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UNDERSTANDING COMMERCIAL URBAN AGRICULTURE
AN OVERVIEW

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UNDERSTANDING COMMERCIAL URBAN AGRICULTURE
AN OVERVIEW

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Foreword

Urban agriculture, which can help stabilize local horticulture supply chains and reduce dependence on global food markets, has rapidly evolved over the last two decades into a capital-attracting business. Investments in the commercial segment of the sector are on the rise thanks to advances in technology and innovative farming techniques and to growing interest among young and motivated entrepreneurs.

By growing plants with controlled environment agriculture technologies in and around cities – greenhouses or indoor vertical farms, for example, using remote-control systems, robotics, LED lighting and soilless mediums like hydroponics – commercial urban agriculture can offer important environmental advantages. It uses less water and land. It also cuts down on food loss, as production is closer to the end consumer and can be planned more efficiently. On the downside, it can contribute to greenhouse gas emissions if its high energy requirements are supplied by non-renewables, or if the technologies adopted are not efficient.

The European Bank for Reconstruction and Development (EBRD) and the Food and Agriculture Organization of the United Nations (FAO) conducted a comprehensive cross-regional study on commercial urban agriculture in 2023. The study's objective was to understand the new wave of urban farming initiatives and identify approaches that could be replicated and scaled up for greater impact.

This report looks at factors like the sustainability of production, collaborations between large food processors and indoor urban farms, and new high-tech and data-driven operations powering competitiveness. It reflects information and data gathered from a series of e-dialogues involving around 950 participants, including representatives from nearly 200 companies in 65 countries.

The report highlights challenges to commercial urban agriculture's development. It also identifies areas where an enabling policy environment coupled with public and private investment – in research and development, energy, a skilled workforce, essential infrastructure – can have a positive impact on its growth, maturity, sustainability and overall contribution to the agriculture sector.

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This report summarizes the findings of a series of reports, papers and articles prepared by a team of experts from FAO, the University of Bologna – *Alma Mater Studiorum* (Italy), the University of Wageningen (Kingdom of the Netherlands), the University of Liège (Belgium), the *Universitat Autònoma de Barcelona* (Spain), the Institutet för Vatten- och Luftvårdsforskning (IVL) Swedish Environmental Research Institute (Sweden), and the *Kungliga Tekniska Högskolan* (KTH) Royal Institute of Technology (Sweden). See list of contributors above for details.

The report also reflects the information and data gathered via 10 online e-dialogues and two workshops involving sector practitioners. The latter attracted a total of 985 live participants and more than 1870 viewers on YouTube, representing a wide range of operators from commercial enterprises (147), public administrations (34), financial institutions (16), universities (71), non-governmental organizations (30), retailers (eight) and urban farming associations (six). E-dialogues and workshop presenters were: Xavier Gabarrel (Vice Rector for Campus and Sustainability, *Universidad Autonoma de Barcelona*), Agnes Lelievre (Researcher, *AgroParisTech*), Laura Talens Peiro (*Universidad Autonoma de Barcelona*), Michele D'Ostuni (Researcher, *University of Bologna*), Jacques-Olivier Bled (*Les Parisculteurs*), Mireia Abril (*Fertilecity*), Antonella Samoggia (Professor, *University of Bologna*), Francesca Monticone (Researcher, *University of Bologna*), Marti Rufì-Salis (Researcher, *Universidad Autonoma de Barcelona*), Christine Oriol (*Urban farming in Grenoble*), Inti Bertocchi (*Municipality of Bologna*), Daiana Nikolova (*Municipality of Sofia*), Toni Karge (*Municipality of Berlin*), Matteo Vittuari (Professor, *University of Bologna*), Isabella Righini (Researcher, *Wageningen University and Research*), Giuseppina Pennisi (Assistant Professor, *University of Bologna*), Runrid Fox-Kaemper, (Senior Researcher, *Research Institute for Regional and Urban Development*), Pietro Tonini (Researcher, *Universidad Autonoma de Barcelona*), Fabio De Menna (Researcher, *University of Bologna*), Pere Muñoz Odina (*The Park Agrari in Sabadell*), Elena Porreca (*Municipality of Milano*), Gaetano Di Gregorio (*Municipality of Venice*), Stella Psarropoulou (*Municipality of Thessaloniki*), Thomas Zoellner (*FarmTech Society*), Lelia Reynaud-Desmet (*La citè Maraichere in Romainville*), Benjamin Franchetti (*Agricola Moderna*), Theo Tekstea (*OSRAM-Fluescent*), Theoharis Ouzounis (*AeroFarms*), Stacy Kimmel (*AeroFarms*), Paul Rousselin (*Cuillette Urbaine*), Sudshanshu Sorronwala (*INFARM*), Tusya Gharibashvili (*Space Farms*), Halil Beskardesler (*Plant Factory*), Andrea Guglielmini (*Dash Farms*), Guillaume Fourdineir (*Agricool*), Bruno Renders (*Institut de Formation Sectoriel du Batiment*), Jakub Zawadzki (*MJZ Architecture*), Leo Marcelis (Professor, *Wageningen Universtiy and Research*), Haissam Jijakli (Professor, *University of Liege*), Joan Munoz-Lieza (Researcher, *Universidad Autonoma de Barcelona*), Marc Juarez (*Association of Vertical Farming*), Marco Maggioni (*Local Green*), Lamber Von Horen (*Rabobank*), Carolina Decastri (*VC Platform Engagement Lead*), Andrius Matiunkchinas (*EBRD*), Iride Ceccacci (*EBRD*), Erifyli Nomikou (*EBRD*), Eri Hayashi (*Japan Plant Factory Association*), Marie Asma Ben-Othman (Professor, *UniLaSalle*), Henry Ernst (*Control Union UK*), Ramin Ebrahimnejad (*Association of Vertical Farming*), Michael Martin (*IVL Swedish Environmental Research Institute*), Victoire DeWever (*FAO*), and Tamara Vlastelica (*FAO*).

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Abbreviations

CapEx	capital expenditures
CAGR	compound annual growth rate
CEA	controlled environment agriculture
CSO	civil society organization
CUA	commercial urban agriculture
EBRD	European Bank for Reconstruction and Development
FAO	Food and Agriculture Organization of the United Nations
GHG	greenhouse gas
HVAC	heating-ventilation and air conditioning
LCA	life cycle assessments
LCI	life cycle inventories
LUE	light use efficiency
LED	light emitting diode
NFT	nutrient film technique
OpEx	operational expenditure
PPFD	photosynthetic photon flux density
R&D	research and development
UA	urban agriculture
UHI	urban heat island
umol	micromole
USDA	United States Department of Agriculture
VF	vertical farming
WTP	willingness to pay

Executive summary

Over the past 20 years, the urban farming sector has rapidly evolved into a capital-attracting business. It is experiencing unprecedented growth and venturing into new areas such as production of raw materials for the food processing and pharmaceutical industries.

Comparisons between commercial urban agriculture (CUA) operations at the sector level are particularly difficult, due to a large variety of business models, strategies, and deployed technologies. In addition, many CUA claims, especially those related to profitability, lack verifiability. While literature confirms assertions about potential productivity, product quality, extended shelf-life, and some environmental benefits, a comprehensive analysis of profitability is absent due to the lack of data and of agreed standards of comparison. Consumer acceptance and willingness to pay higher prices for urban agricultural products also remains only partially explored.

Given their high yield performances (e.g. up to 700 kg/m^2/year[1] of leafy greens), commercial urban farms are typically located close to logistic infrastructures with quick access to food distribution hubs and retailers, but not necessarily within city centres where they could claim to be "km zero." Instead, they are most prevalent in the peripheral areas of large cities, often in dismissed industrial areas.

For high-tech farms in a CUA setting, preferred crops are those with a high harvest index[2] such as leafy greens, herbs and microgreens.[3] This is due to the high capital expenditures (CapEx) – up to EUR 3000 per m^2 – and high operational expenditures (OpEx) – up to EUR 500 per m^2 per year – of these farms (Kusuma *et al.*, 2022a; Pedersen 2022). Most high-tech farming in CUA is performed in large, fully controlled environments (70 percent) (Appolloni *et al.*, 2022). Though various approaches are used, nearly half of all high-tech farming takes the form of vertical farming (40–50 percent), with growing surfaces generally larger than 1000 m^2 and the deployment of advanced equipment for lighting and climate control (Appolloni *et al.*, 2022) leading to values of energy consumption for unit of product of around 4.5 and 2.5 kWh /kg for vertical farm and greenhouse cultivation respectively (Stanghellini and Katzin, 2023). Already high on average, operational costs can be further impacted by external shocks, especially those affecting energy prices. In these circumstances, even though CUA farms are increasing their capacity to produce a diverse range of crops, in practice, only a few can be produced at affordable costs: leafy greens, herbs and microgreens.

While new technologies and energy management processes may reduce energy consumption, access to renewable energy remains an issue because the average availability of renewable energy globally is still below 30 percent (International Renewable Energy Agency, IRENA, 2023). Energy constitutes the primary factor limiting the growth and expansion of UA. Like other industry and agriculture operators, CUA companies need clean, reliable,

1 Advanced vertical farms can reach up to 14.6 growth cycles for lettuce, while conventional open fields achieve only three (Blom *et al.*, 2022).
2 Harvest index is the weight of a harvested product as a percentage of the total plant weight of a crop.
3 Microgreens are a relatively new class of vegetables defined as tender immature greens produced from the seeds of vegetables, herbs, or grains, including local varieties and wild species (Jung, 2023).

and affordable energy. As energy prices rise, a company's energy dependency serves as a good indicator of its financial resilience. Literature shows how investments in infrastructure (e.g. energy, telecommunications, transportation networks *et al*.) have a direct impact on economic growth (Meeks *et al*., 2023). Availability of renewable energy will reduce the overall GHG emissions of CUA companies – a major factor hindering full sustainability – and their overall CapEx, eliminating the need for additional investments in energy production. Today, EBRD countries' energy mix includes only 24 percent renewable energy, compared to 37 percent for the rest of Europe.

CUA farms that are not able to reduce their energy needs and costs face greater inherent risks and may not be viable options compared to open-field farming and traditional greenhouses. High-tech farms, particularly vertical farms, require substantial electrical energy inputs, resulting in costs ranging from EUR 58 to EUR 73 per square metre per year for lighting, heating, cooling, and other purposes (Kusuma *et al*., 2022b; Pedersen, 2022). Although many farms are now producing part of their energy independently – using various technologies and sources such as biogas, solar, wind, and geothermal – energy costs remain a significant operational expenditure in all cases, accounting for up to 53 percent of OpEx (Kusuma *et al*., 2022a; Pedersen, 2022). Because energy constitutes the primary factor limiting the growth and expansion of the UA sector, companies will increasingly have to focus on finding clean, reliable, and affordable sources of energy. In the current context of energy price volatility, a CUA company's success is closely connected to its energy independence.

CUA companies must pay extra attention to costs and end markets. As is the case in other technology-driven sectors, many business plans seem to have focused on high technology – and often high CapEx – solutions while assumptions related to operational costs and end-product markets may have been over-optimistic. This is particularly important given that, in many countries, consumer willingness to pay for CUA products – which are generally more expensive – is not yet well understood. While preparing this study, several notable CUA entities closed down, representing an overall loss for the sector of about USD 737.1 million (Cobank, 2022).

The sector would gain from more transparency, in particular from exchange of information on the economic and environmental performance of various technologies. As in other high-tech sectors, CUA companies are naturally trying to protect their research and development (R&D) investments and are reluctant to share data on the performance of various technologies. However, they often find themselves re-inventing the wheel for each product due to insufficient data on similar approaches adopted by competitors. More transparency on aspects such as emissions, which – from the data collected for this research – may constitute the most significant environmental concern for CUA, would help the sector address this challenge collectively. Some positive examples of data-sharing exist in Japan, thanks to the efforts of the Japan Plant Factory Association. More transparency towards consumers on pros (low water consumption, no pesticides, etc.), but also cons (potential emissions) may also help to gradually build market confidence.

To date, there is no blueprint for scaling high-tech indoor farming in a financially viable manner and no accompanying metrics to measure performance. As evinced, many CUA business plans are based on hypothetical scenarios and benchmarks provided by technology vendors and reference values derived from the greenhouse sector. This, combined with the complexity of operations, can result in cost under-estimations and inaccurate cashflow projections. For these reasons, validating the profitability claims of CUA projects ex ante – especially the most technologically advanced such as vertical farms (VFs) – is difficult.

The success of CUA farming depends highly on a series of country prerequisites and characteristics that go beyond market considerations, i.e. the level of education (to find the right staffing), the availability of general infrastructures, climate conditions and vulnerability to climate change, and food security parameters. Therefore, the analysis of a country's economic, social, infrastructure, education and environmental indicators is a prerequisite to supporting preparation of those business models.

Because CUA investors are increasingly demanding financial returns, companies must focus on achieving and demonstrating profitability. As in other emerging sectors, funding has primarily been in the form of personal loans or venture capital. As companies grow and reach financial maturity, they must attract mainstream forms of financing to secure both CapEx and OpEx, and be prepared to conform to the conditions required by traditional financiers. In this regard, it should be noted that CapEx burdens in the form of maintenance and replacement costs are expected to take a further toll on the bottom line. The replacement of production assets can be the occasion for companies to enshrine lower energy models – and generally lower costs strategies – into their business models.

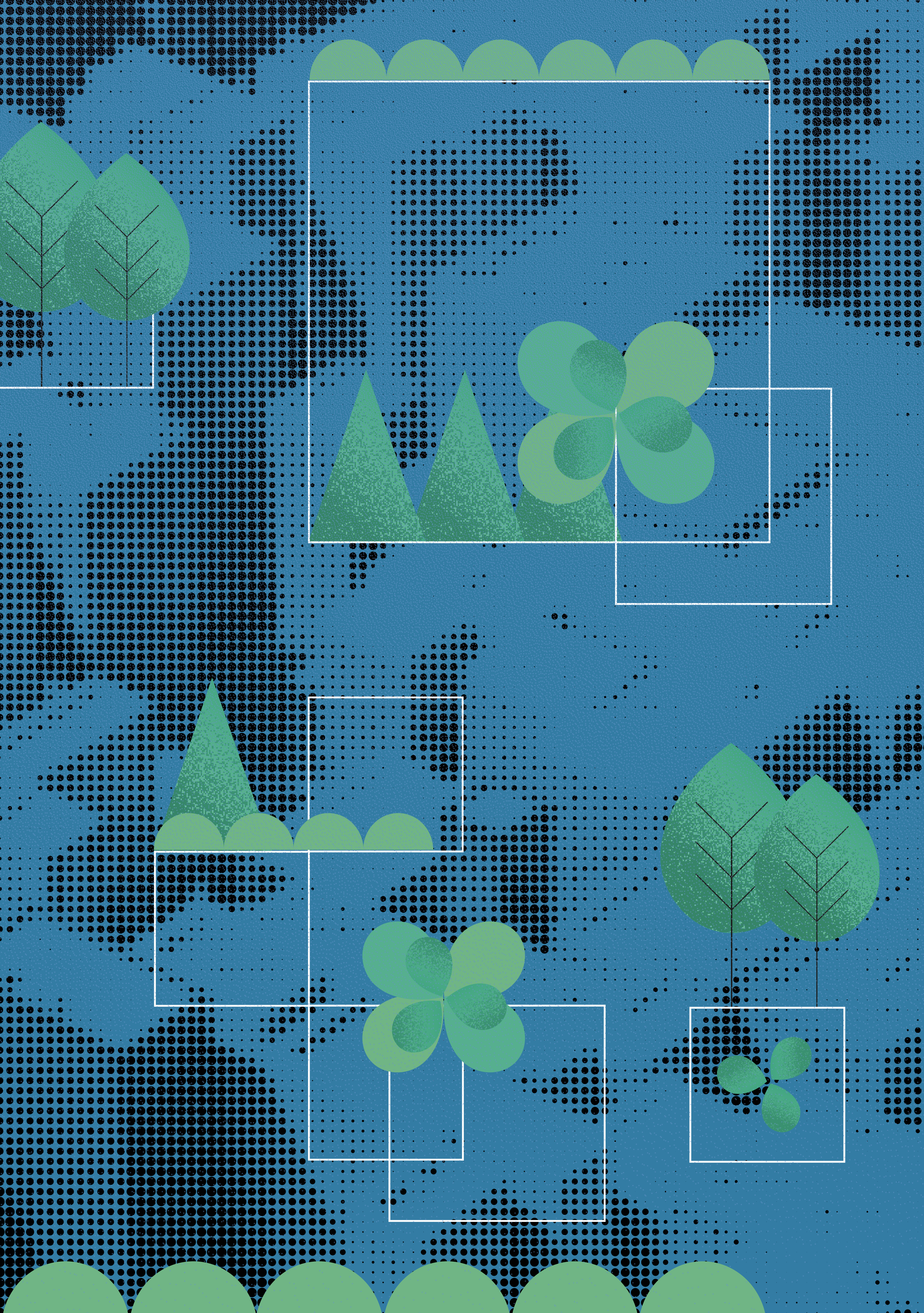
So far, literature has focused on the positive social and environmental impacts of "conventional" urban farming and some of its new manifestations (e.g. rooftop farming). Comprehensive and accurate descriptions of the same positive impacts from high-tech entries such as indoor vertical farms are still too few. While existing literature supports general claims about productivity per square metre, product quality, extended shelf-life, and some environmental benefits (e.g. water savings, absence of pesticides, reduced land use, and reduced food loss), some important aspects – such GHG emissions and origin of water – need further research to provide an overall assessment of the social and environmental impacts of high-tech CUA.

From a policy and regulatory perspective, CUA is still facing a lack of recognition, mainly due to the limited scale of operations and the small share of markets they represent. Some sociocultural biases raised by the contraposition of city and countryside for food production might also explain this lack of recognition. Apart from a few grants from the European Union and the United States Department of Agriculture (USDA), the sector cannot access most of the public subsidies and incentives that are available for agriculture.

The growth of CUA will depend on the sector's ability to overcome four main challenges: (1) its dependency on energy (energy costs are currently up to eight times higher than in traditional controlled environment agriculture, CEA, settings); **(2) the scarcity of specialized human capital** (commercial urban farms are highly dependent on growers with some technical background, as well as engineers and IT specialists); **(3) the lack of essential infrastructures in peri-urban areas, such as modern energy grids**; and **(4) the absence of a clear legal framework for the sector**, i.e. for land and resource use in urban settings or for marketing and labeling.[4]

The potential setback in these crucial areas, among others, carries the risk of undermining the achieved environmental milestones and dampening investor enthusiasm and consumer trust. This, in turn, could relegate the entire sector to a scarcely replicable experiment, viable only in specific and marginal contexts. It is imperative for the industry to navigate these challenges adeptly, ensuring not only its own viability but also maintaining the momentum towards a more sustainable and profitable future.

4 For example, in many countries, commercial urban farming products from indoor farms (e.g. vertical farms), cannot label their products as organic or ready-to-eat.



Introduction

This report provides the main findings of an exhaustive 18-month research project conducted winter 2021 through spring 2023 by FAO, the University of Bologna, the Wageningen University and Research, and the University of Liège, among others. The purpose of the research was to assess the current state of commercial urban agriculture (CUA)[5] globally – with special focus on EBRD's countries of operation[6] – and understand the opportunities and challenges associated with investing in agriculture in urban settings, with due attention paid to social, economic, and environmental implications. It was conducted with a view to inform investment decisions, addressing the inherent risks and challenges associated with CUA. The overview presented here elaborates on the concept of CUA as a for-profit activity, the various business models it can embrace and the issues pertaining to its sustainability, scalability, and overall readiness for investment.

FAO and EBRD gathered an international team of experts with competencies and research experience in the fields of urban agriculture, indoor farming, agricultural economics, plant physiology, social and environmental sciences, technology, urban development, and others. Their objective was to articulate a wide range of aspects including stakeholders, relevance of location, technology, sustainability, potential profitability, and type of investment needed for further growth of the sector. Their findings are derived from: (a) a comprehensive review of more than 200 scientific articles; (b) extensive data collection; (c) multiple sets of case studies, with each group of experts exploring urban agriculture from a different aspect; (d) spot-checking prices at 29 retailers in 11 countries; and (e) extensive consultations with stakeholders, including representatives of 65 companies actively

5 The team considered only those commercial farms that are structured as registered companies; it could not assess those that apply commercial approaches informally.

6 Albania, Armenia, Azerbaijan, Belarus, Bosnia-Herzegovina, Croatia, Cyprus, Czechia, Georgia, Greece, Hungary, Jordan, Kazakhstan, Kosovo*, Kyrgyzstan, Latvia, Lebanon, Lithuania, Mongolia, Montenegro, Morocco, North Macedonia, Palestine, Poland, Republic of Moldova, Romania, Russian Federation, Serbia, Slovakia, Slovenia, Tajikistan, Tunisia, Turkmenistan, Türkiye, Ukraine, Uzbekistan.
*References to Kosovo shall be understood to be in the context of Security Council resolution 1244 (1999).

engaged in CUA; seven retailers; 20 research centres and officials from 30 municipalities around the world. These consultations took various forms, including semi-structured interviews, surveys, bilateral exchanges, participatory workshops, and field visits to companies and technology providers. To complement the work of researchers and to facilitate dialogue and collaboration, a series of 10 online e-dialogues were organized plus two workshops. These attracted a total of 985 participants including a diverse range of commercial enterprises (147), public administrations (34), financial institutions (16), universities (71), non-governmental organizations (30), retailers (eight) and urban agriculture associations (six). Recordings of the e-dialogues have been posted to YouTube and the FAO/EBRD website Agtivate – attracting more than 1870 viewers so far – and shared through LinkedIn and specialized press, facilitating an additional series of exchanges with stakeholders and investors.

More than half of the world's population resides in urban areas (56 percent). This is expected to reach 68 percent of global population by 2050, and most of this increase will occur in low-income countries, especially in Africa and Asia (United Nations Department of Economic and Social Affairs, Population Division, UNDESA, 2019). According to FAO, in 2022, 70 percent of the global food supply was consumed in cities. At the same time, the level of food and nutrition insecurity in urban and peri-urban areas remains high (FAO, 2017). Therefore, cities' limited access to raw materials, rapid growth and growing demand for food and basic services pose major challenges to ensure decent living conditions and food security for all citizens. Moreover, in view of their high demand for food, cities are highly vulnerable to the increasing shocks and stresses related to climate change, economic crises, and health (FAO, 2019a). It is estimated that about 2.5 billion people across 1600 cities will experience declining agricultural outputs, posing tremendous challenges for residents and local authorities (C40, 2018). The COVID-19 crisis has further exacerbated food and nutrition insecurity and compounded existing shocks. Restrictive measures to contain the SARS-CoV-2 virus have generated a broad range of short- and long-term impacts on food production and supply (FAO, 2020). Making agricultural production accessible and bringing it closer to its largest group of consumers constitute a priority and could represent an opportunity to reduce the environmental impact of agriculture, including GHG emissions.

Urban agriculture is not new, but well-rooted in global human history.[7] In recent years, it has generated renewed interest for the potential contribution it could make to increasing resilience of local food systems while reducing dependence on global food markets. Urban agriculture processes themselves do not differ significantly from those of traditional rural agriculture, but urban agriculture is vastly different in terms of invested capital as well as its access to resources, the cost of land and costs linked to urban development and

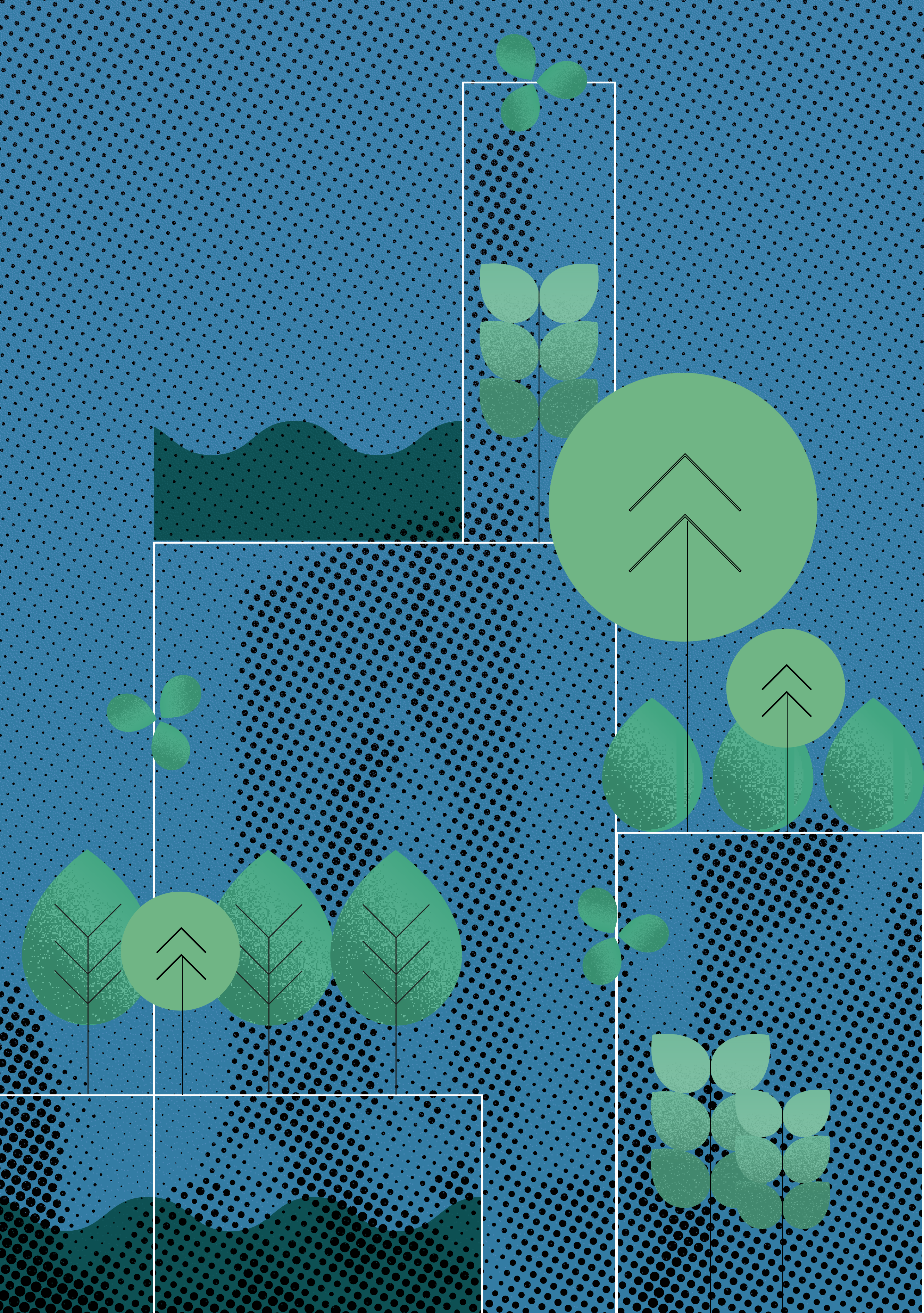
7 Urban and peri-urban agriculture includes food production (mostly horticulture, but also livestock, aquaculture and agroforestry) as well as related processes (e.g. post-harvest management, distribution, marketing, waste disposal and recycling) occurring within cities and surrounding areas, using and regenerating mostly local resources to meet the nutrition needs of local populations while also achieving other goals and functions such as the generation of income, employment, recreation, and ecosystem services (FAO, Rikolto and RUAF, 2022).

proximity to markets. Urban agriculture has also evolved considerably since its original purpose of contributing to the food security of urban households. Depending on context, geography, and economic development, urban agriculture is now practiced for a wide range of reasons including social inclusion, greening of urban areas, environmental management, hobby and profit.

Private investments[8] in high-tech commercial urban farms alone are growing rapidly, scoring a total market value in 2023 of over USD 5 billon even after seven firms exited the sector at an estimated value of about USD 740 million (CoBank, 2022). The sector continued to show financial distress in 2022, with industry leaders such as Fifth Season, Plantise, Glowfarms and Agricool terminating operations, but it is nonetheless projected to increase to USD 24 billion in 2030 (compound annual growth rate, CAGR 27.3 percent) in the vertical farming sector alone (Fortune Business Insights, 2023). Advancements in technology and innovative farming techniques have helped fuel this growth and especially – in some regions – its popularity among a young and highly entrepreneurial generation, who are attracting new investors and initiating the new, year-round farming season.

However, the actual diffusion of urban agriculture in all its forms and expressions, and its true value remains unclear and largely anecdotal. Statistics, data, and evidence on distribution and impacts as well as risks and challenges are significantly lacking at the global level.

8 Apart from a few grants made by the European Union and USDA, there is little evidence of public funding in the sector.



Chapter 1
Multifunctional dimensions and benefits of urban agriculture (UA)

Generally, urban agriculture is intended to contribute food security for those urban centres in which it operates, though products produced in urban settings may also be sold in other areas and even exported. Either way, success rests on proper understanding of the opportunities and challenges it presents. Opportunities for urban agriculture are diverse depending on context and location. In emerging economies, it may contribute to the overall food security of poor households and an informal occasion for additional employment for unskilled workers. In other contexts, such as those in more advanced economies, commercial urban agriculture is considered a for-profit business as well as an opportunity for social inclusion, greening of neighborhoods and community engagement. In all cases – if properly managed and planned – urban agriculture constitutes an opportunity to improve the environmental performance of cities and simplify logistics linked to supply and distribution of food. Challenges limiting growth of urban agriculture – especially its commercial expressions – include legal issues, logistics of urban food production, availability of qualified human resources as well as environmental and climatic constraints affecting quantity and quality of products.

To mitigate those challenges while exploiting its full potential, urban agriculture must be understood according to its three dimensions: spatial, functional, and market domains (Figure 1).

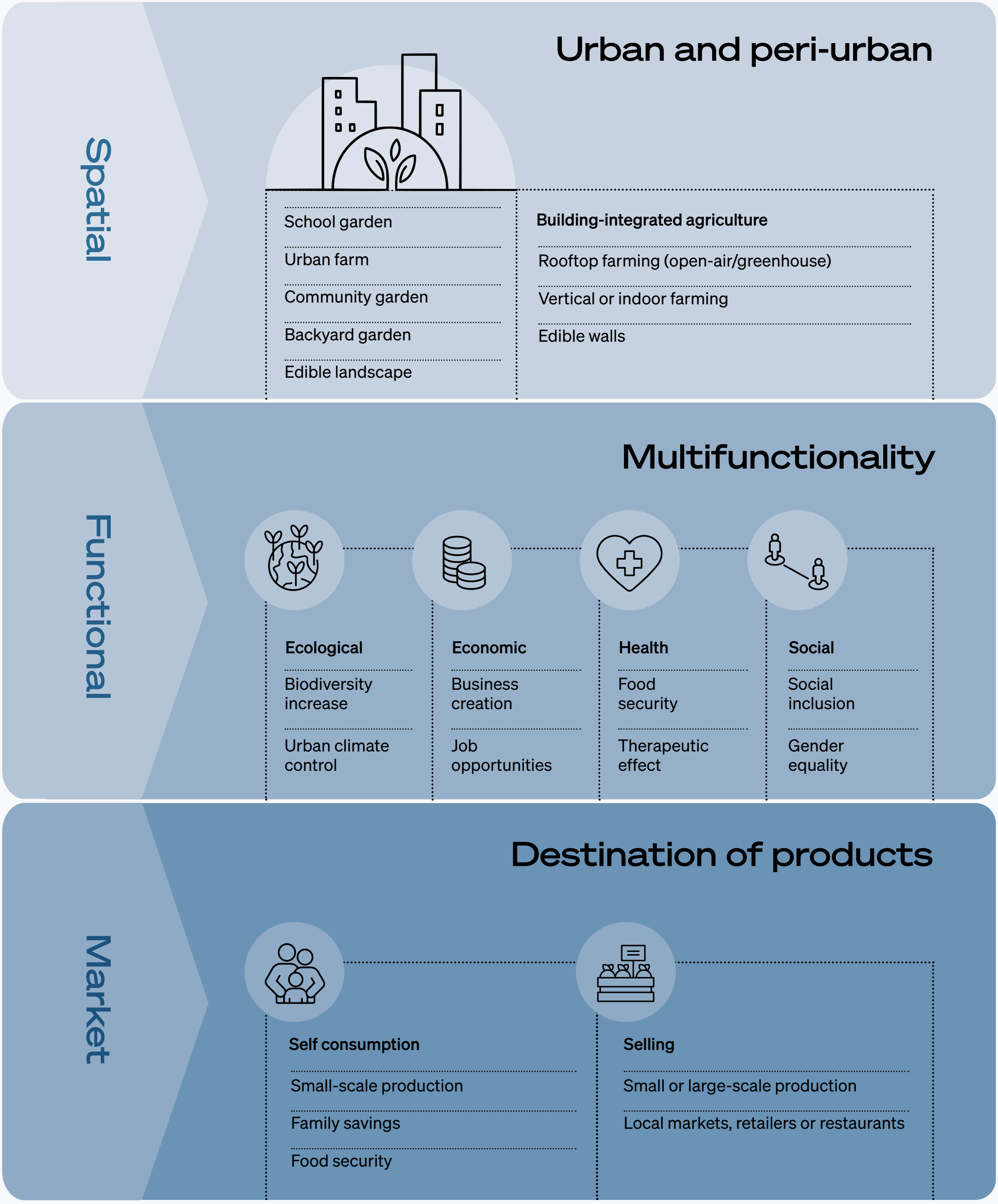


Figure 1
Characteristics of urban and peri-urban agriculture

SOURCE: Author's own elaboration.

The spatial characteristic refers to the location of UA. An initial approach to differentiating sites considers their level of integration within the urban or peri-urban fabric. This characteristic can be further divided into ground-based cultivation (such as community gardens, allotments, and backyard gardens) and building-based cultivation, also known as building-integrated agriculture or zero-acreage farming (such as rooftop and indoor vertical farming) (Figure 2).

Ground-based cultivation can be categorized into different typologies characterized by a mix of commercial and recreational orientations. These include microgardens,[9] allotment gardens,[10] and community gardens.[11]

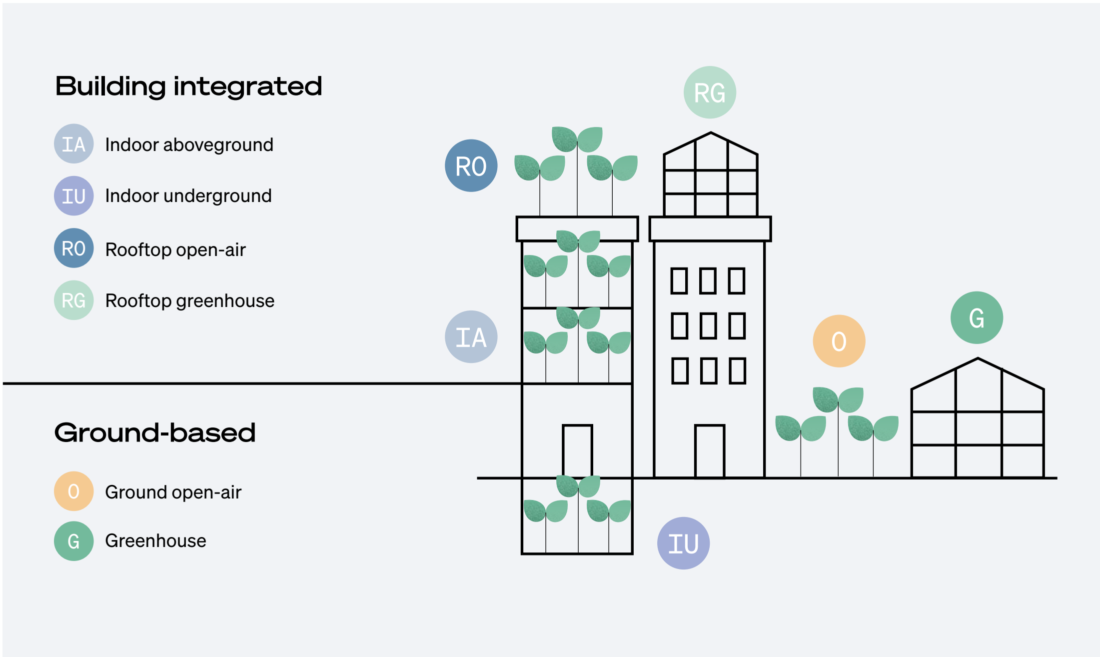


Figure 2
Where urban agriculture farms grow

SOURCE: Authors' own elaboration.

9 Small plots cultivated by families or small communities for recreational or household production.
10 Areas of public land divided into small plots rented or granted to citizens by the municipality for leisure and self-production.
11 Public or private spaces managed by organizations with non-profit social-educational purposes, or with commercial aims as seen in the case of community-supported agriculture.

The dimension and function of urban farms can vary widely as appropriate for the characteristics of the site and the grower's commercial strategy. Urban farms can be soil-based or soil-less, such as hydroponic or aeroponic systems (Figure 3). Soil-less production can be implemented using hydroponic systems such as floating systems, nutrient film technique (NFT), aeroponics, and aquaponics. Cultivation can also be performed in raised containers using various kinds of substrate (e.g. peat, compost, soil, and coconut fiber). Soil-less cultivation reduces the risk of plant contamination from urban pollution, favours resource optimization (e.g. space, water, nutrients) and allows relocating production activities when leases expire or land needs to be allocated to other purposes.

Low-tech systems – usually low cost and using recycled materials – are often developed for small-scale production in low-income settings. Among these, the simplified substrate systems, the simplified floating system, and the simplified NFT are the most represented (Figure 3). High-tech soil-less cultivation is generally applied in commercial businesses where financial and human capital are available. These solutions are generally used in buildings, either indoor (e.g. vertical farms) or on rooftops (building-integrated greenhouses). While rooftop greenhouses are part of the urban farming arena, their technology is very close to controlled environment agriculture greenhouses. Vertical farming or "plant factories with artificial lighting" (Kozai and Niu, 2020; Lubna *et al.*, 2022), though a novel phenomenon, already represent more than 40–50 percent of new urban farming companies created in the past 20 years. Vertical farming refers to the cultivation of plants vertically in towers or stacked layers within insulated chambers using artificial lighting and sensors to control environmental parameters (e.g. air temperature and humidity, CO_2 concentration, and nutrient delivery to the plants), minimize contamination by external pathogens and avoid or reduce the application of pesticides. These systems allow production year-round and usually apply hydroponic and aeroponic technology (Kozai and Niu, 2020; Beacham *et al.*, 2019).

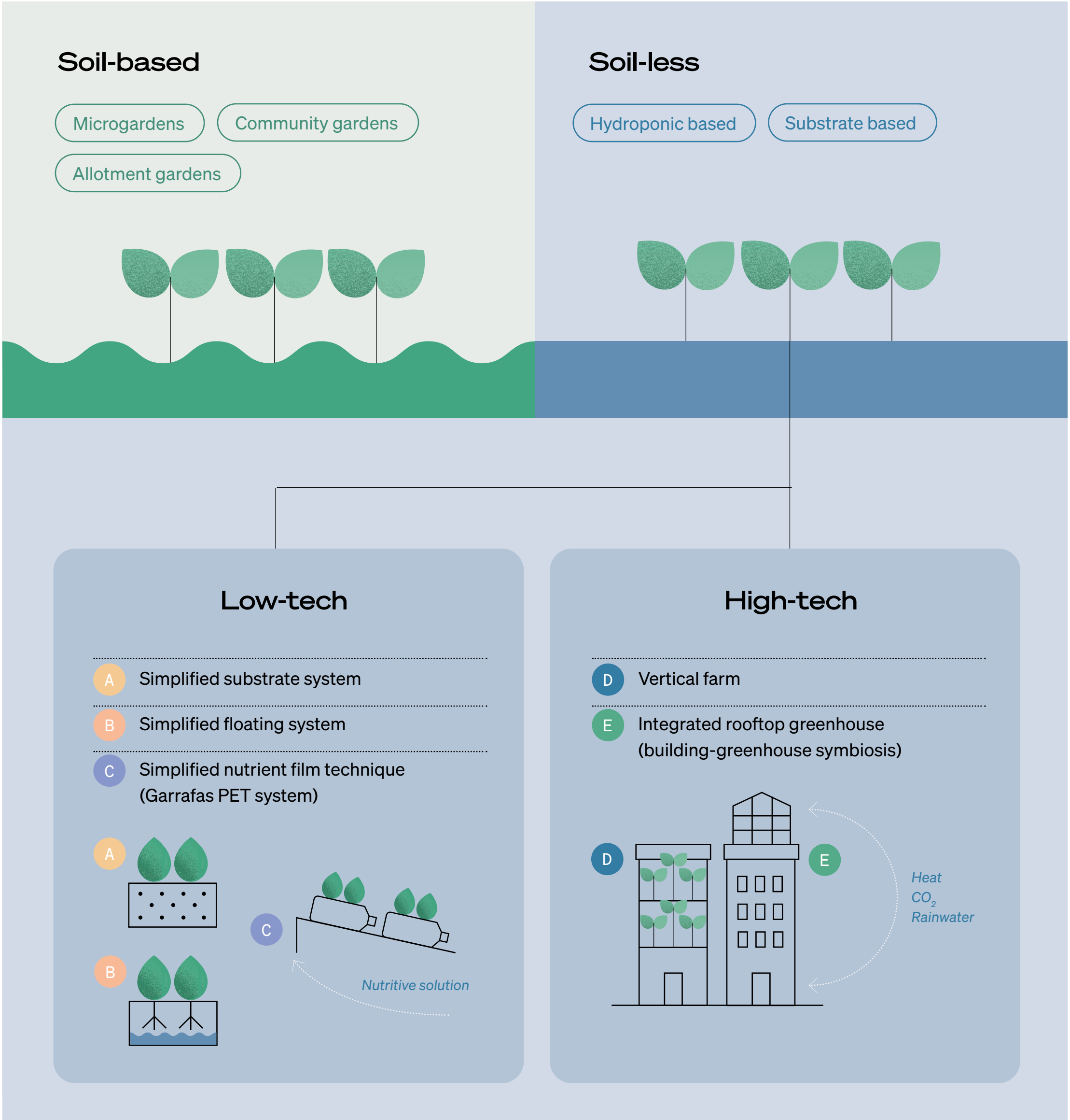


Figure 3
Cultivation systems for urban settings

SOURCE: Authors' own elaboration.

The main goals of urban agriculture are to contribute to food security and incomes for local inhabitants (Orsini *et al.*, 2013). Yet UA – especially the more traditional and less business-oriented expressions of it – can also bring ecological, economic, health, and social benefits to urban communities and beyond. This **functional dimension** encompasses all typologies of production and ought to be considered attentively while planning UA investments (Drescher and Iaquinta, 1999; Mougeot, 1994; FAO, 2001; Ghosh, 2004). The functional dimension influences the type of production selected for the farm with direct impact on funding sources and size, management models and costs.

Consequently, the **market dimension** assumes crucial relevance. While more conventional production in soil approaches to UA appear less commercially viable and more oriented towards subsistence or social and environmental functions, those characterized by advanced technology inputs are profit-driven and market their products via retailers and online shops. Regardless, all forms of UA have economic implications, and most are increasingly relevant to providing key ecosystem services to communities. Nonetheless, estimating how a city benefits economically from UA is complex given that no two cities are alike and UA design and performances appear context-related (Algert *et al.*, 2014; Orsini *et al.*, 2022). Even in different neighborhoods of the same town, UA approaches must be tailored to their setting (Zezza and Tasciotti, 2010). Most evaluations of UA economic feasibility are based on case studies, which are inherently context-specific. A strategy that works well in one city might not be applicable in other places (Benis and Ferrão, 2018).

Within the UA universe itself, new technologies have rapidly emerged during the past 20 years further dividing the category between more "conventional" UA approaches and those that employ even more advanced technology united with advance knowledge of farming practices and plant biology (i.e. CUA).

1.1 WHAT TECHNOLOGY NEEDS TO BE EFFECTIVE

Because innovations are constantly underway, standards are far from set in the UA sector. Literature already recognizes that new technologies are improving outputs and increasing efficiency, though they require significant investment and highly skilled labour. The opportunities to invest in technology in UA settings are diverse and range from very simple to highly complex and capital intense. The more advanced CUA investments (e.g. aeroponic vertical farms) require greater capital investment and a more highly skilled workforce. These represent the most sophisticated and most expensive technological advancements in UA, with productivity of crops that has reached heights never seen before in agriculture (Kozai and Niu, 2020).

CUA's investments in technology are focused on: (1) architecture and automation, (2) lighting, (3) climate control, (4) sensors and algorithms, (5) the root-zones (technology used to provide water and nutrients to the plants), and (6) genetics of crops cultivated in these systems. Because technology alone does not determine the success of an innovation, a seventh need, often neglected, is paramount: human resources.

Finally, the higher a company's technology input, the greater its energy needs. A survey performed in 2021 by the private companies Agritecture and WayBeyond assessed the energy consumption of 336 companies ranging from traditional greenhouses to vertical farms. Their findings confirm that vertical farms – the most technologically advanced urban farms – require more energy per kg of produce (~38.8 kWh) than traditional greenhouses (~5.4 kWh). Vertical farms invest 55 percent of their energy balance in lighting and 30 percent in climate control (WayBeyond and Agritecture Consulting, 2021; Kusuma *et al.*, 2022a). Therefore, the selection of technologies and their applications have major implications on operational costs and environmental impacts.

1.1.1 Architectural and energy requirements

For those ventures executed in protected environments, architecture refers to the infrastructure of a specific CUA operation and may include shelving, wall modulation, and the building itself. There are many types of protected structures with varying degrees of complexity and investment/operation costs involved. The building, or protected structure, provides year-round defence against unfavorable environmental factors like extreme temperatures, precipitation, and pests. The best choice for a protected structure depends on the local environment and the desired level of production. Indoor farms (e.g. vertical farms) are the most protected structures and therefore the most complex. The internal architecture within the cultivation chamber can be composed as a single layer, stacked layers, or vertical walls.

In locations with limited availability of unskilled labour, automation is increasingly seen by companies as a necessary investment. Automated tasks include planting, transplanting, spacing, harvesting, and packaging. The investment in automation is lower for larger operations, where it is estimated to constitute 5 percent of investment costs. Theoretically, the entire system can be automated, though it is still common for unskilled workers to participate in many processes. The investment cost of automation depends on various factors including technology, approaches and crop produced. In general, investment in automation ranges between EUR 17 (basic logistic and machinery) and EUR 1000 (fully automated) per square metre (Kusuma *et al.*, 2022b).

To have full control of light availability, climate and other atmospheric factors, UA increasingly employs electric lighting as either sole-source lighting in indoor environments (e.g. vertical farms) or as supplemental lighting in greenhouses. Electric lighting required for plant growth has changed as the technology has advanced: from about 20 percent efficiency (e.g. fluorescent lamps) to today's high-level efficiency of up to 80 percent with light emitting diodes (LED). LED-based lighting is the preferred option for CUA companies applying indoor technologies. Costs of lighting can vary from EUR 60/m^2 to EUR 335/m^2 on a farm of 1000 square meters depending on brand and technology (e.g. type of light and dynamic lighting). Investment in lighting is a key variable when designing indoor urban farms because its consumption directly affects the farm's production and GHG emissions. Thus, energy constitutes the primary limiting factor for the growth and expansion of CUA. Therefore, companies are keen to optimize lighting to guarantee quality, reduce costs and increase the overall sustainability of production.

Environmental factors work as a matrix of variables that significantly impact plant growth, development, yield, and quality. Light, temperature, humidity, air flow, CO_2, water, fertilization, and substrates are chief environmental factors. Technologies to control indoor climate (e.g. temperature, humidity, air flow and CO_2) in greenhouses and vertical farms are key investments to ensure production. The cost and efficiency of climate control[12] depends on the location, local climate, and the type of production system (e.g. greenhouse or vertical farm). The cost of climate control systems can range from EUR 65.8/m^2 to EUR 179/m^2 depending on crop and production approaches. Access to renewable resources should also be considered when determining where to build greenhouses and vertical farms. Building insulation and local climate (the highest summer temperature and the coldest winter temperature) are important factors because they determine the size of the climate control system. Moreover, a better understanding of plant physiology can reduce unnecessary climate control.

Climate uniformity, temperature, humidity and air flow should be reliably and sensitively monitored both spatially and temporally. Monitoring the parameters of air, substrates, and plants are all possible via different sensors. Sensors related to environmental monitoring (e.g. temperature, humidity, CO_2, air speed, dissolved oxygen concentrations, volumetric water content, light intensity, and light spectrum) involve relatively mature technologies, while sensors related to plant performance, and the algorithms used to interpret the data, are still emerging and considered developing technologies. These two technologies, sensors and algorithms, work in tandem to optimize the system, maximizing both yield and quality, while minimizing energy use. The input (environment) and output (plant performance) data from the sensors are processed through algorithms to find the optimal conditions for optimal growth and performance. Sensors and their accompanying computers are estimated to comprise about 1–5 percent of CapEx according to one interview conducted for this study; others estimate EUR 3/m^2 to EUR 8 EUR/m^2 (Hemming *et al.*, 2020; Zeidler *et al.*, 2017). The energy requirement for sensors is estimated to be only 0.6 percent of the energy expenditure (Zeidler *et al.*, 2017).

The rootzone provides water and nutrients for plant growth, and excesses or deficiencies of either of these can decrease growth. Additionally, the physical structure of the rootzone can affect how crops perform. The physical properties of media are: solids, liquids (or aqueous phase), and gases. Pure water cultures have no physical structures, which alters the root physiology and morphology. Depending on the system, water is either applied constantly or intermittently. In the constant supply systems, dissolved oxygen must be provided to the roots to avoid waterlogging, or oxygen starvation. Methods to ensure adequate dissolved oxygen include bubbling with pumps or allowing for high degrees of mixing. The chemical constituents of a hydroponic nutrient solution can be carefully controlled by frequent measuring and injecting specific salt solutions into the recirculating solution. Alternatively, farms can use soil-less media[13] to ensure transfer of nutrients and water to

12 Heating, ventilation, and air conditioning.

13 Soil-less media can be grouped into three categories: inorganic such as perlite, rock wool, and sand; organic such as peat and coconut coir; or synthetic, such as plastic fibre or foam.

plants. Soil-less media includes both inorganic and organic materials. Among the inorganic media there are naturally occurring materials (e.g. sand, diatomite, tuff, pumice), processed materials (e.g. perlite, vermiculite, zeolite, expanded clay particles, calcined clay) and synthetic materials (e.g. polyurethane, polystyrene, polyester fleece). Local soil is still used in many lower-tech UA environments, while vertical farms and most mid- to high-tech greenhouse operations now employ mostly hydroponic and aeroponic systems (70 percent).

Depending on the media they have chosen, farms apply different irrigation and fertilization strategies (often combined and known as fertigation) with impacts on both investment and operation costs as well as on the environment. A variety of soil-less media exist, and their associated cost depends on a wide range of variables. Nonetheless, considering that the majority of CUA farms apply hydroponic technologies and that these are in general vertical farms (40 percent), the cost of this growing media – including racks, trays, pipes, lifts, and logistics – is between EUR 200/m^2 to EUR 900/m^2. In stark contrast to the advancements in many of the above-mentioned technologies, **little development has gone into targeted plant breeding for vertical farms, though some breeding companies are beginning to fill this gap.** Leafy greens remain the main product of VF due to their compact size, short growing cycles, and high harvest index, though fruit crops are beginning to receive more attention. Since biotic and abiotic stresses typical of outdoor environments are minimized, the focus of breeding can move from tolerating stress to satisfying consumer experience. Facilitating automation in UA requires the plant architecture be uniform and accessible. For example, synchronous ripening would facilitate synchronous harvesting.

1.1.2 Skilled labour

If innovation via technology can bring unprecedented productivity, this is possible only when adequate investments in human capital and knowledge transfer are equally planned. The availability of qualified human resources for UA varies widely depending on a country's economy and the complexity of farms. In wealthier countries, those engaged in CUA are often young (73 percent are under the age of 41) with high levels of education and salaries, and many possess specific competencies in marketing and communication (Pölling *et al.*, 2017). However, when UA is employed as part of social initiatives, those involved are often volunteers or people at risk of exclusion (e.g. inmates, migrants, people with disabilities) who have limited competencies, no knowledge of farming and require extensive training. Conversely, in emerging economies, UA's human resources often consist of people looking for a secondary income, self-employment or reducing the cost of their own food purchases.

Unlike conventional UA farms, indoor and profit-oriented farms (CUA) tend to employ a wide variety of highly skilled workers. For example, in the vertical farming setting, companies typically have about three to ten employees; apart from the company founders, these may include one to four agronomists and at least one data scientist, especially at the earlier stages of establishing the business. As these companies grow, they typically open marketing, secretarial, planning, and quality control positions. Depending on the technology level of the farm, they may also hire other specialty positions (e.g. software engineers, computer vision engineers and other IT figures). When a low level of automation is adopted, it has been estimated that one worker can manage 250 m^2 (recalculation based on Kozai and Niu, 2020). On the contrary, when a farm is fully automated, one worker is expected to manage an area of cultivation up to 2000 m^2. By comparison, a typical greenhouse estimates one worker per 1000/m^2 to 2000/m^2 (Lans, 2022). In general, labour is expected to account for 25–45 percent of operational costs if automation is included. What is more, despite the growing number of companies providing technologies for the vertical farming industry (even turnkey solutions), many companies prefer to develop their own technologies. This in-house designing of equipment requires highly skilled employees who can provide the necessary assistance during operations.

1.2 HOW MUCH TECHNOLOGY IS TOO MUCH?

CUA such as indoor farming and other examples of controlled environment agriculture in urban settings, involve complex systems and targets the highest end of the retail market (e.g. ready-to-eat salads). One size does not fit all. Downscaling technologies and transferring knowledge are important to reduce facility investment, but this may come at the expense of reduced yield and reduced quality. It is necessary to strike a balance. Interviews with the directors of research at the most advanced companies in Europe and the United States of America demonstrate that experts agree that control of the indoor environment remains the utmost priority when simplifying vertical farming systems. In other words, this is an expense that cannot be eliminated. Nonetheless, reducing other areas of automation (e.g. cutting, packaging, and weighing machines) can help decrease the initial costs of investment. Site selection is key to identifying the best technology to use, its level of complexity and the overall investment needed. Given the high OpEx costs of CEA – and of vertical farms in particular – the growing period of the selected product is essential to determine what investment is required for facility and technology. For products with growth cycles longer than 40–60 days (e.g. all tall and vine crops like tomatoes, cucumbers, etc.), it is best and more economically convenient to grow outside the city in greenhouses.

Similarly, reducing technology and automation will diminish the need for energy. Artificial lighting (e.g. LEDs) accounts for up to 53 percent of total energy cost, depending on technology and processes. This can be downsized by taking greater advantage of solar light. Greenhouse and vertical farming hybridization, like rooftop or high-tech greenhouses, is advisable. Nonetheless, experts are concerned that downsizing technology will result in losing control of the vertical farm's interior environment, which could lead to an increase in pathogens and pests. So, maintaining that control is necessary, even when it involves additional costs.

Ultimately, while decreasing CapEx by reducing automation may lead to lower energy bills, it may also result in higher OpEx (e.g. increased labour and management costs), lower yields, and lower quality. Additionally, the balance between CapEx and OpEx is highly dependent on the local labour market and especially the climate, which significantly affects costs related to cooling, heating, lighting, and water use. With regards to water, also its origin requires due consideration and attention. Reportedly, most of the CUA farms use tap water from urban networks for their crops (Kalantari, 2018; Jurga, 2021 *et al*.; Carotti *et al*., 2023). Many of the existing indoor structures available in UA are low-cost structures (e.g. tunnels and simple greenhouses) to protect plants from outdoor stresses, and this alone is sufficient to reduce losses in yield. By adding more technologies to these systems (e.g. highly sealed structures with lighting, precise climate control, rootzone technology, sensors, and their accompanying algorithms, as well as genetics and plant breeding), costs will inevitably increase, but so will yields and quality.

Technology can be dialed all the way back to open field agriculture or dialed all the way up to high-tech vertical farms, yet there are many possibilities in-between. Selecting the right approach rests on well-designed business plans, the climate, access to resources, availability of skilled and unskilled labour, the price consumers are willing to pay for certain products, and the overall investment capacity of the grower, among other variables. No single technological solution will fit all settings. Instead, each of these elements must be carefully weighed considering the overall system's capacity to provide a safe and rapid return on investment (ROI), while ensuring crop performance and the environmental sustainability of the process.

1.3 WHAT STAKEHOLDERS SAY

Analysis of a sample of 765 entities identified via literature, specialized media, LinkedIn and interviews with universities and research institutes, indicates eight groups of stakeholders: (1) CUA farming companies; (2) technology input providers; (3) universities, civil society organizations (CSOs), and research and development (R&D) centres; (4) investors; (5) retailers; (6) head hunters; (7) architecture and real estate firms engaged in urban greening; and (8) municipalities (Figure 4).

Farming companies (n=214)	Companies focused on food production for commercial purposes
Tech-input providers (n=229)	Companies providing technologies, inputs, and technical assistance for cultivation
Universities, CSOs, R&D centres (n=224)	Public and private institutions developing education, research, and innovation in UA
Investors (n=51)	Public and private institutions or companies investing in UA
Retailers (n=7)	Companies focused on retailing but integrating farming systems to expand their market
Head hunters (n=7)	Associations and companies trying to identify expertise in UA
Architecture and real estate (n=14)	Architectural and real estate firms engaged in urban greening
Municipalities (n=19)	City institutions aiming at increasing urban green footprint

Figure 4
Stakeholders in commercial urban and peri-urban agriculture

SOURCE: Author's own elaboration.

Results of this assessment show that the main actors in the CUA arena are largely concentrated in Europe (45 percent), North America (32 percent) and Asia (15 percent); only a few are in South America (3 percent), Africa (3 percent), and Oceania (2 percent). In emerging economies targeted by EBRD, the highest number of UA stakeholders were found in the Russian Federation (17 stakeholders), Türkiye (13), Greece (10), and Poland (9). Within the EBRD region, the most represented stakeholders were technology input providers at 59 percent (= 88 entities); universities, CSOs and R&D centres at 24 percent (36 entities); and farming companies at 14 percent (21 entities). No retailers, headhunters, architecture/real estate firms were identified from EBRD countries, indicating important service gaps that could hinder upscaling CUA there.

Commercial urban agriculture (CUA) farming companies first appeared in the mid-1990s, multiplied from 2010 on and peaked in 2017 with the opening of 19 new farming companies. Entrepreneurs are generally young and relatively gender balanced. Over 80 percent of the companies analysed focus on the ready-to-eat salads/herbs market. For the most part, CUA companies produce leafy greens (76 percent), herbs (47 percent), other vegetables and mushrooms (59 percent), and edible flowers (12 percent).

The category of technology input providers comprises both brand new companies serving the UA sector, and previously existing enterprises entirely or partially converted to urban farming production. Technology input providers are involved mostly in international markets (71 percent worldwide and 75 percent in EBRD countries), exporting new technologies and cultivation systems for CUA. The United States is the worldwide leader for technology input providers with 71 companies identified. In Europe, most technology input providers are in the United Kingdom of Great Britain and Northern Ireland, the Kingdom of the Netherlands, and Italy with 15 companies in each country. In Asia, China has the greatest number of technology providers (eight), followed by the Republic of Korea (five). As noted above, there are 88 such providers in EBRD countries.

R&D provides a fundamental element for CUA, and developing innovation and knowledge for business improvement is a transversal priority to all the actors identified in this assessment. R&D for urban farming is conducted by universities and research centres, as well as by commercial companies characterized by advanced technologies and business-oriented approaches. CSOs are also engaged in R&D when related to technology transfer and subsistence business models. At the worldwide level, a total of 187 research activities are being performed by CSOs (35 percent) and universities (26 percent); while in EBRD countries, 16 research projects are supported by projects financed by a variety of institutions or organizations (44 percent of the 16), and by CSOs (25 percent of the 16).

The stakeholder assessment covered 51 investors investing in urban farming. They interact with other stakeholders through the financing of different areas of investment, including research development, equipment purchasing and the construction of structures. This category can comprise banks, private companies, foundations, and national or international institutions, which support CUA with capital, loans, grants, and leasing. Based on interviews with companies and from the analysis of specialized media and literature, investment in CUA comes primarily from private investors (30 percent), venture capital companies (22 percent) and the farm owners' own capital (22 percent).

Retailers are companies integrating urban farming systems into their infrastructures or including CUA products in their supply chain. Some examples are supermarket chains using in-store farming systems to offer directly harvested products to customers; or furnishing companies designing and selling indoor home gardens and farming systems. From the findings of the assessment, the only products clearly traceable as "urban" are those from vertical and rooftop farms. Retailers include Walmart, Stop&Shop, Whole Foods, Amazon Fresh, Esselunga, Monoprix, Carrefour, Jones Food Company, Auchan, Tesco, COOP, Cortilia and others where products are sold ready-to-eat in the refrigerated area. Finally, large food processors involved in the production of sauces (e.g. Barilla) and other semiprocessed products are also looking closely at commercial urban farms – especially vertical farms – to guarantee continuity, quality and standardization within their supply chain.

Headhunters are stakeholders related to farming companies and technology input providers for the identification and recruitment of different expertise in both the CUA and traditional agriculture sectors. This stakeholder category can include forums, associations or hiring companies offering services of recruitment, human resources, and identification. Although this FAO–EBRD assessment identified only seven companies clearly addressing recruitment for CUA and related business, all focus on sourcing highly qualified human resources for companies active in vertical farming, the demand for which is on the rise, especially since few candidates have accumulated many years of experience, and these few experts are highly paid. Reportedly, a head grower earns more than USD 120 000 per year excluding benefits.

Architecture and real estate companies are involved in UA through the design, construction and consulting for urban green infrastructures. Their contribution can refer to the development of building integrated agriculture (e.g. vertical farms, rooftop greenhouses), green walls, green and sustainable housing, or urban parks, both for private and public parties. Although there is interest from architecture and real estate companies, the number of those actively providing services to UA companies is limited and focused on repurposing infrastructures for farming.

Municipalities are key for the growth and prosperity of the sector, especially in terms of policymaking and directly supportive actions, such as grants and concession of urban areas for UA. Traditionally, the main aim of municipalities is to support green city development, reduce the urban footprint and ameliorate urban living quality. With the development of the new and highly technological urban farming companies, the role of municipalities has changed as advanced urban production needs access to transportation infrastructure as well as to clean sources of energy and a skilled workforce. Planning, infrastructural investments as well as support to develop competencies and knowledge necessary for UA are now standard approaches for municipalities such as Atlanta, Brussels, Dubai, London, Milan, New York, Paris, Shanghai, Singapore, Sofia, Tbilisi, and Thessaloniki to attract and maintain urban farming investments.

Finally, **consumers constitute the ultimate stakeholder in urban farming value chains.** While the willingness to pay for urban farm products produced in traditional settings or greenhouses is positive (Grebitus *et al.*, 2017), data are limited for more advanced production approaches (i.e. indoor) and consumer interest and willingness to pay for these more expensive products is largely undocumented. About consumer trends, research indicates geographic factors, age and income levels play a role in shaping perceptions of VFs (Specht *et al.*, 2019; Perambalam *et al.*, 2021). However, as VFs have yet to fully penetrate the mass retail market data are still scattered and related to specific contexts. To this end, some recent studies, have shown positive attitudes toward VF products in China, Singapore, the United Kingdom and the United States (Ares *et al.*, 2021), as well as Norway (Gustavsen *et al.*, 2022).

1.4 COMPARING TECHNOLOGICAL PERFORMANCE FOR KEY CROPS

While the performance of greenhouse and open field farming are fully discussed in literature, indoor farming such as vertical farming constitutes a novelty. Land availability and ownership as well as land use opportunity costs (e.g. farming vs. construction) no longer constitute a limiting factor for most of CUA companies. Space is rented or leased (65 percent), and most companies opt for soil-less production approaches (72 percent globally and 52 percent in EBRD countries). UA farm sizes vary greatly across the sector but are rarely smaller than 1000 m^2 and stacking at least 15 layers, which can produce up to 100 times more leafy greens than open field agriculture (Kozai, 2013; Kozai, 2020) with a potential theoretical estimation of 700 kg/m^2 of fresh products (Jin *et al.*, 2023).

Table 1
Cultivation inputs and outputs for lettuce production in various systems

	Vertical Farm	High-tech greenhouse	Low-tech greenhouse	Open field	Reference
Cultivation inputs					
Labour (h/kg)	0.067	0.028	0.015	0.014	Moghimi and Asiabanpour 2023; Raaphorst, 2023
Energy (kWh/kg)	5.75	1.37	0.14	0.575	Moghimi and Asiabanpour 2023; Blom *et al.*, 2022
Water (L/kg)	6.25	20	48	250	Carotti *et al.*, 2023; Stanghellini and Katzin, 2023; Raaphorst and Benninga, 2019
Land (m^2/kg)	0.010	0.02	0.03	0.11	Derived by dividing 1 m^2 by the annual yield
Fertilizer (kg/kg)	0.0139	0.004	0.009	0.004	Blom *et al.*, 2022; Foteinis and Chatzisymeon, 2016
Substrate (kg/kg)	0.12	0.011	0	0	Martin *et al.*, 2023a; Blom *et al.*, 2022
Seeds (g/kg)	0.08	0.006	0.006	0.006	Martin *et al.*, 2023a; Blom *et al.*, 2022
Cultivation output					
Yield (kg m/year)	100.00	53.00	29.00	8.9*	Kusuma *et al.*, 2022b; Blom *et al.*, 2022

*Annual yield of open field cultivation only considers one growing cycle per season, even if it could be possible to have more growing cycles per season in some regions.

SOURCE: Authors' own elaboration based on: See references.

The most profitable crops are herbs, followed by vegetables, mushrooms, and leafy greens. Most companies concentrate on crops with the higher harvest index. Recently, companies have also started the production of berries, tomatoes, and medicinal plants for the pharmaceutic industry.

Table 2
Crop varieties grown in vertical farming systems

Category	Representative crops	Yield (kg / m^2 / layer / year)
Leafy greens	Lettuce, brassicas, watercress, pack choi	100 on average, but can be as high as 700
Herbs	Basil, mint, cilantro, arugula	50
Microgreens	Micro brassicas, micro herbs	64
Fruit crops	Tomato, pepper, cucumber, strawberry, blueberry	22
Mushrooms	Shiitake, oyster	N/A
Medicinal plants	Cannabis, Anoectochilus roxburghii, Camellia sinensis	N/A
Others	Hops, all types of plants for propagation purpose	N/A

SOURCE: Authors' own elaboration based on interviews for this report.

Although the trend is still evolving, CUA farming companies focus on local/national markets through retailers or sell directly to consumers, both worldwide (61 percent) and in EBRD countries (64 percent). At the experimental level, some urban farms have managed to produce staple crops such as wheat, but this is limited to a few promising case studies and no company seems to be currently involved in commercial production of grains.

Beyond leafy greens, vertical farm growers are looking to fruit crops like blueberries as well as to medicinal and nutraceutical plants. Especially for medicinal plants, companies' rationale is that the stable environment of indoor farms will ensure that plants uniformly produce desired compounds at a consistent quality standard. Although rare, some companies are actively producing medicinal plants for the pharmaceutical industry, but data on the extent and success rates are not available.

Chapter 2
Investment approaches, opportunities and challenges associated with commercial urban farming

2.1 COMMERCIAL URBAN AGRICULTURE BUSINESS MODELS

Data are limited because urban agriculture and commercial urban agriculture stakeholders are either not collecting data or – because they are highly competitive – are reluctant to share financial information. As a result, it is challenging to calculate return on investments (ROI) or any other parameter related to profitability or financial sustainability. Nevertheless, literature identifies six business models that could represent the CUA arena: (1) cost reduction, (2) diversification, (3) differentiation, (4) shared economy, (5) experience, (6) experimental, and (7) farm management, which is a very recent addition to the mix (Balseca *et al.*, 2022).

The **cost reduction** model serves the mass market and competes directly against conventionally-produced food products. The **diversification** model supplements production with other services such as reselling energy from the farm's solar panels, selling compost produced on the farm, and offering educational workshops, handcrafting or agrotourism opportunities for clients. Companies operating under a **differentiation** business model focus on selling high value niche products to a premium market, principally chefs at elite hotels and restaurants but also directly to consumers. The **shared economy** business model is a collective approach in which risks are shared between members of the community and urban agriculture associations; these are non-commercial entities relying mostly on volunteers and driven primarily by the desire for social and environmental benefits. The **experience** business model offers urban citizens a connection to nature through various activities (e.g. visits, events and classes). The **experimental** model manifests in pilot projects initiated to test production models or innovative technologies. In this approach, investments are fully concentrated on R&D and the objective is to investigate possible crops and innovative production processes. Finally, the **farm management** business model consists of the sale and management of tailor-developed farms, usually to retailers, restaurants and food production companies (Balseca *et al*., 2022). All these elements, scarcely applicable in traditional rural agriculture, may also be merged to further enhance revenues and foster long-term sustainability.

For **cost reduction** models, achieving economies of scale is important and land is a major success factor. For **differentiation** models, having a defined value proposition aligned to demand is crucial. Marketing and branding drive success under **diversification** models, while purpose-led communication is important for both **experience** and **experimental** business models. Access to adequate human capital and strong relationships with clients are fundamental factors for entities operating under the **farm management** business model.

Based on literature and interviews with 24 companies representing the different business models, the analysis identified the following. Companies adopting the shared economy or experience business models, require investments ranging from USD 20 000 to USD 500 000. Because they are focused on conventional agriculture in soil and need limited human capital, the investment requirements here are the lowest. Although such models often do not prove to be economically viable, their value is in the social and environmental externalities they generate, which literature values in a range of EUR 1.3/m^2 of operation (considering only energy savings) and EUR 84/m^2 (including all social values) (Chen *et al*., 2020; Schoen *et al*., 2020; Balseca *et al*., 2022; Orsini *et al*., 2022). Public investment is appropriate to foster the development of such socially driven projects.

The experimental business model requires substantial investment because it is focused on developing and testing innovative technologies, approaches, techniques, procedures and models to enhance production. R&D and highly skilled human resources are fundamental in such projects. These companies are funded by public investments and private investors. The range of investments here is hardly quantifiable as each case is unique. Yet, within the sample interviewed during this study, experimental companies invested up to USD 50 million per enterprise.

The diversification business model requires investment from USD 100 000 to USD 500 000. Because this model is based on diversifying income sources, it does not require significant R&D or skilled human resources. These projects are economically driven and can be viable depending on size, technology (e.g. greenhouses) and crops. However, these models are hardly scalable.

Finally, the differentiation, cost-reduction and farm management business models are purely profit driven and based on implementing innovative technologies (e.g. soil-less, hydroponics, aquaponics) mostly in indoor settings. These business models require substantial investments (several millions of USD) for R&D, technology, infrastructure, and skilled labour. Within the UA universe, the cost reduction and farm management business models are growing faster, both globally and in EBRD countries.

2.2 MARKETING STRATEGIES

Vertical farming, the dominant practice among commercial urban farms, is attracting the most attention and likely offers the greatest potential for scaling up. Its young, tech-and-marketing-savvy entrepreneurs are generating a lot of excitement for the sector. However, most vertical farm research has focused on the technological innovations the sector presents rather than on its overall business environment (Allegaaert, Wubben and Hagelaar, 2020). Therefore, this and following sections of this report focus primarily on vertical farms.

As this is an evolving market, distribution models are constantly being refined. One extensive review provides an overview of various distribution models, including: (1) retail, high value/low volume (the sale of high-cost niche products near points of consumption); (2) wholesale, medium value/high volume (scaled and capital-intensive farms near points of distribution selling commodity crops to wholesale markets); (3) and farming-as-a-service (development of systems to be owned and/or managed by retailers) (Baumont de Oliveira, 2022). Within the sector, a level of vertical integration has been observed, especially by VFs that supply mass retail as their end market. To penetrate the mass retail market, vertical farms may choose to vertically integrate through the insourcing of processing, packaging and logistics functions to shorten the supply chain and increase margins (Allegaaert, Wubben and Hagelaar, 2020). Various examples from Europe, the United States and Asia demonstrate that some vertical farms are bypassing wholesalers altogether by partnering directly with retailers and leveraging the retailers' distribution capacities. When it comes to the overall business and distribution model, a one-size-fits-all approach does not exist, and one model has not proven to be better than the other. The level of vertical integration, centralization and decentralization depends on the operational capacity of the VF operator and its geographical scope, targeted end market, access to finance, its ability to partner with retailers and third-party logistics service providers as well as its expansionary plans.

Many VFs supplying the mass retail market brand their products to distinguish them from conventional products. Promoting distinguishing properties is especially important to justify price points of VF products, which are often at a premium compared to non-VF. Some VFs brand products as local and sustainable, despite the absence or lack of understanding of regulation to support such claims. The 2019 global CEA census found that out of 120 VFs, 73 percent used the term "local" in their product packaging, but only 15 percent knew whether there were regulations on the use of the term (Autogrow & Agritecture Consulting, 2019). The use of private labels enables retailers to directly define product specifications, including its contents, quality requirements, aesthetics, packaging and delivery modalities. For private labels, retailers will often pursue an "everyday low pricing" strategy, which is based on consistently pricing products low, instead of using discount events and promotions to attract and retain consumers. Although private labels have predominantly been used for non-fresh food categories, the use of private labels for fresh produce has gained traction over the last decade. For instance, one study found that in Italy, out of a sample of almost 300 salad packages analysed in 2021, more than 50 percent were private label (Authors' analysis). Although many VF products have penetrated mass retail markets under their own brands, there is a lack of evidence detailing how these brands are performing against non-VF products, both private-label and branded goods.

2.3 CAPITAL EXPENDITURES AND OPERATIONAL EXPENDITURES

Literature shows that capital and operational expenditures vary across typologies of technologies and depend on context factors such as energy availability, type and quality of available energy (e.g. fossil vs. renewable) and strategic decisions on crops, automation and end markets.

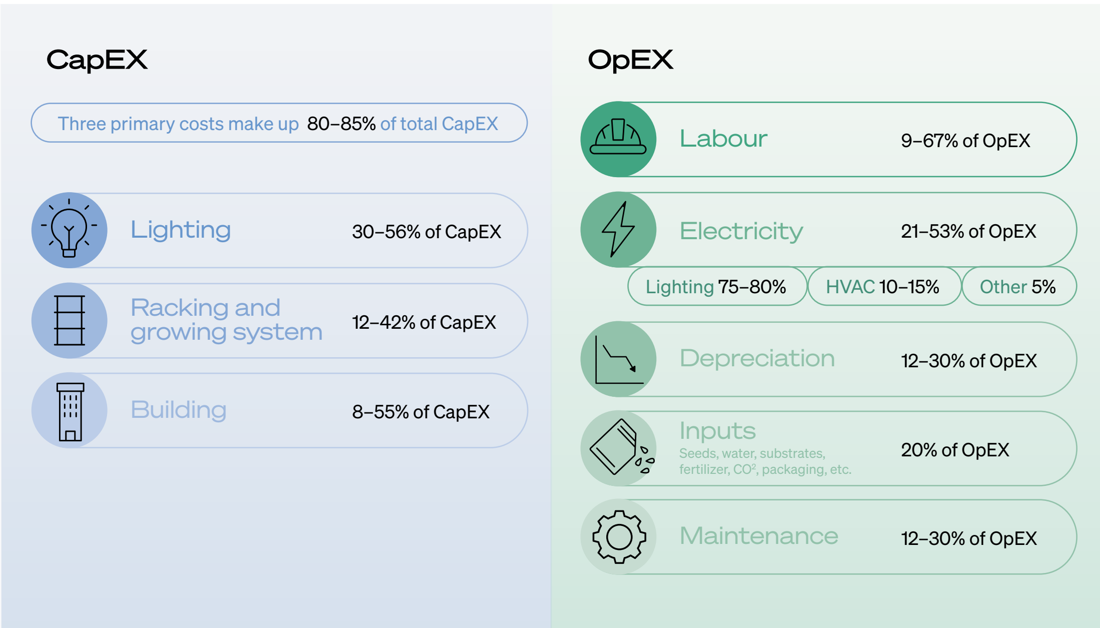


Figure 5
CapEx and OpEx of vertical farming

SOURCE: Authors' own elaboration.

In terms of CapEx, data largely confirm that these are higher for VFs when compared to all other production options in urban and non-urban settings. However, CapEx as a percentage of total VF costs depends on the size of operations and the technologies employed.

A review of more than 40 economic studies on VF reveals that lighting, racking, growing systems and building costs can comprise 80–85 percent of CapEx (Baumont de Oliveira, 2022) (Figure 5). Furthermore, if the vertical farm develops its own software and hardware solutions, CapEx will also include

R&D costs. It is clear that vertical farming is CapEx-intensive, and costs are higher compared to greenhouses. However, differences in costs depend on the metrics used for comparison and no standardized way for conducting such comparisons currently exists. The industrial CapEx for an indoor vertical farm is currently estimated between EUR 1500/m^2 and EUR 2500 /m^2 of growing area (depending on automation level and lighting technologies) and can reach up to EUR 3500/m^2 of growing area (i.e. Türkiye) (Kuzuma *et al.*, 2022a).[14]

The trajectory VFs follow in reducing CapEx costs largely depends on whether technologies that underpin VFs are cost efficient and adaptive to local conditions. Importantly, hardware and software solutions should assume a total cost of ownership perspective and ensure that VF operators are not overly burdened by maintenance and replacement costs.

In terms of OpEx, VF costs typically comprise labour, energy use, maintenance, depreciation and inputs; the first two usually constitute the largest share. Given rising energy costs and the investments required in skilled labour (e.g. vertical farm growers), the cost of operation in vertical farming can reach up EUR 500 per m^2 compared to about EUR 100 per m^2 in a conventional greenhouse.

In terms of OpEx, available analyses show that energy, labour, maintenance, and depreciation make up the bulk of these costs. Cost shares for energy depend on the efficiency and use of technologies employed for lighting, climate control and crop operations, while labour is largely impacted by the level of automation.

A recent analysis compares the average production costs of vertical and field farming across seven sites in the United States of America to produce 90 000 kilograms of lettuce (Moghimi, 2021). Figure 6 shows the results of this comparison, where savings in water use in VFs are replaced by higher labour[15] and energy costs.

14 Excluding the cost of the building itself, which can potentially double the overall expense.

15 In farms with high level of automation, labour cost can decrease by up to 30 percent, but it will increase CapEx.

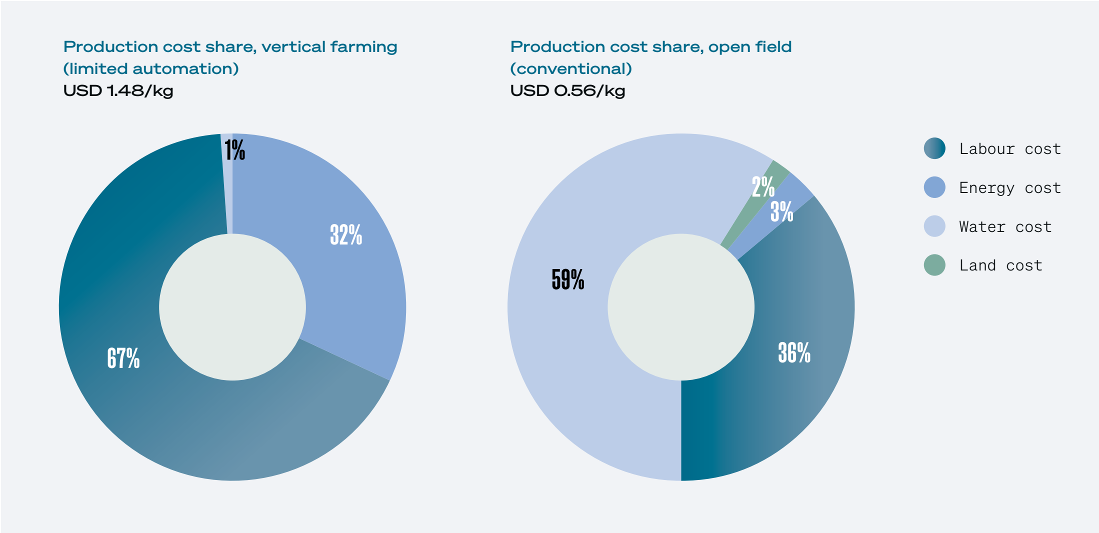


Figure 6

Production cost shares in vertical farming and field farming in the United States of America

SOURCE: Moghimi, F. 2021. Vertical Farming Economics in 10 Minutes. *Rutgers Business Review*, 6(1): 122–131. https://ssrn.com/abstract=3832127

Overall, as the technology level and technology use increase (from open field to greenhouse to vertical farm) the yield of these operations increases significantly, but so do the costs. Based on the yield, CapEx, and OpEx data, the costs of producing one kilogram of leafy greens is estimated to be about EUR 2.4 in a greenhouse and about EUR 7 to 10 in a vertical farm – this latter range is quite close to the value reported by other researchers of EUR 8/kg (Kozai and Niu, 2020).[16] In terms of limitations in identifying and comparing OpEx costs across VFs, many studies do not account for depreciation (Baumont de Oliveira, 2022). Since vertical farms are capital intensive, depreciation can be a significant operational expense and should be considered. Although depreciation will not impact earnings before interest, taxes, depreciation and amortization, these can be influenced by accounting practices and should be analysed with caution. Furthermore, some studies grossly underestimate labour costs and consider hourly salaries rather than monthly or annual salaries (also for management teams) and building leasing costs are also often omitted or kept at a low level (Baumont De Oliveira, 2022).

16 Because CUA companies are often perceived as non-agriculture related companies, it must be noted that high-tech CUA companies cannot access the more than USD 600 billion available worldwide per year (Laborde, *et al.*, 2021) in government support and therefore it is not possible to efficiently compare prices of vertical farms with those from greenhouses and conventional agriculture.

2.4 PROFITABILITY

There is a lack of peer-reviewed economic and risk benchmarks on the financial viability of CUA and particularly of VFs. Limited evidence combined with the absence of a proven track-record of viable vertical farm business models makes it difficult to address claims on profitability (Baumont de Oliveira, 2022). Limited data availability is expected in an emerging sector, as data can be considered proprietary and competitively advantageous. Aggregated surveys do demonstrate that the number of profitable VFs is increasing, but individual studies are largely hypothetical, context specific and may underestimate or omit certain cost elements. This makes it difficult to validate VF profitability claims and to reference reliable financial performance metrics, such as the internal rate of return (IRR), net present value and payback periods.

Despite these challenges, some surveys have been conducted to shed light on the profitability status in the controlled environment agriculture sector or at least to provide information from companies.[17] Based on information provided by companies themselves in the 2021 Global CEA Census, the average scored revenue of USD 116/m^2 for VFs, compared to greenhouse earnings of USD 18/m^2 (WayBeyond and Agritecture Consulting, 2021). Other aggregated studies conducted by the Japanese Government in 2014 and 2018 show that Japan had twice as many profitable vertical farms in 2018 compared to 2014 (Kozai and Niu, 2020). Figure 7 summarizes the results from the various aggregated studies conducted.

17 The 2019 Global CEA Census collected responses from 316 companies across 54 countries, while the 2021 Global CEA Census obtained responses from 371 companies across 58 countries (Autogrow and Agritecture Consulting, 2019; WayBeyond & Agritecture Consulting, 2021).

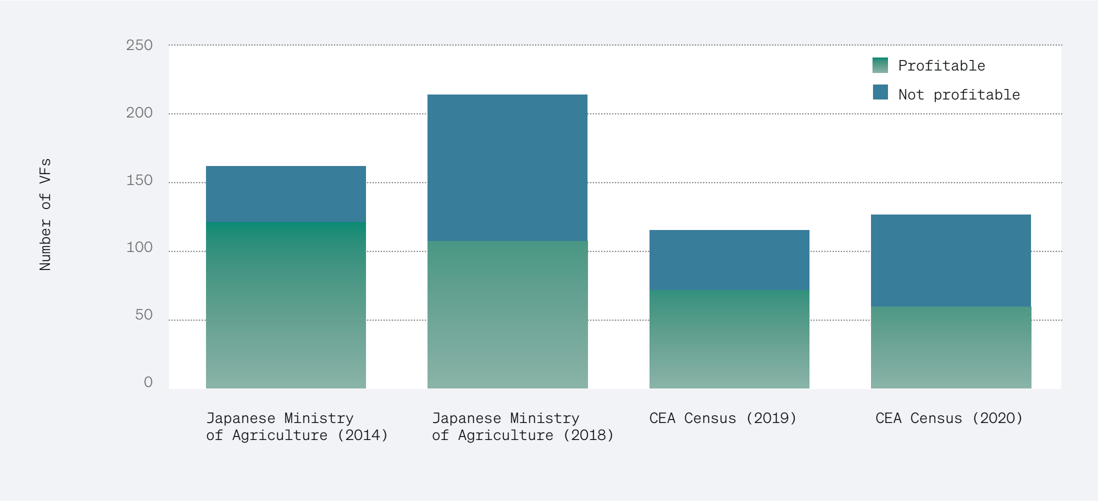


Figure 7
Survey results on profitability of vertical farms

SOURCE: Adapted from: Baumont de Oliveira, F. 2022. *A Typology Review for Vertical Plant Farms: Classifications, Configurations, Business Models and Economic Analyses.* Liverpool, U.K., University of Liverpool. https://doi.org/10.13140/RG.2.2.24729.49766/2; Kozai, T. and Niu, G. 2020. Role of the plant factory with artificial lighting (PFAL) in urban areas. In: T. Kozai, G. Niu & M. Takagaki, eds. *Plant Factory: an Indoor Vertical Farming System for Efficient Quality Food Production*, first edition. Cambridge, UK, Academic Press. https://doi.org/10.1016/B978-0-12-801775-3.00002-0; WayBeyond & Agritecture Consulting. 2021. *2021 Global CEA Census Report*. Auckland, New Zealand and Brooklyn, New York, USA. https://engage.farmroad.io/hubfs/2021%20Global%20CEA%20Census%20Report.pdf; Autogrow & Agritecture Consulting. 2019. *2019 Global CEA Census.* Brooklyn, New York, USA. https://engage.autogrow.com/hubfs/CEA%20Census/2019%20CEA%20Census%20Report.pdf

Literature offers various individual studies – most draw on hypothetical data – to assess the financial viability of vertical farms. Results are not homogeneous and these studies apply diverse methodologies, making comparisons complex and inaccurate. Table 3 provides an overview of some of the financial assessments of vertical farms and their main conclusions.

Table 3
Sample of vertical farming economic analyses

Farm description	Main findings
Hypothetical 1000 m^2 VF	Break-even point achieved in 7–8 years (Banerjee and Andenaeuer, 2014)
Hypothetical 5000 m^2 VF in Wuhan, China	Break-even point reached in 11.5 years (Zhang *et al.*, 2018)
Hypothetical 465 m^2 vertical farms in Brazil vs the United States of America	Uses vendor data in both cases; VF cheaper in Brazil, which achieved IRR of 19.1%, than in the United States of America, which achieved IRR of 14.2%, but cannot compete against field-based farming (Baumont de Oliveira, 2022)
26 VFs across 5 countries (hypothetical and real data)	Impact of economies of scale and construction costs on financial viability shows a 30% decrease in crop yield or price renders VFs economically unviable; VFs depend on scale but also on increasing the number of buyers; minimum scale to ensure break-even is 40 m^2 for lettuce and 100 000 m^2 for strawberries (Zhuang *et al.*, 2022)
Hypothetical VF in Japan, with data substitution (changes to scale, operations, and market context)	Reducing capital costs (especially equipment costs) by 45% increases ROI from 1.8% to 14.3%; scale of operation and fixed costs are critical to profitability; doubling the VF size enhances ROI from 14.3% to 22% (Uraisami, 2018)
Hypothetical six-story VF in Delhi, India of 2000 m^2 with 3 stacked layers in each story	Payback period is 64 years (Sarkar and Majumder, 2019)
Others	Hops, all types of plants for propagation purpose

SOURCE: Adapted from Baumont de Oliveira, F. 2022. *A Typology Review for Vertical Plant Farms: Classifications, Configurations, Business Models and Economic Analyses*. Liverpool, U.K., University of Liverpool. https://doi.org/10.13140/RG.2.2.24729.49766/2

As Table 3 highlights, many of the financial analyses on VFs are hypothetical, making it unwise to draw conclusions. The lack of real case studies, benchmarks and frameworks to analyse financial viability hinders the ability to deduce whether and which VF models are profitable. Although the *2021 Global CEA Census* shows an increase in the number of VFs claiming profitability, transparency and sharing of real data is warranted to determine the integrity and viability of such claims (Waybeyond & Agritecture Consulting, 2021).

2.5 MARKET MATURITY

While the VF sector has already attracted significant investment, the market can still be considered small and growing. The underlying technologies of VFs (e.g. lighting, automation, climate control and processing) have advanced significantly in recent years and this has helped reduce capital costs. However, as already noted, CapEx for VFs is much greater than for other types of UA (e.g. greenhouses). While its technology dimension has created hype for VF, the sector must still mature in terms of operations, including in the optimization of unit costs (e.g. energy and automation), attracting skilled human resources and providing consumers with clear information about product quality.

Evidence suggests that some vertical farms are finding it difficult to access capital and secure returns under stipulated timelines and conditions. The *2019 CEA Census* reported that 63 percent of the 128 VFs it surveyed did not pursue funding, 28 percent pursued and obtained funding, 10 percent pursued funding but were unsuccessful (Autogrow & Agritecture Consulting, 2019). Of all those respondents that sought and obtained financing, 33 percent secured it from private investors, 32 percent from "angel" investors, 24 percent from government agencies; 18 percent from venture capital, 12 percent from banks. The stakeholder assessment carried out by FAO in 2022 for this study surveyed 147 companies and indicates a slightly different range of investors. Only 23 companies agreed to share some data related to CapEx, OpEx and type of investments. Of these, financing was secured via private investors (30 percent), venture capital funds (22 percent) or their own capital (22 percent). Respondents indicated that the funds they secured were used mostly for construction of the VF structure, followed by research and development, and then staffing. Most said they secured loans (73 percent of respondents) ranging from five to ten years.

On the one hand, it could be argued that vertical farming has passed the initial stage of hype. Evidence suggests that the industry may be set to consolidate through mergers and acquisitions as the sector confronts the realities of achieving responsible and sustainable economic growth. As an example, in February 2023, the Dutch indoor farming company Growry acquired all the assets, intellectual property and core team of Kalera International, a subsidiary of the American publicly traded vertical farm company of Kalera (Marston, 2023). On the other hand, specialized media indicate that the industry may have already arrived at a stage of disillusionment, where investors' impatience for results begins to replace initial excitement about potential value (Martin, 2022; Center for Excellence for Indoor Agriculture, 2023; Terazono, 2020; Pratty, 2023; Vertical Farm Daily, 2023).

Because it is so heavily technology driven, it can be argued that the VF market mirrors trends in the online food/technology industry. So, it is helpful to look at this mirror image for clues about VF market dynamics past and future. The online food/technology industry, especially start-ups such as Uber, have enjoyed tremendous growth thanks to unprecedented low interest rates that followed the 2008 financial crisis (Thornhill, 2022). This led to a commoditization of capital, which benefitted opportunistic companies. However, increased interest rates contributed to the crash of the tech-heavy Nasdaq market, which dropped by 26 percent in 2022, resulting in public and private investors alike refocusing investment strategies on profit generation (Thornhill, 2022).

While these examples reflect trends observed in the technology industry and put into question the viability of VF business models, most VF research has focused on the technological innovations the sector presents and less on its overall business environment (Allegaaert, Wubben and Hagelaar, 2020). Due to the novelty of the sector and the variety of VF formats that have emerged, major private players seeking investment are reluctant to share data, which they regard as commercially sensitive. Consequently, a scarcity of publicly available information exists on the economic feasibility, investments, operational costs, benefits, and profit potential of VF business models (Allegaaert, Wubben and Hagelaar, 2020).

2.6 PRICING AND CONSUMER DEMAND

As reported, only CUA products that originate from VF clearly specify their technological "pedigree;" others cannot be differentiated from conventional agriculture. Therefore, prices of vertical farming products were spot checked September 2022 across 29 retailers in 11 countries. This shows that average prices per kilogram for vertically farmed leafy greens (arugula, corn salad, iceberg and romaine lettuce) is on average 70 percent higher than organic salads not grown in VFs.

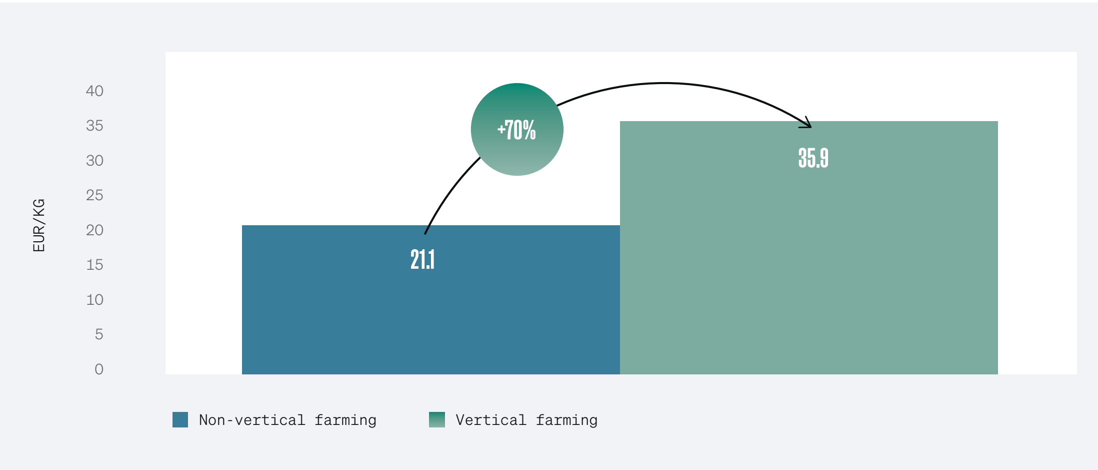


Figure 8
Retail price comparison: non-vertically organic farmed and vertically farmed salads

SOURCE: Authors' own elaboration.

It is estimated that the global market for packaged salads may grow from EUR 11 billion in 2021 to EUR 18 billion in 2025 (Pedersen, 2022). Considering the fast pace at which technology is advancing, as well as energy and labour cost innovations, climatic conditions impacting field-farming productivity, and consumer appetite, the VF market penetration rate could constitute between EUR 900 million and EUR 7.2 billion.

As referenced by some of the financial assessments done on VFs, premium price points are often required to cover investment costs and secure profitability (Baumont de Oliveira, 2022; Pedersen, 2022). Nonetheless, global shocks, such as the invasion of Ukraine by the Russian Federation and war in the Gaza Strip, are contributing to an uncertain post-COVID-19 recovery period. Important trends taking hold in food retailing include: (i) decreasing consumer purchasing volumes; (ii) rising inflation; (iii) widening polarization of purchasing habits, with extreme price sensitivity confronting consumer desire for premium, healthy and sustainable products; and (iv) retailers intensifying their search for new sources of profit (Aull *et al.*, 2022). Furthermore, the lower cost of products from non-vertical farming systems is often linked to the strong presence of farmer subsidies (e.g. from common agricultural policy, CAP) which are usually not available for vertical farmers, further increasing the cost difference.

Updates on these figures from supermarket prices in fall 2023 demonstrate how the situation is rapidly evolving and creating some geographical discrepancies. In Sweden, the two prices are currently aligned at around EUR 22/kg; in Italy – although decreasing[18] – the price discrepancy remains generally high.

The pricing discrepancies presented here between greens grown in open fields/greenhouses and those grown in vertical farms may feed the trend toward consumer polarization. If pricing gaps are not reduced, the VF market may remain niche, continuing to serve only consumers that demand premium products at almost any price. In crafting their commercialization strategies, VF players must factor in the current inflationary environment, in the context of which retailers are likely to cater to consumers' price sensitivity (i.e. vertical farm products may be priced out of the market).

Several studies demonstrate differences in consumer perceptions of vertical farming across various countries (Jaeger *et al.*, 2023; Ares *et al.*, 2021; Yano *et al.*, 2021). Depending on context and approaches used, results are often in contradiction. Studies demonstrate that location and income levels play a role in shaping opinions about vertical farming, and that the VF market has yet to fully penetrate the mass retail market. A recent study of 261 respondents in the United Kingdom, Germany, and Denmark and a survey of 190 individuals in Denmark finds that, on average, consumers "hold negative expectations regarding the sensory properties and holistic characteristics such as freshness and naturalness" – though these negative expectations were largely disconfirmed upon gaining actual product experience – and hedonic acceptability of VF produce was, on average, not below the "neutral" mid-point on a bipolar hedonic scale ('dislike extremely' to 'like extremely') (Jaeger *et al.*, 2023). In other words, customers expect to be disappointed by vertical farm products but, after actual consumption, give them a neutral score.

2.7 INVESTMENT PRECONDITIONS AND ENABLING FACTORS IN EBRD COUNTRIES

Within the UA universe, CUA and indoor vertical farming have the potential to substantially contribute to the agricultural economy, nutrition and food security, but not all countries possess the preconditions necessary for vertical farming investments. Based on the methodology developed (Paucek *et al.*, 2023), EBRD countries were assessed against several indicators reflecting social, environmental and economic variables. This led to the development of a double synthetic feasibility and sustainability index for each of the EBRD countries analysed (Figure 9). Here, feasibility is determined by whether high-

18 In 2024, two of the largest food retailers in Italy, CONAD and COOP, started offering under their own brand names ready-to-eat salads; their prices are aligned with the equivalent from organic farming.

tech farming approaches such as vertical farming are technically, strategically, and financially viable; sustainability is determined by their economic, social, and environmental potential.

The feasibility and profitability of high-tech urban farms are not solely dependent on sound business models but also on the existence of minimum prerequisites within a country to integrate this type of agriculture into urban and peri-urban areas. In order to do so, 13 macro categories were created (agricultural development, climate change vulnerability, urban development, food security, economy and growth, private sector, financial sector, infrastructure, trade, science and technology, energy, environment, social) aggregating more than 147 indicators retrieved from World Bank data. For each macro category, a synthetic index was developed, and the aggregation of these indices identified eight countries as “very favourable” (Poland, the Czech Republic, Estonia, Hungary, Slovenia, Slovakia, Türkiye, and Cyprus), and ten countries as “favourable” (Greece, Ukraine, Lithuania, Latvia, Croatia, Bulgaria, Romania, Serbia, Kazakhstan, and Azerbaijan) in terms of feasibility of indoor vertical farming. For example, Poland and the Czech Republic were rated “very favourable” due to a combination of high access to electricity in both rural and urban areas, very low level of food insecurity within the population, good infrastructure and private sector development as well as strong trade markets. While this analysis cannot guarantee the success of investments, it provides investors and policymakers with valuable insights for planning investments and refining research and development efforts. Furthermore, the analysis could support national and local institutions in securing the enabling conditions for CUA to develop and contribute positively to food systems. This includes developing governance and incentive schemes that will favour the adoption of tailored technologies and approaches as well as guaranteeing quality of products and safety of production.

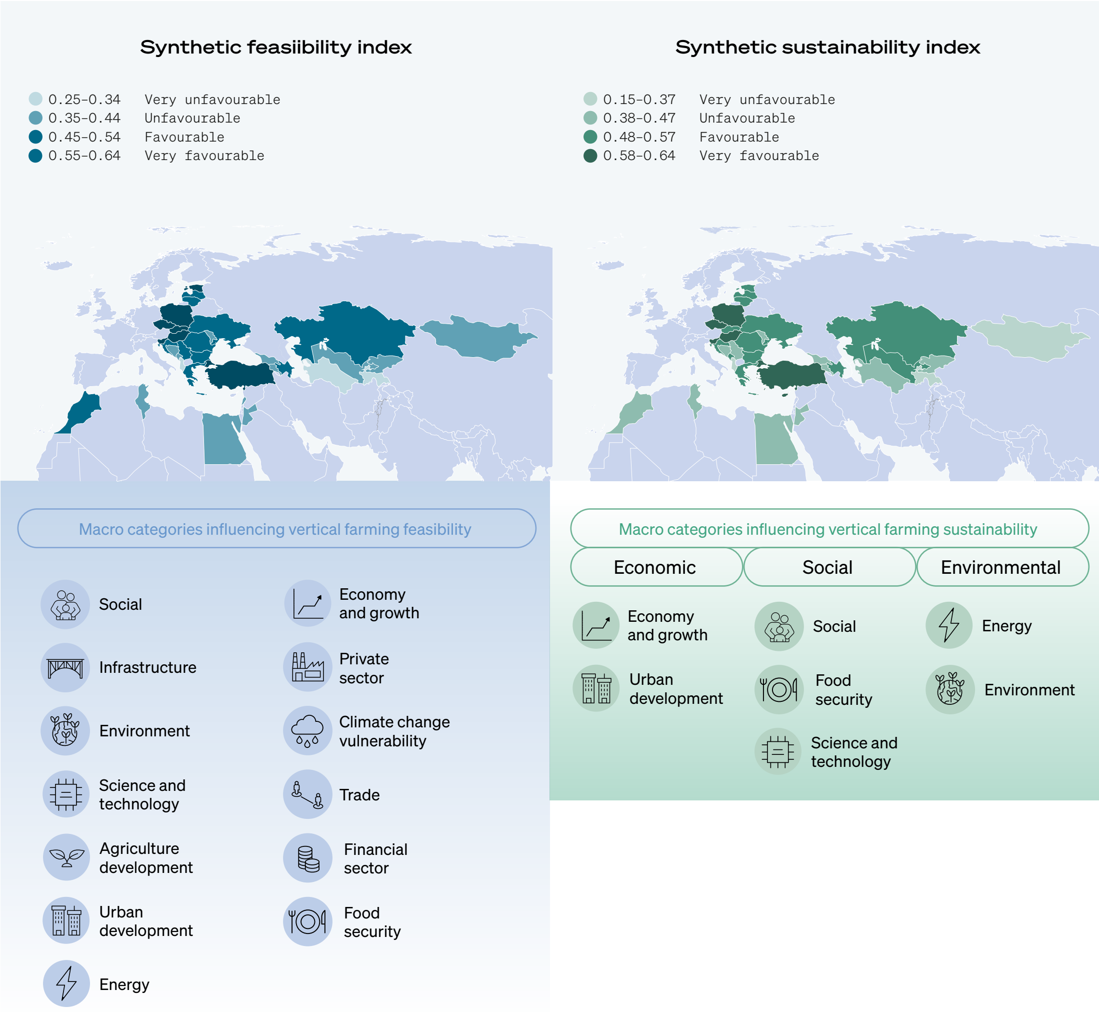
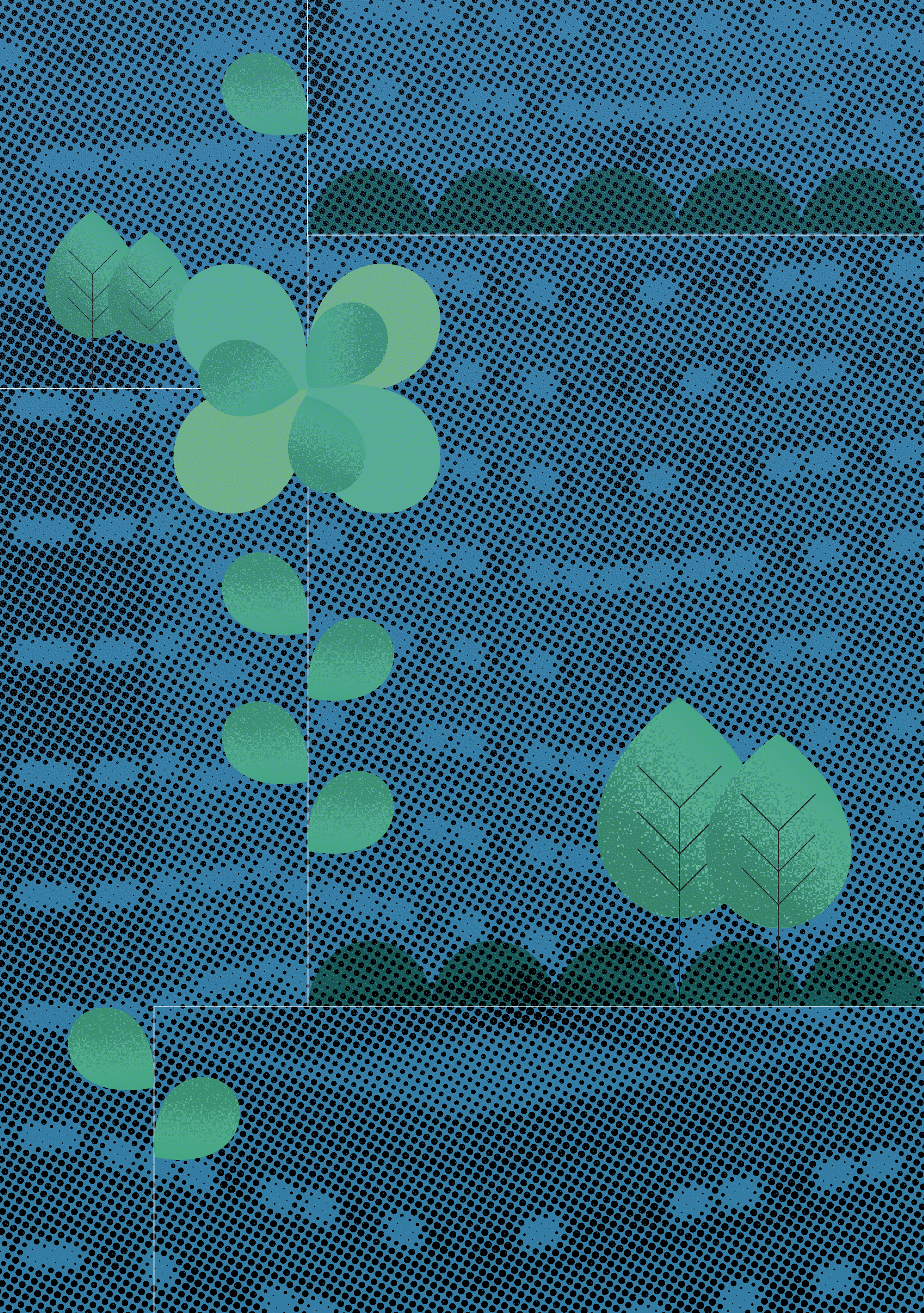


Figure 9
Vertical farming feasibility and sustainability assessments across EBRD countries

SOURCE: Authors' own elaboration.

NOTE: For these maps please refer to the general disclaimer on page ii.



Chapter 3
Environmental performances

There is substantial evidence in literature that UA can positively impact the environmental, social, and economic dimensions of a city. Nevertheless, poor practices in UA – irrespective of the approach and business model applied – can also harm health and the environment (Fleury and Ba, 2005; Orsini *et al.*, 2022). As cities across the globe rapidly grow and densify, UA can play an important role as a nature-based solution to the sustainability challenges associated with urbanization (Langemeyer *et al.*, 2020). Several environmental benefits are associated with UA, which is believed to foster the adaptation of cities to climate-related impacts (Gaffin *et al.*, 2012) and to improve the urban microclimate (Li *et al.*, 2014).

In general, UA environmental benefits are associated with its main functions (e.g. productive or social), typology (e.g. soil or soil-less), dimension (small/large), local climatic conditions, spatial location in the city (i.e. green rooftop) and the plant typologies grown (Aerts *et al.*, 2016). The environmental services of urban agriculture are associated with: (i) a reduction of the urban heat island effect (Hausinger and Weber, 2015); (ii) improvement of air quality (Janhäll, 2015); (iii) increased water resilience in cities (Ebissa *et al.*, 2022); and (iv) reduced food loss and waste thanks to shorter and mare tailored value chains characterized by a growing number of contract farming agreements (e.g. Cortilia with Agricola Moderna in Italy).

The urban heat island effect causes cities to have daytime surface temperatures up to 10°C higher than the suburban and rural areas around them (NASA/Goddard Space Flight Center, 2010). This, in turn, has been associated with increased mortality of the elderly and vulnerable population during heat waves (Morabito *et al.*, 2015; Lemonsu *et al.*, 2015; Holec *et al.*, 2020). Health risks associated with heat waves are reduced in cities where a distributed network of green infrastructure exist (Marando *et al.*, 2019; Leal Filho *et al.*, 2021) because vegetation provides shade and increases the albedo[19] of surfaces to optimize thermal performances. A greened rooftop can reduce the surface temperatures of buildings by as much as 3°C (Smith and Roebber, 2011; Ng *et al.*, 2012; Santamouris, 2014; Hausinger and Weber, 2015) with positive impacts on working conditions in the building while reducing environmental and financial cost (e.g. GHG emissions) of climate control (e.g. temperature and humidity). Urban environments require an uninterrupted supply of energy (75 percent of global primary energy) as more than half of the earth's population lives in densified urban areas (UN-Habitat, 2023). Climate change projections towards higher temperatures will have a knock-on effect on energy use, raising the consumption within cities. UA and green rooftops can reduce building energy consumption by up to 25 percent during the summer (Saiz *et al.*, 2006; Oberndorfer *et al.*, 2007; United States Environmental Protection Agency, 2008; Santamouris, 2014; dos Santos *et al.*, 2019; Ragab *et al.*, 2020; Liu *et al.*, 2021) as well as remove contaminants such as acidic gaseous chemicals and particulate matter (Yang *et al.*, 2008; Heather, 2012).

Furthermore, the green cover UA provides in dense urban areas serves as a buffer, decreasing the impact caused by extreme weather events (Rowe *et al.*, 2011). During intense rainstorms, many urban areas are vulnerable to flash flooding due to the prevalence of impermeable surfaces (e.g. roofs, roads, sidewalks) and the insufficient retention capacity of conventional drainage systems. Green roofs and green/agricultural areas retain more stormwater than artificial surfaces while also reducing peak flows and increasing lag times until runoff (Stovin *et al.*, 2013). The volume of stormwater retention due to green roof vegetation alone has been quantified from 7.5–325 percent in a controlled chamber containing succulents, graminoids, forbs and shrubs (Spolek *et al.*, 2008; Volder and Dvorak, 2014).

19 Albedo is the fraction of sunlight that is reflected by a body or surface.

Another positive aspect is the potential contribution of CUA in general and vertical farming in particular in reducing supply chain food loss and waste, especially of fruit and vegetables, which are most vulnerable to spoiling due to their highly perishable nature. Horticultural food loss and waste generally account for 25–37 percent along the entire value chain (excluding the consumption step) at global level. Roughly 22 percent of crop is lost from post-harvest to distribution, while 3–15 percent of commercialized crop in the wholesale and retail markets is wasted (FAO, 2019b). The greatest waste occurs in leafy vegetables – the preferred product of CUA companies – due to their high-water content, which makes them even more perishable than other vegetables (Buzby *et al*., 2016).

A case study review (including surveys, data analysis and interviews) of 36 CUA companies employing various business models and located across eight countries[20] shows that the absence or reduction of intermediaries and steps in the value chain allows CUA production to reduce food loss by up to 50 percent compared to conventional agriculture (Tonini *et al*., 2022). This is due especially to the short time from harvest to consumption (i.e. 1–2 days) and – for the most advanced high-tech companies – the ability to plan production more efficiently based on seasonal demand and consumption patterns also guaranteed by the growing number of contract farming agreements between companies and food retailers. Also key is the more direct relationship producers have with consumers, which enables CUA to better forecast production based on demand and to push demand to match supply (e.g. marketing the availability of fresh, higher quality produce). In the analysis, vertical farming recorded the lowest values of food loss in the supply chain (7–12 percent). Advanced approaches such as vertical farming demonstrate that – depending on technology, setting and production targets – these farms can reduce water consumption by 30–50 percent compared to traditional greenhouses, and up to 95 percent compared to traditional agriculture (Kozai, 2013; Carotti *et al*., 2023). The water saving potential of vertical farms derives from a combination of soil-less technologies (e.g. hydroponic and aeroponic systems), water management (e.g. precision irrigation, water recirculation and recovery of water vapor) and their high productivity (Stanghellini and Katzin, 2023). These farms are also among the top scorers for efficiency in terms of land use efficiency thanks to their higher productivity per square metre, reduced or non-use of pesticides and reduced transportation distance.

On the other hand, CUA, and especially traditional approaches (e.g. open air in soil) are confronted by and could contribute to environmental contamination. Especially in traditional settings, the risk of crop contamination from chemicals (e.g. heavy metals) and biological contaminants and parasites (e.g. E. coli, Salmonella, Tenia, Fasciola and Ascaris), which may harm the health of consumers (Orsini *et al*., 2022; Yordanova *et al*., 2020; FAO *et al*., 2022). In more advanced settings such as soil-less indoor farming, the risk of contamination appears negligible because production is isolated from the sources of hazard. Nonetheless, especially in vertical farming settings, GHG emissions could be high due to the great energy demand of advanced CUA production (Martin *et al*., 2023b), and this could undo the positive results obtained in water and land use among others (Stanghellini and Katzin, 2023).

20 Spain, 13; Italy, 10; Portugal, 4; France, 4; Greece, 2; Egypt, 1; Türkiye, 1; United Kingdom, 1.

Finally, although water use in CUA is designed to maximize efficiency and sustainability to reduce water waste, tap water from urban networks remains largely used by farms. The cost and risks for the collectivity of such uses – although very limited in volumes – are still to be assessed. Nonetheless, companies are already addressing this issue through rainwater harvesting systems, which are commonly implemented to collect and store rainwater for irrigation purposes, and by applying technologies that maximize the recycling of humidity from production phases, which further reduces reliance on municipal water supplies (Kalantari, 2018; Jurga, 2021 *et al.*; Pacak *et al.*, 2020; Carotti *et al.,* 2023).

To have a better understanding of both traditional and high-tech environmental impacts, we reviewed 42 studies attempting to do just that and found that methodological guidance for performing life cycle assessments (LCAs) of commercial urban agriculture is still limited. Those few studies that do exist employ various methods, resulting in unreliable comparisons between CUA and traditional agricultural methods, and even between various techniques used within the UA sphere.

In addition to that extensive review of literature and for a more hands-on approach to assessing CUA's sustainability in technologically advanced settings, the team also examined six case studies across three countries: three in Sweden, two in Spain, and one in Italy. All used soil-less systems with additional supply of fertilizers either through hydroponics (used in all case studies) or aeroponics. These LCA-based assessments proffered useful insights that can inform future efforts to substantiate the environmental performance of CUA more definitively (Rufí-Salís *et al.*, 2022).

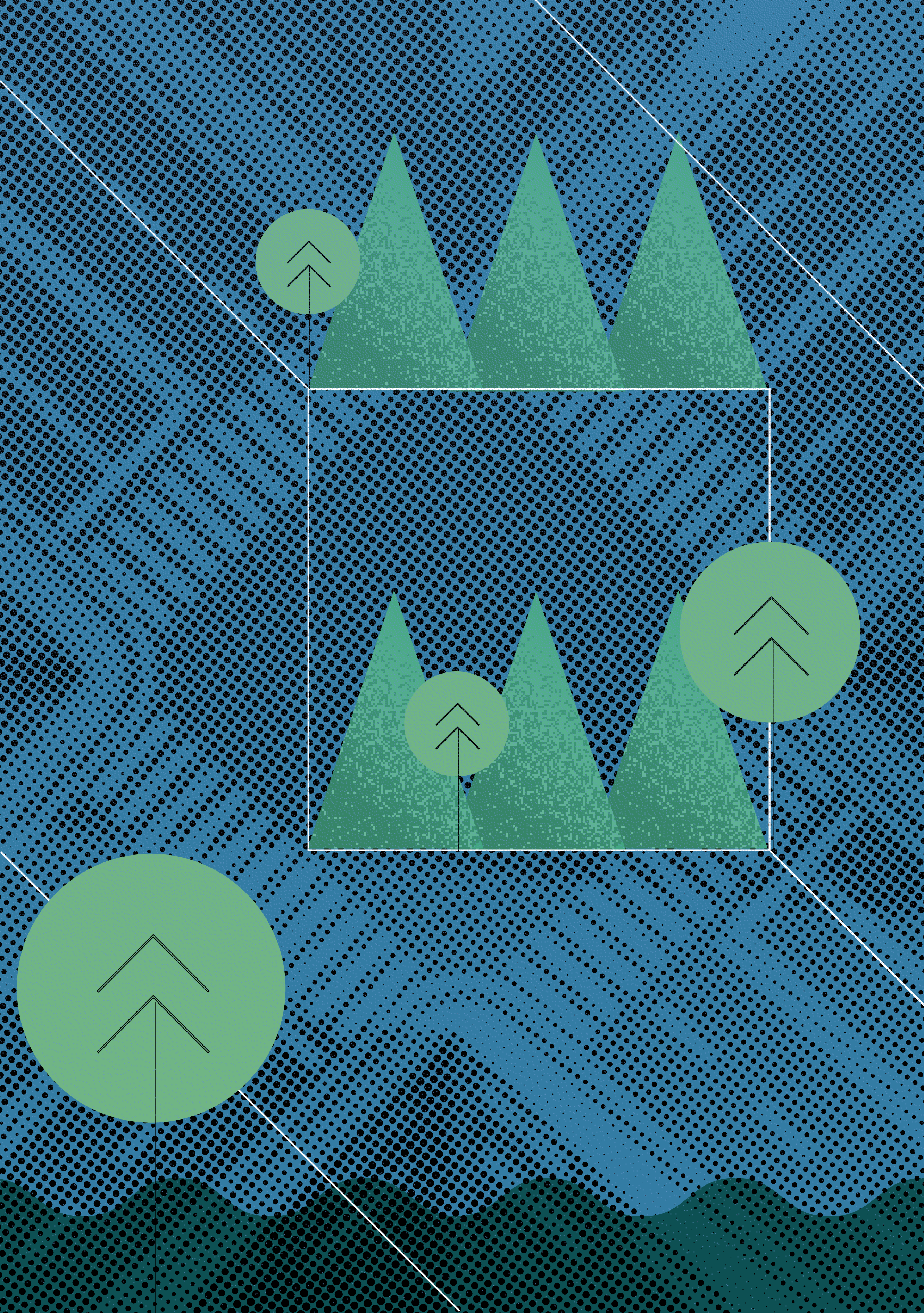
Results of the assessment confirms that environmental performances are context specific depending on both production choices and available infrastructures (Rufí-Salís *et al.*, 2022). Consequently, it is not possible to rightly understand the environmental performance of CUA in technologically advanced settings until uniform methodologies are developed and consistently employed. Thorough and transparent life cycle inventories (LCI) ought to be provided for all LCA studies of urban agriculture. Therefore, although often offered as clean alternatives to traditional agriculture, environmental issues remain a concern also in farms entirely (e.g. vertical farms) or partially (e.g. greenhouses) disconnected from the reference environment. While the sustainability of CUA is a strong political and marketing message for CUA stakeholders, many of these claims remain anecdotal if not fully contextualized (Martin *et al.*, 2022).

What is more, the sustainability of urban agriculture may not be entirely captured through environmental assessments alone. Other aspects of sustainability (e.g. socioeconomic benefits, economic implications, well-being, etc.) are not fully addressed by many of the existing environmental assessment studies of UA. A more holistic approach is required. Including economic and social dimensions is critical for decision-making, as environmental performance alone is not the primary motivation for urban agriculture but could justify public and private investment because of its positive impacts on land and building value, as well as the health and wellbeing of citizens. With reference to the latter, literature provides a large spectrum of economic advantages. Unfortunately, these studies cannot be aggregated or compared directly to one another due to the extreme diversity of case studies and methodologies applied (Table 4).

Table 4
Economic values in USD of ecosystem services provided by UA and estimated through various evaluation methods.

Ecosystem service	Evaluation method	Indicator of evaluation	Value	Reference
Temperature control	Replacement cost or avoided cost	Annual energy savings; annual direct energy savings; indirect energy savings	Up to USD 1.3/m^2 or USD 249/tree	Chen *et al.*, 2020 Wang *et al.*, 2014
Air quality control	Replacement cost or avoided cost	Annual pollutants removal; carbon storage; annual carbon sequestration; annual pollutants removal (PM2.5); annual pollutants removal (PM10)	Up to USD 0.6/m^2	Wang *et al.*, 2014 Chen *et al.*, 2020
Noise pollution control	Avoided cost, contingent evaluation (willingness to pay, WTP)	Annual abatement rate	Up to USD 0.06/m^2 or USD 20/person	Chen *et al.*, 2020 Wang *et al.*, 2014
Rainwater runoff	Replacement cost	Annual vegetation storage	Up to USD 0.09/m^2	Chen *et al.*, 2020
Aesthetic value	Contingent valuation (WTP), hedonic property value		Up to USD 25/person/year or USD 0.005/m^2/person/year	Wang *et al.*, 2014 Brinkley, 2012
Combined environmental benefits (biological control of pests, nitrogen fixation, soil quality, water quality, carbon sequestration, aesthetic view)	Replacement cost, contingent evaluation (WTP), purchase of agriculture conservation easements (PACE)		Up to USD 30.6/m^2 or USD 20/person/year	Chen *et al.*, 2020 Brinkley, 2012

SOURCE: Authors' own elaboration based on: Chen, S., Wang, Y., Ni, Z., Zhang, X. & Xia, B. 2020. Benefits of the ecosystem services provided by urban green infrastructures: Differences betweenperception and measurements. *Urban Forestry & Urban Greening*, 54:126774. https://doi.org/10.1016/j.ufug.2020.126774; Wang, Y., Bakker, F., De Groot, R. & Wortche, H. 2014. Effect of ecosystem services provided by urban green infrastructure on indoor environment:a literature review. *Building and Environment*, 77: 88–100. https://doi.org/10.1016/j.buildenv.2014.03.021; Brinkley, C. 2012. Evaluating the Benefits of Peri-Urban Agriculture. *Journal of Planning Literature*, 27(3). https://doi.org/10.1177/0885412211435172



Conclusions

Urban agriculture in general appears to be a valid investment option to support the sustainable development of urban areas and food security, and to enhance the overall resilience to climate shocks of people and infrastructures. Over the past two decades, new high-tech systems (i.e. CUA) have emerged, rapidly evolving into a capital-attracting business worth more than USD 5 billion globally.

While traditional urban farming has not shown any specific deviation from either its regular agriculture practices or its customary benefits within the social and environmental spheres, its high-tech version (e.g. rooftops and indoor vertical farms) is experiencing unprecedented growth, applying new business models that are fully profit oriented and venturing into other sectors like producing raw materials for food processing (e.g. basil and other herbs) as well as pharmaceuticals (e.g. pharmaceutical compounds).

Today's commercial urban farms, especially indoor vertical farms, represent the most advanced technology available in the agriculture sector and are attracting new actors. Agriculture in cities is no longer the sole domain of farmers and local administrators, but now includes IT and mechanical engineers, architects, builders, energy managers, marketing experts, nutrition scientists and other highly specialized experts. Traditional boundaries to profitable urban farming – such as land availability, access to resources and logistics, among others – are now potentially overcome thanks to its large infusion of technology and research and development investments. If well designed, modern high-tech farms are flexible and can be adaptable to space availability and other site characteristics (e.g. unused industrial sites).

Farms' dependency on geographical appellation (i.e. urban) appears to be linked more to marketing efforts than other considerations. There is an incorrect perception that commercial urban farms and especially vertical farms should be in highly urbanized areas to reduce the distance between production and consumers. Nonetheless, the most relevant geographical feature appears to be proximity to transportation infrastructure and food distribution hubs; features which appear to be more available in the outskirts of cities and in peri-urban areas as confirmed by our analysis of over 180 companies globally.

Commercial urban farming companies employ various strategies, technologies, and approaches, which demonstrates their versatility but makes it difficult to draw comparisons. As the sector continues to evolve and mature, the range of technologies and approaches remains diverse and a "one size fits all" approach is still not an option. While technology surely plays a key role in ensuring the success of CUA companies, the capacity to select and assemble existing technologies to reduce CapEx and OpEx and to guarantee the necessary flexibility is a very high-level skill not common to all urban farmers. Therefore, this study identified human resources as a key investment, but skilled workforce at all levels – with the exclusion of a few countries – is still far from being available at reasonable costs.[21] This aspect is important because the involvement of an innovative and knowledgeable workforce is fundamental to fostering the economic transformation of UA in both low-income and wealthier countries and to reducing the risk of lock-in with ineffective technologies or permanent large R&D costs. This would facilitate the adoption, scaling up and spillover of technologies irrespective of where agriculture investment takes place, and facilitate the shifting of producer demographics in favour of young entrepreneurs. Spillovers from CUA to conventional and controlled agriculture are already noticeable. Hybrid systems (e.g. vertical and greenhouses) are already functioning in countries that are highly specialized in agriculture and where investment in agriculture related education is higher, such as the Kingdom of the Netherlands and Türkiye, but also in Singapore and Saudi Arabia.

The high-tech stem of CUA (e.g. indoor) is still evolving, appears far from being mature and remains highly dependent on the context of operations. Often, companies fail to clarify if their business objective is the production of crops or the technology and expertise developed. While both can occur

21 The annual cost of a skilled head grower in the United States of America can easily surpass USD 120 000, not including taxes and benefits.

simultaneously, the second appears more as a result of the process rather than its objective. This aspect was particularly evident in those companies that recently declared bankruptcy. Since 2021, several companies have declared bankruptcy or had to drastically modify their business models causing investment losses estimated at about USD 740 million. As noted in this report, the feasibility and profitability of urban farms – especially those investing largely in technology (e.g. indoor vertical farms) – are not solely dependent on sound business models but also, when high CapEx/OpEx are expected, on the existence of minimum prerequisites within a country to integrate these agricultural approaches. The analysis of over 147 indicators (economic, environmental, and social) identified as "very favourable" eight countries (Poland, Czech Republic, Estonia, Hungary, Slovenia, Slovakia, Türkiye, and Cyprus), and ten countries as "favourable" (Greece, Ukraine, Lithuania, Latvia, Croatia, Bulgaria, Romania, Serbia, Kazakhstan, and Azerbaijan). While this analysis cannot guarantee the success of investments, it provides investors and policymakers with valuable insights for planning investments and refining research and development efforts. Furthermore, the analysis suggests that a balanced approach combining knowledge and technology is crucial for sustainable and successful CUA practices and to foster their cross-pollination with conventional agriculture.

Energy represents the primary operational cost (up to 53 percent) for high-tech companies and energy needs remain 2 to 18 times higher for vertical farms than for advanced greenhouses and traditional agriculture. On the other hand, vertical farms enable achieving a much higher yield as compared to greenhouses, leading to values of energy consumption for unit of product of around 4.5 and 2.5 kWh/kg respectively for vertical farm and greenhouse cultivation (Stanghellini and Katzin, 2023). Although some farms are now producing energy independently, access to cheap and renewable energy remains a major operational and environmental concern. Companies that do not reduce their energy needs will face greater inherent risks and be less flexible compared to alternative options such as open-field farming and traditional greenhouses.

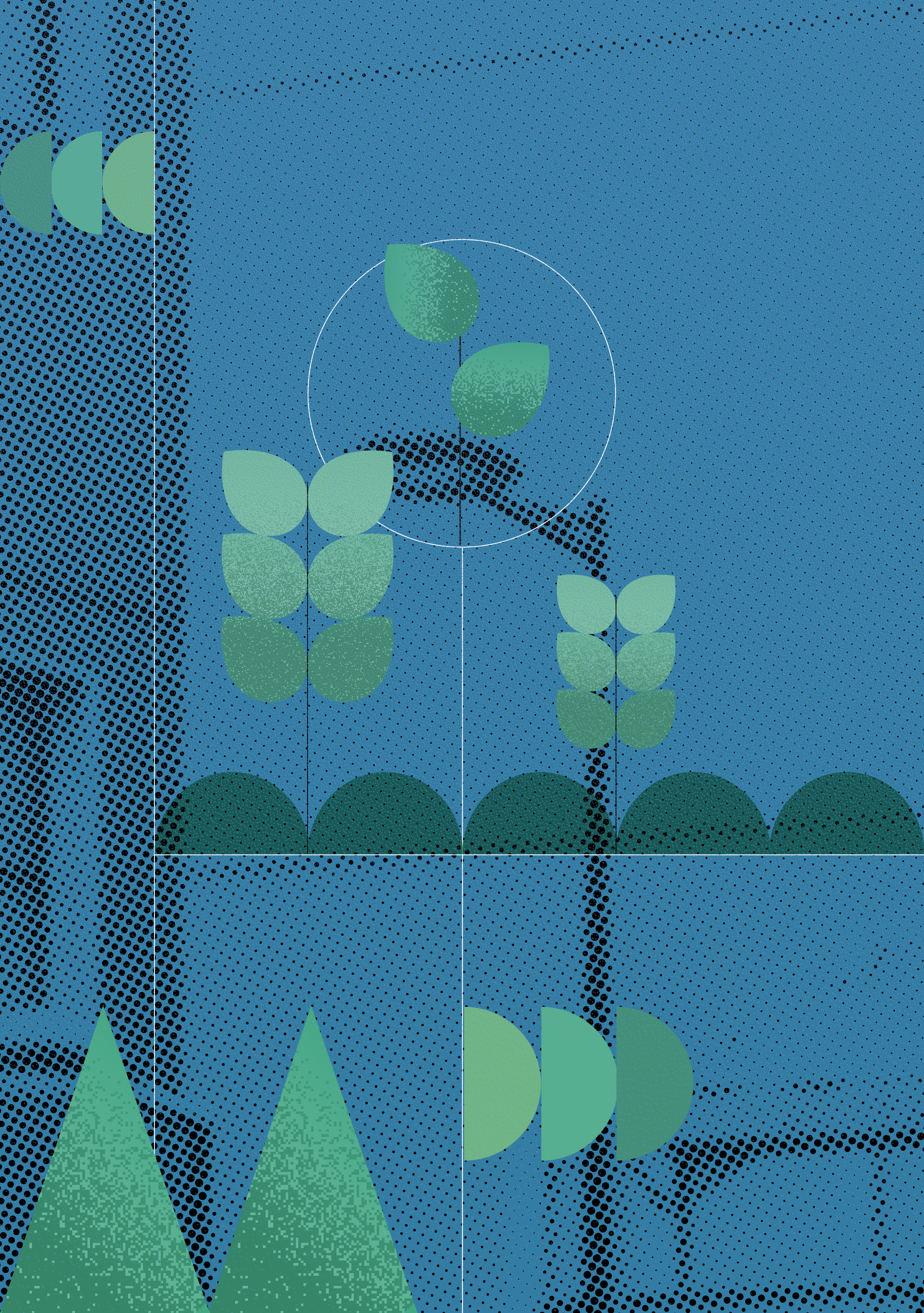
Literature highlights the positive social and environmental impacts of conventional urban farming, including some of its more advanced forms (e.g. rooftop), but this does not necessarily apply to more advanced commercial urban farms such as indoor vertical farms. Concerning the latter, existing literature supports general claims about productivity per square metre, product quality, extended shelf-life, and some environmental benefits (e.g. water savings, absence of pesticides, reduced land use, and reduced food loss), but others such as GHG emissions remain unclear and context-dependent (e.g. energy and climate). Research thus far confirms that, compared to greenhouse and field farms, GHG emissions for vertical farms are probably high at the farm gate due to their significant energy consumption and limited access to renewable energy sources, but could also be lower when adding transportation and retail related GHG emissions. Benefits from the different types of urban farming are linked to the features or technologies that a system may include or exclude as well as to the geographic and climatic context and availabe energy system where farms operate. Regardless, once renewable energy is available in higher shares, and energy management reduces the energy requirements of CUA farms, they can become a strategic tool in responding to various shocks and challenges, such as climate change, and can help reduce the impact of changes in land use and the consequent loss of biodiversity. An example is the 2020–2021 lettuce crises in the United States of America and United Kingdom, where traditional production was affected by soil viruses, resulting in decreased supply and increased prices. In contrast, high-tech farms, not affected by such shocks due to their production model, were able to meet increased demand and stabilize prices.

From a regulatory perspective, CUA is still facing lack of recognition as a professional activity, mainly due to the limited scale of companies, their negligible impact on political decisions and the sociocultural biases raised by the contraposition of city and countryside for food production. One of the main legal constraints pertains to zoning, which categorizes areas for specific use (e.g. commercial, residential, agricultural), making it difficult to employ unused commercial or residential spaces for cultivation. Additionally, the wider uptake of high-tech solutions (e.g. vertical farms and rooftop greenhouses) is further inhibited by the absence of enabling regulations (e.g. building codes, resources use, waste management), the difficulty of municipal administrations to define these cases (e.g. agriculture vs industry), and the inability of high-tech CUA solutions to access agricultural incentives, subsidies and denomination such as "organic,"[22] which are often limited to conventional rural agriculture schemes. Therefore, the need to assess the potential of including CUA and other indoor farming products into the broader agriculture sector and start planning cities with an eye to the documented benefits of urban farming in all its expressions remains high. Levelling CUA and high-tech products with conventional ones may allow for more even standardization of prices and faster uptake and spinoff of technologies. Including urban agriculture among the possible activities in the urban planning will facilitate and speed up the conversion of abandoned industrial areas and the planning of infrastructural investments.

CUA holds significant promise, but structural changes within companies and investments beyond companies (i.e. education and infrastructures) are still needed to foster its growth, maturity, sustainability, and overall contribution to the agriculture sector. Promising variables, including water conservation, enhanced productivity, streamlined supply chain processes, and stringent control over fertilizers and pesticides instill hope and optimism in the outlook of high-tech commercial urban farming. However, despite these positive aspects, the industry must engage with several challenges including high energy costs, lack of a specialized workforce, a murky legal framework of reference, and unclear capacity to yield sustainable profits.

The potential setback in these crucial areas, among others, carries the risk of undermining the environmental milestones already achieved and dampening both investor enthusiasm and consumer trust. This, in turn, could relegate the entire sector to a scarcely replicable experiment, viable only in specific and marginal contexts. It is imperative for the industry to navigate these challenges adeptly, ensuring not only its own viability but also maintaining the momentum towards a more sustainable and profitable future.

22 In the United States of America and Singapore, this barrier is removed and indoor products – including those from vertical farms – regardless of the areas of production, can apply for the “organic” denomination. In the European Union, this is not possible for products that are not grown in soil.



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From 2021 through 2023, the Food and Agriculture Organization of the United Nations, University of Bologna, Wageningen University and Research, University of Liège and others conducted an exhaustive study assessing the state of commercial urban agriculture (CUA) globally, with special focus on countries in which the European Bank for Reconstruction and Development (EBRD) operates. Their key findings are summarized in this groundbreaking report. It differs from other studies in its focus on urban agriculture as a for-profit enterprise, exploring the inherent risks, challenges and opportunities associated with investing in agriculture in urban settings and paying due attention to its social, economic, and environmental implications. The report outlines the pros and cons of the various business models employed by CUA enterprises and addresses issues pertaining to their sustainability, scalability, and overall readiness for investment. The goal is to better inform investment decisions. This publication is part of the Directions in Investment series under the FAO Investment Centre's Knowledge for Investment (K4I) programme.

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