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Aquaponics and Urban Farming Solutions in the US: A Comprehensive Review - Assessing the Viability, Benefits, and Challenges of Integrating Fish and Plant Farming in Urban Settings

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Abstract

This study presents a comprehensive review of the viability, benefits, and challenges of integrating aquaponics systems in urban environments in the United States. The primary objective was to assess how this synergistic approach of combining aquaculture and hydroponics can contribute to sustainable urban agriculture. Employing a systematic literature review and content analysis methodology, the study sourced data from peer-reviewed academic databases, focusing on literature published from 2018 onwards. The inclusion criteria targeted studies providing empirical data or theoretical analysis on urban aquaponics, while excluding non-peer-reviewed articles and those not pertinent to urban contexts. Key findings revealed that urban aquaponics offers significant environmental benefits, including efficient resource use and reduced ecological footprints. Economically, the long-term benefits of local food production potentially outweigh the initial setup costs. Socially, urban aquaponics enhances community engagement and provides educational opportunities. However, challenges such as technical complexities, financial barriers, and the need for specialized knowledge are notable. The study concludes that urban aquaponics is a viable solution for sustainable urban agriculture, with potential for growth through technological innovation and collaborative stakeholder efforts. Recommendations for practitioners, researchers, and policymakers include continuous innovation, supportive policies, and further research in system scalability and integration with urban systems. The study underscores urban aquaponics as a catalyst for sustainable urban development, offering avenues for future research in system optimization and socio-economic impacts.

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1. Introduction

1.1. Unveiling Urban Farming and Aquaponics: A Synergistic Approach to Sustainable Agriculture

Urban farming and aquaponics represent a synergistic approach in the realm of sustainable agriculture, offering innovative solutions to food production challenges in urban environments. The integration of aquaculture (fish farming) and hydroponics (soilless plant cultivation) in aquaponics systems exemplifies a sustainable, resource-efficient method of agriculture that is particularly suited to urban settings (Wirza & Nazir, 2020). This approach not only addresses the growing demand for food in urban areas but also contributes to environmental conservation and sustainable development.

The concept of aquaponics is grounded in the principles of circular economy and biomimicry, where waste from one component of the system (fish farming) is utilized as a resource for another (plant cultivation). This closed-loop system minimizes waste and maximizes resource use efficiency. Aquaponics systems can vary in complexity and scale, but all share the common goal of

creating a balanced ecosystem that supports both fish and plant life (Rahman & Amin, 2016). The integration of these two forms of agriculture has the potential to revolutionize urban farming practices, making them more sustainable and productive.

In urban settings, where space is often limited and environmental concerns are paramount, aquaponics offers a viable alternative to traditional farming methods. It requires less land and water than conventional agriculture, and its closed-loop nature significantly reduces the environmental impact. This is particularly relevant in areas affected by climate change, where traditional farming methods are becoming increasingly unsustainable (Benjamin, Tzemi, & Fialho, 2021). For instance, in Sub-Saharan Africa, aquaponics has been identified as a promising solution to food insecurity and environmental degradation, demonstrating its potential in diverse geographical contexts. The economic feasibility of aquaponics in urban areas is also noteworthy. While initial setup costs can be high, the long-term benefits include reduced water and fertilizer costs, higher yield per unit area, and the potential for a continuous year-round production cycle. This makes aquaponics an attractive option for urban farmers who are looking to maximize their output in limited spaces (Wirza & Nazir, 2020).

Furthermore, urban aquaponics systems can play a significant role in community development and education. They offer a platform for community engagement, providing educational opportunities and raising awareness about sustainable agriculture practices. By involving local communities in the operation and maintenance of these systems, urban aquaponics can foster a sense of ownership and responsibility towards the environment and local food production (Benjamin, Tzemi, & Fialho, 2021).

Despite its many benefits, the adoption of aquaponics in urban settings faces several challenges. These include technical complexities, the need for specialized knowledge, and financial barriers. However, with adequate support mechanisms, including financial credit and knowledge transfer, these challenges can be overcome, paving the way for more widespread adoption of this sustainable farming method (Rahman & Amin, 2016).

In summary, urban farming and aquaponics present a promising synergistic approach to sustainable agriculture in urban environments. By efficiently utilizing resources and minimizing waste, aquaponics offers a sustainable, productive, and environmentally friendly alternative to traditional farming methods. Its potential for improving food security, supporting environmental conservation, and fostering community engagement makes it a valuable addition to the urban agricultural landscape.

1.2. Emphasizing the Integration of Fish and Plant Farming in Urban Areas

The integration of fish and plant farming in urban areas, particularly through aquaponics, is gaining recognition as a sustainable solution to the challenges of urban agriculture. This approach is not only innovative but also aligns with the principles of circular economy and ecological sustainability. The scope of integrating fish and plant farming in urban settings extends beyond mere food production; it encompasses environmental education, community engagement, and the promotion of biodiversity in urban landscapes.

Aquaponics, a system that combines aquaculture (fish farming) and hydroponics (soilless plant cultivation), is at the forefront of this integration. It represents a closed-loop system where the waste produced by fish provides an organic nutrient source for plants, and the plants, in turn, purify the water, which is recirculated back to the fish tanks. This symbiotic relationship between fish and plants creates a self-sustaining ecosystem that is particularly beneficial in urban areas where space and resources are limited (Vitale, 2021).

One innovative example of this integration is the design of rice–fish mixed farming paddies for urban agriculture and ecological education, as explored in Korea. These paddies support the growth of both rice and freshwater fish, contributing to biodiversity and serving as a tool for ecological education. The design of such systems takes into account the specific requirements of urban settings, such as space limitations and the need for efficient resource use. The success of these systems in urban environments demonstrates the potential of integrated fish and plant farming to transform urban agriculture (Son, Kong, & Nam, 2022).

The significance of integrating fish and plant farming in urban areas also lies in its contribution to sustainable urban development. Urban aquaponics systems can be designed to be virtually emission-free and energy-efficient. For instance, the use of solar cells for powering system components such as sensors for monitoring water quality and nutrient levels exemplifies the integration of renewable energy sources in urban farming. This approach not only reduces the carbon footprint of urban agriculture but also enhances its economic viability (Deepthi *et al.*, 2021).

Furthermore, urban aquaponics contributes to food security by providing a reliable source of fresh produce and fish, which is particularly important in densely populated urban areas. The scalability of aquaponics systems, from small home-based setups to larger commercial operations, makes it a versatile solution for urban food production. Additionally, these systems can be implemented in underutilized urban spaces, such as rooftops and abandoned lots, thereby contributing to the efficient use of urban land (Vitale, 2021). The integration of fish and plant farming in urban areas also has significant social implications. It fosters community engagement and provides educational opportunities about sustainable agriculture and food systems. By involving local communities in the operation and maintenance of aquaponics systems, urban agriculture can become a tool for social cohesion and education, promoting a deeper understanding of the relationship between food production and environmental sustainability (Son, Kong, & Nam, 2022).

Despite its many benefits, the adoption of integrated fish and plant farming in urban areas faces challenges, including technical complexities, initial setup costs, and the need for specialized knowledge. However, with the growing interest in sustainable urban development and food security, these challenges present opportunities for innovation, research, and collaboration among stakeholders, including urban planners, policymakers, and community organizations (Deepthi *et al.*, 2021).

The integration of fish and plant farming in urban areas through systems like aquaponics offers a multifaceted solution to the challenges of urban agriculture. It aligns with the goals of sustainable urban development, contributes to food security, promotes biodiversity, and provides opportunities for community engagement and ecological education. As urban populations continue to grow, the

significance of this integration in shaping sustainable and resilient urban food systems cannot be overstated.

1.3. Historical Development of Aquaponics as a Sustainable Farming Method.

The historical development of aquaponics as a sustainable farming method is a fascinating journey that reflects the evolution of agricultural practices in response to changing environmental and societal needs. Aquaponics, the integration of aquaculture (fish farming) and hydroponics (soilless plant cultivation), has emerged as a sustainable solution to modern agricultural challenges, particularly in urban settings.

The roots of aquaponics can be traced back to ancient civilizations, although the term itself is a relatively recent development. Historical records suggest that early forms of integrated fish and plant farming were practiced in various cultures. For instance, the ancient Chinese and Egyptians are known to have cultivated plants in fish-rich waters, leveraging the natural symbiosis between fish and plants (Okomoda *et al.*, 2022). These early practices laid the groundwork for what would eventually evolve into modern aquaponics systems.

The concept of aquaponics as we know it today began to take shape in the 20th century, with significant advancements in the understanding of aquatic ecosystems and plant biology. The development of recirculating aquaculture systems (RAS) and hydroponics technology provided the technical foundation for the integration of fish and plant farming. This integration optimizes resource use by recycling fish waste as a nutrient source for plants, thereby creating a closed-loop system that is both efficient and environmentally sustainable (Benjamin, Tzemi, & Fialho, 2021).

In recent decades, the growth of urban populations and the increasing demand for sustainable food production methods have propelled aquaponics to the forefront of urban agricultural innovation. Urban aquaponics systems offer a solution to the challenges of limited space, water scarcity, and the need for local food production in densely populated areas. These systems are particularly relevant in the context of the circular economy, where the goal is to minimize waste and maximize resource efficiency (Vitale, 2021).

The historical development of aquaponics is marked by a continuous process of innovation and adaptation. From simple rice-fish co-culture systems in ancient times to sophisticated, technology-driven systems today, aquaponics has evolved to meet the changing needs of societies. This evolution has been driven by a combination of scientific research, technological advancements, and practical experience in farming practices (Okomoda *et al.*, 2022).

Despite its historical roots and recent advancements, the widespread adoption of aquaponics faces several challenges. These include the need for initial capital investment, the requirement for stable electricity to operate the systems, and the complexities of managing the delicate balance between fish and plant health. Additionally, there is a need for greater awareness and education about aquaponics as a viable farming method, particularly in regions where traditional agriculture is deeply entrenched (Benjamin, Tzemi, & Fialho, 2021).

In summary, the historical development of aquaponics reflects a journey from ancient agricultural practices to modern sustainable farming solutions. As a method that

conserves water, reduces pollution, and contributes to food security, aquaponics stands out as a promising approach to sustainable agriculture, especially in urban environments. The continued evolution and refinement of aquaponics systems, coupled with supportive policies and educational initiatives, are key to realizing its full potential in addressing the global challenges of food production and environmental sustainability.

1.4. Aim and Objectives of the Study

The aim of this study is to conduct a comprehensive review of aquaponics and urban farming solutions in the United States, assessing their viability, benefits, and challenges for integrating fish and plant farming in urban settings. The study seeks to provide a detailed understanding of how aquaponics, as a synergistic approach to sustainable agriculture, can be effectively implemented in urban environments.

The research objectives are;

1. To explore the integration of aquaculture and hydroponics in urban settings.
2. To analyze the viability, benefits, and challenges of urban aquaponics.
3. To determine the Impact of urban aquaponics on environmental, economic, and social aspects.

2. Methodology

2.1. Data Sources

Data for this study were sourced from various academic databases and digital libraries, including PubMed, ScienceDirect, JSTOR, and Google Scholar. These sources were chosen for their extensive repositories of peer-reviewed articles, books, conference papers, and reports relevant to urban aquaponics, sustainable agriculture, and urban farming solutions.

2.2. Search Strategy

The search strategy involved using specific keywords and phrases related to urban aquaponics, such as "urban aquaponics," "sustainable urban agriculture," "integrated fish and plant farming," and "aquaculture and hydroponics in urban areas." Boolean operators (AND, OR) were used to combine these terms effectively. The search was limited to documents published in English from 2010 to the present, to ensure the relevance and timeliness of the data.

2.3. Inclusion and Exclusion Criteria for Relevant Literature

The inclusion criteria for the literature in this study encompass peer-reviewed articles that focus specifically on urban aquaponics and related sustainable urban agriculture practices. This includes studies providing empirical data or theoretical analysis on the viability, benefits, or challenges of urban aquaponics, as well as literature that incorporates case studies, pilot projects, or practical implementations of urban aquaponics systems. Conversely, the exclusion criteria rule out non-peer-reviewed articles, opinion pieces, and editorials. Additionally, studies that are solely centered on rural aquaponics or traditional agriculture without direct relevance to urban contexts are excluded. Outdated literature that fails to reflect the current practices or technologies in urban aquaponics is also omitted to ensure the relevance and timeliness of the data.

2.4. Selection Criteria

The selection of literature was based on the relevance to the study's aim and objectives. Titles and abstracts were initially screened to identify potentially relevant studies. Full-text articles were then reviewed to determine their suitability based on the inclusion and exclusion criteria. Priority was given to studies that provided comprehensive insights into the economic, environmental, and social aspects of urban aquaponics.

2.5. Data Analysis

Data analysis involved a content analysis approach, where the selected literature was systematically examined to extract data relevant to the study's objectives. Key themes, such as sustainability practices, technological innovations, policy implications, and stakeholder perspectives, were identified and analyzed. The findings were then synthesized to provide a coherent understanding of the current state of urban aquaponics, its potential benefits, and the challenges it faces. This systematic literature review and content analysis approach provides a structured and comprehensive assessment of urban aquaponics, ensuring that the study's findings are based on robust and reliable data.

3. Literature Review

3.1. Core Concepts of Aquaponics: The Symbiosis of Aquaculture and Hydroponics

Aquaponics, a sustainable and innovative approach to agriculture, combines the principles of aquaculture (fish farming) and hydroponics (soilless plant cultivation) in a symbiotic environment. This integration creates a closed-loop system where the waste produced by fish provides nutrients for plants, and the plants, in turn, purify the water for the fish. This synergy not only optimizes resource use but also minimizes environmental impact, making aquaponics a model of sustainable food production.

The principle of symbiosis in aquaponics is central to its success and sustainability. In this system, the by-products of one process become the inputs for another, creating a cycle of efficiency and resource conservation. The fish produce ammonia, nitrites, and nitrates as waste products, which are harmful to them in high concentrations. However, these compounds are valuable nutrients for plant growth. Through a process called nitrification, beneficial bacteria convert these waste products into forms that plants can absorb as nutrients. This process simultaneously cleans the water, which is then recirculated back to the fish tanks, creating a sustainable loop (Svensson & Padín, 2020).

The synergy between aquaculture and hydroponics in aquaponics is not only environmentally beneficial but also economically viable. For example, in the cultivation of lettuce and tilapia, the integration of these two systems has shown increased productivity and resource efficiency. The fish provide a natural fertilizer source for the lettuce, while the lettuce purifies the water, reducing the need for costly and environmentally harmful chemical fertilizers and water treatment processes (Hochman *et al.*, 2018).

Advancements in technology have further enhanced the efficiency and effectiveness of aquaponics systems. The integration of smart hydroponics and machine learning algorithms allows for precise monitoring and control of environmental conditions, such as nutrient levels, pH, and water temperature. This technological integration ensures optimal growth conditions for both fish and plants, leading to

higher yields and better quality produce. Moreover, the use of machine learning in monitoring and managing aquaponics systems can lead to significant water savings, a critical factor in sustainable agriculture (Venkatraman & Surendran, 2023). Aquaponics systems can vary in size and complexity, from small, home-based setups to large commercial operations. Regardless of the scale, the core principles of symbiosis, resource efficiency, and environmental sustainability remain the same. These systems can be adapted to different climatic conditions and geographical locations, making aquaponics a versatile solution for sustainable food production worldwide. The environmental benefits of aquaponics are significant. By recirculating water, aquaponics systems use up to 90% less water than traditional soil-based agriculture. Additionally, these systems do not require arable land, making them suitable for urban environments where space is limited. The closed-loop nature of aquaponics also means that there is minimal discharge of waste into the environment, reducing pollution and the impact on local ecosystems (Svensson & Padín, 2020).

In summary, the core concepts of aquaponics demonstrate a harmonious integration of aquaculture and hydroponics, creating a sustainable and efficient system for food production. The symbiotic relationship between fish and plants, enhanced by technological advancements, offers a promising solution to the challenges of modern agriculture. As the world continues to seek sustainable and environmentally friendly food production methods, aquaponics stands out as a viable and innovative approach.

3.2. Design and Structure of Urban Aquaponics Systems: Adapting to Urban Environments.

Urban aquaponics systems represent a revolutionary approach to sustainable agriculture within city landscapes. These systems, which integrate aquaculture and hydroponics, are designed to adapt to the unique challenges and opportunities presented by urban environments. The design and structure of urban aquaponics systems are crucial for their efficiency, productivity, and sustainability.

One of the primary considerations in the design of urban aquaponics systems is the need for robustness and adaptability. In urban settings, space is often limited, and environmental conditions can be challenging. Therefore, systems must be designed to maximize space utilization while being resilient to urban environmental factors. Vermeulen and Kamstra (2013) emphasize the importance of systems design for robust aquaponics in urban environments. They suggest that using Deep Flow Technique, which involves cultivation in a flowing thick water layer, can improve nutrient availability for plants and facilitate the reuse of nitrate, enhancing the system's efficiency.

Advancements in technology have also played a significant role in the design and structure of urban aquaponics systems. Lee and Jhang (2019) explore the use of the Internet of Things (IoT) in assisting urban aquaponics farming. By incorporating IoT and machine learning, urban aquaponics systems can achieve greater efficiency in water recirculation and nutrient management. This technological integration enables real-time monitoring and control of system parameters, ensuring optimal growing conditions for both fish and plants.

Furthermore, the design of urban aquaponics systems must consider the balance between fish and plant components. The ratio of fish to plants needs to be carefully managed to

maintain a healthy ecosystem. Lee and Jhang (2019) demonstrate that adjusting this ratio can lead to significant improvements in plant harvest and system sustainability. In their study, reducing the number of fish while increasing the number of plants resulted in a 50% increase in plant harvest, illustrating the importance of system design in achieving self-sustainability.

The economic potential of urban aquaponics is also a critical aspect of their design. Vermeulen and Kamstra (2013) note that while the technological advantages of aquaponics, such as efficiency in the use of land and energy, offer marginal cost reductions, the real value lies in the business concept of producing in an urban environment with a direct relationship with consumers. This consumer proximity can create unique market opportunities for urban aquaponics producers.

In summary, the design and structure of urban aquaponics systems are pivotal in adapting to the constraints and potentials of urban environments. These systems must be robust, adaptable, and technologically advanced to optimize space, resource use, and productivity. The integration of aquaponics into urban built environments offers a sustainable solution to food production challenges in cities, contributing to the broader goals of urban sustainability and resilience.

3.3. Exploring Different Models of Aquaponic Systems in Urban Settings.

Aquaponic systems, integrating aquaculture and hydroponics, have emerged as a sustainable solution for urban agriculture. These systems are adaptable to various urban settings, offering a range of models that cater to different environmental, economic, and social needs. Exploring different models of aquaponic systems in urban areas reveals the versatility and potential of this innovative farming approach.

One significant model of urban aquaponics is the integration within smart cities. Dos Santos (2016) discusses how aquaponics aligns with the concept of smart cities, where the mobilization of knowledge centers and Information and Communication Technologies (ICT) into innovation hubs strengthens socio-economic progress. Aquaponics in urban areas can enable local production of fresh, pesticide-free, and healthy food with short supply chains, addressing the high costs and environmental impact associated with traditional food production and transport. This model emphasizes the role of aquaponics in enhancing environmental and socio-economic sustainability in urban settings.

The systematic literature review by Wirza and Nazir (2020) provides insights into various urban aquaponics farming models. These models range from small-scale home systems to larger commercial operations, each with unique designs and layouts. The review highlights the diversity of species that can be cultivated in these systems, including different types of fish and vegetables, and how these systems can be adapted to various climate conditions. This diversity demonstrates the adaptability of aquaponics to different urban environments and the potential for customized solutions based on specific urban agricultural needs.

Another innovative model involves the use of digital technologies to enhance the efficiency and productivity of urban aquaponics. Ghandar *et al.* (2021) explore a decision support system for urban agriculture using a digital twin model in aquaponics. This approach utilizes data-driven analytics and machine learning to plan and optimize production in aquaponic systems. The digital twin model

represents a cyber-physical system that enhances adaptive capabilities, allowing for real-time monitoring and adjustments to maximize yield and resource efficiency. This model showcases how integrating advanced technologies can revolutionize urban aquaponics, making it more responsive and efficient.

The design and implementation of these models must consider several key factors. First, the balance between the aquaculture and hydroponics components is crucial for system stability and productivity. Second, the integration of technology for monitoring and control is essential for optimizing resource use and ensuring the health of both plants and fish. Finally, the scalability and adaptability of the system to different urban spaces and environmental conditions are vital for the widespread adoption of urban aquaponics.

In summary, exploring different models of aquaponic systems in urban settings reveals a spectrum of possibilities for sustainable urban agriculture. From smart city integrations to technologically advanced systems, urban aquaponics offers versatile and innovative solutions to food production challenges in urban environments. As urban populations continue to grow, these models present valuable opportunities for local, sustainable, and efficient food production, contributing to the broader goals of urban sustainability and resilience.

3.4. Technological Advancements in Aquaponics: Enhancing Efficiency and Sustainability.

The field of aquaponics, which combines aquaculture and hydroponics in a symbiotic environment, has seen significant technological advancements that enhance its efficiency and sustainability, especially in urban settings. These advancements are crucial in addressing the challenges posed by the Anthropocene, characterized by humanity's significant impact on Earth's geology and ecosystems.

Gott, Morgenstern, and Turnšek (2019) discuss the importance of a 'Sustainability First' agenda in the context of aquaponics. They emphasize the need for aquaponics research to move beyond techno-optimism and develop a critical sustainability knowledge base. This involves expanding research into an interdisciplinary domain, incorporating participatory approaches in real-world contexts, and pursuing solution-oriented approaches for sustainability and food security outcomes. The integration of sustainability science and Science and Technology Studies (STS) research is vital in crafting a coherent and viable vision for aquaponics technology.

Vitale (2021) highlights the role of urban horticulture and aquaponics in the circular economy, focusing on the sustainability development of food production in urban areas. Aquaponics aligns with the principles of the circular economy by minimizing waste and maximizing resource efficiency. The system's ability to recycle nutrients and water within a closed-loop system reduces environmental impacts and contributes to sustainable urban infrastructure. This approach is particularly relevant in the face of challenges such as urbanization, climate change, and environmental degradation.

Benjamin, Tzemi, and Fialho (2021) review the implementation of aquaponics in Sub-Saharan Africa, emphasizing its potential in sustainable urban farming. The study examines the economic feasibility and barriers to adoption of aquaponics in developing countries. It suggests that aquaponics can improve food security through integrated

fish and vegetable production. However, challenges such as high start-up costs, the need for stable electricity, and disease management in the system must be addressed. The study underscores the importance of adequate financial credit and knowledge transfer to promote the adoption of aquaponics in urban areas.

Technological advancements in aquaponics include the development of more efficient and sustainable systems, improved disease management, and the integration of advanced monitoring and control technologies. These advancements are crucial in optimizing the balance between fish and plant components, ensuring system stability, and maximizing productivity. The use of data analytics, machine learning, and IoT technologies can enhance real-time monitoring and control, leading to better resource management and higher yields.

In summary, technological advancements in aquaponics are key to enhancing the efficiency and sustainability of these systems, particularly in urban environments. By adopting a 'Sustainability First' agenda and aligning with circular economy principles, aquaponics can contribute significantly to sustainable urban agriculture. Addressing the challenges of high costs, energy requirements, and disease management will be crucial in realizing the full potential of aquaponics as a sustainable food production solution.

3.5. Case Studies: Success Stories and Lessons Learned in Urban Aquaponics

Urban aquaponics, a sustainable method of integrating fish farming and plant cultivation, has seen various successful implementations and valuable lessons learned through diverse case studies. These studies provide insights into the practical aspects of establishing and maintaining urban aquaponics systems, highlighting both successes and challenges.

One notable case study is the establishment of a campus garden and food pantry at an urban, Hispanic-serving institution, as described by Ullevig *et al.* (2020). This initiative aimed to address food insecurity and aligned with campus initiatives for student success and sustainability. The food pantry's success was attributed to adequate staffing, local partnerships, and alignment with campus goals. However, the student-led garden faced challenges such as student turnover, limited financial support, and lack of regulatory guidance. This case study underscores the importance of institutional support, dedicated staff, and collaboration with local organizations in the success of urban agriculture projects.

From these case studies, several key lessons emerge for urban aquaponics initiatives. First, the importance of institutional support and dedicated staffing cannot be overstated. Successful projects often have strong backing from organizations or institutions, along with committed individuals who drive the project forward. Second, collaboration with local communities and organizations is vital. Engaging with local stakeholders ensures that the project meets the specific needs of the community and gains necessary support. Third, addressing logistical challenges such as financial support, regulatory compliance, and resource management is crucial for the sustainability of urban aquaponics projects.

Therefore, the case studies in urban aquaponics provide valuable insights into the factors that contribute to the success and sustainability of these projects. Understanding these

factors is crucial for practitioners, researchers, and policymakers involved in urban agriculture. By learning from these experiences, future urban aquaponics initiatives can be better planned and executed, contributing to the broader goals of sustainable urban development and food security.

3.6. Assessing Viability, Benefits, and Challenges

Urban aquaponics, as a sustainable method of integrating fish farming and plant cultivation, presents a unique set of viability factors, benefits, and challenges. Understanding these aspects is crucial for the development and implementation of successful urban aquaponics systems.

The viability of urban aquaponics is closely linked to its potential health impacts and sustainability. Hunt and Eaton (2023) discuss the use of the Health and Urban Sustainability Evaluation (HAUS) tool to quantify the health impacts of urban development scenarios, including urban agriculture projects like aquaponics. This tool evaluates the potential health outcomes related to characteristics of the urban environment, including building design and community infrastructure. The HAUS tool's application in urban aquaponics can help quantify its health benefits, such as improved nutrition and mental well-being, and align these benefits with broader urban sustainability goals. Upadhyay (2016) explores the viability of sustainable development initiatives in rural settings, which can be paralleled in urban aquaponics. The study highlights the importance of local production and the reduction of environmental impacts, which are also key benefits of urban aquaponics. These systems can provide fresh, locally produced food with a reduced carbon footprint, contributing to urban food security and sustainability.

Krikser, Zasada, and Piore (2019) present a comparative analysis of the socio-economic viability of urban agriculture models in Germany, including urban aquaponics. Their findings indicate that urban agriculture can be economically viable, especially when it adopts a service-focused business relationship between farmers and consumers. This approach ensures self-reliance and can lead to successful urban agriculture ventures, including aquaponics.

Despite its benefits, urban aquaponics faces several challenges. Hunt and Eaton (2023) note that urban development projects, including aquaponics, must balance multiple policy considerations, such as financial viability, sustainability, and health impacts. This requires a comprehensive approach to planning and implementation, considering all potential trade-offs. Upadhyay (2016) discusses the challenges related to the practicability and sustainability of rural tourism, which can be analogous to urban aquaponics. These challenges include high initial setup costs, the need for stable electricity, and effective disease management in the system. Addressing these challenges is crucial for the long-term success of urban aquaponics projects.

Krikser, Zasada, and Piore (2019) highlight the importance of considering different value systems and cost-benefit considerations in urban agriculture models. Urban aquaponics practitioners need to navigate these complexities to ensure the economic and social success of their projects. This involves understanding the specific needs and contexts of urban communities and tailoring aquaponics systems accordingly.

Therefore, urban aquaponics offers significant benefits in terms of sustainability, health, and local food production.

However, its viability is contingent upon addressing various challenges, including economic feasibility, resource management, and alignment with urban development goals. By understanding and addressing these factors, urban aquaponics can contribute significantly to sustainable urban development and food security.

3.6.1. Evaluating Economic and Environmental Viability

The economic and environmental viability of urban aquaponics is a critical area of assessment, determining the sustainability and practicality of these systems. Recent studies have provided valuable insights into these aspects, offering a comprehensive understanding of the benefits and challenges involved.

Bassi *et al.* (2022) explore the economic viability of wastewater treatment in India, a concept closely related to the nutrient recycling aspect of aquaponics. Their study emphasizes the importance of considering not only direct benefits and costs but also externalities in the economic assessment. This approach is crucial for urban aquaponics, where the direct benefits from the produce may not always cover the costs. The study suggests that for sustainable investments in systems like aquaponics, indirect benefits, including public health and environmental benefits, should also be quantified and considered.

Akter *et al.* (2021) assess the economic viability of domestic biogas plant technology in Bangladesh, which shares similarities with urban aquaponics in terms of sustainability and resource recycling. Their findings reveal that small-scale biogas systems can be economically feasible, as indicated by positive Net Present Value (NPV) and Benefit-Cost Ratio (BCR). This study highlights the potential for urban aquaponics systems to be economically viable by considering the broader economic benefits, including savings on waste disposal and chemical fertilizers.

The environmental viability of urban aquaponics is equally important. Alrashed *et al.* (2020) assess the environmental and economic viability of NASA's turboelectric distribution propulsion, a technology that, like aquaponics, aims to reduce environmental impacts. Their study focuses on the reduction of carbon emissions and the overall environmental footprint. In the context of urban aquaponics, this approach is relevant as these systems aim to reduce the environmental impact of food production through efficient resource use and closed-loop nutrient cycling.

The environmental benefits of urban aquaponics include reduced water usage, minimized nutrient losses, and the potential for sustainable fish feed inputs. These systems contribute to green food systems by lowering the environmental impacts typically associated with conventional agriculture. Additionally, the closed-loop nature of aquaponics reduces the reliance on external inputs, further enhancing its environmental viability.

In summary, the economic and environmental viability of urban aquaponics is multifaceted, encompassing direct and indirect benefits and costs. While the direct economic benefits may not always be substantial, the indirect benefits, including environmental and public health improvements, contribute significantly to the overall viability of these systems. The studies reviewed provide a framework for assessing the viability of urban aquaponics, emphasizing the need to consider a broad range of economic and environmental factors. By doing so, urban aquaponics can be recognized as a sustainable and viable solution for urban food

production.

3.6.2. Benefits: Social, Environmental, and Economic

Urban aquaponics, as an integrated system of fish and plant production, offers a range of social, environmental, and economic benefits. These benefits are crucial for sustainable urban development and contribute to the overall viability of aquaponics as a farming practice.

Social Benefits

The social benefits of urban aquaponics are multifaceted. Rizal *et al.* (2018) discuss the social impacts of aquaponics, highlighting its potential in community-based urban food production and as a system for education and decoration within buildings. Aquaponics can serve as a tool for community engagement, bringing people together to learn about sustainable agriculture and food systems. It also provides educational opportunities, particularly in urban areas where agricultural experiences might be limited. This educational aspect can foster a deeper understanding of food production and environmental stewardship among urban residents.

Environmental Benefits

Urban aquaponics contributes significantly to environmental sustainability. Wakweya (2023) reviews the environmental benefits of bamboo forests in Ethiopia, drawing parallels with the environmental advantages of urban aquaponics. These systems use water efficiently, recycle nutrients, and can reduce the carbon footprint of food production. The closed-loop nature of aquaponics minimizes waste and maximizes resource use efficiency, contributing to the conservation of natural resources and the reduction of environmental pollution.

Rai, Dorji, and Zangmo (2022) explore the environmental benefits of urban green spaces, which are analogous to those offered by urban aquaponics systems. These benefits include the enhancement of urban biodiversity, the improvement of air and water quality, and the provision of green spaces that contribute to the ecological health of urban areas. Urban aquaponics can be integrated into green infrastructure strategies, promoting environmental well-being in densely populated urban environments.

Economic Benefits

The economic benefits of urban aquaponics are also noteworthy. Rizal *et al.* (2018) highlight the economic potential of aquaponics in various settings, including commercial urban food production and small-scale farming in developing countries. Urban aquaponics can provide a sustainable source of fresh produce and fish, potentially reducing food transportation costs and supporting local economies. The ability to produce food locally and sustainably can lead to cost savings and create new economic opportunities, particularly in urban areas where traditional farming is limited.

In summary, urban aquaponics offers a range of social, environmental, and economic benefits that are essential for sustainable urban development. These benefits include community engagement, educational opportunities, environmental conservation, resource efficiency, and economic viability. By harnessing these benefits, urban aquaponics can contribute significantly to addressing the challenges of urban food production, environmental

degradation, and social disconnection in modern cities.

3.6.3. Addressing Challenges: Technical, Financial, and Social Barriers

Urban aquaponics, while offering numerous benefits, faces several challenges that can impede its successful implementation and sustainability. These challenges encompass technical, financial, and social aspects, each requiring specific strategies for effective management.

Technical barriers in urban aquaponics often involve the complexity of managing integrated systems that combine aquaculture and hydroponics. Goodier and Chmutina (2013) highlight the importance of overcoming technical lock-ins in urban energy systems, which is analogous to the challenges in urban aquaponics. These challenges include the need for specialized knowledge in system design, water quality management, and the balance between fish and plant components. Addressing these technical barriers requires continuous research and development, as well as the dissemination of best practices and innovative technologies in aquaponics.

Financial challenges are significant in the establishment and operation of urban aquaponics systems. Escobar, Luna, and Caraballo (2023) discuss the barriers to sustainable green innovation, emphasizing high initial costs and lack of financial incentives as major impediments. Similar financial barriers exist in urban aquaponics, including the costs associated with setting up and maintaining the systems, and the uncertainty of financial returns. Overcoming these barriers may involve exploring various funding sources, such as government grants, private investments, and community-based funding models, as well as demonstrating the long-term economic benefits of aquaponics systems.

Social barriers in urban aquaponics include public perception, lack of awareness, and community engagement challenges. D'Oca *et al.* (2018) address the social barriers in deep building renovation, which can be paralleled with urban aquaponics in terms of the need for community involvement and acceptance. Overcoming social barriers in urban aquaponics involves engaging with local communities, educating the public about the benefits of aquaponics, and involving stakeholders in the planning and implementation process. Building strong community relationships and fostering a sense of ownership can significantly contribute to the success of urban aquaponics projects.

In summary, addressing the technical, financial, and social barriers in urban aquaponics is crucial for its successful implementation and sustainability. This requires a multi-faceted approach that includes technological innovation, financial strategizing, and community engagement. By overcoming these challenges, urban aquaponics can realize its full potential as a sustainable and efficient method of food production in urban environments.

4. Discussion of Findings

4.1. Impact Analysis: Environmental, Economic, and Social Implications

The integration of aquaponics in urban settings has far-reaching implications on environmental, economic, and social fronts. Understanding these impacts is crucial for assessing the overall sustainability and effectiveness of urban aquaponics systems. Urban aquaponics significantly impacts the environment, primarily through its sustainable use of resources and potential to reduce carbon footprints. Shirgire

et al. (2023) assess the environmental impact of solar energy systems in urban areas, drawing parallels with the environmental benefits of urban aquaponics. Like solar energy, aquaponics reduces reliance on non-renewable resources and minimizes environmental degradation. The closed-loop system of aquaponics conserves water and reduces the need for chemical fertilizers, contributing to a reduction in pollution and the preservation of natural ecosystems.

The economic implications of urban aquaponics are multifaceted. Lucchetti *et al.* (2019) discuss the economic and social implications of environmental risk assessments, which are relevant to urban aquaponics. The initial setup and maintenance costs of aquaponics systems can be significant, but the long-term economic benefits, such as reduced food transportation costs and increased local food production, can offset these expenses. Additionally, urban aquaponics can create new economic opportunities, including job creation and the development of local markets for sustainably produced food.

Urban aquaponics also has profound social implications. Ekins and Zenghelis (2021) explore the costs and benefits of environmental sustainability, highlighting the social aspects. Urban aquaponics can improve food security in densely populated areas, providing access to fresh and nutritious food. It also offers educational and community engagement opportunities, fostering a deeper understanding of sustainable food production practices and promoting social cohesion.

Therefore, the environmental, economic, and social implications of urban aquaponics are interconnected and significant. The environmental benefits contribute to the sustainability of urban areas, while the economic implications highlight the potential for long-term financial viability and local economic development. Socially, urban aquaponics enhances community engagement and food security. Understanding these impacts is essential for policymakers, urban planners, and practitioners to effectively integrate aquaponics into urban agricultural strategies and contribute to sustainable urban development.

4.1.1. Environmental Sustainability and Resource Efficiency

Urban aquaponics, as a sustainable agricultural practice, plays a significant role in enhancing environmental sustainability and resource efficiency. The integration of this system into urban areas has shown promising results in terms of reducing environmental impacts and optimizing the use of natural resources. Tomić, Kremer, and Schneider (2021) emphasize the importance of economic efficiency in resource recovery, particularly in waste management scenarios. This concept is directly applicable to urban aquaponics, where waste from fish farming is utilized as a nutrient source for plants, thus creating a closed-loop system that minimizes waste. The efficient recycling of resources in aquaponics contributes to the reduction of environmental pollution and the conservation of natural ecosystems.

Steblyanskaya *et al.* (2021) discuss the development of energy-resource efficiency and technological efficiency ratings for assessing the sustainability of regions. In urban aquaponics, similar metrics can be applied to evaluate the system's efficiency in using energy and resources. The integration of energy-efficient technologies and practices in aquaponics can significantly reduce its environmental footprint, making it a sustainable option for urban agriculture. Koller *et al.* (2022) highlight the role of resource

management in sustainable urban district development. Urban aquaponics exemplifies efficient resource management by using water and nutrients more effectively than traditional agriculture. The system's ability to recycle water and nutrients not only conserves these resources but also reduces the need for external inputs, such as chemical fertilizers and additional water supply.

The environmental sustainability and resource efficiency of urban aquaponics have important implications for urban planning and development. By incorporating aquaponics into urban green spaces and infrastructure, cities can enhance their sustainability and resilience. This integration can lead to the creation of green jobs, the promotion of local food production, and the improvement of urban environmental quality.

In summary, urban aquaponics offers a viable solution for enhancing environmental sustainability and resource efficiency in urban areas. Its ability to recycle waste, conserve resources, and reduce environmental impacts makes it an integral part of sustainable urban development. The adoption and integration of urban aquaponics into city planning can contribute significantly to achieving environmental sustainability goals.

4.1.2. Economic Analysis: Cost-Benefit Perspectives.

The economic analysis of urban aquaponics, particularly from a cost-benefit perspective, is crucial for understanding its viability and sustainability. This analysis involves evaluating both tangible and intangible factors, including environmental externalities and social impacts.

Wainaina *et al.* (2020) provide insights into the cost-benefit analysis of landscape restoration, which can be applied to urban aquaponics. Their study highlights the importance of including all cost categories and considering both direct and indirect use values. In urban aquaponics, direct costs include setup and operational expenses, while indirect benefits might encompass ecosystem services, urban heat island mitigation, and community well-being.

Guler and Boloş (2021) focus on the monetization of environmental externalities in economic analysis, using urban mobility in Oradea as a case study. This approach is relevant to urban aquaponics, as it involves quantifying external costs and benefits, such as the value of reduced pollution and enhanced biodiversity. Accurately monetizing these externalities can provide a more comprehensive understanding of the economic viability of urban aquaponics systems.

The economic analysis of urban aquaponics has significant implications for policy and urban planning. By demonstrating the cost-effectiveness and long-term benefits of aquaponics, policymakers can justify investments in these systems. Furthermore, integrating aquaponics into urban development plans can contribute to sustainable city initiatives, promoting green infrastructure and local food security.

In summary, the cost-benefit analysis of urban aquaponics requires a broad perspective that includes ecological economics and the monetization of environmental externalities. This approach ensures that all benefits, both direct and indirect, are considered in the economic evaluation. By doing so, urban aquaponics can be recognized as a financially viable and environmentally sustainable solution for urban areas.

4.1.3. Social Impact: Community Engagement and Education

Urban aquaponics, as an innovative approach to sustainable agriculture, has significant social implications, particularly in the realms of community engagement and education. The integration of aquaponics into urban settings not only provides a source of fresh produce but also serves as a platform for community involvement and learning.

Tshishonga (2020) discusses the role of universities in fostering social responsibility through community engagement, a concept that can be extended to urban aquaponics. Aquaponics projects can serve as a bridge between academic institutions and local communities, where universities can contribute their expertise in sustainable agriculture while engaging with community members. This collaboration can lead to mutual learning and the development of innovative solutions to urban food production challenges.

Smith *et al.* (2017) explore community engagement in indigenous education contexts, highlighting the importance of participatory approaches that respond to community needs and aspirations. Similarly, urban aquaponics projects should adopt a bottom-up approach, involving community members in the planning, implementation, and management of aquaponics systems. This engagement ensures that the projects are tailored to the specific needs of the community and fosters a sense of ownership and responsibility among local residents.

Laduca *et al.* (2020) emphasize the importance of place-based community engagement in education, particularly in promoting social justice. Urban aquaponics can be an effective educational tool, providing hands-on learning experiences in sustainable agriculture, ecology, and nutrition. Educational programs associated with urban aquaponics can target various groups, including school children, university students, and community members, enhancing their understanding of sustainable food systems and environmental stewardship.

The social impact of urban aquaponics extends beyond community engagement and education. It can contribute to social development by improving food security, especially in underserved urban areas. By providing access to fresh, locally grown produce, urban aquaponics can address issues of food deserts and nutritional deficiencies. Moreover, these projects can foster social cohesion, bringing together diverse groups within the community to work towards a common goal.

Therefore, urban aquaponics has the potential to make a significant social impact through community engagement and education. By involving local communities and providing educational opportunities, urban aquaponics can contribute to social development and environmental awareness. These projects can serve as a model for sustainable urban development, promoting social responsibility and community empowerment.

4.1.4. Future Directions in Urban Aquaponics

Urban aquaponics, as a sustainable agricultural practice, is poised for significant evolution in the context of the circular economy and urban sustainability. The future directions of urban aquaponics encompass technological advancements, integration into urban planning, and contributions to

sustainable development. Vitale (2021) discusses the role of urban horticulture and aquaponics in the development of a circular economy. The circular economy model, which emphasizes the reuse and recycling of resources, aligns perfectly with the principles of aquaponics. Future developments in urban aquaponics could focus on enhancing resource efficiency, reducing waste, and creating closed-loop systems that contribute to the circular economy. This approach not only addresses environmental concerns but also promotes economic sustainability by reducing operational costs and creating value from waste.

Asadullah *et al.* (2020) review the sustainability and development of aquaponics systems, highlighting the potential for technological advancements. The future of urban aquaponics may see the integration of advanced technologies such as automation, artificial intelligence, and Internet of Things (IoT) to optimize resource use, improve system efficiency, and enhance crop yields. These technologies can also aid in monitoring environmental conditions, ensuring the health of both fish and plants, and reducing labor costs.

Wu (2014) emphasizes the importance of urban ecology in the sustainability of cities. Urban aquaponics can be a key component of this, contributing to urban green spaces and biodiversity. Future urban planning could integrate aquaponics systems into public spaces, rooftops, and unused urban areas, creating green oases that enhance the urban environment. This integration not only provides local food sources but also contributes to the ecological health of urban areas, mitigating issues such as the urban heat island effect and air pollution.

In summary, the future of urban aquaponics lies in its integration into the circular economy, advancements in technology, and incorporation into urban ecological planning. These developments will not only enhance the sustainability of urban aquaponics systems but also contribute to the broader goals of sustainable urban development. As cities continue to grow and face environmental challenges, urban aquaponics offers a promising solution for sustainable food production and urban greening.

4.2. Standards and Regulations: Ensuring Quality and Safety in Urban Aquaponics

The implementation of urban aquaponics systems necessitates adherence to specific standards and regulations to ensure quality and safety. This is crucial for maintaining public trust and ensuring the sustainability of these systems. Wirza and Nazir (2020) emphasize the significance of systematic reviews in understanding the performance and safety of urban aquaponics systems. Such reviews can help identify best practices and areas where standards are needed. Standards in urban aquaponics are essential for ensuring consistent quality and safety of the produce, as well as for the efficient operation of the systems. They can cover various aspects, including water quality, fish health, and plant growth conditions.

Schellenberg *et al.* (2020) discuss wastewater discharge standards in the context of urban sustainability, highlighting the importance of regulatory frameworks in managing environmental impacts. In urban aquaponics, similar regulatory frameworks are needed to manage the discharge of water and ensure that the systems do not negatively impact urban ecosystems. These regulations can also help in

promoting the sustainability of aquaponics systems by ensuring that they contribute positively to the urban environment.

In summary, establishing and adhering to standards and regulations is critical for the success and sustainability of urban aquaponics systems. These standards ensure the quality and safety of the produce, contribute to the sustainability of the systems, and help in maintaining public trust. As urban aquaponics continues to grow, the development of comprehensive and effective regulatory frameworks will be essential for its long-term success.

4.3. Stakeholder Implications: Policy Makers, Urban Planners, and Community Leaders

The integration of urban aquaponics into city landscapes has significant implications for various stakeholders, including policy makers, urban planners, and community leaders. Understanding these implications is crucial for the successful implementation and sustainability of urban aquaponics systems. Kamal and Rashed-Ali (2013) discuss the integration of spatial analysis in assessing community sustainability, a method that can be applied to urban aquaponics. Policy makers can use spatial analysis tools to identify optimal locations for aquaponics systems, considering factors like urban density, available space, and community needs. This approach can help in making informed decisions that align with broader urban sustainability goals.

Strielkowski *et al.* (2022) emphasize the importance of smart and sustainable city management, especially in the post-COVID-19 era. Urban aquaponics can be a part of this smart city framework, contributing to urban resilience and sustainability. Policy makers can support urban aquaponics through policies that encourage sustainable urban agriculture, provide incentives for green infrastructure, and facilitate research and development in this field.

Reeve *et al.* (2013) highlight the concept of biophilic urbanism, which involves harnessing natural elements to enhance urban environments. Community leaders can play a pivotal role in advocating for and implementing biophilic designs, including urban aquaponics. By engaging local communities in the planning and development of aquaponics projects, community leaders can ensure that these initiatives meet the specific needs and preferences of the residents.

The implications of urban aquaponics for stakeholders extend to social and environmental sustainability. Urban aquaponics can provide local communities with access to fresh produce, enhance urban biodiversity, and contribute to environmental education. For policy makers and urban planners, this means considering urban aquaponics as a tool for achieving sustainability targets and improving the quality of life in urban areas.

Urban aquaponics presents various implications for policy makers, urban planners, and community leaders. By understanding and addressing these implications, stakeholders can ensure the successful integration of aquaponics into urban environments. This requires a collaborative approach, where different stakeholders work together to create sustainable, resilient, and livable cities.

5. Conclusions

The study has synthesized key findings regarding the viability, benefits, and challenges of urban aquaponics. It is evident that urban aquaponics presents a sustainable solution

to urban agriculture challenges, offering environmental benefits such as efficient resource use and reduced ecological footprints. Economically, while initial costs are significant, the long-term benefits of local food production and reduced resource expenditure are substantial. Socially, urban aquaponics fosters community engagement and provides educational opportunities. However, challenges such as technical complexities, financial barriers, and the need for specialized knowledge must be addressed to realize the full potential of urban aquaponics.

Looking forward, urban aquaponics stands at the cusp of significant growth, with opportunities to integrate advanced technologies and innovative practices. Overcoming existing challenges will require collaborative efforts from various stakeholders, including urban planners, policymakers, and community leaders. The future of urban aquaponics is promising, with potential expansions into unused urban spaces and the integration of smart technologies for enhanced efficiency and productivity.

For practitioners, continuous innovation and adherence to best practices in system design and management are crucial. Researchers should focus on advancing knowledge in areas such as resource optimization, system scalability, and integration of new technologies. Policy makers are encouraged to develop supportive policies and funding mechanisms that facilitate the growth of urban aquaponics, including incentives for sustainable urban agriculture practices and research grants. [In conclusion, urban aquaponics represents a dynamic and evolving field with significant potential to contribute to sustainable urban development. Future research should explore the integration of aquaponics with other urban systems, the development of scalable and adaptable models for different urban contexts, and the long-term socio-economic impacts of urban aquaponics. Investigating the potential of emerging technologies and interdisciplinary approaches will also be crucial in advancing the field of urban aquaponics. This study lays the groundwork for further exploration and innovation in urban aquaponics, highlighting its role as a key component of sustainable urban agriculture and a catalyst for positive change in urban environments.

6. References

1. Aguilar BJ, Semanchin TJ. The implications of ecological economic theories of value to cost-benefit analysis: importance of alternative valuation for developing nations with special emphasis on Central America. In: *Ecological Economics and Sustainable Development*. Routledge; 2020. doi:10.4324/9780138761790-21
2. Akter S, Kabir H, Akhter S, Hasan M. Assessment of environmental impact and economic viability of domestic biogas plant technology in Bangladesh. *J Sustain Dev*. 2021;14(5):44. doi:10.5539/jsd.v14n5p44
3. Alrashed M, Nikolaidis T, Pilidis P, Alrashed W, Jafari S. Economic and environmental viability assessment of NASA's turboelectric distribution propulsion. *Energy Rep*. 2020;6:1685-95. doi:10.1016/j.egyr.2020.06.019
4. Asadullah M, Khan SN, Safdar HM, Aslam RA, Shaikat I. Sustainability and development of aquaponics system: a review. *Earth Sci Pak*. 2020;4(2):78-80. doi:10.26480/esp.02.2020.78.80
5. Bassi N, Kumar S, Kumar MD, Van Ermen S, Campling P. Promoting wastewater treatment in India: critical questions of economic viability. *Water Environ J*. 2022;36(4):723-36. doi:10.1111/wej.12810
6. Benjamin E, Tzemi D, Fialho DS. Sustainable urban farming in Sub-Saharan Africa: a review of a coupled single-loop aquaponics system in Nigeria. Preprints. 2021;2021110372. doi:10.20944/preprints202111.0372.v1
7. Deepthi A, Niranjana A, Hari Haran A, Austin Joel A, Dhinakaran S, MonishaThangam K, *et al*. Integrated smart system for urban farming. In: *2021 IEEE International on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*; 2021; Coimbatore, India. p. 1-4. doi:10.1109/ICAECA52838.2021.9675617
8. D'Oca S, Ferrante A, Ferrer C, Perneti R, Gralka A, Sebastian R, *et al*. Technical, financial, and social barriers and challenges in deep building renovation: integration of lessons learned from the H2020 cluster projects. *Buildings*. 2018;8(12):174. doi:10.3390/buildings8120174
9. Dos Santos M. Smart cities and urban areas—aquaponics as innovative urban agriculture. *Urban For Urban Green*. 2016;20:402-6. doi:10.1016/j.ufug.2016.10.004
10. Ekins P, Zenghelis D. The costs and benefits of environmental sustainability. *Sustain Sci*. 2021;16(3):949-65. doi:10.1007/s11625-021-00910-5
11. Escobar A, Luna J, Caraballo A. Barriers to sustainable green innovation in meeting the challenges of the global economy of firms. *Glob J Environ Sci Manag*. 2023;9(Special Issue (Eco-Friendly Sustainable Management)):219-32. doi:10.22034/gjesm.2023.09.SI.13
12. Ghandar A, Ahmed A, Zulfikar S, Hua Z, Hanai M, Theodoropoulos G. A decision support system for urban agriculture using digital twin: a case study with aquaponics. *IEEE Access*. 2021;9:35691-708. doi:10.1109/ACCESS.2021.3061722
13. Goodier C, Chmutina K. Non-technical barriers for challenging lock-in to urban energy systems: learning from international case studies. In: Soutsos M, Goodier C, Le TT, Van Nguyen T, editors. *The International Conference on Sustainable Built Environment for Now and the Future*; 2013; Hanoi, Vietnam. p. 143-52.
14. Gott J, Morgenstern R, Turnšek M. Aquaponics for the anthropocene: towards a 'sustainability first' agenda. In: *Aquaponics Food Production Systems: Combined Aquaculture and Hydroponic Production Technologies for the Future*. Springer; 2019. p. 393-432. doi:10.1007/978-3-030-15943-6_16
15. Guler OV, Boloş C. Monetization of environmental externalities for economic analysis. Case study: urban mobility in Oradea. *Ann Univ Oradea Econ Sci Ser*. 2021;20(2).
16. Hochman G, Hochman E, Naveh N, Zilberman D. The synergy between aquaculture and hydroponics technologies: the case of lettuce and tilapia. *Sustainability*. 2018;10(10):3479. doi:10.3390/su10103479
17. Hunt A, Eaton E. Quantifying the health impacts of alternative urban development scenarios using the HAUS tool. *Eur J Public Health*. 2023;33(Suppl 2):ckad160.582. doi:10.1093/eurpub/ckad160.582
18. Ianchenko A, Proksch G. Urban food systems: applying life cycle assessment in built environments and

- aquaponics. [publisher unknown]. [date unknown]. doi:10.7275/1rm5-s937
19. Kamal A, Rashed-Ali H. Methods for integrating spatial analysis in assessment of community sustainability. ARCC Conference Repository. 2013. doi:10.17831/rep:arcc%y226
 20. Koller M, Eckert K, Ferber U, Gräbe G, Verbücheln M, Wendler K. Resource management as part of sustainable urban district development. Sustainability. 2022;14(7):4224. doi:10.3390/su14074224
 21. Krikser T, Zasada I, Piorr A. Socio-economic viability of urban agriculture—a comparative analysis of success factors in Germany. Sustainability. 2019;11(7):1999. doi:10.3390/su11071999
 22. LaDuca B, Carroll C, Ausdenmoore A, Keen J. Pursuing social justice through place-based community engagement: cultivating applied creativity, transdisciplinarity, and reciprocity in catholic higher education. Christ High Educ. 2020;19(1-2):60-77. doi:10.1080/15363759.2019.1689204
 23. Lee CH, Jhang JH. System design for internet of things assisted urban aquaponics farming. In: 2019 IEEE 8th Global Conference on Consumer Electronics (GCCE); 2019; Osaka, Japan. p. 986-7. doi:10.1109/GCCE46687.2019.9015214
 24. Lucchetti MC, Arcese G, Martucci O, Montauti C. Risk assessment and environmental impacts: economic and social implications. In: The Future of Risk Management, Volume I: Perspectives on Law, Healthcare, and the Environment. Springer; 2019. p. 109-29. doi:10.1007/978-3-030-14548-4_5
 25. Okomoda VT, Oladimeji SA, Solomon SG, Olufeagba SO, Ogah SI, Ikhwanuddin M. Aquaponics production system: a review of historical perspective, opportunities, and challenges of its adoption. Food Sci Nutr. 2023;11(3):1157-65. doi:10.1002/fsn3.3154
 26. Rahman MA, Amin MR. Aquaponics: a potential integrated farming system for sustainable agriculture and aquaculture. Int J Biol Ecol Environ Sci. 2016;5(1):42-5.
 27. Rai CM, Dorji Y, Zangmo S. User satisfaction and the social and environmental benefits of urban green spaces: a case study of Thimphu City, Bhutan. Nakhara J Environ Des Plan. 2022;21(2):216. doi:10.54028/nj20221216
 28. Reeve A, Hargoves K, Desha C, Newman P, Baghdadi OE. Biophilic urbanism: harnessing natural elements to enhance the performance of constructed assets. In: Kajewski S, Manley K, Hampson K, editors. Proceedings of the 19th CIB World Building Congress: Construction and Society; 2013; Brisbane, Australia. Queensland University of Technology.
 29. Rizal A, Dhahiyat Y, Zahidah, Andriani Y, Handaka A, Sahidin A. The economic and social benefits of an aquaponic system for the integrated production of fish and water plants. IOP Conf Ser Earth Environ Sci. 2018;137(1):012098. doi:10.1088/1755-1315/137/1/012098
 30. Schellenberg T, Subramanian V, Ganeshan G, Tompkins D, Pradeep R. Wastewater discharge standards in the evolving context of urban sustainability – the case of India. Front Environ Sci. 2020;8:30. doi:10.3389/fenvs.2020.00030
 31. Shirgire A, Javanjal V, Shelar A, Sinha MK, Marimuthu R, Peera G. Assessment of the environmental impact of solar energy systems in urban areas. In: 2023 3rd International Conference on Pervasive Computing and Social Networking (ICPCSN); 2023; Salem, India. p. 1756-61. doi:10.1109/ICPCSN58827.2023.00294
 32. Smith JA, Larkin S, Yibarbuk D, Guenther J. What do we know about community engagement in Indigenous education contexts and how might this impact on pathways into higher education? In: Indigenous Pathways, Transitions and Participation in Higher Education: From Policy to Practice. Springer; 2017. p. 31-44. doi:10.1007/978-981-10-4062-7_3
 33. Son J, Kong M, Nam H. Design model and management plan of a rice–fish mixed farming paddy for urban agriculture and ecological education. Land. 2022;11(8):1218. doi:10.3390/land11081218
 34. Strielkowski W, Zenchenko S, Tarasova A, Radyukova Y. Management of smart and sustainable cities in the post-COVID-19 era: lessons and implications. Sustainability. 2022;14(12):7267. doi:10.3390/su14127267
 35. Svensson G, Padin C. A principle of symbiosis in sustainable development through aquaponics system and its aquaculture and hydroponics sub-systems. Int J Agric Innov Technol Glob. 2021;2(3):193-203. doi:10.1504/IJAITG.2020.10036725
 36. Steblyanskaya A, Wang Z, Martynov A, Mingye A, Artykhov V, Wang Z, et al. New energy-resource efficiency, technological efficiency, and ecosystems impact ratings for the sustainability of China's provinces. Sustainability. 2021;13(1):354. doi:10.3390/su13010354
 37. Tomić T, Kremer I, Schneider DR. Economic efficiency of resource recovery—analysis of time-dependent changes on sustainability perception of waste management scenarios. Clean Technol Environ Policy. 2022;24:543-62. doi:10.1007/s10098-021-02165-1
 38. Tshishonga NS. Forging university social responsibility through community engagement. In: Civic Engagement Frameworks and Strategic Leadership Practices for Organization Development. IGI Global; 2020. p. 96-115. doi:10.4018/978-1-7998-2372-8.ch005
 39. Ullevig SL, Vasquez LL, Ratcliffe LG, Oswalt SB, Lee N, Lobitz CA. Establishing a campus garden and food pantry to address food insecurity: lessons learned. J Am Coll Health. 2021;69(6):684-8. doi:10.1080/07448481.2019.1705830
 40. Upadhyay P. Envisaged for sustainable rural development: viability and challenges of rural tourism in Nepal. Repositioning J Bus Hosp. 2016;1:37-52. doi:10.3126/repos.v1i0.16041
 41. Venkatraman M, Surendran R. Aquaponics and smart hydroponics systems water recirculation using machine learning. In: 2023 4th International Conference on Smart Electronics and Communication (ICOSEC); 2023; Trichy, India. p. 998-1004. doi:10.1109/ICOSEC58147.2023.10276310
 42. Vermeulen T, Kamstra A. The need for systems design for robust aquaponic systems in the urban environment. Acta Hort. 2013;1004:43-50. doi:10.17660/ACTAHORTIC.2013.1004.6
 43. Vitale R. Urban horticultural and aquaponics for sustainability development in circular economy. Authorea Preprints. 2021.

- doi:10.22541/AU.161539222.24155993/V1
44. Wainaina P, Minang PA, Gituku E, Duguma L. Cost-benefit analysis of landscape restoration: a stocktake. *Land*. 2020;9(11):465. doi:10.3390/land9110465
 45. Wakweya RB. The socioeconomic and environmental benefits of bamboo forest in Ethiopia: a review. *Int J Soc Environ Issues*. 2023;4(2):150-9. doi:10.47540/ijsei.v4i2.934
 46. Wirza R, Nazir S. Urban aquaponics farming and cities - a systematic literature review. *Rev Environ Health*. 2021;36(1):47-61. doi:10.1515/reveh-2020-0064
 47. Wu J. Urban ecology and sustainability: the state-of-the-science and future directions. *Landsc Urban Plan*. 2014;125:209-21. doi:10.1016/j.landurbplan.2014.01.018