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Urban vertical farming: Innovation for food security and social impact?

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Abstract

Urban vertical farming has emerged as a potential solution to improve food security and safety for urban populations, as well as to transform wider food systems (FS) to ensure greater sustainability. Existing literature has highlighted both direct and indirect benefits from vertical farming (VF) to individuals and communities through novel technology alongside social entrepreneurial innovation. These include the creation of green jobs, greater access to fresh, healthy food produced locally, as well as community development programmes and avenues for civic participation.

We explore relevant literature to critically examine the socio-economic impact of VF, drawing out key issues of debate, while identifying areas of future research and recommendations for practice. We draw attention to critical accounts which have highlighted a need to consider the role of technology within social and political processes. Studies have noted key challenges to VF in achieving social and economic benefits to urban populations, as well as in contributing to food security. Examining VF as an intervention within a wider political economy enables a more rigorous exploration of social impact. A research, policy and practice focus beyond production and business model design is needed to situate VF within broader efforts to transform FS.

Keywords: controlled environment agriculture; food systems; vertical farming; urban agriculture

Introduction

The scale of the challenges facing our food systems (FS) demands new approaches to growing, processing, and distributing healthy and sustainable food for all. Escalating challenges related to population growth, urbanisation, climate change, and diminishing

37 arable land necessitate urgent and innovative solutions to secure food for future
38 generations [1]. The United Nations (UN) estimates that the global population will exceed 9
39 billion by 2050 [2] with the majority of this growth concentrated in urban areas, especially in
40 secondary cities and smaller urban centres [3]. In 2022, food insecurity affected 26 and 28
41 percent of adults living in urban and peri-urban areas, respectively [4].

42 Conventional agriculture faces several well-documented challenges, including inefficient
43 resource use, substantial greenhouse gas emissions, and significant environmental
44 degradation from practices such as deforestation, over-fertilisation, and pesticide
45 application [5, 6]. These practices also contribute to soil erosion and loss of arable land,
46 limiting long-term productivity [7]. Globally, agriculture is responsible for approximately
47 70% of all freshwater withdrawals, while also being vulnerable to climate change impacts
48 such as extreme weather and changing rainfall patterns [8]. These environmental drawbacks
49 are coupled with systemic inequities in food distribution and access, exacerbating global
50 food insecurity, particularly in low-income populations and regions most affected by climate
51 change [4]. As global food demand continues to rise—projected to increase by 60% from
52 2005 to 2050, there have been increasing calls for the adoption of advanced technology in
53 agricultural production [9–12].

54 Rapid changes in urban populations represent a further significant challenge to the supply
55 and accessibility of fresh food [3]. Urban agriculture (UA) has the potential to contribute
56 towards addressing these challenges. The term is used to refer to a diversity of practices
57 ranging from intensive commercial farming to informal livelihood strategies. UA has been
58 associated with a wide range of positive outcomes at multiple scales, including health and
59 wellbeing of urban inhabitants [13], providing ecosystem services, and fostering community-
60 building [14, 15]. However, a growing body of critical literature has highlighted the potential
61 of UA to contribute to gentrification and displacement, to entrench social inequalities, and
62 reinforce neoliberal ideas regarding the responsibilities of individuals and the state [16–20].

63 In recent years, indoor vertical farming (VF) has received attention as a promising approach
64 to UA that has the potential to contribute to the supply of fresh food while fostering a range
65 of social, economic, and environmental benefits in urban settings. Indoor VF is a form of
66 controlled environment agriculture (CEA) [21]. By operating in controlled environments,
67 vertical farms can potentially mitigate the risks posed by climate variability, pests, and
68 pollution [22], and offer a healthier setting for crop growth [23, 24]. VF, which utilises
69 vertical space through columnar structures or stacked layers, has the potential to improve
70 resource efficiency and reduce the environmental impact of food production. As such, it
71 may offer a more sustainable and resilient approach to urban food security, providing
72 stable, year-round food production [25].

73 While the environmental benefits and technical dimensions of VF have been a primary focus
74 of research, the ways that VF may contribute to a wider range of interconnected FS
75 challenges, particularly social and economic challenges, are less well understood. Broader
76 literature has highlighted a need to understand technological innovation within wider social
77 and technical transitions [26], as well as a need to place such transitions within an analysis
78 of political economy, politics and inequalities in FS [27, 28]. In research, policy and practice,
79 this body of literature points to a need for a critical approach to charting pathways for
80 transforming FS [29, 30].

81 In this article we critically review existing evidence to examine the potential of VF to
82 contribute towards addressing a range of critical social and economic challenges. Our aim is
83 not to restate the case for VF, rather it is to situate the rise of VF within broader
84 understandings of the socio-economic impact of UA. In doing so, the article contributes to
85 understand the role of VF within the wider suite of transformations necessary in our FS as
86 well as the conditions under which VF may contribute towards addressing multiple,
87 interconnected societal challenges.

88 **Methodology**

89 The methodology for this narrative review draws on recent studies (adapted from [31]), to
90 explore the current and potential socio-economic impact of VF as a form of CEA, as well as
91 to identify areas of future research and recommendations for practice. The studies included
92 were selected through keyword searches conducted on PubMed in October 2023, February
93 2024, and April 2024. The search terms used, individually and in combinations of up to three
94 terms, included: urban farm, urban agriculture, city farms, urban farming, controlled
95 environment agriculture, precision farming, sustainable agriculture, vertical farming, indoor
96 urban farming, indoor urban agriculture, precision agriculture, social impact, community
97 impact, social well-being impact, and variations thereof. Titles of over 300 papers were
98 initially screened, and 151 relevant scientific publications were selected for this review. The
99 types of articles considered included books and documents, meta-analyses, reviews, and
100 systematic reviews.

101 Studies were included in the reading if they: (i) reviewed the current state of urban
102 agriculture, indoor farming or specific aspects of it; (ii) contained unique research and
103 findings not typically found in other reviews, especially with regard to the social impact of
104 urban food production; (iii) addressed emerging topics such as food justice, vertical farms,
105 innovative technologies, and advanced cultivation methods; (iv) discussed combinations and
106 integrations of current technologies and practices; or (v) examined broader aspects of urban
107 food production, including logistics, economics, social and environmental impacts,
108 implementation, and policy.

109 Additionally, further studies were identified by examining the references and citations of the
110 most relevant papers and authors to ensure a thorough understanding of the current state
111 and future potential of urban indoor agriculture. The literature reviewed included peer-
112 reviewed articles, books, conference proceedings, technical documents, technical bulletins,
113 project reports, and commercial websites.

114 **Situating Controlled Environment Agriculture** 115 **and Vertical Farming within the Field of Urban** 116 **Agriculture**

117 UA can be defined as the cultivation, processing, distribution, and marketing of food and
118 other agricultural products within urban areas primarily to feed the local population [3, 32].
119 Typically, UA is not only located within cities, but also embedded within urban processes
120 and dynamics [33]: it utilises urban resources (land, labour, organic wastes, water); it is

121 influenced by urban policies, spatial constraints, and market conditions; and it has the
122 potential to impact urban populations and the urban environment.

123 Over the past 25 years, governmental support for UA has grown at the international,
124 national, and local levels, despite some institutional reluctance to incorporate it into
125 broader urban planning [34, 35]. Some countries have adopted national policies that
126 promote urban horticulture, including Argentina, Brazil and Cuba [36, 37]. The UN has also
127 recognised UA as a key strategy for achieving the Sustainable Development Goals [22, 38].

128 UA encompasses a diverse variety of practices, from neighbourhood allotment gardens to
129 intensive commercial production units, and from rooftop gardens to environment-
130 controlled farms [39]. Each type represents a function of multiple influences, including
131 business models, governance structures, and socio-economic context, and can be associated
132 with a diversity of social and economic impacts.

133 The current and potential multi-dimensional significance of UA is well-documented [40–42].
134 Some scholars have emphasised the contribution of UA to the health of urban inhabitants
135 [43, 44] and to sustainable livelihoods [45], and the therapeutic benefits of urban food
136 growing [46]. Others have emphasised the circular integration of UA into the urban
137 environment through, for example, the re-use of grey water [47], providing ecosystem
138 services [48], and closing the nutrient loop [49].

139 This latter strand of the UA discourse resonates closely with the more recent discourse on
140 CEA systems, which have been heralded as a form of UA that has the potential to make a
141 significant contribution to the long-term sustainability of cities for its advanced
142 technological approach and potential for significant, high-impact changes [50].

143 CEA farms are characterised as either enclosed or closed depending on factors such as sun
144 exposure, farming techniques, irrigation methods, size, density, level of control, layout,
145 building type, location, and purpose [51]. Enclosed systems include greenhouses; closed
146 systems include indoor farms and vertical farms that use LEDs instead of sunlight [52–55].
147 CEA systems protect crops from external weather and regulate microclimates to produce
148 higher, year-round yields [21]. Many of these systems use advanced technology for
149 comprehensive monitoring and automation to maintain optimal environmental conditions
150 and improve energy management [52, 56, 57].

151 CEA systems can be established in a wide range of facilities such as warehouses, shipping
152 containers, or empty buildings [58, 59]. They range from very small mobile systems to large,
153 highly sophisticated systems in high-rise buildings [53]. Both enclosed and closed systems
154 are primarily soil-less and can achieve water savings of up to 95% compared to conventional
155 farming [10, 59, 60]. While greenhouses are typically located away from urban areas, VFs
156 can be situated in urban or peri-urban locations, which can reduce food miles, CO₂
157 emissions from transportation, and food waste in the supply chain [61].

158 VF represents an area of rapid innovation and expansion within CEA [62]. It is an example of
159 an enclosed CEA system. Using advanced irrigation systems such as hydroponics or
160 aeroponics, VF can potentially produce food more sustainably than conventional agriculture
161 by reducing the need for water, fertilisers, and pesticides [23] and reducing industrial
162 pollution [25] VF uses only about 10 percent of the water required in conventional farming
163 [51].

164 Vertical farms can be categorised based on their size and purpose. Each category utilises LED
 165 lights, irrigation systems, and vertically stacked shelves or towers for growing various plants.
 166 These shelves/towers typically feature computer-controlled growth management systems,
 167 allowing users to monitor all systems remotely. Key differentiating factors are their
 168 structure, location and mobility, encompassing purpose-built or repurposed urban buildings,
 169 modular mobile units, in-store or rooftop systems, and small-scale appliances integrated
 170 into homes or offices (Table 1).

171

Category	Characteristics
Building-based vertical farms	Constructed in either purpose-built or repurposed buildings in urban areas. They include growing plants with artificial light in a shielded space like a factory [51, 58, 59, 63].
Shipping-container vertical farms	Modular and potentially mobile farms built in repurposed shipping containers which typically measure 2.44m (w) x 2.59 m (h) and vary in length between 3.05 – 12.19m [51, 59, 63].
In-store vertical farms	Farms located within the place of consumption or purchase, e.g., retail or restaurants [53, 58]. This includes units located within or on the rooftops of both old and new buildings, including commercial and residential structures [64, 65].
Appliance farms	Mobile farm appliances that may be integrated into homes or offices [53, 58].

172 Table 1: Typology of vertical farms

173

174 Advocates of VF argue that it can address vulnerability to climate change-induced weather
 175 events, including their effect on agricultural land and the global economy [21, 66–68]. By
 176 reducing the need for conventional farming's substantial fossil fuel consumption and
 177 minimising food miles (the distance food travels to reach urban consumers), VF can enhance
 178 sustainability and efficiency in food production [67]. Moreover, indoor growth systems
 179 protect plants from adverse weather and climate change by allowing year-round production
 180 and making it feasible to grow crops in harsh environments, where conventional farming is
 181 difficult [69].

182 Proponents have suggested that producing just ten percent of the food consumed in urban
 183 areas through VF could reduce CO₂ emissions, sufficient to foster technological
 184 advancements that may lead to long-term improvements in biosphere health [25, 70].
 185 Despommier [71] further argues that transitioning to vertical farming could alleviate the
 186 environmental pressures of conventional agriculture, enabling natural ecosystems to
 187 recover and flourish. These studies suggest potential broad impacts, but lack detail on the
 188 specific nature of these improvements (e.g. the level of CO₂ emissions VF could reduce).
 189 While assessing the environmental impact of VF is not the aim of this paper, it is important
 190 to note that VF has received criticism in existing literature due to the high energy

191 requirements needed to support CEA systems, including lighting and temperature. These
192 requirements represent potential trade-offs to the potential environmental benefits
193 suggested in VF literature [52, 72, 73]. However, studies applying life cycle analysis suggest
194 that integrating renewable energy sources, such as solar or wind, into VF systems could
195 significantly reduce these environmental impacts, potentially making VF more competitive
196 with other farming methods [74, 75].

197 While the current and potential contribution of VF and CEA systems to urban sustainability
198 has been increasingly asserted, less attention has been given to analysing how such
199 contributions correspond with the wider benefits and limitations associated with UA. A
200 substantial body of evidence has demonstrated the contribution of more traditional and
201 community-based methods of UA to urban food security, both in terms of contributing to
202 food supply as well as to generating household income [42, 45, 76, 77]. Some studies
203 indicate that UA could play a significant role in feeding cities in the global North [78], and
204 global South [79]. However, other studies have exposed the difficulty, if not impossibility, of
205 accessing the amount of land required for UA to make a significant contribution to a city's
206 food demands [80].

207 The past two decades have seen the rise of a discourse which focuses on the social
208 significance and potential of UA. UA has been linked closely with community-building,
209 particularly for marginalised urban groups [81, 82]. Urban community gardens, for example,
210 have been celebrated for their capacity to foster diverse communities [83, 84], and engage
211 children and young people in community projects [85].

212 In some contexts, this social impact has extended into the political sphere [86]. Staeheli et
213 al. [87], for example, describe the formation of a counter-public in community gardens in
214 New York, through which marginalised urban inhabitants develop alternative visions of
215 urban management. In this vein, other studies have identified the potential for UA to be a
216 socially transformative activity [88].

217 Yet there is also recognition that the positive social and economic impact of UA can be
218 overstated. The literature on urban farming has highlighted the potential of multiple social
219 benefits, including contributions to food security, public health, skill building and jobs,
220 community development, and FS change, leading to an association of UA with food justice
221 [89]. However, there is a need to examine whether socioeconomically disadvantaged
222 communities benefit. It is also evident that UA alone cannot address the fundamental
223 causes of food injustice, which include economic disparities, poverty, and historical and
224 structural racism [90]. Some projects may even perpetuate existing inequities [90].

225 Urban community gardens can, for example, become exclusionary spaces [91]. Scholars
226 have recognised contradictory politics – a dialectical tension [92]– at the heart of UA [93].
227 Whilst UA can open new spaces for participation, enhance claims to public space, and
228 support access to healthy and affordable food, it can also exacerbate existing dynamics of
229 social, spatial and economic marginalisation [94, 95], through, for example, ecological
230 gentrification [96]. These authors draw attention to a need to consider systemic conditions,
231 including poverty, low wages, and income disparity that produce food insecurity [97, 98].

232 A significant body of critical literature has explored the limitations of UA for escaping or
233 operating beyond neoliberalism [99, 100]. However, Ghose and Pettygrove [101] argue that
234 in the USA, urban community gardens simultaneously contest and reinforce neoliberal
235 practices. Ernwein [102] has argued that UA simultaneously contests the neoliberalisation of

236 urban space, while reproducing a neoliberal governmentality. The implication across this
237 scholarship is that while UA can deliver significant benefits, it risks entrenching notions of
238 individualism, minimising the responsibility of the state in FS change, and reinforcing
239 structural inequalities [103, 104].

240 **The current and potential socio-economic** 241 **impacts of vertical farming**

242 This section reviews the evidence for the social and economic impacts of VF. Importantly,
243 across much of the academic discourse, VF practices are rarely disaggregated into the
244 categories identified in Table 1. Further analysis that examines the social and economic
245 impacts of different forms of VF represents an important area for further research. We
246 organise this section around three key areas of current and potential impacts that have
247 received most of the scholarly attention: contributions to urban food security through
248 enhanced access to healthy food; contributions to an inclusive urban economy; and
249 contributions to urban civic life. Within each section, we reflect on the extent to which
250 evidence regarding the socio-economic impacts of VF aligns with the impacts, opportunities
251 and challenges identified within the wider UA discourse.

252

253 ***Contributions to urban food security***

254 Existing literature highlights vertical farming as a key innovation for improving urban food
255 security [21, 23, 65, 105, 106]. In densely populated areas, VF can maximise production in
256 confined spaces, enhancing the availability of healthy fresh food [105, 107, 108]. Further
257 benefits of produce from VF relate to food safety and quality, enhanced due to a controlled
258 indoor environment and minimal use of pesticides and herbicides [3, 21, 25, 65, 109].
259 However, much of this literature identifies pathways to potential impact on urban food
260 insecurity rather than evidencing impacts to date. To some extent this is likely to reflect the
261 recent proliferation of VF and the more gradual emergence of an academic discourse. It may
262 also reflect a significant gap in terms of the types of research studies that are conducted in
263 relation to vertical farms.

264 In terms of prevailing international definitions of food and nutrition security [110] –
265 organised in terms of the four pillars of access, availability, utilization and stability – VF has
266 the potential to make significant contributions to the physical availability of food and food
267 stability over time. For example, scholarship has drawn attention to the potential role of VF
268 in supporting the transformation of so-called food deserts, urban neighbourhoods and rural
269 towns without ready access to fresh, healthy, and affordable food [111]. In this context,
270 vertical farms, and CEA systems more broadly, have the potential to ensure greater
271 availability of food and a more stable food supply, through efficient growing cycles,
272 protection from variations in weather and other growing conditions, and their ability to
273 operate outside of growing seasons [112]. However, Carolan [16] has argued that this
274 perceived stability is not necessarily a long-term solution; rather it only addresses existing
275 gaps in otherwise unjust and unsustainable food value chains.

276 The contribution of VF to the other pillars of food security – access to food and food
277 utilisation – is less straightforward. High initial investment costs [53, 113] as well as high

278 running costs associated with VF mean that produce can be limited in range and is often
279 priced relatively highly and less accessible to low-income groups. Currently, the relatively
280 high production costs mean that vertical farms focus on rapidly growing crops such as leafy
281 greens, microgreens, and herbs to remain as cost-effective as possible [113–115]. Marketing
282 these crops as premium products – emphasising their traceability, pesticide-free status,
283 freshness, and local production – can enhance their economic viability [53, 69, 116, 117] but
284 also raise the price for consumers.

285 This is particularly important in the context of the intersecting drivers and manifestations of
286 urban inequality [118], such that expanding UA will not automatically improve food security.
287 As low-income communities are likely already subject to “underinvestment and
288 discriminatory patterns”, vertical farms are vulnerable to falling into a corporate food
289 system model of “profit maximization and resource use efficiency”, in which social justice-
290 oriented practices are sidelined [119]. A number of studies have also shown a concentration
291 of urban farms in places where they are not most needed to address food insecurity, linked
292 with the role of urban farming in greening areas, which Yuan et al. [104] argue risks making
293 them a tool in gentrification “to make neighbourhoods more attractive to the upper class”.
294 An increase in property prices through such urban development is one example given as
295 needing consideration in exploring the social aspects of urban farming.

296 High production costs can potentially be mitigated in certain climates and through
297 technological advancements [55]. For example, vertical farms are reported to be more
298 efficient in regions where heating requires more electricity than lighting, such as at higher
299 latitudes, or in areas where water is scarce and energy is more affordable, such as parts of
300 the Middle East, where water-use-efficient vertical farms may be more desirable [55, 116].
301 However, this review has not found evidence of vertical farms that produce healthier and
302 more sustainable food than conventional agriculture at a lower price to direct consumers
303 than existing, supermarket dominated value-chains.

304 Cost of food, especially healthy fresh produce is often in tension with other high costs of
305 living in urban areas, causing low-income residents to become dependent on emergency
306 food services and food pantries [119]. Seigner et al. [119] highlight affordability challenges
307 to urban-produced food and cite examples of urban farms donating to food banks but
308 caution the lack of scholarship on the consumption or impact of these donations.

309 As indicated above, it has been argued that vertical farms could play a key role in addressing
310 the food security of poor and ethnically diverse urban neighbourhoods that lack access to
311 affordable, healthy food options [120, 121]. This may be more likely where vertical farms
312 are small-scale and built, for example, in un-used buildings that have been repurposed [25].
313 However, there is a lack of empirical cases documenting this in practice.

314 This is not to say that VF cannot contribute to urban food security. Rather it means that the
315 pathways of impact are distinct from other forms of urban food production for example,
316 scholarship from the global south has emphasised the contribution of urban agriculture to
317 food security through the development of additional household income [104], while
318 scholarship in allotments and other forms of urban community gardens from the global
319 north have emphasised contributions to food security through subsistence, social education,
320 and communal utilisation of healthy foods [104]. This diversity of pathways to food security
321 through urban agriculture points to the need for a diversification of approaches to meet the

322 diversity of needs of different urban inhabitants, of which VF is likely to be one important
323 approach.

324

325 **Contributions to an inclusive urban economy**

326 VF literature has highlighted the role of innovative technology together with a viable
327 business model [50] in creating both direct and indirect impacts, such as ground-breaking
328 new food supply and distribution networks, while also addressing food security and
329 environmental challenges [122]. Some of these potential economic and social impacts
330 include the creation of new much-needed green collar jobs from farm nursery management
331 and resource procurement to IT, office personnel and other areas [25]. Further jobs,
332 literature suggests, will be created in grocery stores, organic food markets as well as local
333 distribution and transportation networks [21, 121]. However, as above, these impacts are
334 highlighted as potential contributions, rather than arrived at through an analysis of the
335 impact of VF. Such assertions of impact, including job creation, are also made largely
336 without consideration of inequities within FS and the wider political economies in which
337 vertical farms exist [123].

338 The conceptual focus placed upon an interlinked triumvirate of novel technology, viable
339 new business models and agricultural productivity also concurs with mainstream
340 approaches to FS in research, policy and practice. What unites dominant visions is
341 adherence to a predominantly productionist perspective, which focuses on the need to
342 significantly increase food production and calorie availability, through production
343 efficiencies, capital investments and new technologies [123]. In contrast to the *a priori*
344 privileging of production and novel technology, critical studies have drawn attention to the
345 need to understand VF (and FS interventions) as both technical and social transitions [26,
346 124].

347 To understand and identify the pathways through which VF may contribute to inclusive
348 urban economies, it is crucial to broaden the discussion to consider, for example, who
349 benefits from VF projects, and how? Such questions are however left relatively unexplored
350 in the mainstay of existing and emerging literature. Instead, studies on VF have emphasised
351 its potential to create not only jobs, but new business ventures, while leveraging automated
352 technology to aid the development of smart cities by providing locally sourced food,
353 reducing the need for extensive transportation networks, and promoting efficient use of
354 space [64, 65, 68, 122, 125, 126]. Further contributions noted include the attraction of VF to
355 a younger generation, due to its intensive use of advanced technologies in controlling
356 indoor environments [127, 128]. Moreover, it is argued that the involvement of this
357 generation may drive further innovation in agricultural technology.

358 Rather than providing a socio-economic analysis, much literature tends to follow a
359 tautological approach, in which the wider impact of VF is attested to by its innovative
360 nature, and presumed advantages in agricultural production and environmental impact. For
361 example, Biancone et al. [122] argue that VF may be a solution to urban food security
362 through spreading new technologies and improved engagement with local economies. In
363 ensuring vertical farms are such a solution, emerging literature has highlighted the key role
364 of novel and viable business models along with entrepreneurship [129–132]. The focus of

365 analysis among some studies has therefore explored the nature of successful business
366 models in VF. One such study has concluded that entrepreneurship, for instance, should aim
367 for an efficient growing system aided with technologies in achieving environmental and
368 economic sustainability goals [122]. Organisational design, as these authors argue, is critical
369 to building innovative business models to ensure VF can deliver a socially sustainable supply
370 of food and the development of transformative technologies [133].

371 Literature on VF has thus emphasised a need for new approaches, for innovations,
372 techniques, and processes for both food production and consumption [134]. As such an
373 innovation, VF is presented by this body of literature as constantly improving and
374 expanding, and as changing the way food is produced and consumed [134]. One example of
375 this is modular, small-scale vertical farms which make significant use of automation, and can
376 be set up in a range of settings, such as restaurants, residential areas and supermarkets
377 [134]. The value of these “growing-service systems”, argues one review, rests on intangibles
378 such as fresher products, local production and automated control. In this manner, VF firms
379 are experimenting by adapting business models and enabling sustainable development as a
380 goal [134].

381 Emerging VF literature has argued that, as both a technological and entrepreneurial
382 innovation, VF has the potential to disrupt and decentralise the conventional FS by
383 operating across different scales and locations, while increasing local decision-making
384 autonomy [135, 136]. Some authors have associated UA more broadly as contributing to a
385 redistribution of resources and power by commoning urban resources, for example by
386 turning urban wastelands or interstitial areas into community managed farmland [124, 136,
387 137]. However, in our review, we find that these studies do not provide a pathway for, or a
388 sufficiently critical analysis of how, such redistribution might be achieved through VF, and
389 neither do they provide sufficient empirical evidence. In addition, studies which have
390 highlighted the potential game-changing role of VF, have also noted that many VF firms
391 across North America, Europe, and the Middle East have yet to fully address broader
392 sustainability goals beyond environmental impacts, with little focus on social or economic
393 sustainability [134]. There is also a dearth of literature on specific case studies of vertical
394 farms of different scales [134]. Despommier [65], a key proponent of VF, has reflected that
395 it is unclear whether VF would be successful globally, either from an economic and/or social
396 perspective, since the concept is still too new.

397 While much of the existing and emerging literature on VF makes implicit or in some cases
398 explicit references to direct individual or indirect community/collective social and economic
399 benefits, a smaller body of studies has taken a more critical approach [138, 139]. One review
400 exploring the potential of scaling up VF, has noted that the contextual conditions required
401 for VF to be sustainable have not yet been holistically assessed [124]. These authors used a
402 multi-level perspective approach to analyse VF as part of a sociotechnical transition,
403 examining three levels: *niches*, *landscapes*, and *regimes* [26, 124]. Niches refer to potential
404 novelties and social innovations which may challenge the dominant regime, including VF but
405 also alternative food networks and community agriculture. Landscapes refer to broader
406 processes that exert pressure on the prevailing regime, potentially enabling transformation.
407 Regimes represent the existing structures comprising various actors, market forces,
408 technologies, policies, and cultural and industrial norms [26, 124]. For these authors, the
409 dominant regime is the current FS, while the landscape of broader processes includes the

410 approaching food crisis and globalised neoliberal capitalism [124]. Specific examples of
411 landscape pressures include climate change, which exacerbates agricultural vulnerabilities,
412 and shifting demographic patterns, such as urbanization and population growth, which alter
413 food demand and land use [124]. These broader processes also include industrialised
414 farming, which contributes to biodiversity loss and environmental degradation, extensive
415 food miles leading to higher carbon emissions, increasing corporate involvement in UA, and
416 the growth-oriented focus of neoliberal political economy [122].

417 Scaling up VF, argue Petrovics and Giezen [124], requires the optimal combination of
418 contextual factors, emphasising the importance of understanding the particular elaboration
419 of niches, landscapes, and regimes, for example the role of VF investment schemes like
420 venture capitalism in North America; its implications for land ownership, as well as
421 ownership of the means of food production, and intellectual property in VF operations.
422 Carolan [140] has argued that capital-intensive large-scale VF in North America provides a
423 short-term “fix”, potentially shortens food supply chains but gives unsustainable and unjust
424 systems a new lease of life until the next crisis. These authors argue for a need to consider
425 the systemic issues that necessitate interventions such as VF and caution that, without a
426 reflection on VF as a social and technical intervention, VF could lead to further
427 commodification of agricultural products, further segregation between the experience of
428 food and its modes of production, and its catering to the wealthy [16, 89, 124, 140].

429 From an inclusive urban economy perspective, some studies have raised important concerns
430 about the actual impact of UA on skill building, education, and community development
431 [89]. These authors point out that urban farms often struggle to provide sufficient living-
432 wage jobs, rely heavily on unpaid labour, and face financial instability due to dependency on
433 grants, donations, and off-farm income [89, 90, 141–143]. Moreover, the context and
434 specifics of UA projects influences who benefits, with advantages often accruing to property
435 owners and new residents more than disadvantaged groups, while UA may also be situated
436 within processes of gentrification [89]. To identify a pathway for how VF as a form of UA
437 may contribute to inclusive urban economies, it is therefore critical to situate it within the
438 broader political economy of urban development. This requires moving beyond the focus of
439 much existing literature – the technicalities of agricultural production and the presumed
440 role of technological and entrepreneurial innovation [89, 104]. There is a need for both
441 rigorous analysis of socio-economic impact, as well as deeper attention to questions of
442 power in FS interventions, and transformations [89, 144–146].

443

444 **Contributions to urban civic life**

445 Alongside urban food security and economic impacts, literature has noted the role of VF in
446 community development, with studies pointing to a wide range of potential benefits
447 including outreach programmes, education, establishing business centres, as well as linking
448 with social workers and facilitating community advocacy in urban governance [121, 147].
449 Through the involvement of social workers, one study has argued that interdisciplinary
450 teams can address issues of food access and sustainable production in low-income
451 neighbourhoods [121]. Social participation through education, training and community
452 engagement programmes, alongside the sale of healthy food locally, argues another study,
453 can have economic, social and health benefits [147]. Through such social entrepreneurial
454 and technological innovation, vertical farms, some literature has suggested, can even

455 become sites for community advocacy and civic virtue development, as citizens are
456 empowered to engage with urban planners, public authorities and decision-makers [121].

457 While such contributions to urban civic life through VF may be possible, as above, our
458 review has not found studies which present empirical evidence of such contributions.
459 Instead, literature has focused on an implicit or explicit presentation of the role of
460 technological and entrepreneurial innovation. To leverage multiple environmental,
461 economic and social benefits, the prevailing approach in VF literature has highlighted the
462 way new business models are being developed, for example to provide functions and
463 services instead of traditional products [134]. Social and economic impacts, including the
464 role of such innovation regarding existing dynamics in FS and wider political economies are
465 largely presumed, rather than analysed. Wider literature on UA has however drawn
466 attention to the inevitable intersection between urban farming and social injustices as
467 projects develop [104, 140]. In one study, authors note the need for deliberate processes of
468 community inclusion in urban decision-making to address social injustices, through which
469 mutual relations can be built between public officials and civil society. Rather than a singular
470 focus on urban farming, such processes include local government structures, as well as food
471 policy councils, local activists and community organisations [104, 140].

472 As a note of caution, some authors have argued that not all UA practitioners connect food
473 cultivation to political values or actions, and in those conditions, UA is unlikely to function as
474 a mechanism for food democracy, other movements for social justice, or structural change
475 [89, 141]. On a related point, one review has noted that not all UA planning efforts seek to
476 help disadvantaged residents suffering from food injustice [89]. Furthermore, although
477 urban farming projects such as community gardens have been praised for fostering mental
478 health, civic participation, and community pride, the benefits are not always equitably
479 distributed [89]. Broadening out a focus on urban civic life to the role of UA in addressing
480 food injustice experienced by disadvantaged communities, McClintock et al. [89] argue that
481 UA by itself is unable to address the structural causes of inequities in FS, and is fairer viewed
482 as one possible strategy among an array of others, including poverty alleviation, in seeking
483 greater food justice.

484 This sentiment was shared by Horst et al. [89] who concluded that UA should not be viewed
485 as a panacea, but instead as one potential intervention among an array of strategies, that
486 may enhance food justice but only if the benefits accrue to urban residents who experience
487 food injustice and insecurity. Similarly, based on their research, Petrovics and Giezen [124]
488 highlighted the limitations of single socio-technical interventions and argued that due to the
489 complexity of urban reality, VF should not be assessed from the perspective of single supply-
490 end interventions. In considering how to scale-up VF, one challenge these authors note is a
491 common focus on the role of technology as independent of social and political processes
492 [89, 124].

493 To understand the contribution of VF to urban civic life, it is therefore necessary to
494 understand VF as not only a transformation of technological processes but as a
495 phenomenon with transformative power in the societal sphere [89, 124]. To understand
496 such transformation, contextual spatial factors, power relationships and the productive
497 nature of political struggles are important to consider [89, 124]. If VF becomes a key aspect
498 of urban development, it is even more important to question not only who benefits and

499 how benefits can be justly distributed, but to situate these questions within a critical
 500 analysis of the relationship between power and innovation in FS [28, 140].

501 A structured framework to synthesise the advantages and disadvantages from the three
 502 potential impact categories identified is presented in Table 2. This emphasises the tension
 503 between potential and realised impacts in each category, highlighting the need for more
 504 empirical evidence, nuanced approaches, and policies addressing equity and inclusion.

505 Table 2. Advantages and disadvantages of urban VF in the three potential impact categories
 506 emerging from the literature.

Impact Category	Advantages	Disadvantages
Urban Food Security	<ul style="list-style-type: none"> - Potential to increase food availability and stability of food supply through CEA (efficient growing systems and year-round production). - Potential to transform food deserts by increasing the availability of healthy, fresh food. - Controlled indoor environments improve food quality and safety, reducing the need for pesticides. - Protection from climate and seasonal variability, potentially enhancing food stability. 	<ul style="list-style-type: none"> - Limited evidence for impact on urban food insecurity, including access to food and food utilisation. - High production costs make produce less accessible to low-income populations. - Risk of aligning with corporate models focused on profit rather than food justice. - Limited crop range (e.g., leafy greens) due to economic constraints. - Potential role in gentrification, raising property prices and excluding marginalised groups. - Perceived increases in food supply stability and availability mask unsustainable and unjust food value chains.

Inclusive Urban Economy	<ul style="list-style-type: none"> - Potential creation of green jobs across agriculture, distribution, IT, and retail, alongside new food supply networks. - Potential for entrepreneurial and technological innovation to transform conventional FS: Opportunities for small-scale farms and new business models. - Potential to attract younger generations through technological innovation. - Possibility for VF to disrupt conventional food systems and foster resource sharing. 	<ul style="list-style-type: none"> - Limited empirical evidence of job creation or impact on food supply networks, alongside evidence of low wages and unpaid labour in urban farming. - Presumed role and impact of technological and entrepreneurial innovation vs a lack of socio-economic analysis and evidence. - Lack of research on VFs of different scales and sizes. - Economic benefits may favour property owners or wealthier individuals over marginalised communities. - Risks of prioritising capital-intensive VF projects that replicate unsustainable systems. - High dependency on grants or donations in small-scale urban farming projects. - May perpetuate segregation between food consumers and producers, focusing benefits on affluent markets. - Few case studies evaluate long-term social and economic sustainability goals.
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Urban Civic Life	<ul style="list-style-type: none"> - Potential for community-building through education, training, and outreach programs. - Potential opportunities for community advocacy in governance and urban planning. - Potential for economic, social and health benefits through integrating community engagement programmes with the sale of healthy food locally. - Potential for promoting civic participation through citizen engagement. 	<ul style="list-style-type: none"> - Limited evidence of impactful contributions to community advocacy or civic life. - Risk of perpetuating social inequities if community participation is not explicitly integrated into projects. - Focus of VF literature being on technical and entrepreneurial innovation over socio-political analysis of urban inequities. - Lack of deliberate inclusion processes risks excluding marginalised voices in urban planning. - Inability of VF or UA projects by themselves to address structural causes of inequities in FS.
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Conclusions: Opportunities to enhance the contribution of vertical farming to food systems transitions

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Much existing and emerging literature on VF has focused on analysing the production aspects of this novel and evolving technology [60, 129]. Alongside this literature, studies have sought to explore VF as an innovative business model [25, 122]. In both cases, the focus of research is on defining and delineating effective technological and organisational features for successful VF operations. In reference to both novel technology and organisational design, VF as an entrepreneurial innovation is credited with a series of agricultural production, economic and environmental benefits, alongside a number of social benefits. As discussed, a smaller body of literature has sought to question this panacea presentation of VF as a solution not only to agricultural challenges, but to urban development, food security and societal challenges more widely [89, 121, 124, 140]. It is also the case that much existing literature has focused on North America, as well as on large-scale VF operations.

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We hope that this review is timely, as technical innovations in VF and CEA are increasingly matched by the strength of desire across societies to trial new approaches to food production, distribution, and consumption, as well as scholarly and policy interest. Our contribution is to highlight the limits of any one approach or set of technologies in isolation,

527 and to advocate for a critical and evidence-led approach to enabling equitable socio-
528 technical transitions within our food systems.

529 Our review has highlighted a number of *potential* social benefits associated with VF, both to
530 individuals as well as to wider urban communities. These include the creation of green jobs
531 and local food supply chains, and greater access to healthy fresh food (transforming food
532 deserts), leading to health and economic benefits. However, crops produced in vertical
533 farms are generally sold as premium products. In addition, literature has pointed to
534 community development work and potential avenues for civic participation, as well as
535 integration of these activities with public and community services [121]. Most of these social
536 benefits are listed as potential (unevidenced) benefits within existing literature, and rest on
537 a conceptual presumption concerning the role of social entrepreneurial innovation in
538 agricultural production and business model design in urban areas, as well as the presumed
539 direct and indirect impacts on urban populations. Critical studies have highlighted
540 challenges to these benefits including corporate investment models, gentrification,
541 unaffordability or inaccessibility of VF produce to low-income communities, as well as low
542 wage levels among urban agricultural workers and a reliance on unpaid labour. Finally,
543 community development and civic participation activities can be both inclusionary and/or
544 exclusionary.

545 Our review has highlighted the need to consider the role of pre-established socioeconomic
546 structures [104], policy contexts and the wider FS when seeking to understand the social
547 impact of VF, especially beyond the individual level to wider community benefits. This
548 requires examining VF as a sociotechnical intervention [26], as well as considering the
549 broader political economy and particular urban context in which vertical farms are
550 implemented. Much VF literature to-date reflects a technocratic, productionist perspective
551 typical of mainstream FS analysis, where power dynamics and institutional frameworks are
552 taken as given, rather than socially constructed [148]. VF may form part of wider efforts to
553 transform FS, but as Anderson and Leach reflect [28], rather than technical transitions, the
554 need is for “deeper transformations” for global FS and for sustainability and equity more
555 broadly. Such transformation is inevitably profoundly political, requiring power and political
556 economy “to be addressed head-on” [11, 27, 28, 122, 149, 150].

557 There is therefore a need for further research exploring the social implications of VF of
558 different models, scales and geographical locations, especially small-scale and outside North
559 America. Such research may also critique the artificial separation of VF technology from its
560 social, economic and political context. In this sense, the key question may not necessarily be
561 to explore the social impact of VF, but to understand the way in which VFs develop through
562 organisational, social, economic and political relations. In contrast to much of the research
563 that has examined the socioeconomic impacts of VF, future research could productively
564 focus on the interactions between VF and their contexts; unpacking the specific local
565 conditions that enable the positive potential impacts of VF to be realised. Avenues of
566 research may explore VF organisational development beyond a focus on business model
567 design [122] to the ebb and flow of VF innovation, including efforts to create social impact
568 or to engage communities, from a political ecology, or critical institutional perspective [151].
569 Such a focus on the interactions between VF practices and their contexts is vital for better
570 understanding the contribution of VF to more equitable and sustainable food systems within
571 a broad range of emerging technological, organisational, and policy innovations. Beyond
572 these broad research areas, specific knowledge gaps also remain regarding, for example,

573 attitudes (including issues of desirability and cultural appropriateness) towards the types of
574 foods predominantly produced by VF by low-income groups.

575 Suggested research approaches to explore the social implications and impact of VF include
576 community-based participatory and ethnographic methodologies, longitudinal case studies
577 and political economy analysis of FS interventions (drawing on existing work [28]). Building
578 on studies which have sought to qualify the prevailing panacea-based approach to VF in
579 literature, policy and practice, adopting a critical focus on VF development and impact may
580 help to explore why, despite an emphasis on effective organisational structures [25] an
581 understanding of social benefits and impact is often difficult to ascertain, define (or
582 achieve). Exploring the way in which VF is embedded within wider political economies as a
583 socioecological innovation, should provide a key step in this direction.

584

585 **Author Contributions**

586 Conceptualization—wrote the main research proposal from which this manuscript is part of
587 B.D., K.D.; designed the scope of this manuscript A.K., C. Y., P. H., K.D; methodology—
588 developed the methodology A.K. K.D; formal analysis—conducted literature review A.K.,
589 P.H., C.Y.; writing—original draft preparation A.K., C.Y, P.H.; writing—review and editing
590 A.K., C.Y, P.H., U.E., B.D., K.D.; funding acquisition B.D., K.D. All authors have read and
591 agreed to the published version of the manuscript.

592

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596

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