Providing Food Security through Hydroponic Systems

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Key Messages

- Hydroponic systems, a soil-less technology, can serve as a sustainable alternative to conventional farming to feed the growing world population in a resource-efficient way.
- Achieving 11 times higher yields and using approximately 80-90% less water, hydroponics emerges as a promising agricultural innovation that minimizes environmental impact and maximizes crop yields.
- This technology is not widely adopted due to the fragmentation of the provision system. That is the accessibility to materials such as seeds, fertilizers, and pesticides.
- Hydroponic systems need to be integrated into international policy frameworks such as the United Nations Framework Convention on Climate Change (UNFCCC), which in turn should support the establishment of an integrated provision system in developing countries to make them more independent.

In 2023, the world population is expected to reach 8.5 billion [14]. As the global population increases, so does the demand for resources such as food, water, and land, directly impacting our future generations [16]. At the same time, people living in arid regions are increasingly affected by droughts, water scarcity, and food deserts. This has a considerable impact on these specific populations as traditional agricultural practices are hindered causing a reduction in food availability[11]. Hydroponics is a soil-less method of cultivating plants that utilize water-based nutrient solutions instead of traditional soil [See Figure 1 & 2; See Annex 1]. It has emerged as a promising agricultural innovation with the potential to enhance food security, particularly in regions susceptible to drought[10].

Hydroponic Systems in Practice

Hydroponic systems can be an answer in aiding climate resilience and food security. This technique presents benefits such as "precise nutrient control, higher density planting, reduced space, and water requirements"[4]. Due to its resilience and high yield, hydroponics can be of special importance in arid regions. The resilience within this system stems from its controlled environment agriculture (CEA); meaning that factors that are crucial for cultivation such as temperature and humidity are controlled[9]. In addition to controlling the environment, CEA is also responsible for mitigating the impact of water scarcity while providing a sustainable solution to address food production challenges by optimizing yields year-round [1,9]. The further benefits of hydroponic systems such as the efficient use of resources and the improvement of food security will be highlighted in the section below.

Figure 1. Floating Systems[6]

Figure 2. Hydroponic Systems[5]

Benefits

Efficient use of Resources

The main benefits of hydroponic systems are related to the efficient use of resources.

Water: While conventional agriculture exhausts water usage through evaporation and leaching, hydroponics is more efficient as it recirculates the water supply; approximately, 80-90% of irrigation water can be saved in this process[1].

Growing Medium: Hydroponic systems utilize minimal growing medium for plants, which eliminates the need for soil [15].

Land: The high yield of hydroponics is notable, as it reduces the amount of land needed for production growth[12]. Thus, freeing up land for other purposes. A comparative study demonstrated that lettuce cultivated in a hydroponic system yielded 11 times more than in open-field agriculture, because of the controlled environment which ensures optimal growing conditions throughout the year[2].

Fertilizer: The technique allows for highly precise application of nutrients, which can greatly reduce the amount of fertilizer needed. Furthermore, applying the fertilizer in a closed system prevents any leaching into the environment [4,10].

Food security

Hydroponic systems not only promise resource-efficient agriculture but also hold the potential to enhance food security. These systems are promising in bridging gaps during periods when conventional farming faces challenges, for example, during extreme weather events such as droughts and monsoons[13]. Hydroponic systems can operate year-round and are resilient to diverse climate conditions, serving as a practical solution to mitigate food shortages[3]. Additionally, the introduction of hydroponic systems increases local food sovereignty, gives rise to local food markets, and decreases local food prices [7,13]. This provides communities with more affordable and accessible options for healthy food [13].

Challenges

Besides the benefits, it is also important to recognize the inherent challenges associated with the adoption of hydroponic systems.

Fragmented Provision System of Hydroponics: The current challenge lies in the fragmented provision system of hydroponics in developing countries, limiting its widespread adoption[3]. The fragmented production and distribution of essential materials such as fertilizers, seeds, and pesticides present an obstacle to its implementation[3]. For instance, the biggest cluster in terms of seed breeders and farm material companies for hydroponic systems are based in Western countries, which forces other regions to rely on imports, which increases dependency, upfront costs, and operational costs. Therefore, it is crucial to concentrate supply, production, and consumption locally.

Knowledge and Expertise: Furthermore, in hydroponics, knowledge and expertise are obtained from external sources, highlighting the reliance on insights from outside the system. Both training and support must be recurrent while operating on a hydroponic farm seeing as there is continuous innovation in the sector [7, 8, 12]. Thus, small-scale farmers, without the proper aid, may face challenges when managing their systems[7].

The Future of Hydroponic Systems

The following scenarios examine the future potential of hydroponics implementation, revealing both the potential benefits and challenges within these contexts [See Figure 3, See Annex 2]. Central to these are two driving factors. These include:

Nature of provision system: This represents the sourcing of materials, nutrients, pesticides, and fertilizer necessary to implement hydroponics. A farmer's ability to access all these inputs and to execute the supplier process, the implementation, and consummation within its reach, is represented by an integrated provision system. On the contrary, a fragmented provision system indicates that a farmer must import these inputs and cannot successfully carry out the procedure without employing scattered actors internationally.

Level of hydroponic farm: Hydroponics can be implemented on a household level, which suggests that the hydroponic farm is maintained by a single person/household/family. On a community level, the hydroponic system is maintained by more than one household.

Scenario 1: "Home-based Hydroponic Farming": In this scenario, the household operates within an integrated provision system, where the farmer achieves a significant level of autonomy. By utilizing locally sourced materials, the farmer establishes an affordable low-tech hydroponic system that is simple to maintain. Within the household, there is a culture of knowledge sharing. The demand for people is equal, requiring a mix of both experts and laborers to effectively build and maintain the hydroponic farm.

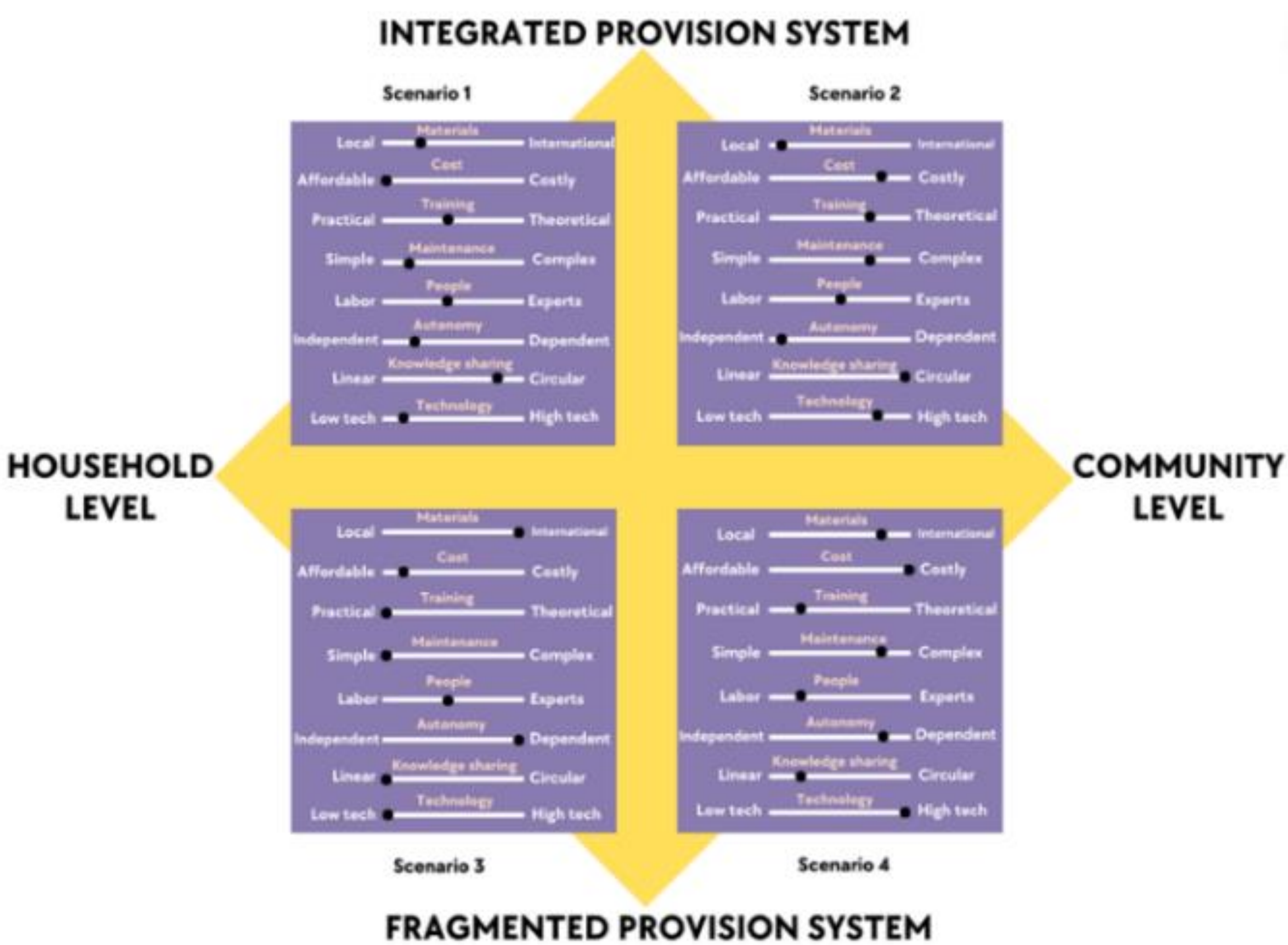
Scenario 2: "Collaborative Community Farming": In the context of a circular integrated system on a community level, the emphasis is on

achieving maximum independence and food self-sufficiency. This system uses local knowledge, avoiding the need for external knowledge transfer. As the community grows, farms expand to meet demand by incorporating advanced hydroponic technologies. The integration of such technologies also presents opportunities for job creation within the community.

Scenario 3: "Commercial Hydroponic System": In a fragmented provision system, households rely on external inputs, raising dependency and material costs. Importing a hydroponic system can eliminate the necessity for extensive internal expertise but increases reliance on external experts. This dependence can pose risks when encountering system failure or maintenance requirements. Balancing reduced external expertise with dependency risk highlights the complexity of the scenario.

Scenario 4: "Scaling Hydroponic Farms": Within a fragmented system, a community strives to establish a large-scale, high-tech hydroponic farm. The community's ability to import expertise and materials elevates the project's scale and level of technology but brings risks of increased dependency and costs. Relying extensively on external inputs increases the community's vulnerability, particularly when circumstances prevent these imports. The possibility of small setbacks poses significant risks, due to the community's reliance on external resources, emphasizing the need to balance growth ambitions with vulnerability awareness.

Figure 3. Scenario Analysis of Hydroponic Implementation



Hydroponics Africa Case

Based in Kenya, Hydroponics Africa aims to improve the integration of the provision system so that farmers can get all they need to implement hydroponic farming systems successfully[7]. They provide training and materials to support farmers in the implementation of hydroponic systems. The company uses local materials to avoid a costly fragmented system, prioritizing low transport expenses and localized production. Additionally, they contribute to food security in drought-prone regions where food is exceedingly expensive and often imported [See Annex 3].

Policy Recommendations

- **Support the Establishment of an Integrated Provision System:** Advocate for the establishment of an integrated provision system that addresses the fragmented supply chain of hydroponic materials. For instance, national governments could make essential materials like seeds, fertilizers, and pesticides more accessible and affordable in regions where hydroponic systems are implemented.
- **Promote Hydroponic Systems for Food Sovereignty:** Advocate for supportive policies at the national and international levels that recognize the benefits of hydroponic systems and incentivize their adoption. For instance, national governments could consider implementing direct subsidies for locally produced and hydroponic crops, prioritizing sustainable practices inherent to hydroponic systems, and emphasizing reduced land, water, soil, and fertilizer usage.
- **Facilitate Knowledge Sharing through and with Farmers' Networks:** Supporting the development and implementation of education and training programs for farmers to enhance their knowledge and skills in operating hydroponic systems. For instance, by collaborating not only with agricultural research networks but also with farmers' organizations.
- **Integrate Hydroponic Systems in International Policy Framework:** Positioning hydroponics as a viable solution to address food security challenges in regions affected by adverse weather conditions. For instance, national governments could integrate hydroponics technology into National Adaptation Plans under the United Nations Framework Convention on Climate Change (UNFCCC).

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Annex

Annex 1. Hydroponic Systems

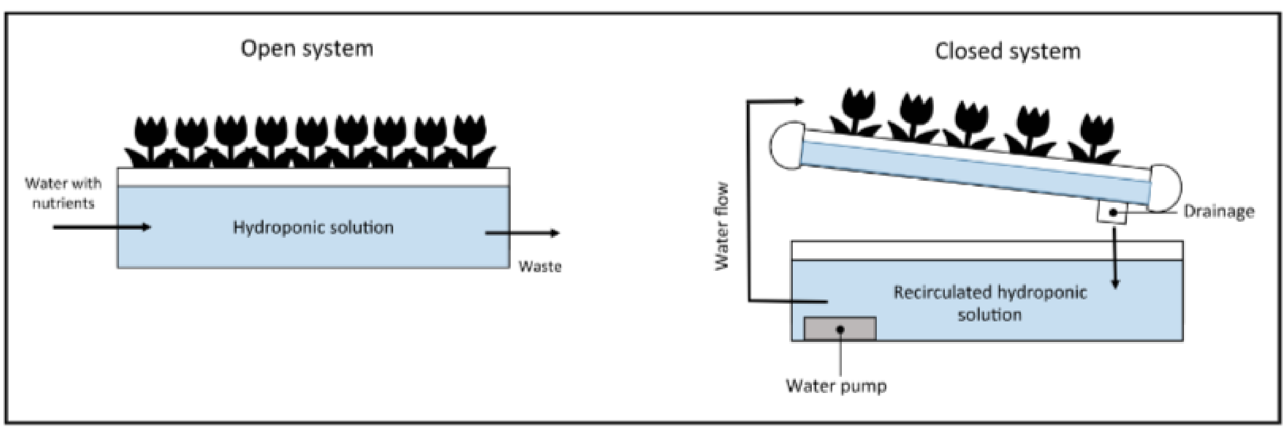
Hydroponic Systems – Open and closed

Hydroponic systems grow plants on a water-based nutrient solution instead of conventional soil. They can be classified into two categories: (i) open systems, in which the nutrient solution is applied once (ii) closed systems, in which the nutrient solution is recycled [See Figure 4].

Open (non-circulating) systems are generally cheap, low-tech hydroponic solutions. Since they do not recycle the water supply, no water pumps are needed. All excess water and nutrients are discharged as effluent. This low-tech approach lowers the upfront cost of the system. However, the water and nutrient supply in an open system need to be refreshed every cycle, raising operational costs.

Closed (circulating) systems use water pumps and reservoirs to recycle the excess water and nutrients. Setting up a closed system requires more expertise and raises upfront costs but saves water and nutrients. Especially in larger systems with considerable quantities of water, regularly refreshing the whole water supply is simply not practical. This is why most large-scale hydroponic systems use a closed system.

Figure 4. Comparison between an open system and a closed system[3]



Hydroponic Techniques

Within open and closed hydroponic systems, many different techniques can be practiced. These systems vary in their complexity and operating needs.

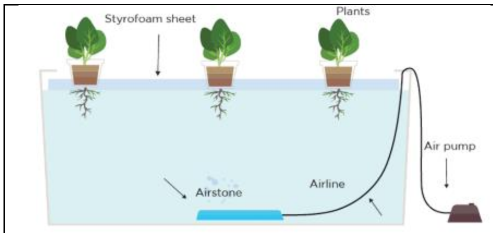


Figure 5. Hydroponics Deep Water Culture[10]

Deep water culture suspends the roots in a container with still water [See Figure 5]. This technique can be entirely pump-free, requiring only oxygenation. Air stones are commonly used for this purpose, though there are also alternative methods for oxygenation such as injection of liquid oxygen (LOx). It is one of the simplest hydroponic techniques, with relatively low upfront costs[7].

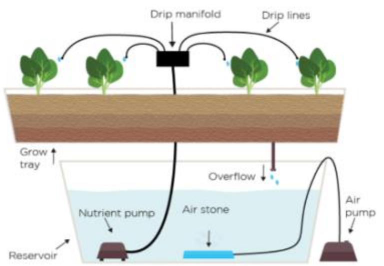


Figure 6. Hydroponics Drip System[8]

Drip hydroponic systems can be circulating or non-circulating. In these systems, a nutrient solution is pumped through tubes to the plant base, where drip emitters release adjustable flows, saturating the growing medium. Non-circulating systems ensure a consistent nutrient supply while circulating systems allow excess nutrients to flow back into the reservoir [See Figure 6]. The drip system allows for a very precise application of water, making drip systems one of the most water-efficient systems

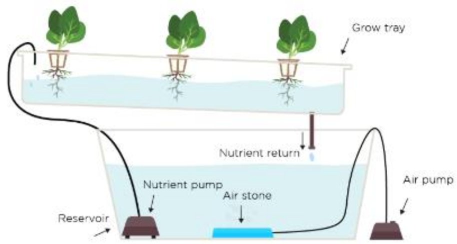


Figure 7. Hydroponics NFT System[11]

Nutrient-Film Technique, together with Deep Water Culture, forms one of the most used techniques in hydroponics. NFT applies a film of nutrient solution in a slightly slanted grow tray, where it encounters plant roots. Gravity causes the solution to flow through the slanted tray, returning to the reservoir at the end of the tray [see Figure 7]. Water pumps are used to bring the nutrient solution to the top of the growing tray, repeating the cycle.

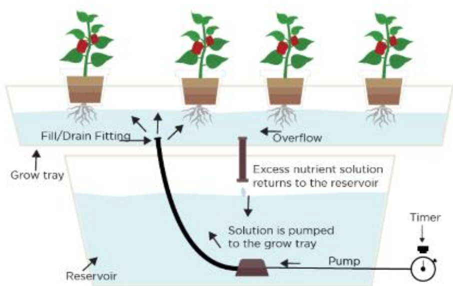


Figure 8. Hydroponics Systems Ebb-Flow[9]

Ebb-flow systems provide nutrients to the plants by flooding the grow tray with a nutrient solution. When the growing tray is flooded, the plant roots can take up nutrients from the solution. After a set time, the growing tray is drained, and the plant roots can take up oxygen from the surrounding air [see Figure 8]. This enables Ebb and flow systems to forego active oxygenation of the water[9].

Considerations

Beyond the specific hydroponic techniques, some considerations apply to all hydroponic systems. First, the temperature of the water is important for oxygenation and disease control. Cold water can hold more dissolved oxygen than warm water, so preventing the water temperature from increasing too much is vital[2]. Additionally, cooling the water also helps to control diseases. In this line, proper disease control is crucial for the longevity of any hydroponics project. Diseases can move easily through the water supply, forming a threat to crop health. Common methods to control diseases include pesticides, UV treatment, and ultrafiltration. Additionally, some emerging growing techniques require little to no treatment at all, instead relying on oxygenation and natural control[2,4,5]. Lastly, plants in hydroponic systems are generally anchored in a growing medium. Common growing media include rock wool, peat, coconut fibre, and perlite. Peat mixtures are currently one of the most frequently used media, due to their excellent growing properties[4]. However, the selection of a growing medium often comes down to local availability and price[7].

Annex 2. Methodology

Expert Interviews

For this policy brief, 10 experts from different fields (Academia, government, IIOO, private sector) were consulted through semi-structured interviews. The meetings were in real life or online, notes were taken during the interview and almost all interviews were recorded.

Table Interviews

No.	Institution	Topic	Country	Date
1.	Hydroponics Africa Limited	Low-tech hydroponic challenges and benefits	Kenya	15.11.23
2.	Research and innovation for Brazilian agriculture	Hydroponics in Brazil	Brazil	15.11.23
3.	TGS Agribusiness Solutions	Hydroponics benefits and challenges	The Netherlands	16.11.23
4.	Wageningen University & Research	Different systems of hydroponics	The Netherlands	17.11.23
5.	FAO	Hydroponic project in Jamaica	Jamaica	21.11.23
6.	Dutch Greenhouses	The market for hydroponics	The Netherlands	22.11.23
7.	ADAFSA	Hydroponics in UAE	UAE	23.11.23
8.	Dry Hydroponics	System of provision and challenges hydroponics	The Netherlands	24.11.23
9.	Kamala Farms	Hydroponics setup	India	28.11.23
10.	Botman Hydroponics	Disease pressure in hydroponics	The Netherlands	30.11.23

Literature review

Many articles were reviewed to require knowledge about hydroponics. The WUR library, Google Scholar, LinkedIn, and UN reports were used to find these articles. Search words included the following: “hydroponics”, “hydroponics systems”, “food security”, “benefits to hydroponics”, and “challenges to hydroponics”.

Future Analysis

To discover the potential of hydroponics, a future scenario analysis was conducted. These can foresee certain benefits and challenges to certain situations [See Figure 3]. These scenarios employ driving forces that would have an essential role in the future of hydroponics:

→ **Nature of provision system:** This represents the sourcing of materials, nutrients, pesticides, and fertilizer necessary to implement hydroponics. A farmer's ability to access all these inputs and to execute the supplier process, the implementation, and consummation within its reach, is represented by an integrated provision system. On the contrary, a fragmented provision system indicates that a farmer must import these inputs and cannot successfully carry out the procedure without employing scattered actors internationally.

→ **Level of hydroponic farm:** Hydroponics can be implemented on a household level, which suggests that the hydroponic farm is maintained by a single person/household/family. On a community level, the hydroponic system is maintained by more than one household.

→ **Materials:** The origin of materials for hydroponic systems can be either local or international, impacting accessibility and costs.

→ **Cost:** Costs are influenced by the need to import materials; especially as hydroponic systems advance towards higher technological aspects.

→ **Training:** Training includes practical skills for building and maintaining hydroponic farms, as well as a focus on the technological aspects, including research and development.

→ **Maintenance:** The difficulty of maintaining hydroponic farms increases with technological advancements, necessitating higher skills and expertise.

→ **People:** Hydroponic farms require a mix of experts and labor, with the demand for experts rising as technology advances. The size of hydroponic farms also determines the balance between skilled experts and laborers. These farms may seek external experts, potentially altering the ratio of labor and experts.

→ **Autonomy:** Hydroponic farms differ in autonomy, ranging from dependence on external materials and services to complete independence.

→ **Knowledge sharing:** Knowledge sharing can follow linear paths from external sources or circulate within, which can continuously improve innovation.

→ **Technology:** Hydroponic technology exists on a scale from high-tech solutions to low-tech systems, providing options based on resource availability and operational preferences.

Based on these driving factors, different micro scenarios were conceptualized with the two main driving factors plotted on the axes: **the nature of the provisioning system and the level of hydroponic farms.**

Scenario 1: "Home-based Hydroponic farming": In this scenario, the household operates within an integrated provision system, where the farmer achieves a significant level of autonomy. By utilizing locally sourced materials, the farmer establishes an affordable, low-tech hydroponic system that is simple to maintain. Within the household, there is a culture of knowledge sharing. The demand for people is equal, requiring a mix of both experts and labourers to effectively build and maintain the hydroponic farm.

Scenario 2: "Collaborative Community Farming": In the context of a circular integrated system on a community level, the emphasis is on achieving maximum independence and self-sufficiency in food production. This system relies on utilizing local knowledge, eliminating the need for external knowledge transfers. The growing demand of a community results in larger farms. As these farms expand, they incorporate more advanced hydroponic technologies. The integration of such technologies also presents opportunities for job creation within the community. This differs across both labour-intensive roles and positions requiring expert knowledge.

Scenario 3: "Commercial Hydroponic System": In a fragmented provision system, households rely on external inputs, making them dependent and resulting in increased material costs. While importing a hydroponic system from outside can eliminate the necessity for extensive internal expertise, it introduces an increased reliance on external experts. This dependence on external knowledge becomes a potential risk, particularly when the system encounters failures or requires maintenance. The careful balance between reducing the need for internal expertise and navigating the risks associated with external dependencies highlights the complexities of this scenario.

Scenario 4: "Scaling Hydroponic Farms": Within a fragmented system, a community strives to establish a large-scale, high-tech hydroponic farm. The community's ability to export both expertise and materials from external sources contributes to the scale and technical level of the project. However, this increase in size and advanced technology introduces inherent risks tied to external dependencies. Relying extensively on external inputs increases the community's vulnerability, particularly when circumstances prevent these imports. The possibilities of small setbacks lead to heightened risks, as they have the potential to lead to significant impacts due to the community's heightened dependence on external resources. Balancing ambition with the awareness of vulnerability becomes an important consideration in this scenario.

Annex 3. Case Hydroponics Africa Limited

The following tabs detail the different prices of the greenhouse structure and the necessary components a household would need to get started on hydroponics[6].

QUOTATION DETAILS: 8m by 30m GHS Structure (Empty)					
No.	Item	Description	U.O.M Quantity Unit	Unit Price (Ksh)	Total (Ksh)
1.	Wooden Greenhouse Structure	8m by 30m Empty	1	176,400	176,400
2.	Metallic Greenhouse Structure	8m by 30m Empty	1	337,000	337,000

*For indication: 1 Ksh = 0,0065 USD - 176 400 Ksh = 1 150,68 USD/ 337 000 = 2 198,30 USD

QUOTATION DETAILS: HYDRO-TROUGH SYSTEM UNDER NORMAL DRIP IRRIGATION					
Item	Description	U.O.M	Quantity	Unit Price (Ksh)	TOTAL (Ksh)
Hydro-Trough	UV-Treated	M^2	240	400	96,000
Dripline Piping					10,000
Hydroponic Media(pumice)	Inert media	Kg	10,000	10	100,000
Seedlings	Capsicum	Piece	1000	20	20,000
Hydroponic starter Nutrients	-	Kg	16	250	4000
Installation and Supervision	-	-	-	-	35,000
Total					**265,000**
Total for a wooden greenhouse					**441,400**
Total for a metallic greenhouse					**605,000**

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