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Feasibility study of an aquaponic plant in Korhogo

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Finally, I want to dedicate this thesis to my family which has supported me despite my problems and has helped me overcome a very difficult period.

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List of abbreviations

USDA United States Department of Agriculture

FAO Food agricultural organization

WHO world health organization

GII (Gender Inequality Index)

GAM Global Acute Malnutrition

WB World bank

EU European Union

INS National Institute of Statistics

NFT Nutritive film tecnic

DWC Deep water culture

PNIA Plan national du développement (National plan of development)

DO Dissolved Oxygen

KH Carbonate hardness

GH General hardness

INS National Institute of Statistics

CI Confidence interval

GFSI Global Food Security Index

NA Nangasseregue,

KAS Kassoumbarga

KAF Kafiokaha

KO Kounigekaha

MFB Media filled bed

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Abstract

The city of Korhogo in the North of Côte d'Ivoire is an area focused on the primary sector. Located in a tropical and wet climatic zone with a low thermal excursion, it is suited for agricultural purposes. A solar power plant of 50 Megawatts made Korhogo more attractive but reduced arable areas. The combination of these factors, together with the effects of climate change, land overexploitation and bad water management, are threatening sustainability of the agricultural production. Additionally, despite the situation still being suitable for human settlement, there is a high percentage of people with problems of malnutrition which can only be made worse by what was mentioned earlier. For these reasons, it is necessary to intervene.

Aquaponics, a combination of hydroponic and aquaculture methods, has been taken into consideration in similar contexts.

Hence, this thesis will focus on a feasibility study of an aquaponic plant in the sub-prefecture of Korhogo as a means of improving food security and of protecting the environment.

It will be explained in detail where the system will be located, how the aquaponic system could be built, focusing on the kind of system which will be chosen , which environmental impact it could have, its economic cost and the nutritional improvement that could bring to the local population.

Therefore, this research thesis clearly focuses on the preparation of a theoretical model useful for humanitarian purposes.

Additionally, this research aims at presenting aquaponics in a country where it does not exist yet but where there are suitable conditions for proposing this kind of project.

1 Introduction: Aquaponics as a mean to improve food security in Côte d'Ivoire

Food security consists of the physical, social and economic possibility at all times sufficient for individuals to permanently have healthy food and nutrients in order to satisfy their needs and lead a healthy and active life. (.Mark Gibson, 2012) It is based on three dimensions: affordability, availability, quality and stability.

In 2015, About 795 million people are undernourished globally, down 167 million over the last decade, and 216 million less than in 1990–92.

To stem this problem, the number of projects regarding the protection of food security in these countries has steadily increased in the 20th century and in recent years.
In particular, these projects have been developed mainly by large international bodies such as the FAO and the World Bank or by the various national governments that have worked to improve the well-being of their countries.
Awareness of these issues is also growing at company level, since there is a growing public interest towards the precarious life situation in some countries of the globe.

Due to its characteristics, the Côte d'Ivoire turns out to be an interesting case study.

The Côte d'Ivoire ranked 171st out of 189 countries in 2018 151st out of 155 on the GII (Gender Inequality Index). Poverty has increased after the civil war achieving an estimated rate of 46.3% people living below the threshold of Ivorian income poverty (US $ 1.22 per day). (National Household Survey conducted in 2015).
In Côte d'Ivoire , life expectancy is 54 years with a children rate of 5.0 for per woman .
Unfortunately, there is a high maternal mortality rate 614/100000 and a huge children mortality rate before age 5 (92.6/1000).
The Global Food Security Index (GFSI) is used to quantify its nutritional situation internationally.
The Côte d'Ivoire is the 84th country out of 113 analyzed.

Fig.1 reports 19 variables related to food security in Côte d'Ivoire, which were grouped into three main categories:

Affordability: 87/113

Availability: 62/113

Quality and safety: 104/113

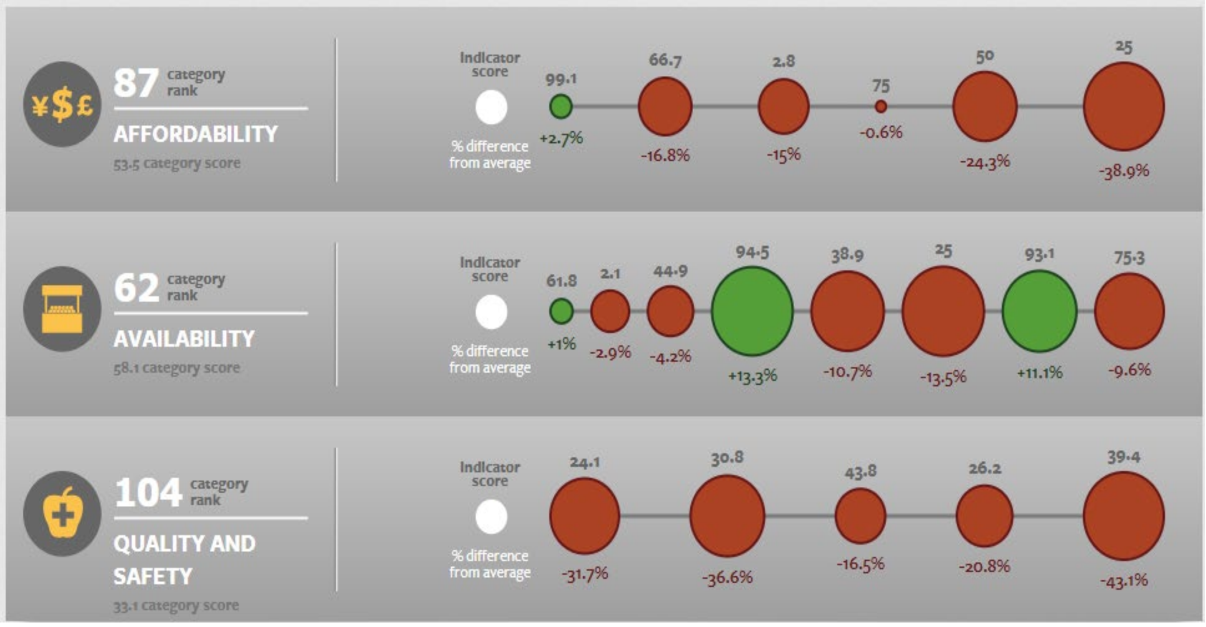

Fig. 1: The 19 variables of the Global food security index

Source: foodsecurityindex.eiu.com, The economist group 2020

Although the nutritional situation is in fairly problematic conditions, The economy of the country mainly is based on the primary sector.

Indeed, the primary sector contributes to more than a fifth of the national GDP and it employs a little less than half of the active population.

The country is the world's largest producer and exporter of cocoa (30% world production) and one of the major exporter of cashew nuts, palm oil coffee and oil.

Despite that, strong food insecurity is concerning. About 15% of rural households and 10.6% in urban areas are vulnerable to food insecurity.

Additionally, 8 percent of children under 5 in Côte d'Ivoire suffered from Global Acute Malnutrition (GAM).

Poor households spend 50.2 percent of their income on food. For non-poor households this figure is only 40.7 percent, showing that in the event of a financial shock, poor households would slip more easily into food insecurity (WFP).

In 2006 stunting was just a little below the 30 percent warning threshold . In 2012, stunting was particularly high in the North and North-East with a percentage of 39 %, 32% in the North-West,

and 34% in the West (WFP). These high values depend on lack of diversity in a diet which is based for 65% on tubers and cereals.
Undernutrition among women in childbearing age and a lack of awareness on good nutrition practices contribute to high rates of low birth weight (14.8 percent) (WFP)
However, despite equal access to the property of land for men and women having been stipulated in 1998 by law, just approximately 10 % of total land are owned by women.
Therefore, generally, in Côte d'Ivoire women are more threatened by food insecurity than men.
To improve food security , Côte d'Ivoire has started to develop a national plan of action:
In 2012 the government has started actions in order to improve the situation in the most affected areas (North and West).
This plan has been developed between 2012-2015 by the National Agricultural Investment Program (PNIA) Metti report. (i)The project consisted of

1) Increasing rice production from 800,000 tonnes to around 2,000,000 tonnes , (ii)
2) Increasing the productivity of food crops by at least 15 to 20% (yam , corn, plantain and cassava),
3) Improving the competences of stakeholders in the agricultural sector through a significant support in the training of the actors and of others, such as the Agriculture Council and the National Agricultural Research System and
4) Increasing livestock, fisheries and aquaculture production. With an investment of 414 million of Euro (PND, 2012)

A report of 2015 has shown that food production had increased by 8 percent between 2010 and 2015 thanks to this project (PNIA report, 2011).
According to WFP analysis, food insecurity situation in Côte d'Ivoire moved from 5 zones (West and North-East)before 2015 to 2 zones (West and North) in 2016.
However, Because of climate change, there was an increase of food insecurity.
In fact, in February 2016 72% of people reported a reduction in the number of daily meals compared to 2000 (WFP).
Hence, these interventions are not enough.
In table 1 are been reported the best and worst parameters on food security considered in fig.1.
Having analyzed the local situation, it is once again clear that usual business is not the solution against food security and malnutrition in Côte d'Ivoire.

As results for table 1, the best and worst parameters regarding food security are:

1)Lacking on dietary diversity

2) Low domestic product per capita in the field of agriculture

3)Small public expenditure on agricultural R&D

4) Protein quality

5)Corruption

6)Access to finance for farmers

A type of project that has already been adopted in similar situations and that would be suitable for this context appears to be aquaponics.

In fact, this system allows us to improve most of the indicators that have a negative value in Côte d'Ivoire.

In particular, dietary diversity, the public expenditure on R&D, protein quality would be immediately improved.

Strength	Score over 100
Change in average food cost	99.1
Volatility of agricultural production	94.5
Urban absorption capacity	93.1
Food loss	75.3
Agricultural imports tariffs	75
Challenges	
Protein quality	26.2
Corruption	25
Access to finance for farmers	25
Dietary diversity	24.1
Gross domestic product per capita(US$ PPP)	2.8
Public expenditure on agricultural R&D	2.1

Table 1: Strength and Challenges of food security in Côte d'Ivoire

A type of project that has already been adopted in similar situations and that would be suitable for this context appears to be aquaponics.

As a matter of fact, this type of cultivation combines the growth of plant species with fish farming.

The waste liquids of the tanks are used to irrigate crops that grow quickly thanks to the fertilizing substances present in the water that would otherwise be poured into the waterways.
Plants feed on harmful substances and return clean water to the tank, significantly reducing the number of complete spare parts needed for fish health.

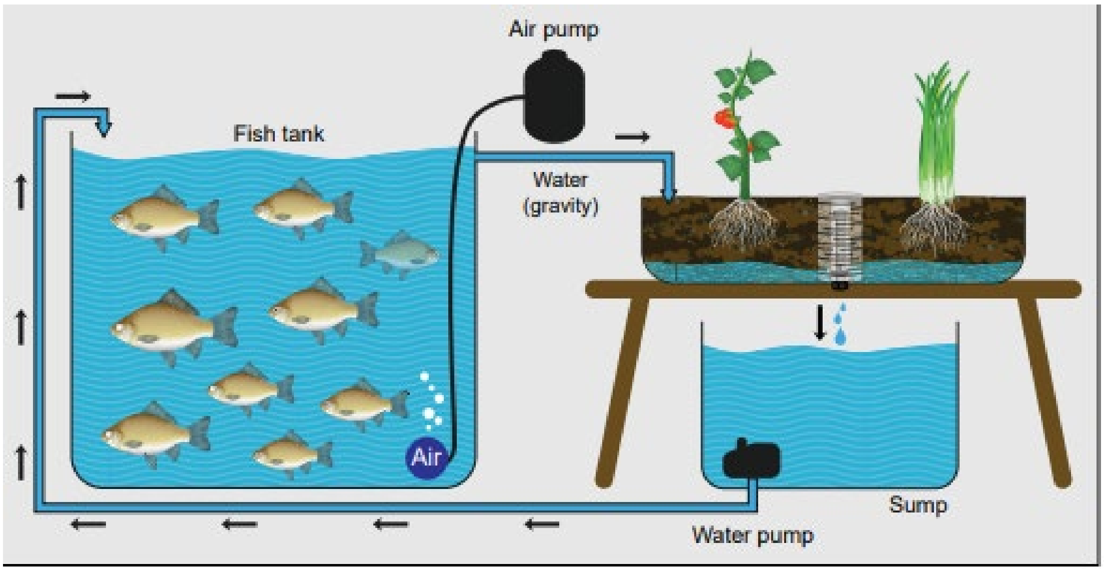

Figure 2: Example of aquaponic operation. Source: Sommerville et Al. (2014)

Aquaponics is really useful because it uses a new technology to dramatically reduce the impact of agriculture and fishing on the planet.
The best advantages can be found in this list:
1)Aquaponics reduce water by 95 % compared to classic agriculture, since the water in the fish pond is purified by plants, hence it is not continuously renewed.
2)It increases biodiversity in cities by reducing human impacts.
3) Aquaponics is part of these responsible systems that facilitate access to healthy, locally-sourced, low-resource products.
4)Reduced space for food crops
5)Overall reduction of energy footprint required for food production
6)Preservation of wild fish stocks
7)It Limits the distribution of pathogens and air pollution
8) It Limits or avoids the use of fertilizers
9)Reduction of erosion and soil overexploitation

Therefore, this technique shows a different way of doing agriculture that uses innovation to preserve ecosystems and produces food where it would not be possible.

1.1 Objective of the project

This study aims to define if aquaponic can bring a positive contribute in the field of food security in a specific location of Côte d'Ivoire.
More specifically, the area considered will be that of the sub-prefecture of Korhogo .
This choice was made in agreement with a company operating in the place (Tosco Solution) which is in contact with local government and intergovernmental entities.
In addition, as already mentioned, the North of the Côte d'Ivoire appears to be poorer and with greater problems of malnutrition than the South (therefore a food security project would be more suitable in these areas and more easily financed).
Finally, the climatic conditions make the use of aquaponics a better solution in this region than it would be in the south.
This depends on the fact that the aquaponic system works with a very little amount of water so it can produce food where this resource is scarce.
While the south of the Côte d'Ivoire has a tropical climate, the north has the typical savannah climate, therefore rainfall is scarcer.

These three reasons prompted me to select this specific area of the country.

To understand if aquaponics can work and really make a contribution to the place a technical feasibility of a pilot aquaponic plan will be described in details.
It will be explained, how to select a suitable location in the chosen sub-prefecture , and why a specific aquaponic system and a specific target have been chosen .
So, the research aims at showing a project that might be presented to institutional investors and / or to non-profit organizations.
They have been chosen as hypothetical financiers, for two main reasons:
1)The objective is not that of an economic gain (as it is difficult with aquaponics to have a gain especially in areas where technology has never been implemented)
2) The local population is unlikely to be willing to ask for loans and financing in this direction, their agricultural habits being very different.
This project will hence be presented in the context of sustainable development, in order to bring well-

being that cannot be quantified only from an economic point of view,

The analysis will take into consideration the three main pillars of sustainability:

Society, environment and economy

These elements will be analyzed deeply in the methodology section.

2 Literature review

In this section, the reference literature used for writing the thesis will be shown.
It is composed by three main elements:
Literature regarding Primary sector in Côte d'Ivoire (with a focus on Korhogo sub-prefecture)
Literature regarding aquaponics
Literature regarding social situation in Côte d'Ivoire

2.1 Primary sector in Côte d'Ivoire

The primary sector contributes to more than a fifth of the national GDP and employs a little less than half of the active population.

2.1.1. Agricultural production

The strong agricultural vocation allows the Cte d' Ivoire to be among the leaders in some types of production. In particular, it is the largest producer of cocoa and Cashew. Other important crops are:

1)Pineapple and mango: second and third world exporters respectively

2)It ranks third in the production of the Yam

3)He is seventh in coffee production

It should be emphasized that the major crops are devoted to exportation and not for local consumption.

This means that despite a large production there is still a large percentage of malnutrition.

Further information is summarized in table 2

Product	Production Structure: PV and PI % of the production	Regulatory body	Inter-professional organization	Main destination	Production (in t.)	Export (in t.)	Percentage on world production	Ranking on world production
Coffee	PV	Conseil du Café et du Cacao		Export	107 000 (2015)	88 000 (2015)	1.2% (2014)	7
Cocoa	PV	Conseil du Café et du Cacao		Export	1 581 000 (2015)	1 537 000 (2015)	40% (2015)	1 Producer
Cotton	PV	Conseil Coton Anacarde	INTERCOTON	Export	328 000 (2016/17)	327 600 (2016/17)	0,5% (2014)	16
Cashew	PV	Conseil Coton Anacarde	INTERCAJOU activités suspendues	Export	702 000 (2015)	665 000 (2015)	24% (2015)	1
Palm oil	PI (47%) & PV (53%)	Organe de régulation des filières hévéa et palmier à huile (en cours de création)	AIPH	Export Internal market	460 000 (2016)	231 000 (2016)	<1%	10 3 Africa
Rubber wood	PI (24%) & PV (76%)		APROMAC	Export	359000 (2016)	359 000 (2016)	3% (2014)	10 World 1 Africa
Sugar cane	PI (90%) & PV (10%)			Internal Market	180 000 (2015/16)	19 000 (moy. 2014-16)	1% Sugar cane	47 (sugar cane)
Bananas	PI		Associations d'exportateurs : OCAB/OBAM-CI	Export	384 000 (2016)	364 000 (2016)	n.d.	
Ananas export	PI & PV		Associations d'exportateurs : OCAB/OBAM-CI	Export	n.d.	25 500 (2016)	n.d.	2 Export
Mango export	PV		Associations d'exportateurs : OCAB/OBAM-CI	Export	n.d.	23 000 (2016)	n.d.	3 Export
Coconut	PI (30%) & PV (70%)[1]			Export	70 000 (2016)	21 600 (nuts) 11900 (oil)	n.d.	
Rice	PV	ONDR[2]		Internal Market	1 335 000 (2016)	24 500 (2016)	0,3%	28
Maïs	PV			Internal Market	700 000 (2016)	14 000 (2016)[4]	<0.1%	68
Yam	PV			Internal Market	5 730 000 (2013	10 100 (2016)[4]	10%	3 World 3 Africa
Cassava	PV			Internal Market	2 430 000 (2013)	13 200[5] (2016)		
Plantain	PV			Internal Market	1 625 000 (2013)	20 400 (2016)[4]	4,2%	8

Table 2. Main cultivations in Côte d'Ivoire. *Source:L'agriculture de la Côte d'Ivoire à la loupe, 2018*

Agro-ecological characteristics and opportunities have led to a certain specialization of regions that can be grouped into six zones.

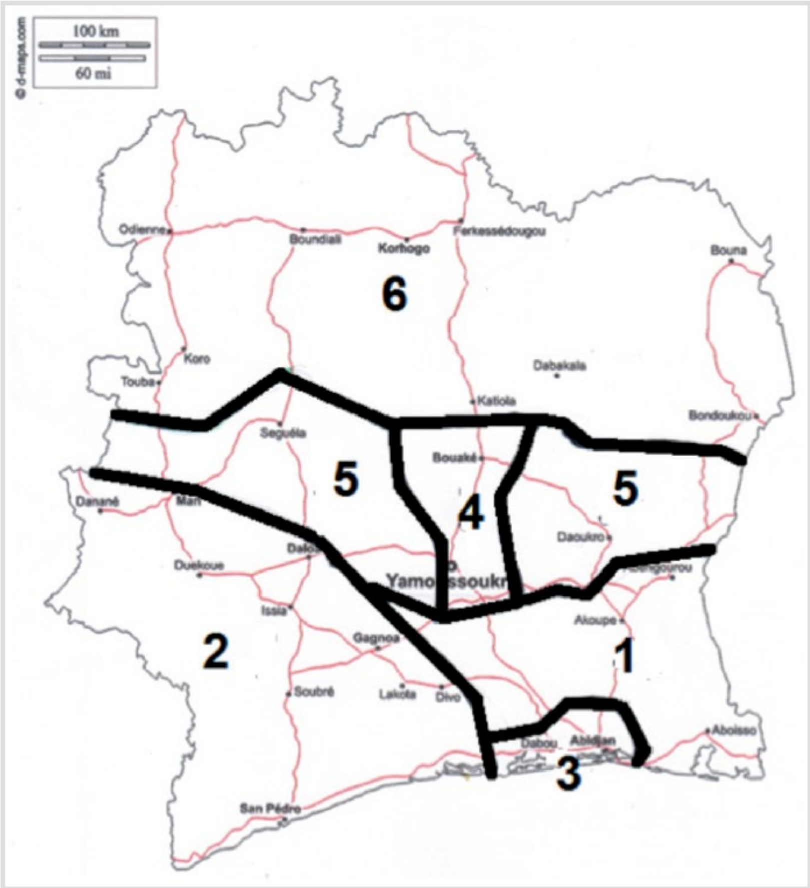

Figure 3: Maps of Côte d’Ivoire agricultural zone

Source:L’agriculture de la Côte d’Ivoire à la loupe, 2018

1) Zone 1: Southern Forest: Export crops and tubers. Farms integrate their coffee-cocoa fields with food crops, mainly tubers. The rice is not grown.

2) **Zone 2: "Southern Forest:** Export crops and industrial + rice growing ”. Farms integrate their coffee-cocoa crops with rice. There are also traditional pig farms

3)**Zone 3: "Abidjan agricultural belt"**. Industrial crops are still present,but other production system are preferred. In details there are intensive soilless breeding (poultry farming, pig farming), or peri-urban market gardening. (WFP report, 2018)

4**. Zone 4: "V Baoulé"**. It is characterized by Sudano-Guinean agro-climatic conditions.. Cash crops have never been established there, and farms favor the growing of food crops to take advantage of the big markets of both Bouaké and Yamoussoukro .(WFP report, 2018)

5. Zone 5: "The forest-savannah transition" There is coexistence of coffee-cocoa cropping systems and cotton-cashew crop systems. It is a transition zone between the forest cultivation and the savannah cultivation systems, .(WFP report, 2018)

6) Zone 6: **"Savannah: rice / cotton + crops food "**. it is grown mainly Cotton with a diversity of annuals mainly c and cashew during crop rotation which have gradually transformed annuals crop production systems in arboriculture for commercial purposes(WFP report, 2018).

It will be in this last zone that we will locate our project.

The dependence of Korhogo sub-prefecture on food products is related to a particularly sensitive land pressure. Indeed, due to the high increase of population density which now has achieved 100 inhabitants per km2, there has been a significant decrease in land crops. Indeed, due to a lack of agricultural land, the hitherto marginalized lowlands are increasingly being demanded.
However, the use which is made of these spaces does not encourage an increase in their production capacities. Indeed, market gardening replaces rice in the off season in these lowlands. This crop rotation is generally against vegetable crops. Market gardeners are regularly ordered to harvest as quickly as possible to give the plot to the rice farmer.
Hence,The relative vegetative cycle of rice which is 5 to 6 months.
Instead, the cycle vegetative relative to market gardeners 2 to 4 months.

The profitability of market gardening is linked to the shortness of the crops and the possibility of increasing production during the year.
The rice produced on this site is rain-fed rice which is sown with the onset of the rains in May and harvested in October. Other speculations such as lettuce, cabbage, carrots and several ranges of vegetables are grown for their leaves and then took over. Korhogo region in search of suitable land for the cultivation of the yam.

The other vegetables produced in Korhogo divided for sub-prefectures are summarised in the table 3.

FOOD PRODUCTS	ORIGIN									
	Niakara	Kong	Dikodougou	Guiembe	Napie	Ferke	Niofoin	M'bengue	Sinematiali	Komborodougou
Mais	x	X	X	x	x	x		X	x	x
Yam	x	X	X							
Peanut	x	X	X	x	x	x	X	X	x	x
Egg plant						x			x	
Chili pepper						x				
Tomato									X	
Onion									X	
Sweet potato			X	x	x	x	X	x	X	x
Sweet banana	x									
Pistachio	x	x	X	x	x	x	X	x	X	x
Mil					x			x		
Rice				x		x		x		x
Mango						x			X	

Table 3. Vegetables for internal consumptions in Korhogo. Source:L'agriculture de la Côte d'Ivoire à la loupe, 2018

2.1.2 Fish production

The fisheries and aquaculture sector occupies an important place in the Ivorian economy in terms of food security issues. Although its contribution to GDP is marginal (less than 1%), the fishery products sector gave rise to 97,100 direct jobs in Côte d'Ivoire in 2011 (Decroquet et. Al, 2018).

The development of fishing activities has been essentially driven by a growth in domestic but also international demand for canned tuna. The role of the State has been essentially a regulatory one, and one of general governance.

Local fish production stands at around 60000 tons on average but with a variability that can even be of

100 percent.

Regarding the redistribution by type of fish, it can be said that:

1) the production of acquadolce is on average around 10,000 tons

2) Pelagic fish production averages around 110000 tons

3) The production of marine fish averages around 25,000 tons

It is Also to be considered the presence of a very high variability; in fact from 1997 to 2012 the production varied from 37000 tons to 72000 tons without a defined growth trend.

Finally. it should be underlined that the balance on the catch is however strongly negative. In fact, between fish import and export there is a negative balance of about -20000 tons per year
Further information is contained in table x

Année	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Crustacés																
Pêche locale	464	635	697	810	491	2 037	1 082	277	497	726	474	284	163	696	606	555
Importation	279	308	499	327	470	763	585	895	506	611	728	864	948	925	515	727
Exportation	708	916	1 162	1 113	913	506	313	227	130	233	91	128	699	241	72	27
Disponibilités	35	27	34	24	48	2 294	1 354	945	872	1 104	1 111	1020	412	1 380	1 049	1 255
Poissons d'eau douce																
Pêche locale	12 716	13 615	11 870	11 824	11 191	21 380	21 960	6 253	14 523	7 763	4 969	6 090	7 339	8 633	9 818	10 937
Importation	84	56	64	39	29	23	24	42	41	57	41	61	184	52	191	57
Disponibilités	12 800	13 671	11 934	11 863	11 220	21 403	21 984	6 295	1 4561	7 820	5 010	6 151	7 523	8 685	10 009	10 994
Poissons pélagiques																
Pêche locale	25 700	25 747	29 922	35 519	33 217	23 494	20 240	25 105	12 478	13 753	14 245	18 385	12 556	20 641	11 520	23 119
Importation	156 507	169 000	201 586	146 507	164 985	195 953	203 763	161 059	170 096	180 129	193 265	221 689	245 187	234 704	240 248	177 877
Variation stock	0	0	-200	200	0	-5 556	-11 111	16 667	0	0	0	0	0	0	0	0
Exportation	112 589	103 734	100 872	115 865	94 856	106 562	91 979	102 884	62 235	72 302	85 906	84 112	82 452	58 041	45 957	68 150
Disponibilités	69 618	91 012	130 436	66 361	103 345	107 330	120 913	99 947	120 339	121 580	121 604	155 962	175 291	197 304	205 811	132 847
Autres poissons marins																
Pêche locale	19 930	25 659	28 252	24 214	27 579	17 579	21 300	19 000	10 325	28 400	25 129	23 000	22 132	34 440	46 212	38 293
Importation	84 683	94 337	113 175	105 916	94 753	82 893	90 550	101 483	115 467	99 059	106 695	128 827	147 642	94 585	82 464	125 377
Exportation	1 761	4 324	7 942	6 292	3 404	2 772	2 087	1 211	839	657	499	1353	676	752	88	888
Disponibilités	102 853	115 673	133 485	123 838	118 928	97 700	109 764	119 273	124 953	126 802	131 325	150 474	169 098	128 273	128 588	162 782
Autres produits halieutiques non déterminés par ailleurs[35]																
Disponibilités	9107	7481	8403	9794	4272	5996	4905	4657	6333	6185	4257	3443	3566	7492	6369	6698
Total disponibilité de poisson pour l'alimentation																
Pêche locale	58 810	65 656	70 741	72 367	72 478	64 490	64 582	50 635	37 823	50 642	44 817	47 759	42 190	64 410	68 156	72 904
Importation	241 553	263 701	315 324	252 789	260 237	279632	294 922	263 479	286 110	279856	300 729	351 441	393 961	330 266	323 418	30 4038
Variation stock	0	0	-200	200	0	-5 556	-11 111	16 667	0	0	0	0	0	0	0	0
Exportation	115 058	108 974	109 976	123 270	99 173	109 840	94 379	104 322	63 204	73 192	86 496	85 593	83 827	59 034	46 117	69 065
Disponibilités	194 413	227 864	284 292	211 880	237 813	234 723	258 920	231 117	267 058	263 491	263 307	317 050	355 890	343 134	351 826	314 576
Consommation kg/hab	12,7	14,5	17,6	12,8	14,1	13,7	14,8	13,0	14,7	14,3	14,0	16,5	18,1	17,0	17,1	14,9

Table 4. Evolution of the availability of fishery products in Côte d'Ivoire. Source:L'agriculture de la Côte d'Ivoire à la loupe, 2018

Finally. it is important to underline that aquaculture has been growing significantly in the examined quidicennium (1997-2012), going from a production of 500 tons to almost 4000.

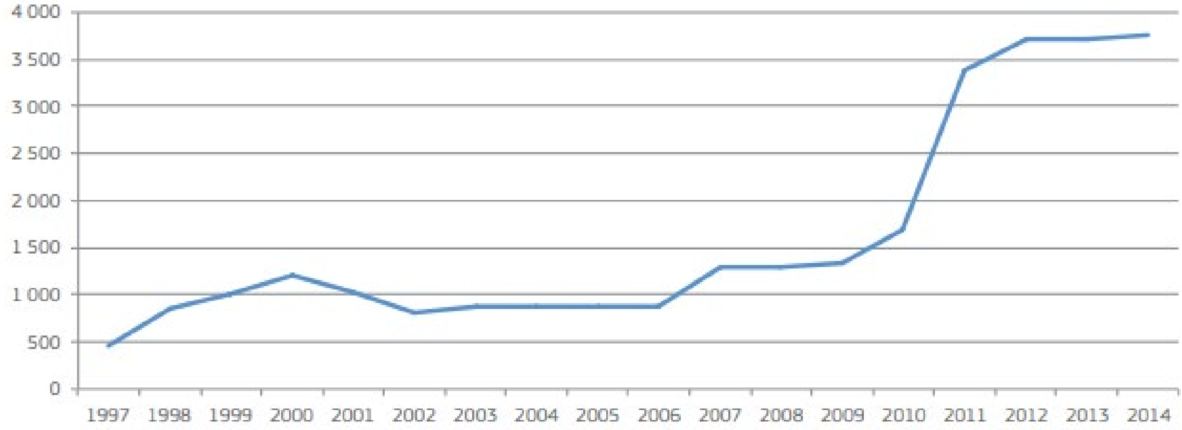

Fig. 4 Aquaculture fish production. *Source:L'agriculture de la Côte d'Ivoire à la loupe, 2018*

Unfortunately, the sub-prefecture of Korhogo did not follow the same trend.
Among 270 fish ponds listed in the department of Korhogo, only 17 operate as part of the activity, with a dropout rate of almost 94%.

Statistical data on fish farming in the Korhogo department are difficult to access and not very reliable. According to the structures in charge of the issue, the information available before the 2002 rebellion was destroyed during the socio-political crises between 2002 and 2010.

Even the National Association of Aquaculture Producers of Côte d'Ivoire (ANAQUACI) born after the post-electoral crisis of 2010, does not have figures on the case of department of Korhogo unlike other areas of production of the country in 2014.
Does this mean that on this date aquaculture production in the Korhogo department was zero?

In 1997, according to PROGRAM ECOLOQ-Korhogo, the production of the Natio-Kobadara experimental site was of 3.56 tonnes of fish.

A. Instead, in 2016 because of the crisis the farm of Natiokobara who ultimately produces in the whole department has 1.6 tonnes of Tilapia in 2016.

2.2 Food insecurity

Côte d'Ivoire has developed a national plan of action to reach Sdgs:

In 2012 the Government has started actions in order to improve food security especially in widely affected areas (North and West). . A 2015 assessment reported that food production had increased by 8 percent between 2010 and 2015 thanks to the National Agricultural Investment Program (PNIA).

According to WFP analysis Côte d'Ivoire moved from 5 zones (West and North-East) under pressure for food insecurity before 2015 to 2 zones (West and North) under pressure in 2016,

The degree of poverty and hunger implies that many interventions are still needed to reach the SDG 2.The PND national plan of development has formulated a strategy to modernize the primary sector in order to increase resilience, competitiveness and agricultural production.

The smallholders farmers in 2016 were 80% of the total (WFP report, 2018). Because of climate change, there was an increase of food insecurity. In fact, in February 2016 72%of people reported a reduction of number of daily meals compared to 2000 (WFP).

Moreover, despite equal access to women and men being ensured by law since 1998, just approximately of 10 % of total land is owned by women.

The sustainability of food is threatened by climate change, which causes soil erosion, deforestation, bad impact on biodiversity, water availability, agriculture and fisheries exerting pressure on their cost.

In Côte d'Ivoire the problem of climate change is worsened by poor water management, and low level of mechanization and low public investment (FAO)

Climate change impacts food security, nutrition and economic capacity because of natural disasters and land degradation

Furthermore, it impacts differently the Ivorian population. Indeed, North, Western people, women and children are the most threatened.

To limit this phenomenon,the Ivorian Government has created new regulations to manage and finance protected areas. However, these regulations do not take into consideration the differences between gender.

Finally, , Côte d'Ivoire has also committed itself to Reduce Emissions from Deforestation and forest Degradation (REDD+), becoming a signatory of the initiative(WFP) and a National Plan of development (PND report, 2016).

In the field of food security, the National agricultural Investment Programme has been developed between 2012-2015 in order to reduce poverty and increase food security. The aim is to increase rice production from 800,000 tonnes to around 2,000,000 tonnes o, (ii) increase the productivity of food crops by at least 15 to 20% (yam , corn, plantain and cassava), (iii) build the capacities of the stakeholders of the agricultural sector through a significant support for the training of the actors and of others, such as the Agriculture Council and the National Agricultural Research System and (iv) increase livestock, fisheries and aquaculture production. With an investment of 414 million of Euro (PND, 2012)

2.3 Aquaponics

2.3.1 History of aquaponics and analysis of the different uses

Aquaponics is an ancient cultivation technique.
It was already used 1500 years ago by Chinese , Incas and Mayas as a means to produce food (Scott Jones, 2002).
After a period in which it was not exploited anymore, it has been retaken into consideration starting from the 90s of the 20th century.
The rediscovering father can be considered Rakocy who has made several experiments in the United States.
The first study was made for the department of Southern Regional Aquaculture Center of United States (Rakocy, 1990) to describe tilapia tank culture of tilapia.
Then, Rakocy provided verification of aquaponic correct functioning (and possibility to have an economic return .
After that, more and more people started to be interested in this technology for different purposes.
Indeed, aquaponics can be implemented for two main reasons:
a) As a source of income (Goodman, 2011) (Konig et.Al, 2016) (Rizal et.Al, 2017)
B) As a means of food protection (Er Goodman, 2011) (Konig et.Al, 2016) (Rizal et.Al, 2017)
In the first case, the plants are mainly located in developed countries (Rakocy et.Al,2005) (Lapere, 2010) (*Tokunaga et.Al 2013)*.

Instead, plants constructed for the second purpose are mainly located in developing countries. (Travis Hughey 2005) (Konig et.Al, 2016) (Sommerville et.Al 2014) (AGROTEC, 2013) (Rizal et.al, 2017)
So, aquaponics has already been used to alleviate food insecurity.
Aquaponics is technology which can be adapted for different environments, it can be built with different scales and materials and in different versions. (Sommerville et.al, 2014).
This technology can be replicated in different contexts,
Given these premises, it must be underlined that aquaponic does not exist in Côte d'Ivoire yet.
Hence, the model should be created following similar project of other countries.

In particular, in poor countries, aquaponic plants have been financed by international agencies such as FAO, World Bank or European Union (Sommerville et.al 2014) (AGROTEC, 2013) with the same

objective to improve the food security situation.
In this sense, the most important bibliographical reference results to be
Small-scale aquaponic food production: Integrated fish and plant farming (Sommerville et.Al, 2014) where it is explained how to build aquaponics systems for developing countries.
Additionally, Sommerville shows all the parameters that must be taken into consideration to be successful in aquaponic food production.
With regard to this aspect, the bibliographical research has not been explored in detail.
Indeed, it is not possible to predict precisely and without approximation the plant production because there are too many variables to take into consideration. .
Hence, the quantity of food produced will be estimated sketchily relying on previous literature.

2.3.2 Water quality and component Ratio

As stated before, this thesis will not show in detail the necessary characteristics of water quality in order not to have failure in food production because the calculation will be based on similar experiments, given the lack of precise data.
However, it is necessary to give brief information regarding the water parameters.
An excellent summary is provided in Sommerville et Al. (2014).
The most important parameters are reported in Table 3.
pH should be maintained at a compromised level of 6–7, or slightly acidic.
Since The pH scale is logarithmic, a pH of 7 has 10 times fewer hydrogen ions than a pH of 6, 100 times fewer than a pH of 5, and 1000 times fewer than a pH of 4. For example, if the pH of an aquaponic unit is recorded as 7, and later the value is recorded as 8, the water now has ten times fewer freely associated H+ ions (Sommerville et.Al 2014).
A pH of 7.5 can lead to nutrient deficiencies of phosphorus and manganese and iron.
The capacity of nitrifying bacteria to convert ammonia into nitrate reduces dramatically in ph below of 6.

Organism type	Temp (°C)	pH	Ammonia (mg/litre)	Nitrite (mg/litre)	Nitrate (mg/litre)	DO (mg/litre)
Warm water fish	22–32	6–8.5	< 3	< 1	< 400	4–6
Cold water fish	10–18	6–8.5	< 1	< 0.1	< 400	6–8
Plants	16–30	5.5–7.5	< 30	< 1	-	> 3
Bacteria	14–34	6–8.5	< 3	< 1	-	4–8

Table 5: Water quality *Source: Sommerville et Al. (2014)*

Instead, **temperature** depends on the kind of fish and plant species taken into consideration.

The range of temperature varies from 10°C to 30°C depending on the species
Therefore, the location influences which plants and fish will be selected, since temperature is the most discriminative element.

Another important element is **dissolved oxygen** (DO).

Oxygen is essential for all the organisms in aquaponics; fish, nitrifying bacteria and plants
The optimum DO levels for each organism to thrive are 5–8 mg/litre.
Instead, tilapia and carp, can tolerate DO levels as low as 2–3 mg/litre, (Sommerville et.Al, 2014)

Nitrogen is another crucial parameter. Nitrogen originally enters an aquaponic system from the fish feed. Some of this protein is used by the fish for growth, and the remainder is released by the fish as waste. (Sommerville et.Al 2014).
The biggest waste is mostly ammonia (NH_3) released through the gills and as urine. Solid waste is also released, some of which is converted into ammonia by microbial activity. Then bacteria nitrify ammonia converting it into nitrite (NO_2^-) and nitrate (NO_3^-). All three forms of nitrogen (NH_3, NO_2^- and NO_3^-) can be used by plants but are poisonous at some concentrations (Ammonia is 100 times poisoning than other elements.
In a fully functioning aquaponic unit with adequate biofiltration, ammonia and nitrite levels should be close to zero, or at most 0.25–1.0 mg/litre. The bacteria present in the biofilter should be converting almost all the ammonia and nitrite into nitrate before any accumulation can occur (Sommerville et,Al, 2014).
For instance, at levels 1.0 mg/litre of ammonia. Tilapia and carp show symptoms of poisoning. It causes problem to the central nervous system and gills bringing convulsions and loss of equilibrium.

- Above 0.25 mg/litre. nitrite is toxic to fish. High levels of NO_2 can bring rapid fish deaths.

Toxic levels of NO_2 - prevent the transport of oxygen causing blood darkening.
Nitrate is a far less toxic than the other forms of nitrogen.

Fish can tolerate levels of up to 300 mg/litre, with some fish tolerating levels as high as 400 mg/litre. (Sommerville et.Al 2014) High levels (> 250 mg/litre) bring an excessive growth vegetation and nitrates accumulation inside the vegetables that are harmful for human beings. Therefore, the recommended level of nitrate is betweent 5–150 mg/litre

The last water quality parameter is **water hardness**. There are two major types of hardness: general hardness (GH), and carbonate hardness (KH).

General hardness (GH)

General hardness is the amount of magnesium (Mg^{2+}), calcium (Ca^{2+}) and, to a lesser extent, iron (Fe^{+}) ions present in water.
Hard water can be a useful source of micronutrients for aquaponics, and has no health effects on the organisms (Sommerville et.Al 2014).
Calcium in the water can prevent fish from salts losses leading fish to a healthier stock.

Component ratio

The system that will be created needs to be balanced. Fish have to supply an adequate quantity of food for plants.
Instead, plants need to filter the water to allow fish to live without problems.
Hence, it is necessary to have a big biofiltration and enough water circulating through the system.

The most successful way to balance an aquaponic system is to use the feed rate ratio described in Section 2.1.4. This ratio is the most important calculation for aquaponics because fish and plants live symbiotically within the aquaponic ecosystem. The ratio estimates how much fish feed should be added each day to the system, and the calculation is based on the available area for plant growth. This ratio depends on the type of plant being grown; fruiting vegetables require about one-third more nutrients than leafy greens to support flowers and fruit development. The type of feed also influences the feed rate ratio, and all calculations provided here assume an industry standard fish feed with 32 percent protein.

The ratio of fish and plant are connected since they live symbiotically in the aquaponic system. More specifically, the amount of plant depends on the feed ratio.

Indeed, plant nutrients come from fish escrements ; the quantity of escrements depends on the quantity of food eaten by fish.
Hence, the right ratio of fish and plant is summarised in the table 2 (Sommerville et.Al, 2014)

Leafy green plants	Fruiting vegetables
40–50 g of fish feed per square metre per day	50–80 g of fish feed per square metre per day

Table 6. Grams of fish food for m2 of plants. Source: Sommerville et Al. (2014)

Instead, the ratio of plant per m2 depends on the type of plant; fruiting vegetables require more nutrients than leafy greens.

Leafy green plants	Fruiting vegetables
20–25 plants per square metre	4–8 plants per square metre

Table 7. Number of plant per m2. Source: Sommerville et al. (2014)

Regarding the fish stock, two different interpretation are being adopted.

Indeed, it can be calculated the number of fishes per m2 or the total weight.
As it is possible to see from the literature the optimal amount of Tilapia (the fish that will be chosen) per m2 result to be 106- 90 and 77 (Rahmatullah et.Al, 2010) (Estrada-Perez et.Al, 2018) (Rakocy et.Al 1997).
Considering the total weight, the maximum stock density should be 20kg for 1000 (in small scale plant.
Since the plant proposed will be a medium size one, the first approach has been used because it is simpler to manage (it is not necessary to change fish tank).

2.3.3 Kinds of Aquaponics plants

There are three main types of plant culture which are used in aquaponics:

1) **Raft or Float System**: Plants are grown on polystyrene tables that are placed directly on the water. Generally, the tanks of fish and plants are separated. Thanks to biofilters, water flows continuously from fish tanks to plants, where the beneficial bacteria for nitrification live, supplying useful nutrients to the plants. One of the main advantages of this system is the fact that the two tanks are divided and that the water circulates quickly, so that the fish tanks always have a considerable amount of water reducing the stress they have to face. This system allows the greatest yield per m2 density, also optimizing the production space, but it needs oxygen addition because roots are always immersed in the nutrient solution.

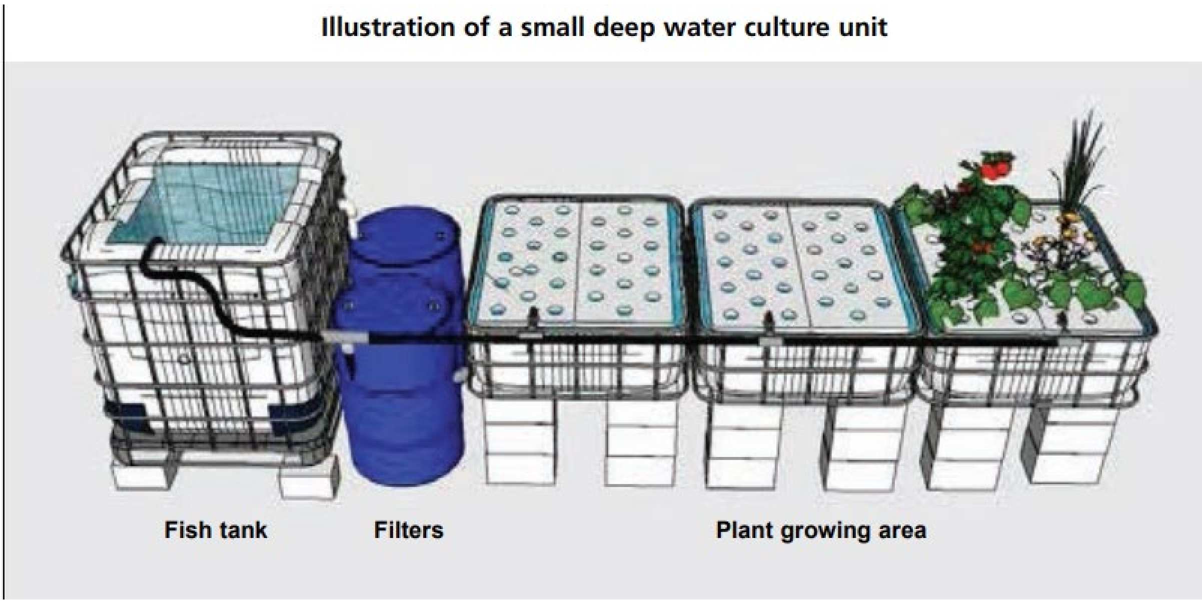

Fig. 5 Illustration of a small deep water culture unit. Source: Sommerville et Al. (2014)

2)**Flood and drainage system (media bed)**

This system uses a container full of gravel, perlite or clay for the vegetable beds. Beds are flooded at regular time intervals Then, water drains back to the fish tank. Almost all the scraps are disposed inside the vegetable beds. In this system it is not necessary to add oxygen since the roots are periodically exposed to air. This system has a slightly lower yield than the others but it has the lowest costs

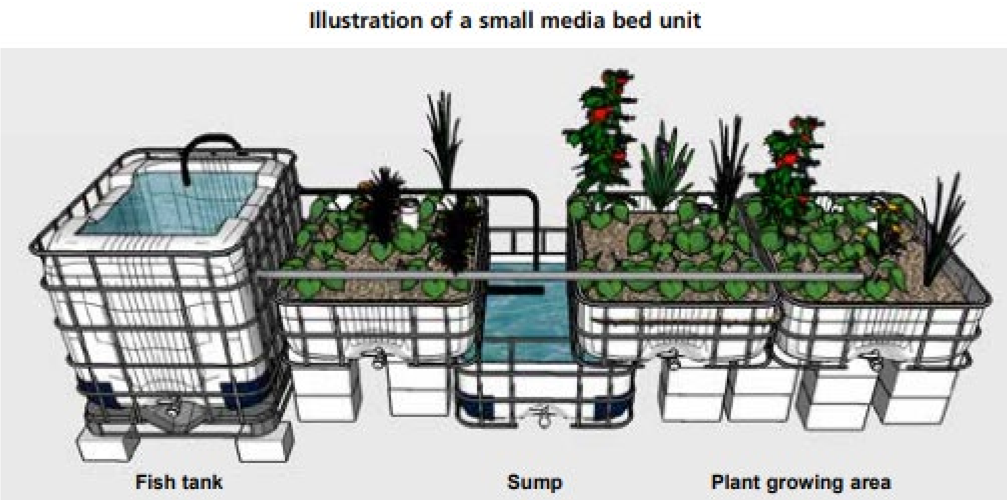

Fig. 6 Illustration of a small dmedia bed unit. Source: Sommerville et Al. (2014)

3) Nutritive film Technic (NFT): Plants are cultivated inside channels. Water flows continuously inside tubes providing all the necessary elements for plant growth . Water. oxygen and nutrients make a circular movement between tubes and fish tanks. In NFT systems, a separate biological filter is needed, since there is not a large amount of water on the surface. This system requires ducts of greater size than hydroponics because, due to the organic nature of the system and continuous flow of water, the pipes could clog up. it has good potential but it is used for the production of leafy plants which are the only ones which grow well with this system.

Illustration of a small nutrient film technique unit

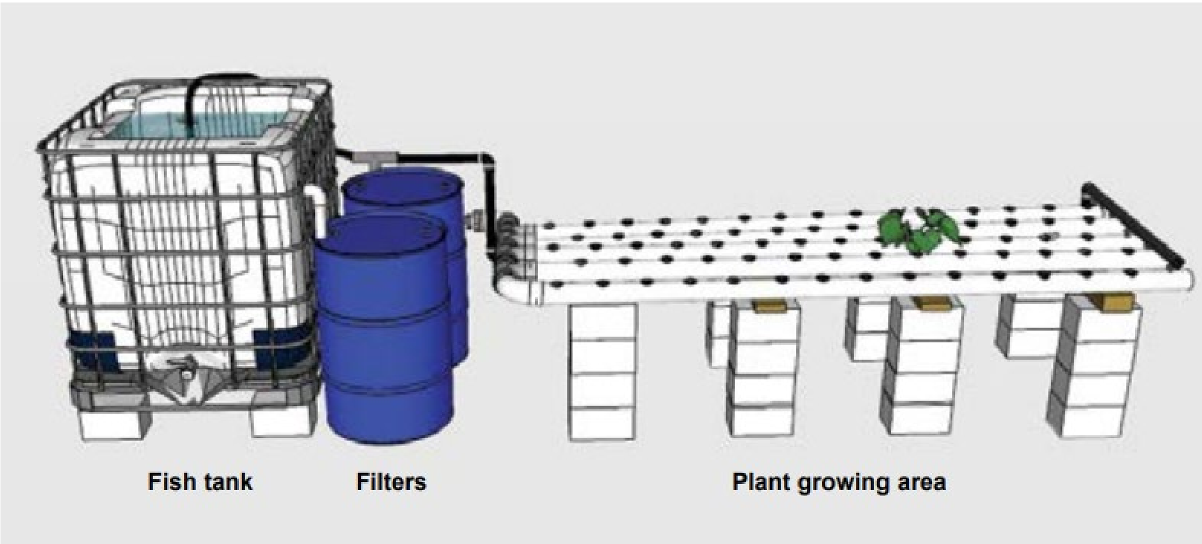

Fig. 7 Illustration of a small nutrient film technique unit. Source: Sommerville et Al. (2014)

2.3.4 Small scale aquaponics in Africa

The systems that are known to exist are generally small scale with the goal to feed some families.
Companies promoting aquaponics are active in Africa so there is an expectation that these systems will become more prominent over time (agrotec, 2013).
African countries where aquaponics is known to exist include; South Africa, Botswana, Malawi, Kenya, Zambia, and Rwanda.
Many of the initiatives are proposed by groups concerned about alleviating local poverty and nutritional deficiencies.
The development of primary human needs related to health and survival will be the dominant driving force.
An example of a recent aquaponics development in Africa is the Portable Farms system being

established in Botswana.
The benefits of the system include low monitoring and cleaning requirements, operation by semi-skilled labour, and a focus on sustainability (Agrotec 2013).

2.4 Economic and social situation in the sub-prefecture of Korhogo: Target definition

As we will see in the fourth section, the chosen location will be located in the city of Korhogo in the North of the Côte d'Ivoire. For this reason, for the writing of the thesis it was necessary to look for information regarding this specific location.
In the community field, to be successful projects must respect the characteristics of the local population and the territory.
Without this integration within the analysis, it is much easier to make serious mistakes in the target audience and in how the project will be implemented.
So the following aspects were taken into consideration:

Population (Sinali,1961) (Fauré et.Al 2002)
Education (Fauré et.Al 2002)
Economy (Ducroquet et Al 2017) (Fauré et.Al 2002)
Environment (Ducroquet et Al 2017) (Boko et.Al, 2016)
Politics (Sinali,1961) (Fauré et.Al 2002) (Albergel, 2007)
Cultures (Sinali,1961) (Fauré et.Al 2002)

This aspects can be summarised in the table 8.

Population profile	How many people are in the community?	570000 ab

	What is the age distribution of these people?	0-4yrs= 19,97% 5-9yrs= 15,85% 10-14yrs= 12,98% 15-19yrs= 11,65% Over 19yrs= 39,55%
	What is the (estimated) percentage of men and women?	Males= 48,7% Females=51,3%
	What ethnic groups are represented in the community? What is their distribution (as estimated percentage)?	X= 78% senoufos Y= 15% doufac Z= 7% others
	What languages do people in the community speaks?	X= French Y= Voltaic

Education profile	What are the literacy rates of the community?	= 60,3%
	What percentage of community members graduate primary school?	= 41% (36% girls)
	What percentage of community members graduate secondary school?	= 7,8%
	What percentage of community members graduate university?	= 2,4%

Unfortunately, many data are referred to 20 years ago because was not possible to find other data. Nevertheless, since there was a war in the north of Côte d'Ivoire between 2008 and 2011 with a decrease of life quality, these data can be considered no too far from actual situation (Obviously with some discrepancy).

Economic profile	What percentage of child mortality ?	= 9,22%
	What percentage of population have stable access to food? Serious percentage of malnutrion?	=65% = 10% children 0% adults
	What kind of jobs do people in the community?	= Farmers, artisans, Merchants High percentage of informal jobs
	What are the key areas of economic growth in the community?	= Primary sector Commerce

Environmental profile	What type of environment is the community located in?	Tropical
	How big is the geographical area covered by the community?	700km2
	How easy is to access different areas of the community?	NO Found

	How far away is the closest hospital /secondary school/major metropolitan area? It is on the area but it is not efficient

Political profile	What are the current major political issues? No found
	What are the political priorities of the current government? = Reduce poverty Increase food security Limit climate change effects Limit HIV infection Promoting gender equality and child protection Promoting tecnhnologic improvement
	How is the government viewed within the community? No found
	How well do local government representatives function and work together with national government, law enforcement and other public departments? No found

Cultural profile	What are the major values of the community? = Senoufo think of themselves as one group Male secret society Strong importance of religious rites
	Are there any major cultural conflicts between different sectors of the community? No found

Table 8: Situational analysis of the sub-prefecture of Korhogo Source of data: Bobo et Korhogo dans les défis de la décentralisation IRD Éditions 2002

Another reason that led us to choose this location is the relationship between the Senoufo population (local ethnicity) and fish farming.

In fact, in the past, 6 fish farming projects have been implemented to provide a source of protein to the local population.

But these experiments have all failed because people returned to growing rice (one of the main crops of this location) because it provides a greater sense of satiety (Nanan et.Al, 2018).

Aquaponics could be a hybrid solution because it can be integrated with other plants and can be used in the city, remedying the problem that has been encountered in the past

3 Methodology

In order to obtain a model as detailed as possible, a set of quantitative methods will be used.
These methods have been selected to assess economic, environmental and social dimensions related to the feasibility study of an aquaponic system in Côte d'Ivoire.

Before explaining the development of the methodology, we must consider the initial assumptions.
In fact, the animal and plant species were chosen before the development of the model to simplify the study.
The choice of species was therefore based on those that are already present in the chosen area.
So the fish species selected is the scientific **Oreochromis niloticus** or commonly called Nile Tilapia because it is the only native species that can be used for aquaponics.
As for the plant species, it is been selected tomato because it si cultivated locally and tolerate fairly well the heat.

So having clarified these premises, it is now possible to define the methodology.

To begin with, the site location of the system will be selected between different options,
To do that a multi-criteria analysis will be developed, which considerers three main aspects:
1) Water quality
2)Infrastructure and social analysis

This last part of the analysis will also be useful to define the target of the project.

This analysis was done because these factors influence the technical feasibility and the costs of the project.

Before defining the structure of the system, an analysis of the climatic conditions will be carried out as they also influence the management of the system (the quantity of plants produced and the energy developed by each solar panel.

Finallt, the aquaponic system will be designed. The designed project will be utilized as the scope for environmental impact, costs and nutrition improvement analysis.

The following graph represents in detail the structure of the methodology

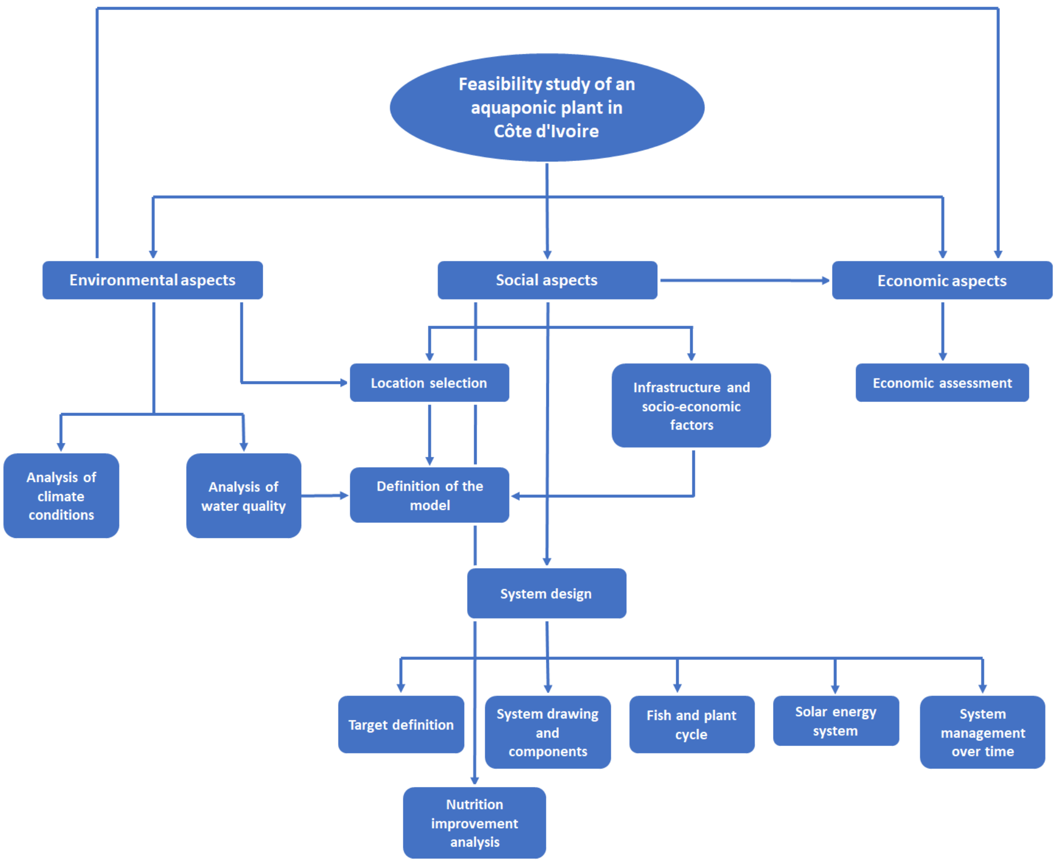

Fig. 8 Schematic structure of the methodology

3.1 Location selection

After describing the general information of the area under consideration (which are useful for contextualising the project and understanding the type of fish plants which, as we will see, will be grown there), we must go into detail to understand the specific area where it is possible to build the project and those where it is not possible.
In this project 4 different areas will be examined in the sub-prefecture of Korhogo with a number of wells that varies from 3 to 4 for each area.
The project will select the best well for each area considering the characteristics of tilapia as this is the only fish that can be found in the local market.
Then, the suitability of   every possible location will be described considering different criteria.

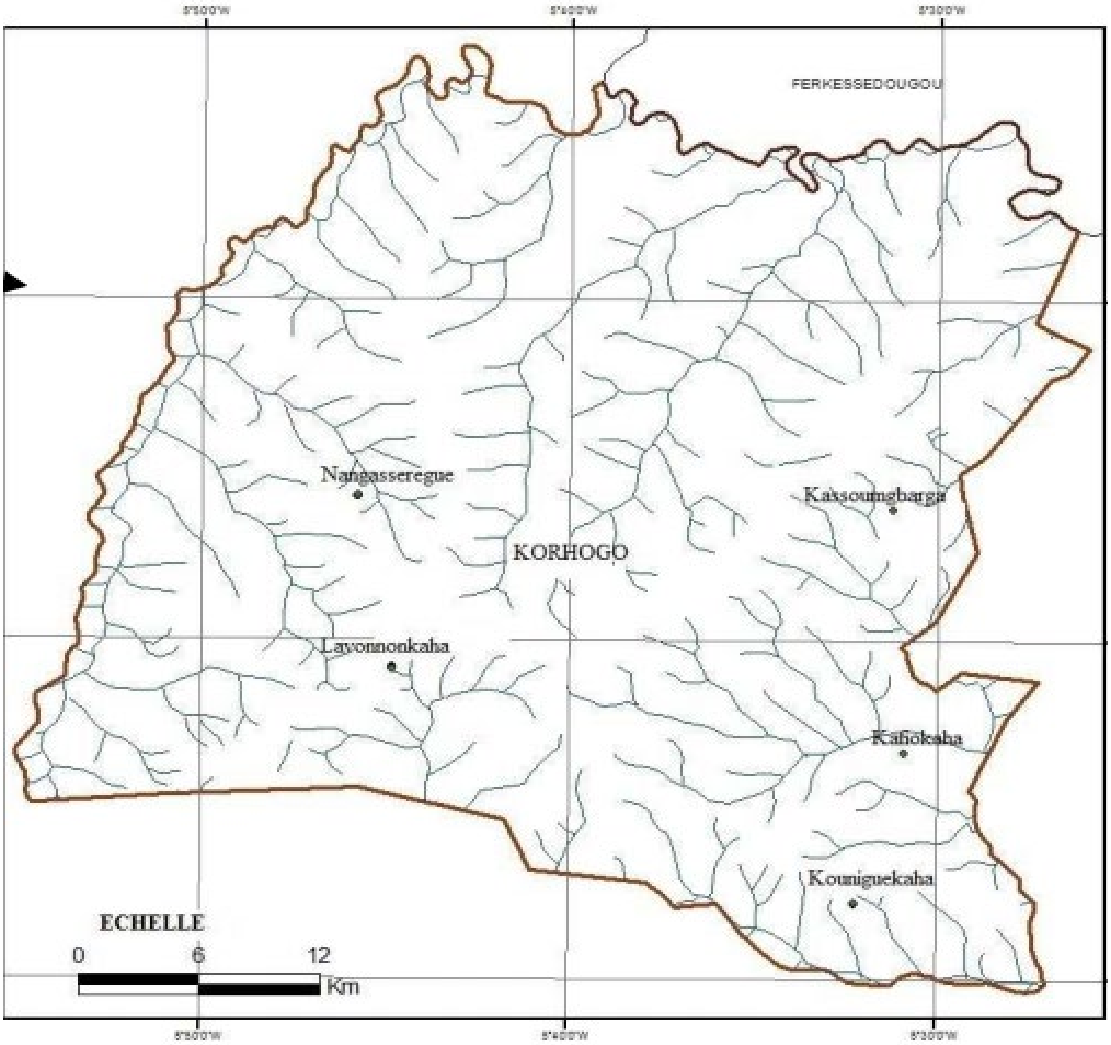

Fig. 9 Map of examined locations

3.1.1 Multi-criteria analysis

A multi-criteria evaluation approach was used to choose the best location, based on the method of Hossein et.Al 2007, but adapted to our specific case.

In fact, given that Hossein's paper analyzes aquaculture in a different context, some variables have been changed or adapted.

This model considers only fishes and not plants.

This choice was made as an intake, in fact the main missing nutrient in the locals dietary habits is the protein intake. For this reason, the model was designed to describe where the implementation of tilapia would be more suitable.
The only environmental element to present a significant change is the quality of the water, which is fundamental for the fish that are the engine of the system.
Therefore this will be the first sub-model.

In addition there should be other two other sub-models.

In fact, this system is also influenced by the topography of the territory and by the characteristics of the infrastructures and socio-economic factors.

Hovewer, there are not data about topography, so this part of the model is not been included.To quantify the variables three main categories will be underlined: Suitable, partially suitable and unsuitable (FAO 1993, Hossein et.Al, 2007).

The ranges of the tilapia have been obtained from several articles.
In this way it will be possible to select the areas based on the adaptability of the tilapia.

1)Water quality
The water quality analysis focuses on 7 main parameters
1)Temperatures
2)pH
3)Dissolved oxygen
4)Conductibility
5)Ammonia
6)Nitrate
7)Nitrite
These parameters have been chosen considering their range of variability during the course of the year (Rachelle Ida yapo et.Al 2016).
Thanks to the comparison of the data of the wells and ranges found in the different articles, the first part of the model is defined

2)Infrastructure and socio-economic factors
The analysis of this section will focus on two main parameters
1)Distance of the place from the supply of the fry
2)Percentage of women out of the total population
The last data will be chosen following the analysis of the social situation,
In fact, once the target has been defined (if the project will be for men, women, or for both), the segment of population with which the project is concerned will be defined and consequently these data will be calibrated.

3.1.2 Definition of the model

Having all the elements available, it is now possible to build the model that will allow you to decide the location of the project.

It comes as it will happen, The model, as previously said, will be a multivariable one.

In detail, the variables were analyzed taking into consideration ranges from the literature.

Table 9 summarizes all the ranges in which the variables must find themselves to be acceptable, partially acceptable or unacceptable.

Land characteristics	Most suitable	Moderately suitable	Not suitable	References
Water quality				
Temperature	27-30C°	14-26C°/31-36C°	<14C°/ >36C°	Sommerville et.Al 2014
Conducibility	60-2000µS/cm	30-59 2001-5000	<30 >5000	Stone et.Al 2013
pH	7-8	5.5-6.9 8.1-9.5	< 5.5 >9.5	El-Sherif et.Al 2009
Dissolved oxygen	>4	1.5-4	< 1.5	Tawwab et. Al 2015
Ammonia	< 0.4	0.4-2	>2	Sommerville et.Al 2014

Nitrite	< 0.1	<1	>1	Sommerville et.Al 2014
Nitrate	< 150	150-400	>400	Dampin, N et.Al 2012
Sub-overall				
Topography				
Slope	0-2	2-4	>4	
Type of soil	Clay	Silt	Sand	
Sub-overall				
Infrastructure and socio-economic factors				
Distance to road	0-1	1-3	>3	Hossein et. Al 2007
Distance to sources of fish fry	0-15km	15-30 km	>30km	Hossein et. Al 2007
Percentage of women out of the total population	>55%	45-55%	<45%	This study

Table 9 Multi-criteria analysis

Once the ranges have been defined, the model can now be constructed by drawing the result of the variables.

Before completing the model, it must be remembered that not all variables have the same weight (Hossein et.Al, 2007).

The calculation of the coefficients of each variable are based on the study by Hossein et.Al, in 2007, whose calculations, in turn, refer to the specific impact that each variable can have on the model and on the possibility of intervening to modify the parameters.

Instead, there are data which will not be considered since they are thought not to be impactful. (it has been hypothesized by assumption that near each selected well there is a community living, and that this happens in the presence of stable and flat terrain.

Therefore, the topography of the place will not be included in the final model

The data with the related coefficients are summarized in table 10.

Land characteristics

Water quality		
Temperature	**Rachelle Ida yapo et.Al 2016**	**0.09**
Conductibility	**Rachelle Ida yapo et.Al 2016**	**0.16**

pH	**Rachelle Ida yapo et.Al 2016**	**0.14**
Dissolved oxygen	**Rachelle Ida yapo et.Al 2016**	**0.06**
Ammonia	**Rachelle Ida yapo et.Al 2016**	**0.13**
Nitrate	**Rachelle Ida yapo et.Al 2016**	**0.06**
Sub-overall		
Infrastructure and socio-economic factors		
Distance to sources of fry fish	**Lazard et.Al 1980, 1995; Pramong 1988**	**0.12**
Population composition	**Institut national de statistique Côte d'Ivoire 2015**	**0.25**
Sub-overall		

Table 10. Weights of variables

3.2 Analysis of climatic conditions

It is also important to analyze the climatic conditions because they influence some elements of the system.

In fact, This analysis is useful to understand:

1) If the system needs ventilation or heating to control plant product

2) To understand if the chosen vegetable are the suitable to grow, taking into consideration the climatic condition of the territory

3) The amount of energy which could be produced by solar panels (this system will be designed with solar panels since the system will be implemented in villages with a maximum of 1000 people, where electricity often is not accessible)

Hence, the climate elements which will be taken into consideration are:

1) Air temperature: (considering the seasonal differences)

2) Solar radiation:

Air pressure has to be determined since, it has an impact on DO in water. However, since, this data have already been analyzed in the previous chapter and there are data in literature regarding the water characteristics, analyzing air pressure will be superfluous.

Last of all, the wind has no significant effect, either.

It achieves a maximum of 12 mph during the year and it frequently changes direction. Therefore, consideration of this variable is not necessary. Finally, also rain was not taken in consideration because the plant will be covered. The only data the is interesting for us regarding rain si how to impact solar radiation that will be analyzed.

1) Air Temperatures

The temperature analysis will focus on the range between the minimum and maximum temperatures.

In fact, plants have an optimal growth temperature and survival range.

The data are been selected by *Weather Spark.com.*

Thanks to this information it is possible to understand how to manage plants.

2) Solar radiation

The analysis of solar radiation is very important to understand if the solar intensity is too strong for the plants that have been chosen.

The data have been selected by *Weather Spark.com*

As a matter of fact, this element is also very useful to understand how much the energy of the system will cost.

This system will work thanks to the solar panels which owe their power precisely to the intensity of the solar rays.

To illustrate it, the following formula of energy conversion will be used

Total Power Output=Total Area x Solar Irradiance x Conversion Efficiency (Villalva et Al 2009)

On the basis of this formula, the quantity of solar panels needed to produce the energy required by the system will be analyzed in the following paragraphs (cost analysis).

3.3 Plant species management

To obtain the maximum yield in the production of plants, some main parameters must be respected (in addition to the nutrients deriving from the balance between plants and fish)

Following Sommerville et Al, to 2014 these parameters are:

T °

pH

Light exposure
The growth ranges of the selected plants are summarized below.
:To have an optimal production, try to stay as close as possible to the average value.
The chosen vegetable since it is already cultivated locally and because it fits well in an area characterized by high temperatures

TOMATO pH: 5.5–6.5 Plant spacing: 40–60 cm (3–5 plants/m2) Germination time and temperature: 4–6 days; 20–30 °C Growth time: 50–70 days till first harvest; fruiting 90–120 days up to 8–10 months (indeterminate varieties) Optimal temperatures: 13–16 °C night, 22–26 °C day Light exposure: full sun Plant height and width: 60–180 cm; 60–80 cm Recommended aquaponic method: media beds and DWC.

3.4 System design

After having established the amount of food that the system will use, it is now possible to define in detail the construction of the plant.

More specifically, the following information will be discussed

1)Target definition

2)System drawing and components

3)Fish and plant cycle

4)Solar energy system

5)System management over time

1) Target definition

To define the structure of the system, the number of people with specific plant management tasks will be defined.

To do this, the data obtained in the previous chapter (Target definition) and from Sommerville et. Al, (2014) which describes the size of a small production plant and how to manage it.

2)System drawing and components

The chosen system will be represented with the autocad software, thanks to which every detail of the

system will be drawn.

Instead, the set of elements that make up the aquaponic system will be defined according to the information found in the previous sections.

In fact, the presence of some elements such as the oxygenation of the water depends on the peculiarities of the area.
Therefore, this information will be explained through a summary table, where will show all the elements of the system.

3) Species

The species will be selected based on the information found in the previous chapters

In particular, the choice depends on these two factors

1)Environmental vocationality

2)Target audience preferences

Therefore, after defining the choice, their main characteristics will be explained through the following table(), in order to understand how their growth should be managed

4) Solar Energy system

The choice of the energy system was based on these principles:

1)Green project

2)Enhancement of local resources

3)Ability to build it anywhere

For this reason a panel system will be implemented.

In this section the energy requirement will be quantified and therefore the size of the system will be defined

5) System management over time

This type of system was built with the aim of continuously supplying food to a segment of the population in the Côte d'Ivoire.

For this reason, the management of the plant must be done through different tanks, in order to have a continuous food supply.

Additionally, it will also be explained how locals should manage food resources within the population.

This will be part of the training that the local population will receive.

Accordingly, this analysis is important because it impacts the costs of the project.

The references of this section coming from Sommerville et. Al, (2014)

3.5 Economic feasibility

The aim of this thesis is to provide a prototype for the Côte d'Ivoire, with the hope of finding institutional investors or facilitated forms of financing.

Moreover, the goal is to improve food security, not having a monetary gain.

For this reason, this part of the analysis will focus on costs and not on revenues because of the project goal.

FAO, World bank and private citizens have experimented this technology in other developing and developed countries.

Hence, the costs will come from the analysis of different papers focusing on the systems implemented in developing countries (Rakocy et. Al, 1997 and 2000) (plant discounting to current prices in Côte d'Ivoire.

Moreover, for the construction costs a price quotation has also been used, which was presented by Tosco Solution S.R.L, the enterprise which is collaborating to try to spread Aquaponics on the territories of Côte d'Ivoire.

The costs will be quantified according to this scheme:

1)Initial investments (which will be divided into: material costs, labor cost costs, solar system cost

2)Operating costs (which will be divided into fixed and variable)

3.6 Nutrition improvement analysis

In this section, the goal is to explain how much food will be produced by the plant.

Fish and vegetable production will be quantified on the basis of the nutrients they can supply the population with, namely the **proteins**, the most important **minerals** and the **vitamins** contained in the species produced.

These data will be explained through a summary table.

This part of the analysis will therefore allow you to quantify whether this type of system is useful and sufficient for the needs of the local population or if you can better think of another project.

This approach was chosen because the funding target is institutional.
Therefore the possibility of being financed does not depend on the economic return but on the number of benefits that this project can have compared to a possible competitor project based on improving the nutritional situation.

4 Results

4.1 Location definition

4.1.1 General information

The sub-prefecture of Korhogo is part of the Poro Region, bordering Mali and Burkina Faso. Korhogo is located 635 km from Abidjan, the economic capital and largest city in the country, and 500 km from Yamoussoukro, the political capital. This town is located at 9 ° 53 N latitude and 6 ° 49 W longitude.

Figure 10: City of Korhogo

Chief town *Korhogo*

District	*Poro*
Population	*498,320 (2012) sub-prefecture*
Area	*City 115km2 Department 12500km2*
Vegetation	*Savannah and forests*
Altitude	*380 m*
Life expectancy	*54 years*
Mortality rate before 5 years	*9,26%*
HIV positive	*3,7%*

Korhogo is a medium-sized city (however large for the Côte d'Ivoire). The population is very young with a low life expectancy (54 years).

Infant mortality is very high with almost 12% in the rural areas and 9.26% inside the city, among the highest percentage of the Côte d'Ivoire. 91.55% of the population consists of citizens and 8.45% are non-citizens .

According to estimates by the National Institute of Statistics (INS), in accordance with the new administrative division, the population of the sub prefecture was 498,320 inhabitants in 2012 with a constant and high growth rate .

The main ethnic groups present are the Senoufo (originating from the Côte d'Ivoire) and other ethnic groups arriving from outside the Ivorian state which are the Burkinabes, Malians and Doufic.

History

The city of Korhogo was founded between 1300 and 1700 by Nanguin Soro.

The name of this city derives from the word Korgo which in Senoufo means fortune or inheritance.

The name of this region, which is called Poro, derives from an initiation rite that young people must do to enter the society-

This ritual consists for the boys in spending a week during which they have to survive by managing all by themselves. It is still practiced nowadays.

Physical characteristics

The Korhogo department is made up of several plateaus and granite hills.

The Climate is tropical, with a dry season from November to April and a rainy season from May to October. As far as protection is concerned, its vegetation mainly consists of grassy trees and savannas.

But there are also some forests, many of which are considered sacred.
The rainfall varies from 1200 to 1400 mm and is washed by the Bandama river.

Economic characteristics

The population of the Korhogo department bases its economy on the primary sector.
Cotton is the crop that provides most of the money in the Savannah district, which makes the Côte d'Ivoire the third largest producer in the world.
Mainly perennial crops such as mango, corn, peanuts, rice and millet are grown.
Cotton is the first crop in the Côte d'Ivoire for production, which makes the area the third largest producer in the world.
In the 2012/2013 season, production in the Korhogo department was 180,000.
The cashew sector is not regulated. In 2012, 42,000 Tons were recorded but many escaped control so true production cannot be established.
Horticultural crops are also developed. Many groups of women practice growing cucumbers, chili peppers, aubergines, carrots, tomatoes, cabbage, lettuce, green beans, okra, onion, green beans, melon and pepper.
Breeding also plays an important role. In fact, some of the breeds are: poultry, pigs, cattle, sheep and goats.
The second main activity after agriculture is trade. This is mainly managed by the Doufics competing with the Aboriginal Senoufo.
Several products are sold, from the food industry, to clothing, up to construction materials.
Mechanics and motorcycle shops are present almost everywhere.
The other sectors are poorly organized.
The industry is almost absent except for four cotton ginning companies and a dozen mango processing companies in Korhogo.
Tourism could potentially bring a lot of money but it is not yet developed.
Finally this is a mining area. In fact there are gold and colton mines.

The administration well represented

All the main administrative structures are located in the city of Korhogo. There we find:
the sub-prefecture of Korhogo, the municipality of Korhogo, the court of first instance, the regional prefecture, the general treasury, financial control and 24 regional directorates representing civil ministries. There are also the 4th military region, the 4th legion of gendarmerie, the police prefecture, an infantry battalion, the regional directorate for water and forests, the regional customs directorate, a

gendarmerie squadron and a gendarmerie company.

Infrastructure

In Korhogo there are several primary and secondary schools, a university and even a hospital. In addition, almost all banking and administrative institutions are found in this city

Political life

In the department of Korhogo there are the main political parties (which are different). However, the Rassemblement des Républicains (RDR, presidential party) remains the majority.

4.1.2 Well selection

The analysis was carried out on 15 wells that are present in the following 4 villages

Nangasseregue, Kassoumbarga, Kafiokaha, Kounigekaha

As a first step, the best well for each village was identified with a preliminary analysis. The values of the ranges of each variable for each well are visible in appendix 1

	Na 1	Na 2	Na 3	Na 4	Kas 1	Kas 2	Kas 3	Kas 4	Kaf 1	Kaf 2	Kaf 3	Kaf 4	Ko 1	Ko 1	Ko 1	Coeff
Temperature	3	3	3	3	2	2	2	2	2	2	3	2	2	2	3	**0,09**
pH	2	2	2	1	2	2	2	2	2	2	2	2	2	3	2	**0,16**
Dissolved Oxygen	1	2	2	2	1	1	1	2	2	2	2	1	1	3	1	**0,14**

Ammonium	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	**0,06**
Nitrate	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	**0,13**
Conductibility	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	**0,06**
Result	1.48	1.62	1.62	1.4	1.33	1.27	1.33	1.47	1.47	1.47	1.56	1.33	1.33	1.77	1.42	

Table 11. Best wells in the four villages.

As shown in table x, the wells selected in the study areas included are

Na2 o Na3 = 1.62

Kas 4= 1.47

Kaf 3= 1.57

Ko 2 = 1.77

4.1.3 Infrastructure and socio-economic factors

After selecting the best well for each village, it is still necessary to integrate the two variables belonging to infrastructure and socio-economic factors.

1) The first figure consists of the distance between the villages and the closest source of fry.

Unfortunately in this area there is only one supplier of small tilapia, which is located in Natio-Kobadara in the city of Korhogo

The distance between the four villages and the supplier has been calculated with google maps and reads as follows:

Nan 17,8 km

KAS 12,4 km

KAF 19,7 km

KOU 32,9 km

2) The second datum (population composition) refers instead to the target of the project.
As can be seen from table 8(pag 35, the only ethnic group present in these villages is Senoufo (Fauré et.Al, 2002).

You can notice a very high infant mortality rate of 9.22% which is largely due to the rate of malnutrition, which is very serious for children in 10% of cases, while it is absent in adults (despite a very high and stunning rate of 34 %)

Also to be considered is the fact that government policies are aimed primarily at Promoting gender equality and child protection.

Furthermore, the level of literature differs greatly between men and women 52% vs 28%.

Finally, within the community it is women who tend to carry out agricultural jobs (when they work) due to the fact that they have many children (average 5 per woman).

Hence, the target of the project will be referred to women who have infants.

For all these reasons, to quantify these data within the model, given the lack of data on the child population of each place, the percentage of women compared to the total population was the used indicator.

The data about the composition of the population of the 4 villages are in table 12.

City	Men	Women	Total population	Percentage of women
NANGASSEREGUE	520	516	1 036	49.8
KASSOUMBARGA	403	401	804	49.8

KAFIOKAHA	344	426	770	55.3
KOUNIGUEKAHA	211	177	388	45.6

Table 12. Population composition in the four villages.

4.1.4 Multi-variables model

Once defined all parametres, it is now possible to build the multi-variables model by integrating all the elements, to select the village where the project will be developed.

	Na 1	**Na 2**	**Na 3**	**Na 4**	**Kas 1**	**Kas 2**	**Kas 3**	**Kas 4**	**Kaf 1**	**Kaf 2**	**Kaf 3**	**Kaf 4**	**Ko 1**	**Ko 1**	**Ko 1**	**Coeff**
Water quality																
Temperature	3	3	3	3	2	2	2	2	2	2	3	2	2	2	3	0,09
pH	2	2	2	1	2	2	2	2	2	2	2	2	2	3	2	0,16
Dissolved Oxygen	1	2	2	2	1	1	1	2	2	2	2	1	1	3	1	0,14
Ammonium	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	0,06
Nitrate	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0,13

Conductibility	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	0,06
Result	1.48	1.62	1.62	1.4	1.33	1.27	1.33	1.47	1.47	1.47	1.56	1.33	1.33	1.77	1.42	
Infras and socio-econo factors																
Distance to fry		2						3			2			1		0,12
Women %		2						2			3			1		0,25
Results		0,74						0,87			0,99			0,37		
Total results		2,36						2.34			2.55			2.14		

Table 13. Multi-variable model results.

At the end of the multivariable analysis, the well selected will be that of Kafiokaha n.3.
In fact, within this village, the water parameters of the selected well are all within the optimal range or at least in the tolerability range, the distance from the source of the fry is average and not prohibitive, and it is the village with the largest number of women in population compared to men (over 55%).

4.2 Analysis of climate conditions

1) Air Temperature

In the hot season (3 months from January 22 to april 19) the temperatures vary from an average minimum of 22 ° C to a maximum of 36 ° C (Weather Spark.COM, 2018)

In the cool season (3 months from 12 July to 5 October), the average maximum daily temperature are below 30 ° C. The coldest day of the year is January 1, with an average minimum temperature of 16 ° C and a maximum of 34 ° C .

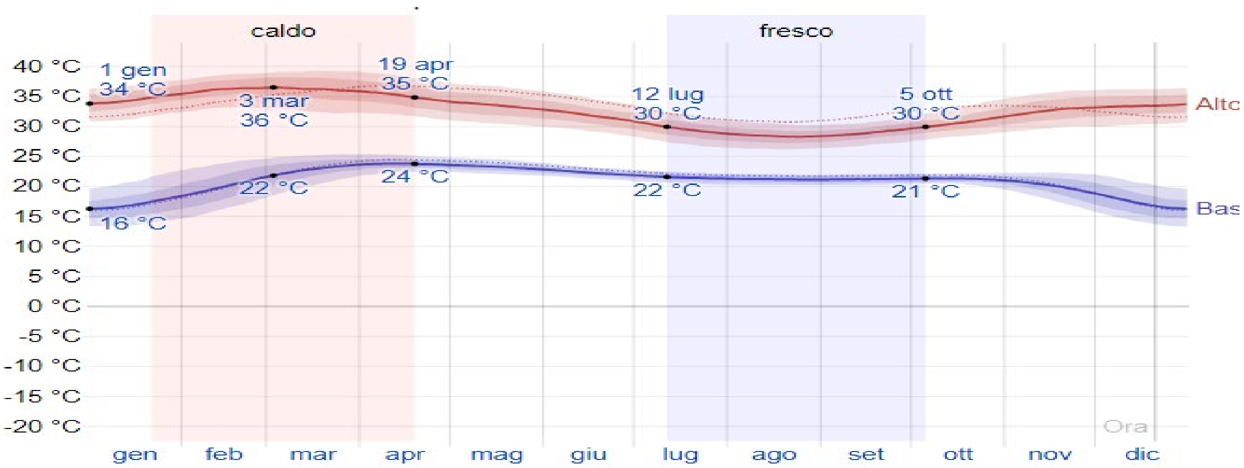

Fig. 11 Daily average air temperatures in Korhogo. *Source: Weather Spark.com*

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2)Solar radiation/ Solar energy

The average daily incident shortwave solar energy experiences some seasonal variation over the course of the year.
The brighter period of the year lasts for 1.8 months, from January 16 to March 9, with an average daily incident shortwave energy per square meter above 5.8 kWh. The brightest day of the year is February 13, with an average of 6.0 kWh. (Weather Spark.com)
The darker period of the year lasts for 2.0 months, from July 10 to September 10, with an average daily incident shortwave energy per square meter below 5.1 kWh. The darkest day of the year is August 18, with an average of 4.8 kWh. (Weather Spark.com)

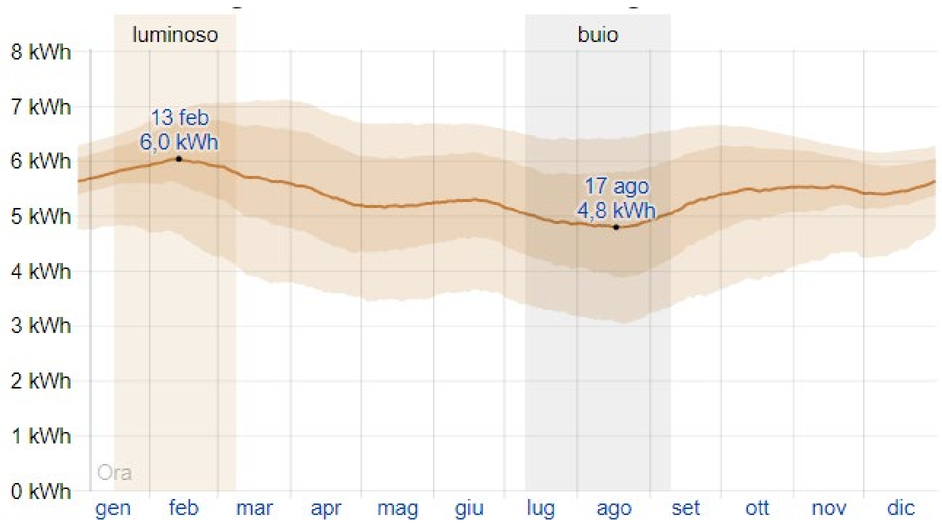

Fig. 12 Daily incident shortwave energy per square meter in Korhogo. Source: Weather Spark.com

The length of the day in Korhogo does not vary substantially over the course of the year, staying within 40 minutes of 12 hours throughout. In 2020, the shortest day is December 21, with 11 hours, 34
minutes of daylight; the longest day is June 20, with 12 hours, 41 minutes of daylight.
Hence, it is possible to see that the Temperature in Korhogo results to be high on average.
Plant crops will be selected choosing between the one which tolerate high temperature , discriminating between winter and summer type.

4.3 System design

Since the plant will be built in the village of Kafiokaha with the aim of improving nutrition for the most defenseless population (post-pregnancy women and young children), the system must have the following characteristics:

- Continuous supply of fish
- Use of recycled material
- Low technology and easy-to-use system
- Continuous supply of fish

Given this information, the best solution is the Media-bed System (Sommerville et.Al 2014)

1) **Easy to use**

As seen in the literature review, the easiest method to be managed results to be the MEDIA-BED system.

For this reason, the kind of plant that will be proposed is similar to the model proposed in the following picture:

Figure 13: Example of Media bed-system aquaponics Source: Sommeville et. Al 2014

2)System drawing and components

The project was conceived following the lines of Sommerville et, as of 2014 where a plant of a 1m2 fish tank and a surface area three times as big for plants has been tested.

However, this type of plant was designed for a nuclear family.

So the next step is to determine the specific size of the plant.

Senoufos wimen ,especially in the villages, still live with a great sense of community.

Therefore, growing children at group level and not individually, the plant will be designed to provide food to four women with children and not just one.

Since people live near the well, the distance from the houses to the plant is negligible as it has no impact on production.

2) System drawing and components

Since we want to have a continuous supply of food with multiple-raring tanks os have been chosen. For this reason, 9 tanks containing fish have been hypothesized.

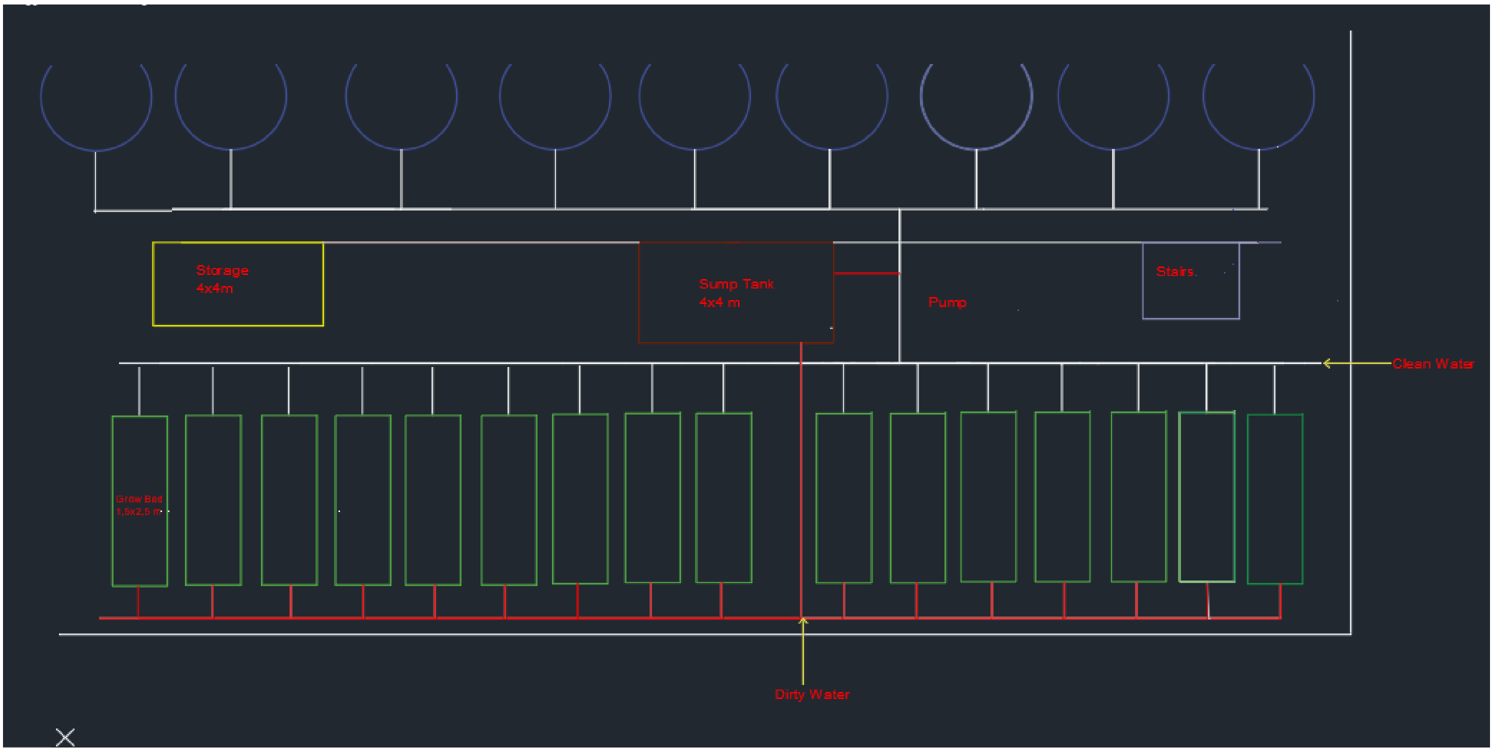

Fig. 14. Acquaponic plant scheme

Considering that the tilapia cycle is around 6 months, the fish supply would take place every 21 days.

In addition, each family will have 3 fish tanks with 5 media beds for the plants because the single system would have produced too little food for the needs of a large family (Sommerville et. Al, 2014)
The plant was designed for 3 families with three infats each. Hence, the system will produce food for 9 infants and 3 breestfeeding wimen.

Structural elements of the system include Hydroponics media-bed, fish tank, s a plumping a irrigation system, and a sump tank.

Furthermore, to prevent plants from being attacked by pests and to be able to control the climatic conditions, the project will be set up inside a gazebo which will be made up of a roof structure (which also allows to mitigate the strong solar radiation) and a PVC sheet that can be closed or opened as needed.

Component	Element	Description	Notes
Fish tank	Shape	Square	
	Volume per unit Radius Height	1.25m*1.25m	Fish density will be 40 fish for every tank that means 40 fish for 1000l of water
	Material	Alluminium Tarpaulin sheet	9 fish tanks with alluminium structure and a heat-sealed pvc tarpulin
Media-filled beds	Shape	Rectangular	Width of 1 m for easy access, maintenance and harvesting
	Surface area Volume Dimension	$27m^2$ 1,4 x 1,5 x 0.5 m each, 9 beds in total	Obtained with a ratio of 51m2 of tomato plant each 60g of fish feed per day
	Material	Acacia Tarpaulin sheet	Local material
	Media	Expanded clay	
Sump (in-ground)	Shape	Rectangular	
	Volume Dimension	4,000 L 1 x 4 x 1 m	
	Material	Bricks Tarpaulin sheet	Local material
Plumbing	Material	PVC pipes, and other connectors	Locally available and safe
Irrigation		Auto-siphon Water pump	
Roof structure	Dimension	17*12*3m	0.5m larger than the aquaponic system
	Material	Polypropylene with acacia wood structure	Economic and durable system

Table 14. Aquaponic system design.

To obtain optimal system operation, the location of the various elements has been carefully designed. The fish tanks will be placed in the highest place so the water can percolate inside the media beds which will be placed at a lower level. Finally, the sump where the pump that will pump the water back into the fish tank will be located at the lowest level.

3)Fish and plant cycle

Fish cycle management will take place thanks to the use of 9 tanks of the same size. Juveniles of the same size will be inserted inside each tank.
Each tank will be filled after 21 days in order to have continuous food supply and a total quantity of fish inside the 9 tanks always in balance.
This is an important aspect to take into consideration because it means that the supply of nutrients to the plants will also be constant.
The collection of fish will take place after 6 months from their insertion into the plant.

The number of fish for each tank will be 60. This choice was made not to put too much stress on the fish, given that for each m3 of water there should be a ceiling of 30kg.

3.2 Fish and plants production

The plant species and the type of fish (which have been chosen previously) are Oreochromis nicotilus (Nile Tilapia) and tomato
After building the structure the production cycle can begin.
Inside the system, firstly, juveniles of about 50 grams will be inserted inside the system since the longest part of the growth is that of the first phase of life.
The same process will be repeated for the further 8 tanks every 21 days in order to have the first production after 6 months.
To calculate fish production it is necessary to consider the water quality:(See Kaf 3)
Considering that the only values that are not within the optimal range of growth of tilapia are dissolved oxygen,, the pH and the Dissolved oxygen (see Kaf 3),, and that that these elements can be managed thanks to an aerator and calcium carbonates ($CaCO_3$), the production of Tilapia is optimal. Based on Sommerville et. As of 2014, tilapia should weigh approximately 500g after approximately 500g after 6 months in simple small-sized plants

As for the production of plants, this subdivision will be made for simplicity and we will only have a production of tomatoes because it is a species already present locally and well adaptable to aquaponics As for the production of plants,, thanks to the roof covering which mitigates solar radiation and the PVC cover that allows you to control the internal environment (the temperature and the possible pests) for intake, we consider an optimal production for tomatoes throughout the year.

The following procedure was used to define the crop production data:

The calculation of the square meters of plants was carried out using this datum by Sommerville et, Al. 2014

Leafy green plants	Fruiting vegetables
40–50 g of fish feed per square metre per day	50–80 g of fish feed per square metre per day

Considering that once in operation the system should produce approximately 270kg of food every six months, thus having an average growth of 1.436 kg per day and a feed ratio of 1.4 (Sommerville et. Al 2014) we should provide approximately 2 kg of mangime per day.

This implies the construction of 33.5m3 of culture beds considering the data of 60g of fish to to feed per square meter (since were are using a Fruiting vegetables)

Instead the tomatoes will be grown 12 months a year and since since a cycle lasts x,, you can put 5 plants per m2 and produce 3 kg per month per square meter (Sommerville et.Al, 2014)

So the total production will be 1206 kg.

4) Solar energy system

Since the project was designed for a village, the construction of a solar system to operate the aquaponic was conceived. Very similar systems have already been implemented in other countries such as Botswana (Agrotec, 2013).

In addition, this type of technology removes the greater weight of population management costs that could cause the plant to fail

The solar energy system will therefore have this configuration:

1) Daily energy requirement: 137W*24h (water pump) + 35W*24h (aerator)= 4,128 Wh
2) Solar panels= daily energy requirement/ average daily sun hours= 4,129/10.1= 408.8W
3) Battery bank= 4,128/24*2= 344 Ah

Six 120Ah 12v batteries connected in series will bring a360Ah 36v. Indeed, because of Lead-acid battery usable capacity is only 50% of full capacity.

5) Over time management system

The system will be managed within the community by three women who will be in charge of 3 tanks each. This is because the system was designed for 3 women who have 3 young children each.

Since, Senoufo women often work the fields in groups, this division of labor is actually only theoretical. Once the system has been put into operation, women should be able to better manage the system among themselves thanks to their cultural disposition.

4.4 Cost analysis

1) Fixed costs

The following tables show the fixed costs of building the plant. They also included the transportation cost for those items that cannot be found in the area

Item	Qty.	Unit	Price per unit	Total Cost	Note
			EUR	EUR	

Fish tanks (9 Units

Alluminium structure	9		95	855	
Cement	6	sack	5	30	60 kg per sack
Sand	1	m^3	10	10	
Heat-sealedPVC tarpulin sheet	9	sheet	15	135	6 x 12 m
Aerator	1	piece	70	70	
Air stones	9	piece	45	405	
Air tubes	1	roll	75	75	Length: 200 m

Total 1580

MFB (16 units)

Acacia wood	64	piece	6,50		1) 32 of 1,2*0,3m 2) 32 of 1,4*o,3m length:6-8 m
Rope	25m	roll	0.2		

Tarpaulin sheet	6	sheet	15		
Gravel	5000	l	0.15 per litro		1-2 cm in size

Total 1262

Sump					
Bricks	450	piece	0,2	90	
Cement	1	sack	5	5	
Sand	1	m^3	18	18	
Tarpaulin sheet	1	sheet	15	15	

Total 128

Plumbing and irrigation					
Water pump	1	unit	126	126	Max capacity: Submersible Electric Water Pump 6000l / H 370w 230v

PVC pipe 4”	1	piece	45	45	Length: 6 m each
PVC pipe 3”	17	piece	23	391	
PVC pipe 1”	2	piece	6	12	
Elbows, connectors, valves, etc.	150	piece	0,5	75	Average price of different elements
Total 649				**3618**	
Final Total					
Shade structure					
Acacia wood	4	Piece	52	204	0,5*0,5*3m
UV Plastic roof	175	sheet	6	1050	
Total 1204					

Activity	No. of workers	Duration (days)	Per hour	Range of total wage	
			EUR		EUR
FT, MFB and sump construction	4	10		3	960
Roof structure	3	5		3	360
Solar power system	2	3		5	240
Total	**1540**				
Averaged total					

Item	Qty	EUR per unit	EUR total	Note
Solar panels	9	150	1350	100w
Charge	1	30	30	200W
Controller	1	15	15	
Battery deep cycle	6	300	1800	12V 120Ah
Inverter	1	45	45	

NYM cables	2	55	55
Total			3285

Table 15: Cost of aquaponic plant

Source (Tosco solution enterprise)

According to calculations , the construction of the aquaponic system will cost 9648€. The most expensive component results to be solar panels (3248€) that corresponds to 33,6% of the total cost.

Despite being expensive and having a huge impact on the plant costs, the solar system has to be built because the village of Kafiokaha does not have a safe source of energy. Because of that, the whole aquaponic plant could fail really quickly so it is necessary to do this expenditure.

The second most expensive items result to be the fish tank with 1580€, which corresponds to 16,4 % of the total costs.

Following that, starting from the bigger to the smaller we have labor cost, MFB, Roof structure water pump and sump which correspond respectively to 16%, 13,3%, 12,5%, 6,7% and 1,3%.

2) Operational costs

Fortunately, the system requires very low management costs, in fact the greatest cost is represented by energy, but thanks to the use of solar panels, there is no need to spend money on this resource.

First of all, the plant must be started so it will be necessary to replenish the first tank of fingerlings and to buy the tomato seeds.

Fish and plants					
Nile tilapia	360	fish	0.15	54	6-8 cm
Tomato seeds	1	pack	15	15	Approximately 1,750 seeds
Total				**69**	

Table 16. Starting costs

So after this small initial expense of just 69 euros, considering also that there is a supply of well water which the locals don’t have to pay for, the only costs will be those related to fingerlings and fish feed.

The costs after the plant will be operating are the following (every year).

Item	Qty.	Unit	EUR per unit	Total EUR
Fish pellet	720	kg	1.20	864
Fingerlings	720	num	0.15	108
Total				972

Table 17. Operational costs

The annual costs for maintaining the plant will therefore be 972Eur, of which 864Eur for fish pellets and 108Eur for fingerlings .

4.5 Nutrition improvement analysis

In the analysis of integrated nutrients it must be considered that some nutrients are more important than others in some specific ages or in the case of pregnant or breastfeeding women.

Therefore, only women under these specific conditions and children under 2 years of age will be considered in this analysis.

The amount of food the system supplies can be summarized as follows

1) Monthly fish production: 60kg

2) Available fish grams per days 64g (the calculation was obtained in this way 540/12/365 * 0.516 which would be the quantity of flesh of the fish on the total weight Begum et. Al, 2005)

3) Estimated monthly production tomato 81kg (Considering 3kg per m2 of tomato production every month (Sommerville et. Al, 2014)

4) Available tomato per day: 275g

Nutrient	Per 100 g raw		Daily Production per person			Recommended Daily Intake	
	Oreochromis niloticus	Tomato	*Oreochromis niloticus*	Tomato	Total	Infants 0-24 months	Pregnant/ Breastfeeding
Energy (kcal)	129	18	82.56	49.5	132.06	464-948 kcal	(+) 85-475 (+) 460-675
Protein (g)	19.9	0.88 g	12.74	2.42	15.16	4.90-11.20 [1]	50.80-80.80
Minerals							
Iron (mg)	1.61	2,7	0.71	7.425	8.135	5.80-9.30	15
Calcium (mg)	30.5	10	22,82	27.5	50.32	300-500	1,000-1,200
Zinc (mg)	0.5	0.17	0.32	0.4675	0.7875	2.80-4.10	5.50-10.00
Phosphorus	160	25	1.41	68.75	70.16	0.1-0.2	310-350
Magnesium	60	15	102.4	41.25	143.65	0.1-0.2	900
Vitamins							
Vitamin A (RAE) (µg)	0	42	0	115.5	115.5	375-400	800-850
Pyridoxine (B6) (mg)	1	0.08	0.64	0.22	0.93	0.10-0.50	1.90-2.00
Vitamin C (mg)	1.60	13.70	1.43	37.675	39.105	25-30	55-70
Vitamin D (µg)	31	0.00	19.84	0.00	19.84	5.00	5.00

Table 18. Nutritional requirements of 0-2 infants and pregnant/breastfeeding.

Nutrient	Fulfillment (%) of Nutrition Daily Recommended Intake from the Average Daily AP Production			
	Infants 0-24 months		Pregnant/lactating	
	Min	Max	Min	Max
Energy (kcal)	13.9%	28.2%	3.6%	6.3%
Protein (g)	135.3%	309.3%	18.8%	29.8%
Minerals				
Iron (mg)	87.4%	140.5%	54.2%	54,2%
Calcium (mg)	10.1%	16.7%	4.2%	5%
Zinc (mg)	19.2%	28.1%	7.9%	14.3%
Phosphorus	35080%	70160%	20%	22,6%
Magnesium	71800%	143600%	16%	16%
Vitamins				
Vitamin A (RAE) (µg)	13.6%	14.4%	13.6%	14.4%
Thiamin (B1) (mg)	186%	930%	46.5%	48,9%
Vitamine C (mg)	130%	156.3%	55.9%	71.1%
Vitamine D (µg)	397%	397%	397%	397%

Table 19. Nutrients provided by the system.

It is important to underline that this type of system was not designed to completely replace any other food supply so it is normal that there are some nutritional area which are not covered enough.
The main thing to note is that thanks to this system, children would cover their protein needs (unfortunately, it is not enough for women where the percentage will be 18,8% and 28,8%).

Additionally, It is also important to consider that the quality of these proteins.
In fact, tilapia is also rich of vitamins and amino acids.
In this regard, it can be noted that the amount of fish supplied daily to the children meets all their requirements in vitamin b1,C and D, phosphorus magnesium, and iron.
Instead, the other nutrients are not adequately supplied and must be integrated with other foods source.
For women, however, the situation is different.
As a matter of fact, the quantity of fish supplied is not sufficient on its own to supply the complete requirement of the amino acids and vitamins examined (except for vitamin D)
However, vitamins B and C are supplied at a high percentage.
Finally, although the presence of magnesium and phosphorus does not reach very high percentages, it can be seen that this fish is a good source of these substances.

5 Discussions and conclusion

Before the conclusion of the thesis it is still necessary to underline some aspects.

1) Chosen Location
The parameters behind the choice of the location can be contested. The reason lies in the fact that it was decided to give the female population a great deal of weight since it is the target of the project together with the children. However, this parameter can have some shortcomings in the sense that it is not possible to establish whether in an area with a higher percentage of women, the percentage of children is proportionally high, and, moreover, it could be possible that people suffering more from malnutrition live in other areas.

2) Climatic aspects
The analysis of the climatic aspects has not been estimated in detail but it is hypothesized that the system works in an optimal way given that the temperatures will be driven through a cover.

3) System design
The system was designed based on the literature as we did not have the opportunity to make an inspection; therefore, it could be changed in the event of adverse topographical conditions or a social structure different from the one which has been assumed.

4) Cost analysis
It is based on previous literature trying to adapt costs to the Cote d' Ivoire. So there may be some calculation errors. Furthermore, it can be noted that the cost of the plant (thought over a period of 20 years) is greater than the total amount of money saved if the population bought tomatoes and tilapia locally. Indeed, tomato cost 0,93eur per kilo and Tilapia 1,25 eur per kilo.
Therefore, considering annual production the monetary value of the production is 1795eur. Since the annual costs are 972 eur, the economical value of the yearly production is 803 eur.
With a life span of approximately 15 years the system will have the value of 12045eur the system will have 2328 eur of positiive income. Hovewer, in this calculation is not been calculated the labor cost and the possible special intervention of maintainance.
For these reason, the margin is too low to be considered a good investment from an economic point of view.

5) Nutritional improvement
Nutritional improvement relies on the fact that production runs smoothly and that the locals are willing to feed on what is produced. This is not always the case since local people often prefer to eat other sources of food such as rice.

6) Absence of Social acceptance of technology
Before starting any project in developing countries, it is necessary to understand if the population will welcome the technology
A large number of projects in Africa have failed precisely for this reason.
Therefore before implementing the project you have to be sure that the population wants it and will be necessary assess it through a survey.

Hence, it is possible to affirm that Aquaponics is a system that can improve people nutrition, especially for children in developing countries but it still presents several implementation difficulties and requires long analyzes before being implemented.

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