A Work Project presented as part of the requirements for the Award of a Master's degree in Management from the Nova School of Business and Economics.

CHALLENGES OF URBAN AGRICULTURE: CENTRALIZED OR DISTRIBUTED NETWORKS?

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16/12/2022

Acknowledgments: First and foremost, we would like to thank our supervisor Professor Utku Serhatli, for providing us with all the necessary assistance in this project. A special thank you goes out to Mr. Artur from Hortiart, Mrs. Francelina Santos and Mrs. Ana Lúcia Santos from Hexágono Padrão, and Mr. Gonçalo from Thomar Land, for their valuable time in sharing with us their systems of production. Also, a thank you goes to those who took the time to respond to our public survey. Lastly, to our families, friends, and colleagues at Nova SBE, for all their support and inspiration.

Abstract: About 60% of the global human population is expected to be living in cities by 2030 (UN 2020). Complex food supply chains will be disrupted, and meeting demand will be an increasing challenge. This thesis aims at finding to which extent it is more beneficial for Urban Farms to centralize or distribute operations. Economies of Scale and Risk Pooling are found to be factors in favor of centralized networks, while Transportation Costs and other intangible benefits are shown to be factors in favor of distributed networks.

Keywords: Urban Agriculture; Z-Farming; Controlled Environment Agriculture; Building Integrated Agriculture; Producer Organizations; Centralized Networks; Distributed Networks.

This work used infrastructure and resources funded by Fundação para a Ciência e a Tecnologia (UID/ECO/00124/2013, UID/ECO/00124/2019 and Social Sciences DataLab, Project 22209), POR Lisboa (LISBOA-01-0145-FEDER-007722 and Social Sciences DataLab, Project 22209) and POR Norte (Social Sciences DataLab, Project 22209).

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1. Introduction

1.1. Problem Definition

The 21st century is considered by many as the first "urban century", with an expected 60% of the global human population living in cities by 2030 (UN 2020). Urban agriculture has gained increasing notoriety in the last decade, with this demographic shift and the growing need for more sustainable cities and food production systems (Stewart et al. 2013). As centers of production, distribution, consumption, and waste generation, the energy and material flows within the urban comprise around 70% of global GHG emissions (Economist Impact 2022). Therefore, Urban Agriculture (UA), in attempting to be part of a shift toward more sustainable and resilient cities, seeks to address these co-existing human and environmental crises. However, new and innovative forms of scaling UA, associated with Zero Acreage Farming (Z-Farming) and Controlled Environment Agriculture (CEA), have found themselves at somewhat of a crisis point. CEA systems are transitioning from an emerging market, but many have struggled to find funds to scale and a market to achieve profits, with industry leaders announcing major redundancies (Colangelo 2022; Marston 2022).

1.2. Research Goals

This thesis seeks to provide an outline of the challenges and opportunities for scaling UA in Portugal, where innovative forms of UA have yet to gather momentum (Delgado 2017).

The literature review will elaborate on how this thesis embraces the multipurpose strategic and operational capabilities of the different representations of UA, which are presented here in three mutually inclusive categories. These are: Urban Allotment gardens; Z-Farming; and CEA and TCEA (Total Controlled Environment Agriculture) systems. Indeed, we suggest that these categories are mutually inclusive rather than exclusive because there is some overlap between their different production methods. Recognizing that the adoption of different forms of UA is context specific, a series of environmental, economic, and social advantages and disadvantages, that reflect the relationship between UA perspectives and their impacts will be presented. Portugal, and more specifically the strawberry production industry, have been used to narrow the market analysis and producer insights, before finally moving on to a capacity size and location strategy discussion of best policy practice.

Touching on this, the present work aims at answering two different Research Questions:

1.2.1. What are the principal market challenges to scaling Urban Agriculture initiatives in Portugal?

1.2.2. Centralized vs. Distributed Networks: Which one best suits Urban Agriculture?

This part of the research will aim at finding the best network strategy to adopt: whether it is more beneficial for Urban Farms to centralize or distribute its operations. In order to discuss the implications of each of the strategies, an in-depth analysis is performed focused on the advantages and disadvantages of Urban Agriculture – in its higher-tech forms, – that will later impact the discussion.

The most relevant advantages and disadvantages are analyzed: Productivity proves to be better in high-tech UA installations as space is used more efficiently (Kalantari et al. 2017) and plants themselves become more efficient (Max 2011); Environmental impacts, mostly in the form of water and energy requirements. Water consumption is reduced to around 10% of what traditional agriculture requires (Besthorn 2012; Foroohar 2020), while energy requirements represent the main drawback of TCEA installations, showing consumption higher than 1,300kWh per ton of strawberry produced; Furthermore, reduced variability represents a principal benefit of indoors production since the impacts of Climate Change and the risk of pests and plagues are reduced, or even eliminated, reducing yield variability; Benefits related to the quality of product are also pointed out, such as improved nutritional value, color and flavor due to controlled flows of compounds in the solution (Parkes et al. 2022; O'Sullivan et al. 2019), and reduced damages to the produce due to shorter supply chains (Despommier 2013).

Alongside this analysis and whenever data is available, two different scenarios are built: one of a small city farm with 375m^2 and the second of a peri-urban farm with 2,800m^2; This helps quantify the impact of certain advantages and disadvantages of UA in each of the scenarios and support further discussion where factors in favor of each of the strategies are clearly defined. This discussion is built around an analysis of Scale Economies, Risk Pooling Effect, Outbound transportation costs, and Intangible Benefits. Therefore, this project's originality is the studied interaction between capacity size and location, applied to the context of high-tech forms of Urban Agriculture.

2. Literature Review

2.1. Definitions

Urban Agriculture (UA) can be defined as an activity that involves the production, raising, processing, or distribution, of a range of food and other non-food products, located within the urban or peri-urban regions (Delgado 2017; Parkes et al. 2022).

Peri-urban agriculture (UPA) is situated at the interface of the urban and rural regions, in which the urban itself is fragmented rather than clearly demarcated. Through these regions, UA and UPA thus follow a local-to-local model from production to consumption (Delgado 2017).

Building Integrated Agriculture (BIA) implies a synergy between the production installation and the building (O'Sullivan 2019). For instance, it may represent flows of heat and water wasted from the building to the installation (Astee, Kishnani 2010; Thomaier et al. 2014; Cerón-Palma et al. 2012).

2.2. Urban Agriculture: An Overview

UA is a heterogenous term, that should always be context specific in its application, and which can provide different perspectives on how it is viewed, whether as an environmental, economic, or social action (Cabannes 2012; Delgado 2018). These different perspectives, which orient UA towards different impact objectives, have meant that UA serves as an umbrella term for a multitude of different urban agricultural practices, each with different systems of production and incorporations of technology. Hence, UA cannot simply be separated into conventional agricultural methods located in the urban sphere, and new high-tech forms of agriculture such as TCEA, as recent literature has highlighted the significance of other forms of UA, in a halfway point in between, such as Z-Farming.

i. Firstly, the most common and traditional form of UA worldwide, as in Portugal, is known as "Hortas urbanas", which can be roughly translated as "urban allotment gardens". UA in this manner can be dated back to Mesopotamian farmers, around 4000 to 600 BC, who began creating small farming plots in cities. The UN estimates that there are currently 800 million people worldwide cultivating food products in cities, most of which, in this manner (Dieleman 2017; FAOU 2022). These "hortas", as they are commonly understood in Portugal, are generally low-tech and adopt conventional soil-based farming methods. These are generally for individual production purposes, whether in the form of a privately owned, or a rented-out public allotment garden (Simon-Rojo et al. 2015). There are also "hortas" based on collective schemes or projects with a range of educational, therapeutic, social/recreational, or community-based objectives (Simon-Rojo et al. 2015; Richter et al. 2022). In this instance, more commercial or market-driven objectives are largely absent.

Figure 1: Urban Allotment Garden in front of Colombo Shopping Centre, Lisbon. Source: Rito 2018.

ii. Secondly, there is Z-Farming, which can be understood as advanced models of green infrastructure that bring together architecture, food, and production, in an attempt to scale urban food production both in and on buildings within the urban sphere (Specht et al. 2014). Z-Farming is associated with "multifunctional buildings", that can include “rooftop agriculture (RT), rooftop greenhouses (RTG), and integrated rooftop greenhouses (IRG)” (Parkes et al. 2022, 5), the latter reflecting a Building Integrated Agriculture (BIA) approach (Parkes et al. 2022). These context-specific interpretations of Z-Farming adopt different degrees of technology. RT is often quite low-tech and similar to traditional urban allotment gardens and RTG is equally low-tech but inside a greenhouse, whilst IRG adopts more advanced technological practices that embrace a synergistic use of energy resources between the agricultural process and the urban building in which it is located on (Buehler, and Junge 2016).

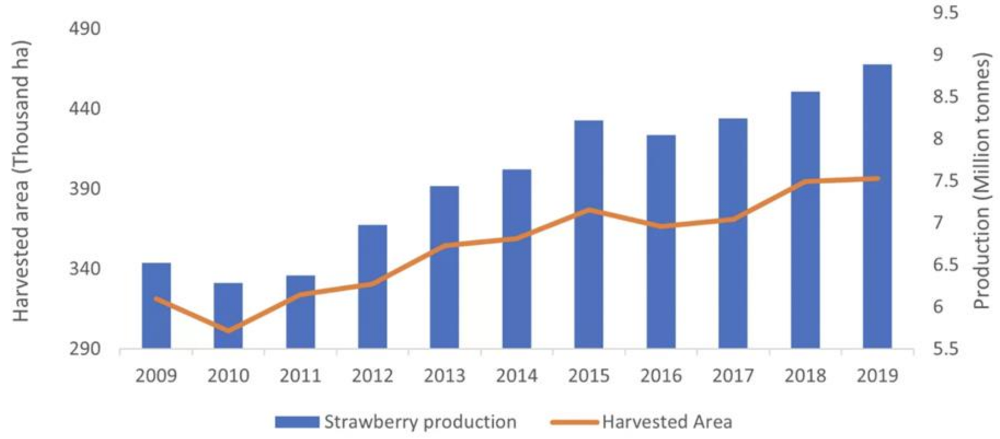
This second category of UA does indeed share some blurred overlaps between the previous urban allotment gardens, and the following category focused on CEA systems. However, it is precisely in Z-Farming´s ability to share production methods and impact objectives from both urban allotment gardens and CEA systems, that its unique identity lies. As argued by (Buehler, and Junge 2016) Z-Farming activities "include the development of community gardens on vacant land as well as agriculture in and on buildings" (Buehler, and Junge 2016, 1). Brooklyn Garage, part of the Community-Based Green Infrastructure Programme of New York´s Department for Environmental Protection is an example of this; And Montreal based Luffa Farms, who built the "world´s first commercial rooftop greenhouse on an industrial building" (Luffa Farms 2022), is also an example of Z-Farming, this time with distinctly commercial and market-oriented impact objectives (Luffa Farms 2022).

iii. Thirdly, there is CEA, or Controlled Environmental Agriculture, in which all environmental factors of the growing process are controlled. Some authors consider Total Controlled Environment Agriculture (TCEA) as a step further from CEA. While CEA may still yield inconsistently, TCEA allows for total predictability and consistency by taking away all external factors (IGS 2022; Zacharaki 2021). IRG Z-farming methods are an example of CEA. Other Z-Farming methods, however, are not generally associated with TCEA systems which are either built for purpose or operate closed circuit systems, rather than following a building-integrated approach. Vertical farming, understood as "an urban, indoor, high rise, climate-controlled factory with renewable energy" (Benke, and Tomkins 2017, 14) is an example of a CEA system. In fact, a controlled cultivation environment is the first requirement of Vertical Farming, followed by a lighting system, and a soil-less growing system. Soil-less growing systems can be hydroponic, aeroponic, or aquaponic (Parkes et al. 2022). Hydroponic systems involve plants grown in Nutrient Filled Water solutions (NFT) and can exist within Z-Farming methods. The degree of control over environmental factors must be seen as a spectrum leading toward TCEA. Aeroponic systems use nutrient-rich sprayed mist, and aquaponic is based on plants grown in fish-filled water tanks (Parkes et al. 2022). Unlike urban allotment gardens and Z-farming methods, TCEA systems tend to have strictly commercial and market-driven objectives, since the investment and technological costs are so high (Despommier 2013).

Figure 2: Raiz Vertical Farms, Lisbon – Pilot Project of a CEA system. Exterior and interior. Source: photo taken by authors.

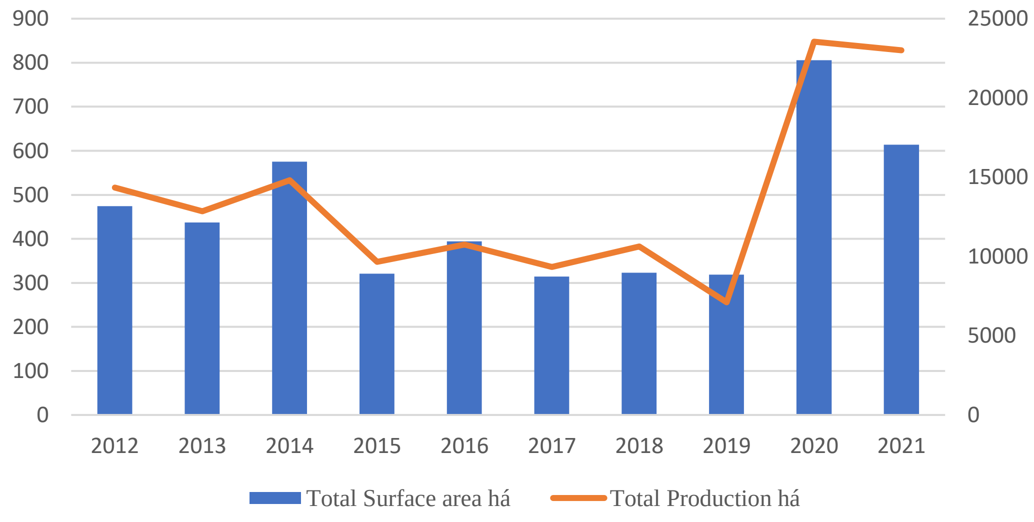
Although urban allotment gardens in Portugal date back to the beginning of the 21st century, the aforementioned Z-Farming, and CEA/TCEA categories of UA are a novel phenomenon in the country. With the second-highest fruit consumption in Europe, and an unbalanced food system requiring food imports to supply domestic needs, Portugal would seem to greatly benefit from UA´s advanced production methods and local-to-local model (Landgeist 2021). UA in Portugal has yet to scale towards more advanced Z-Farming and CEA/TCEA systems of production. Despite that, Portugal ranks 11th out of 78 countries in the "Food Sustainability Index" (FSI), by the Economist Impact (2022), composed of an average of three key pillars: food loss and waste, agriculture, and nutritional challenges.

Worldwide, contemporary strawberry producers have increasingly made use of innovative agricultural methods such as hydroponic farming, partly as a result of an increased trend towards more efficient production methods. This notion can be supported by Zacharaki's (2021) findings that show an increase in production at higher rates than the total harvested area, over recent years (see Graph 1).



Graph 1: Global strawberry production and area harvested for the years 2009-2019. Source: Zacharaki 2021.

Graph 2 shows that Portuguese strawberry production slightly decreased from 2012 to 2019 although did not alter much over these years. There was then a significant boom in strawberry production after 2019. Although not conclusive, it may indicate there was some production system improvement as seen in Graph 2.



Graph 2: Portuguese strawberry production and area harvested for the years 2012-2021. Source: INE 2022b.

This would go in line with global strawberry production, which also increased at higher rates than the total harvested area over recent years, as outlined by Zacharaki (2021). These production increases compared to harvested area, may also be indicative of how strawberry production methods have increasingly made use of innovative agricultural methods.

The greater increase in total production compared to the total harvested area for 2021 reflects that the global trends in strawberry production efficiency that Zachariki (2021) is referring to, are perhaps reaching Portugal. However, there is no concrete data to demonstrate that this improvement is correlated with more efficient methods of production and thus, that this is going to be sustained in the following years. 2021 can be an outlier. Therefore, there is still a long way to go in scaling more efficient production methods in Portugal. In the following section, a macro market analysis of Portuguese strawberry will be given in order to further elaborate on this matter.

2.3. Impacts of Urban Agriculture

UA is always context-specific in its application, which, as stated before, can provide different perspectives of how it is viewed, whether as an environmental action, an economic market-oriented action, or a social action (Cabannes 2012; Delgado 2018). As argued by Cabannes (2012), UA is a dynamic fusion between these three impact objectives, and each stands out differently based on the context in which UA is being practiced. In the table below they have been used as categories to summarize a series of advantages and disadvantages related to UA, based on different readings (Despommier 2013; Specht et al. 2014; Benke, and Tomkins 2017).

Table 1: Environmental, Economic, and Social Impacts of Urban Agriculture. Source: Despommier 2013; Specht et al. 2014; Benke, and Tomkins 2017.

Advantages	Disadvantages/Limitations
Environmental Impact	
Efficient energy usage and reduction of GHG emissions through; decreased transport time, increased use of renewables, recycling organic waste, and energy saving through closed circuit systems	Technical constraints: multiple environmentally friendly technologies yet to operate as a whole, with a need for improved linkage between theoretical and practical issues
Sustainable cities: Eco-effective architecture and urban landscapes, and designing the urban architecture for a wide variety of functions	"Local trap" in food systems innovation: assuming urban farming is inherently sustainable is the wrong approach as renewable technology is still highly energy intensive
Ecological restoration: rejuvenation of natural ecosystem with no depletion of soil or groundwater	
Economic Impact	
Increased yield and productivity	High cost of urban real estate
Reduced cost of fertilizers, herbicides, and pesticides	High transport costs may remain depending on the market served
Produce and quality increase – a premium product	Cost of retrofitting urban buildings for urban farming
Urban food production as a form of biosecurity for urban food demand	The increased cost of high-end technology in production systems, including production/energy inputs
Energy inputs are controlled and programmed	
Reducing transport costs as production is close to the consumer, local-to-local model	
Reduced costs incurred from unpredictable climate disturbances	
Social Impact	
Educational: urban communities are more in touch with nature through eco-effective buildings	Social and cultural acceptance of urban farming techniques and methods in both rural and urban spaces

New urban job market relating to biochemistry, bioengineering, and new R&D in the area	Threat to agricultural lifestyle, culture, and communities - exclusionary practices and the question of how agricultural lifestyles are to be included in this new undertaking
Re-use of abandoned urban buildings and rejuvenating of old neglected neighborhoods	
Re-skilling of rural workers and new lifestyle opportunities for them	

3. Methodology

The research design in this thesis uses qualitative as well as quantitative data collection methods to develop the discussion on UA in Portugal. Quantitative data collection methods involved a public survey made up of 13 questions and 56 responses from the public, alongside an excel data set on existing UA initiatives in Portugal. The latter data set was based on Cecilia Delgado´s (Delgado 2017) existing data set on UA initiatives in Portugal, although a further 25 initiatives and a new category were added.

Quantitative data was also collected from our site visits to three different strawberry farms; Hortiart, Hexágono Padrão, and Thomar Land (see Table 2), related to the production operations of each respective farm. Regarding the qualitative data collection methods, a series of 3 semi-structured interviews were carried out with the owners of the strawberry farms. A template was designed for these field excursions (see Appendix 1), with pre-planned questions based on our existing theoretical research on UA, and the intended research avenues. However, it must be recognized that interviews are "more of a collaboration than an interrogation" (DeLyser, et al. 2009, 162). The semi-structured nature of the interviews allowed for an interactive and reflexive exchange of ideas (DeLyser et al. 2009).

From Hortiart, we interviewed Mr. Artur, farmer and owner, on the 3rd of November 2022, at the Farm’s location in Torres Vedras, Portugal. From Hexágono Padrão we have interviewed

Mrs. Francelina Santos on the 18th of October 2022, at the farm's location in Penafiel, Portugal. Following the site visit, Mrs. Francelina provided further information over two phone calls. From Thomar Land, we interviewed Mr. Gonçalo, on the 25th of October 2022, at the farm´s location in Tomar, Portugal.

The initial research idea was focused on a strategy and operations approach towards vertical farming but going through the many literature debates we began to appreciate the context-specific nature of vertical farming. Instead, approaching the topic from an Urban Agriculture perspective seemed to be more valuable, as it allowed for a broader debate on UA in Portugal that could incorporate the multiple economic, environmental, and social advantages and disadvantages of UA. Whilst the broader focus on UA allowed for a more context-specific analysis within the Portuguese market, the focus on strawberry production, equally allowed for a breakdown of the macro market towards a more micro analysis of best location network strategy. Therefore, from a research perspective, this thesis develops from a relatively macro market analysis of the Portuguese UA market and strawberry production, towards a more detailed microanalysis of capacity size and location strategy.

4. Results

As already mentioned, our producer insights were gathered from 3 different strawberry farms across Portugal: Hortiart, Hexágono Padrão, and Thomar Land. Based on our script template for our onsite interviews (see Appendix 1) we gathered a variety of information relating to the production outline, energy inputs, and outputs of each farm. We did not always get every piece of information we would like, mostly due to some lack of tracking of that data from the producer's side. Such limitations have been identified. Missing information was marked in Table 3 as "unknown".

To give some context to the findings from our visits, we hereby present the profiles of the different strawberry producers:

Table 2: Strawberry Producer Profiles. Source: authors' elaboration based on site visits.

HortiArt HORTICULTURA E ARTEFACTOS, LDA.	HEXAGONO PADRÃO	Thomar Land
› Mr. Artur, a farmer by profession › Family business › Founded in 2005 › 160,000 m^2 › Rural, municipality of Torres Vedras	› Mrs. Francelina Santos and Mrs. Ana Lúcia Santos - two sisters, not farmers by profession › Family business › Founded in 2017 › 10,000 m^2 › Rural, municipality of Penafiel	› Mr. Gonçalo, a farmer by profession › Non-family business › Founded in 2017 › 10,000 m^2 › Rural, municipality of Tomar

Table 3: Production outline, energy inputs, and output. Source: authors elaboration based on site visits.

Category	**Hortiart**	**Hexágono Padrão**	**Thomar Land**
Total production area	16 ha	1 ha	1 ha
Production outputs	40 tonnes per year, per hectare	100 tonnes per year, per hectare	70 tonnes per year, per hectare
Production structure	Plastic-covered overhead macro and micro tunnels and open-air production	closed greenhouse structure with an oscillating hydroponic system	closed greenhouse structure with an oscillating hydroponic system
Product	strawberries, pitaya	strawberries	strawberries until 2020, since then lettuce and chives
Workers	50 people, with reinforcement of 10 to 20 at maximum production	12 people working	15 people working

Water	Water through pipes connected to local supply, quantity unknown	In winter 4 watering sessions compared to 7 in summer, quantity unknown/not shared	Quantity unknown
Electricity	specific electricity inputs unknown, 50 solar panels reducing electricity costs for fridge chamber by 50%	3800kwh per month	unknown
Growing/substrate solution	Soil-based farming	Water solution and coconut fiber	water solution and coconut fiber
Water solution electrical conductivity (hydroponic only)	unknown	electrical conductivity of water solution at 1.5 to maintain consistent PH at 5.5	electrical conductivity of water solution at 1.8
Nutrients for Growing	fertilizer, phosphorous, potassium, nitrogen	calcium and Nitroplus (nitrogen), phosphorous, potassium	calcium and Nitroplus (nitrogen), phosphorous, potassium
Bees input	unknown	bees used for permanent interior pollination	bees used for permanent interior pollination
Pests and diseases	mites, lice, botrytis, mildew	mites, lice, botrytis, mildew	mites, lice, botrytis, mildew
Pest control	pesticides	beneficial bugs/bioagents, foliar treatments using biological products	beneficial bugs/bioagents

5. **The national strawberry market, producer organizations, and producer insights**
6. **The Portuguese Urban Agriculture market and the need for an "all urban system complexity"**
7. **Consumer insights on Urban Agriculture**

8. Main Advantages and Disadvantages of Urban Farming

From the short review above, emerges the understanding of Urban Farming as a broad concept that includes all types of farming in the city – from lowest or zero-tech Urban Allotment Gardens to high technological TCEA installations. The first of which widely exists in Portugal (Delgado 2017). While recognizing its importance, the other types of UA mentioned are still to gather momentum and thus, are the focus of this study. Hence, in this section, an analysis of the advantages and disadvantages of Urban Farming (excluding Urban Allotment Gardens) is performed. Furthermore, whenever data is available, scenarios are built for better visualization and to serve as the basis for Discussion. Those scenarios are built mainly from data relating to TCEA, as it represents the most complex of the UA types discussed.

8.1. Productivity and Yield

The utmost generally accepted benefit of Vertical Farming systems relates to the increased yield when compared to traditional agriculture. Space can be used efficiently by planting crops vertically as opposed to ground-based production, achieving higher crop yields per square meter. Contingent upon the structure and number of levels of the farm, these yields are multiplied (Kalantari et al. 2017). Furthermore, TCEA allows the plant to become more efficient. "Plants need only specific wavelengths of light to grow, but in nature, they must adapt to the full range of light as a matter of survival", added Gertjan Meeuws, a TCEA entrepreneur, during an interview with The Associated Press (Max 2011). When in a manipulated environment, plants use less energy to grow and grow bigger and faster (Kalantari et al. 2018). According to Hornyik and Lennox (2021), strawberries produced indoors in a Vertical Hydroponic Farm can be fully grown in half the time it takes outdoors. Despommier (2010, 150) suggests that with appropriate technology and skilled farmers, a vertical farm yields 29 times more strawberries than a traditional outdoor farm. While Despommier is criticized for being an "optimist" by some authors (Marris 2010), his view is not far from Agrotonomy's (n.d.) - a company that installs TCEA solutions for strawberry plantations with hydroponic systems and promises a yield of up to 821 tons per hectare in a farm with 2,800m2 (see Appendix 6).

Table 5: Summarized comparisons of productivity, across the different scenarios. Source: Lieten 2008; Own field research; INE 2022b; Agrotonomy (n.d.).

	Portugal's National Average (2021)	Outdoors Traditional Agriculture	Macro tunnels (Hortiart)	Rural CEA Greenhouse (Hexágono Padrão and Thomar Land)	City Centre Farm 375m^2 – Simulated Scenario [4]	Peri-urban Farm 2,800m^2 – Simulated Scenario [4]
Plants ($\times 10^3$) / ha	-	50 [1,2]	48 [1]	200	640	686
Tons/ ha/ year	37.6 [5]	35 [2,3]	40 [3]	100 [3]	747	821
				Corridors and technical area	20% of total area	14% of total area

[1] In double row systems.
[2] According to Lieten (2008).
[3] Production from fresh dug plants.
[4] Assuming a one-floor urban farm. According to Agrotonomy (n.d.)
[5] According to INE (2022b).

Thomar Land was expecting a production of 100 tons and the producer assumes it could be achieved if not in the steep early stages of the learning curve. Due to certain setbacks such as pests and consequent safety intervals, and due to not knowing exactly how to control humidity inside the greenhouse, Thomar Land's production was set at around 70 tons. Hexágono Padrão, on the other hand, has achieved the expected 100 tons per hectare in past years.

8.2. Variability

Any small change in weather conditions may affect productivity. Droughts, floods, changes in temperature, and photo-intensity beyond the requirements of the plant are common problems in traditional outdoors agriculture (Banerjee, and Adenaeuer 2014). Producing indoors reduces or even eliminates these risks. Being able to control temperature, humidity, and photo-intensity to optimal conditions allows to reduce variability and better predict productivity. Ultimately, it allows for increased food security for populations (Besthorn 2012). Furthermore, production indoors is not affected by seasonality which allows for multiple harvests during the year (Kalantari et al.2018).

Indoors CEA can minimize and even eliminate the risk of pests and plagues, therefore reducing variability (Despommier 2013). Current research appears to validate that view. While not TCEA, both producers from Thomar Land and Hexágono Padrão farms share the same feeling that "it is difficult for pests to get inside the greenhouse". Once inside, the latter producer claims it has found solutions, less labor intensive and less costly than the use of pesticides, to eliminate the pests, namely the use of selected beneficial bugs. In sum, these predator insects are used as biological control. Sporadically, the producer still recurs to foliar treatments, however only using biological products which, while more expensive and equally labor intensive as applying pesticides, do not require safety intervals (the period which certain chemicals should elapse from the plant after application and during which producers cannot harvest for safety reasons). Otherwise, during such intervals, some strawberries would rot, representing a loss of production, and "a big loss of revenues", adds Francelina Santos, Hexágono Padrão farmer, and co-owner.

In extreme cases, adds Despommier (2013), an indoor farm can sanitize and replant in a matter of weeks while an outdoors farmer may need to wait for the following year.

8.3. Environmental Impact

The main drawback associated with indoor agriculture, especially of TCEA, is the high energy demand due to lighting, water pumping, and climate control systems to artificially provide plants with ideal growing conditions. RTG systems, as in rural greenhouses, may use the sun as the primary source of light and heat, however, it is contingent upon the weather, location, and specific crop requirements (Parkes et al. 2022).

Weighting the benefit of putting the product out on the market during the month of January and the energy consumption it requires, Hexágono Padrão producers choose not to crop during that month and have stopped using the greenhouse heaters. By the same token, Thomar Land has decided to sell the heaters to prevent high energy costs. This is possible when considering the Mediterranean climate experienced in Portugal and the ideal temperatures between 10ºC and 26ºC, and day lengths of up to 14 hours optimal to grow most strawberry varieties.

Table 6: Summarized comparisons of energy consumption per month, across the different scenarios. Source: Own field research; Agrotonomy (n.d.).

	Rural CEA Greenhouse (Hexágono Padrão)	City Centre Farm[1] – Simulated Scenario for 375m^2	Peri-urban Farm[1] – Simulated Scenario for 2,800m^2
Energy consumption in kWh ($\times 10^3$) / ha	3.8	1,000	1,071.5
kWh / ton produced	456	16,071	15,652

[1]Assuming a one-floor urban farm. According to Agrotonomy (n.d.)

On the flip side, water consumption in indoor agriculture is much less than in conventional agriculture. Whichever growing system and physical configuration, the nutrient solution is pumped to the crop, and any water not absorbed by the roots is then processed to the correct chemical composition and circulated again (Birkby 2016; Benke, and Tomkins 2017). This allows to dramatically increase efficiency.

Table 7: Summarized comparisons of water consumption per ton produced, across the different scenarios. Source: Own field research, Sesma 2021; Agrotonomy (n.d.).

	Outdoors Traditional Agriculture [1]	Rural CEA Greenhouse [1]	City Centre Farm [2] – Simulated Scenario for 375m^2	Peri-urban Farm [2] – Simulated Scenario for 2,800m^2
Water consumption m^3 / ton produced	160	45	21	21

[1] According to Sesma (2021)
[2] According to Agrotonomy (n.d.)

According to Sesma (2021), in Traditional Agriculture, to produce 1 ton of strawberry, it requires around 160m^3 of water, while using oscillating hydroponic systems, such as the ones used by Hexágono Padrão and Thomar Land, the same amount of strawberries would take around 45m^3. About one fourth, representing a reduction of 72%. Compared with a TCEA solution, the simulated scenarios built based on data provided by Agrotonomy (n.d.), reveal a consumption of 21m^3 per ton produced for both scenarios, a further reduction of 53%, and 87% less than in Traditional Agriculture. These findings are directly in line with several authors referring to the saving in water to be around 90% (Besthorn 2012; Foroohar 2020).

Building-integrated Agriculture (BIA) implies a synergy between the UA setting and the systems of the building (O'Sullivan 2019). BIA suggests not only harvesting rainwater and recycling water from condensation as ways to reduce further water consumption, but also treating the building's greywater to be used for irrigation (Astee, and Kishnani 2010; Thomaier et al. 2014; Cerón-Palma et al. 2012).

Furthermore, BIA is emerging as a solution with great potential to tackle the question of high energy requirements, especially in CEA settings that rely mainly on artificial lighting and heat, and do not use direct sunlight as the primary source. BIA implies a synergy between the UA setting and the climate management systems of the building. The heat generated, and normally wasted by the building, may be exploited as a way of obtaining ideal conditions in the UA installation and reducing energy consumption. RTG can also provide natural ventilation to the building (Parkes et al. 2022).

The reduction in transportation distances incurred, as a result of the local-to-local model, is one of the main environmental advantages of UA (Kalantari et al. 2018). The evident advantage resulting from that is the reduced fossil fuel/energy consumption required (Besthorn 2012) and the consequent decrease in nutritional quality over long transport times and storage (Rickman, Barrett, and Bruhn 2007). Furthermore, traditional agriculture relies on machinery for plowing, seeding, harvesting, applying fertilizers, and so on (Voss 2013). As a result, high fossil fuel inputs are required. On the other hand, UA does not require the use of fossil fuels (Banerjee, and Adenaeuer 2014).

To summarize, Table 8 has been constructed:

Table 8: Summary of Environmental Drawbacks and Benefits.

Drawbacks	Benefits
High energy demand due to artificial lighting, climate control, and water pumping.	Energy can be produced in-situ through: - The use of solar panels; - Exploiting the building's wasted heat (BIA);
	Low water demand, because: - Water is recirculated; - Rainwater can be harvested; - Water from condensation can be used; - Building's greywater can be treated to put to use (BIA);
	Reduced fossil fuel requirements due to: - Reduced transportation distances; - No need for heavy machinery to plowing, seeding, harvest, applying fertilizer;

8.4. Quality of the product

Hydroponics, as in aeroponics and aquaponics, can produce at higher quality and bring together several other benefits that further improve the quality of the product. By quality, it is meant the quality in taste, nutritional value, and condition at which it gets to the end-consumer. These systems have shown advantages relating to plant quality because of the "input and output control of material flow" (Parkes et al. 2022, 4). Hexágono Padrão producers assert they can control the amount and type of nutrients in the mixture sent out to the plants controlling the color and sweetness of the strawberry. In fact, O'Sullivan (2019) suggests there exists a broad range of beneficial compounds such as proteins, vitamins, and minerals, and harmful ones such as nitrates that can be controlled to increase the nutritional value of crops. Plus, the protection of the crop from wind has a positive impact on fruit quality (Lieten 2008).

Furthermore, producing closer to end-consumer eliminates the need to crop early, seen as an absolute necessity by commercial growers in traditional agriculture, as it allows their produce to travel long distances while minimizing damage from handling and packaging (Despommier 2013). Eliminating the need for long-distance transportation, urban farmers can sell on-demand, hours-old, locally grown, and pathogen-free produce (Besthorn 2012; Despommier 2013).

9. Discussion

Having stated some of the benefits and drawbacks of taking agriculture to the urban setting and building scenarios that allow for comparisons with traditional agriculture, the focus of this new section is to bring discussion onto the topic of whether it is more beneficial to distribute or centralize operations. Relevant arguments are developed to clearly define the factors in favor of each strategy.

9.1. Economies of Scale

Consolidating operations in a single or few locations allows for resource sharing. When comparing the two simulated scenarios (see Table 5) there is an evident loss in the number of plants per hectare, and consecutively in production, when producing in smaller plants. This is mainly due to the space inevitably needed for corridors and technical areas and represents, in small plants, a higher portion of the area – 20% as opposed to only 14% at the bigger plant, within the context of the simulated scenarios. On the other hand, bigger plants allow for aggregated volumes with better utilized capacity – scale economies.

While discussing economies of scale, it is worth referring to the benefit in overhead costs. In an urban setting, whereas the built scenarios have shown a slightly higher energy consumption per hectare in the bigger plants, mainly due to the larger crop area per hectare, when examining the same consumption per ton produced, the bigger plants show small savings of about 34kWh per ton (see Table 6). Water consumption was shown to be equivalent in both scenarios (see Table 7).

Owing to these high energy costs, finding ways to produce energy in-situ recurring to renewable sources is an essential aspect to consider for UA projects using CEA (Parkes et al. 2022). A study by Al-Chalabi (2015) has quantified energy demand and generation in several scenarios to explore whether those buildings with different dimensions could accommodate enough photovoltaic panels to supply the energy required. The research has found that using solar panels on the roof and facade of buildings, certain dimensions allow for a building to generate enough energy for lighting and water pumping. These dimensions are around $500m^2$ or less. Any scenario with more area shows insufficient energy production since more panels would be required than the building could accommodate. These findings seem to support the distributed network scenario, as smaller plants would be able to produce at lower costs than farms in a centralized network.

Furthermore, centralized sourcing may represent benefits from quantity discounts. Costs such as the ones incurred with the nutrients, fertilizers, and plants from plant nurseries when bought in bulk can have the price reduced since the bargaining power of suppliers is lowered.

Additionally, centralized networks can better guarantee quality standards are met.

Economies of Scale often capture some realities in capacity investment. To see this, let us build two scenarios: A report from Direção-Geral do Território (2019) has defined what areas to consider urban and peri-urban within the Metropolitan Area of Lisbon. From the identified 30 parishes within clusters 3 and 7 – the ones considered to be urban – the median value of sales per existent (not new) square meter of family dwellings referring to the 3rd Quarter of 2021 was assessed and chosen the second lowest value (see Appendix 9). The second lowest value was preferred over the lowest due to its proximity to the city center. The same data was recovered for the 41 parishes considered within the peri-urban clusters 2 and 6, and the lowest value was chosen (see Appendix 8). These clusters have been chosen over clusters 1, 4, and 5, due to their proximity to Lisbon and higher population density, while the latter are also considered peri-urban.

The parish with the second lowest value within clusters 3 and 7 is *União das Freguesias (UF) de Póvoa de Santo Adrião e Olival Basto* (represented with a green dot in Figure 7) with a median price of 1,817€ (INE 2022). The parish with the lowest value within clusters 2 and 6 is *UF de Baixa da Banheira e Vale da Amoreira* (represented with a pink dot in Figure 7) with a median price of 838€ (INE 2022).

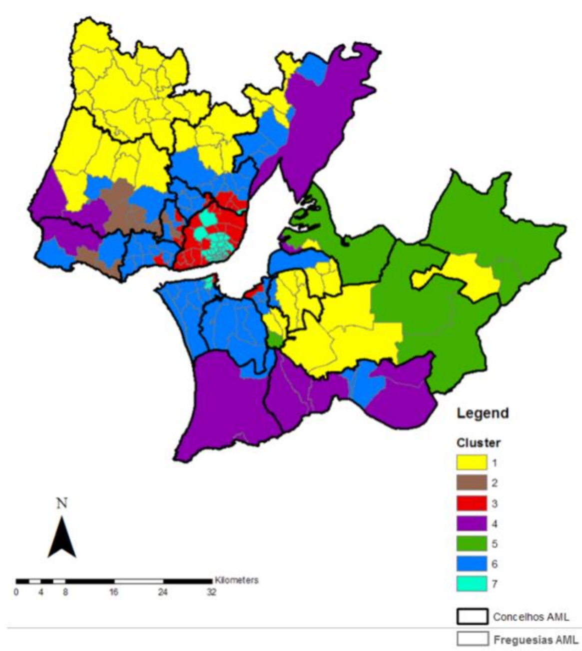


Figure 6: Map of Urban (Clusters 3 and 7) and Peri-urban (Clusters 1, 2, 4, 5 and 6) regions of Lisbon. Source: Direção-Geral do Território (2019).

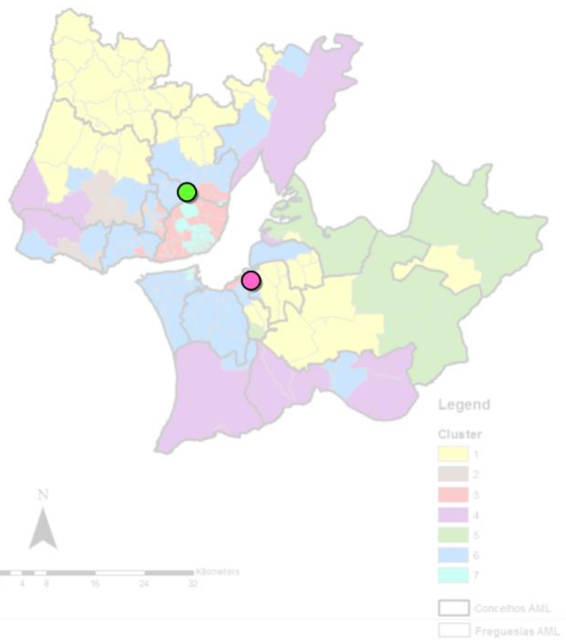


Figure 7: Selected Parishes for Urban Location – Green Dot – and Peri-urban – Pink Dot.

Peri-urban construction of Farms has the advantage of land being regularly more affordable the further away from the city center one goes (Despommier 2013). While the data available is related to existent family dwellings' square meter cost of sale, it still represents a good measure of comparison between the two scenarios.

Denoting the size of capacity by *K*, and the capital expenditure (CapEx) by *C(K)*, capacity investment exhibits economies of scale when *C(2K) < 2C(K)*. CapEx should account for equipment, machinery, building, furniture and fixtures, business vehicles, software, or intangible assets such as licenses (Fernando 2022). However, assuming only the price of the square meter previously found for the urban and peri-urban scenarios as the *C(K)*, and *K*=375m^2, economies of scale can be proven to exist (see Table 9). Costs grow sublinearly in a concave function due to the fixed cost component and decreasing marginal costs, *C(K)/K* declines as the capacity size *K* increases (Mieghem, and Allon 2015).

Table 9: Capacity Investment shows Economies of Scale.

	City Centre Farm – Simulated Scenario for 2 farms of 375m^2 in UF de Póvoa de Santo Adrião e Olival Basto	Peri-urban Farm – Simulated Scenario (for simplicity, 2x375m^2 = 750m^2) in UF de Baixa da Banheira e Vale da Amoreira
Price / m^2	1,817 €	838 €
Price per *K*	681,375.00 €	314,250.00 €
Total price	*2C(K)* = 1,362,750.00 €	*C(2K)* = 628,500.00 €

9.2. Risk Pooling

In terms of yield variability, both scenarios – centralized and distributed networks – can decrease this kind of variability and therefore produce at a steady rate. Despite that, the decreased yield variability is more valuable in one of the scenarios due to demand variability. When aggregating two demands, individual fluctuations partly cancel out, thus reducing total relative volatility. By pooling demand, the inter-arrival times are curtailed, and so specific demand increases and becomes more predictable than fragmented distributed demands. Bigger plants can then better match supply with demand, and by doing so, take higher value from their stable yield.

This value stems from reduced safety capacity and overstocking costs – which is critical taking into consideration the perishability attribute of the product – and higher fill rate, representing fewer stock outs and lost sales. In fact, safety levels scale proportional to volatility as well as capacity fill rate descends proportionally to volatility (Mieghem, and Allon 2015).

By pooling demand, waiting times are also shortened due to fewer inefficiencies, namely idle times, which may affect distributed networks when *Farm X* has produce waiting while *Farm Y* is overwhelmed and stocked out. All combined, centralized networks benefit existing customers and have the potential to attract new ones, and increase revenues and service levels while reducing profit variance risk.

To satisfy the same demand fulfillment rate, distributed networks incur higher inventory, due to fragmented demands. Nonetheless, the possibility of having surplus capacity and a distributed network of farms may allow for extremely fast service to customers that are willing to pay a premium for high-quality produce at such highly responsive service. While a not very useful recommendation for specific decision-making, it is worth noting, taking that strategy is gradually shaped over time – emergent strategies (Slack, Chambers, and Johnston, 67).

9.3. Outbound Transportation Costs

Outbound transportation costs from a central location to a distributed set of customers increase rapidly and nonlinearly in the sales area and consequently encourage a firm to have many local plants. To see this, if customers were uniformly distributed over a line and served individually by a centrally located farm, customers on the top side of the line would be at a distance of $\frac{1}{2}r$ from the farm, where r is the radius of the delivery zone. Assuming customer density is 1 per km, there would be r customers on the top side and so their total transportation distance is $r \times \frac{1}{2}r$. Considering the other side of the line is symmetric, the total distance would be r^2. Assuming transportation costs are linear, total transportation costs increase with the square of the radius of the delivery zone, such that the total transportation costs to serve an area of double the length is $(2r)^2 = 4r^2$, higher than $2r^2$, the cost incurred by two farms delivering to a zone of length r. (Mieghem, and Allon 2015).

Taking the previous locations defined as urban and peri-urban, and assuming their distance to the city center as straight lines of 6.5km and 13km (according to Google Earths measurements, see Appendix 10), respectively (see Figure 8); and keeping previous assumptions, it can be shown that the average transportation cost per unit between a central location and a distributed set of customers, increases in scale (see Table 10).

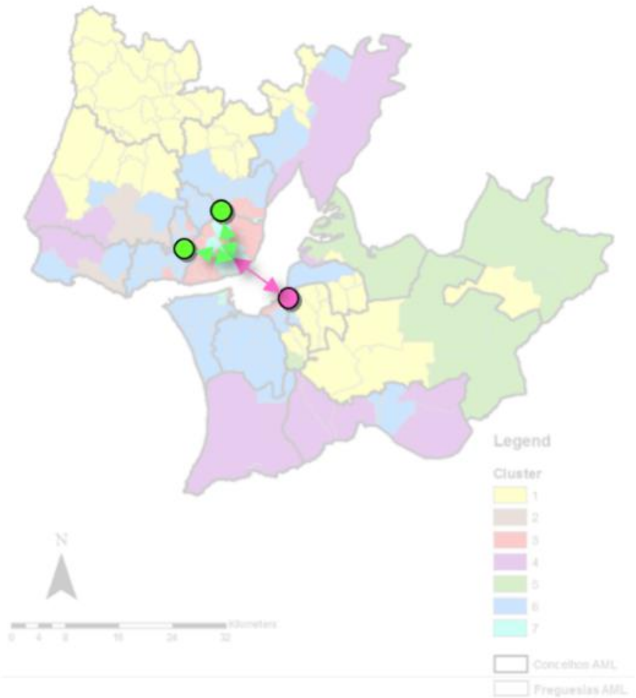


Figure 8: Distances from the City Centre to two Urban Farm – Green Arrows, - and to one Peri-urban Farm – Pink Arrow.

Table 10: Demonstration of Total Transportation Costs.

	City Centre Farm – Simulated Scenario for 2 farms of $375m^2$ in UF de Póvoa de Santo Adrião e Olival Basto and other random location	Peri-urban Farm – Simulated Scenario (for simplicity, $2x375m^2 = 750m^2$) in UF de Baixa da Banheira e Vale da Amoreira
r (km)	6,5	$2r$ = 13
Total transportation costs	$2r^2 = 2x6,5^2 = 84,5$	$(2r)^2 = (13)^2 = 169$

Furthermore, a shorter supply chain allows for a longer shelf-life. The Global CEA Census Report (Agritecture 2021) shows that urban farmers believe the extended shelf-life of their produce to be on average 8.5 days more than that of traditional agriculture. This is mainly due to shorter logistics and the fact that some crops can be harvested, stored in shelf, and sold with roots, prolonging freshness, and acceptance from consumers. The ultimate benefit is reduced food waste resulting from longer shelf-life (Despommier 2013).

9.4. Intangible Benefits

Since the primary strategic reason for a facility's location can be shaped by intangible factors, as opposed to a myopic scope over costs, some of those benefits are here forth considered:

- Social impact: A distributed network of Farms may incite greater community involvement and become a link between agriculture production and consumers, giving them greater responsibility and the chance to participate in producing their food locally (Besthorn 2012; Macias 2008). In centralized networks, this is virtually nonexistent since farms are fewer or in remoter areas away from community life, as happens in Singapore (Astee, and Kishnani 2010). Moreover, from a psychosocial perspective, consumers find comfort in knowing where and how their food is being produced (Dixon et al. 2007), and for farmers, they may enjoy benefits from fostering face-to-face relationships with consumers and from selling food they have produced to people with whom they have gradually built relationships (Macias 2008).
- Psychological and Spiritual Health: Contact with nature has been shown to improve a person's creativity, stability, and focus, lower stress, and develop self-value and self-perception (Kalantari et al 2018). It has further been demonstrated its positive effects on obesity and human mental health (Safikhani et al. 2014).
- Roofscapes and landscape opportunities: A distributed network of farms has the potential to create aesthetically pleasing landscape elements such as ponds to retain

surface runoff, channeled to the farm. Likewise, rooftop hydroponic structures and greenery can have a great impact on a country's skyline (Astee, and Kishnani 2010).

- Reduction of urban heat island and increased air quality and sound insulation: Re-radiation and absorption of solar energy forms what is called an urban heat island. To reduce this effect, greenery is known to enhance the cities' microclimates (Thomaier et al. 2014, Safikhani et al. 2014), and urban farms pose a great opportunity to help control those microclimates (Banerjee, and Adenaeuer 2014). Furthermore, plants can trap gas pollutants and dissolve them, improving air quality in the city (Kalantari et al. 2018). Additionally, plants and air restrained inside greenhouses act as sound insulators, reducing the noise from traffic and planes (Safikhani et al. 2014).
- Education: Engaging schools and farms can increase comprehension of nature and food in the educational system (Kalantari et al. 2018). In fact, any visitor can learn more about the food it consumes and share the knowledge which will result in further participation and better customer acceptance (Thomaier et al. 2014; Kalantari et al. 2018).

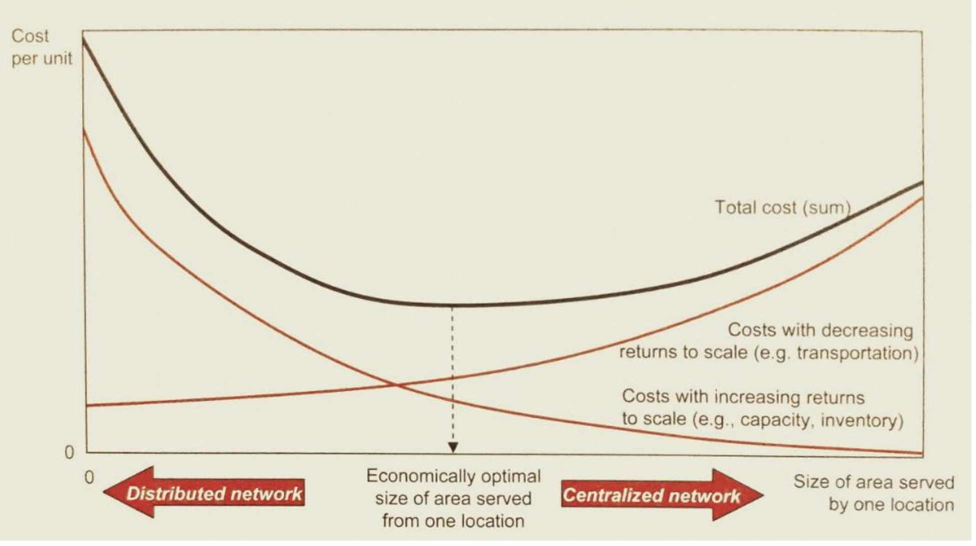
10. Conclusion

This study presented the main advantages and disadvantages of moving agriculture to the urban setting. Related to those topics, scenarios have been built that not only allowed comparison with the traditional agriculture reality but also served as the basis for discussion. The first conclusion is that at many stages of the value chain, a centralized network enjoys economies of scale: Productivity is higher since less space is "wasted" for corridors and technical areas allowing it to have more plants per hectare; Centralized sourcing may represent a per unit reduced cost due to quantity discounts; Overall quality is more uniform and consistent; and capacity investments benefit from scale economies due to heavier CapEx in distributed networks. While energy consumption per ton produced was shown to be lower in bigger plants, the savings were modest;

and water consumption per ton produced was shown to be nearly the same in both scenarios. Furthermore, Al-Chalabi (2015) has shown in his study that smaller farms (around $500m^2$ or less) have a higher chance of meeting energy demand by in-situ energy produced from renewable energy sources, such as photovoltaic panels located on the roof and the facade of the building. Therefore, since in TCEA installations, energy and water represent the main overhead costs and neither benefit from scale economies, it is considered a factor in favor of distributed networks.

The second conclusion is that by pooling demand, centralized networks benefit from a steadier demand, which allows to reduce safety capacity and overstocking costs as well as having a higher fill rate and less waiting times. Overall, pooling demand allows centralized networks to increase service levels and revenues while reducing profit variance risk.

Moreover, outbound transportation costs are reduced for the distributed network of farms. The average transportation cost per unit between a central location and a distributed set of customers, increases in scale.



Graph 8: Economically optimal point found through trading off two sets of costs: the ones with decreasing returns to scale and the ones with increasing returns to scale. Source: (Mieghem, and Allon 2015).

Thus, transportation costs are an example of costs that increase with the size of the plant – or decreasing returns to scale – while capacity, overhead, and inventory are costs reducing with the size of the area served – or with increasing returns to scale. Therefore, a final conclusion is that this optimal point trades off the different costs to the extent of which total costs are the lowest, between the two network strategies. This is the economically optimal size of the area to be served that determines the extent to which a network should be centralized or distributed (see Graph 8).

However, taking only a cost analysis exclusively to base decisions might not be the most beneficial, as it poses the threat of a myopic scope. Depending on the specific strategic role of location, a company or local government might choose to deviate the real point from the economically optimal. Intangible benefits and the weight in the decision-making that each of those poses, might help in choosing to which side this real point will shift.

11. Limitations

There were a few limitations in the research and analysis conducted, relating to the availability of data and potential generalization of results. Both in the market analysis and capacity size and location analysis, only 3 different farms (Hortiart, Hexágono Padrão, and Thomar Land) were researched, while more farms could have been used for an analysis that more accurately reflected producer insights of macro-tunnel and hydroponic strawberry production systems nationally. Further, in the capacity size and location analysis, productivity and yield as well as energy and water consumption figures were retrieved from TCEA suppliers such as Agrotonomy (n.d.), which represents a limitation since suppliers tend to exaggerate the benefits and understate the drawback of the product they sell, as in fact asserted both producers from Hexágono Padrão and Thomar Land. Also, the data for various production inputs and outputs was scarce, and sometimes difficult to gather from the producers visited. Namely, water consumption values were never disclosed as well as production over the course of a full year to study variability, which led us to use literature available data for the sake of comparison and discussion. In the case of variability, it could not be quantified.

A literature review was conducted to estimate the amount of carbon associated with developing Urban TCEA cultures, to better explore environmental impacts, however, no tangible studies were found. Regarding the UA initiatives across Portugal, it must be noted that there could well be some initiatives missing since not all have a public profile. Consumer insights were also limited to 56 responses, so result interpretations could have been generalized or biased toward our research intentions. Location analysis limitations include the fact that data for m^2 price in Lisbon referred to existent family dwellings, and market prices can always vary.

12. Recommendations

Looking at the challenges of UA in Portugal, a combination of two separate research questions was answered. The first of which looked at "What are the principal market challenges to scaling Urban Agriculture initiatives in Portugal?" and the second of which looked at "Centralized vs. Distributed Networks: Which one best suits Urban Agriculture?" By looking at the market-based challenges, several conclusions were addressed. Scaling UA in Portugal cannot be left to market dynamics alone due to the strong influence of POs and the existing macro-tunnel production systems. Furthermore, since the current UA market in Portugal lacks the presence of innovative Z-Farming, CEA, and TCEA systems, there needs to be greater local government involvement in co-opting such innovations with existing UA networks in the cities. However, in moving on to the second part, the discussion rests on how best to initiate the development of UA from a capacity size and location analysis. In recognizing that UA is always context-specific, the choice between a centralized or distributed network for developing UA in Portugal may benefit from taking into account the aforementioned market analysis.

Through a joint production and location analysis it was noted how UA centralized networks would profit from economies of scale, in their ability to reduce costs per unit, have better utilized capacity, provide greater uniformity in quality, and pool demand. Alternatively, distributed networks, allowed for smaller farms to better meet energy demands with their in-situ energy production, and generally reduce outbound transportation costs. The choice of which location strategy is the best is context specific to the existing market context, it seems the commercial agricultural market cannot be relied upon to scale UA and carry out the task of embracing an "all urban system complexity" (Delgado 2017). What can be recommended from this research is that a flexible policy-making approach should be adopted from a local government perspective in which UA´s manner of implementation can be located at an optimal point between descending and ascending cost curves, but taking into consideration less tangible factors, such as the benefits to communities, the environment and to the urban setting itself (see Graph 8).

For the context of Lisbon, a strategy can be suggested. Only a few projects involving indoors production of food exist in the city, so Lisbon is a “blank sheet” to apply such a strategy and help UA to scale. While considering the economically optimal point as the measure in between the two strategies – centralized or distributed networks – that provide the overall lower costs, meaning both strategies should be applied to a certain extent, other factors should be accounted for. Such factors can be, for instance, the lack of awareness and education found in the data retrieved from the public survey, about the indoors production of food, which may convey that a distributed network of farms can be more beneficial. In fact, a distributed network, closer to the end consumer has the potential to educate and increase participation and customer acceptance (Thomaier et al. 2014; Kalantari et al. 2018). A study by Borrego, Barros, and Miranda (2000), has shown that it is urgent to find a strategy to reduce air pollution considering the contribution of traffic in Lisbon. Aiming to improve such a situation, and other impacted-by-traffic issues such as the health of inhabitants and urban noise, a distributed network should be considered. Such intangible aspects, if taken into consideration will influence the decision, pushing the optimal point further to the left, toward a more distributed network. It may slightly increase costs, but it will bring other important returns to the city.

Adopting a UA approach that is market specific, and that builds upon predominantly social, community, and local government-driven UA initiatives in Portugal, seems even more critical when recognizing the recent crisis in the industry. Indeed, the aforementioned innovations of UA, such as Z-Farming, CEA, and TCEA systems, currently find themselves at a crisis point with industry leaders announcing major redundancies, and smaller initiatives struggling to gather funds or find a market. However, it seems that where there is uncertainty there is also opportunity, to showcase many of UA’s already discussed advantages.

13. Bibliography

Agritecture, and WayBeyond. 2021. "Global CEA Census Report". Agritecture, and WayBeyond. Accessed September 25. https://engage.farmroad.io/hubfs/2021%20Global%20CEA%20Census%20Report.pdf

Agrotonomy. n.d. 2022. "Grow 28 tons of strawberry in 375m^2!" Agrotonomy. Accessed September 25. Accessed November 25th, 2022. https://agrotonomy.com/indoor-strawberry-vertical-farming/

Al-Chalabi, Malek. 2015. "Vertical farming: Skyscraper sustainability?" *Sustainable Cities and Society*, Volume 18, June 12. https://doi.org/10.1016/j.scs.2015.06.003

Astee, Lim Yinghui, and Nirmal T. Kishnani. 2010. "Building integrated agriculture: Utilising rooftops for sustainable food crop cultivation in Singapore." *Journal of Green Building* 5, no. 2: 105-113. https://doi.org/10.3992/jgb.5.2.105

Banerjee, Chirantan, and Lucie Adenaeuer. 2014. "Up, Up and Away! The Economics of Vertical Farming." *Journal of Agricultural Studies*, March. http://dx.doi.org/10.5296/jas.v2i1.4416

Benke, Kurt, and Bruce Tomkins. 2017. "Future food-production systems: vertical farming and controlled-environment agriculture." *Sustainability: Science, Practice and Policy*, 13:1, 13-26. November 20. https://doi.org/10.1080/15487733.2017.1394054

Besthorn, Fred H. 2012. "Vertical Farming: Social Work and Sustainable Urban Agriculture in an Age of Global Food Crises." *Australian Social Work,* November 12. http:/ / dx.doi.org/ 10.1080/ 0312407X.2012.716448

Birkby, Jeff. 2016. “Vertical Farming.” *ATTRA: Sustainable Agriculture*, January. https://attra.ncat.org/publication/vertical-farming/

Borrego, C., O. Tchepel, Nelson Barros, and A. I. Miranda. 2000. "Impact of road traffic emissions on air quality of the Lisbon region." *Atmospheric Environment* 34, no. 27: 4683-4690. https://doi.org/10.1016/S1352-2310(00)00301-0

Buehler, Devi. and Ranka Junge. 2016. "Global Trends and Current Status of Commercial Urban Rooftop Farming." *Sustainability* 8 (11). October 29. https://doi.org/10.3390/su8111108

Cabannes, Yves. 2012. “Financing urban agriculture.” *Environment and Urbanization* 24 (2): 665-683. October 12. https://doi.org/10.1177/0956247812456126

Cerón-Palma, Ileana, Esther Sanyé-Mengual, Jordi Oliver-Solà, Juan-Ignacio Montero, and Joan Rieradevall. 2012. "Barriers and opportunities regarding the implementation of Rooftop Eco. Greenhouses (RTEG) in Mediterranean cities of Europe." *Journal of Urban Technology* 19, no. 4: 87-103. http://dx.doi.org/10.1080/10630732.2012.717685

Colangelo, Robert. 2022. "The CEA Wars!" Green Sense Farms. November 30. https://www.greensensefarms.com/new-blog/the-cea-wars

Delgado, Cecília. 2017. "Mapping urban agriculture in Portugal: Lessons from practice and their relevance for European post-crisis contexts" *Moravian Geographical Reports 25* (3): 139-153. October 27. https://doi.org/10.1515/mgr-2017-0013

Delgado, Cecília. 2018. “Contrasting practices and perceptions of urban agriculture in Portugal.” *International Journal of Urban Sustainable Development* 10 (2): 170-185. June 18. https://doi.org/10.1080/19463138.2018.1481069

DeLyser, Dydia, Steve Herbert, Stuart Aitken, Mike Crang, and Linda McDowell, eds. 2009. *The SAGE handbook of qualitative geography*. Sage.

Despommier, Dickson. 2010. The Vertical Farm: Feeding the World in the 21st Century. *New York: Thomas Dunne Books*. https://books.google.pt/books?id=0DxTK0jW35sC&printsec=frontcover&hl=pt-PT#v=onepage&q&f=false

Despommier, Dickson. 2013. "Farming up the city: the rise of urban vertical farms." *Trends Biotechnol* 31, no. 7: 388-389. https://doi.org/10.1016/j.tibtech.2013.03.008

Dieleman, Hans. 2017. "Urban agriculture in Mexico City; balancing between ecological, economic, social and symbolic value." *Journal of Cleaner Production* 163: S156-S163.

Direção-Geral do Território. 2019. "PERIURBAN, Territórios Periurbanos: Documentos de Orientação 03/2019." *Direção-Geral do Território*. Accessed September 25, 2022https://www.dgterritorio.gov.pt/sites/default/files/publicacoes/V6_PERIURBAN_25Mar2021_semApresent.pdf

Dixon, Jane, Abiud M. Omwega, Sharon Friel, Cate Burns, Kelly Donati, and Rachel Carlisle. 2007. "The health equity dimensions of urban food systems." *Journal of Urban Health* 84, no. 1: 118-129. https://doi.org/10.1007/s11524-007-9176-4

Economist Impact. 2022 "Food Sustainability Index: Interactive World Map", *Economist*. Accessed November 25th, 2022. https://impact.economist.com/projects/foodsustainability/interactive-world-map/

FAOU. 2022. "What is Urban and Periurban Agriculture?" *Urban and Peri-urban Agriculture Sourcebook: From production to food systems, Food and Agriculture Organization of the*

United Nations, FAOU, Rome, Italy, 2022. https://www.fao.org/documents/card/en/c/cb9722en

Fernando, Jason. 2022. “Capital Expenditure (CapEx) Definition, Formula, and Examples.” *Investopedia*. Accessed October 30, 2022. https://www.investopedia.com/terms/c/capitalexpenditure.asp

Foroohar, Rana. 2020. “Strawberries tell the story of an era of disruption.” *Financial Times*. Accessed October 10, 2022. https://www.ft.com/content/ce337152-a9be-4d23-9fb7-decf4fce6550

Hornyik, Csaba, Peter-James Lennox. 2021. “Discover the UK strawberry vertical farming industry.” Filmed March 2021 in United Kingdom, Youtube Video, 1:07:56. Accessed October 24, 2022. https://youtu.be/sRUfAxWVW_U

IGS. 2022. “Guarantee a consistent crop supply and meet shifting market demands with vertical farming.” IGS. October 20. Accessed October 24 https://www.intelligentgrowthsolutions.com/news/guarantee-a-consistent-crop-supply-and-meet-shifting-market-demands-with-vertical-farming

INE. 2022 a. “Valor mediano das vendas por m2 de alojamentos familiares nos últimos 12 meses (€) por Localização geográfica e Categoria do alojamento familiar; Trimestral.” INE. February 1. Accessed October 29 https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_indicadores&indOcorrCod=0009484&contexto=bd&selTab=tab2

INE. 2022 b. "Agricultural Statistics" "Estatísticas Agrícolas", *National Institute of Statistics Portugal, annual publication*, Lisbon, Portugal, 22nd July 2022 Edition. Accessed October 29 https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&PUBLICACOESpub_boui=31589846&PUBLICACOESmodo=2

Kalantari, Fatemeh, Osman Mohd Tahir, Ahmad Mahmoudi Lahijani, and Shahaboddin Kalantari. 2017. "A review of vertical farming technology: A guide for implementation of building integrated agriculture in cities." *In Advanced engineering* forum, vol. 24, pp. 76-91. Trans Tech Publications Ltd. https://doi:10.4028/www.scientific.net/AEF.24.76

Kalantari, Fatemeh, Osman Mohd Tahir, Raheleh Akbari Joni, and Ezaz Fatemi. 2018. "Opportunities and challenges in sustainability of vertical farming: A review." *Journal of Landscape Ecology* 11, no. 1: 35-60. https://doi:10.1515/jlecol-2017-0016

Landgeist. 2021. "Fruit Consumption in Europe", Landgeist, 3rd December 2021. Accessed November 25th 2022. https://landgeist.com/2021/12/03/fruit-consumption-in-europe/

Lieten, Philip. 2008. "Strawberry Production in Central Europe." *International Journal of Fruit Science* Volume 5, October 12. https://doi.org/10.1300/J492v05n01_09

Luffa Farms. 2022. About Lufa Farms. Accessed 28 November 2022. https://montreal.lufa.com. https://montreal.lufa.com/en/about

Macias, Thomas. 2008. "Working toward a just, equitable, and local food system: The social impact of Community-Based agriculture." *Social science quarterly* 89, no. 5: 1086-1101. https://doi.org/10.1111/j.1540-6237.2008.00566.x

Marris, Emma. 2010. "Agriculture: Greenhouses in the sky." *Nature* 468, no. 7322: 374-374. https://doi.org/10.1038/468374a

Marston, Jennifer. 2022. "Brief: Vertical Farm network Infarm to lay off "more than half" of workforce, downsize operations" *AgFunder News*, November 29, 2022. Accessed November 25th. https://agfundernews.com/infarm-to-lay-off-more-than-half-of-its-workforce

Max, Arthur. 2011. “Future farm: a sunless, rainless room indoors.” PhysOrg, April 11. Accessed November 20th, 2022. https://phys.org/news/2011-04-future-farm-sunless-rainless-room.html

Mieghem, Jan A. V., and Gad Allon. 2015. *Operations Strategy: Principles and Practice*. 2nd Ed. USA: Dynamic Ideas

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

Parkes, Michael G., Duarte Leal Azevedo, Tiago Domingos, and Ricardo FM Teixeira. 2022. "Narratives and Benefits of Agricultural Technology in Urban Buildings: A Review." *Atmosphere* 13, no. 8: 1250. https://doi.org/10.3390/atmos13081250

Richter, Marc François. Luiza Vigne Bennedetti, Bruna Raquel Rodrigues Teixeira, Maico Ismael Klein e Angélica Gomes Florczak dos Santos. 2022. "Hortas urbanas – História, Classificação, Benefícios e Perspectivas." *Revista Franco-Brasileira de Geografia*, 55. https://doi.org/10.4000/confins.46324

Rickman, Joy C., Diane M. Barrett, and Christine M. Bruhn. 2007. "Nutritional comparison of fresh, frozen and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds." *Journal of the Science of Food and Agriculture* 87, no. 6: 930-944. https://doi:10.1002/jsfa.2825

Rito, André. 2018. "As hortas urbanas continuam a invadir Lisboa", *New In Town*. Accessed November 20th, 2022. https://www.nit.pt/fora-de-casa/as-hortas-urbanas-continuam-a-invadir-lisboa.

Safikhani, Tabassom, Aminatuzuhariah Megat Abdullah, Dilshan Remaz Ossen, and Mohammad Baharvand. 2014. "A review of energy characteristic of vertical greenery systems." *Renewable and Sustainable Energy Reviews* 40: 450-462. http://dx.doi.org/10.1016/j.rser.2014.07.166

Sesma, Valentín. 2021. "VENTAJAS DEL NUEVO SISTEMA ROTACIONAL NGS." April 27. Youtube Video. 4:30. Accessed November 10th, 2022. https://youtu.be/puMCBACxZ6k

Simon-Rojo, Marian, X. Recanes, S. Cllau, Barbora Duzi, Sebastian Eiter, Verónica Hernández-Jiménez, Patricia Kettle et al. 2016. "From urban food gardening to urban farming.": 22-28. *Urban Agriculture Europe, Edition* 1, COST. https://hdl.handle.net/11311/1042359

Slack, Nigel, Stuart Chambers, and Robert Johnston. Operations management. Pearson education, 2010. https://books.google.pt/books?id=ZhLBcfUXaNwC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

Specht, K., Siebert, R., Hartmann, I. et al. 2014. "Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings." *Agric Hum Values 31*, 33–51. https://doi.org/10.1007/s10460-013-9448-4

Stewart, R., Korth, M., Langer, L. et al. 2013. "What are the impacts of urban agriculture programs on food security in low and middle-income countries?" *Environ Evid* 2, 7. https://doi.org/10.1186/2047-2382-2-7

Thomaier, Susanne, Kathrin Specht, Dietrich Henckel, Axel Dierich, Rosemarie Siebert, Ulf B. Freisinger, and Magdalena Sawicka. 2014. "Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming (ZFarming)." *Renewable Agriculture and Food Systems*: 30(1); 43–54, April 24. http://doi.org/10.1017/S1742170514000143

UN, 2020. "Policies on spatial distribution and urbanization have broad impacts on sustainable development" Population Facts, Department of Economic and Social Affairs, United Nations, December 2020. Accessed November 20th 2022.https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undes_pd_2020_popfacts_urbanization_policies.pdf

Voss, Peter M. 2013. "Vertical Farming: An agricultural revolution on the rise." *Halmstad University*, June 14. http://hh.diva-portal.org/smash/get/diva2:628988/FULLTEXT01.pdf

Zacharaki K. 2021. "What is the role of TCEA in the worldwide strawberry product?" UKUAT. Accessed November 20th, 2022. Available at: https://www.ukuat.org/post/what-is-the-role-of-tcea-in-the-worldwide-strawberry-product

14. Appendices

14.1. Appendix 1: Production Insights template script. Source: authors elaboration.

Script template for field excursions to Hortiart, Hexágono Padrão and Thomar Land

Questions on the background of farm and its systems:

- Introduce yourself and the project you are doing
- Name of farm, people involved/interviewee names
- How old is the farm/how long has it been in operation?
- What is the structure of the open-air farm and the greenhouse, closed/semi-closed, and how is the climate regulated indoors?

Production and operations questions:

Land Usage/cost

- Dimension of the farm (m2)? - specifically covered and uncovered
- How many foot plants per m2?

Productivity/yield

- when and what time of the year does production happen
- How much do you produce, per sqm or another metric? (Numbers, percentages)
- Has does the open air compare to the covered greenhouse in terms of productivity?

Variability

- Are there any fluctuations in productivity? (Yes, then why?)
- How frequently do you register productivity? (If possible, get access to that data to calculate variability)
- Has does the open air compare with the covered greenhouse in terms of productivity

Disease/pest/bacteria prevention

- Are there any bacteria/pests/disease that influences strawberry production? (if yes the...)
- How frequently do these appear? are they easy to control/manage? how does it impact productivity?
- Are these easier to manage open air or under the covered greenhouse

Resources management/water and fertilizer management?

- How much water do you use per month, or per sqmt/month?
- How has water management changed between the two different systems
- How much nutrients/fertilizer do you use?
- How have you managed resource input?

Environmental Impact?

- Do you have measurements of CO_2e or other environmental impact assessments?

Operations - (data/numerical answers)

	Metrics, numbers, percentages, quantities ect...
Land/usage and cost	
Productivity/Yield	
Variability	
Disease/pest/bacteria prevention	
Resources management/water and fertilizer/nutrients	
Environmental Impact	

Market-related questions:

Clients

- they sell to the national market, especially the markets of Lisbon and Porto - they also export with the main clients abroad being of the Spanish market
- do you export elsewhere? what is the value of the different markets...

Business model of selling

- What is the business model, do you sell to retailers/shops/cooperatives B2B, or do you sell directly to consumers D2C?

Transport time and cost

- What is the transport time, and cost of transport?

Food Waste

- Is there any food waste?

Shelf-life

- What is the shelf-life, and from cultivation to in-store?

14.2. Appendix 2: Strawberry Production in Portugal, 2021 (Source: INE 2022b)

Strawberry Production in Portugal (2021)					
Annual Production		Annual Import and Export		Annual Prices	
Total Surface Area (ha)	614	Total Import (t)	13,807	Price per 100kg (€)	274.47
Total Production (t)	23,012	Total Import Value (€)	28,994	Average Price per kg (€)	2.7447
Average production (t) p/(ha)	37.6	Total Export (t)	4,768		
		Total Export Value (€)	9,997		

14.3. Appendix 3: Urban Agriculture Initiatives in Portugal, Excel Dataset (Source: Delgado 2017, with elaboration from authors' own UA findings and added CEA category (E).

14.4. Appendix 4: Categorization of Urban Agriculture In Portugal for Excel Dataset (Source: Delgado 2017, with elaboration from authors' own UA findings and added CEA category (E)

14.5. Appendix 5: "Summary of Typology of UA initiatives" (Source: Delgado 2017, 143:146)

14.6. Appendix 6: Data regarding the two scenarios – Urban and peri-urban according to Agrotonomy (n.d.).

	Total Area	Number of Plants	Estimated Crop Yield	Hall & Technical Area	Water usage/ month	Electrical Output / month
City Center	375m^2	24,000	28 tons	75m^2	50m^3	37,500kWh
Peri-Urban	2,800m^2	192,000	230 tons	400m^2	400m^3	300,000kWh

14.7. Appendix 7: Summarized comparisons of productivity, energy, and water consumption across the different scenarios.

	Portugal's National Average (2021)	Outdoors Traditional Agriculture	Macro tunnels (Hortiart)	Rural CEA Greenhouse (Hexágono Padrão and Thomar Land)	City Centre Farm 375m² – Simulated Scenario [4]	Peri-urban Farm 2,800m² – Simulated Scenario [4]
Plants (× 10^3) / ha	-	50 [1,2]	48 [1]	200	640	686
Tons/ ha/ year	37.6 [6]	35 [2,3]	40 [3]	100 [3]	747	821
Corridors and technical area					20% of total area	14% of total area
Energy consumption in kWh (× 10^3) / ha				3.8	1,000	1,071.5
kWh / ton produced				38	1,339	1,305
Water consumption in m^3 / ton produced		160 [5]		45 [5]	21	21

[1] In double row systems.
[2] According to Lieten (2008)
[3] Production from fresh dug plants.
[4] Assuming a one-floor urban farm. According to Agrotonomy (n.d.)
[5] According to Sesma (2021)
[6] According to INE (2022).

14.8. Appendix 8: Median value of sales per existent m² of family dwellings, 3rd Quarter of 2021, Parishes in the Peri-Urban region of Lisbon (INE, 2022a)

Geographical Location (Parish)	**The median value of sales per m² of family dwellings**
	Data period: 3rd Quarter of 2021
	Category of family dwellings: Existent
	€
Costa da Caparica	2456
UF de Caparica e Trafaria	1699
UF de Charneca de Caparica e Sobreda	1847
UF de Laranjeiro e Feijó	1565
Águas Livres	1722
Falagueira-Venda Nova	1785
Mina de Água	1717
Venteira	1788
UF de Alto do Seixalinho, Santo André e Verderena	1200
São Domingos de Rana	2404
UF de Carcavelos e Parede	3019

UF de Cascais e Estoril	3383
Loures	1955
UF de Camarate, Unhos e Apelação	1447
UF de Santa Iria de Azoia, São João da Talha e Bobadela	1726
UF de Santo António dos Cavaleiros e Frielas	1760
UF de Baixa da Banheira e Vale da Amoreira	938
UF de Montijo e Afonsoeiro	1309
Odivelas	2097
UF de Pontinha e Famões	2007
UF de Ramada e Caneças	2102
Barcarena	2036
Porto Salvo	2350
UF de Carnaxide e Queijas	2360
UF de Oeiras e São Julião da Barra, Paço de Arcos e Caxias	2668
Amora	1289
Corroios	1504
Fernão Ferro	1575
UF do Seixal, Arrentela e Aldeia de Paio Pires	1383
Quinta do Conde	1467
Setúbal (São Sebastião)	1143
Algueirão-Mem Martins	1388
Casal de Cambra	1720
Rio de Mouro	1389
UF de Agualva e Mira-Sintra	1438
UF de Massamá e Monte Abraão	1529
UF de Queluz e Belas	1548
UF do Cacém e São Marcos	1526
UF de Alverca do Ribatejo e Sobralinho	1571
UF de Póvoa de Santa Iria e Forte da Casa	1666
Vialonga	1393

14.9. Appendix 9: Median value of sales per existent m^2 of family dwellings, 3rd Quarter of 2021, Parishes in the Urban region of Lisbon (INE, 2022a)

Geographical Location (Parish)	**The median value of sales per m^2 of family dwellings**
	Data period: 3rd Quarter of 2021
	Category of family dwellings: Existent
	€
UF de Almada, Cova da Piedade, Pragal e Cacilhas	1884
Alfragide	2093
Encosta do Sol	1855
UF de Barreiro e Lavradio	1213
Ajuda	3081
Alcântara	3089
Alvalade	3749
Areeiro	3428
Arroios	3281
Avenidas Novas	4009
Beato	2640

Belém	3671
Benfica	2832
Campo de Ourique	3580
Campolide	3592
Carnide	3343
Estrela	3778
Lumiar	3170
Marvila	2935
Misericórdia	3797
Olivais	2654
Parque das Nações	4201
Penha de França	3033
Santa Clara	2433
Santa Maria Maior	4034
Santo António	4979
São Domingos de Benfica	3341
São Vicente	3377
UF de Póvoa de Santo Adrião e Olival Basto	1817
UF de Algés, Linda-a-Velha e Cruz Quebrada-Dafundo	2617

14.10. Appendix 10: Distances from the Urban and the Peri-Urban Farm locations to Lisbon's City Centre, retrieved from Google Earth.