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Challenges of Commercial Aquaponics in Europe: Beyond the Hype

Maja Turnsek [1,*], Agnes Joly [2], Ragnheidur Thorarinsdottir [3] and Ranka Junge [4]

1 Faculty of Tourism, University of Maribor, Cesta prvih borcev 36, SI-8250 Brežice, Slovenia
2 AQUAPRIMEUR SARL, rue de la Mer, 14550 Blainville-sur-Orne, France; aj@aquaprimeur.fr
3 Faculty of Civil and Environmental Engineering, University of Iceland, Taeknigardur, Dunhagi 5, 107 Reykjavik, Iceland; rith@hi.is
4 Institute for Natural Resource Sciences, ZHAW Zurich University of Applied Sciences, CH-8820 Waedenswil, Switzerland; ranka.junge@zhaw.ch
* Correspondence: maja.turnsek@um.si

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Abstract: In recent years, aquaponics has been receiving increased interest globally as a commercial food production technology and aquaponics start-up companies have been formed in most European countries. Between 2014 and 2018, the European-funded COST Action FA1305 "The EU Aquaponics Hub-Realising Sustainable Integrated Fish and Vegetable Production for the EU" created a strong network of researchers and entrepreneurs. However, surveys show that the aquaponic production in Europe is still very limited, and very few companies are economically viable. In order to obtain insights into the barriers to early development of commercial aquaponics, two surveys were carried out—one in Europe, which included France, and one in France alone, with a different protocol. Henceforth, for simplicity, the former will be referred to as Europe and the latter as France. The results reveal that the development of commercial aquaponics has hit the level of "disillusionment", caused by numerous challenges facing commercial food production. As the understanding of the processes involved in aquaponics is increasing, it will be very interesting to follow the developments in the field over the coming years in order to ascertain whether aquaponics will follow the phases outlined by the "Gartner's Hype Cycle" and thus proceed to become an established technology, or whether it will remain an "one hit wonder" and disappear in the "Trough of Disillusionment".

Keywords: aquaponics; innovation adoption; Gartner's Hype Cycle

1. Introduction

1.1. Adopting Commercial Aquaponics: Mere Hype or Hype Cycle?

Modern aquaponics emerged simultaneously with recirculating aquaculture technology in the 1970s [1,2]. Many backyard systems and farms producing both fish and vegetables have emerged in the last decade in Australia and the United States [3]. At the same time, the first commercial farms started operation too [4].

The first wave of research on economic aspects of aquaponics started in the USA. It focused on evaluation and development of specific, mostly research institutes-led case studies with a very optimistic outlook for the future [5–7]. Similarly, the first marketing reports were highly favourable, predicting the growth of the industry to $906.9 m by 2021 [8]. In Europe, aquaponics has developed at a slower rate, largely within research institutes and to a large extent with public funding [9]. Aquaponic systems of different sizes, designs, and purposes have been constructed in most European countries [10–12]. These prototypes range from classroom to backyard farm systems and to a few

full-scale farms. However, only very few of them reach a production area of more than 100 square meters [12]. With increased research and development in the field in recent years, the trend has been toward larger and more technically-evolved systems, although the largest ones are still very small compared to conventional aquaculture and horticulture farms.

From 2014–2018, the development of aquaponics in Europe was further stimulated by the European-funded COST Action FA1305 "the EU Aquaponics Hub" [13], forming a network linking research and small and medium-sized enterprises (SMEs) across Europe. Aquaponics reached the interest of European policy makers, and the European Parliament Research Services elected aquaponics as one of the "ten technologies which could change our lives" [14]. Moreover, several European cities started looking for sustainable methods and ideas for urban farming, and are increasingly interested in aquaponics as a solution, e.g., the Climate-KIC (2019) competition on Urban Food from Residual Heat and the Reinventing Cities Competition C40 (2018), to drive carbon neutral and resilient urban regeneration.

Recent research in the USA [3,15] revealed a more critical state of the industry than previously envisaged. The USA census of 2012 reported 71 aquaponic farms, which represented 2% of all aquaculture farms [15]. Of these, only 11% had sales of $50,000 or more, compared to 60% of pond-based aquaculture operations that had sales of $50,000 or more. Love et al. [3] surveyed mainly US-based participants (n = 257), who, in the previous 12 months, had sold aquaponics-related food or non-food products and services. The results showed that the average size of production site was very low, compared to traditional hydroponic and aquaculture farms.

Whilst the survey of Love et al. [3] focused on Australia and United States, Villarroel et al. [11] performed a similar survey focusing on Europe. Of 68 participants, 51% were universities or vocational schools, followed by commercial (19%), and non-profit organisations (15%). Thorarinsdottir et al. [12] identified 10 pilot aquaponic systems in Europe, approximately half of which were at the stage of setting up first systems for commercial production. Villarroel et al. [11] estimated that there were about 20 commercial aquaponic enterprises in Europe. Three years later, Villarroel [16] identified 52 research organisations (universities, vocational schools, research institutes) and 45 commercial enterprises in Europe working on aquaponics. The latter offer a range of services—from large-scale food production, developing IT support, selling aquarium sized systems, to education and consultancy. In 2016, as a spin-off from the COST FA1305, the Association of Commercial Aquaponics Companies [17] was founded, currently involving 30 companies from 14 European countries, only about a third of which focuses on food production. Others offer mostly aquaponics-related services such as engineering and consulting.

We hypothesize that the development of aquaponics might be following the so-called "Gartner's Hype Cycle" of innovation adoption, a combination of two theories on innovation adoption: Hype Curve and Technology S-Curves [18]. Gartner's Hype Cycle is one of the most prominent and influential consultant models for advising large companies on their technology strategy [18].

Gartner's Hype Cycle, introduced in 1995, is a theory of how innovations are adopted. It claims that emerging technology progresses from overenthusiasm (hype) through a period of disillusionment to an eventual understanding of the technology's relevance and role in a market or domain. According to this theory, the first part of the hype curve is driven by "vacuous hype"—mainly by the media, which speculates on the technology's prospects. The second part of the hype curve is supposed to be driven by performance gains and adoption growth [18,19] (Figure 1).

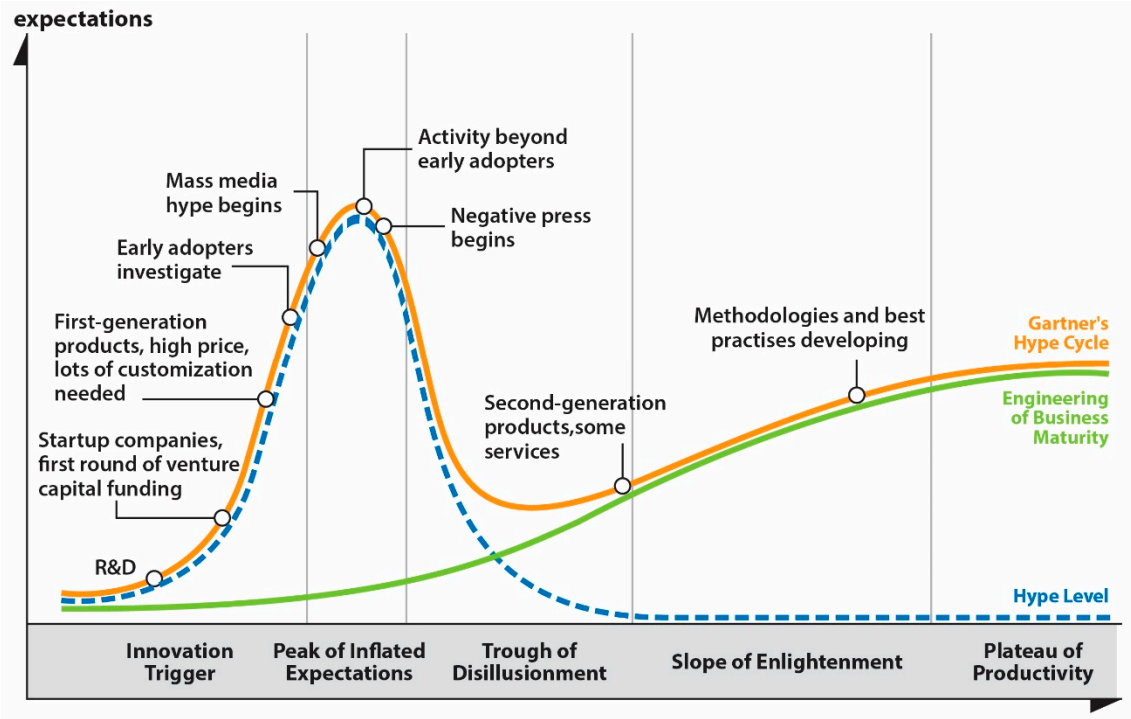

Figure 1. Gartner's Hype Cycle curve and the two curves it combines: Hype Level curve and Engineering of Business Maturity Technology S-Curve (adopted from [18]).

As Steinert & Leifert [18] warn, the analysis of Gartner's life cycle needs to consider rigorous methodology, which was not the focus of the current research, but will have to be left for future research. One of the problems with the Gartner's Hype Cycle is that it is not quite clear how to measure "hype". One possibility was suggested by Junge et al. [20], where the hype ratio was defined as an indicator of the popularity of a subject in the public media in comparison with academic circles and calculated as search results in Google divided by search results in Google Scholar at a certain point in time.

Another possibility is to consult the Google Trend analysis (Figure 2), which shows that from 2004 on, at least in the English-speaking world, the term "aquaponics" reached the highest level of interest in 2012 and then showed a "trough of disillusionment" that currently seems to be continuing downwards. Optimists may argue that the development of aquaponics will progress in the future to follow the Gartner's Hype Cycle towards a "slope of enlightenment" and establish itself as mature technology. As Linden & Fenn [19] point out, the important lesson from Gartner's Hype Cycle theory is twofold. First, enterprises should not invest in technologies just because the technologies are being hyped, and second, enterprises also should not ignore technologies just because the technologies are not currently living up to early, inflated expectations. Pessimists, however, may argue that aquaponics in the future will not follow the "hype cycle" development, but was merely "vacuous hype", with small chances of further development.

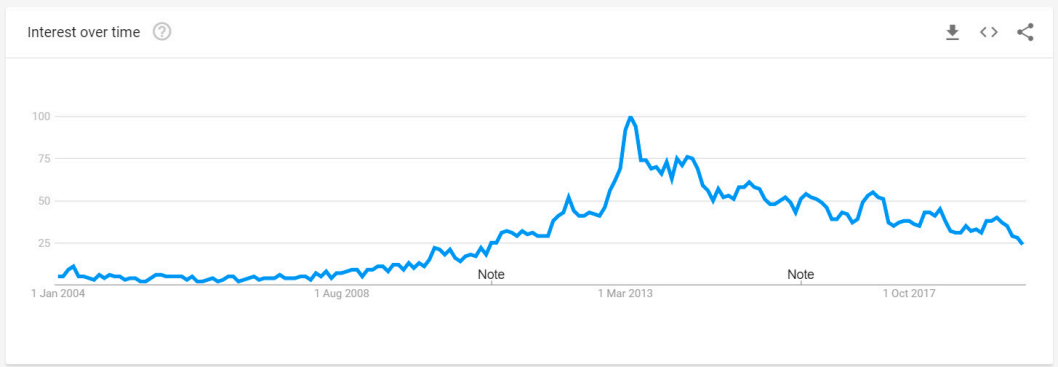

Figure 2. Google Trends for the term "aquaponics" (accessed on 7 August 2019) [21].

An important difficulty of analysing the aquaponics adoption innovation cycle is its nature as a long-term process. Only after the cycle has been fully carried out can it be analysed. But before that, multiple "snapshot" investigations that show the state of the art at the given point in time need to be collected. If we have witnessed or are indeed still witnessing a period of hype in aquaponics, it is important to learn what the "inflated expectations", as termed in Gartner's Hype Cycle, were. Turnšek et al. [22] refer to so-called "myths" of aquaponics. These are statements about extreme profitability of aquaponics based on untested claims of the economic superiority of aquaponics in terms of output, growth time, and diversification possibilities in a commercial setting, such as "Aquaponics uses 90% less land and water than agriculture but has the potential to generate 3 to 4 times more food than the latter". As Turnšek et al. [22] point out, statements like these are an exaggeration since they lack a clear reference unit of comparison.

Although the recent surveys provided information on number, type, and technological aspects of aquaponic commercial facilities [3,4,11,23], little is currently known about the state of attitudes towards aquaponics and expectations from aquaponics. Indications exist that it is primarily the promise of sustainability of aquaponics that attracts the early adopters of commercial aquaponics. In a survey conducted by Villarroel et al. [11] most respondents agreed or strongly agreed that aquaponics improves the sustainability of food production (96%) and decreases the effects of climate change (68% agreed or strongly agreed). Yet little is known about what "inflated expectations" the early adopters have with respect to the current state and the future of aquaponics. Similarly, there is a dearth of information about the recruitment rate from the pool of "enthusiasts" to actual start-up of commercial aquaponics. This study fills this gap in research.

1.2. Purpose of Our Study

The purpose of the study was to quantify the experience and expectations of aquaponics entrepreneurs, and to evaluate the status, obstacles, and expected future development of the commercialisation of aquaponics in Europe. The objective was to contact the early adopters of commercial aquaponics, either individuals or organisations, in order to ascertain the status of their plans after the initial years of planning an aquaponics business. Earlier studies on commercial aquaponics include information only on participants who have made the necessary steps in the process from initial enthusiasm to project realisation [3,11,12].

The aim was to ascertain the initial motivation of early adopters, their main sources of information, reasons to either continue or abandon their start-up plans, what obstacles they encountered, what they need to facilitate their endeavours, and what are their plans for the future. Two surveys were carried out, one in France, and one in Europe, focusing on the start-up of aquaponics businesses and the successes and difficulties that they encounter.

The results could support start-up candidates and inform them about the difficulties they might encounter. Moreover, they could also assist policy makers by informing their actions regarding

aquaponic entrepreneurship. Finally, the results provide an important snapshot of the European aquaponics within its long-term process of adoption.

2. Materials and Methods

The survey in France was based on a contact list of early enthusiasts compiled by Agnès Joly, representative of France in the Management Committee of the EU aquaponic Hub [23]. Early in 2014 she installed the first aquaponic demonstrator in Paris, open to the public. Between 2014 and 2016, over 250 persons contacted her with inquiries about aquaponics. Hundred and three contacts were selected for the survey because they were considering investing their time and/or money in a commercial project. Of these, 43 persons (42%) were willing to participate in the study. The survey was conducted in February–March 2017 using an online questionnaire combined with a telephone interview.

Based on experiences from the French study, the second phase of the research was to interview early adopters of commercial aquaponics elsewhere in Europe. The questionnaire was improved based on the French data and the European survey was distributed online in 2017, using the snowball sampling method via the network of the members of COST Action FA1305 [13] and aquaponic national associations. The questionnaire was answered by 60 participants (3 from France which were not the same as the participants in the French study). The exact participation rate cannot be evaluated, as the questionnaire was very widely distributed and there was no way to monitor this distribution. Nevertheless, based on previous studies [11,12], it can be estimated that more than 50% of all commercial aquaponics start-ups in Europe in 2017 were included.

It is important to note that the survey addressed only participants who either are, or were, involved in aquaponics as a commercial activity and excluded all others such as non-governmental organisations (NGOs), educational organisations, and backyard systems that never intended to develop into an entrepreneurial activity, but did include those who claimed that this was one of the potentials they hoped for while starting a system.

Using the SPSS software, the data were analysed separately for each sample and compared. In cases where there were multiple answers were possible, the sum of percentages of answers can exceed 100%.

It is also important to highlight that in France, interviews were conducted on the telephone. Therefore, all questions were answered, some in more depth than the online questionnaire. In the second survey, no personal interviews were conducted, and 14 respondents did not answer all the questions. The difference in sampling of the two populations also explains some of the differences in results. In France, people who had queries about commercial aquaponics some 2 or 3 years earlier were contacted. Many of them were still at the very early stage of their experience with aquaponics. This sample was valuable, since it allowed us to have close insight into the process of adoption—from the first queries to the creation of the business idea. We were thus interested in the question of how many of those who inquired about commercial aquaponics actually did transform the idea into business and what the reasons are for doing so or deciding not to.

Since, as far as we know, no similar list of contacts exists in other countries of Europe, we contacted the aquaponics enthusiasts through European Aquaponics Hub COST network, which resulted in a sample of people at a further progression of their aquaponics plans. In that respect, the two samples differ primarily in terms of the stage at which the participants are with their aquaponics plans.

3. Results and Discussion

3.1. Demographics, Background, and Organisation

The European survey reached 60 respondents from 24 European countries, with mostly one to 3 representatives per country. In terms of regions (using UN statistical categorisation), Southern Europe and Western Europe predominate over Northern and Eastern Europe. The French survey included 43 respondents from all French regions (Table 1). In terms of gender, both samples included significantly more males than females, confirming that aquaponics seems to be a male-dominated field [3,11]. In

contrast, this study reports higher percentage of younger aquaponists, thus showing a "younger" picture than the previous study [11].

Table 1. Demographic characteristics of participants, education and background, years of familiarity with aquaponics, and team size.

Characteristic	European Study (N [1] = 60)	French Study (N = 43)
	%	%
Country-European Regions [2]		
Eastern Europe	7	0
Northern Europe	12	0
Southern Europe	30	0
Western Europe	26	100
Not specified	25	0
Gender		
Male	63	77
Female	13	23
Not specified	27	0
Age (years)		
23–30	32	37
31–50	40	51
50–65	13	12
Not specified	22	0
Year when the respondents first started considering aquaponics		
1990–2000	7	9
2001–2010	17	19
2011–2017	78	70
Education		
Graduate degree or above	60	67
Vocational college diploma	5	16
High school or lower	5	7
Other or not specified	30	9
Background in terms of field of education and/or experience		
Aquaculture	15	26
Natural sciences /technology other than aquaculture	13	14
Social sciences and business	7	30
Other	17	30
Not specified	22	0
How many people (even part time) have been involved in your project/idea, including yourself? [3]		
1	3	53
2–3	28	26
4–8	23	21
9–75	22	0
Other or not specified	23	0

[1]: N denotes the size of the sample. [2]: The European regions are defined according to United Nations geoscheme for Europe [24]. [3]: The independent sample T-test shows significant difference between the two samples (F = 9.343; Sig = 0.003).

As in survey of Love et al. [3], most of the participants first started to consider aquaponics only after 2010, with no major difference between the two samples. Most participants were highly educated,

with 60% of the European sample and 67% of the French sample having a graduate degree or above. In the survey by Love et al. [3], just over a quarter of respondents (27%) had a graduate degree. Even taking into account the snowballing sampling technique via the research-based European COST aquaponics network, the European sample still shows a very high level of education of participants in comparison to the USA sample.

Most of participants in both the European and the French survey had a background in aquaculture, the same percentage in both surveys had a background in natural sciences, engineering, specifically software engineering, or biotechnology, but surprisingly none reported a background in horticulture. In the French survey, 30% of respondents had a business or social sciences background, whereas this group formed only a minor fraction of the European respondents. The dominance of aquaculture versus horticulture background might be originating from the fact that aquaculture perceives problems where aquaponics can be a solution, while horticulture does not. The treatment of nutrient-rich fish sludge is an important environmental problem for aquaculture, and aquaponics is a potential solution to that. On the other hand, hydroponic horticulture does not perceive the issue of plant nutrients availability/sustainability (where aquaponics is a potential solution) as a central problem since nutrients can be easily supplemented in hors-sol cultures, and pests and fungal diseases pose the more pertinent problems. The predominant involvement of aquaculture specialists correlates with a perceived lack of horticultural knowledge identified by Villarroel et al. [11], who reported that the lowest level of self-reported knowledge amongst European aquaponists was knowledge of how to eliminate plant pests: 40%, in contrast to 64% who reported they think they know how to deal with fish diseases.

The two samples were analysed for differences using an independent sample t-test. The only area where they were statistically different was the number of people involved in the team ($F = 9.343$; $Sig = 0.003$). In the European sample, 22% projects included more than 9 persons. It can be surmised that this trend towards larger team size was caused by the inclusion of research institutes and universities in the sample, and that this does not realistically reflect the start-up reality. Yet, when excluding the latter and keeping only participants involved in companies or not involved in any formal type of organisation, the most common size of the European entrepreneurs' team seems to be two people and only one in France, with the European mean team size higher than in France (Table 1). As the two samples differed primarily in terms of the stage at which the participants are with their aquaponics plans, the European being more advanced, the larger team size probably reflects this development.

A difference between the European and French results was again reflected in the type of organisation that participants were involved with (Figure 3). The French sample was composed almost exclusively of participants who were either owners of farming or aquaculture companies or were not involved in any type of an organisation but were still considering the ideas as individuals. The European sample, on the other hand, included mostly spin-offs from universities or research institutes, company owners or employees, and fewer individuals.

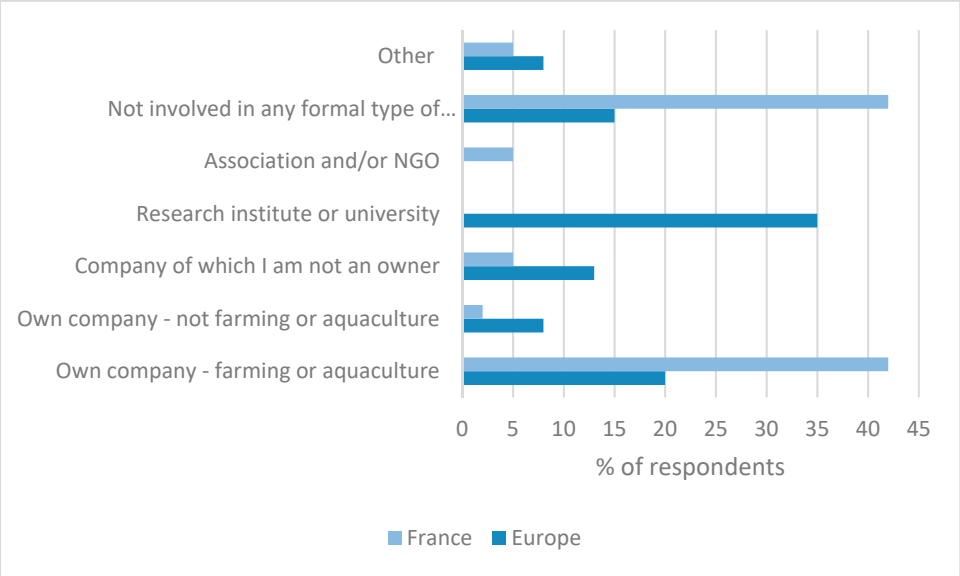

Figure 3. Answers to the question: What type of an organisation have you been in or still are involved in when planning or considering aquaponics as a potential business idea or a social/community project? One or more answers were selected.

3.2. Type of Funding and Revenues

Funding sources were very different comparing European and French samples (Table 2). While over one-third of the private (non-public) European projects benefitted from international or national grants, only very few private French projects did. Also, the number of aquaponics projects with no external funding at all was extremely low (3%) in the European sample, while it was 67% in the French sample. Based on these numbers it can be concluded that the majority of French early enthusiasts invested private time and money.

Table 2. Answers to the question: Could you please share with us more detail about the source of revenue for your aquaponics activity?

Sources of Funding and Revenues	European Study		European Study (Universities Excluded)		French Study	
	N [1]	% [2]	N [1]	% [2]	N [1]	% [2]
National public grants	16	27	8	11	1	2
International public grants	8	13	6	8	1	2
Private investment	25	42	18	24	14	33
Food products sales	15	25	12	16	4	9
Sales or design of aquaponic systems	20	33	16	21	9	21
Courses, visits, consulting	16	27	13	17	5	12
Other or none	3	5	2	3	29	67

[1]: N denotes the size of the sample. [2]: Where several answers were possible, the % do not add up to 100.

The most common source of funding were external private investments: 42% in the European sample and 33% in the French sample (Figure 3). The aquaponics funding relies heavily on the aquaponics enthusiasm, with some companies raising tens of millions of euros. If the universities are excluded from the European sample (Table 3), the samples become more similar in regard to sources of funding.

Table 3. Rationale, initial objectives, and initial drivers for aquaponics activity.

Aspect	European Study		French Study	
	n	% [3]	n	% [3]
Why did you choose aquaponics over other available techniques? (several answers possible):				
More sustainable and/or environmentally friendly in terms of saving resources	41	68	32	74
Having a higher economic potential	13	22	23	53
Having better social applications (e.g., applicable to working with disabled, unemployed, marginalised people)	16	27	9	21
Having better community applications (e.g., creating community farms)	14	23	/ [2]	
Allowing healthier products	27	45	12 [1]	29
Allowing fresher products	24	40	12 [1]	29
Allowing more local production	32	53	12 [1]	29
More modern and applying contemporary technologies	25	42	/ [2]	
More fun	11	18	/ [2]	
Other	9	15	1	2
What was the objective of your planned project at the start (several answers possible)?				
Commercial production of fish and vegetables	30	50	34	79
Systems design and set-up, consulting business demonstration	34	57	3	7
Pedagogic or demonstration goals, consulting	27	45	12	28
Social/community enterprise	14	23	1	2
Some family consumption	10	17	8	19
Personal development and/or socialising with others	14	23	3	7
Other	4	7	/ [2]	/ [2]
Not specified	6	10	2	5
At the time you started planning your aquaponics project, what were your intentions?				
Project without an income from the aquaponics (other funding source)	8	13	8	19
Project providing some income from aquaponics	19	32	20	47
Project providing entire (or main) income from aquaponics	22	37	15	35
Other	5	8	0	0
Not specified	6	10	0	0

[1]: In the French study, the three questions of the quality of produce were under the same wording: "quality of produce"; [2]: In the French study, these answers were not yet added to the survey. This was amended in the European study; [3]:Where several answers were possible, the % do not add up to 100.

However, sales revenues were very different between the European and the French sample. While most European projects do sell something from their aquaponics activity, French aquaponics projects hardly do, scoring less than half the European scores in all types of sales (Table 3). This illustrates again the less advanced stage of the process of the aquaponics adoption cycle in France at the time of the survey.

Selling food products comes in the last place of sales income source. Only a quarter of the participants in the European sample and not even a tenth of the French sample reported revenue from selling the produce. The most common source of income was selling knowledge of aquaponics: system design, courses, visits, and consulting comprised 72% of the European and 33% of the French sample. This high interest in domestic devices, family systems, and knowhow, and the fact they rarely progress beyond this level, illustrates the enthusiasm of hobby users in Europe while being indicative of and reflecting the numerous challenges associated with commercial aquaponics. According to Joly [23], several entrepreneurs who wanted to start as aquaponics farmers changed their business plan to selling small, aquarium-sized systems, and family greenhouse systems.

3.3. Initial Drivers and Intentions

Environmental considerations were the most common reason for choosing aquaponics over other production technologies in both samples. The perceived high quality of produce was also a strong driver for both samples (Table 4).

Table 4. Answers from the European survey (N = 60) to the questions about attitudes about aquaponics. Respondents marked the level of their agreement with each of the statements, whereby 1 means "strongly disagree" and 5 means "strongly agree".

Attitudes	1	2	3	4	5	Average Answer (Weighed Mean)	Std. Deviation
"Inflatedness" of Perception of the Current State of Aquaponics	**(in % of All Answers)**						
Lower cultivation costs in aquaponics with substantially higher yields equals more net returns.	13	11	17	32	23	3.4	1.3
Aquaponic produce grows in half the time of conventional means.	21	15	23	19	15	2.9	1.4
Aquaponics has all the great points of traditional gardening, without all the back-breaking toil necessary to bring in a great harvest.	13	19	23	17	28	3.3	1.4
Optimism for the future of aquaponics							
Aquaponics has a key role to play in food provision and tackling global challenges such as food security.	2	11	13	23	47	4.1	1.1
Aquaponics will develop competitive commercial systems delivering cost effective food production.	2	11	30	26	23	3.6	1.4
Aquaponics is the answer of the future to water scarcity.	4	13	30	11	34	3.6	1.3
Aquaponic farms will prove to be economically sustainable in the future.	0	0	26	19	49	4.3	0.9

The perception of economic potential of aquaponics was very different for both samples: 53% of the French, but only 22% of European respondents selected aquaponics because of its higher economic potential compared to other agricultural techniques (Table 5). However, when both populations were questioned about their revenue expectations, proportions were similar (Table 4). It has to be noted that 17% of respondents in the European sample did not answer, thus impeding comparisons with the French sample where the direct interview facilitated the answering of all questions.

Table 5. Status of the project and reasons for abandonment.

Aspect	European Study (N = 60)		French Study (N = 43)	
	n	%	n	%
Status of the project				
The aquaponics project was planned but never started	7	12	15	35
The aquaponics project has been or is currently being planned and is on hold, or under study	7	12	15	35
The aquaponic facility/farm is under construction	4	7	4	9
You are involved in an aquaponics activity without having to create revenue (such as research)	19	32	0	0
You are involved in an aquaponics activity which creates a revenue	14	23	9	21
You have started an aquaponics project but abandoned it later	4	7	0	0
Other or not specified	5	8	0	0
If abandoned: To what degree did you abandon your aquaponics project (only one answer)?				
Continue with the project, but without aquaponics	1	2	2	5
Continue with aquaponics but without an economic goal	3	5	1	2
Abandoned it all: project and aquaponics	7	12	11	26
If abandoned: Could you please share with us a few words on why you have abandoned your aquaponics project/idea?				
European sample:				
We have set up a 400 m^2 commercial system. Have been selling fresh cut herbs for two seasons. Found it was not economically viable due to too high labour costs and too high plant disease risks.				
Mostly lack of funds—no access to courses/conferences, no-one in local area practicing to learn from/no response from them.				
Lack of finance and time.				
Not feasible.				
At the time aquaponics did not attract investors, due to high risk investment.				
No proper space, high initial costs, high maintenance.				
Moving house, kids.				
French sample (comments of the interviewer):				
The partner was unemployed, the project was difficult to launch; the partner went back to a normal job				
Planned to do it with a farmer, but he retreated and she stopped				
Couple broke up and both stopped				
Too many obstacles: regulations, finance … he went for family production only				
Too many obstacles, he changed for insect farming				

The third question in Table 3 shows again a distinction between both populations: 79% of French respondents had the initial objective of a commercial production of fresh produce versus 50% only for the European. Social activities rank as one of central objectives in the European sample, but not in the French. These differences regarding revenue expectations can probably be explained by both: the type of affiliation of responders and the stage at which the participants are with their aquaponics plans. In addition, the emphasis on social activities in many European funded projects may have had an impact.

Since the French sample seemed to be in earlier stages of the implementation of their aquaponics project, their perceptions of aquaponics might correspond to earlier phases of the "Gardner's hype cycle", with high levels of optimism and belief in "aquaponics economics myths" [22]. The respondents from the European sample might have already analysed challenges; thus, the economic reasons were reported to be the least common rationale for selecting aquaponics. However, many of them were not specifically concerned with revenues, as their revenues were secured by their organisation (not their own company or universities).

The data thus show that the early adopters in the European sample seem to be aware of the potential risks of commercial economic activity, but that economic motivations were not the main reason for their enthusiasm for aquaponics. Rather, their motivation is rooted in environmental, health and, to a smaller extent, social sustainability values. Nevertheless, at the time when they started to plan their aquaponic project, they did have commercial goals in mind, either to obtain part or even the entire income from aquaponics. Similar intentions, yet more commonly, were reported in the French sample (Table 4).

3.4. "Inflated" Perceptions and Optimism for the Future

The European survey attempted to ascertain the level to which the participants agreed with highly positive, "inflated" perceptions of the current state of aquaponics (Table 4). On a scale from 1 to 5 on how strongly the participants agree with these "inflated" statements, the mean was in two cases well above 3, meaning more participants agreed with the statements:

"*Lower cultivation costs in aquaponics with substantially higher yields equals more net returns.*" (mean = 3.4), and "*Aquaponics has all the great points of traditional gardening, without all the back-breaking toil necessary to bring in a great harvest*" (mean = 3.3). In the case of the statement: "*Aquaponic produce grows in half the time of that produced using conventional means*", the mean was just below 3. We can conclude therefore that the participants had high opinions of what aquaponics is and what it can achieve, and that this is consistent with "inflated" expectations in terms of the Gartner's Hype Cycle.

Most participants, however, agreed that aquaponics has an important role to play in the future and thus showed very high hopes for its future (Table 4). This may indicate that if aquaponics development does follow Gartner's Life Cycle, it has not yet hit the "trough of disillusionment" amongst its early adopters in Europe.

3.5. Challenges Encountered

Aquaponics being a rather novel technology, the industry is barely beyond the research and development stage and the early adopters necessarily have to go through the phase of trial and error, making it a highly risky endeavour. Aquaponics incorporates all the risks of both aquaculture and hydroponics [18]. It is thus not surprising that the early adopters face income losses, due for example to fish or plant diseases or pests, or system malfunctions [7].

The current literature on commercialisation of aquaponics identifies several areas of challenges for aquaponics on a commercial scale: technical, socio-ecological, and economic [22,23,25,26]. Regarding technological challenges, the main issues faced by entrepreneurs are system complexity, caused by joining two very different food production technologies, the need for further research to optimise production conditions, and the lack of large-scale units to demonstrate the potential, subsequently resulting in the challenge to convince investors and other potential sources of finance. Once the "trial and error" phase in the production has been negotiated, the most important challenge for commercial aquaponics producers seems to be their size, since most are very small and cannot be expected to compete with large scale competition [22,23,25–29].

The currently small average size of aquaponics farms is due to the high initial investment required coupled with the novelty of the technology [22]. Because investors are reluctant to invest several Mio EUR in largescale farms, small-scale pilot facilities are expected to provide twofold proof-of-concept: technological and commercial. This leads into a "chicken versus egg" dilemma: large scale farms are not built because investors require comprehensive proof of concept, and the small-scale farms are not able to provide this, because they are simply too small. To become commercially viable, businesses need to either scale up to be competitive with conventional production or to develop additional innovative business models, such as an expanded product range, tourism, consulting, and education.

The current research shows that aquaponics farms rely on other forms of income. Only 37% of 257 participants in Love et al. [3] study were commercial producers who gained their revenue from selling fish and/or plants. Thirty-six percent of respondents combined the sales of produce with aquaponic-related material or services, such as the sale of supplies and equipment, consulting fees for design or construction, and fees associated with workshops, classes, public speaking or agro-tourism. Almost one third (27%) of responders sold aquaponic-related materials or services and no produce at all.

Aquaponics in Europe is still to a large extent based on research-directed attempts. Thirty-two percent of European participants are dealing with an aquaponics project without having to create a revenue stream, while such a category does not exist in the French sample. In both samples, only about one fifth of the participants are involved in an aquaponics activity that generates revenue.

Compared to 257 (100% of the sample since this was the prerequisite for inclusion) in the USA [3], this is a very low number, illustrating the much slower development of aquaponics in Europe. The fact that commercial aquaponics in Europe is very limited is supported by other studies [11,12]. Nineteen percent of participants in the European sample and 44% in the French sample are still planning their project, which confirms the findings that in France, the aquaponics adoption has been slower than in the rest of Europe.

Unlike other studies, the current study aimed to include the early aquaponics enthusiasts in their process of deciding their plans regarding aquaponics. Nineteen percent of European and 35% of French respondents have completely abandoned the aquaponics project. Of these, most said that they had abandoned their plans completely. The reasons for abandonment could be grouped in three categories: (a) difficulties with securing initial investment; (b) difficulties in securing a viable business model; and (c) personal reasons, such as moving and family reasons (Table 5).

The main difficulties encountered by the European enthusiasts were connected to investment and operation costs, and administrative obstacles, followed by technical issues such as installations, and fish and plants disease (Figure 4). Surprisingly, resources (water and energy) did not play a central role as one would expect, especially when considering their role for starting aquaponics (Table 1). Marketing and sales were not (yet?) an issue. This could be due to the limited production quantities in small scale systems connected to limited sales of products, all characteristics of a niche market.

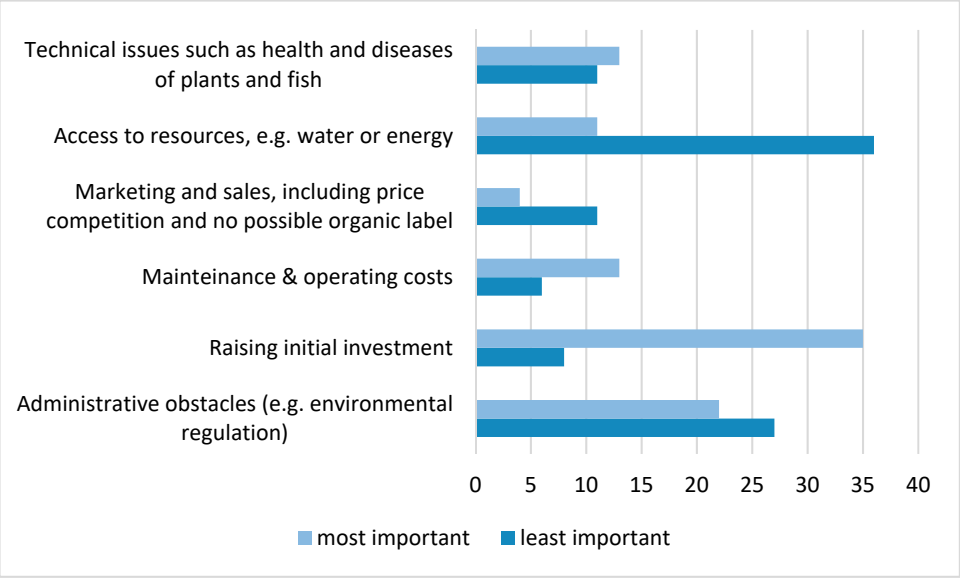

Figure 4. Main challenges of commercial aquaponics as perceived by the European responders (N = 60). Answers to the question: Relating to the project's life cycle, what main difficulties have you encountered? Please rank them from 1 to 6 according to importance from most important to least important.

French study used a different wording (only frequency of mentions and not the importance of each mention, Table 6). The French responders nominated investment costs as the main difficulty encountered, followed by unexpected regulations, and lack of skilled labour and price competition on the market. As in the European sample, water and energy sources were the least important factors. The regulation referred to by the French respondents were: (a) a ban for tilapia farming in France, while tilapia is the most documented and most tolerant fish species in aquaponics production elsewhere; (b) the fact that aquaponics produce cannot be labelled as organic; (c) mandatory sanitary rules for food distribution, even if for free; (e) mandatory sanitary declaration for fish farming and mandatory veterinary certification for fish processing; and (f) the fact that insect feed was not yet authorised for fish farming at the time.

Table 6. Main challenges of commercial aquaponics as perceived by the French responders (N = 43). Answers to the question: Relating to the project's life cycle, what main difficulties have you encountered? Several answers were possible.

Project Obstacle	Frequency of Mentions
Energy source	5
Water source	4
Season/climate	9
Investment costs	33
Unexpected regulation	21
Competition on market prices	10
Lack of skilled labour	11
Cost of labour	5
Other	8

The participants in both samples identified investments and growth to reach the economy of scales as the most important areas that are lacking for their project to succeed (Table 7). However, gaining experience and enlarging the team were perceived by the French respondents as the second most important challenge—all typical challenges associated with earlier start-up phase in comparison with the European sample. Finding the right location, however, was an issue for more than 10% of participants, which might be a reflection of common intentions to locate aquaponics in urban environment, where the regulations are complex, and the appropriate land is difficult to obtain.

Table 7. Areas of support needed in commercial aquaponics. Answers to the question: Today, what do you lack most so that your project runs better/more quickly (one or more answers could be selected)?

Areas of Support Needed	European Study (N = 60)	French Study (N = 43)
	Frequency of Mentions	
Technical advice	11	-
Administrative assistance	8	-
Consulting on investments	8	-
Financing for either investment or running costs	23	43
Finding the right location	13	15
Time to really do it	13	6
Gaining experience	9	29
Enlarging my team	9	16
Marketing	8	-
Growing to reach the economy of scale	17	8
Other	3	-

4. Conclusions

Aquaponics has recently been receiving increased interest from researchers, entrepreneurs, and policy makers. Aquaponics research has increased exponentially since 2012; strong international interdisciplinary collaboration networks have been established, resulting in stronger SMEs and larger aquaponics production units being implemented. Although Europe has been lagging behind the USA in the number of large-scale commercial aquaponics projects, pilot aquaponics systems have been built in most, if not all European countries. However, these are mainly small-scale research units and very few aquaponics systems reach the large scale required to become economically viable. The driving force for the development of commercial aquaponics seems to originate predominantly from the aquaculture branch, rather than horticulture, probably due to environmental issues of farms releasing excess nutrients into the environment, causing eutrophication.

This study included two surveys, one in Europe (including France) and one just in France, including participants experiencing different stages of the aquaponics adoption process. The special benefit of the French study is that it is a rare case of including participants very early on within their plans and getting back to them a few years after to see what happened with their plans and what challenges they faced in between. For many, enthusiasm for aquaponics stems from the ideas of sustainable life, and several enthusiasts who were looking for a life-change became aquaponic farmers. Yet, these start-ups face the harsh reality of high risks and competition in commercial food production.

A major source of challenges for commercial aquaponics originates from its complexity: as it includes both aquaculture and horticulture, most investment costs are doubled when compared to the competing enterprises that engage only in aquaculture or horticulture. The same is true for the competencies required to operate the system. Furthermore, to ensure quick response to pests and disease, and also because of strict animal welfare regulations, the system requires alarm protocols and personnel on permanent stand-by. This complexity causes high labour demand [15]. On the other hand, the survey of Love et al. [3] revealed that most of the respondents had less than 10 years of experience with aquaponics. The reason for this can be attributed to the relative novelty of technology since the first users are barely within the "early adopters" stage of innovation diffusion [30].

The next challenge is the lack of policy recognition [28]. Regulation obstacles are at least doubled as the farm needs to adhere both to the regulations pertaining to aquaculture and horticulture, and this is further complicated in an urban environment [29]. Finding public funding opportunities is difficult, since the aquaculture funds mostly do not finance the plant side of production and vice versa. Furthermore, while aquaponics in the USA. can be certified as organic, the aquaponics producers in Europe cannot benefit from an official label, as the technology is currently not recognised under any official label [31,32].

The third major challenge for commercialisation of aquaponics is the marketing of aquaponic produce. Here again the definition of the business model is complex since the customers, restaurants or end-consumers, preferably purchase either fish or vegetables, but rarely from the same source. Consumer acceptance is a crucial element for the success of commercial aquaponic production. Studies in Canada [7], Malaysia [33], and Romania [34] showed a generally positive attitude of end-consumers towards aquaponics. On the other hand, a survey in Berlin revealed that only 28% of those interviewed approved of aquaponic production in urban areas and only 27% expressed willingness to buy aquaponics products [35]. A more nuanced picture is presented by Miličić et al. [36], who conducted a survey of consumers´ knowledge and their acceptance of aquaponics products in several European countries, mostly from Belgium (41.3%), followed by Greece (9.4%), Iceland (9.1%), Slovenia (3.8%), and the Netherlands (3.5%). Most respondents had a generally positive attitude towards aquaponics; however, nearly half had never heard about the aquaponics before. This shows that the main challenge is building the awareness of aquaponics and positive associations related to it. In addition, the study participants reported a willingness to pay a premium price for aquaponics produce because they perceived the aquaponic products as free of antibiotics, pesticides, and herbicides, and connected with local producers, but not because of aquaponics as a type of production as such. While some consumers in the study seemed to appreciate the innovation aspect of aquaponics, others expressed concerns about animal welfare as well as disgust with fish faeces being used as plant nutrients.

The aquaponics start-ups often fail due to the insufficient initial investment and a lack of experience and skills. Farming is a demanding business and aquaponics is subject to both business and agriculture rules [12]. Even well-funded and widely marketed start-up companies in Europe had to announce failures (e.g., Ponika from Slovenia) and even bankruptcies (e.g., Urban Farmers from Switzerland). These very recent events demonstrate that commercial aquaponics faces harsh realities as it must show that it can be competitive with conventional aquaculture and horticulture systems. This means that aquaponics systems either need to reach the same production scale as their competitors (which amounts to hundreds of tons of fish and thousands of tons of vegetables), or address niche markets and integrate other income resources. The study shows that for early adopters of commercial aquaponics

sustainability was an important motivator in addition to financial gains. At this stage, it is too early to predict whether the development of aquaponics follows the Gartner's Hype Cycle towards a "slope of enlightenment" or whether it will remain a "hype" over longer period of time. Our data show that the European and French early adopters indeed showed levels of inflated early expectations about commercial aquaponics. Moreover, whilst the participants of the survey still very much believe in the future of aquaponics, several expectations were thwarted.

As there are certain signs suggesting that the development of aquaponics has hit the "trough of disillusionment", it is ever more important for the research on aquaponics to continue. We cannot predict the future of aquaponics, but we can speak of hope—if aquaponics is to be an important step in solving the issues of circular food production and sustainable resource use, then we can hope for an ever increasing "slope of enlightenment", when aquaponics matures towards a reliable and accepted technology.

Although the future of aquaponics cannot be predicted with certainty, there are grounds for optimism. If aquaponics is to be an important step in solving the issues of circular food production and sustainable resource use, then an ever-increasing "slope of enlightenment", when aquaponics matures towards a reliable and accepted technology, would be a welcome development.

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