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# Structured Literature Review on the Challenges and Opportunities for Urban Vertical Farming Systems in Australia

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## Abstract

Urban vertical farming systems are claimed to be a sustainable solution to counter the challenges of food security and resource limitations in the context of rapid urbanisation. By cultivating crops in vertically-inclined structures, these systems optimise land use and reduce transportation distances, thereby minimising environmental impact. Vertical farming systems can meet daily consumer demands for nutritious, fresh products, enhancing food system resilience in densely populated areas. Although a lot of research has been conducted on the technical and science-related aspects, there are few studies on the value chain aspects. That is the focus of this study. Additionally, current trends in consumer preferences, the heterogeneity of perceptions and the reasons for successful acceptance are investigated. In this paper the emphasis is on providing a detailed understanding of the challenges and opportunities of the urban vertical farming landscape in Australia and suggesting a way forward for advancing research and industry development.

***Keywords:*** urban vertical farming systems, sustainable farming, consumer preferences, value chain, Australia

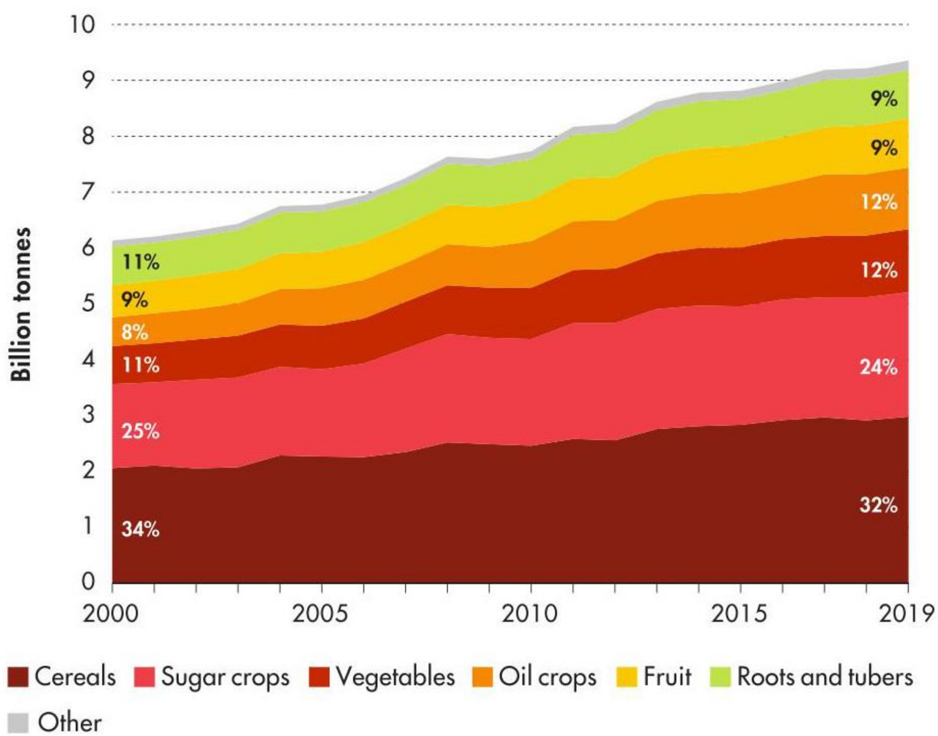
## Introduction

The intensification of global food systems has had an adverse impact on achieving the United Nations' Sustainable Development Goals (SDGs), which strive for a more sustainable future (FAO, 2018). The United Nations (2022a) stated that there would be difficulty in achieving the SDGs with the current challenges facing global food systems. In this discourse, the term 'sustainable' refers to practices and approaches that, over the years, have generally been understood as meeting the needs of the present without compromising the ability of the future generations to meet their own needs, encompassing ecological, economic, and social considerations (WCED, 1987). It is important to note that the definition of 'sustainable' is not fixed and has been evolving with emerging perspectives and global developments, as reported by (Hajian and Kashani, 2021).

The global challenges of providing food security (SDG #1) and eradicating hunger (SDG #2) have become more formidable due to a range of factors, including the COVID-19 pandemic, the Russia-Ukraine war, and other global uncertainties (da Costa et al., 2023). Disruptions in supply chains have resulted in food insecurities, malnourishment, and the imposition of trade sanctions by several countries. The recent ban on the export of rice from India to the United States, the European Union, Australia and many other countries is a consequence of such unprecedented challenges (Rajendra Jadhav, 2023). Preserving natural resources and promoting sustainable practices to enhance productivity (SDG #6, SDG #7 and SDG #12) have become increasingly difficult amid the impacts of intensive global food systems (Campbell et al., 2018). The need to adapt to climate change mitigation strategies (SDG #13) is also complicated by the uncertainties arising from heightened heatwaves and forest fires, extreme weather variations, droughts and floods worldwide (Reckien et al., 2017, Campbell et al., 2018). Amidst these challenges, ensuring food security has become a critical issue that requires collaborative efforts to find effective solutions.

The United Nations predicts the world's population to be 8.5 billion by 2030, 9.7 billion in 2050 and 11.5 billion in 2100 (United Nations, 2022b). Crop production was forecast by the Food and Agriculture Organization (FAO, 2020) to achieve 10 billion tonnes by 2021 with overall growth increasing by 3.5 per cent from the previous year (Figure 1). The rising rates of environmental damage, shifting climates, mismanaged land, and pandemics are anticipated to pose challenges to the existing food production systems and supply chains. These issues clearly indicate a need for a radical and diversified agriculture production system. Here, 'radical' denotes a profound departure from conventional agricultural norms, emphasizing innovative and sustainable strategies to tackle challenges like environmental degradation and food security amid population growth.

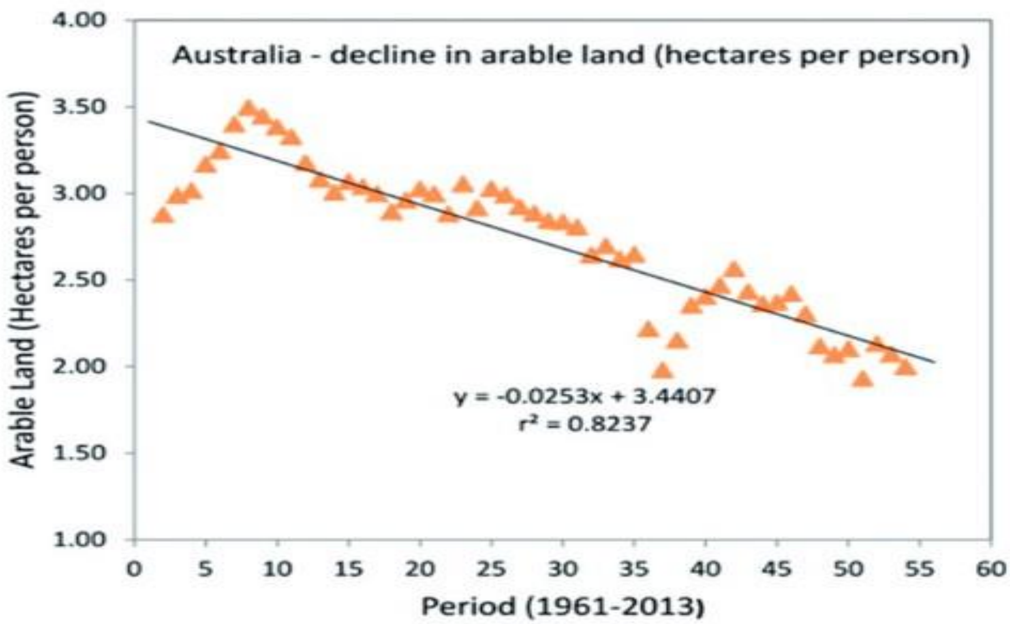
**Figure 1. Global crop production, 2000 to 2019**




*Source*: (FAO, 2020)

The growing global population's increasing food demand has led to a decline in the per capita agricultural land area over time. In Figure 2 is shown the decrease of arable land (hectares per person) in Australia, clearly suggesting a stress on land availability for agriculture (Benke and Tomkins, 2017). Despite adopting new technologies and practices, the Australian irrigated grains sector has experienced stagnant yields since 2002. This stagnation is notable amid increasing demand for irrigation water and a decline in its availability, suggesting that current productivity measures have not fully countered the influence of changing climatic and economic factors on crop yields at a continental scale (Muleke et al., 2022). Of particular concern is the warning given in 2014 that the world's topsoil may be exhausted within 60 years, as approximately one-third of the world's landmass has already degraded (Gomiero, 2016). Consequently, there is an immediate need for a sustainable approach to address the escalating food demand caused by the population increase, safeguard global food security, and tackle the issue of soil degradation.

**Figure 2. Decline of the total arable land (hectares per person) in Australia, 1961-2013**




*Source*: (Benke and Tomkins, 2017)

Despommier (2010) put forward the concept of vertical farming systems (VFS) as a solution to address the future challenges of depleting agricultural resources and changing climate. This approach entails creating urban, indoor, high-rise farms equipped with climate control, renewable energy sources, and waste recycling. These vertical farms would be situated within the heart of urban environments. The key advantages of vertical farming include year-round crop production in a controlled environment, leading to decreased transportation costs, enhanced food safety and biosecurity, and significantly reduced requirements for water supply, pesticides, herbicides, and fertilisers (Eldridge et al., 2020; Benke and Tomkins, 2017; Gomiero, 2016).

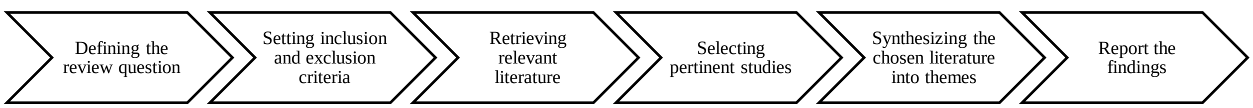
While acknowledging Australia's substantial agricultural production, 72 per cent of which is exported (ABARES, 2023), it is crucial to address the specific challenges posed by urban areas where a significant portion of the population resides. In metropolitan regions, land scarcity presents a pressing issue, necessitating innovative solutions like urban vertical farming to complement traditional agriculture, especially in the face of climate change impacts and the imperative to reduce carbon emissions associated with long-distance food transportation (Lu, 2023).

In the following parts of the paper, various aspects of urban vertical farming in Australia are examined using a Structured Literature Review process. Structured Literature Reviews often use predetermined criteria for inclusion or exclusion of studies. This helps maintain objectivity and ensures that the selected studies meet specific quality standards, contributing to the reliability of the review (Page et al., 2021; Siregar et al., 2022). The review is focused on the potential of the technology, key value chain factors, recent developments, consumer preferences, challenges, and prospects. Through this exploration, the aim is to contribute to the existing body of knowledge surrounding the emerging agricultural practice of vertical farming. The research seeks to provide insights that can inform discussions and decisions related to its potential implementation and integration into the Australian food system.

## Literature Review Method

Initially employed exclusively in medical research, the use of a ''Systematic Literature Review'' (Denyer and Tranfield, 2009) or ''Structured Literature Review'' (Koufteros et al., 2018) has extended to other domains of scientific research including a recent paper on supply chain management. The initial five-step process as deduced by Denyer & Tranfield (2009) has been extended to a six-step process (Durach et al., 2017) when the focus is on supply-chain searches, as depicted in Figure 3.

**Figure 3. Six-step process for structured literature review**




Source: (Durach et al., 2017)

The research question posed for the review was: "Can urban vertical farming become a preferred source of fresh produce in the market, considering the increasing demand for locally-grown and sustainable food?" Here, the research question acknowledges the broader context of a rising demand for locally-grown and sustainable food. A consumer-centric approach is adopted, which means incorporating scientific research analysis and empirical evidence on consumer preferences. In this analysis, pertinent journals include *Urban Agriculture & Regional Food Systems, Journal of Cleaner Production, Journal of Horticulture Science and Biotechnology, Sustainability, Food Quality and Preference, Journal of Agriculture, Food Systems and Community Development, Agronomy, Sustainable Cities and Society* and *Food Policy*, among others.

The initial sample of literature was retrieved using relevant keywords and phrases such as "urban vertical farming systems," "value chain factors," "sustainability," "consumer preferences," "technology," "indoor farming," "nutrition value," "market demand," "regulations," and "growth potential."

Due to the recent emergence of this agricultural technology, there is a restricted availability of academic papers, being limited to those published within the past five to ten years. Most of the focus of this literature is on achieving maximum production and innovation in agriculture farming (Kalantari et al., 2017; Beacham et al., 2019; Mir et al., 2022). There is also a significant body of work exploring customer preferences and perceptions of the sustainability of production and quality and nutritional value of the final product. Also included were contributions from various institutions such as the Food and Agriculture Organization, government agencies, research institutes, and non-governmental business partners.

The externalities associated with conventional agriculture practices have long provided a persuasive rationale for VFS (Stein, 2021). While a dearth of relevant consumer behaviour analysis exists, the available literature centres on consumer perceptions of VFS produce. These studies are subsequently employed to evaluate the implications for VFS products within the Australian market.

## Issues With Business-as-Usual Agriculture Systems

The world's current agriculture production systems are responsible for generating around 13.7 billion tonnes of carbon dioxide, accounting for 26 per cent of all human activity-based greenhouse gas emissions (Poore and Nemecek, 2018). These systems also play a significant role in global terrestrial acidification and eutrophication, contributing approximately 32 per cent and 78 per cent, respectively (Sala et al., 2017). The farm stage of the food chain stands out as the main contributor, responsible for 61 per cent of food's greenhouse gas emissions, 79 per cent of acidification, and 95 per cent of eutrophication. The agricultural system as a whole is very resource-intensive, leading to considerable environmental damage and degradation of the arable land base (Poore and Nemecek, 2018).

Conventional crop production systems, in particular, have adopted the strategy of industrialising farming practices to meet ever-rising global demand while facing constraints in available farmland. If the current conventional agricultural system persists and sustains the growing global population without any dietary changes, it is estimated that the associated social costs mentioned above will surpass $US1.7 trillion annually by 2030 (FAO, 2022).

Modern farming has experienced considerable advancements in crop production efficiency, evident in both the substantial increase in the yield of fresh produce and reduced workforce requirements. These improvements can be attributed to the introduction of heavy machinery, the use of synthetic fertilisers and pesticides, the development of high-yield crop varieties, and better farming management practices (Trautmann et al., 1985; Li et al., 2020). However, despite these advantages, many of these innovations do not ensure long-term sustainability. The use of machinery, water irrigation, and chemical fertilisers in industrialised farming results in increased energy and water consumption, leading to significant environmental impacts. Among these impacts are the potential degradation of soil and water resources (Li et al., 2020; Trautmann et al., 1985).

Considering the existing challenges and issues with current farming practices, the FAO emphasised the necessity for novel solutions and innovative technologies that promote sustainability, judicious water use, better land utilisation, as well as greenhouse gas reduction. These efforts aim to steer farming practices away from the "business as usual" approach and towards a more sustainable mode of production (FAO, 2018).

In the transition towards efficient and sustainable agriculture, numerous innovative farming systems have been introduced. One such system gaining popularity is urban farming, which involves the agriculture activities of cultivation, production, harvesting, packaging, processing, and distribution within urban and semi-urban areas, providing an alternative to traditional rural agriculture. Urban farming offers several benefits, including providing a locally-available fresh food supply to urban consumers, job opportunities, enhanced supply chain efficiency (creating value) and reduced urban waste, and bolstering cities' resilience to climate change (Zezza and Tasciotti, 2010). One such mode of urban farming is urban vertical farming.

**Enhancing resilience and sustainability in food security**

The High Level Panel of Experts (HLPE) on Food Security and Nutrition has defined a sustainable food system as ‘‘a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised’’ (HLPE, 2014, 12). The term ‘‘not compromised’’ suggests a balanced and responsible approach and implies that while meeting current needs for food security and nutrition, the actions and practices within the food system should not excessively deplete or harm the economic, social and environmental foundations that support future generations.

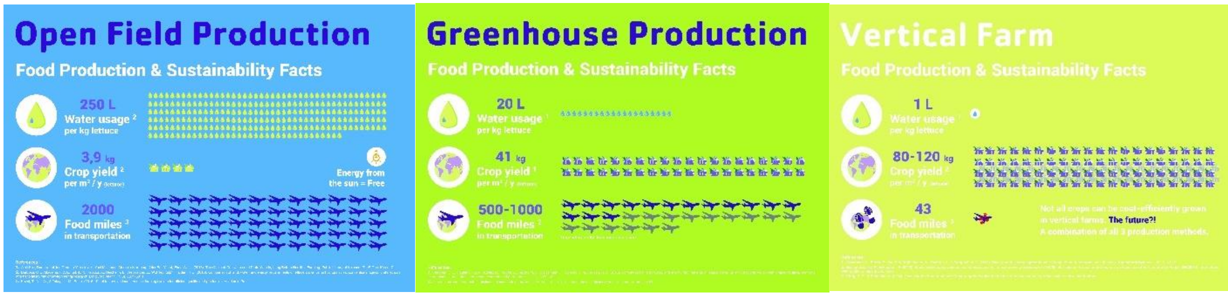
To understand the approach to enhancing resilience on agri-food systems, Bullock et al. (2017) describe the major factors affecting food production. The most common drivers having a direct impact on crop yield with variations in response are due to climatic fluctuations, temperature and light sensitivity, and water availability. Other exogenous environmental factors affecting crop yields include pests and pathogens, chronic factors such as soil fertility, pH and salinity and the decreasing natural pollinators (Ray et al., 2015). Not all these drivers have a negative impact, with some examples of symbiosis. For example, Caffarra et al. (2012) describe the eradication of pests due to adverse weather compensating for the decreased growth of crop production. The ability to enhance resilience in food production comes with the consideration of both acute and chronic perturbations across many dimensions. The dimensions to consider for enhancing resilience in food production encompasses ecology, engineering, agriculture, and economics (Bullock et al., 2017).

Sustainability is the constructive collaboration of efficiency and the ability to successfully integrate the resilience to acute and chronic perturbations in a food system. Resource management complements the factor of environmental stability in food production. By effectively managing resources such as water, soil nutrients, and energy inputs, it contributes to minimizing environmental degradation and ensuring long-term productivity and resilience of agricultural systems (Viana et al., 2022). Naus (2018) reported the resilience and sustainability of conventional farming methods versus greenhouse versus vertical farming in the European region, as depicted in Figure 4. The high sustainability score, along with its strong resilience capability due to the controlled environmental agriculture (Vatistas et al., 2022), makes the urban vertical farming system a focus of research.

## Urban Vertical Farming: Concepts and Technologies

Urban vertical farming systems (VFS) or “urban farming” is a modern agriculture practice “vertically skywards” (Hearn et al., 2021) which incorporates controlled-environment agriculture features to provide optimum growing conditions for the crop. This innovation has gained popularity given its ability to address

**Figure 4. Food production and sustainability facts of open field v greenhouse v vertical farm production**




*Source*: (Vatistas et al., 2022; Naus, 2018)

the challenges of limited arable land availability in urban areas and to produce fresh, nutritious food locally, reducing long distance logistics and enhancing food security (Despommier, 2010).

The literature review revealed three major vertical farm models. The first type involves constructing tall structures with multiple levels of growing beds, often equipped with artificial LED lights. These modest-sized urban farms have been implemented worldwide over the past decade (Despommier, 2013; Touliatos et al., 2016). The second type occurs on rooftops of existing and new buildings, including commercial and residential structures, as well as restaurants and grocery stores (Muller et al., 2017; Despommier, 2013). The third type is the visionary multi-story building concept. In the last decade, there has been a growing number of serious proposals for such structures, though none have been built yet. It is important to recognise the interconnection between these three types; the success of smaller-scale vertical farm projects and the advancement of their technologies are likely to pave the way for the realisation of skyscraper farms.

Choosing the right crop, as part of studying the feasibility of these systems, is a prerequisite to establishing a successful urban VFS. Wong et al. (2020) reported leafy greens (57 per cent), tomatoes (16), herbs (11), flowers (10), and microgreens (6) to be the major crops grown in several existing VFS spread across the world, with major concentrations in the United States and the European Union. Australia also has similar crop varieties in presently-operating VFS firms (Hearn et al., 2021).

**Key concepts of urban vertical farming systems**

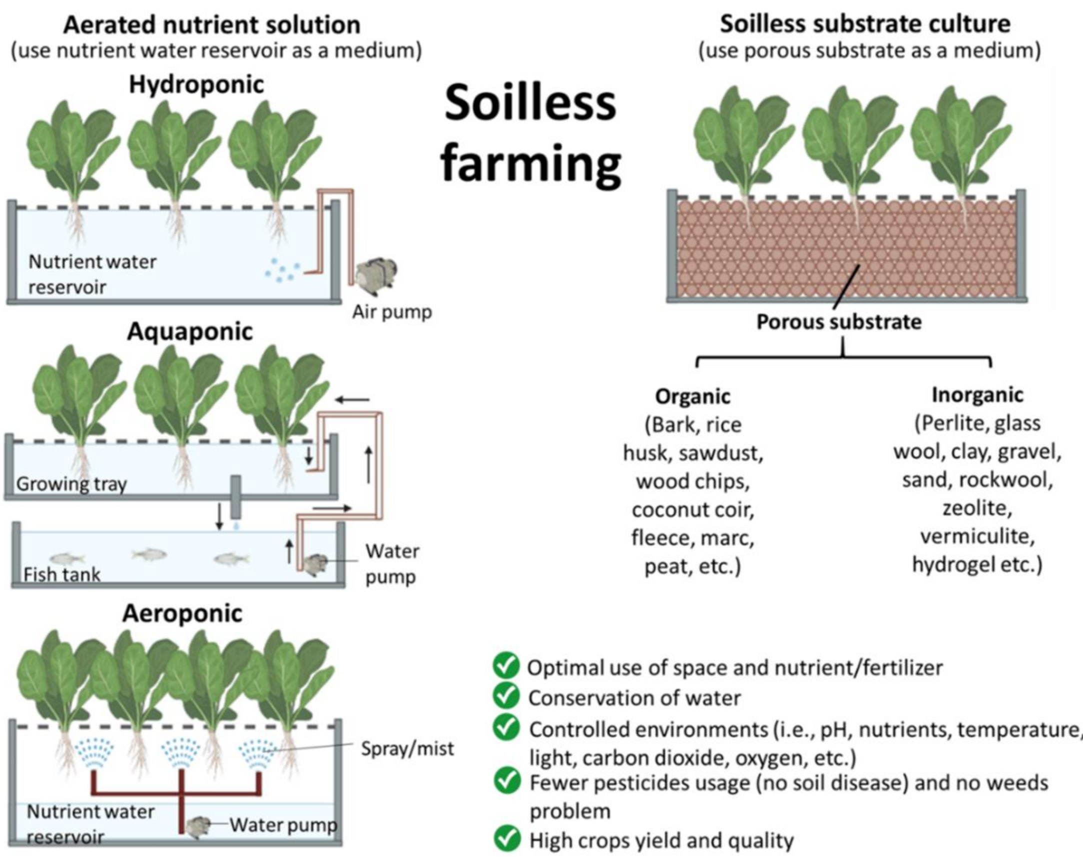
***Vertical growth systems***: The fundamental concept of urban vertical farming is growing crops in stacked layers or vertical shelves, often using hydroponic, aeroponic, or aquaponic systems (see Figure 5). These systems provide a controlled environment where crops receive precise amounts of nutrients, water, and light, leading to faster growth and higher yields (Al-Kodmany, 2018).

***Space efficiency***: Urban vertical farming maximises the use of limited urban spaces, making it suitable for high-density urban areas with limited available land. By stacking multiple layers of crops, the production capacity per square foot or metre is significantly increased compared to traditional farming methods (Al-Kodmany, 2018).

***Controlled environment***: Indoor vertical farms offer a controlled environment, allowing farmers to regulate factors like temperature, humidity, light and CO2 levels. This level of control minimises the impact of external factors, resulting in consistent crop yields and reduced dependency on weather conditions (Maluin et al., 2021; Al-Kodmany, 2018).

***Year-round production***: Vertical farming is not limited by seasonal changes or geographic constraints. With the ability to control the environment, crops can be grown year-round, ensuring a stable and reliable supply of fresh produce regardless of external weather conditions. This concept especially appeals due to extreme climatic changes happening around the world. Ensuring a guaranteed harvest as a consequence of controlled environment saves the compensation money that is often given to farmers under climatic stress (Maluin et al., 2021, Mir et al., 2022).

**Figure 5. Illustration of different vertical growth systems**




Source: Maluin et al. (2021)

**Key technologies used in urban vertical farming systems**

***Hydroponics***: Hydroponics is a soilless cultivation technique where plants are grown in nutrient-rich water solutions, delivering essential nutrients directly to the plant roots. This method maximises water efficiency and reduces the use of pesticides, making it environmentally friendly (Al-Kodmany, 2018).

***Aeroponics***: Like hydroponics, aeroponics is a soilless system that suspends plant roots in the air and delivers nutrients through a mist or fine spray. This technology minimises water usage, encourages rapid plant growth, and reduces the risk of diseases (Al-Kodmany, 2018).

***Aquaponics***: Aquaponics is a symbiotic system that combines hydroponics and aquaculture. It integrates fish farming with hydroponic plant cultivation, where fish waste provides nutrients for the plants, and the plants' roots filter the water for the fish (Al-Kodmany, 2018). A much more efficient emerging technology, modified from aeroponics, is "fogponics" (also called "Aeroponics 2.0") which uses an ultrasonic atomisation method to introduce nutrient-mixed water media as droplets or foggy mists as small as 5-30µm. It achieves a significant oxygen and nutrient diffusion capacity straight to the roots of the plants, reducing the water and fertiliser usage by 50-60 per cent compared to hydroponics and aquaponics (Oh and Lu, 2023) (see Table 1).

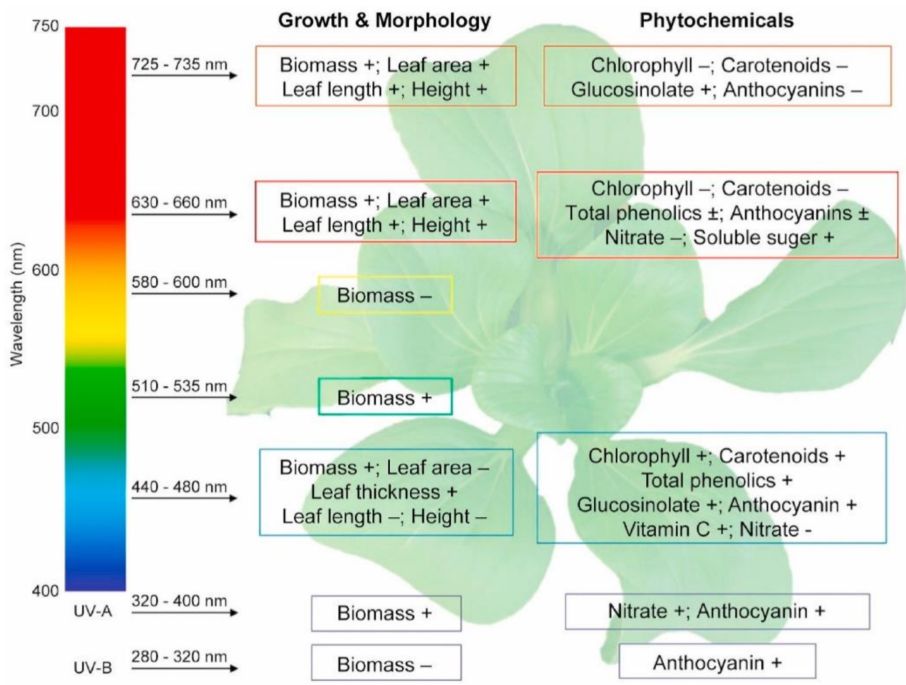
**Table 1. Different farming methods and their benefits and applicable technologies**

<table>
<tr><th>Farming Method</th><th>Characteristics</th><th>Major Benefits</th><th>Applicable Technologies</th></tr>
<tr><td>Hydroponics</td><td>Soilless base, uses water as the growing medium with or without mechanical support such as perlite or sand or peat.</td><td>Fosters rapid plant growth; reduces soil-related cultivation problems; reduces the use of fertilisers or pesticides.</td><td rowspan="3">Computerised monitoring systems; cell phones, laptops, and tablets; food growing apps; remote control systems and software (farming-from-afar systems); automated racking, stacking systems, moving belts, and tall towers; programmable LED lighting systems; renewable energy applications (solar panels, wind turbines, geothermal, etc.); closed-loop systems, anaerobic digesters; programmable nutrient systems; climate control, HVAC systems; water recirculating and recycling systems; rainwater collectors; insect-killing systems; robots</td></tr>
<tr><td>Aeroponics</td><td>A variant of hydroponics; it involves spraying the roots of plants with mist or nutrient solutions.</td><td>In addition to benefits mentioned above, aeroponics needs less water.</td></tr>
<tr><td>Aquaponics</td><td>It integrates aquaculture (fish farming) with hydroponics.</td><td>Creates symbiotic relationships between the plants and the fish; it uses the nutrient-rich waste from fish tanks to "fertigate" hydroponics production beds; and hydroponic bed cleans water for fish habitat.</td></tr>
</table>

*Source*: (Al-Kodmany, 2018)

***Artificial lighting***: Artificial lights, a critical component of VFS, are used to imitate sunlight conditions no matter the time of the day. For this purpose, LED (Light Emitting Diode) growlights are used in indoor vertical farms to provide the specific spectrum of light needed for optimal plant growth. A successful vertical farm requires LED throughput efficiency of about 50-60 per cent whereas the current capability at a commercial level is 28 per cent (Al-Kodmany, 2018). A group of Dutch light engineers working at Philips have produced LED efficiency at 68 per cent, at an experimental level, but this is yet to be commercialised to the agriculture industry (Al-Kodmany, 2018). The effects of the spectrum of LED wavelengths on the growth, morphology and phytochemical composition of the green leafy vegetables have been intensively researched (Figure 6). Nevertheless, deriving an ideal lighting recipe from existing research is challenging due to inconsistent experimental parameters, including variations in the precise spectral composition and treatment duration. Additionally, the presence of species-specific and cultivar-specific differences further complicates the extrapolation of research data from one plant species to another (Wong et al., 2020).

**Figure 6. Different response of green leafy vegetable for spectrum of LED wavelengths**




*Source*: (Wong et al., 2020)

***AI and automated systems***: Many urban vertical farms utilise automation and sensor technologies to monitor and control environmental factors, such as temperature, humidity, nutrient levels, and lighting. Automated systems help optimise resource use and reduce human labour inputs. Artificial intelligence, deep learning, and genetic algorithms help navigate the automation close to, or far away from, the place of VFS; all it requires is an internet connection and a cloud storage facility (Siregar et al., 2022). Siregar et al. (2022) reported a detailed review on the use of AI and relevant software to automate a smarter VFS unit. Some of the major and latest technologies mentioned (Oh and Lu, 2023; Siregar et al., 2022) are Wireless Sensor Actuator Network (WSAN), IoT for smartphone, monitoring and control, Arduino IDE, Fuzzy Logic, Integer Linear Program (ILP), Mixed Integer Linear Program (MIP), Computer vision (machine learning), Feed Forward Neural Network and many others.

Technological advancements are an increasing topic of interest to make urban farming more competitive with conventional farming practices.

## Customer Acceptance and Value Creation Factors

In a competitive fresh produce market, flooded with abundant choices and products tailored to meet various consumer diets, the demand from consumers plays a critical role in shaping the direction of food production systems (Hume, 2010; Marcus et al., 2022). As the product category is still in its preliminary stages of development and not widely accessible, the analysis of salient consumer behaviour is primarily predictive and anticipatory. However, a few studies have successfully extrapolated consumer opinions through focus groups and data collection, shedding light on potential trends. This review examines the factors influencing this category based on previous research papers and categorises them to understand how they could either facilitate or hinder the progress of the development of the VFS value chain.

**Nutritional value**

Offering identical nutritional value is likely a major driver for consumer acceptance of urban farming products. Vertical farming grown under controlled environmental conditions is often falsely considered as involving a restriction to nutrients reaching fresh produce. To the contrary, (Benke and Tomkins, 2017) demonstrate the complete retention of nutritional value in the fresh produce from VFS. A survey reported by Perambalam et al. (2021) on Gen Y consumers, or the "millennials", considered nutritional value as the major acceptance factor for vertical farming. The participants chose the products only if they saw that the nutritional value was represented on the product labels, or they were certified as organics. Most of the consumers are aware that the fresh produce is nutritious but lack the awareness from the label that the end-product is the work of an urban farming facility in their local street (Grebitus et al., 2017).

**Sustainability**

Consumers purchasing fresh produce from a retail shop place considerable thought on the sustainability of the product sourcing (Jaeger et al., 2023). While the paper primarily delves into attitudes toward output from Vertical Farming Systems (VFS), it indirectly implies that consumer attitudes towards sustainability play a pivotal role in shaping purchasing intentions. VFS levers this consumer acceptance criteria and allows producers to categorise fresh produce as highly sustainable. On the contrary, (Perambalam et al., 2021), suggest a lack of awareness of product sourcing or blindness of the sustainability benefits of the VFS. Urban farming value creation is critical to exposing the sustainability towards the change of consumer attitude. Consumer attitude to 'likely' purchasing fresh produce from urban farming solely depends on the information generated by the VFS farmers to depict their sustainability achievement (Shao et al., 2022; Perambalam et al., 2021).

In Table 2 is one proposal of the key environmental, social, and economic sustainable benefits of VFS that may provide bases for urban farmers to promote their products into the market to match possibly relevant consumer preferences, in turn producing positive social benefits.

**Pricing**

As indicated by (Perambalam et al., 2021), 42 per cent of the participants they surveyed expressed a willingness to pay a premium for a fresh and locally produced product (although the size of this premium was not specified). Interestingly, additional environmental benefits are the major cause for an increasing percentage of consumers willing to pay a premium. However, recent research highlights negative attitudes towards the financial implications of producing fresh produce in VFS (Coyle and Ellison, 2017; Jaeger et al., 2022; Yano et al., 2021), suggesting a reluctance to pay premium prices. Certifications indicating positive contributions to environmental and social sustainability could potentially mitigate these concerns (Jaeger et al., 2023). Studies on other food categories, such as organic, healthier, and traceable foods, have shown consumers' willingness to pay premium prices (Alsubhi et al., 2023; Katt and Meixner, 2020; Vriezen et al., 2023), indicating a possible market for VFS products with similar attributes.

**Table 2. Key value creating sustainability benefits of VFS**

| **Benefit** | **Environmental** | **Social** | **Economic** |
|---|---|---|---|
| Reducing food miles | Reducing air pollution | Improving air quality improves environmental and people's health. Customers receive 'fresher' local food | Reduce energy, packaging, and fuel to transport food |
| Reducing water consumption for food production by using high-tech irrigation systems and recycling methods | Reducing surface water run off traditional farms | Making potable water available to more people | Reduce costs |
| Creating local jobs | People do not have to commute to work and hence will decrease ecological footprint | Create a local community of workers and social networks with farmers | Benefits local people economically |
| Reduced fertilisers, herbicides, and pesticides | Improve the environmental well-being | Improve food quality and subsequently consumers' health | Decrease costs |
| Improve productivity | Needs less space | Reduce redundant, repetitive work, and save time to do productive and socially rewarding activities | Offer greater yields |
| Avoid crop losses due to floods, droughts, hurricane, over exposure to sun, and seasonal changes | Decrease environmental damage and cleanups of farms after damage | Improve food security | Avoiding economic loss |
| Control product/produce regardless to seasons | Produce regarding season | Increase accessibility year-round and improve respond to population demand | Fuel economic activities year-round |
| Using renewable energy | Reducing fossil fuel | Improve air quality | Reduce costs |
| Promoting high-tech and green industry | 'Green technology' reduce harm and improve environmental performance | Encourage higher education and generate skilled workers | Provides new jobs in engineering, biochemistry, biotechnology, construction and maintenance, and research and development |
| Repurposing dilapidated buildings | Enhance the environment. Remove eye sores and stigma from neighbourhoods | Create opportunities for social interaction | Revive economy |

*Source*: (Al-Kodmany, 2018).

However, selling products at premium prices may exacerbate societal divisions, potentially excluding certain demographics due to affordability concerns (Specht et al., 2019). It is essential to note that the size or range of the premium price consumers have in mind remains unclear due to limited available data. Understanding the magnitude of these premiums is crucial for informing pricing strategies, market positioning, and evaluating consumer preference accurately.

Shao et al. (2022) suggest that the uncertainty surrounding the actual market price led many consumers they surveyed to envision personal benefits and that there would be a preference for a partial shift from their traditional fresh produce rather than a complete transition.

## VFS Value Chain in Australia

'Once we started to assess the value chain in Australia, it showed that it's complicated, expensive and doesn't produce the best fresh produce' (Julia Prichodko, a co-founder of Eden Towers, as reported by (Boekhout, 2021). VFS face challenges due to their intricate technology, high costs, and concerns about the taste and nutritional quality of their crops compared to traditional farming. Additionally, the energy-intensive nature of VFS raises environmental sustainability issues, and regulatory hurdles and public skepticism may impact their widespread adoption. These detriments underscore the need for ongoing research and innovation to enhance the economic viability, environmental impact, and quality of VFS in the agricultural sector.

In the formal SLR there were very few research papers mentioning the VFS value chain or its performance. The exception is the work of (Van Tuijl et al., 2018). This paper sought to understand the dynamics of the value chain in a VFS, although via a very basic value chain representation. In Figure 7 is depicted the existing value chain representation of VFS in a much more generic nature which is applicable to the Australian market given the same industrial scale and the consumer sample space.

Some of the key operators in current Australian vertical farming systems are as follows:

*Stacked Farm* - Australia's biggest such business which owns a 4000 sqm plant factory on the Gold Coast and produces 450 tonnes of fresh produce per year.

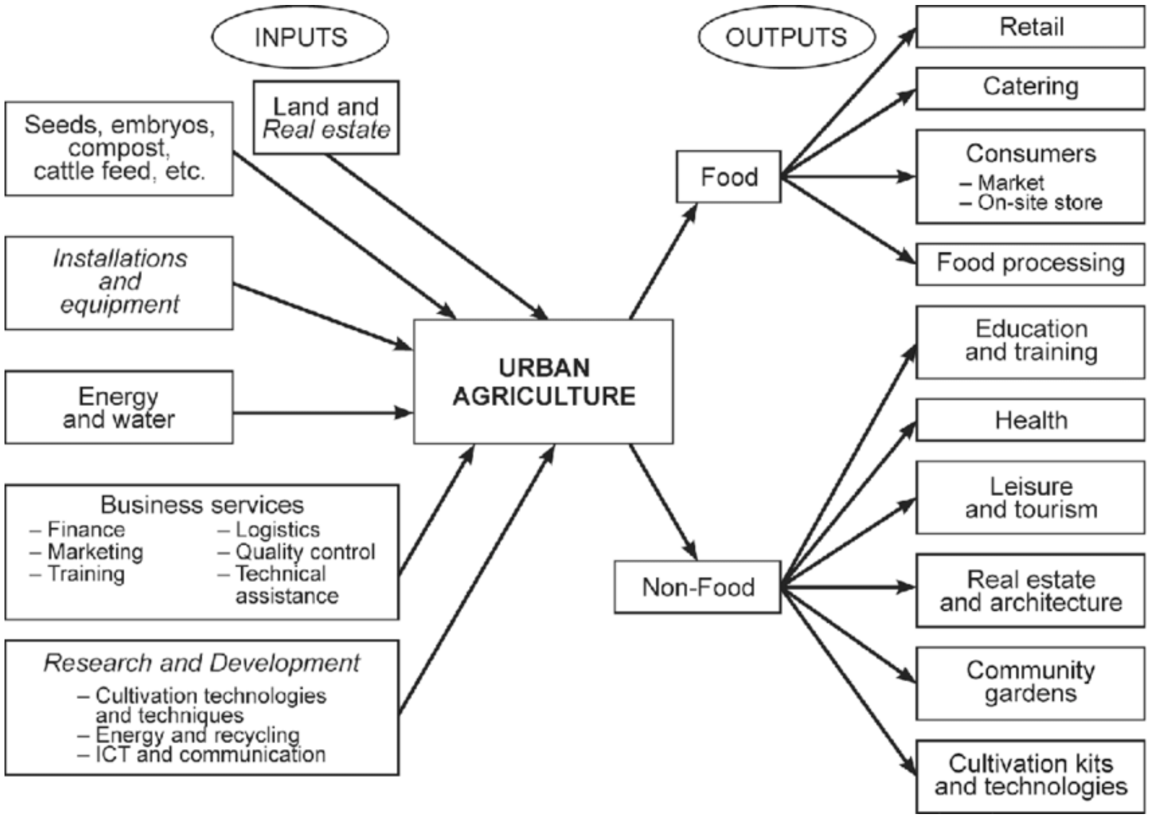
*InvertiGro* - a Sydney based company which specialises in construction, design, and modeling of the VFS to the needs of the client: highly customisable, flexible and has a wide range of scalability and operation models.

*Eden Towers* - a working vertical farming system in an office building with possible links to local retail stores for supply of fresh produce (Simons, 2023).

All these companies follow a similar value chain model for their production.

Other crucial supporters of the VFS value chain are research and development (R&D) teams, building owners/real estate agents, engineering teams, and architecture teams (Van Tuijl et al., 2018). These stakeholders contribute significantly to various aspects of vertical farming, from technological innovations and infrastructure development to market accessibility and consumer acceptance.

**Figure 7. Existing value chain representation of the urban vertical farming system**




Source: (Van Tuijl et al., 2018).

It is also essential to acknowledge the broader range of input suppliers, distributors, government regulators, financial institutions, and intermediaries (Stein and Barron, 2017). While the presence of intermediaries may currently be lacking, their inclusion can potentially optimize distribution efficiency and mitigate high premium prices, fostering a more accessible and sustainable vertical farming market (Cardona et al., 2021). It is noteworthy that there is a paucity of academic literature specifically concentrating on the roles and interactions of these stakeholders within the vertical farming value chain, highlighting a gap in research that warrants further exploration and analysis.

## Regulations and Certifications

Urban farming has gained commercial importance only in recent years with products appearing in retail shops categorised as “organic” and “premium” products (Padilla et al., 2018). There is no established regulatory body focusing specifically on VFS technologies because applicable regulation authorities are substantially the same as for the products produced from conventional methods which lay out general guidelines and initiatives in place to ensure food safety, quality, and environmental sustainability. Some of these regulatory bodies and certification authorities in Australia are as follows.

### Food Standards Australia New Zealand (FSANZ)

FSANZ sets the standards for food safety and quality in Australia and New Zealand. While there are no specific regulations for urban vertical farming systems, the general food safety standards set by FSANZ apply to all food producers, including urban vertical farms. This includes guidelines on hygiene, storage, labeling, and handling of produce (FSANZ, 2023).

**State-specific regulations**

Different Australian states have their own specific regulations or guidelines regarding urban vertical farming systems. New South Wales, Victoria, and other states have individual agencies overseeing food safety and quality standards. Producers consult their respective state's government websites for state-specific regulations (Hearn et al., 2021). In Queensland, the Safe Food Production Queensland (Safe Food Queensland) (Food Act 2006) is the regulatory body responsible for ensuring food safety and compliance with relevant laws. Urban vertical farms in Queensland are subject to inspection and certification by this agency (Queensland, 2023). South Australia (Food Act 2001) has a cohesive authority between SA Health, local government and other government agencies to ensure food safety (PIRSA, 2023). None of the recent updates to the Food Acts include vertical farming in specific or product-related terms.

**Organic certification**

Organic certification ensures that farming practices meet specific organic standards and principles. For those urban farming crops involving the incorporation of aquaponics, the scope for organic fresh produce is high. Such farming systems seek organic certification from organisations such as Australian Certified Organic (ACO) but the ACO has clearly denied the status of organic for any product coming from vertical farming as reported in their official website (ACO, 2023).

## Opportunities and Challenges

Vertical farming represents a revolutionary advancement in traditional agriculture. Unlike conventional soil-based farming with crops grown horizontally, vertical farming utilises soilless cultivation within a protected and controlled environment. This innovative approach enables year-round production of fresh, safe, and nutritious food while enhancing the productivity and profitability without the interference of soil-borne pathogens (Benke and Tomkins, 2017). The plant productivity per unit area of vertical farming system is far above that from conventional farming practice (Maluin et al., 2021; Touliatos et al., 2016). The implementation of AI and automation in constant monitoring and control systems allows growers to devise flexible growing schedules and nurture crops under precisely-calculated optimal environmental conditions and nutrient solutions.

Furthermore, vertical farming boasts highly efficient resource utilisation in terms of water, CO2, and fertilisers, leading to minimal environmental pollution (Kozai, 2018). By enhancing resource efficiency, including land, water, light energy, electrical energy, and inorganic fertilisers, vertical farming can contribute to preventing water scarcity through closed-loop water systems. The reduction in unsustainable global demands for arable land and water could attract investments, making industrial-scale vertical farms commercially viable (Kalantari et al., 2018; Kozai, 2018).

Despite its promise as a sustainable solution for food security, vertical farming faces certain challenges. One major obstacle is the high initial expense of the infrastructure. Modern vertical farming must focus on enhancing resource efficiency to improve crop yield and quality while implementing intelligent automated control systems to optimise labour and energy efficiency (Kalantari et al., 2018; Li et al., 2020). Additionally, the energy-intensive nature of vertical farming, including lighting, temperature, and humidity control, necessitates efficient energy management. Various strategies, such as using cost-effective and energy-efficient LED lighting, matching spectral characteristics to plant physiology, and employing renewable energy sources like solar, wind-based, or geothermal energy, can help reduce electricity costs and enhance energy efficiency (Van Delden et al., 2021; Wong et al., 2020).

Another challenge lies in the limited range of crops currently suitable for this business model (Van Delden et al., 2021). Although vertical farming technically allows the cultivation of various vegetables, including leafy greens, herbs, medicinal plants, fruiting crops, root vegetables, and grains, the commercially viable scope of vegetables is limited to only a few high value crops. Advanced technologies and innovations are needed to expand the scope of crops viable for vertical farming, including functional foods from medicinal plants and micronutrient-fortified food crops that carry high value and profit potential. Studies have shown that certain cereal crops, tuber crops, strawberries, potatoes, beans, and wheat can thrive in vertical cultivation with controlled environmental conditions, hinting at the possibilities for diversifying crops in the future (Muller et al., 2017; Oh and Lu, 2023; Sala et al., 2017; Van Delden et al., 2021; Van Tuijl et al., 2018). Further advancements in technology will be crucial in facilitating the cultivation of a wide range of crops through vertical farming.

## Conclusion

The rise of urban vertical farming systems as a promising sustainable crop production alternative is the result of a collaborative endeavor involving many participants. As they seek to seize the market opportunities, these stakeholders encounter various trade-offs in their decision-making processes. Ongoing research in the realms of science, technology, and consumer perception serves as the foundation for these decisions, with the goal of reducing risks and uncertainties. Producers face trade-offs in the value chain that revolve around achieving cost efficiency while maintaining responsiveness to market demands. As companies invest heavily in optimising vertical farming systems for commercial and household markets, justifying their premium price points necessitates additional research and scientific development. Simultaneously, consumers' willingness to pay for produce from urban VFS depends on factors such as awareness, affordability, and overall nutritional value and sustainability compared to conventionally produced fresh produce. Regulatory agencies are working towards establishing approvals and guidelines for producers, aiming to strike a balance between market power and consumer protection in terms of food safety (Van Delden et al., 2021).

Stakeholders coming together with a collaborative and cohesive approach is crucial to mitigate externalities stemming from the current conventional agriculture practices. Given the potential mismatch in perspectives between consumers and producer on the VFS based product, there is a risk of strategic fit misalignment, drastically inhibiting the progress or leading to misinterpretation of objectives.

Australia shows high promise for the coexistence of urban vertical farming system produce alongside conventional agriculture produce on market shelves, showing equal competitiveness, and catering to diverse consumer and commercial preferences. While the complete transformation of agriculture production to urban VFS is not practical, urban VFS clearly shows signs of immense potential to alleviate some of the food production pressure on conventional farming systems.

To ensure maximum market acceptance in all the major urban and semi-urban cities in Australia, all aspects of the value chain necessitate further research and analysis, aiming to reach a consensus. The strategy can be staggered and customised according to the specific target audience, yet it has the potential to improve sustainability within global food systems.

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