Sustainable urban and vertical farming

STFC Food Network+

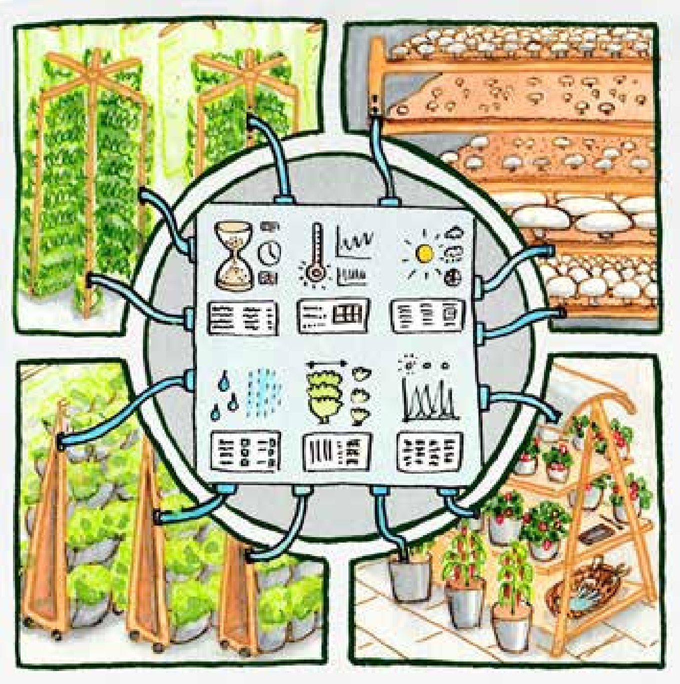
Summary

Globally food supply chains are associated with 26% of anthropogenic greenhouse gas (GHG) emissions, equivalent to ~13.7 billion metric tons of carbon dioxide equivalent (CO2eq); the farming stage is the major contributor to emissions, acidification and eutrophication.[1]

Urban farming (UF) and vertical farming (VF) can contribute to building sustainable food systems via: a) reducing the need for additional arable land, b) supplying locally-grown nutrient-dense foods, c) enhancing food security in cities, d) providing new sources of employment, e) improving food systems' resilience, and f) reducing food supply chains' environmental footprints. However, UF and VF face technological, sustainability and social challenges in need of further research. VF is highly energy intensive, and its automation and monitoring are costly. Conversely, urban farming and agriculture have been largely an informal sector not well integrated into agricultural policies or urban planning.[2]

Between 2020 and 2021 the SFN funded 4 scoping projects and 1 Proof of Concept project exploring the different challenges around UF and VF. Solutions explored include improving it's circularity and developing data analysis methods to improve food security, growing efficiency and most usefully exploiting vacant spaces.

Globally food supply chains are associated with 26% of anthropogenic greenhouse gas (GHG) emissions, equivalent to ~13.7 billion metric tons of carbon dioxide equivalent (CO2eq); the farming stage is the major contributor to emissions, acidification, and eutrophication. Urban farming (UF) and vertical farming (VF) can play a major role in shortening distances from production to consumption, hence, lowering GHG emissions, improving water and fertiliser usage for agriculture, reducing pesticide usage, and fundamentally contributing to achieving food security and safety for an increasingly globally urbanised population.



Vertical Farming is just one type of Controlled Environment Agriculture (CEA). These include the whole range of semi- and fully closed systems, with varying degrees of control & automation, set out in variable platforms like cabinets, shipping containers, roof-tops, towers, tunnels, and greenhouses.

Illustration by Sarah Hannis

SFN+ projects - Which challenges were targeted?

- **Enhancing the circularity of vertical farming: making the most of local waste.** VF can be high energy and inputs intensive. Instead of sunlight and rain, VF operates mostly on LED lighting and controlled growing and nutrition systems, where plants are generally stacked vertically in layers.[3, 4] Questions arise then on how to exploit circular economy principles for UF and VF? How to ensure that vertical farms operate with short resource loops (reusing resources), and with lower waste and short place-based loops? In the UK 47.3% of vegetables and 84% of fruits are imported, and supply chains have been significantly affected by Brexit and Covid-19. Similarly, the UK generates ~9.5M tonnes of food waste each year, revealing the need to work around reducing and reusing it.[5]

Urban areas can have little open green space for growing. However, by taking advantage of any vacant walls, lots, balconies, and rooves a surprisingly large amount of growing space can be exploited, particularly vertical growing of leafy greens up walls. Photograph of vertical grow bags to grow leafy greens in an alley in Yogyakarta, Indonesia.

Photo courtesy of Prof Catur Sugiyanto

- A 2021 SFN+ scoping project explored the possibilities of making VF a circular way of farming. The focus was on developing the science of modelling local food systems, creating a tool to model local fruit and vegetable production, and providing policy makers with insight to foster local farm production. The main goal was to assess opportunities to make the most of what is already available in a (hyper) local setting for urban food production, e.g., exploiting local wastes to promote local food production. This 'small is beautiful' thinking has potential to counter the wasteful mass production and global movements of foods (food miles). As well as avoid missing opportunities to make the most of local wastes for high value applications. The project used data from two vertical farms and two companies producing valuable materials for VF to model waste flows in an urban area and optimise those flows to minimise carbon impact.

- **Can we use vacant urban spaces for food supply functions?** In the UK, there are three major issues within urban food growing that need to be resolved: distribution, function, and connectivity. Currently, food growing activities are concentrated on a limited number of sites, leading to overworked soil and limited accessibility and distribution of produce for local communities. Additionally, sites designated for urban food growing tend to be used solely for cultivation, which means that other critical functions of the food supply chain cannot take place. Finally, many essential parts of the food supply chain are displaced to locations beyond cities, creating challenges around sustainability and waste reduction.

- Growing demands for healthy, sustainable, and resilient food supply chains call for a more efficient use of existing urban space. Exploring the potential of using under-utilised and vacant spaces for food growing activities is needed to avoid further intensification of already in-use sites. Building on existing STFC-developed crop growth models, and assembling environmental and spatial datasets, a multidisciplinary team of researchers working on a Proof-of-Concept project entitled 'Urban Cultivate' proposed the development of a new decision-making platform to identify and optimise vacant urban spaces for food growing functions.

Linking all types of urban crop growing and food waste recycling across cities and regions can help both inform and control supply and demand. Growers can potentially switch crops and time harvests according to demand and likewise, sellers, local consumers, and planners can know what supplies are available close by

Illustration by Sarah Hannis

- **Urban food security under pressure: what role for UF?** Globally, the impacts of ongoing food security and malnutrition challenges are anticipated to be magnified by climate change effects on food supply, and further expansion of urban populations. At present, accumulated and novel food security endeavours already exert significant pressure in the wellbeing of urban and peri-urban inhabitants. Yet worldwide ~79% of all food produced is destined for cities. By 2045, six billion people are expected to live in cities (~1.5 times the current 4.4 million). Many new cities inhabitants will belong to low and middle-income countries in Africa and Asia.[6] Putting spatial data platforms to work for urban food security is crucial.
- In 2020, researchers assessed the feasibility of building a smart UF data system to optimise the benefits of urban farming and contribute to improve urban food security in Yogyakarta (Indonesia). A digital platform was piloted to test how spatial visualisation of multi-layered information streams could aid decision making. Specifically, researchers collected locations of urban farms, along with information on production and socio-economic characteristics of farmers to produce a geographical data information system which can be inquired to support decisions from different stakeholders. Employing digital technology platforms to visualise spatial characteristics of urban farm systems enables stakeholders with better information for decision-making. To illustrate, layering urban maps with complementary health and environmental information, e.g., malnutrition incidence or urban biodiversity indexes, could help identify opportunities to reduce food insecurity in cities.
- **Improving the efficiency of VF using Big Data and IoT.** Across several parts of the world, the VF industry is still undergoing its initial stages with several inefficiencies (high energy/ labour costs, limited crop choice, high levels of contamination), resulting in poor Return on Investment (ROI). To drive the industry forward, collecting, and analysing precision data is essential to monitor and control plant performance factors in the growing environment, as well as to increase yields and efficiency in resource use. Currently, the lack of real-time and precise crop data compromises the VF potential.
- A consortium of SFN+ backed-up researchers assessed the feasibility of developing IoT precision data solutions for VF. The aim was to explore an all-encompassing automated monitoring and control system that creates precise and timely proprietary Big Data, generated against multiple inputs/ingredients from a VF growing environment. Alongside, the scoping project aimed to develop an algorithm to calculate optimum growing recipes for nutritionally dense crops and improve resource efficiency.

Results – STFC working for smart and sustainable urban and vertical farms.

1. Circularity and optimisation of waste flows.

Researchers in York developed a modular circular economy urban/vertical farm-food model. Modelling technologies were used to capture the dynamics of the flows of waste for nutrients and the use of wastes for construction. Using IntelliDigest's digestors as potential inputs to VF as nutrients, the researchers explored the potential for waste from Food Operating Businesses (FOBs), by examining a possible match of these nutrients i.e., are these flows operational? To determine how urban waste could be used for building materials, they worked with spent grain (waste) from a brewery in York (BrewYork), and the industry partner Wasware which processed the waste into bio-resin and then, created bio-leather and bio-board.

The success with using local urban waste as input for building material showed the potential for waste use in VF construction. Researchers successfully mapped out potential flows of wastes and created two models to understand how the flows of wastes and products can be used in a circular context. One was a logistics model demonstrator using a freemium version of Anylogistix commercial software, and the other was a bespoke analysis looking at some farming elements including crops perishability. Results of digital twin explorations were published by DAFNI, using the Anylogistix software to create datasets that allow the evaluation of model results for nutrition flows and for construction flows. To evaluate the feasibility of sourcing farms' automated data collection (environmental and plant growth) and integrating such data into a single modelling environment the group of researchers used OpenMaps for geographic data, and assessed how to integrate it with IntelliDigest's World Food Tracker. Additionally, the consortium examined the use of the API and routines to access LettUs Grow's 'Ostara' data for the York vertical farm. Have a look at the two-minute web animated video of this project.

Controlled Environment Agriculture can run under circularity principles, using local food waste as inputs and producing not only food but other agri-food materials and outputs for other industries. The plants' growing process is monitored permanently to assess the most efficient growing methods.

Photo by the Circular urban vertical farming Scoping Project

2. Use of GIS data to obtain spatial data and assess candidate sites for UF.

The first case study of Urban Cultivate was focused on the London Borough of Islington, which is one of the most densely populated areas in London and is perceived to have few opportunities for urban food growing activities. However, with careful analysis, possible candidate sites began to emerge, including spaces between buildings, along alleyways, courtyards, and car parks. The project worked closely with the Octopus Communities, a network of active and engaged food growing volunteers in the borough who have helped to design, create, and maintain over 50 different urban agriculture spaces. The Islington Borough Council supported their activities and the project. The pilot study concentrated on the Octopus Community Plant Nursery; a hidden plant-growing paradise situated off Tufnell Park Road. Initially, nearly 100 candidate sites of vacant or underutilised land were mapped around the Nursery, and then a shortlist of these sites was selected into two clusters.

Environmental and spatial data were collected from each identified site. The environmental analysis includes measurements of air and soil quality, and microclimate information.
The spatial analysis considers the size and shape of each site and calculates metrics of accessibility, integration, and connectivity, within the community. Developed and supported by STFC, the optimization model and dashboard were used to predict the most suitable food growing functions for each space within both

Results – STFC working for smart and sustainable urban and vertical farms.

clusters. These spaces were then put to the local community in a policy-focused workshop attended by members of local government, and a Community Open Day where the public were invited to comment about the use of these new spaces for food growing activities. Visit the Urban Cultivate website which details more information about the project and next steps.

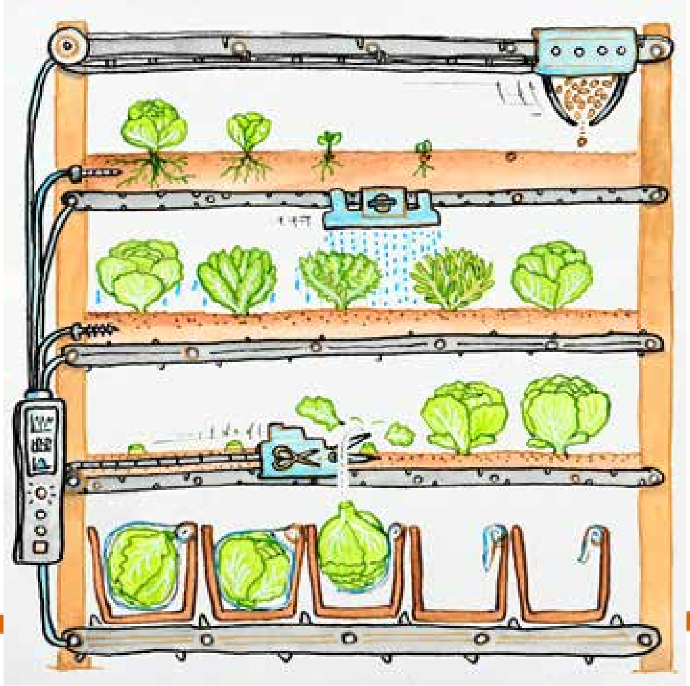
3. Building smart urban farming data systems.

Researchers explored the development of a smart platform considering DAFNI and STFC Analytics Facility that already hosts a similar system for several British cities. The goal was to determine the viability of a digital spatial platform, layering different types of urban farm information, to identify opportunities to improve food security (namely reducing malnutrition and stunting) in low and middle-income cities. Researchers asserted that to support decision-making around urban farming, the proposed platform needs to compile environmental, geographical, governance, marketing, production, and socio-economic data.

The addition of a geographical dimension to the analysis of urban farming contribution to food security enabled a richer picture to the analysis of the Yogyakarta urban farming system. In line with other studies,[7] results for the pilot project showed that most farms produce fruits and vegetables, namely chilies, tomatoes, and leafy greens. Interestingly –perhaps reflecting the geography and climate of Indonesia–, Yogyakarta has a diverse UF system not only in terms of crops produced but also of farm types. Regarding drivers of auto-consumption and sales of urban farms output, in the city there are lower odds of sale for women-led farms, which is consistent with literature[8], previously showing that while most urban farms are operated by women the most entrepreneurial are men-led. Concerning market orientation, in this project's sample only about a third of farmers sold their produce. The latter aligns with other work suggesting that the potential of urban farming to become a significant contributor to food security requires investments in technological and production innovations.[9]

Conceptual technical solutions for improved efficiency in vertical growing. For example, developments in automated seed sowing, water/light/nutrient receipes and delivery, harvesting and packaging.

Illustration by Sarah Hannis



In relation to the role urban farming can play in mitigating food security, the project's results echo the literature in that the level of production is quite small and there is no clear evidence that more production reduces for instance, childhood stunting.[10] Still, the fact that researchers found such a diverse urban system may open opportunities for reducing carbon footprint of fresh produce, at least for some groups of urban dwellers.

4. Automated monitoring and control systems.

To assess the feasibility of an all-encompassing automated monitoring and control system that creates precise and timely propriety Big Data, researchers utilised existing microgreen data from sensors and plant performance-based computing to develop an IoT Precision Data Solution for the VF environment. At NTU, the consortium worked with a shipping container farm, a crop growth model, and remote sensing data (collected from previous research), to obtain plant growth efficiency, and stress information (water, nutrient, ambient conditions) of horticultural crops. The team has worked with lettuce, tomatoes, strawberries, basil, and other crops. The application of artificial neural network (ANN) techniques is used to assess plant care parameters and the conditions to maximise crop yield. These techniques are useful in establishing data fusion models of multiple and heterogeneous data.

Future research opportunities and next steps

1. Around exploring the circularity and optimisation of waste flows.

In the York circular VF project, the researchers found further funding is needed to advance the evaluation of the model's ability to 'game' or perform Q&A to better understand how to optimise, what are the minimum levels of data, what will break the model, etc. Similarly, for scaling up the modelling technology, researchers are calling for further funding with the aim to do live-data capture in order to use models for decision making as 'digital twins' and extend the scope of the modelling to a local setting such as the centre of York to capture actual flows from food operating businesses, food production vertical farms and breweries.

A funding for a follow-on project has been granted funding (IBioIC) for studying the development of material waste conversion to building materials, not just to replace existing materials like-for-like but to question the fundamental design of building structures, if new building biomaterials are available. Finally, a relevant area for future research was identified around exploring the social and behavioural challenges that UF and VF encompass; namely, what about the public and consumers' acceptance of VF and UF grown crops? What is the value proposition of VF for different food supply chain stakeholders?

2. For building smart urban farming data systems.

The Yogyakarta project researchers only collected production and socio-economic information. Future research will test the feasibility of developing a modular structure to integrate other streams of information; namely, remote sensors' data (e.g., farms' pollutants and carbon capture). The ambition is to enable all agents involved in the urban farming ecosystem to make better policies and strategies and monitor their impact. Future research questions include:

- How a more sophisticated UF digital platform can be employed to test alternative incentives and policies to improve urban farming contribution to food security?
- How cultural and sociological factors may hinder the empowerment of women and their contribution to the development of an inclusive and purposeful UF system to improve food security?
- How UF systems can contribute to an improvement of both physical and mental health?

Unused urban spaces with environmental conditions suitable for food-growing were mapped across the London Borough of Islington, UK, as part of Urban Cultivate.

Photo courtesy of Dan Evans, Cranfield University

3. Integrating environmental, spatial, and social data to assign food supply chain functions across urban space.

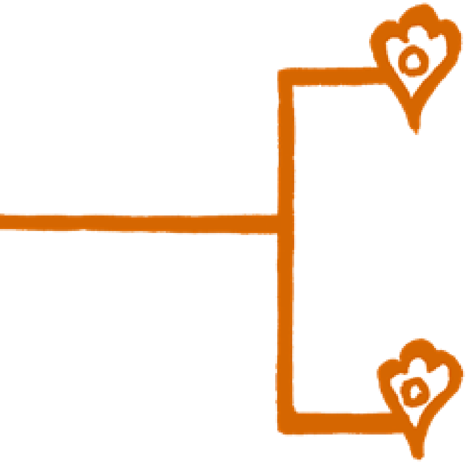
The Urban Cultivate model and prototype dashboard trialled in the London Borough of Islington has shown success in mapping vacant urban spaces that can be used for food supply functions. Researchers explored the development of a dashboard that enables customisation of the importance of certain spatial and environmental criteria so that the output can be based on the bespoke requirements of the user. Future research is needed to continue working on the development of a prototype dashboard website which links a map with the results. Recently, Urban Cultivate launched its website which details more information about the project and next steps. To name a few, a potential partnership with Borough of Lambeth to undertake a similar exercise, upscaling across London via consultations with the Mayor's Office, and working with OS maps to develop automated methods of identifying and mapping candidate vacant sites.

Sustainable VF through automated monitoring and control systems.

The NTU-led scoping project exploring the automation of VF was successful in obtaining data that was later analysed by STFC Hartree Centre's scientist/VF specialists to develop algorithms and calculate optimum growing recipes. Yet three main challenges call for further research. First, the practical issues of high energy usage to yield performance (estimated around 250kWh of energy a year for every square metre), the high capital cost (CAPEX), and the shortage of highly educated workforce. Secondly, the technological endeavours around monitoring and automation in VF, a limited number of plants, the lack of systems for optimisation, and a limited scalability of technologies. Thirdly, the absence of standards and best practices guidelines for VF that ensure the industry operates under and for a sustainability paradigm.

A set of other key areas in urgent need of grant fundings are listed below:

- **Development and testing of LED light recipes.** In VF environment, LED light is crucial to ensure plant growth and industry stakeholders are eager to collaborate with researchers to develop those recipes that lead to higher micronutrients. Academia and industry partnerships are essential.
- **Robotics for automated VF and AI for integration of VF into supply chains.** While AI and Big Data are already leading research agendas for automated, for instance for efficient sowing of seeds, future research would need to explore how these can be further integrated into supply chains and consumer preferences.
- **Breeding genetics and gene editing.** For VF crop improvement research is essential to achieve higher yields and plants quality, as well as to incorporate further crops varieties to urban farming. Further exploration of gene editing for better understanding of ripening processes can lead to more efficient VF systems regarding use of inputs.
- **Alignment of VF with Net Zero food systems.** Exploring the possibilities to design and operate VF systems aligned with Net Zero goals is a major area for research. VF significantly reduces direct GHG emissions such as N_2O, CH_4 and CO_2 when growing some crops.[11] VF systems maximise crops' nutrient content while minimising resource use in plant growth cycles, and higher efficiency can be achieved through the implementation of AI for dynamic control of lighting, heat, and nutrient recipes. Research shows that AI light recipes and nutrient recipes can increase ~25%-45% resource use efficiency (e.g., nutrients, energy), thus contribute to Net Zero goals (SFN+ Scoping Project).
- **Knowledge transfer opportunities.** Researchers found knowledge transfer opportunities should be further explored, particularly a combination of technologies and knowledge that can be applied to tackle food security challenges in Global South countries through sustainable VF. E.g., using solar powered VF with automated light recipes could be of high use across Asia and Africa.
- **Best practices for standardising VF requirements.** For smart, sustainable, and safe VF to become mainstream several areas of research are to be developed. The industry lacks product standards and guidelines that set up the infrastructure and align it to sustainability goals. The expansion of the industry requires product standard profiles, country specific standards, machine specifications and process standards. Studies around key corporate and organisational policies and guidelines for VF will guide the pathway for designing an effectively smart, sustainable, and safe VF industry.



Growing food through UF and VF can leverage the transition towards smart and sustainable food systems. Both are expected to play a major role in shortening distances from production to consumption, contribute to lowering food GHG emissions, improve water and fertiliser usage for agriculture, reduce pesticide usage and fundamentally contribute to achieve food security and safety for an increasingly globally urbanised population. Research in technological innovations for automated growing methods, innovative farming materials, circularity farming models, are all key components of the future success of urban and vertical farming. To explore some of these areas the SFN+ has launched its first Round of Expert Working Groups, including a group working on Sustainable Vertical Farming, with members bringing their expertise from a wide diversity of institutions, including NIAB, the STFC Hartree Centre and the University of York. You can find more information on the SFN+ website.

Assessing the Feasibility of IoT Precision Data Solution for Vertical Farming

PI: Professor Chungui Lu (Nottingham Trent University - NTU)

Food Side Co-Investigators: Dr Wantao Yu (University of Roehampton - UR) and Steven Grundy (NTU)

STFC Side Co-Investigators: Dr Tom Kirkham (STFC Hartree Centre)

Modelling, optimizing, and identifying vacant urban spaces for urban food production

PI: Dr Dan Evans (Cranfield University)

Food Side Co-Investigators: Mr. Spencer Leung (GO Organics Peace International), Dr Mehroosh Tak (Royal Veterinary College, University of London), Pareena Prayukvong, (Wastegetable, Bangkok)

STFC Side Co-Investigators: Peter Hurley (STFC Research Fellow and Business Development Lead, University of Sussex)

Non-academic partners: Phil James (Newcastle Urban Observatory)

Building Smart urban Farming data systems: A Case study

PIs: Dr Lilik Sutiarso (Universitas Gadjah Mada, Indonesia - UGM), Dr Diogo Souza Monteiro (Newcastle University), Dr Catur Sugiyanto (UGM)

Food Side Co-Investigators: Ambar Pertiwiningrum (UGM), Prof Chungui Lu (NTU), Dr Elisa Lopez-Capel (Newcastle University)

STFC Side Co-Investigators: Jens Jensen (STFC Scientific Computing/DAFNI) and Marion Samler - (STFC Scientific Computing/DAFNI)

Acknowledgements and more information

Circular urban vertical farming. Data, models and optimisation of waste flows

PI: Professor Peter Ball (University of York)

Food Side Co-Investigators: Lydia Smith (National Institute for Agricultural Botany - NIAB), Prof. Nicola Holden (Scotland's Rural College - SRUC), Dr Ifeyinwa Kanu (IntelliDigest Ltd), Dr Xiaobin Zhao (Wasware Ltd), and Dr Ehsan Badakhshan (University of York)

STFC Side Co-Investigators: Jens Jensen (STFC Scientific Computing/DAFNI)

Integrating environmental, spatial, and social data to assign food supply chain functions across urban space (Proof of Concept project)

PI: Dr Dan Evans (Cranfield University)

Co-Investigators:: Peter Hurley (STFC Sponsor, University of Sussex)

Non-academic partners: Russell Whitaker, Brent Richards and Abdul Mohamed (Agrotectur Global), Julie Parish (Octopus Communities), Andrew Bedford (London Borough of Islington Council), Cllr. Rowena Champion (London Borough of Islington), Joseph Starkey (University of Sussex)

Booklet compilation

Authors: Prof Sonal Choudhary (SFN+ Principal Investigator, University of York), Dr. Raymond Obayi (The University of Manchester) and Ms Paulina Flores-Martínez (SFN+ Knowledge Exchange Coordinator, University of York)

Design: Sarah Hannis

STFC
Food
Network+

UKRI
Science and
Technology
Facilities Council

Newcastle
University

NTU
Nottingham Trent
University

SRUC

AGROTECTUR GLOBAL

UNIVERSITY
of York

IntelliDigest
Empowering Global
Food Sustainability

GO
ORGANICS

ISLINGTON
For a more equal future

University of
Roehampton
London

Cranfield
Environment
and Agrifood

URBAN CULTIVATE

NIAB

UNIVERSITAS
JOGJAKARTA

RESEARCH
COUNCILS UK

US
UNIVERSITY
OF SUSSEX

Top: Controlled Environment Agriculture grow tray
Bottom: Locally recycled waste streams reformed into products useful to VF to improve its circularity
Photos courtesy of the Circular urban vertical farming Scoping Project

References

1 Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science, 360(6392), 987–992. https://doi.org/10.1126/science.aaq0216

2 The World Bank (2013). Urban agriculture. Findings from four city case studies. Retrieved from: https://documents1.worldbank.org/curated/en/434431468331834592/pdf/807590NWP0UDS00Box0379817B00PUBLIC0.pdf

3 Benke and Tomkins (2018). Future food-production systems: vertical farming and controlled-environment agriculture. Retrieved from: https://www.tandfonline.com/doi/pdf/10.1080/15487733.2017.1394054

4 Masterson, V. (2022, 24 May). Vertical farming – is this the future of agriculture? Retrieved from: https://climatechampions.unfccc.int/vertical-farming-is-this-the-future-of-agriculture/

5 WRAP (2021). Food surplus and waste in the UK – key facts. Retrieved from: https://wrap.org.uk/resources/report/food-surplus-and-waste-uk-key-facts

6 FAO (2022). Urban and periurban agriculture sourcebook. From production to food systems. Retrieved from: https://www.fao.org/3/cb9722en/cb9722en.pdf

7 Grafius, D. R., Edmondson, J. L., Norton, B. A., Clark, R., Mears, M., Leake, J. R., Corstanje, R., Harris, J. A., & Warren, P. H. (2020). Estimating food production in an urban landscape. Scientific Reports, 10(1), Article 1. https://doi.org/10.1038/s41598-020-62126-4

8 Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: A review. Agronomy for Sustainable Development, 33(4), 695–720. https://doi.org/10.1007/s13593-013-0143-z

9 O'Sullivan, C. A., Bonnett, G. D., McIntyre, C. L., Hochman, Z., & Wasson, A. P. (2019). Strategies to improve the productivity, product diversity and profitability of urban agriculture. Agricultural Systems, 174, 133–144. https://doi.org/10.1016/j.agsy.2019.05.007

10 Warren, E., Hawkesworth, S., & Knai, C. (2015). Investigating the association between urban agriculture and food security, dietary diversity, and nutritional status: A systematic literature review. Food Policy, 53, 54–66. https://doi.org/10.1016/j.foodpol.2015.03.004

11 Siddique (2022, 23 May). How is vertical farming impacting on climate change. Gelponics. Retrieved from: https://aehinnovativehydrogel.com/news/how-is-vertical-farming-impacting-on-climate-change/#:~:text=How%20does%20vertical%20farming%20cut,and%20pesticides%20and%20extensive%20transportation