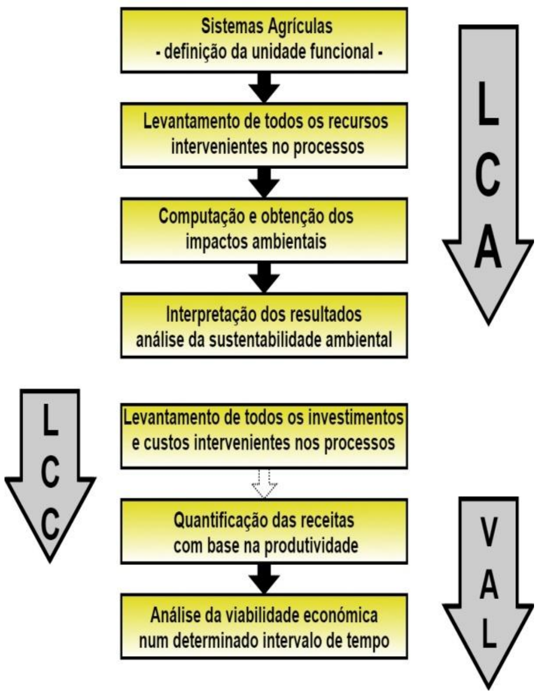

Figure 2 – Used methodologies

3. Analysed agricultural processes

In the present study three distinct farming systems were analyzed. One of them is a conventional agricultural system and the other two are alternative systems – Hydroponic and Aquaponic respectively.

3.1 Conventional farming

In general, the conventional term refers to the cultivation of the fields using traditional techniques of soil preparation. This can be outdoors or in a protected system, inside a greenhouse, allowing a certain control over climatic variables such as temperature, wind, solar radiation and air humidity. It may also be Organic or Biological, in which synthetic chemical fertilizers, pesticides, growth regulators or genetically modified organisms are not used [3].

Advantages	Disadvantages
Possibility of relatively low investments	High water consumption
Low energy consumption	Lower yield of the used area
Possibility of Biological certification	Lower productivity associated with longer production cycles
	"Tiredness" and nutritional imbalances in soils

Table 1 – Advantages and disadvantages of conventional farming

3.2 Hydroponics

The most common systems of agricultural production without soil are the hydroponics. In these, through a water pump, the nutrient solution circulates between the nutrition tank and the support / growth system of the plants, where it is then usually through the action of gravity that it returns to the nutrition tank. The most widely used are the Nutrient Film Technique (NFT) system and the Deep Water Culture (DWC) system, widely used in large commercial facilities.

Advantages	Disadvantages
Water saving	Relatively expensive technology
Better utilization of useful area of production	Constant dependence of electric energy
Greater pest control	Impossibility of biological certification
High productivity	
Possibility of integration of systems in urban areas	

Table 2 – Advantages and disadvantages of hydroponic systems

3.3 Aquaponics

Aquaponics is a technique for producing food with low water consumption and high utilization of organic waste. This consists of the integration of a conventional aquaculture system, creation of aquatic organisms, in a hydroponic system of plant breeding, through closed water circuit. In this system, as a consequence of feeding the fish, their excrements are converted, through bacteria, into natural fertilizers that will nourish the plants. When consumed, the nutrients "treat" the water making it ideal for the fish, and then reintroduced into the fish tank [4].

Advantages	Disadvantages
Possibility of joint production of fish and plants	Relatively expensive technology
Water saving	Constant dependence of electric energy
Better utilization of useful area of production	Impossibility of biological certification
Greater pest control	Permanent dependence on electrical energy
High productivity	Limitation on the use of pesticides and antibiotics
Possibility of integration of systems in urban areas	Limited legislation on the possibility of selling fish for consumption

Table 3 – Advantages and disadvantages of Aquaponics

"*It's a new revolution in food production. Aquaponics is a sustainable food model, based on the basic principle of organic farming, which combines hydroponics (...) with aquaculture (...). The idea is to combine these two techniques in a single system in order to reinforce the positive effects of each technique and eliminate the negative effects* "(in official Journal of the European Union 11/07/2014)

Figure 3 – Aquaponic biological cycle [5]

4. Case Studies

As previously mentioned, in the present study, four case studies - three of them real, and one virtual one - were analyzed. To collect data visits were made to three agricultural production projects, each with a different cultivation system and, with the exception of the farm with Aquaponic system, are mainly engaged in the production for commercial purposes of multileaf vegetables. The analysis and the study focused on the production of Lettuce and Watercress, having been extracted data of the means, the equipment and the average values of the monthly resources used in the production. It was also made a survey of the investments spent in each system, as well as the average monthly costs associated with them.

4.1 Conventional farming system

The conventional farming system analyzed was a biological certificated farm – Ideia Rural – located in Vale da Pedra, Cartaxo, which main activity is the production and commercialization of agricultural products, both in greenhouse and abroad. The analysed greenhouse, with 2500 m^2, is dedicated to the production of Lettuce and Watercress, which production cycle lasts approximately two months, twice the production time of alternative systems.

Resources	Quantities
Area	1980 m^2
Iron	4000 kg
Water/2month	600.000 l
NPK fertilizer/2month	750 kg
Limestone/2month	255 kg
Diesel/2month	40 l
Manure/month	12500 kg
Energy/2month	1188 MJ

Table 4 – Resources of Convention system

Productivity	Quantity [kg]
Lettuce	7700 kg
Watercress	4400 kg

Table 5 – Productivity of Conventional system

4.2 Hydroponic system

The analysis of the hydroponic system took place in a small family business located in Almeirim - Estufas Martins. This is dedicated to the agricultural production of multifolium vegetables through the hydroponic system. Two greenhouses, each with a 1500 m2 area, contain inside it a hydroponic system of the NFT type section 4.2.1.1, with a total of about 11,000 m of PVC pipe.

Resources	Quantities
PVC	7771,8 kg
Area	2064 m^2
Iron	160 kg
Water/month	75.000 l
$Ca(NO_3)_2$/month	156,25 kg
$MgSO_4$/month	37,50 kg
KH_2NO_4/month	62,50 kg
KNO_3/month	75 kg
Energy	1.681,77 MJ

Table 6 – Resources of Hydroponic system

Productivity	Quantity [kg]
Lettuce	7700 kg
Watercress	4400 kg

Table 7 – Productivity o Hydroponic system

4.3. Aquaponic system

The analysis of the Aquaponic system took place in the fifth Aberta Nova, a 300 hectare estate located in Melides, whose main activity is based on the design and development of ideas and agricultural solutions. An aquaponic system was designed and built, and was operated continuously for four years in a 500 m2 greenhouse, where the most diverse vegetables, fruits, vegetables and tropical plants were grown.
Contrary to other commercial cases, this was of a completely experimental nature, having been cultivated of the most varied products, including tropical ones, almost always in small quantities.

It should also be noted that, given the legal limitation of sailing for consumption of fish produced in aquaponic systems that in this system there was no fish production. At the time of spawning the fish were removed from the respective fish to avoid their reproduction.

Resources	Quantities
PVC	494 kg
Area	140 m^2
Iron	160 kg
Wood	5160 kg
Aluminium	145,8 kg
Epoxy fiberglass	1824 kg
Styrofoam	36 kg
LECA	13260 kg
Water/month	6000 l
Fish food/month	256,2 kg
Energy/month	5164,9 MJ

Table 8 – Resources of Aquaponic system

Productivity	Quantity [kg]
Lettuce	524
Watercress	300

Table 9 – Productivity of Aquaponic system

5. Sustainability assessment

The sustainability analysis was made using the methodologies previously explained. For each case study, environmental sustainability was first evaluated, and economic sustainability was subsequently assessed.

In this present paper, it will only be demonstrated, by way of example, the application of the methodologies for the aquaponic case, being in the end, the results for all cases compared.

5.1 Environmental sustainability

In order to carry out the analysis and evaluation of environmental sustainability, we began by surveying all stakeholders - inputs, in each case study, in order to relate them with the output of each process - Lettuce and Watercress, in order to obtain the resources used per kilogram of production. So a inventory data of all resources was built.

Resource/kg	Lettuce	Watercress
Water	5,72 l	10 l
Fish food	0,24 kg	0,42 kg
Energy	5,44	9,50
PVC	0,0078 kg	0,014 kg
Useful area	0,0028 m^2	0,0049 m^2
Iron	0,0008 kg	0,0014 kg
Wood	0,08 kg	0,14 kg
Aluminium	0,0023 kg	0,004 kg
Styrofoam	0,0006 kg	0,001 kg
Epoxy+Fiberglass	0,029 kg	0,051 kg
LECA	0,21 kg	0,368 kg

Table 10 – Data inventory for aquaponic system

Using the SimaPro, 2011 LCA software and the Eco Invent 3 database, the data previously presented was processed. The ReCiPe Midpoint (H) V1.11 and ReCiPe Endpoint (H) V1.11 methods previously described were used, to compute the entries of each process in order to obtain the respective environmental impact indicators. The functional unit is one kg of product produced, and consists of 0.5kg of Lettuce and 0.5kg of Watercress.

5.2 Impact network

The Impact network was computed and shows bigger impacts related with de energy consumption, fish food and epoxy reinforced resign production.

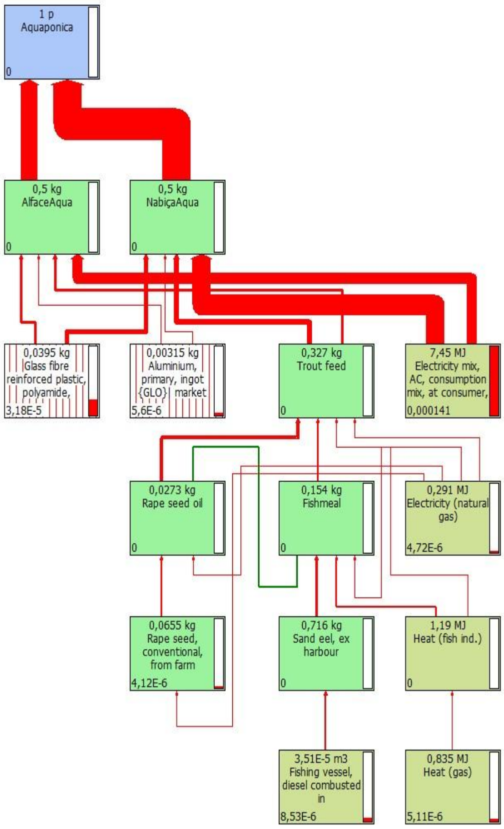

Figure 4– Aquaponic system impact network

As showed in figure 4 the Impact network of aquaponic system shows bigger impacts related with de energy consumption, fish food and epoxy reinforced resign production. The value of electric energy has a considerable weight due to the still relatively high level of dependence on fossil fuels these days(R. Garcia et al., 2014).

For the remaining case studies , a similar analysis of the previous one was performed. The results of the Endpoint indicators and their comparison are shown in the following table.

Damage (mPts)	Conventional	Hydroponic	Aquaponic	HidroFood
Human Health	7,93	8,21	93,8	8,58
Ecosystems	4,33	4,07	62	8,22
Resources	7,13	5,39	68,2	6,68
Total	19,4	17,7	224	23,5

Tabela 11 – Environmental impacts (EndPoint Indicators) for analysed production systems

5.3 Economic sustainability

As for environmental sustainability, for the evaluation of economic sustainability, in the present paper only the application of the methodology of economic sustainability assessment of the Aquaponic case study has been developed as an example. For each case study, a survey of investments was carried out with project's managers, and the average annual costs were estimated as well as, based on productivity and sales price of the products, the annual revenues.

First, the assessment of economic sustainability was made taking into account the legal limitation of the possibility of selling fish in aquaponic systems, and finally considering the hypothesis of selling it.

Investments	Value [€]
Greenhouse	20.000
Aquaponic equipment	50.000
Area	1.250
Fish	200
Total	71.450

Table 12 – Investments of aquaponic case

Costs / Year	Value [€]
Direct labour	12.740
Fish food	6.763,68
Energy	7.867,14
Plants	1.257,52
Total	28.464.86

Table 13 – Annual costs of Aquaponic case

Taking into account the price of the sale of lettuce and fillet of 1,5 € / kg and in the case of sales of fishes of 10 € / kg the annual revenues were obtained.

Product	Revenues/Year [€]
Lettuce	9.432
Watercress	5.400
Fish	12.500
Total	27.332

Table 14 – Annual revenues of Aquaponic case

Taking into account the investments, costs and revenues related to the aquaponic system studied, the Net Present Value was calculated in a 6-year project. As previously mentioned the analysis was made first without considering the possibility of the sale of fish, and then, in the expectation of making the project economically viable, considering the possibility of selling the fish produced in it.

	NPV						
Year	0	1	2	3	4	5	6
Investiments	71450						
Costs		28628,5	28628,5	28628,5	28628,5	28628,5	28628,5
Revenues		14832	14832	14832	14832	14832	14832
Actual value	-71450	-12.542,3	-11.402,1	-10.365,5	-9.423,2	-8.566,6	-7.787,8
NPV	-71450	-83992,3	-95394,4	-105759,4	-115183	-123750	-131537,5

Table 15 – Net Present Value calculation for Aquaponic case without fish selling profit

	NPV						
Year	0	1	2	3	4	5	6
Investiments	71450						
Costs		28628,5	28628,5	28628,5	28628,5	28628,5	28628,5
Revenues		27332	27332	27332	27332	27332	27332
Actual value	-71450	-1178,67	-1071,52	-974,11	-885,55	-805,05	-731,86
NPV	-71450	-72629	-73700	-74674	-75560	76365	77097

Table 16 – Net Present Value calculation for Aquaponic case with fish selling profit

6. Conclusions

For the three case studies analyzed, Conventional system, Hydroponic system and Aquaponic system, and for a fourth case of virtual study, Hidrofood adapted system, through the application of the methodology of life cycle assessment (LCA) were obtained the indicators of environmental impact Human Health, Ecosystems and Climate Change. They were computed taking into account all resources, materials and energy, per kilogram of production, in each case study, and indicating that the system with the lowest total value of environmental impact indicators and Hydroponic system with 17.7 mPts. This is followed by the increasing number of environmental impact indexes of the Conventional agricultural system with 19.4 mPts, the HidroFood adapted system, a simplified aquaponic system described in Chapter 5.4 with 23.5 mPts and finally with a much higher value than the Aquaponic system With 224 mPts. This difference is mainly due to the energy consumption for the Aquaponic system to be much higher than the other case studies because the water pumps are permanently running, but also due to an extension of quality and quantity of materials for a system construction which is not used in other systems.

It should be noted that the system of the Aquaponic case study analyzed was an experimental "refinement" system, of medium dimensions with 140 m^2 of useful production area, which could have been constructed using other types and smaller quantities of resources, getting this compared to other compromised commercial optimized systems.

Regarding the economic sustainability analysis of the different case studies, it was verified, through the application of the NPV method, that as expected, given the commercial nature, the systems of the Conventional and Hydroponic case studies are economically viable. Regarding the case study of the Aquaponic system Aberta Nova, given its characteristics, it does not present economic feasibility for the simplification of producing only lettuce and watercress. It should be noted that for the establishment of a comparative functional unit for the three case studies, since the Conventional and Hydroponic systems are optimized systems of Lettuce and Watercress production, it was necessary to consider only the production of the same products in the Aquaponic system. It is concluded that given the relatively low price of sale of lettuce and watercress that it is not economically feasible a system with the characteristics of the Aquaponic system studied for the production and commercialization of such products.

In a second phase of the analysis of economic sustainability for aquaponic case studies, Quinta Aberta Nova and adapted virtual system HidroFood, considering now the possibility of the sale of fish, it is verified that the Aquaponic study case of Quinta Aberta Nova still does not present economic viability. As for the HidroFood virtual system, with this hypothesis, for the six-year period considered, the system would be economically feasible and the NPV would be positive in the sixth year with a value of approximately € 38,000.

In summary, for aquaponic systems, given the low environmental performance and not economic sustainability of the case study Aquaponic analyzed, it is suggested a more rational use of materials, with recourse whenever possible to recycled materials, and other materials with lower costs environmental conditions for the construction of reservoirs and the substrate of plants, the use of only one water pump for water circulation of the system, and alternative systems, for example solar for energy generation and reduction of associated energy costs. It will also be advantageous from the economic point of view to produce products with higher sales prices, such as tropical products that allow for greater profits and can be related to lower expenses related to the concession of simpler systems.

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