Urban aquaponics in the European Union

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Abstract

- Urban aquaponics is an urban agricultural technology currently in its infancy stage, which produces fish and vegetables in a closed-loop system;
- Aquaponics technology has adaptable characteristics that allow for a broad application in many social, environmental and economic contexts;
- The main barriers to mainstream urban aquaponics include high energy demands, high initial set-up costs, lack of adequate regulation, and limited knowledge sharing opportunities;
- Urban aquaponics contributes to green food systems by reducing environmental impacts (e.g. low water usage, no nutrient losses, alternative and sustainable fish feed input);
- Urban aquaponics contributes to resilient food systems by combining commercial goals with socio-economic benefits for local communities.

Introduction

Together, global issues around hunger, health, and climate change emphasize the need for **green** and **resilient food production** in urban areas. Green, in the context of food production, means having a neutral or positive environmental impact in terms of energy usage, water usage, and waste generation; resilient means having the ability of an urban food production system to withstand, manage and adjust to economic, social and environmental threats.[1] The current food production system uses around 70% of the global, limited fresh water supply, accounts for a quarter of the greenhouse gas emissions, and occupies around half of the habitable landmass.[2] COVID-19 highlighted the vulnerability of current **food systems**, which might become more apparent during future shocks and crises, such as droughts and floods.[1]

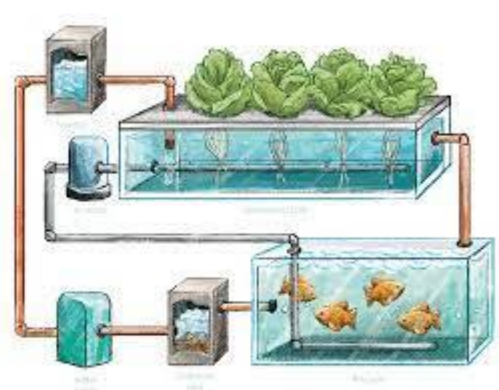
Current farming practices contribute to climate change and biodiversity loss, which shows a need for new agricultural technologies exceeding traditional paradigms. **Urban agriculture** comes in many forms and utilizes new technologies, one of which is **urban aquaponics.** Urban aquaponics has the potential to make urban food production greener and more resilient in the coming years. This desire to rethink farming practices aligns with the environmental targets set by the European Union (EU) in the EU Green Deal and the Farm to Fork strategy, highlighting the EU's commitment to transition to more sustainable food systems (Annex 2).[3,4]

This brief illustrates urban aquaponics' potential to contribute to greener, more resilient food systems in the EU through literature research, expert interviews, and horizon scanning (Annex 3). Then, recommendations for policy makers are given that can foster the development of urban aquaponics.

Urban Aquaponics Technology

Aquaponics is a food production technology that combines hydroponics (soilless crop cultivation) with aquaculture (fish farming) in a closed-loop system (Figure 1).[6] This production system, therefore, does not require soil to grow crops. The Recirculating Aquaculture System (RAS), a technology present in all aquaponics systems, filters the fish effluent from the water and mineralizes it into bioavailable nutrients for the plants[7]; plants thus depend on aquacultural waste streams.

Figure 1. Schematic drawing of a coupled aquaponics unit.[5]



Source: (Souders W, McDowell J. Hydroponics & Aquaponics, 2019)

There are two main types of aquaponics. First, in coupled aquaponics systems, the water recirculates from the plants to the fish.[8] In decoupled aquaponics systems, which is the most common, the water does not return to the fish. This enables the system to be fine-tuned to the fish' and plants' needs separately (e.g., water temperature, pH level), and provides a physical separation between both production units.[9] Additionally, saltwater aquaponics, albeit in early research phase of development, seem to have a potential for utilizing saltwater (Annex 4).[10,11]

A Life Cycle Assessment (LCA) shows that aquaponics' closed-loop principle nearly halves the negative environmental impact of stand-alone hydroponics systems.[12] RAS systems reuse around 90% of the water, thus decreasing overall water use up to 93% compared to conventional farming.[13] Other benefits of aquaponics are its ability to minimize nutrient loss, chemical outputs, and pesticide use.[14,15]

Aquaponics facilities can be installed on any flat surface, can range from low-tech to high-tech, and can vary in terms of set-up costs, scale, and complexity.[16,17] Urban aquaponics specializes in embedding systems in potentially small spaces in the urban context, which may take the shape of vertically placed units or of using unused spaces such as on rooftops, underground, or on **marginal lands.**[8] However, aquaponics can also be fitted to a commercial scale as there are no limits to their maximum size.

Current State of Urban Aquaponics

Although the EU has previously funded the EU Aquaponics Hub, which focused on mainstreaming the industry, aquaponics is still described as a technology in its infancy phase.[19,20,21] In the EU, most aquaponics projects are small scale and are either funded through external private investments or associated with university research.[22] In practice, most aquaponics systems cooperate with educational or community-based projects in order to increase their resilience rather than just focusing on increasing urban food production.[14] In contrast, in the United States and Australia most aquaponics farms are of commercial scale, because they benefit from an appropriate regulatory framework and a longer history of the industry.[23] The EU is missing such a fitting framework due to fragmented governance on multiple levels (Annex 2).[24] However, as emphasized by various aquaponics practitioners and researchers, aquaponics has a potential important role to play in greener and more resilient EU cities.[21,22]

Environmental Potentials & Barriers

Despite the opportunities for greener food production presented by urban aquaponics, these systems do require inputs, such as fish feed and energy. According to several LCAs and experts,[12,16,25,26,27] energy requirements and fish feed are two major environmental constraints of aquaponics.

Energy Requirements

Compared to conventional farming, aquaponics has a three-times lower environmental impact by reducing water use, waste discharge, and increased space use efficiency. However, energy inputs are higher using aquaponics technology.[12,25,26] Heating, water recirculation, and light all require constant energy supply. Especially in cold regions, heating the water of an aquaponics system results in a higher environmental impact compared to conventional fish farming.[26] This impact could be greatly reduced by using renewable energy sources,[25,26] or by locating the aquaponics farm close to wasted sources of energy, a practice common to many urban aquaponics farmers.[14,28,29] For example, Brussel's BIGH aquaponics farm is built on the roof of a 2,000 m2 market hall which enables them to remediate the heat produced from the market's refrigerators as energy for their installations.[30] Reusing these energy waste streams contributes to greener food production systems.

Fish Feed

Fish feed, which mainly consists of commercially available feed, is often enhanced with fish meal, which is the main polluting required input.[25,26] To make food production greener, alternative fish feed sources such as plant protein substitutes (e.g., soy), and new sources like insects (particularly black soldier flies)[16,17] and reactor generated protein[31] should be further explored. Although these developments have the potential to decrease aquaponics' environmental impact, current EU legislation limits the use of insect-based fish feed due to health regulations.[32,33]

Economic Potential & Barriers

Although EU interest in organic and local food production is rising[5] and technical innovations are optimizing aquaponics systems, current aquaponics farmers still struggle to keep their business from going bankrupt. According to experts and practitioners, barriers such as a lack of regulation and knowledge sharing platforms hinder them from becoming **economically resilient**.

Initial Costs & Considerations

High initial costs are required when setting up new urban aquaponics systems.[34] When applying for EU funding, aquaponics entrepreneurs find limited sources for aquaponics systems, as most grants are isolated per disciplines (e.g., entrepreneurs can only receive a grant for one part of the system, not both production sides).[10,24,35] Additionally, the high costs of urban land and the requirement of a building permit increase the initial investment of commercial scale systems.[36]

However, once building permits are obtained, it may work to incentivize external investors to get involved in the project.[36]

High initial costs can be compensated for with an effective, year-round production of both fish and vegetables,[13] which increases profitability,[34] making the system more economically resilient. In addition, urban aquaponics systems have the potential to be flexible and adapt production to current and variable market demand. This flexibility is enabled especially in decoupled systems and amplified when growing plants or fish with a shorter life span.[35] Since fish and plants systems require different optimal conditions, all aquaponics systems face the challenge of achieving the highest yield for both outputs simultaneously.[16,18,37]

Premium Product Pricing / Market Demand

In order to make urban aquaponics systems cost-effective, sufficient demand for the produce needs to exist at the local level.[16,18] Both vegetables and fish need to be sold at a premium price for the farm to be economically resilient.[18,38] Premium prices can be reached by marketing the products as ‘local' or ‘green', allowing them to be sold at a higher price.[39] Payback times of the initial investment are expected to be 7.5 years or less if the products can be sold at the same price as organic food.[19] However, selling products at a premium price means that aquaponics food production might not be able to compete with conventional food production.[10,16] In addition, purchasing power of consumers needs to be high enough (i.e, middle- to high-income households) to afford these products,[40] which explains the current unequal accessibility of aquaponics products.

Organic Certification

Current EU regulations prohibit soilless vegetable production from falling under organic certification.[36,41] Similarly, RAS produced fish cannot fall under any aquacultural sustainability label such as the new ASC certification (Aquaculture Stewardship Council). This limits aquaponics farmers in obtaining a premium price for their products and limits consumers' knowledge of the green characteristics of aquaponics products.[16,18] In the US and Australia, such limitations do not exist, allowing aquaponics farmers to benefit from the organic certification schemes, thereby increasing economic resilience.[37]

System Optimization

Due to high initial costs, optimization of aquaponics production system is needed. Artificial Intelligence (AI) and big data technology are potential ways to increase the productivity of urban aquaponics systems.[40,42] AI technology could help monitor levels of important thresholds, while big data can help optimize the systems to eventually achieve the highest possible yield of both fish and plants contributing to a more resilient system.[43]

Knowledge Sharing

There is a need to share experiences and teach best practices because few successful examples of commercial urban aquaponics exist.[27,40,44] Lack of structure and disparities in functional units and level of detail (fish/plant combinations) used to document aquaponics systems hinder practitioners in learning from each other. Disparities are magnified because aquaponics systems require diverse expertise and skills ranging from agronomists, technical experts, and entrepreneurial urban farmers.[35] As most urban farmers are entrepreneurs, they lack specific agricultural and technical expertise to maintain aquaponics systems, resulting in system failure.[38,40]

Socio-Economic Considerations

To achieve economic resilience, urban aquaponics needs to be financially successful. However, considering the potential for socially resilient aquaponics can complement their economic resilience. The concept of **hybrid food systems** refers to “an economic organization chosen when a certain scale of food production is being provided to a community”.[20] Simultaneous to working to achieve its economic goals, a hybrid food system provides social benefits to the community in the form of job creation, social inclusion, and environmental education. For example, urban aquaponics systems that include an educational aspect by involving schools or youth centers have been found to be more profitable and long-lasting.[45] Research on commercial aquaponics production showed that “gross sales revenue and profitability were higher for operations that diversify their revenue stream by selling non-food products, services, or educational trainings”.[46]

The Potential of Urban Aquaponics

Through the analysis of barriers and opportunities of urban aquaponics the following future potentials of urban aquaponics to contribute to green and resilient food systems have been identified:

- Decoupled systems allow for a physical separation between the hydroponic and aquacultural unit. This leaves room for existing aquaculture and hydroponic farms to cooperate, and to reuse treated aquacultural wastewater in hydroponic facilities;[35]
- Urban aquaponics can be a part of hybrid food systems because of the potential to combine market and community goals. Both an increase in commercial urban aquaponics systems and

increased cooperation between the local communities and aquaponics experts is expected;[20]

- Salt and saline water aquaponics are upcoming potential solutions to expected freshwater shortage and salinization of groundwater.[10,47] Saltwater aquaponics systems can grow marine fish and sea vegetables utilizing salt water, which is relevant for coastal cities and cities experiencing salinization of groundwater.[11]

Recommendations

The following recommendations can enable urban aquaponics to reach its full potential to contribute to green and resilient food systems:

- Include soil-less grown produce in organic certifications with defined standards specific to different aquaponics systems and expand the current ASC (Aquaculture Stewardship Council) certification to include aquaponically produced fish. Including aquaponics in such certifications will allow for practitioners to sell at a premium price.
- Capitalize on aquaponics' closed-loop principle by combining either existing aquaculture or hydroponic systems to valorize waste streams and minimize negative environmental output in terms of nutrients, water, and energy.
- Promote EU-level R&D to advance greener fish feed, such as insect-based alternatives, as well as policy investigation to expand legislative limits on insects for fish feed.
- Standardize monitoring documentation by aquaponics practitioners to support practitioners to learn from each other to prevent business failure. Sharing of such documentation on knowledge platforms, e.g. the previously EU-funded Aquaponics Hub and develop such platforms further.
- Analyze existing environmental, social and market conditions in order to set up and fulfill location-specific needs and increase production (e.g., for environmental: alternative energy sources; social: community specific needs; market: consumer demand).
- Improve aquaponics funding in terms of availability, research parameters, and ease of application for grants. For example, current EU grants limit funding to either aquaculture or hydroponics. Research grants need clear parameters on deliverables beyond just research (e.g., sufficient guidance in terms of revenue planning, food planning).

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ANNEX 1. Glossary

Urban agriculture: “Food production that occurs within the confines of cities. Such production takes place in backyards, on rooftops, in community vegetable and fruit gardens and on unused or public spaces. It includes commercial operations that produce food in greenhouses and on open spaces, but is more often small-scale and scattered around the city”.[48]

Food system: “The entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded”.[49]

Green food production system: A food production system with a neutral or positive environmental impact in terms of energy usage, water usage and waste generation, compared to conventional food systems.

Resilient food production system: A food production system with the capacity over time “to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances”.[50] This includes the ability to withstand, manage and adjust to economic, social and environmental threats.[1]

Economic resilience: Long term and fair economic return for a business.

Hybrid food system: “An economic organization chosen when a certain scale of food production is being provided to a neighborhood or a community—for example an urban farm. The food system is in the same time also providing various types of social and/or environmental goods to the community in terms of job creation, social inclusion and environmental education. Typically, a public or a non-profit entity will support such an economic organization in return, hence making it a hybrid between a pure market and non-market economic organization".[20]

Marginal land: Land that has little or no agricultural or industrial value. Marginal land has little potential for profit and often has poor soil or other undesirable features. Aquaponics systems show potential to give value back to these lands, by giving these lands a new function.

ANNEX 2. Methodology

Expert interviews

Many experts of multiple aspects concerning aquaponics were interviewed through semi-structured interviews or consulted through emailed questions. All interviews were recorded and transcribed, after which they were analyzed and thematically organized. Whereas most interviewees were asked subject related questions, the final interviewees also provided feedback for the policy recommendations. A full table (table 1) of all consulted experts can be found below.

Literature review

Over the past years, there has been a rise in aquaponics related literature. Many articles were analyzed to form a foundation in aquaponic knowledge. The WUR library, Google Scholar, and FAO and UN reports were used for finding these articles. Searches included but are not limited to the following concepts: ‘aquaponics’, ‘urban aquaponics’, ‘food security’, ‘barriers to aquaponics,’ ‘food systems,’ and ‘urban farming.’ Most articles are dated post 2016 to ensure the most up-to-date research.

Horizon scanning

Through a horizon scanning approach, barriers, emerging issues, and opportunities of urban aquaponics were identified. Since urban aquaponics is an emerging technology, horizon scanning provides the possibility to systematically analyze future implications and possibilities to implement this technology. Table 2 highlights all the identified barriers and opportunities of urban aquaponics.

Table 1. Expert interviews

Name	Institution	Position	Interview date	Country	Topic
1. Benz Kotzen	EU Aquaponics Hub	Founder	09-11-2021	United Kingdom	Aquaponics
2. Sarah Milliken	EU Aquaponics Hub	Project Manager	10-11-2021	United Kingdom	Aquaponics
3. Austin Stankus	Fisheries and Aquaculture Division - Food and Agriculture Organization of the United Nations	Aquaculture Officer	12-11-2021	Italy	Aquaponics
4. Sander van der Jagt	Department of Environmental Sciences at Wageningen University and Research	Postdoctoral researcher	12-11-2021	The Netherlands	Nature-based solutions in urban areas
5. Jan-Eelco Jansma	Wageningen Plant Research at Wageningen University and Research	Researcher 'feeding the city'	16-11-2021	The Netherlands	Urban agriculture
6. Daniel Reyes Lastiri	Department of Plant Sciences at Wageningen University and Research	Researcher	17-11-2021	The Netherlands	Technical side of aquaponics
7. Steven Beckers	BIGH aquaponic farming	Founder	17-11-2021 (conducted via email)	Belgium	Aquaponics
8. Alexander Laarman	Amsterdam Institute for Advanced Metropolitan Solutions	Program Developer Business Development Nature Based Solutions	18-11-2021	The Netherlands	Urban agriculture

9. Erik Moesker	NoordOogst Aquaponics	Founder	19-11-2021	The Netherlands	Aquaponics
10. Karel Keesman	Department of Plant Sciences at Wageningen University and Research	Professor	23-11-2021 (conducted via email)	The Netherlands	Aquaponics
11. Tilman Reinhardt	GFA Consulting Group	Consultant	23-11-2021	Germany	Regulatory frameworks for aquaponics in the EU
12. Sabine O'Hara	College of Agriculture, Urban Sustainability and Environmental Sciences of the University of the District of Columbia (UDC)	Distinguished Professor & PhD Program Director	24-11-2021	USA	Urban food security
13. Edoardo Pantanella	Fisheries and Aquaculture Division - Food and Agriculture Organization of the United Nations	FAO consultant	26-11-2021	Italy	Aquaponics
14. Mirta Alessandrini	Department of Social Sciences at Wageningen University and Research	Researcher	01-12-2021	The Netherlands	Food law, short supply chains
15. Frank Bakkum	Department of Urban Planning and Sustainability at City of Amsterdam	Urban Planner	07-12-2021	The Netherlands	Urban agriculture
16. Maja Turnsek	University of Maribor	Doctor of Philosophy	08-12-2021	Slovenia	Economic aspect of aquaponics

17. Lorena Silva Araujo	Wageningen University and Research	PhD in aquaponic business models	08-12-2021	The Netherlands	Business models of aquaponics

Table 2 - barriers and opportunities of urban aquaponics

	Environmental	Economic	Social
Opportunities	-No soil input needed -Lowered water consumption, ability to reuse water streams -Minimize nutrient loss -No chemical output -None or limited pesticide use -Potential to use renewable energy sources or reusing energy waste streams -Potential to use alternative, less environmentally damaging fish feed input -Combine existing aquaculture and hydroponics systems -Decrease biosecurity risks*	-Low-tech to high-tech systems available -Small- to high-scale systems available -Higher space use efficiency -Potential to set up in unused spaces or marginal lands -Increased demand of local and organic food products -Year-round production -Potential higher profitability because of combined production -Flexible production system can adapt to market demand -Products can be marketed as 'local' or 'green' -Opportunity to include products in organic certification or alternative food labeling scheme -Use AI and big date to optimize system and increase productivity -Potential to contribute to local economy*	-Potential to share knowledge and best practices -Potential collaboration between stakeholders -Increase job availability -Social inclusion and community involvement -Environmental education -Increase availability of healthy and nutritious food* -Potential of grassroots initiatives*
Barriers	-Initial freshwater input needed -Current fish feed input options have a negative environmental impact -Relatively high energy input needed	-Relatively high initial investment costs -Difficult to find funding/loans -Relatively high cost of urban land -Building permits required -Suboptimal production of fish/plants due to	-Lower accessibility of premium-priced products -Expertise and knowledge needed on aquaculture, hydroponics and farming

	-Current EU legislation does not allow for alternative fish feed	compromising on optimal conditions -Sufficient market demand required -Premium price required to make system cost-effective -Hard to compete with conventional food products -Lack of organic certification -Limited funding for combined agricultural disciplines -Costs of maintenance*	-Support needed for grassroot initiatives*

*These barriers and opportunities were encountered during research, but not discussed in the policy brief.

ANNEX 3. Past and Current EU Level Support

The environmental targets set by the EU in the **European Green Deal** highlights the EU's commitment to transition to more sustainable food systems and strive "to be the first climate-neutral continent."[3] Adopted by the European Commission, the Green Deal offers a set of proposals to make the EU's climate, energy, transport and taxation policies reach net greenhouse gas emissions reductions by at least 55% by 2030, compared to 1990 levels.[3] The financial instrument contributing to reaching these goals is **Horizon Europe,** allocating a total of €95.5 billion between 2021 and 2027.[50] This is an initiative funding innovation and research in five mission areas: *Adaptation to climate change, including societal transformation; Cancer; Healthy oceans, seas, coastal & inland waters, Climate-neutral & smart cities, Soil health & food.* Specifically, €8.952 billion is allocated for the Food, Bioeconomy, Natural Resources, Agriculture & Environment cluster. Core to the Green Deal is the **Farm to Fork Strategy,** which aims to make food systems fair, healthy and environmentally friendly.[4]

In terms of current regulation, aquaponics is regulated through Common Agriculture Policy (CAP) and Common Fisheries Policy (CFP), as well as falling under food safety, animal wellbeing, and environmental policies on both a local and the EU level.[52] This results in a fragmented governance of aquaponics which is an important reason hindering the mainstreaming of these systems. This fragmentation forms a complex set of regulations for aquaponics practitioners, who rate such administrative obstacles as the main barriers they face when setting up a farm.[22] Furthermore, currently, there are no EU laws and regulations concerning urban agriculture,[52] therefore they are often excluded from urban spaces.

Horizon Europe's predecessor, **Horizon 2020**, previously funded the **EU Aquaponics Hub** from 2014 to 2018. This hub was a four-year COST (Cooperation in Science and Technology) networking action uniting scientists, researchers and SMEs from across the EU and around the globe to better understand the state of knowledge in aquaponics to facilitate innovation and education in this field. The EU Aquaponics Hub focused on three primary areas: 1) 'cities and urban areas' – urban agriculture aquaponics, 2) 'developing country systems' – devising systems and technologies for food security for local people and

3) 'industrial scale aquaponics' – providing competitive systems delivering cost effective, healthy and sustainable local food in the EU.[6] The hub helped launch multiple enterprises of which few if not, none, remain in existence today.

Today, new projects, supported in part by the EU, are focused on integrating aquaponics into urban farming initiatives like **CITYFOOD** or into Eco-Industrial Parks like **BLUE-CYCLING** are still ongoing.[53,54,55] CITYFOOD has worked to investigate the consequences of upscaling a nature-based solution in a circular city. More recently, BLUE-CYCLING's core unit is an aquaponics system, to be integrated with other food production practices to close the cycles in an Eco Industrial Park (EIP).

ANNEX 4. Aquaponics technology

Aquaponics dates back to 1000 A.D. and have existed in different parts of the world. From ancient Mayan and Aztec civilizations as well as in Southeast Asia,[7] fish farming was combined with crop farming to maximize system outputs (food production) and minimize losses such as nutrients and water. This farming method mimics nutrient cycles that are present in natural ecosystems; one organism's waste is used by another as a nutrient source.

The technology as it is known today emerged in the 1970's in the United States.[7] Even though these current systems have developed to use modern technology, the principles remain the same. Several variations combining fish and plant farming appeared, such as coupled and decoupled systems. Additionally, saltwater aquaponics technology is upcoming and holds a promise to become more influential in the future.

Despite the different variations, each fresh water aquaponic system consists of a fish tank, a solids removal unit, biofilter tanks, a plant growth bed, and pumps (one for water circulation and one for aeration).[12] Systems might differ in their exact technology, but the components mentioned above are generally present in each system. Inputs are limited and mainly consist of water (which is greatly reduced since the system can reuse about 90% of the water,[13] fish feed, and energy. The system is designed to reuse nutrients and water, thereby minimizing outputs and external waste streams.

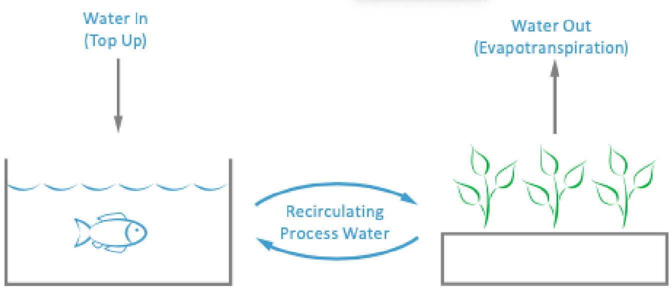
Almost all modern aquaponic systems combine tank-based aquaculture in the form of Recirculating Aquaculture Systems (RAS) with a hydroponics component. In RAS, the water in the fish tanks can be monitored and adjusted to the exact needs of the fish, for example pH control, solid waste removal, and temperature. After the water is filtered and the solid fish waste is transitioned into bioavailable nutrients, the water can flow towards the hydroponic part of the system. Depending on the financial and environmental circumstances, this technology can have many shapes and forms, as long as plant production does not happen in the soil.[56] Plants grow in nutrient solutions in a closed and controlled system; in the case of aquaponics the closed system is attached to the RAS component.

As mentioned above, several technological variations exist. In coupled aquaponic systems, the water recirculates between the fish tank and the hydroponic unit (Figure 2). The following points are characteristics and benefits of these type of systems:

- Because the water recirculates between the water and plants, it is impossible to use pesticides and herbicides to protect the plants from pests as this will contaminate the water, and thus affect the fish health negatively;
- Since the system mimics the natural connection between the fish and plants, there is the belief that both are benefitting from a positive synergy[57];

- When the scale of production increases, so does the technical complexity due to the required water treatment.

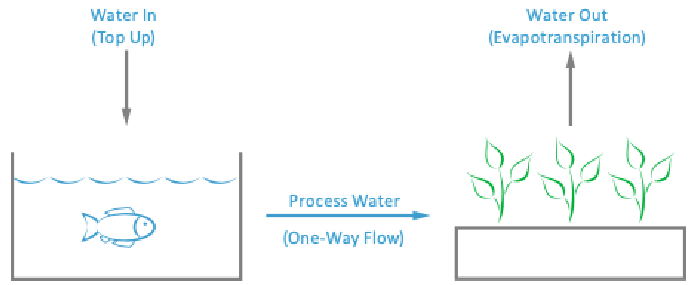
Figure 2. Schematic drawing of a coupled aquaponics system.[7]



In contrast to coupled systems, the water in decoupled systems only flows from the fish to the plants, (Figure 3*).* These systems were developed as a reaction to the different nutrient and environmental requirements of the fish and plants, which can be optimized for both segments separately in decoupled systems. This results in a more efficient recycling process of the fish effluent. These types of systems are currently the norm in most aquaponic farms. Additional benefits include:

- Decoupled systems allow for a physical separation between the hydroponic and aquacultural unit. This leaves room for existing aquaculture and hydroponic farms to cooperate, and reuse treated aquacultural wastewater in hydroponic facilities;
- As water does not flow back from the hydroponic part of the system to the fish, there is some room for pest control as the toxic pathogens will not contaminate the water in the fish tanks;
- Additional loops can be added to a decoupled system that can capture more nutrients in the transition process that would otherwise be lost.[7]

Figure 3. schematic drawing of a decoupled aquaponics system.[7]



Finally, saline/saltwater aquaponics is an emerging technology amongst the already existing coupled and decoupled systems. This type holds the capacity to grow marine organisms (e.g. shrimp) while at the same time cultivating sea vegetables such as Salicornia using alternative water sources. The technology could be especially relevant in coastal cities. Although the technology is still in its research phase,[10,47] attention should be given to its development since fresh water is becoming increasingly scarce.[8] Therefore, further research is needed to make predictions on the potential of saltwater aquaponics and how it can contribute to urban food production.

The explanation provided above is a simplified technological explanation of the three most common aquaponic systems. For a more in-depth and technical understanding of all the systems, the following sources are recommended:

- Lennard W, Goddek S. Aquaponics: The Basics. In: Goddek S, Joyce A, Kotzen B, Burnell G, ed. by. Aquaponics Food Production Systems. Cham: Springer; 2019.
- Palm H, Knaus U, Appelbaum S, Strauch S, Kotzen B. Coupled Aquaponics Systems. In: Goddek S, Joyce A, Kotzen B, Burnell G, ed. by. Aquaponics Food Production Systems. Cham: Springer; 2019.
- Goddek S, Joyce A, Wuertz S, Körner O, Bläser I, Reuter M, et al. Decoupled Aquaponics Systems. In: Goddek S, Joyce A, Kotzen B, Burnell G, ed.

by. Aquaponics Food Production Systems. Cham: Springer; 2019.