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How to make urban farming economically viable?

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Abstract

Urban farming, also called urban agriculture (UA), represents a promising solution to achieve some of the SDGs (sustainable development goals) identified by United Nations. Indeed, UA is a multifunctional activity that presents interesting social, economic and environmental opportunities. The economic viability of UA is a hot topic, given the recent exponential growth in interest by companies and investors throughout the last ten years. The interest is also reaching public and private investors, being an opportunity for economic advancement in most countries, including EBRD (European Bank for Reconstruction and Development) countries of operation. Despite the growing interest and the manifested potential, some drawbacks are still hindering the development of UA, raising questions especially on the feasibility from a financial point of view. In particular, aspects such as the resource use efficiency, technological inputs and business models, still need to be expanded in order to correctly and efficiently apply and adapt UA to different local environmental and socio-economic conditions. The present paper aims to summarize the ongoing situation of UA, with respect to the main resources, technologies and business models to identify weaknesses and strengths for further improvement of the sector.

Keywords: urban agriculture, vertical farming, EBRD, business models, resource use efficiency

INTRODUCTION

Urban farming, also called urban agriculture (UA), is the cultivation of plants and livestock within cities and towns or in their immediate surrounding (FAO, 2003). It is acquiring a global interest, as it can contribute to the achievement of different sustainable development goals (SDGs) identified by the United Nations (Stevens and Kanie, 2016), and to the creation of a green economy (Merino-Saum et al., 2020), countering the economic and environmental crises that the world is facing. Indeed, with more than half of the global population currently living in cities – which is only expected to increase (FAO-FCIT, 2022) – urban areas must play a central role in achieving a sustainable growth and in assuring sustainable food systems. In this context, expanding green and productive agrifood infrastructures can represent an innovative solution to improve urban sustainability, while promoting ecological, social and economic benefits.

Since competition for urban land use and the resulting excessive costs could hinder profitability and therefore the increase in UA practices, the exploitation of unused city spaces such as rooftops or abandoned buildings, or the optimization of surface use cultivating on vertical layers, may represent solutions to overcome these barriers (Beacham et al., 2019; Appolloni et al., 2021). Thanks to new farming technologies, UA can be performed inside or on top of buildings with different modalities, called building-integrated agriculture (BIA) (Specht et al., 2014).

Urban farming has different degrees of technological integration, ranging from low tech

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systems (e.g., simplified hydroponics, commonly used in community gardens), to more intense ones (e.g., rooftop greenhouses in BIA and commercial aquaponic systems). Among the different forms of BIA, vertical farming (VF) is the one requiring the greatest number of technological inputs, including climatic insulation, environmental control, and artificial lighting. VFs are also referred to as plant factories with artificial lighting (PFALs) (Kozai et al., 2019). These indoor systems can allow for cultivation in different contexts independently of outdoor conditions, protecting the production from pests and climate change impacts, and contemporarily guaranteeing high yield and quality products optimizing use of agricultural inputs, including land, water and nutrients (Benke and Tomkins, 2017). Given these characteristics, VF, and UA in general, present interesting commercial opportunities for economic development especially in emerging countries, including European Bank for Reconstruction and Development (EBRD) countries of operation. However, the current status, including resource use efficiencies, technological inputs, and business models (BMs), need to be properly defined and discussed in order to better understand the economic viability of UA and adapt the business to the specific local conditions. With this purpose, the Food and Agriculture Organization (FAO), together with University of Bologna, Wageningen University, and University of Liege, developed three analyses to respectively investigate the state of the art, technologies, and BMs of UA, presenting the results during the workshop organized by FAO and the EBRD, held at the 31st International Horticultural Congress (IHC 2022) in Angers, France, on August 18, 2022. The present paper summarizes the main outputs presented during the seminar, with the final aim of discussing new solutions to render UA more economically viable and inclusive.

URBAN FARMING ECONOMIC VIABILITY

Agri-cities reinventing rural and urban areas – University of Bologna

UA presents interesting economic, environmental and social benefits. In order to evaluate the opportunities related to this form of agriculture, a study identifying over 750 key actors in 82 countries was developed by the University of Bologna, Italy, together with FAO. The key actors include 250 large and medium farming companies, 218 technology and input providers, 222 universities and research centers, 50 investors, 7 retailers, 14 architecture studios and real estate developers, 6 human resources (HR) recruiters and 19 lead municipalities.

The data collected demonstrates the existence of a diverse group of operators, while the analysis shows that the majority of commercial production is performed in rented spaces (65%), using soilless controlled environment technologies (70%), with VF being the most used form of UA (40%). Furthermore, farming companies showed to operate at least 1,000 m^2, and mainly serve local and national markets (80%). Finally, especially in VF systems, results show that urban farming companies can save up to 90% of water kg^{-1} vegetable and achieve 70 times higher yield per unit land area (Orsini et al., 2020). On the other hand, these systems are still highly energy-intensive although improving year by year (with an estimated reduction of energy needs by 30% in 5 years) and sourcing more and more from renewable energy sources (van Delden et al., 2021).

Over the last 10 years, the number of commercial urban farms and tech providers has significantly increased. At the same time, the average data from market studies showed an exponential growth in investment in VF reaching about USD 6 billion in 2022 (Markets and Markets, 2022). Companies also reported a change in investors in the last 3 years. Although venture capitals and private investors are still the main players, other actors are entering into the sector (e.g., commercial banks, retailers, property and real estate developers, public investors), suggesting that the sector may be exiting the start-up phase and gaining maturity.

The VF sector still have many drawbacks and opportunities especially related to resource use efficiency. In particular, energy use efficiency, intended as the fresh weight (FW) produced kWh^{-1} (g FW kWh^{-1}) has been a major focus. Indeed, the sector is highly energy demanding, with energy consumption requirements close to those of the meat production sector (1-50 g FW kWh^{-1} for lettuce production and 80-130 g FW kWh^{-1} for meat production)

(Orsini et al., 2020). It is of fundamental importance to achieve an abatement of energy consumption in VF sector, improving research and technology, and applying artificial light reduction strategies such as pulsed light or shorter photoperiods. Nonetheless, use of renewable energy sources can support the remaining energy demand with less impacting solutions. Although GHG emissions (g CO_2 kg^{-1} of plant fresh biomass) for UA are high (10-25 g CO_2 kg^{-1} in VF for lettuce production) compared to other more traditional cultivation systems, such as field and greenhouse production (0.01-0.38 and 0.21-3.15 g CO_2 kg^{-1}, respectively) (Orsini et al., 2020), emissions have been continuously decreased over the years, with values going down to 5.7 kg CO_2 kg^{-1} in recent reports for VF (Vatistas et al., 2022). Even after reduction, the impact still remains more than 10 times higher than traditional cultivation techniques. However, margin for improvement in reducing impacts is still possible, without mentioning that the hydroponic systems, as those applied in vertical farming, can increase yield by 10 times and reduce water consumption by 10 times as compared traditional agriculture (Beacham et al., 2019). In particular, water use efficiency (fresh biomass produced per unit of used water, g FW L^{-1} H_2O) can be much higher in the case of VF (45-80 g FW L^{-1} H_2O for lettuce production) as compared to field (3-20 g FW L^{-1} H_2O for lettuce production) and greenhouse systems (5-60 g FW L^{-1} H_2O for lettuce production) (Orsini et al., 2020). Finally, land surface use efficiency (fresh biomass per unit of occupied land, kg m^{-2}) is drastically higher in VF systems, given by the possibility to cultivate on multiple layers (FAO/EBRD survey, 2022).

Business models in urban and peri-urban agriculture – University of Liege

The University of Liege, Belgium, developed a research report with the objective to define, analyse and present the different business models (BMs) of UA. To achieve this objective, the methods applied consisted in an online questionnaire to obtain quantitative data, semi-structured interviews to collect qualitative data, and compilation of BM canvas templates to compare the different models. The sample of the evaluation was made by 24 organizations and companies across 17 countries.

A business model describes the rational of how an organization creates, delivers and captures values (Osterwalder and Pigneur, 2010). Literature identifies six main BMs in UA (Pölling et al., 2015):

- The shared-economy BM focuses on participative projects that connect people with nature, with the final aim of building community and social cohesion;
- The experimental BM focuses on testing the viability of new technologies, techniques, or business models;
- The experience BM focuses on the development of events and well-being activities to favour connection with nature and social cohesion;
- The diversification BM focuses on offering local, sustainable, and healthy products, as well as a connection to nature;
- The differentiation BM focuses on high added-value products such as microgreens, herbs, or edible flowers, with the aim of offering unique quality products usually addressed to premium costumers (e.g., restaurants);
- The cost-reduction BM focuses on production of easy to grow crops such as lettuce, aromatics, and microgreens with selling points of quality, locality, and nutrition for the mass market.

The above BMs can differ depending on technology applied, occupied surface, number of employees, and HR qualification level, influencing business profitability. The results of the research showed that, in a shared-economy, experience and diversification BMs, high qualification level in terms of specific technical knowledge is not requested. On the contrary, in the case of experimental BMs, differentiation and cost-reduction, high qualification is fundamental, given the specialization of production and high economic investment. Indeed, in a shared-economy, experience and diversification BMs present investments ranging among 20,000-500,000 USD, often supported by public investments; in an experimental BM, differentiation, and cost-reduction can constitute investments above 1 M USD. These investments are particularly high in the case of a cost-reduction BM, ranging between 2 M to

10 M USD, as they are more driven by economic interest. From a technological standpoint, shared-economy and experience BMs often apply traditional on-soil agriculture, opposite to the other business models, which are more open to innovative cultivation systems such as hydroponic, aeroponic, aquaponic, vertical farming, rooftop farming, etc. The cultivation system applied can also influence the occupied surface, reaching 40 ha in case of shared-economy. On the other hand, the other BMs use less surface (from 0.1 to 5 ha), although cost-reduction normally employs higher surface, increasing production and reducing total costs. Given the intensive production, cost-reduction BM also requires the highest number of employees (15 employees per company on average), while shared-economy, experience and diversification BMs make use of limited number of employees and volunteers (2-6 employees or volunteers per company). Finally, each BM presents success factors and challenges, which have been summarized in Table 1.

Table 1. Success factors and challenges of urban agriculture (UA) business models (BM).

Business model	Success factors	Challenges
Shared-economy	- To ensure land access - To create a strong community - To define clearly the company's purpose	- Public authorities' involvement - Economic viability - Customers' involvement (voluntaries, etc.)
Experimental	- To ensure land access - To create a strong community - To define clearly the company's purpose	- To find investors who agree to invest in pilot projects - Design scalable projects - To ensure economic viability
Experience	- To ensure land access - Strong communication strategy - To respond to customers' needs	- To reach customers - To retain customers - To ensure economic viability
Diversification	- Offer based on customers' needs - Limited number of diversification offers - Attractive and positive branding	- To cover farm costs with products sales - To reach different customers segments - HR able to manage all the proposed activities
Differentiation	- To identify locally demanded high value-added products - To ensure the quality of products - Know-how and trained HR	- To find enough customers to sell HQ products - To distinguish from competition - To have access to highly qualified human capital
Cost-reduction	- Sufficient size for scale economy (>1 ha) - R&D pre-creation investment (>1 M USD) - Existing know how and presence of trained HR	- To find market to sell high quantity of products - To minimize the cost of production - To have access to highly qualified HR

During the research a new business model was identified, namely the farm management BM. This type of business is often implemented by experimental teams that developed high level know-how on building and managing farms. The farm management BM consists in selling tailor-made farms, and managing it for their clients such as food production companies, hotels or restaurants. This type of business needs high pre-investment for research and development (R&D). Once it starts operating, it would start being profitable and scalable. This BM strives to develop commercially-driven companies, addressing private companies involved in food industry, therefore establishing a direct relationship with customers. The companies offer to build and manage the farm, often developed using hydroponics in closed environments. High qualification level of HR is required, with about 10 employees. The investment usually ranges between 100,000 and 5 M USD, with 3 to 5 years to reach the breakeven point, depending on farm size, type of production or level of automation, for instance.

The research pointed out that companies refusing to share financial information cause uncertainty among investors and a general misunderstanding over the economic viability of UA. Accordingly, to boost scaling up of the sector, it is crucial that consolidate economic figures become available. Furthermore, it is important to consider that the viability of BMs can be affected by the evolution of the global context, including climate change, lack of resources and technology improvements. Urban farming should implement marketing strategies suited to costumer demand, rather than only focusing on technical analyses and technological improvements, or public subsidies (e.g., share economy BM, experimental BM and others).

Technologies in urban and peri-urban agriculture – Wageningen University

Research on the most advanced technologies in UA was developed by Wageningen University, The Netherlands, with a specific focus on VF systems. The research specifically built upon both a literature review and interviews with the operators of the sector, mainly commercial farms. It considered aspects like crop variety, yields, costs, architecture and automation, lighting, climate, root zone, sensors and algorithms, genetics, as well as potential of downscaling of technology.

Crop yield is an important focus of technologies for UA, specifically VF. Annual leafy green and tomato yield in VFs can almost double compared to greenhouse on a growing area basis, and achieve a 50 times higher yield compared to open field. Although, these yields for tomato have been achieved, costs still remain too high for profitability. One of the aspects that can hinder VF applications are the capital expenditures (CapEx, € m^{-2} of production area). Compared to open field with CapEx ranging from 0.5 to 50 € m^{-2}, a VF can easily achieve a CapEx between 1,000 and 4,000 € m^{-2}, excluding the costs of the building. The operational expenditures (OpEx, € m^{-2} of production area $year^{-1}$) are mainly related to energy and labour, which respectively represent 20-40 and 25-40% of total OpEx, while the estimated costs can be 58-73 and 20-400 € m^{-2}, respectively.

Energy cost of VF can be divided into three categories: light, climate control, and crop operations. Light is the largest energy cost, representing 42-80% of the total (Table 2). In the past 20 years, lamps efficiency has significantly increased, which significantly reduces the total energy cost for lighting although, because other efficiencies are also increasing, the percentage of energy cost that is lighting will likely remain the same. Cost of climate control refers to temperature, humidity, airflow, and CO_2, which are essential factors for optimal plant development, photosynthesis and transpiration. These parameters can be easily monitored by sensors. Sensors related to light intensity, spectrum, temperature, humidity, air flow, CO_2, oxygen concentration, and volumetric water content, are already available and widely applied in the industry, while those for plant performance evaluations and phenotyping, as well as algorithms to interpret large quantities of data, are still immature. However, algorithms applications may significantly optimize plant growth and increase system efficiency, merging machine learning with existing plant knowledge to predict plant performances.

Table 2. Energy costs in vertical farms (L. Marcelis, pers. commun.).

Cost category	Crop	Lighting	Climate control (HVAC)	Crop operations
Proportion (%)		42-80	16-43	0.4-3
Energy use (kWh m^{-2} $year^{-1}$)	Lettuce	960	406	11
Energy use (kWh m^{-2} $year^{-1}$)	Tomato	753	233	20

The specific architecture of a VF – including aspects like stacked layers vs vertical walls, modularity, size, and level of automation – can increase the investment cost, but at the same time it can allow for increased resource use efficiency, yield and quality. A VF can assume different forms, including in-store mini-systems, productive containers, indoor productive modules, and entire buildings (Figure 1). Within these systems, plants can be cultivated as stacked layers or vertical walls. In the first case, the installation is easier and potentially more cost efficient, although the maintenance of climatic conditions among layers can be more difficult. On the contrary, vertical walls or towers can increase climatic uniformity, but can be less easy to install and manage. The vertical walls also present a more feasible opportunity for automation, such as moving between growing stations or automatically rise and lower cultivation layers. Automation represents an important point to increase the efficiency of these growing systems, increasing crop uniformity, reducing labour costs, and reducing investment into sensors technology. However, high automation can represent significant costs, ranging among 830-1,270 € m^{-2} of the growing area.

Figure 1. Vertical farms (VF) typologies, including: a) in-store mini-systems (Infarm), b) productive containers (Agricool), c) indoor productive modules (Infarm), and d) entire buildings (Aerofarms).

The type of growing system can influence the overall efficiency of VF, allowing for a recirculation of water and nutrients, thanks to the application of hydroponic systems (e.g., drip system, deep water culture, nutrient film technique, flood and drain, aquaponics, high pressure atomization and aeroponics) (van Delden et al., 2021). Genetics can also play an important role in increasing the efficiency of VF, helping to maximize the light use efficiency, increase the marketable yield, improve the quality, facilitate crop management and reduce costs.

Despite above-mentioned systems do increase efficiency, the downscaling of technologies should consider a reduction of investment costs through the reduction of automation, horizontal rather than vertical growth, and an application of simple flexible systems. Reduction of operational costs would also be important, considering the application of VF/greenhouse hybrid systems, which may reduce the ability to control the climate, but also reduce the associated capital investments and operational costs (e.g., for lighting). Although downscaling of technology may reduce production quality, businesses should consider the local demand, market and environment in applying the most adequate production system.

CONCLUSIONS

The research highlighted the current potential and limits for the economic development of UA. A change in investors was observed in recent years, due to a growing interest by different UA stakeholders. Energy sourcing and management still present constraints, although the observed speed in technological development leaves a wide margin for reducing energy requirements and costs. VF represent an interesting opportunity for UA business development. However, some aspects should be considered. Automation, horizontal vs. vertical cultivation systems, and potentialities for the application of simple and hybrid systems need to be properly assessed against market demand and context. The lack of knowledge on economic viability is still hindering the sector development, and this is mainly due to the limited openness to share financial information of companies. Nonetheless, to achieve economic sustainability, urban farming should consider the customer demand more, and invest in marketing, rather than only focusing on technological improvements.

During the workshop, discussion was raised in the audience, especially in reference to the high investment required by VF systems and consequent feasibility for the technology adoption in the global south. High-tech commercial farms are already growing in of Africa, Caribe and Asia. However, research and technological development for VF downscaling remains fundamental to support a better distribution across emerging economies. The studies presented in the workshop do not necessarily advocated for VF, but indeed explored how different business models and technological opportunities may make a difference on the future food systems.

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