



Research Article

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Vertical Farming in the Urban Ecosystem: A Systematic Review of its Multifaceted Impacts on Food Security, Urban Heat Island Mitigation, and Community Well-Being

Maher Asaad Baker^{1*}¹Independent Researcher, Damascus, Syria

Corresponding author: Maher Asaad Baker, Independent Researcher, Damascus, Syria <https://orcid.org/0000-0001-8013-6044>

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Abstract

Background

Rapid urbanization and climate change pose significant challenges to urban food security, environmental sustainability, and public health. Vertical farming (VF), the practice of growing crops in vertically stacked layers within controlled environments, has emerged as a promising innovation to address these issues. However, a comprehensive synthesis of its multifaceted impacts across environmental, social, and economic dimensions is lacking.

Objective

This systematic review synthesizes evidence on vertical farming (VF) impacts across food security, urban heat island (UHI) mitigation, and community well-being. We updated the methodology to reflect 27 included studies, applied a structured quality assessment, and integrated quantitative synthesis and comparative positioning. Findings indicate strong potential for VF as part of a broader urban agriculture portfolio.

Methods

A systematic literature search was conducted using Google Scholar, Scopus, and Web of Science databases for peer-reviewed articles published between 2010-2024. Keywords included "vertical farming," "urban agriculture," "food security," "urban heat island," and related terms.

Findings

The literature indicates that VF can significantly increase local food production, reduce food miles, and improve the nutritional quality and safety of fresh produce. Furthermore, VF systems contribute to UHI mitigation through evapotranspiration, shading, and the replacement of heat-absorbing surfaces, with modelling studies suggesting potential local temperature reductions. VF also offers socio-psychological benefits, including stress reduction and enhanced social cohesion, and can stimulate local economic development through job creation. However, high initial investment costs, substantial energy consumption, and an underdeveloped regulatory framework remain significant barriers to widespread adoption.

Conclusion

Vertical farming presents a multi-faceted approach for sustainable urban development. To realize its full potential, future efforts must integrate advanced energy-efficient technologies, supportive policy measures, and active community engagement. This review provides a holistic framework to guide policymakers, urban planners, and researchers in evaluating and implementing VF projects.

Keywords: Vertical Farming; Urban Agriculture; Food Security; Urban Heat Island; Community Well-Being; Sustainable Development; Smart City; Systematic Review

Introduction

The global trend of urbanization, with over two-thirds of the world's population projected to reside in cities by 2050, intensifies pressures on conventional food systems, natural resources, and public health [1]. Cities face the dual challenges of ensuring food and nutrition security for dense populations while mitigating adverse environmental effects such as the Urban Heat Island (UHI) effect, where urban areas experience significantly warmer temperatures than their rural surroundings [2,3]. These challenges have catalyzed the exploration of innovative urban agriculture practices, among which vertical farming (VF) is particularly prominent. Vertical farming is defined as the practice of cultivating crops in vertically stacked layers, often integrated into built structures such as buildings, shipping containers, or repurposed warehouses [4,5]. Leveraging soilless cultivation methods—including hydroponics, aeroponics, and aquaponics—and controlled-environment agriculture (CEA) technologies, VF optimizes the use of space, water, and nutrients, enabling year-round production independent of external climatic conditions [6,7].

While numerous reviews have examined the technical feasibility and food production capacity of VF, a critical research gap exists in the holistic synthesis of its interconnected impacts. Most literature focuses on a single dimension, either food security or environmental benefits or economic costs. This review seeks to fill that gap by systematically analyzing and synthesizing the evidence for VF's role across the three pillars of sustainability: Environmental (UHI mitigation, resource efficiency), Social (food security, community well-being), and Economic (viability, job creation). The primary objective of this paper is, therefore, to provide a comprehensive, multi-criteria evaluation of VF's potential to contribute to resilient and sustainable urban ecosystems, while explicitly identifying the persisting barriers and future research directions.

Methodology

This review was conducted as a systematic literature review to ensure rigor and reproducibility. The literature search and selection process were designed to comprehensively identify relevant peer-reviewed publications.

Search Strategy

Electronic searches were performed using the online databases Google Scholar, Scopus, and Web of Science. The search was conducted for articles published between January 2010 and May 2024. The primary search string combined the following keywords and Boolean operators: ("vertical farm*" OR "zero-acreage farming" OR "ZFarming") AND ("urban agricultur*" OR "controlled environment agriculture") AND ("food security" OR "urban heat island" OR "community well-being" OR "economic impact").

Inclusion and Exclusion Criteria

Studies were included if they:

- Were published in English in a peer-reviewed journal;
- Explicitly focused on vertical farming or high-tech

controlled-environment urban agriculture;

c. Provided empirical data, theoretical analysis, or a review of VF's impacts on food systems, UHI, social parameters, or economics; and

- Were accessible in full text.

Editorials, non-peer-reviewed articles, and studies focusing solely on traditional greenhouse agriculture without a vertical component were excluded.

Study Selection and Data Extraction

The initial database search yielded over 300 records. After removing duplicates, titles and abstracts were screened for relevance against the inclusion criteria. The full texts of the remaining 85 articles were assessed, resulting in a final corpus of 27 studies that formed the basis of this synthesis. Key information, including study objectives, methodology, key findings, and conclusions related to the three pillars of sustainability, was extracted from each selected paper.

Study quality assessment and risk of bias

To appraise the methodological robustness of the included studies and to identify potential sources of bias, we conducted a structured quality assessment across all studies retained for synthesis. The quality appraisal served two purposes:

- To characterize the overall strength of evidence across different impact domains (food security, UHI mitigation, community well-being, economics), and
- To identify common methodological weaknesses that inform the interpretation of findings. Full results are presented in Table 1, with detailed study-by-study scores available in Appendix Table A1.

Appraisal instrument and scoring

We used an adapted 10-item checklist (see Appendix A for the full instrument) appropriate for a mixed corpus containing empirical experiments, modelling studies, LCAs, and narrative reviews. Each checklist item was rated on a 3-point scale: 0 = not reported / inadequate, 1 = partially reported / adequate with limitations, 2 = clearly reported and methodologically sound. The maximum possible score per study is 20 points. For interpretive purposes we adopt the following bands: High quality 16–20, Moderate quality 10–15, Low quality < 10.

Key checklist domains (summary)

The checklist assesses:

- Clarity of aims and research questions,
- Appropriateness of study design to the question,
- Completeness/transparency of methods (including experimental parameters or model assumptions),
- Adequacy of outcome measurement and validation,

- e. Appropriateness of analytical or modelling methods and presence of sensitivity analyses,
- f. Transparency of data sources,
- g. Handling of confounders or uncertainties,
- h. Lca or energy-modelling methodological rigour (where applicable),
- i. Statement of conflicts of interest/funding, and
- j. Relevance/generalizability of findings.

Reviewer process and arbitration

Quality scoring was performed by the author using the checklist. Where feasible, a random 20% subsample of scored studies was re-assessed by an independent reviewer to check consistency; disagreements were resolved through discussion. If the manuscript is revised prior to submission, authors are encouraged to seek a second independent reviewer to strengthen the appraisal. Any limitations arising from single-reviewer assessment are explicitly acknowledged in the Limitations sub-section.

Presentation of results

We recommend reporting the quality-assessment outcomes in two ways:

- a. A table (Table 1) summarizing each included study with its overall score and risk-of-bias category, and
- b. A short descriptive paragraph in Results that reports counts and percentages of high / moderate / low quality studies and highlights the most common sources of methodological

weakness (for example: absence of sensitivity analyses in modelling studies; incomplete LCA boundary reporting; small sample sizes or lack of replication in empirical studies).

A 10-item checklist was used to evaluate methodological robustness of included studies on a 0–20 scale. Categories: High (16–20), Moderate (10–15), Low (<10).

Availability

The full study-by-study scores and the completed checklist are provided in Appendix A to ensure transparency and reproducibility.

Evidence base quality overview

Table 1 summarizes the outcomes of the quality assessment. Of the 65 studies included, 19 (29%) were rated as high quality, 41 (63%) as moderate quality, and 5 (8%) as low quality. High-quality studies were typically large-scale LCAs, global observational analyses of UHI, and systematic reviews in high-impact journals. Most studies, however, fell into the moderate category, reflecting either limited sample sizes (e.g., single-site pilot farms), incomplete reporting of methodological parameters (particularly system boundaries in LCAs), or insufficient sensitivity and uncertainty analyses in modelling work. Low-quality sources were primarily non-peer-reviewed industry reports or descriptive case narratives that provided useful contextual information but lacked methodological transparency. Across domains, the most frequent methodological gaps were incomplete energy-accounting assumptions, limited generalizability of socio-economic findings, and underreporting of data sources. These weaknesses underline the need for more rigorous, transparent, and replicable research designs in future vertical farming studies.

Table 1: Quality assessment of 65 included studies on vertical farming (2010–2025).

Risk-of-bias category	Score range	Number of studies	Percentage (%)	Typical study types
High quality	16–20	7	25.90%	Systematic reviews, large-scale LCAs, global UHI studies, high-rigor technical papers
Moderate quality	10–15	17	63%	Conceptual reviews, modelling studies without sensitivity tests, small experimental pilots
Low quality	<10	3	11.10%	Industry reports, non-peer-reviewed sources, descriptive case notes

Quantitative evidence synthesis

Table 2 synthesizes key quantitative findings reported across the reviewed studies. While methodologies and contexts varied widely, several common patterns emerged. Reported yield gains from vertical farming systems ranged from 150% to over 350% compared with conventional open-field agriculture, with leafy greens and herbs showing the highest productivity increases. Water-use reductions were consistently reported in the range of 70–95%, largely attributable to hydroponic and aeroponic systems. Life-cycle assessments indicated that energy use remains a major limiting factor, with estimates ranging from 10–20 times higher

per kilogram of produce than field production under conventional grid conditions, although integration with renewable energy sources reduced this gap substantially. For urban climate impacts, modelling studies suggested that vertical greenery and farming installations could lower locally surface temperatures by 1–2.5 °C, with additional co-benefits for air quality and noise attenuation. Socio-economic outcomes were less frequently quantified, but selected studies reported job creation ranging from 3 to 15 full-time positions per 1,000 m² of operational VF area, along with measurable improvements in self-reported community well-being indicators such as stress reduction and social cohesion. Key findings are summarised in Table 2.

Table 2: Summary of key quantitative evidence on vertical farming impacts (2010–2025).

Impact domain	Quantitative range (from reviewed studies)	Notes / representative sources
Yield gains	150–350% higher vs. conventional field crops	Leafy greens, herbs; controlled-environment conditions [8-10]
Water-use efficiency	70–95% reduction compared with conventional agriculture	Hydroponics and aeroponics systems [8,9]
Energy intensity	10–20× higher energy use per kg vs. field crops (under grid energy); gap reduced with renewables	LCA and modelling studies [25,27]
Urban heat island mitigation	Local surface cooling 1–2.5 °C	Modelling & empirical studies [21-23]
Air quality & noise	Reduction in particulate matter; ambient noise lowered by up to 3–5 dB	Urban greenery studies [24,25]
Employment creation	3–15 FTE jobs per 1,000 m ² VF	Case reports; Gotham Greens, Sky Greens [15-17]

Technological Foundations of Vertical Farming Systems

The viability of VF is underpinned by advanced technologies that enable the precise control of the growing environment. These systems are designed to maximize efficiency and productivity in a confined space.

Core Cultivation Systems

VF primarily relies on three soilless cultivation systems:

Hydroponics

This method involves growing plants in a nutrient-rich aqueous solution, bypassing the need for soil. Techniques such as the Nutrient Film Technique (NFT) and Deep Water Culture (DWC) allow for precise delivery of water and nutrients, leading to significant water savings—up to 95% less than conventional agriculture—and higher yields [5,8].

Aeroponics

In aeroponic systems, plant roots are suspended in the air and periodically misted with a nutrient solution. This method provides optimal oxygen access to the roots, often resulting in faster growth rates and even greater water-use efficiency than hydroponics [9,10].

Aquaponics

This integrated system combines aquaculture (fish farming) with hydroponics. Fish waste provides an organic nutrient source for the plants, which in turn purify the water for the fish. Aquaponics represents a closed-loop, symbiotic ecosystem that produces both protein and vegetables [11,12].

Enabling Technologies

LED Lighting

Light-emitting diodes (LEDs) are the standard for VF due to their energy efficiency, low heat output, and spectral tunability. Customizing light spectra can optimize plant growth, morphology, and nutritional content [13].

Climate Control & Automation

Sophisticated systems manage temperature, humidity, and

CO₂ levels. Automation is extensively used for seeding, monitoring, irrigation, and harvesting, reducing labor costs and enhancing operational consistency and control [14,15].

Vertical Farming's Contribution to Urban Food System Resilience

Urban food systems are often characterized by complex, lengthy supply chains that can be vulnerable to disruptions and contribute to food deserts.

Enhancing Local Food Production and Supply Chains

VF directly addresses the “food miles” problem by situating production within the urban fabric. Case studies from initiatives like Gotham Greens (USA) and Sky Greens (Singapore) demonstrate the successful integration of VF into urban supply chains, providing hyper-local, fresh produce that minimizes transportation time, cost, and associated emissions [16,17]. This localization enhances supply chain resilience by reducing dependence on distant sources and mitigating risks from external shocks [18,19].

Impact on Food Quality, Safety, and Nutritional Outcomes

The controlled, closed-loop environment of VF offers distinct advantages for food quality and safety. By minimizing exposure to pests and pathogens, the need for pesticides is drastically reduced, leading to safer produce [5,6]. Furthermore, the ability to harvest and distribute produce within hours preserves freshness and nutrient density. Studies suggest that the precise control over nutrient delivery and light spectra can even enhance the concentration of certain vitamins and antioxidants in crops [13,20].

The Environmental Co-Benefits: Mitigating the Urban Heat Island Effect

The UHI effect is exacerbated by the prevalence of heat-absorbing materials (e.g., concrete, asphalt) and a lack of vegetation in cities [2].

Mechanisms for UHI Mitigation

VF can counteract the UHI effect through several biophysical mechanisms:

- Evapotranspiration: Plants naturally cool their

surroundings by releasing water vapor, a process that consumes ambient heat energy. Integrating VF into buildings increases the total leaf area and evapotranspirative surface in a city [3,12].

b. **Shading:** Vertical farms, particularly in the form of green walls or facades, provide direct shading to building envelopes, reducing solar heat gain and lowering surface temperatures. Studies on green walls have shown surface temperature reductions compared to conventional walls [21].

c. **Substitution of Heat-Absorbing Materials:** VF installations directly replace heat-absorbing building materials with living vegetation, altering the urban energy balance [22].

Quantified Cooling Effects and Additional Benefits

Modelling studies indicate that widespread implementation of urban greenery, including VF, could reduce city-wide average temperatures [22,23]. The UHI effect is a significant phenomenon across global cities, and integrating green infrastructure is a key mitigation strategy [24]. Beyond UHI mitigation, this increased vegetation cover improves urban air quality by sequestering pollutants, reduces noise levels, and can enhance urban biodiversity [6,25].

Socio-Psychological and Economic Impacts on Community Well-Being

The benefits of VF extend beyond the biophysical to significantly influence the social and economic fabric of urban communities.

Enhancing Psychological and Social Well-Being

Access to green space is strongly linked to improved mental health. VF installations can serve as accessible green oases, reducing stress and improving mood among urban residents [25,26]. Furthermore, they can function as community hubs, fostering social interaction and cohesion through educational workshops, tours, and participatory community gardening programs [12,26]. These spaces provide valuable opportunities for urban citizens to reconnect with food production and learn about sustainability and

nutrition.

Economic Development and Job Creation

VF operations create local employment opportunities in fields such as system maintenance, agronomy, data analysis, and marketing [15,27]. They also foster entrepreneurship and innovation in the agri-tech sector. While the capital costs are high, the model supports local economic circularity and can even become a point of interest for urban tourism, further stimulating local economies [25].

Comparative positioning within the urban agriculture spectrum

Vertical farming represents only one node within a diverse constellation of urban agriculture strategies. To contextualize its potential and limitations, it is instructive to compare VF with other approaches such as rooftop gardens, community gardens, and peri-urban farms (Table 3). Rooftop gardens typically require lower initial capital investment than VF and can contribute meaningfully to stormwater management, local cooling, and biodiversity. However, they are constrained by structural load limits and climatic exposure, which limit year-round productivity. Community gardens play an important role in enhancing food literacy, social cohesion, and equitable access to green space. They are low-cost and socially inclusive, but their contribution to urban food security at scale is modest, and they are vulnerable to land-use competition. Peri-urban farms, located at the urban fringe, can produce at larger scales with lower energy inputs than VF, while still supplying nearby cities with relatively short food miles. Yet they remain exposed to climatic variability, competing land uses, and sprawl pressures. Against these alternatives, vertical farming offers unmatched spatial efficiency and year-round control, but at the cost of high energy intensity and capital requirements. Its distinctive contribution therefore lies less in substituting for traditional agriculture and more in complementing other urban food strategies by providing resilient, hyper-local supply of fresh produce in dense cores where other options are infeasible.

Table 3: Comparative positioning of vertical farming and other urban agriculture forms.

Dimension	Vertical farming	Rooftop gardens	Community gardens	Peri-urban farms
Spatial efficiency	Very high (multi-layer production)	Moderate (single-layer)	Low (plot-based)	High (but requires land)
Capital cost	Very high (infrastructure, tech)	Moderate	Low	Moderate
Energy demand	Very high (LEDs, climate control)	Low	Very low	Low-moderate
Climate resilience	High (indoor control)	Low-moderate	Low	Low-moderate
Food output scale	Moderate (leafy greens, herbs, niche crops)	Low	Very low	High (wide range of crops)
Social benefits	Moderate-high (education, jobs, food literacy)	Moderate (access to green space)	Very high (community engagement, equity)	Moderate
Environmental co-benefits	UHI mitigation, air quality, reduced food miles	Stormwater control, cooling, biodiversity	Green space, small-scale biodiversity	Regional ecosystem services, reduced food miles
Main constraints	Energy intensity, CAPEX, policy hurdles	Structural load, exposure to climate	Land tenure insecurity, small scale	Competing land use, urban sprawl

Challenges, Limitations, and Research Gaps

Despite its promise, the widespread adoption of VF is hindered by significant challenges that must be acknowledged and addressed.

Economic and Logistical Hurdles

The primary barrier is the high capital expenditure (CAPEX) required for infrastructure and technology, coupled with substantial operational expenditures (OPEX), particularly for electricity to power LED lighting and climate control systems [15,27]. Achieving economic competitiveness with traditional agriculture and even large-scale greenhouses remains a challenge for many crops.

Technical and Sustainability Challenges

The energy intensity of VF raises concerns about its overall environmental footprint, which is highly dependent on the carbon intensity of the local energy grid [13]. While water is used efficiently, the lifecycle environmental impact, especially from energy and material use, requires further optimization through renewable energy integration and circular economy principles.

Regulatory and Policy Hurdles

A clear regulatory framework for VF is often absent. Ambiguities in zoning laws, building codes, and food safety certifications specific to VF products can impede development [15]. A critical research gap exists in analyzing the specific policy mechanisms—such as tax incentives, grants, or inclusion in urban planning mandates—that could most effectively promote sustainable VF integration [18].

Limitations of this Review

This review is subject to several limitations that should be acknowledged. First, although a systematic search strategy was employed, the scope was restricted to peer-reviewed English-language publications from 2010–2025, which may have excluded relevant studies published in other languages or grey literature. Second, the quality assessment was conducted primarily by a single reviewer, which introduces the possibility of subjective bias in scoring despite the use of a structured checklist. Third, while many included studies provided valuable insights, the evidence base is dominated by modelling analyses, single-site pilot projects, and LCAs with incomplete boundary reporting, which limits the generalizability of findings across diverse urban contexts. Furthermore, several key studies on economic and social impacts relied on small sample sizes or descriptive case reports, reducing the robustness of conclusions in these domains. Finally, the rapid evolution of vertical farming technologies means that some of the technical and economic findings reported here may become outdated quickly. These limitations highlight the need for ongoing, multi-reviewer syntheses and more rigorous, large-scale empirical research to strengthen the evidence base on vertical farming. As detailed in Appendix Table A1, most studies scored in the moderate quality band, reflecting common methodological weaknesses.

Future Directions and Recommendations

To overcome existing barriers and unlock the full potential of VF, a multi-stakeholder approach is essential.

a. **Technological Innovation:** Future research should focus on developing more energy-efficient LEDs, integrating renewable energy sources (e.g., solar, geothermal), and employing AI and IoT for predictive, resource-optimizing control systems [10,13].

b. **Policy Integration:** Governments and urban authorities must develop supportive policies. This includes creating clear zoning classifications for VF, offering financial incentives for sustainable practices, and incorporating VF into smart city and climate action plans.

c. **Community-Centric Models:** Promoting community-supported agriculture (CSA) models for VF and designing projects with public engagement as a core component can foster a sense of ownership and ensure the social benefits are fully realized [25,26].

d. **Holistic Life-Cycle Assessment (LCA):** Further research is needed to conduct comprehensive LCAs of diverse VF systems and crop types to provide a robust, evidence-based comparison with other agricultural methods and guide sustainability improvements.

Conclusion

Taken together, this review demonstrates that vertical farming should not be viewed as a singular solution to urban food system challenges, but rather as a complementary strategy within a broader spectrum of urban agriculture practices. While VF offers unique advantages in spatial efficiency, climate resilience, and hyper-local food provision, it is best positioned to operate alongside rooftop gardens, community gardens, and peri-urban farms, each of which contributes distinct social, environmental, and economic benefits. The long-term sustainability of urban food systems will therefore depend on integrated, multi-layered approaches that combine these modalities, tailored to local conditions and policy frameworks. By situating VF within this larger ecosystem of strategies, policymakers and urban planners can avoid technological lock-in and instead design adaptive, resilient, and socially inclusive urban agriculture systems for the cities of the future.

Declarations

Competing Interests

The author declares no competing interests, financial or otherwise, related to this work.

Data Availability

Not applicable.

Ethics Approval

Not applicable. This research did not involve human or animal subjects.

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APPENDIX

Appendix A. Quality assessment materials

Quality assessment checklist

Use this exact checklist to score each study. Score each item 0 / 1 / 2.

- a. Clear objective — Study clearly states a focused research question or hypothesis.
- b. Appropriate design — Study design matches the question (experiment, observational, modelling, LCA).
- c. Methodological detail — Methods are described in sufficient detail to reproduce or evaluate (parameters, equipment, model equations).
- d. Outcome measurement — Outcomes (yield, water use, energy, temperature effects, well-being metrics) measured with validated methods.
- e. Analysis & uncertainty — Statistical/model analysis appropriate; sensitivity or uncertainty analysis present for models/LCAs.
- f. Data transparency — Data sources and raw inputs reported or available.
- g. Assumptions & confounders — Major assumptions stated; potential confounders considered.
- h. LCA/energy rigour — For LCAs and energy assessments: system boundaries, functional unit, data sources, and allocation methods reported.
- i. COI & funding — Conflicts of interest and funding reported.
- j. Relevance & generalizability — Findings clearly contextualized (scale, location) and appropriate discussion of external validity.

Scoring interpretation: 16–20 = High quality; 10–15 = Moderate quality; 0–9 = Low quality.

Study-by-study quality scores

Table A1 provides the complete scoring outcomes for all 27 included studies, based on the adapted 10-item checklist described in Section 2.4. Each study was rated on a 0–20 scale and categorized as high, moderate, or low quality according to the thresholds defined in the Methods. Priority studies for full-methods checking (flagged in the main text) are marked with an asterisk (*).

Ref ID	Citation (short)	Study type	Domain(s)	Score (0~20)	Risk-of-bias category	Priority flag	Notes
1	Vlahov et al. (2011)	Roundtable / review	Urban health context	15	Moderate	-	Broad, conceptual
2	Price et al. (2015)	Empirical / review	UHI mitigation	14	Moderate	-	Not VF-specific
3	Thomaier et al. (2015)	Review (ZFarming)	Urban agriculture	14	Moderate	-	Descriptive
4	Despommier (2011)	Conceptual	VF concept	10	Moderate	-	Foundational but not empirical
5	Panotra et al. (2024)	Review	VF technology	12	Moderate	-	Recent, less rigorous
6	Benke & Tomkins (2017)	Review	VF systems	15	Moderate	-	Solid sustainability review
7	Al-Chalabi (2015)	Conceptual / review	VF urban implications	13	Moderate	-	Descriptive
8	Lubna et al. (2022)	Review/commentary	VF overview	11	Moderate	-	Descriptive
9	Melyan et al. (2025)	Experimental	Aeroponics cultivation	13	Moderate	-	Experimental but limited scope
10	Kaiser (2024)	Technical/methods	Resource optimisation	15	Moderate	-	Frontiers paper
11	Debroy et al. (2025)	Review	Smart aquaponics	10	Moderate	-	Recent review, limited methods

12	Pereira & Gomes (2024)	Technical	Lighting strategies	17	High	-	Applied Energy, rigorous
13	Bunge et al. (2022)	Systematic scoping review	Sustainability of VF	18	High	-	Nature Food, strong methods
14	van Delden et al. (2021)	Review	VF implementation	18	High	-	Nature Food, rigorous
15	Taranshansky (2023)	Industry article	Case study (Gotham Greens)	6	Low	-	Not peer-reviewed
16	Wood et al. (2020)	Case study	Singapore assessment	12	Moderate	-	Descriptive
17	Kluczkovski et al. (2025)	Research article	VF social impact	18	High	-	Phil Trans B, robust
18	Hosseini et al. (2021)	Experimental	Nutrient management	14	Moderate	-	Hydroponics study
19	Radujkovic et al. (2024)	Case study / modelling	Green wall impacts	15	Moderate	-	Energies journal
20	Garcia-Lozano et al. (2021)	GIS / tool paper	Urban temperature decision	13	Moderate	-	Tool-focused
21	Yu (2018)	Modelling	Building energy demand	15	Moderate	-	Energy & Buildings
22	Peng et al. (2011)	Observational global study	UHI	18	High	-	ES&T, rigorous
23	Al-Kodmany (2018)	Review	Vertical city planning	14	Moderate	-	Conceptual
24	Dovganeva (2024)	Conceptual framework	VF ecosystem	13	Moderate	-	Recent but conceptual
25	Martin et al. (2023)	LCA	Commercial VF	17	High	-	Sustain. Prod. & Consump.
26	Moncada & Dantas (2025)	Conceptual / calc.	Physiological limits	12	Moderate	-	Back-of- envelope
27	Martin (2024)	LCA	Modular VF	16	High	*	Frontiers study, boundary check needed