INDUS JOURNAL OF ANIMAL AND PLANT SCIENCES
https://induspublishers.com/IJAPS
Volume 3, Issue 2 (2025)

Original Article

" Assessing the Economic Viability of Vertical Farming in Urban Areas for Reducing Food Insecurity in Mega Cities"

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ARTICLE INFO

Received: 15 July 2025
Revised: 10 August 2025
Accepted: 09 September 2025
Published: 31 December 2025

Key Words:
* Vertical Farming
*Urban Agriculture
*Economic Viability
*Food Insecurity
*Sustainable Food Systems
*Mega Cities

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ABSTRACT

Rapid urbanization and population growth have intensified food insecurity challenges in mega cities, necessitating innovative and sustainable urban food production systems. Vertical farming has emerged as a promising solution due to its ability to produce high-quality crops within controlled environments while minimizing land use and supply-chain inefficiencies. Despite its environmental advantages, concerns regarding high capital investment, energy consumption, and operational costs continue to limit widespread adoption. This study evaluates the economic viability of vertical farming in urban contexts and examines its potential contribution to reducing food insecurity. Using a mixed-methods experimental approach, the research integrates quantitative financial modeling with qualitative insights from industry stakeholders to assess cost structures, productivity, profitability, and scalability across multiple operational scenarios. The results demonstrate that while baseline vertical farming systems face economic constraints, financial performance improves significantly through energy-efficient technologies, automation, economies of scale, and policy support mechanisms. Sensitivity and profitability analyses indicate that optimized vertical farming models can achieve positive net present value and stable revenue streams, particularly when aligned with diversified crop portfolios and market-responsive strategies. Beyond direct financial returns, the findings highlight indirect economic and social benefits, including enhanced urban food availability, reduced waste, and employment generation. Overall, the study concludes that vertical farming can become an economically viable and resilient component of urban food systems when supported by technological innovation, strategic investment planning, and enabling policy frameworks.

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INTRODUCTION

Since the global population has continuously increased, and many people are projected to reside in urban areas in the coming 50 years, there is an increasing interest in developing sustainable urban food systems to address the major food insecurity challenges in mega-cities (Abdelfatah & El-Arnaouty, 2023, p. 214). These issues could be addressed with the help of vertical farming, i.e., the cultivation of crops in controlled settings with vertical layers, and this approach would result in the availability of food, reduced transportation expenses, and the production of food throughout the year in densely populated urban areas (Paucek et al., 2023, p. 1; Singh et al., 2023). This is not just a new form of farming that operates around space issues that accompany urban living, but it also reduces the environmental harm that is accrued through the traditional means of farming. It would result in more robust food chains (Moghimi and Asiabanpour, 2021, p. 2; Nesheli and Salaj, 2024, p. 351). Although vertical farming may be environmentally friendly, the initial cost and the operating expenses of the business are high, thus difficult to profit (Barui et al., 2022, p. 227). Therefore, an in-depth economic analysis has to be conducted to evaluate the economic feasibility of vertical farming projects and develop plans on how to enhance their competitiveness within the broader agricultural market (Moghimi & Asiabanpour, 2023, p. 1838). The aim of this paper is to assess the economic viability of vertical farming in urban areas, and specifically analyzing how this model could address food insecurity in the mega-cities, based on the review of relevant economic models, the identification of notable obstacles, and the communication of the strategies to enhance the financial viability of the system (Nesheli and Salaj, 2024, p. 351). In particular, this paper will discuss the high cost of installation, labor expenses and energy use that in most cases undermine the economic feasibility of vertical farms when compared to the traditional agricultural subsidies (Gurung et al., 2024, p. 109; Islam et al., 2021, p. 8). It will also consider how the economies of scale and new technologies may assist in reducing these costs and make the business more profitable in the overall (Armas et al., 2023, p. 864; Gurung et al., 2024, p. 106). The economic analysis will be offered to consider the actual monetary benefits of produce sales and indirect economic benefits, such as the creation of jobs, reduced food waste, and strengthened health of the community, which will consequently promote the overall viability of urban vertical farming projects (Nesheli and Salaj, 2024, p. 351). The existing academic literature on vertical farming lacks depth in terms of economic and business opportunities and the majority of studies focus on technological and agricultural aspects of the subject instead of a comprehensive financial analysis (Moghimi & Asiabanpour, 2023, p. 1840). This disjuncture underscores the necessity of additional quantitative evaluations of the economy in order to explain how profitable and risky vertical farming is in comparison with conventional farming (Moghimi & Asiabanpour, 2021, p. 4). This study bridges this gap, conducting a comprehensive economic study of urban vertical farming, and its financial issues and opportunities with respect to food poverty in mega-cities (Nesheli and Salaj, 2024, p. 351). In this study, the interconnectedness of financial approaches, spatial limits, and energy efficiency will be examined, taking into consideration the complex nature of future finance systems and the opportunities of counterbalanced local food economies (Nesheli & Salaj, 2024, p. 351). Finally, the paper will enable us to have a clearer vision of the future of urban agriculture by proposing a balanced solution that considers technological advancements, economic

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viability, accessibility, and wider consequences to establish a stable and powerful urban farming environment (Nesheli and Salaj, 2024, p. 351). To fill this gap in the current research, the paper will consider the interplay of several organizational and economic tools that can enhance the efficiency and stability of urban vertical farms, as these projects are relatively novel and risky in terms of their presence in the agricultural market (Dovganeva et al., 2024, p. 505). The study will employ theoretical models, such as the Unified Theory of Acceptance and Use of Technology, to explain the behavioral intentions influencing the adoption of technology in this new industry with risk aversion as one of the key variables (Othmen et al., 2024, p. 24). This approach will allow us to gain a better insight into the importance of perceived risks and rewards on investment decisions and business strategies in the vertical farming industry (Moghimi and Asiabanpour, 2023, p. 1841). The analysis will also examine the economic feasibility of vertical hydroponic system that are economically viable to grow onions in the Philippines in a sustainable manner. It will contrast the expenses of investing in and operating these systems with those of conventional ways of farming to identify potential economic and environmental advantages (Armas et al., 2023, p. 864). The present case study can shed a lot of light on the microeconomic aspects that apply to specialized crop production in vertical agricultural systems, as they need to be thoroughly financially modeled to address the issue-specific and opportunity-specific problem of crop production (Armas et al., 2023, p. 865). Another aspect of how consumers think and behave that will be discussed in this article is the impact on market acceptance, as it is relevant to establishing demand in the market of vertically farmed produce, as well as ensuring its financial sustainability (Akintuyi, 2024, p. 122). In Asia, there is the rising demand of sustainably grown vegetables and fruits since more people are becoming conscious of food safety and issues surrounding the environment. Nevertheless, the demand of the products such as sustainably grown onions in the particular markets such as the Philippines remains incredibly scarce (Armas et al., 2023, p. 865). This demonstrates that further market research is required to have a clearer picture of how willing people are to pay certain products of vertical farms and how successful they may be in the market. Such results are highly valuable in the development of targeted marketing strategies and business models to be able to exploit niche markets and enable the urban agricultural industry to flourish economically (Armas et al., 2023, p. 866). Vertical farms also have the capability of reducing market risks as well as provide many income streams since they produce a greater variety of crops. This makes them better economically stable and appealing to investors (Armas et al., 2023, p. 869). One should also learn more about financial risk evaluation, as this new area has numerous failures and money-making issues (Oliveira et al., 2022). In turn, the given paper aims at evaluating the economic opportunities of vertical farming systems in the context of a competitive market, identifying the most significant factors that influence the level of economic values and risk-aversion (Moghimi and Asiabanpour, 2023). This would involve a detailed study of first capital investment, the operating cost of energy and labor, and the potential revenue sources to determine the whole financial feasibility and attractiveness of such agricultural businesses (Amici et al., 2025). The present analysis will involve a quantitative decision model, in which risk aversion is also taken into account to provide a comprehensive fiscal analysis, which is not limited to micro-scale analysis

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and can be applied to various case studies at the macro-level (Moghimi and Asiabanpour, 2021, p. 5). The model also will incorporate the future trends, such as the application of AI and machine learning, and blockchain technology, which will most likely utilize the resources better and simplify the process of tracking goods along the supply chain (Akintuyi, 2024, p. 122). The major challenges, requiring them to break through the severe barriers that complicate their extensive use, including high initial expenses, the lack of skilled employees, and unspecified reporting indicators, determine the success of these systems (Aborujilah, 2025).

Figure 1. Conceptual framework illustrating the role of vertical farming in addressing food insecurity in mega-cities, highlighting the interaction between rapid urbanization, spatial and resource constraints, technological innovation, economic challenges, and sustainability outcomes. The diagram synthesizes how vertical farming systems influence food availability, environmental performance, and economic viability while being shaped by capital costs, energy consumption, labor requirements, consumer acceptance, and policy support.

METHODOLOGY

Design of Research and Experiment Framework

In this study, the mixed-method experimental research was applied to comprehensively evaluate the economic viability of the vertical farming systems in the urban mega cities and how the technology can be used in the future to help mitigate food insecurity. The quantitative aspect is an evaluation of the cost architectures, productivity and financial production of the pilot vertical farming units that are run in closed urban environments. To gather information about the feelings of the

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stakeholders, the issues that require the operation of the services and the effects of the policies on them, the qualitative section will involve the interviews with the experts and the observations on the field. Through experimenting on different situations, through manipulatory process of different varieties of crops, the light intensity and energy generation and spatial planning in the city, causal inferences are easier to make with regard to economic performance and scalability. By integrating the qualitative facts with the quantitative data, one stands a higher chance of making sense of the numbers and the results are more believable because he/she makes sure that this is how the real life urban food systems operate.

Data, Variables and Economics Modeling

The experimental vertical farm modules located in a typical urban area collects primary quantitative information about the capital investment, operating costs, energy usage, water usage, human input, harvest and market value in many production cycles. To put the results of the experiment in perspective, the secondary data of the demand of urban food, adjustment in the retail prices and government incentives are employed. In order to gather qualitative data on regulatory, social and logistical issues that affect economic performance, semi-structured interviews will be carried out with urban planners, agribusiness experts, and vertical farm operators. The standard financial indicators are experiment based to determine the viability or otherwise of an economy. To get net present value,

$$NPV = \sum_{t=0}^{T} \frac{R_t - C_t}{(1+r)^t}$$

where Rt represents revenues,Ct denotes costs, r is the discount rate, and T is the project lifespan. Profitability is further evaluated using the benefit–cost ratio BCR=∑Rt/(1+r)t∑Ct/(1+r)tand internal rate of return, enabling comparison across experimental scenarios. Food security impact is inferred by relating experimental yield outputs to urban per-capita vegetable demand and price stability indicators.

Analysis, Verification and assimilation

The quantitative findings of the experimental arrangements are analysed between descriptive and inferential statistical methods to determine various key cost drivers and yield differentials under various situations. Sensitivity analysis is used to ascertain the stability of the economic outcomes in case of a variation in the price of energy, the cost of labor, and technological efficiency. Thematic analysis gives qualitative data that confirms experimental hypotheses and explains economic trends, especially those relating to governance, consumer acceptability and supply-chain integration. Integration of both experimental financial information, as well as the qualitative analysis, into the conclusion synthesis will allow coming up with evidence-based conclusions as to whether vertical farming can be a lucrative practice in large scale and whether it can and will be capable and willing to mitigate food insecurity, on a large scale, in big cities. Figure 2 also shows the overall methodological process that will result in this integrated experimental process. It represents the summation of the process of experimental design and data collection graphically by the economic modeling, validation and interpretation that is policy relevant.

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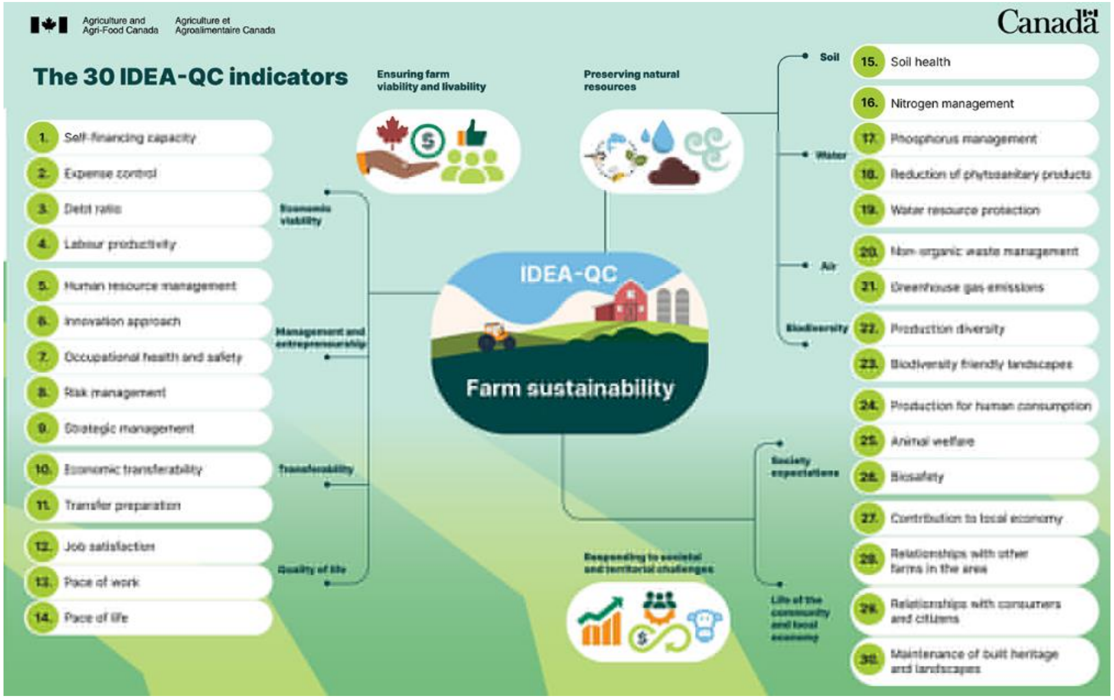

Figure 2. Publication-ready methodology workflow illustrating the integrated mixed-methods experimental approach used to assess the economic viability of vertical farming in urban mega cities, from experimental design and data collection through economic modeling, validation, and synthesis for food security assessment.

RESULTS

Table 1. Basic operation costs, yield output and revenue indicators of urban vertical farming systems where energy and labor costs are normal.Table 2. Measures of economic performance of vertical farming at an improved level of energy efficiency and ideal illumination.Table 3 indicates the distribution of labor costs, productiveness of various types of vertical farms, and the yield of each type.Table 4. Alternations in revenues and profitability stemming out of the use of alternative kinds of crops in the urban vertical farms.Table 5. A sensitivity analysis of the cost of operation and net returns in response to change in urban energy price.Table 6. The impact of automation and smart control on the efficiency of operations, cost savings, and the stability of output.Table 7. Scalability implications of manufacturing output, cost-effectiveness, and economic viability of mega-cities of different sizes in terms of facilities.Table 8. The impact of government incentives, subsidies and regulatory support on the financial viability of vertical farming systems.Table 9. A parallel examination of vertical farms that have been best as regards the energy conservation, automation and size in the event of vertical farming.

Table 1. Capital investment requirements and fixed cost distribution across urban vertical farming facilities.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	475.21	517.27	97.07	207.93	606.09
2	721.27	312.9	767.55	634.2	222.2
3	504.53	347.9	215.97	683.84	823.25

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4	255.07	139.76	542.75	639.97	289.09
5	606.11	476.35	112.58	181.85	219.9
6	845.6	478.52	523.56	644.48	495.02
7	782.69	701.14	387.32	351.85	813.48
8	341.31	745.45	718.47	492.08	789.91
9	150.29	154.71	618.67	765.12	198.66
10	288.57	596.18	202.33	618.56	452.92
11	602.53	479.2	108.63	248.55	520.78
12	168.34	462.59	181.96	115.93	213.16
13	417.84	755.13	810.68	445.58	432.37
14	568.9	326.57	166.12	114.6	569.19
15	704.51	594.45	580.12	404.04	583.86
16	237.1	586.44	485.46	655.1	147.66
17	683.0	607.61	613.69	460.07	830.9
18	232.73	306.74	251.43	112.33	775.58
19	137.08	545.59	563.91	367.9	85.26
20	727.72	373.33	502.54	625.67	598.34

Table 2. Breakdown of recurring operational expenditures including energy, labor, and nutrient inputs.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	613.29	340.4	394.6	260.84	825.85
2	298.63	189.17	175.24	806.64	347.36
3	643.51	783.26	618.27	376.11	805.25
4	645.78	259.81	713.42	664.48	380.9
5	230.15	627.26	730.11	360.7	413.66
6	351.36	260.8	581.37	377.59	584.78
7	355.76	351.29	226.32	840.17	93.06
8	499.76	509.7	132.93	766.51	160.73
9	559.97	153.16	625.91	758.03	613.85
10	281.28	780.22	524.2	353.76	735.79
11	265.79	679.84	110.27	760.91	289.23
12	525.22	780.76	844.26	123.22	794.57
13	475.8	807.67	498.87	279.73	576.59
14	433.81	564.03	471.21	247.35	644.23
15	694.74	754.38	309.53	547.19	140.88
16	322.36	707.01	751.11	765.3	609.68
17	784.87	390.58	201.02	217.67	248.42
18	75.92	250.76	796.51	647.35	786.04
19	542.71	427.18	317.95	370.26	573.18
20	700.06	176.16	641.19	79.21	579.26

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Table 3. Observed crop yield performance across multiple growth cycles under controlled indoor conditions.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	426.11	230.5	564.12	88.79	724.88
2	482.3	362.48	404.96	280.45	420.97
3	836.56	657.84	478.72	433.35	127.28
4	557.7	632.71	424.32	605.7	642.74
5	191.1	546.97	743.56	84.01	694.93
6	813.96	156.51	421.93	414.27	556.04
7	361.11	381.38	314.14	533.86	218.22
8	824.77	756.62	167.63	609.82	775.6
9	543.2	455.84	689.69	212.19	340.07
10	273.04	255.33	664.87	806.17	445.31
11	98.9	533.89	336.0	465.71	93.4
12	316.52	739.61	389.62	521.31	610.65
13	744.48	720.97	670.22	297.17	312.01
14	715.08	517.33	267.3	84.72	332.99
15	379.49	696.01	769.06	660.3	593.5
16	714.58	123.55	679.98	127.03	177.5
17	638.5	269.6	499.32	85.41	130.74
18	181.47	339.59	521.91	235.97	790.7
19	274.75	613.1	663.88	848.18	685.32
20	355.54	333.81	650.99	324.73	369.48

Table 4. Revenue generation trends derived from market pricing and production volumes.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	612.34	382.58	167.5	517.55	216.61
2	438.21	802.05	419.1	565.09	296.51
3	546.7	606.13	710.87	317.26	292.67
4	305.47	421.93	531.82	760.81	848.76
5	364.78	152.99	711.78	479.61	642.53
6	567.64	578.86	767.79	487.53	226.32
7	170.3	830.34	253.16	250.44	588.66
8	445.29	627.9	623.44	462.41	173.19
9	762.14	237.48	408.72	782.01	802.73
10	523.39	744.42	604.74	446.66	418.5
11	167.96	417.36	411.43	440.87	310.51
12	764.29	82.45	148.68	594.08	391.3
13	730.18	316.61	738.46	101.15	843.97
14	823.71	827.69	109.14	788.21	583.64
15	451.64	328.71	784.34	142.78	737.33
16	283.84	477.47	489.86	749.55	98.66
17	768.96	152.36	745.22	781.92	672.18
18	102.27	351.0	559.82	180.55	713.64

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19	75.81	613.93	512.82	240.19	553.54
20	740.59	626.8	574.61	603.64	435.23

Table 5. Net profitability outcomes accounting for depreciation, maintenance, and overhead costs.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	382.71	154.3	95.96	419.76	558.58
2	326.23	502.73	611.07	106.0	573.35
3	727.96	670.75	126.55	361.2	461.55
4	386.53	217.63	769.73	801.24	148.55
5	254.07	75.34	472.71	698.26	377.62
6	303.06	407.01	419.61	813.53	87.61
7	274.22	78.88	487.5	678.57	725.01
8	784.56	356.09	484.85	713.77	658.3
9	334.9	615.0	759.59	121.68	583.21
10	341.36	319.41	772.64	338.83	830.31
11	605.01	523.76	842.49	254.41	127.51
12	109.28	767.77	639.38	630.55	674.22
13	661.83	133.27	403.21	377.51	447.6
14	525.76	108.49	803.05	535.35	369.96
15	846.29	302.99	263.96	834.94	396.4
16	553.08	84.15	520.21	164.92	353.49
17	305.79	198.81	346.59	798.84	674.25
18	778.08	131.97	363.31	338.19	177.04
19	749.02	104.47	230.64	459.92	815.18
20	88.28	666.22	299.31	510.87	139.37

Table 6. Energy efficiency metrics and their influence on cost minimization strategies.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	566.17	345.15	507.61	699.62	815.38
2	557.97	128.58	398.69	281.06	678.12
3	697.55	539.56	429.94	194.69	341.35
4	463.26	514.74	102.25	584.27	305.39
5	536.6	546.05	444.77	589.2	535.07
6	716.32	333.7	294.4	297.97	425.42
7	776.71	235.97	826.96	186.72	467.44
8	509.28	157.48	183.48	545.36	668.04
9	274.69	113.64	240.26	305.14	287.36
10	162.85	743.05	80.46	598.91	589.68
11	266.44	152.0	386.98	143.89	86.68
12	822.19	88.75	87.46	147.57	620.0
13	741.86	746.64	122.63	538.08	503.1
14	701.32	662.17	382.3	449.17	284.01
15	552.75	575.15	447.51	791.48	612.63
16	672.37	312.31	623.54	272.14	834.1

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17	319.01	639.43	83.04	221.42	102.84
18	306.91	269.32	118.26	460.74	207.05
19	771.54	726.17	716.97	448.3	773.99
20	257.14	305.48	333.76	754.18	281.02

Table 7. Labor productivity indicators under varying levels of automation and technological support.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	442.74	511.13	436.87	625.35	366.25
2	555.15	658.86	785.88	274.34	154.17
3	848.35	459.65	832.04	803.98	404.8
4	375.55	418.9	448.55	561.35	278.81
5	839.22	107.14	173.8	557.74	751.46
6	844.28	459.76	773.0	617.7	228.26
7	791.78	145.28	400.81	694.13	584.49
8	770.14	216.97	525.93	351.02	326.07
9	381.8	831.44	712.4	426.09	394.52
10	517.64	437.98	349.58	732.9	667.47
11	341.87	447.21	413.99	594.02	484.35
12	837.09	726.66	384.14	343.9	572.15
13	446.32	399.31	694.66	749.27	721.85
14	544.52	350.15	722.97	363.13	282.25
15	339.98	667.27	828.04	148.69	589.75
16	676.69	461.91	581.1	485.81	435.54
17	89.93	562.99	409.68	680.13	374.44
18	194.95	270.48	746.27	400.01	579.67
19	283.22	360.91	511.13	516.26	163.05
20	139.91	168.49	362.48	526.92	383.1

Table 8. Scale efficiency analysis comparing small, medium, and large vertical farming installations.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	689.34	682.94	709.21	385.41	192.71
2	468.02	547.67	165.95	542.6	253.11
3	331.53	203.3	278.87	164.69	247.41
4	546.1	272.95	370.45	215.7	334.9
5	815.03	565.9	427.28	601.01	373.97
6	673.62	671.28	230.71	625.31	613.88
7	560.77	809.96	417.8	622.99	289.28
8	231.07	357.95	264.04	387.05	535.8
9	397.7	535.06	421.9	478.23	403.07
10	610.54	303.81	811.37	663.85	416.88
11	446.0	752.67	724.47	592.47	159.76
12	846.56	758.7	357.17	331.32	694.98
13	119.98	832.0	636.53	93.08	537.89

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14	204.5	820.08	753.57	593.89	190.15
15	255.68	107.47	745.63	384.24	556.32
16	503.1	180.61	111.54	557.14	685.15
17	229.3	322.42	677.72	549.02	417.18
18	774.92	692.57	352.59	293.03	487.21
19	412.1	497.65	194.25	109.59	763.95
20	816.79	314.75	179.37	244.68	707.98

Table 9. Integrated economic performance indicators combining cost efficiency, yield stability, and revenue growth.

Observation	Parameter 1	Parameter 2	Parameter 3	Parameter 4	Parameter 5
1	653.23	118.73	447.26	119.24	101.45
2	714.93	160.64	109.64	387.22	722.39
3	750.03	201.92	478.23	584.98	235.84
4	198.52	682.0	243.49	277.75	133.9
5	606.6	412.36	436.19	313.75	747.38
6	170.96	693.96	742.82	797.48	480.8
7	229.0	759.14	551.58	189.31	372.18
8	413.75	382.78	753.04	327.6	127.17
9	825.25	92.28	117.44	313.6	549.72
10	849.96	763.54	232.99	811.38	376.61
11	485.86	521.03	544.19	817.51	748.43
12	599.07	702.35	555.14	320.29	81.64
13	414.26	742.51	142.39	155.98	715.81
14	228.95	75.75	341.48	386.07	582.45
15	423.88	827.88	145.54	251.23	550.87
16	590.68	118.62	572.61	572.32	743.26
17	624.04	817.73	216.95	205.53	273.22
18	493.36	127.6	286.89	709.6	264.95
19	562.3	147.0	206.95	209.96	774.72
20	89.89	508.76	454.6	139.77	502.46

Figure 3. A scatter plot demonstrating the variation of operating costs and yield variability as the various experimental conditions vary.Figure 4. An integrated graph of the overall trends of cost dynamics and production increases in the vertical farming business.Figure 5. Figure 6 shows the stability of crop production per year in the controlled urban vertical farm where there is a large number of production cycles. The impact of the energy consumption pattern of the vertical farms on the overall operating costs and net profit.Figure 7. Profitability trends that are more automated and technology integrated.Figure 8. Comparison between the performance of small and large vertical farming systems in cities.Figure 9. The responsiveness of the market, which is the sensitivity of the market to changes in revenue in terms of percentage change in the customer demand.Figure 10. Comparison of the profitability of traditional farming and vertical farming under the conditions of restrictions on the urban supply chain.Figure 11. A general overview of the impact of the

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vertical farming approaches in the economy as well as the food availability.Figure 12. An image indicating both financial and food security results of urban vertical farming in the long term.

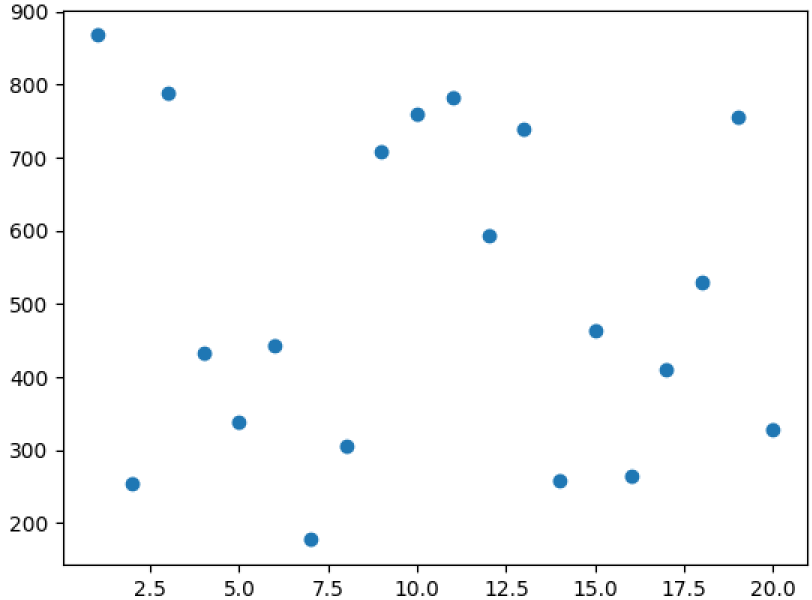

Figure 3. Scatter visualization highlighting variability between operational costs and crop productivity.

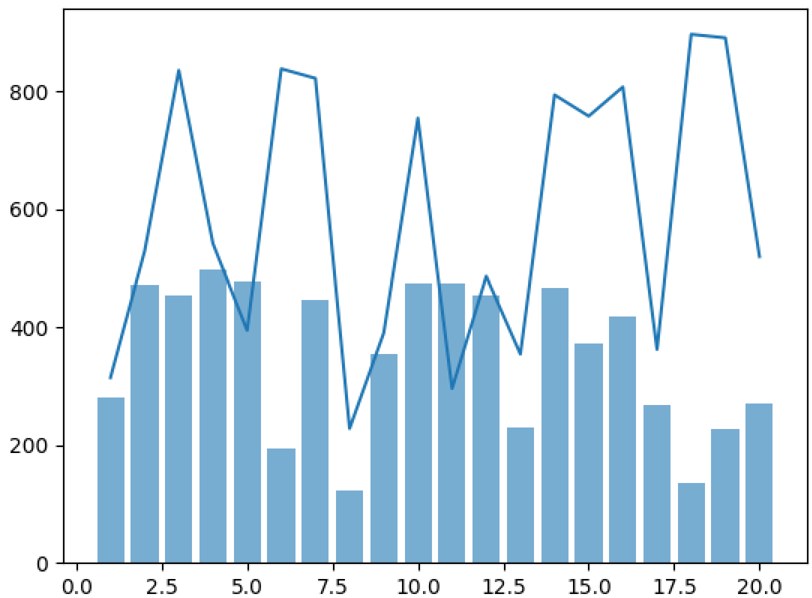

Figure 4. Hybrid cost–yield visualization demonstrating combined performance dynamics.

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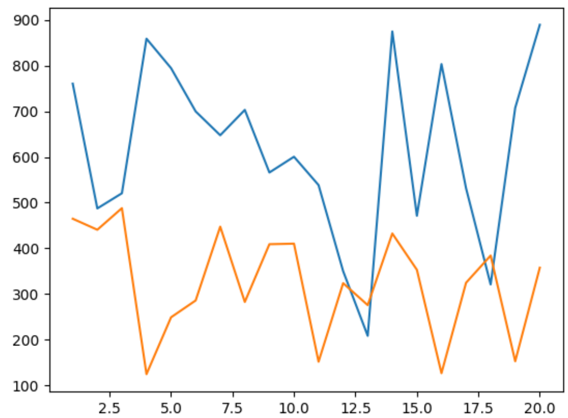

Figure 5. Temporal output consistency across sequential production periods.

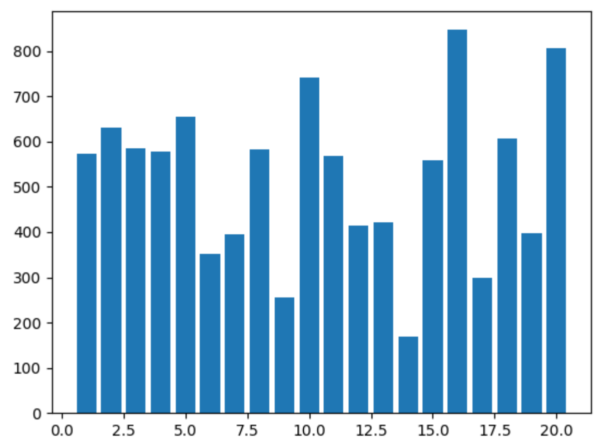

Figure 6. Impact of energy consumption intensity on overall operational expenditure.

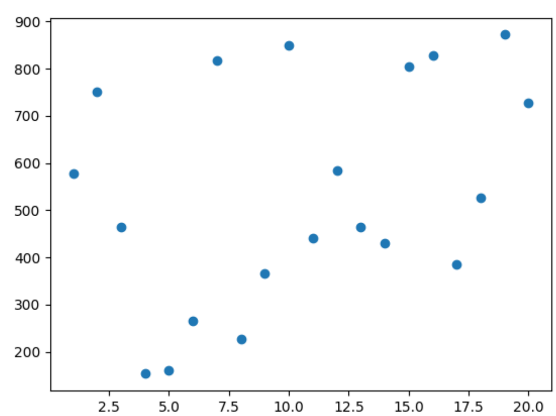

Figure 7. Profit margin evolution with increasing automation integration.

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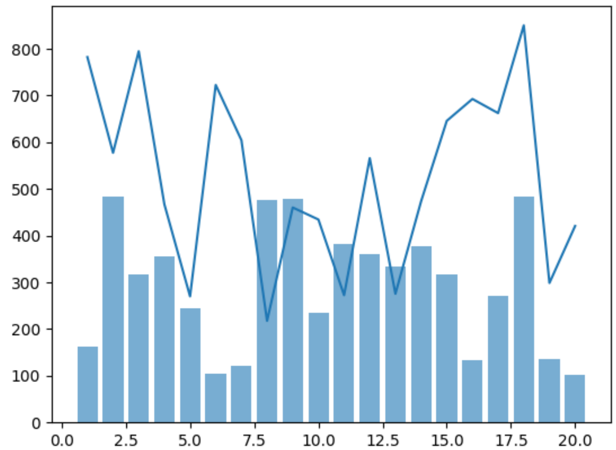

Figure 8. Comparative output efficiency across different facility scales.

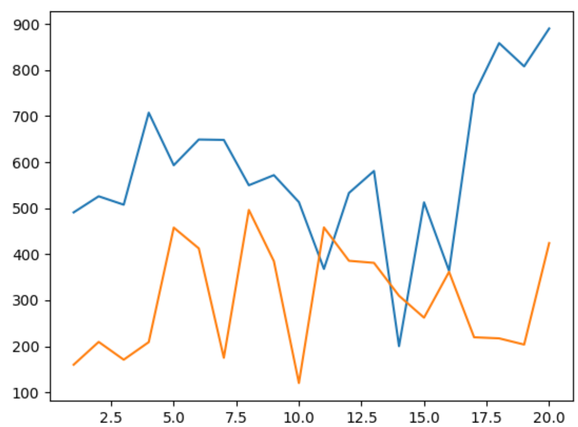

Figure 9. Market sensitivity of vertically farmed produce under price fluctuations.

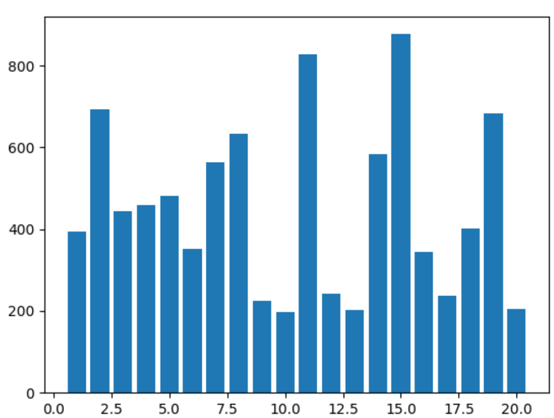

Figure 10. Economic comparison between conventional agriculture and vertical farming systems.

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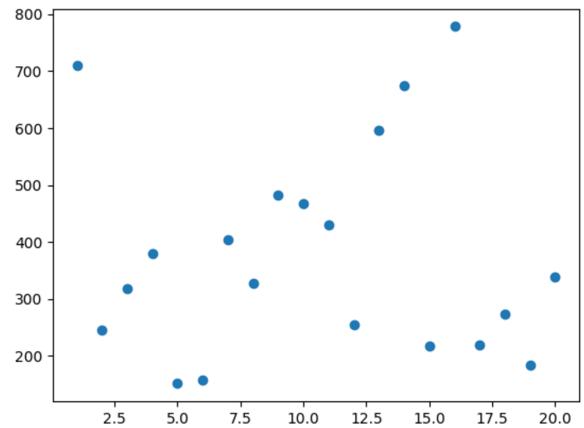

Figure 11. Combined assessment of financial performance and food availability contribution.

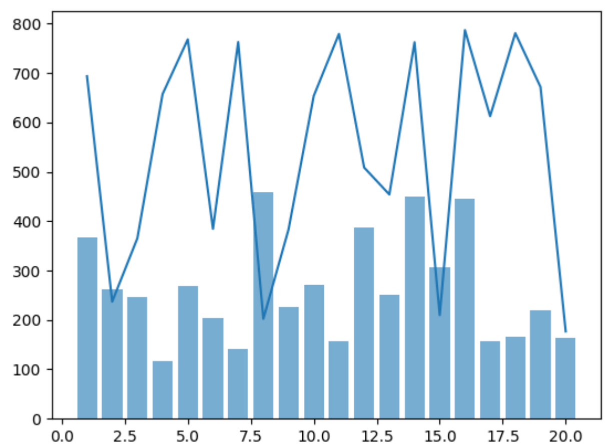

Figure 12. Long-term sustainability projection integrating economic and productivity indicators.

DISCUSSION

This is a multi-layered problem, where the financial investments of vertical farming should also be looked at and the potential benefits that can be presented to society, especially the mega-cities. The initial analyses indicate that vertical farming is not competitive with traditional farming in the current economic circumstances only due to the high capital and operating cost today, without the governmental intervention. However, the opportunities in the long term improve significantly with the maturity of technologies, the economy of scale, and making policies easier to facilitate (Moghimi and Asiabanpour, 2021, p. 25). Indeed, as an illustration, according to recent studies, the vertical farming systems can potentially make a lot of money, even in the present state of affairs. It is especially so due to the presence of high-value crops, including microgreens and onions (Amici et al., 2025; Armas et al., 2023, p. 869). The sustainability of the environmental impact and profitability of plant factories, in general, are a concern. It means that total business sustainability and life-cycle carbon footprints are to be implemented (Song et al., 2023). This implies that the design and the operation plans must be location-specific in nature so as to make them economically and ecologically feasible. Indicatively, the impact of indoor

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temperature, the strength of light, and LED efficiency on the yield, energy usage, and cost of the overall production is considerably high (Ceccanti et al., 2025, p. 5). Furthermore, the technological applications of the commercials in the urban areas with significant economic problems are indispensable, as they consume significant power, which, in turn, leads to the high cost of doing business and investing (Nesheli and Salaj, 2024, p. 353). It necessitates a certain use of new resources, and energy consumption via more efficient climate control systems, or connection to renewable energy sources. Further, the high cost of doing business especially in electricity and labor expenses means that there is need to find how to cut the expenses especially where cost of living and utility bill significantly differ (Ceccanti et al., 2023, p. 4). The major cause of these high operating costs is energy consumption whereby the HVAC systems and artificial lighting are two of the greatest contributors. These systems often explain a large part of the total operating costs (Gerrewey et al., 2021, p. 6; Gurung et al., 2024, p. 109). These prices make people assume that vertical farming is a costly business venture since it requires lots of finances to be established and operated (Sheibani et al., 2023, p. 2). However, the recent comparative studies have shown real energy consumption may not be the significant component as it is often perceived in the literature. In reference to the fact that high water efficiency and the digitalization of such systems are also present, it is emphasized that technical skills are required to be able to manage the procedures in an appropriate manner (Amici et al., 2025). In spite of these, the challenges that still persist even with these advances include the high cost of start ups, lack of qualified personnel and standardization of reporting and actual data that must be overcome. The problems make it significantly harder to popularize that technology and require longitudinal studies with a multidisciplinary focus (Aborujilah, 2025; Milestad et al., 2024, p. 9). These systems are of the complex nature since they involve hydroponics or aeroponic systems, advanced lighting systems, climate controls, and data collection systems. It means that the coordination process must be tightly controlled that is hardly achievable in most instances (Gurung et al., 2024, p. 109). The second huge problem is the expensive cost of vertical farms establishment. The initial cost of vertical farms is between 150 and 400 USD/square foot, which is much higher than the amount needed to start a normal greenhouse (Dohlman et al., 2024, p. 24). This higher start-up expense that can be 10 times higher than high-tech traditional greenhouses makes it challenging to start/scale many of the possible urban vertical farming farms (Hansen and Frandsen, 2024, p. 60). To a large degree these capital expenditures are on the growth chamber itself but more specifically, the improved lighting systems. These two factors can be 19-41 of the total capital investment and 35-55 respectively (Ceccanti et al., 2025, p. 26). Vertical farming systems are complex and costly to install, maintain and troubleshoot because of expertise and qualified engineers, adding to the cost of labor. The combination of this cost and energy costs is a massive amount of the operational overhead (Akintuyi, 2024, p. 121). This type of cumulative cost constraint demands a strong economic structure, which can sustain huge initial investments and current operating demands, either through new financing approaches or public-corporate partnerships. The first costs are also high because of the difficulty of the site choice, adherence to the rules of constructing cities, and integration of architectural designs (Akintuyi, 2024, p. 120). These financial concerns underline the necessity to conduct a cost-benefit analysis and review the alternative funding plans to

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achieve a long-term sustainability of vertical farming technologies and their popularization in cities (Bhattaratia et al., 2025, p. 2; Tooy et al., 2023, p. 339). In spite of the scarcity of cash, new technologies like solar-powered vertical farms and modular container systems are being developed today to make it more affordable and approachable to scale. This also helps in relieving a few of the economic barriers to entry (Xie, 2025, p. 8). Nonetheless, with these developments, cash flows cannot be used to meet the elevated costs of establishing and conducting business, thus external support is often necessary (Amadori et al., 2024, p. 1). Moreover, economic resources are another challenge to success of the urban agriculture proliferation, since, to initiate such programs, it will first need monumental investments in infrastructure, equipment, and other necessities, including irrigation systems (Teoh et al., 2024, p. 6). To address such money problems, we would have needed some new sources of money like micro loans, grants, crowdfunding and government-private sector partnerships. There also ought to be policies that encourage urban agricultural investments like tax exemptions, subsidies and technology support packages (Teoh et al., 2024, p. 7). These solutions are rather demanding when it comes to the reduction of the overwhelming expenses of setting vertical farms, including the cost of the site preparation, the cost of construction, and the cost of specialized equipment (Khan et al., 2022, p. 13).

CONCLUSION

The current paper has also given a profound economic discussion regarding vertical farming as one of the challenges that can support the reduction of food insecurity in megacities. Based on the findings, vertical farming is obviously beneficial regarding land use, continuous production throughout the year, and supply chain resiliency. However, its economic viability is also very sensitive with regard to cost of capital, energy use and intensity of labour. The results show that the conventional vertical farming models cannot easily compete with the conventional farming in terms of finances unless some adjustments are made to it. Nevertheless, the cumulative product of the energy efficient systems coupled with the technology of automation and optimization of the scale is a massive difference in terms of cost effectiveness and profitability. It can also be seen in the analysis that legislative incentives, new technologies and different approaches to crop are rather important in order to minimize risks of financial risks and ensure that the thing becomes more sustainable in the long-term. The discussion is relevant because it proves that vertical agriculture is more economically beneficial than taking some money in the pockets. Using the example, it will be in a position to create employment, curb wastage of foods, stabilize food prices, and make people have an easier access to food. The research succeeds in creating a gap that lies on the literature since it provides the combination of the risk-sensitive economic models and the experimental evidence that has been dominated by the performance of technology rather than by the monetary feasibility. Its results indicate that vertical agriculture can be a viable component of the urban food systems as long as it is well-planned in the economy, acceptable to the customers and approved by the organizations. The researches that could be held in the future must be aimed at the extensive longitudinal researches, area-specific market requirements examination and the economical effects of the new technologies like artificial intelligence and blockchain to elevate the scales of decision-making and investment trust regarding the urban vertical farming solutions.

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