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VERTICAL URBAN AGRICULTURE IN THE CONTEMPORARY CITY

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Aos meus Avós

O sucesso é ir de fracasso em fracasso sem perder o entusiamo

Winston Churchill

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RESUMO

O crescimento contínuo da população mundial tem vindo a resultar no constante aumento do consumo. Esta tendência está já prevista para os próximos 40 anos (Godfray et al., 2010). Neste período de tempo, em que é expectável que cerca de 80% da população mundial residirá em áreas urbanas, tornar-se-á cada vez mais evidentes os problemas, já verificados em alguns locais, inerentes à crescente competição pelos bens essenciais como o solo, a água e a energia. Já se regista atualmente a sobre-exploração de alguns componentes do setor primário, como a pesca.

As alterações climáticas são um fenómeno já conhecido há vários anos, mas ainda pouco encarado com a seriedade e urgência que lhe é necessária. Os seus efeitos, cada vez mais apreciáveis e menos reversíveis, também ameaçam comprometer as gerações futuras e no que às suas culturas agrícolas diz respeito. As alterações dos solos e do clima, por exemplo, afetarão não só as condições de implantação de uma cultura agrícola como irão desde logo comprometer a sua perseverança. Tudo isto acabará por ditar a limitação da capacidade de produção de alimento, e a subsistência da população mundial futura poderá ser comprometida.

É nestes princípios que assenta a Agricultura Urbana. A agricultura praticada no contexto do interior ou da periferia de um meio urbano que cultiva, produz, processa e distribui uma variedade de produtos alimentares e não alimentares usando recursos humanos, materiais e serviços disponíveis nesse mesmo meio. Este método agrícola potencia a resiliência urbana através, desde logo, das relações interpessoais das pessoas que o praticam, mas também permite que se aumente a eficiência da produção de bens de primeira necessidade nas imediações dos locais em que estes vão ser consumidos. Isto não só ajuda a satisfazer a necessidade alimentar da população urbana local como previne em grande parte a pegada ecológica resultante da sua produção e, assim, fomenta a Adaptação Climática.

Uma das ramificações deste método é a Agricultura Vertical, cujo conceito é a alteração da disposição habitual das culturas. Posicionando-as na vertical, aumenta-se a produção por unidade de área através da combinação de sistemas automatizados com tecnologias modernas de manutenção e monitorização das culturas. A Agricultura Vertical pode ser potencialmente benéfica no aumento da produção alimentar, mantendo uma elevada qualidade e segurança.

O estudo para determinar o alcance desse mesmo potencial é feito através de um enquadramento geral da situação atual e da sua previsível evolução, identificando os principais temas mais alarmantes. Os conceitos de Agricultura Urbana e, mais especificamente, o de Agricultura Vertical surgem como possibilidades de inverter algumas dessas tendências. São definidas as suas principais áreas de influência, salientando-se o seu potencial na Adaptação Climática. Para tal, são definidos os principais desafios e o papel que a Agricultura Vertical poderá assumir, com base em projetos já existentes em todo o mundo. São depois caracterizadas algumas possíveis estratégias de promoção deste método, desde as normas de implementação à revisão de legislação já existente.

Seguindo esta metodologia, conclui-se que a Agricultura Vertical tem potencial para ser realmente influente na minimização dos efeitos desta alarmante realidade ambiental. É importante que se dissemine a informação acerca deste método, com a consciência de que tem limitações, para que algumas delas possam ser trabalhadas e melhoradas. A nível de legislação, o que existe é muito vago, mencionando a agricultura como um todo e sem pormenorizar as várias representações que ela pode ter. Este deverá ser um dos fatores a ter em conta com vista à proliferação do método e à sua implementação.

PALAVRAS-CHAVE: Agricultura Urbana, Agricultura Vertical, Adaptação Climática, Resiliência Urbana, Sustentabilidade.

ABSTRACT

The continuous growth of the world's population has resulted in a constant increasing consumption. This trend is already predicted for the next 40 years (Godfray et al., 2010)). In this period of time, when it is expected that around 80% of the world's population will live in urban areas, the problems already experienced in some places, with increasing competition for essential goods such as land, water and energy, will become more and more visible. In addition, overexploitation of some components of the primary sector, such as fishery, has already been occurring.

Climate change is a phenomenon that has been named for several years but it is still not regarded with the seriousness and urgency that it requires. Its effects, increasingly appreciable and less reversible, also threaten to compromise future generations and their agricultural crops. Changes in soil and climate, for example, will not only affect the conditions for the establishment of an agricultural crop, but it will also jeopardize its perseverance. All this will ultimately dictate the limitation of food production capacity, and the livelihood of the future world population may be compromised.

This is the basis of Urban Agriculture, agriculture practiced in the inner or peripheral urban context that grows, produces, processes and distributes a variety of food and non-food products, using the human resources, materials and services available in the urban environment. This method of agriculture enhances urban resilience through the interpersonal relationships of the people who practice it, but it also allows increasing efficiency in the production of basic necessities in the vicinity of the places where they will be consumed. This not only helps meeting the food needs of the local urban population, but also, prevents the ecological footprint resulting from their production and thus fosters Climate Adaptation.

One of the ramifications of this method is Vertical Farming, which concept is to change the usual arrangement of crops. By positioning crops vertically, production per unit area is increased by combining automated systems with modern crop monitoring and maintenance technologies. Vertical farming can be potentially beneficial in increasing food production while maintaining high quality and safety.

The study to determine the scope of this potential is done through a general context of the current situation and its foreseeable evolution, identifying the main alarming issues. The concepts of Urban Agriculture and, more specifically, Vertical Agriculture emerge as possibilities to reverse some of these trends. Their main areas of influence are defined, highlighting their potential in Climate Adaptation. To this end, the main challenges and the role that Vertical Agriculture could play are defined, based on existing projects around the world. Some possible strategies for promoting this method are then characterized, from implementation standards to the revision of existing legislation.

Following this methodology, it is concluded that vertical farming has the potential to be really influential in minimizing the effects of this alarming environmental reality. It is important to disseminate information about this method, with the awareness that it has limitations, so that some of them can be worked on and improved. In terms of legislation, what exists is very vague, mentioning agriculture as a whole and without detailing the various representations it can have. This should be one of the factors to be taken into account with a view to the proliferation of the method and its implementation.

KEYWORDS: Urban Agriculture, Vertical Agriculture, Climate Adaptation, Urban Resilience, Sustainability.

INDEX

INDEX OF FIGURES

INDEX OF TABLES

SYMBOLS, ACRONYMS AND ABBREVIATIONS

CO_2 – Carbon Dioxide

IPMA - Instituto Português do Mar e da Atmosfera

1
INTRODUCTION

1.1 OVERVIEW

The expected continuous population growth is becoming really alarming as the challenge of providing food for future generations is increasing. Cities are becoming denser, energy consumption is increasing, and production areas are beginning to have little room for expansion. This will mean an environmental imbalance that will eventually spill over into the social and economic sphere. Then the production system will be compromised, and sustainability will be jeopardized.

According to several studies, it is foreseeable that the overwhelming majority of the world's population will reside in urban environments in a short/medium term. This trend is especially worrying when one thinks of the need to support this population, which is increasingly distant from agricultural production areas. At a time when the ecological footprint associated with this industry is already so large, the prospect that production needs will increase and move further away from the consumer could not be less encouraging.

Besides the predictable continuous increase in energy consumption, it is undeniable that the planet will be increasingly susceptible to extreme weather phenomena. Extreme drought scenarios are already relatively common today, damage from floods or storms is not easily mitigated, and climate adaptation has not been effective.

It was in this context that the concept of urban agriculture was born and in which it has been evidenced. This alternative agricultural technique to the more conventional ones allows, from the outset, the proximity between the place of production and the consumer. This means a great reduction in energy consumption. In addition, it has the potential to enhance the social sector of a city, whether through community gardens or the simple fact that a green space can function as a support for leisure activities. One of the branches of urban agriculture is vertical farming. With the great advantage of changing the usual arrangement of crops, vertical layout allows for maximum production efficiency per unit area. Additionally, it is an agricultural technique closely linked to technological means of maintenance and monitoring. Thus, important tools are gathered to ensure crop prosperity.

This innovative agricultural method could and should be a tool for future urban planning, in a world where environmental concerns are growing, with sustainability increasingly under threat.

1.2 OBJECTIVES

The main objective of this work is to ascertain the potential of this alternative farming technique to climate adaptation. To do so, it is important to define the best way to put it to practice and to point out

what needs to be done to continue its development and really sprout it worldwide. First, as a means of mitigating some of the main current problems, such as the lack of cultivable area, for example. Additionally, in the possibility of acting as a possible tool for climate adaptation.

In this sense, first of all it is important to define the concepts of urban agriculture and vertical farming in order to do the work indicated above. It is important to characterize their advantages and limitations, their types of implementations as well as the most favourable contexts for them. This way, it will be possible to relate these themes and study them as potential mitigation or climate adaptation tools.

In order to achieve the proposed objectives, a comparison was made between examples of existing projects that apply these ideologies. The results obtained between them, together with the information gathered about the various types of application, made it possible to establish the application conditions that most favour each of these means of application. A review of the existing legislation is also made, either to encourage this technique or to support it when it is already in motion. Thus, it is also possible to evaluate where this practice stands and what should be done so that it can develop and spread.

1.3 Structure of the Research Report

The study is divided into 3 key parts: urban agriculture as a whole, the particular case of vertical farming, and its potential to climate adaptation.

Chapter 2 introduces the concept of urban agriculture, according to the various types of application and their pros and cons. One aspect of urban agriculture, vertical farming, is highlighted, describing the aspects in which this concept does or does not improve on more conventional farming methods.

Having clarified the concept, it is time to explore its potential for climate adaptation. This analysis is done in chapter 3, starting by identifying the main challenges to be faced. Then it is important to define the role that this farming technique could play to overcome them, based on proven projects already in operation.

The chapter number 4 chapter deals with the legislative aspect. It begins with a review of existing policies and strategies, with particular attention to whether or not vertical farming is specifically mentioned. It then addresses the topic from an implementation perspective, from the requirements to the supportive mechanisms that vertical farming should have.

Chapter 5 specifies the case of the Portuguese context, both at the regulatory level and at the level of implementation of this type of projects.

The conclusions that the process described above allows us to determine are reiterated in chapter 6, based on the literature review. These, in a generalized way, serve as a basis for the recommendations suggested for the future approach to this matter.

2
URBAN AGRICULTURE: REVIEW OF MAIN CONCEPTS

2.1. INTRODUCTION

The ever-increasing need to feed a constantly growing population leads to the necessity to adopt new measures to meet this need.

This chapter is the precursor to all the work developed and reported ahead. Its aim is to define the concept and application of urban agriculture and how it can help to meet the needs currently faced worldwide. One of the ramifications of this method, which will be the focal point of the paper, is then presented: vertical farming. The concept, initially presented in 1999 by Dickson Despommier, is described and its pros and cons are highlighted in the response to the problem.

2.2. URBAN AGRICULTURE

2.2.1. OVERVIEW ON URBAN AGRICULTURE

Urban agriculture has existed all around the globe for centuries and has undergone several advances over the years. Primitive civilizations appeared and evolved around specific areas, aiming for fertile terrains, pleasant weather, and primary resources such as potable water and wild fruits. Normally, these conditions would be accomplished near freshwater bodies, such as rivers and/or lakes whose water would help to irrigate the agricultural crops and whose shoals would also help to feed the residents. Ancient civilizations observed that warm climatic river valleys presented multiple optimal conditions, for the creation of a permanent settlement as well for their territorial and population expansion, so they started to prefer those locations (Lovell, 2010). Years gone by and multiple cities emerged, with new opportunities and challenges, but still, near or actually around farms, whose production would still provide for bigger cities nearby. At the XXth century cities expanded more than ever, leaving not much space to expand to and, worse than that, creating big distances between the crops and the people. Sometimes too far, meaning enormous costs of packaging and transportation, compromising many important aspects, such as food security and sustainability. This all resulted in the need to bring the crops to the cities, to bring the food closer to the people again (Tornaghi, 2014). That's what urban agriculture is all about.

Historically, this method has been particularly linked to cities of developing countries since it can be a first aid kit against hunger and malnutrition (Smit & Nasr, 1992). But nowadays it has been growing stronger in developed countries so that they can produce their own food. In fact, the emerging concern about food security while overcoming the challenge of feeding a growing population, as well as the over exploration of some of our resources are turning into a serious concern. Over the years and can turn into

a real threat, unless the food production strategy becomes more efficient and equitable (Godfray et al., 2010). The concern is emerging and taking measures is urgent. Nowadays urban agriculture begins to be seen as a potential part of the solution, so that food security can be achieved without compromising the economic sector and being able to maintain its affordability.

Urban agriculture, urban farming or urban gardening are similar terms meaning almost the same. All of them assume the need to cultivate the cities' land, the main difference resides in the purpose that can be merely aesthetic or the actual production of food.

In this research, the term "Urban Agriculture" will be the one used as the general concept, as it is the term mainly used by the Food and Agriculture Organization of the United Nations (FAO).

Several definitions can be found in the literature, as reported on Table 1:

Table 1 - Definitions of Urban Agriculture (Source: Skar [et al.] (2020))

Definition	Source
"Urban agriculture is an industry that produces, processes and markets food and fuel, largely in response to the daily demand of consumers within a town, city or metropolis, on land and water dispersed throughout the urban and peri-urban area, applying intensive production methods, using and reusing natural resources and urban wastes, to yield a diversity of crops and livestock."	(Smit, 1996)
"Urban agriculture is an industry located within (intra-urban) or on the fringe (peri-urban) of a town, a city or a metropolis, which grows and raises, processes and distributes a diversity of food and non- food products, (re-)using largely human and material resources, products and services found in and around that urban area, and in turn supplying human and material resources, products and services largely to that urban area."	(Mougeot, 2001)
"Urban Agriculture is the growing, processing and distribution of food or other products through intensive plant cultivation in and around cities"	(Tornaghi, 2014)
"Urban and peri-urban agriculture can be defined as the growing, processing and distribution of food and other products through plant cultivation and (seldom) raising livestock in and around cities for feeding local populations."	(Game & Primus, 2015)
"Urban agriculture spans all actors, communities, activities, places and economies that focus on biological production in a spatial context which – according to local standards – is categorized as 'urban'. Urban agriculture takes place in intra- and peri-urban areas and one of its key characteristics is that it is more deeply integrated into the urban system compared to other agriculture. Urban agriculture is structurally embedded in the urban fabric; it is integrated into the social and cultural life, economics and the metabolism of the city."	(Vejre et al., 2015)
"Urban food gardening encompasses agricultural activities with generally low economic dependence on the material outputs while using food production for achieving other, mostly social, goals."	(Simon-Rojo et al., 2015)

"Urban agriculture is growing, processing and distribution of food or livestock within and around urban centers with the goal of generating income."	(Roggema, 2016); (McEldowney, 2017)
"Urban and peri-urban agriculture (UPA) can be defined as the growing of plants and the raising of animals within and around cities. Urban and peri-urban agriculture provides food products from different types of crops (grains, root crop, vegetables, mushrooms, fruits), animals (poultry, rabbits, goats, sheep, cattle, pigs, guinea pigs, fish, etc.) as well as non-food products (e.g., aromatic and medicinal herbs, ornamental plants, tree products). UPA includes trees managed for producing fruit and fuelwood, as well as tree systems integrated and managed with crops (agroforestry) and small-scale aquaculture."	(FAO, 2019)

In this research, Urban Agriculture will be defined as "the growing, processing and distribution of food or other products through intensive plant cultivation in and around cities" (Tornaghi, 2014) representing an alternative and powerful land use that can articulate multiple city functions and land types so that it can be implemented even in the most densely populated urban centers.

The concept can be represented by small urban farms, agricultural production in residential buildings, community farms, rooftop gardens and/or greenhouses, as well as vegetable farming on balconies and windowsills. Other examples are aquaculture in tanks, rivers and coastal bays, livestock raised in backyards, urban orchards (Smit & Nasr, 1992) as well as the cultivation of medical plants, fruit trees and other productive plants (Lovell, 2010). It is clear that these activities can have multiple forms and scales. In fact, they should be as adapted as possible to the city in question, responding to its residents needs and preferences (Lovell, 2010), so that they can achieve their full potential in reducing the ecological footprint of cities, increasing community cohesion and resilience, while promoting urban sustainability. Indeed, the ability to provide fresh food and local produce goods to nearby urban neighborhoods can actually sustain biodiversity in and around urban areas by decreasing or eliminating the need to expand into natural areas and by providing a stronger vegetation structure (Clucas et al., 2018).

2.2.2 Types of Urban Agriculture

Urban agriculture could, and should, adapt to each city, considering its several forms and scales. Indeed, one of the main features to evaluate is the typology (Table 2) of the city area and, according to that, setting the most efficient ways of urban agriculture in each of those spaces:

Table 2 - The Typologies of Growing Spaces for Urban Agriculture (Adapted from: Skar [et al.] (2020))

Typology of the City Area	Urban Farming Spaces in Cities
Land Spaces	Cultivable land Allotment gardens Family gardens

	Leisure gardens Urban derelict land Guerrilla land
Mobile and Soil-Independent Systems	Growing boxes Mobile containers
Building Bound Spaces	Rooftop Greenhouses Facades: Living Walls Building extensions: - Balconies - Window sills Indoor farms
Water Spaces	Urban watercourses Urban standing waters Amphibious systems

The lack of soil availability and/or fertility, agricultural sectors' long distances from the urban centers represent multiple challenges in a daily basis. On the other hand, several opportunities to develop urban agriculture come with them. That's why there are already some different ways of urban agriculture:

- **Soilless Cultures and Hydroponics** - Depending on the soil availability and fertility could not be easy to be efficient with the conventional growing techniques in soil. Over the years, several soilless techniques were successfully invented and now are pointed out as a potential way of urban agriculture. Soilless culture is a method of growing plants without the use of soil, using inert media (e.g. rockwool, clay, pebbles) or no media at all, and providing a nutrient solution (Skar et al., 2020). Hydroponics is a similar technique, however its origin meant growing in a nutrient solution without growing substrate.
  Currently, these are the most important growing methods for greenhouse systems. According to Skar et al. (2020), they are classified depending on multiple factors, such as: existence and respective characteristics of substrates and containers, arrangement, location, process of administering the nutrient solution, and type of water supply system installation. The species most commonly grown in this type of culture are vegetables, herbs, and medicinal plants. However, under favorable circumstances, it is also possible to grow decorative plants.
- **Aquaponics** - To increase the effectiveness of this type of growing systems, it is very common to seek for multi type production. In this sense, aquaponics emerges. This farming technology is a combination of aquaculture farming in revolving aquaculture facilities and soil-less growing of crops (Skar et al., 2020). Very commonly, integration of fish (or other aquatic organisms) allows to use their effluent production unit to supply the horticultural unit with water and nutrients in order to grow the plant. It is possible to adjust the nutrients to each plant culture, so it is allowed to grow multiple plant species in polycultures beyond the monocultures. Vegetables, flowers, fruits, herbs and berries can be produced with this type of culture.

- **Vertical Farming** - Vertical farming is an agricultural technique of producing fresh goods stacked on top of each other in a vertical arrangement. These systems are quite effective, especially in terms of reduced land use due to its lower reliance on land resources, responding to the growing arable urban's land scarcity. One way of doing that consists of the construction of high-rise buildings with multiple levels of greenhouses or building crops on the building's facades. This way it is possible to multiply the efficiency of the same land portion, producing vegetables and/or plants without the need of more area, and to accomplish considerable water savings by articulating this process with soilless cultures and hydroponics.

2.2.3 Benefits of Urban Agriculture

This alternating land use has multiple benefits in multiple ways, as it was already said. The benefits will naturally vary over time and from place to place but it truly enhances all the ecosystems' services:

- **Provisioning Service**: any kind of benefit for people that can come from nature;
- **Regulating Service**: the benefit resulting from ecosystem dynamics that moderate natural phenomena;
- **Cultural Service**: non-material benefit that enhances the development and cultural improvement of people;
- **Supporting Service**: natural processes such as photosynthesis, nutrient cycle, soil creation and water cycle are the support for everything else. They allow the Earth to be able to maintain basic forms of life. Without them, all other services could not exist.

The most obvious is the proximity between the production site and the consumer which can even allow the possibility to consume the agricultural products directly by the producer, enhancing the access to health products and granting food security (Smit & Nasr, 1992). The opportunity to access fresh fruits, vegetables and others is very valuable, even more in cases of neighborhoods suffering from food shortages Urban agriculture can contribute to overcome this kind of problems, by improving nutrition, health and equity of access to primary goods such as fruits, vegetables, mushrooms, herbs, medicinal plants, meat, milk, cheese, eggs and others. The method is flexible, so every community can adapt the crops to its needs and preferences and do it in a fair scale, so everyone can access it.

The ecological functions and environmental benefits often outweigh the production ones. The consumption of local produced food balances the ecological impact, since transportation would not be needed, reducing the use of fossil fuels and consequent CO_2 emissions and other greenhouse effect gases. Urban waste products can also be reused locally, for example biodegradable waste can be recycled and used as crop fertilizer and waste water can be filtered and used for irrigation (Lovell, 2010), closing ecological loops specially when occurring on idle land and/or water bodies. This way the city can conserve much of its energy consuming and self-manage its waste. Besides, community and backyard gardens contribute to the greening of dense urban areas, improving the aesthetics and well-being of the community. Over and above, it has a major impact increasing air quality and reducing pollution.

Additionally, many of those products can reach the consumers through local markets ensuring the economic sector of the neighborhood and/or community. The implementation of these kind of techniques specially in an intensive production strategy can result in a very substantial economic value. It can really impact the city economy and make it prosper since it does not only have direct effect on the food production and consumption but it can as well create job opportunities for local residents and generate income, increasing entrepreneurship (Lovell, 2010; Smit & Nasr, 1992). Besides, it creates an

import substitution industry that ensembles production, processing, packaging and marketing (Smit & Nasr, 1992).

However, the population benefits from multiple ways, not only on an economic way. Indeed, urban agriculture can provide opportunities to meet, socialize and cooperate with family and neighbors, besides working as support to their cultural heritage and as a tool of empowering the sense of neighborhood, improving the environment for living (Lovell, 2010). Urban agriculture can prevent heritage losses, by providing access to ethnic foods that are typically not available in large supermarkets. In multicultural neighbors this effect is enhanced, since different cultures can spread their traditional food and taste new ones. Children and adults can learn about foods, nutrition, cooking, environment, economics and cultures through urban agriculture.

Last but not least, the support service is enhanced (Clucas et al., 2018). In fact, urban agriculture in the form of urban gardens for example, can also contribute to biodiversity conservation and urban microclimate regulation by regulating humidity, reducing wind and providing shade. This way it represents a new form of planning and landscaping transforming cities to support community farms, allotment and/or rooftop gardens, edible landscaping and urban forests among others. Moreover, urban agriculture can contribute for soil renewal, as the crops get seeded, grow and get renewed, and ensure the water cycle and photosynthesis. All of them are vital processes of the environment and inherent to the normal functions of plants and crops. In order to be properly described, the information was organized in Table 3:

Table 3 - Ecosystems' Services (Adapted from: Hasan [et al.], 2020))

Ecosystems' Service	Benefits of Urban Agriculture
Provisioning Service	**Production** Urban agriculture provides fresh fruits, vegetables, medicinal plants, meat, cheese, eggs and other food local produced for urban residents. This way it is possible to enhance food quality and security and overcoming the constraints of transportation. On other hand, this method is able to match the crops to the residents' preferences and to do it in the right scale.
Regulating Service	**Energy Conservation** Local production methods make it possible to reduce energy consumption due to packaging and transportation needs. **Microclimate Control** Urban Agriculture is able to enhance microclimate regulation through humidity control, wind protection and shade provision. The presence of green spaces in cities assume particular importance as the pollution levels keep on rising. Indeed, plants and crops are natural devices of air cleaning through photosynthesis and carbon capture. Moreover, they will help on water regulation and may prevent damages due to floods. **Urban Greening and Biodiversity**

	Community gardens promote urban greening and community well-being. Besides, these systems can help to sustain a wide spectrum of plant species, promoting biodiversity.
Cultural Service	**Community Cohesion** Cultural urban crops can boost the neighborhood spirit around them, since both tasks and goods are split. Neighbors can socialize and help each other while cultivating and then share the results while fruitling. **Cultural Heritage** The crescent community spirit can improve the cultural heritage and the bond between people and their home town. Social gardens and crops enhance the process by rewarding the residents with fruits of their own work. **Education** Children and their parents can improve their knowledge about foods, nutrition, cooking, environmental issues, economics and community culture.
Supporting Service	**Waste Management** Organic waste products can fertilize the crops. This way they got recycled and reused for growing vegetables and flowers. **Soil Management** Adding plants and crops to the commonly overload and spoiled urban soils can improve them a lot. Water cycle gets enhanced, photosynthesis and nutrient cycles help revitalizing the soil and ensure its renovation.

2.2.4 Limitations of Urban Agriculture

Urban Agriculture is increasing its popularity for social and economic benefits. However, this method has some limitations too. According to Sanyé-Mengual et al. (2015), there is a limitation in the application of rooftop greenhouses. The environmental burdens and economic costs of the adaptation of old buildings to greenhouse structures might be a significant issue. Besides, the legislative process of these changes might represent heavy costs and time consuming that can compromise the efficiency of the process.

Some other issues come from the contamination possibility (Antisari et al., 2015; Lal, 2020). Either soil pollution, through the use of pesticides and other chemical products, or edible crops contamination and consequent loss of food security, caused by airborne pollutants commonly present in the urban centers.

These issues should not be ignored, this is not a perfect method. All the factors should be considered and, the most important, evaluated and monitored.

2.3 VERTICAL FARMING

2.3.1 CONTEXTUALIZATION ON VERTICAL FARMING

There are some prominent threats to face about arable land availability in the near future. Some of the most important are the decreasing stock of agricultural land per capita, climate change, increasing urbanization, rapidly population growth. These threats are already impacting our daily lives, especially in the farmers point of view, by the rising costs of agribusiness and soil depletion, among others, leading to problems like over-farming or poor production practices which will directly influence the food quality, soil productivity (Benke & Tomkins, 2017) and may even put at risk some or all of the ecosystem services.

Nowadays, it is estimated that there are about 800 million hectares of land used for agriculture worldwide, which is about 38% of the total land area. Furthermore, 80% of the total cultivable land is already being used worldwide. Therefore, it is easy to identify this issue as an urgent and critical problem to be solved (Kalantari et al., 2018). In fact, one of the most emerging problems, in a long-term, is the continuing world population growth at a rapid rate that also means a gradual bigger food demand, which is already foreseen to be critical in the upcoming 50 years. By that time, 80% of the world population is expected to be living in urban areas, being not self-sufficient and thus having to rely on distant agriculture areas, with all the setbacks and obstacles this means. Initially, cities' food safety will depend on these distant foods' cost, transport, and distribution which quality and variety (Pons et al., 2015) which may be compromised during the process. Packaging and massive transportation will be needed, and consequently all the CO_2 emissions and fuel consumption, among other issues, will increase, compromising the sustainability. It's then clear to observe that, in order to minimize these severe effects, sustainable food production systems will be needed knowing that in order to produce sustainably, all factors should be considered as a whole. This includes environmental, social and economic advancements (Kalantari et al., 2018).

One way of contradicting this trend of land scarcity is, from the outset, to use the maximum available land in the most efficient way. Vertical farming can ensure both, since it is a concept that implies a vertical layout of the crops, stacked above each other, using all the space available and enhancing it in height. This way, vertical farming can help to reduce the need for arable land for crops by building in height instead of length; besides allowing multiple crops and cultures within the cities, near to their consumers (Despommier, 2010). Vertical cultivation allows the use of space to be reduced, leading to a higher yield per square foot of used land. Vertical farms are mainly located indoors, facilitating the control of environmental conditions for plants and crops to succeed, enhancing its growth and vitality. Moreover, it allows to boost and control the cultivation processes and make them viable all year round, which represents a great advantage versus the conventional agricultural methods. From window beds to rooftop greenhouses, vertical farming can match any form and size and should be adapted to the city layout and residents' needs and desires, overcoming the increasing distance between agricultural sites and urban centers.

On the other hand, vertical farming might not be able to be the holy solution for the next generations by itself, but it can certainly help. Converting vacant and unused spaces, such as high-rises' rooftops into productive space is a strategy towards sustainability and empowers the cities' food production. Farming up, rather than out, allows to take cities' agricultural production to its full potential, either in quality and quantity, being able to feed more people. Vertical farming can act not only on production but also on waste limitation, since local produced products and its packaging and transport exemption allows to avoid food damage and waste along the way.

The method is not new, in fact the first experiences of vertical farming go back to a long time ago (Bowery Farming, 2019). Many ancient civilizations have worked on the manipulation of their environments in order to potentiate its production and to make them easier to farm. Vertical farming was already used about 2.000 years ago in Africa and Central America, with Aztecs being one of the pioneers even in the hydroponics. It is estimated that these societies started to build their crops upwards to avoid damage due to floods and other natural events. For example, one of the first demonstrations of vertical farming in Europe goes back to 1600s with the French and Dutch civilizations. They grew Mediterranean fruits using elaborated "fruit walls" made of stone, that worked to absorb the heat in the daytime and to release it in the cooler evenings, easing the temperature and protecting the fruit.

Through the years, the method has been established and evolving with new techniques and technologies depending on the needs and objectives. With recent increasing of concerns about population continuous growth and arable land scarcity, vertical farming is in the order of the day, since it may be a good solution to face the challenges and tackle the problems or, at least, to minimize them.

2.3.2 Types of Vertical Farming

Aiming for a sustainable urban food producing method, a new concept has been proposed to address this issue and to tip the scales between sustainability and the growing food demand, without needing much arable land. In fact, it may not even be necessary at all by designing and implementing vertical farms. According to Eigenbrod and Gruda (2015), vertical farming might be the most complex and innovative concept of urban agriculture and consists in cultivating plants, possibly with the help of livestock depending of the case, on vertically inclined surfaces. Vertical farming can be quite varied; therefore, it can be pretty much implemented anywhere, but will be particularly efficient in highly dense urban centers characterized by a lack of available land and space. Vertical production cultures would provide additional growing area and thus reduce the common need to increase arable land (Eigenbrod & Gruda, 2015). This way, vertical farming is a farming method that entails large-scale food production in high-rise buildings that may be located in urban areas, incorporating both engineering disciplines and natural sciences, with numerous applications in society and in the environment (Kalantari et al., 2018).

Lu and Grundy (2017) define it as an indoor agricultural strategy to grow food in protected environments, for example buildings and glasshouses. In fact, there are several ways to put vertical farming in practice in a building:

- **Windows Seedbeds** – Each resident can have his private crop, normally dedicated to medicinal plants or aromatic herbs. Although they are quite limited in terms of space, they can be efficient if well exposed to the sun. Since they are vulnerable to the wind, they are not very common in high-rise buildings.
- **Greening Facades** – This type of vertical farming is not new but has been evolving in order to reach its potential. Conceived according to the direction of sunlight, this method has quite an impact on the plants and on the building itself. In summer, the green facade keeps the interiors and courtyards cooler because the plants protect the building from overheating due to water evaporation. On the other hand, the plants shield the building from the excessive cold in the winter, acting like green fur. This has effects not only in the temperature but also in the quality of the air, since the green façade acts like a filter to dust and the inherent photosynthesis of the plants helps improving the air quality. Moreover, the vegetation gives protection against noise, UV rays, hail and wind and may serve as habitat for animals like birds and insects which are essential for the environment and may

even be active agents in the process, like the bees that play a major role in flowers' pollination, for example.

- **Rooftop Greenhouses** – Another type of vertical farming is located on the roofs of buildings, whether commercial or residential. Rooftop farms may provide food while combating the heat-island effect, mitigating storm-water runoff and insulating buildings (Al-Kodmany, 2018). Despite the location, rooftop greenhouses will work as a normal greenhouse, with the same principle: converting light energy into heat, enhancing the growing process of the crops through the buffering of the ambient temperature and protecting the crops from the extreme cold. Common features include the use of recycled wastewater and rainwater. But throughout the years, some technologies might push this method even further by air-temperature and humidity control, solar panel lightning and heating, 24-hour LED illumination, among others.

2.3.3 Benefits of Vertical Farming

When compared to the traditional method, vertical farming offers multiple employment opportunities since building a vertical farm requires a multi-disciplinary team. Another social benefit is the creation of new social networks among producers, farmers and consumers that create new friendships in the workspace and around it. Vertical farms could perform an important role in education as well. Through them, residents can learn about plants, crops and productions and share knowledge with each other. Besides, citizens' health is enhanced by vertical farming due to the fact that this method directly provides fresh and local produced vegetables and fruit, avoiding the spread of noxious and infectious diseases present in food grown by traditional agriculture methods, polluted and frequently plagued with bacteria. Moreover, since vertical farming can use no soil at all, its products turn immune to soil pollution, often observed in urban centers. Additionally, mental health gets enhanced as well, since being near to the environment can help to reduce stress (Al-Kodmany, 2018).

Environmentally speaking, vertical farming assumes a major role. In conventional farming, food travels on average 1.500 miles, according to Al-Kodmany (2018). Bringing the crops to the cities implies a massive reduction of fuel usage and CO_2 emissions. In other way, indoor farming is immune to the weather outside, therefore vertical farming does not get damaged by temperature changes, wind, storms and all the other weather impacts/factors that can compromise the produce yields. This assumes special relevance nowadays, where pollution starts to really affect cities' weather on a daily basis. Current advances in technologies, for example in LED lightening and climatization, increases the yields of these cultures, providing the optimal conditions for crops to grow. Vertical farming also reduces the use of fertilizers, herbicides and pesticides which have been contributing to globally polluting the water and soil and can help to cool the environment, mitigate the urban heat island effect and to tackle climate changes. The urban heat islands phenomenon deteriorates the quality of life in cities. According to (Elghonaimy & Mohammed, 2019), urban encroachment and losing greenery are the major reasons for this phenomenon to occur. Therefore, facing this phenomenon is one of the main concerns for many different specialists whose research try to control the causes and dramatic results in decreasing vegetation within the city. The vertical farm is one of the promising ideas to enrich the vegetation areas and reduce the different types of pollution besides increasing food productions, especially in highly populated countries, and have a harsh natural environment. The vertical farms focus on the opposite practice of traditional farming in terms of surface area, environmental conditions, water, energy consumption, and energy-generating methods (Figure 1). Additionally, they rely on controlled processes achieved by technological cultivation techniques, as renewable energy systems operate them. Thus,

getting natural resources, so that future generations can have a healthy and active life. The building itself has thermal advantages since there will be needed less energy in order to cool it off in the summertime and it will have reduced carbon dioxide emissions. Moreover, vertical farms help in sound absorption, reducing city noise all around them because of the vegetation ability to reduce sound reflection. In fact, rooftop farming can absorb some of the noise generated by car traffic, machineries and airplanes. Last but not least, this method has the power to enhance biodiversity as a result of the environmental quality and diversity which can support different types of cultures, animals and insects.

Figure 1- Comparison Between the Two Types of Farming
Source: Skyfarms, 2019

The third main topic refers to the economic perspective. In fact, for Kalantari et al. (2018) vertical farming has a major impact in diminishing costs with considerable savings. First, it allows to minimize damage and losses due to floods, drought and sun. Almost no fertilizer is needed so its costs are avoided, beyond that almost no machinery is needed. Since the food is locally produced, near to consumers, there is no need to transportation or to packaging. All these reasons represent major economic savings while at the same time the method overcomes seasonality, allowing to have yields all year long therefore the profits are also maximized. If these methods start spreading, rural farms can become less overloaded, although still fulfilling other relevant purposes like producing electricity from wind or solar panels, for example. Vertical farming is not a matter of substituting services but rather of leveraging resources to its maximum potential value.

The above information is summarized in the Table 4:

Table 4 - Summary Table of the Benefits of Vertical Farming

Scope of Influence	Vertical Farming Benefits
Social	New job opportunities New social networks

	Enhanced education Improved food security Enhanced mental health
Environmental	Reduced fuel usage and CO_2 emissions Immunity to outside weather Technologies increase produce yields Reduced usage of chemicals Reduced urban heat island effect Vegetation can work as cooling systems Sound absorption Enhanced biodiversity
Economic	Minimized damages due to natural disasters Low investment needed either on chemicals and machinery No need of transportation and packaging Overcome seasonality

2.3.4 Limitations of Vertical Farming

Despite all the possible benefits of Vertical Farming, this method is not flawless. The weak spots must be considered whenever planning a vertical farming project. As mentioned, this agricultural technique can be represented by quite different projects, both in their structure and method of operation.

Generally speaking, edible crops grown in cities, especially those raised outdoors, are always vulnerable to airborne pollutants, which can lead to serious health risks (Antisari et al., 2015). In fact, it is absolutely imperative to acknowledge this issue so that it can be understood and prevented. In the particular case of hydroponic systems, some more issues come up. The main problem is the high initial setup cost, due to the high prices of the fundamental supplies (Domingues et al., 2012).

Furthermore, the kind of systems are also quite vulnerable to power outages. Since all watering and nutrient supply systems are electrical-driven machines, an electricity failure compromises the project. Hydroponic systems may be prone to the development of waterborne diseases if crops get contaminated by phytopathogens (Schnitzler, 2004). This way, it is imperative to have specialized operators with all the skills and knowledge that is required to produce high yields of crops and to keep them sane. Thus, it is not unusual to imply high costs due to pest control, for example. Despite being able to reuse much of the resources it requires, a system like this can still generate a lot of plastic waste that may negatively impact the environment (Kumar & Cho, 2014).

Regarding rooftop greenhouses, some limitations are frequently pointed out, such as the ecological burden and economic costs of bringing greenhouse structures into compliance with building regulations (Sanyé-Mengual et al., 2015).

Overall, when designing this type of structure, it is imperative to evaluate the possible methods of application and their pros, but also to be aware that they will all have their cons. All of this must be evaluated in order to define the most efficient solution.

2.4 SYNTHESIS

The scarcity of arable land is an ever-growing reality, and the problems related to food availability for a growing world population will get worse. The overwhelming majority of the world's arable land is already in use today. However, the subsistence of a growing population that is increasingly concentrated in large urban centers, far from the cultivation sites, cannot be guaranteed.

Urban agriculture is defined as “the growing, processing and distribution of food or other products through intensive plant cultivation in and around cities” (Tornaghi, 2014). It combines the ability to increase the existing area with the ability to grow crops much closer to consumers. Thus, it is possible to combine increasing agricultural production with the advantages inherent to reducing energy use and reductions in transportation and packaging needs, for example. Despite it is not a new method, it is clearly on the rise due to the urgent need to find alternatives to traditional methods that are unable to meet the demand. The efficiency of the method depends on its suitability for the site and its surrounding area. It is therefore essential to evaluate the various possibilities in order to be able to choose the most suitable type of exploitation for a given site. This has to do, first of all, with the characterization of the available space and its typology of use. Then, there are already some styles of agriculture application in urban environments that are important to analyze and choose. These include: Soilless Cultures and Hydroponics, Aquaponics and Vertical Farming. Moreover, it is important to highlight how this method has the ability to enhance all ecosystem services and thus increase their sustainability. This must be considered as well as the fact that there are still some limitations that are felt in the implementation and/or management of such a project, typical of methodologies still in expansion.

The particular case of Vertical Farming has special potential in terms of space occupation since 80% of the total cultivable land is already being used worldwide. Its innovative layout, arranged vertically, allows a better process efficiency per unit of area. It is a method that cuts across the various spheres of daily life: social, environmental, and economic. As such, its potential advantages should be analyzed based on the weaknesses and strengths of each location, so that the best application of the method can be defined. Like these, limitations should also be analyzed and considered in the process of designing such a production. Thus, seek to make the most of the potential of each type of application of vertical agriculture, indoor or outdoor.

In the context of this work, it is now important to study in a greater detail the influence this method can have on climate adaptation and how it can assume an increasingly important role.

3

THE POTENCIAL OF VERTICAL FARMING TO TACKLE URBAN CLIMATE ADAPTATION

3.1 INTRODUCTION

It is now important to individualize vertical farming and its potential for climate adaptation.

This analysis is done in this chapter, starting by identifying the main obstacles that will have to be overcome for a climate adaptation. Then it is important to understand how vertical farms can influence and help to overcome them, and the scale at which they operate. Furthermore, it begins to be possible to define the role that vertical farming can take, identifying its main areas of influence, where it can have a particular impact. This information is supported by the examples presented of projects already implemented and with concrete results, all over the world.

3.2 MAIN CHALLENGES OF CLIMATE ADAPTATION

According to Simmons (2019), there are reports describing how climate change is affecting the world. The threats of higher temperatures, drought, heat waves, and sea level rise are increasing. These can threaten health, infrastructures, ecosystems, and social systems. As carbon pollution continues to accumulate in the atmosphere, it is expected to worsen the current situation. Scientists and politicians around the world have been urging cuts in carbon pollution. But due to the pollution that is already in the atmosphere, reducing emissions will no longer be enough to avoid the impacts of climate change. Therefore, new measures need to be taken into account and bigger effort has to be done, adapting it to the multiple ways that climate change can impact each location. It can include some of the following challenges:

1. Longer and more intense fire seasons

Warmer and drier weather conditions are predicted to occur in the future.

2. Sea-level rise

The sea level is expected to rise and, among other consequences, to endanger coastal areas.

3. More severe weather

Severe storms and extreme heat can become more often and have notable impacts upon public health.

4. Climate impacts

Temperature oscillation, extended droughts, severe storms, and other weather impacts are jeopardizing long-standing farming methods.

5. Poor air quality

Climate change can cause more airborne bacteria, which can harm the respiratory and cardiovascular systems.

6. Climate justice

Lower income and marginalized people are often impacted in a much bigger scale by extreme weather conditions and further aggravation of air pollution.

7. Need to managed retreat

populations should be prepared to react to extreme phenomena, minimizing damage.

Adaptation and decision-making responses can be intended to both:

Building adaptive capacity - establishing the information (research, data gathering and tracking, awareness raising), supporting social frameworks (organizational development, partnership working, institutions), and supporting governance (regulations, laws, and guidelines) that are required to establish adaptive measures;

Delivering adaptation actions — measures to reduce vulnerability to climate hazards.

These two categories demonstrate the spectrum of adaptation measures and strategies out of which a good adaptation response can be established (Source: World Meteorological Organization). It is crucial to establish targeted measures to generate response capacity in order to reach successful adaptation measures. In regard to willingness and capacity to adapt, these are frequently constrained by barriers or restrictions that may lead to questioning the need for adaptation. These constraints or barriers include: (Source: APA Website):

- Limited comprehension of the nature and scope of risks and vulnerabilities - existing and foreseen;
- Lack of supporting policies, standards and regulations;
- Existing legal or other regulatory restrictions;
- Prohibitive costs of potential adaptation options when budgets are limited;
- Limited access to appropriate technologies;
- Social, cultural and financial inflexibilities and resulting conflicts;
- Short-term character of decision-making and planning timeframes;
- Belief that there is still too much time to start deciding on climate adaptation;
- Failure to accept the need for adaptation associated with perception of uncertainty.
- The clearance of these obstacles is being facilitated by systematic analysis of the constraints on the actual adaptation measures and by gradually raising consciousness of the hazards and consequences of climate change in their decision-making domains.

Food production has a major influence in the climate system, as shown in (Figure 2). A sustainable project is expected to be the result of this kind of idea. It should provide answers to the questions that closely touch future situations to maintain sustainable environments and feed the rapidly growing population. This type of project should be able to produce healthy environments, even in crowded urban areas, through its design-integrated solutions, such as water reuse and waste recycling systems and renewable energy sources (Benke & Tomkins, 2017).

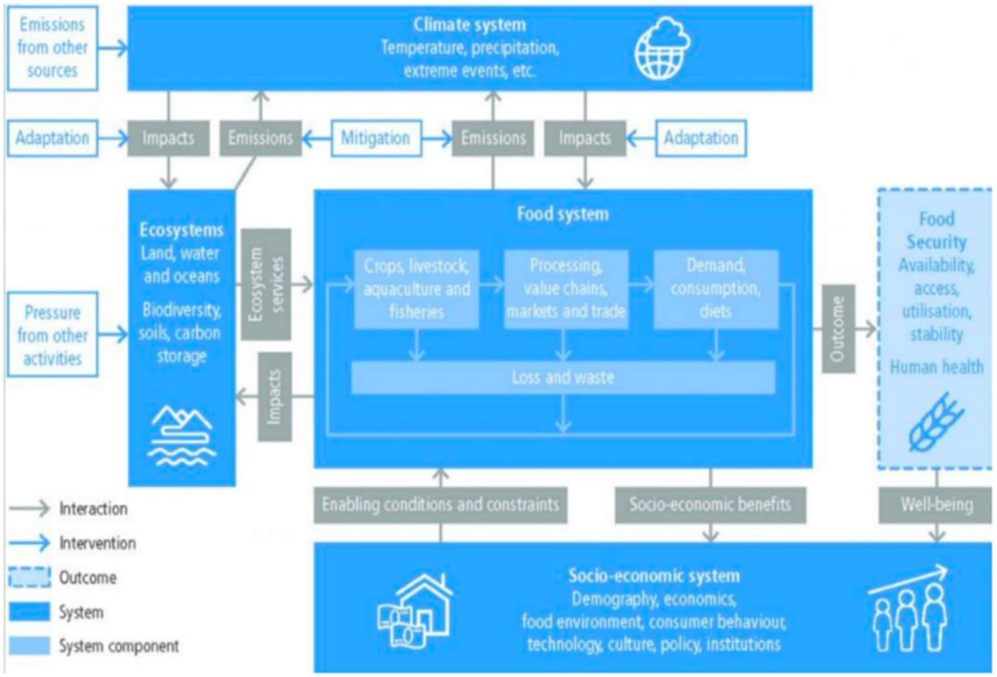


Figure 2- The Relation Between the Food System and Climate

Source: Mbow, 2019

Vertical farming can play a decisive role in climate adaptation, and can do so at various scales as depicted in Table 5:

Table 5- Multi-scale environmental influence of vertical farms (Source: Zaręba, A. [et al.], 2021)

3.3 THE ROLE OF VERTICAL FARMING FOR CLIMATE ADAPTATION

As mentioned before, despite some limitations, vertical farming can have many positive effects. When applied properly it can enhance food safety, food quality and, first of all, food provisioning for an ever-growing population that has less and less cultivable area available. Alternative methods of farming like this are urgently needed therefore this alarming situation may be mitigated and managed. Consequently, vertical farming is becoming a topic of the moment, and its benefits are being tested in many pilot projects worldwide. The previous chapter described several of these possible benefits, divided in three scopes: social, economic and environment which will be the main topic of this chapter. The goal is to understand how this alternative land use and farming method can help on climate adaptation and how it can be put into practice.

Vertical Farming can have major impact on climate adaptation, influencing it in seven main areas:

i. Low Resource Requirements

Its ability to dismiss the need of transportation is a very good benefit to begin with. Since this method allows to produce and collect the goods near to their consumers, it also reduces packaging requirements, which means a great reduction in the consumption of fossil fuels and plastic. Additionally, vertical farms can produce crops with 70 to 95% less water than the conventional field farming which can be particularly helpful at a time when it is urgent to have more control over water expenditures and/or in areas of the world that have less water available but which depends on agricultural production for their own food (Pure Green, 2016). Vertical farms allow farmers to produce a significantly larger quantity of plants without necessarily needing an extensive area, on the contrary, this form of cultivation allows them to maximize the production per square meter by growing upwards and positioning the crops closer together and stacked on each other. It should be mentioned that there are techniques that require a low amount of soil or, for example hydroponics, that even do not use soil at all.

ii. Invulnerability to the Weather

Furthermore, the crops can be quite invulnerable to the weather and climate changes due to the possibility to be raised indoors and away from temperatures and/or winds that compromise their longevity. By raising crops in rooftop greenhouses, for example, they are safeguarded and its productivity is ensured.

iii. Water Cycle Enhancement

According to Liu et al. (2022), this emerging technology allows to enhance the crops' productivity compared to the conventional farming and to have a faster growth cycle, both key factors to support the method. The reduced need for water and pesticides and the possible elimination of fertilizers (if hydroponic systems were used) prevent water pollution and soil contamination due to chemicals runoffs. In addition, vertical farming grants all year-round production with lower environmental impacts, such as the water cycle. With this method, the water used is cycled back, directed to a water tank, and available for reuse. This is possible due to the fact that this water is monitored by electrical conductivity so that the nutrient solution can be evaluated and the water quality can be ensured. In fact, the nutrient management system used in Vertical Farming features an automated fertilization process that ensures that only the necessary nutrients are supplied so that crops can grow optimally. This is, after all, one more way to prevent waste and runoffs.

In dry areas, like the Persian Gulf countries and most African countries, threatened by fast demographic growth, climatic conditions and water shortage, vertical farming can be a key factor in adapting to climate change and seeking to mitigate current food supply risks (Liu et al., 2022).

iv. Temperature Regulation

One of the basics and most important indicators about climate situation is the temperature, outside and inside. Seeking to manage the results of the climate adaptation and, very often, the consequent temperature increase it is urgent to find ways to control it, and to do so Vertical Farming might be helpful. Indeed, the accelerated expansion of cities all around the globe is followed by less vegetation. This combination often results on the increase of the urban heat island effect (Davis & Hirmer, 2015), that happens when cities replace natural covered land by dense sidewalks, buildings and other heat-absorbing and heat-retaining surfaces. It means that the heat in urban areas can increase up to 15ºC compared to the non-urbanized surrounding areas. Necessarily, this will result in an increased demand for indoor cooling systems that represent an important increase in the electricity usage, that will be as significant as the need for cooling. When this need is generalized it starts to have expression on the environment, since it consumes resources and has impact on the air conditions. Davis and Hirmer (2015) consider that urban vegetation can mitigate these effects, since greening allows the heat transfer between a building and the environment to be reduced while it helps on CO_2 capture, and the consequent increase of the quality of urban air conditions.

According to Loh (2008) a vertical garden (that can be represented by green walls or green façades) made up from substrate panels allow to reduce building façade surface temperature fluctuations, as well as cooling ambient temperatures on the surroundings. Other representation of vertical gardens are the rooftop gardens or rooftop greenhouses that, due to its position, can provide sound isolation and, most of all, can provide shade that absorbs solar radiation and prevent it from reaching the building. Therefore, it is possible to identify 4 main mechanisms in the use of vertical gardens as cooling systems (Loh, 2008):

- Shade produced by the vegetation;
- Solar radiation protection provided by the vegetation and substrate;
- Cooling by plant evapotranspiration;
- Protective barrier against wind;

In addition, plants can hold water on their leaves' surfaces for longer than the facades of buildings, and this then acts as an additional buffer for insolation. All this, combined with the natural transpiration of plants, leads to a more comfortable urban climate (Source: Farm Progress Website).

v. Carbon Sequestration

Plants have the natural ability to improve air quality, through photosynthesis. This is how plants use the sunlight, water, and carbon dioxide to create both oxygen and energy in the form of sugar. During this chemical process the concentration levels of carbon dioxide (from urban pollution) are reduced and the oxygen gets renewed meaning that air quality is improved. The urban environment becomes more pleasant and sustainable.

vi. Minimized Damage due to Natural Disasters

There are a variety of important benefits due to land management to be more resistant to heavy rains and to be less likely to flood. Enhancing water infiltration - the rate at which water goes through the surface into the soil - can help to prevent local floods and restock groundwater. Better infiltration can also lead to potential increases in water held in the soil. This benefit, not only increases water availability for plants, but also decreases the flow that can waste nutrients and cause soil erosion. Nevertheless, vertical farming techniques can overcome its performance by its vertical layout which can prevent the flood waters from reaching the crops at all.

Fassman-Beck et al. (2013) consider that living roofs can actually provide a unique opportunity to manage rainfall events and mitigate damage. It is pointed two great advantages for urban storm water management: living roofs act as at-source control to avoid runoff generation from an area that would be impervious otherwise, and they can provide an opportunity to give a good use to a space/building that would otherwise have no use. Since rooftops represent a significant part of the total urban impervious area there are plenty opportunities to explore.

Sun can be harmful for structures which can also warm up making their components to expand and contract, usually at different rates from one another. The differential motion can then lead to stress causing damage to the structure. They may also dry out, once again leading to differential movement, along with surface cracks and fissures. The implementation of vegetation on buildings' façades and/or rooftops allows solar energy to be absorbed by the plants and not by the building itself, preventing it from being damaged or, at least, mitigating the damage.

vii. Non-seasonal Production

Since this agricultural technique can be implemented with no use of fertilizers and doing a proper water management, it can overcome seasonality, especially in cases of indoors farms which can be implemented in ground soil or on skyscrapers rooftops. This can assume a major role in remote locations with dry climates, that need to maximize the efficiency of their scarce resources, or in dense urban centers, which need to maximize its resources to food production to feed its ever-growing population.

The previous information is summarized in Table 6 for easier analysis.

Table 6 - Summary Table of the Role of Vertical Farming for Climate Adaptation

The Role of Vertical Farming for Climate Adaptation	
Low Resource Requirements	Fuel use is reduced or even avoided Plastic packaging is reduced Water use is highly reduced
Invulnerability to the Weather	Crops can be raised indoors
Water Cycle Enhancement	Low usage of water Reduced use of pesticides Reduced pollution risks Waste prevention and runoffs avoided
Temperature Regulation	Urban Heat Island effect is reduced Green facades can work as climatization Rooftop Greenhouses can absorb UV rays
Carbon Sequestration	Enhanced photosynthesis process
Minimized Damage due to Natural Disasters	Elevated crops are immune to drought and floods Living Roofs can regulate rainfall
Non-seasonal Production	Indoor crops can have all year yields

3.4 Projects and Initiatives of Vertical Farming for Climate Adaptation

3.4.1 Worldwide Context

Newark, United States

Founded in 2004, Aerofarms have been working to transform agriculture, aiming to shape it according to people wants and needs, never forgetting the resilience of the planet and its endangering factors such as the rampant lack of arable land. This company applies the latest innovations in indoor vertical farming, artificial intelligence, and crop biology to fix a faulty food system and to better the way to obtain fresh products. These production compounds should then grow the goods to distribute them after, locally and globally. Nowadays, this company already owns an agricultural platform built by them that is able to grow a wide range of products, through research and development farms. These facilities can enhance its growing process, using sensing technologies, data science and artificial intelligence. So that they can achieve superior flavour, higher quality and enhanced nutrition with the most upscale levels of most monitoring and food safety in the industry. The majority of these Research and Development farms are currently based in Newark, New Jersey, but there is already in motion a new compound in Abu Dhabi that will feature new technologies such as phenotyping, advanced speed breeding, phytochemical analysis and more. (Source: Aerofarms Website)

Since its foundation, AeroFarms is the pioneer and the commercial leader in large-scale commercial indoor vertical farms. They exclusively use proprietary aeroponics to optimize their growing, while optimizing the process in order to be able to use up to 95% less water and no pesticides or other chemicals at all. At AeroFarms, horticulture meets genetics, engineering, food safety, data science and nutrition, turning them the noticeable capability to understand plant biology beyond the standard processes (Kozai et al., 2019). Their commercial farms (Figure 3) are closely monitored so that they can ensure an optimization for year-round production, despite the season or the weather, of over 550 different species of plants from berries, leafy greens, tomatoes and many more.

The primary goals are to comprehend plant biology in order to be efficient farmers and to be able to solve larger issues in farming. In this way, it is possible to serve communities by providing high quality, consistent and safe products on a daily basis. In order to proliferate its ideals, AeroFarms is partnering with cities and schools to bring its customised indoor vertical farms to communities. Ultimately, this approach aims to provide tools to preserve the environment for the generations to come, by growing more while consuming less.

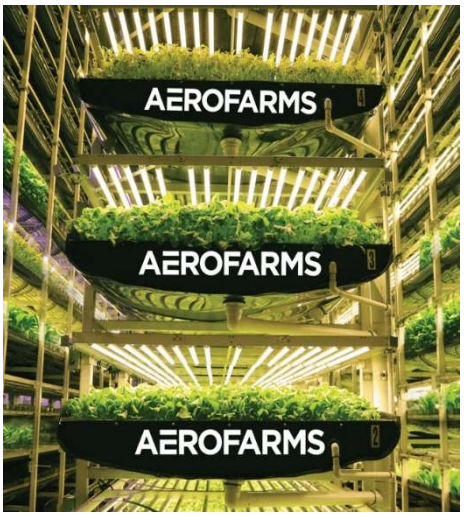


Figure 3 - AeroFarms, 2004
Source: AeroFarms Website

Seoul, South Korea

Kim et al. (2018) identify high density residential complexes as the image of the South Korean city of Seoul, which grants it the potential to explore urban agriculture, especially vertical farming. A city like Seoul, which is highly populated and highly developed, becomes more vulnerable to possible shortages of food resources. As such, it is urgent to find alternative solutions to conventional agricultural production, practiced far away from this huge urban center. There is potential to explore ground-level open space farming in high-density residential complexes. They are usually characterized by large open spaces between buildings that can provide good access and provide a safe and comfortable environment for people to be and share.

Seoul has been experiencing a rapid expansion of the area dedicated to urban farming. Indeed, it went from 29 HA in 2011 to 162 HA in 2016, that is 5 times bigger in 5 years long (Kim et al., 2018). The majority of this area is located in the city's greenbelt in the outskirts but there is already a percentage represented by rooftops, schools, parks or small vacant spaces in the city. The Seoul Metropolitan Government announced the "Seoul Urban Agriculture Visions" projects, the first in 2012 and the second in 2015. The second one had the goal to secure between 400 to 450 HA of space in the city for urban agriculture by 2018 which would already mean a significantly improvement.

However, this was not achieved because the expansion of farming spaces of the early 2010s slowed down over the years, because of the lack of approach variety and resource scarcing according to some local critics (Kim et al., 2018). Indeed, the measures should not be limited to production at ground level because the height of the buildings in the vicinity could be an obstacle to one of the main requirements: sun exposure. Bulky and high-rise buildings tend to prevent sunlight from directly hit the ground floor, possibly becoming insufficient for the needs of agricultural crops to grow (Figure 4). That is where vertical farming can play a major role on overcoming this issue. It can take the results even further, taking advantage of its chameleonic power, adapting to the needs of the city without requiring a larger available area and, instead, taking advantage of the existing large residential buildings turning them into large agricultural urban crops.

Figure 4 - Seoul Urban Agriculture Visions Project, 2012
Source: HANKYOREH Website

Japan

The low requirement for nutrients in vertical farming means that the potential for lower environmental impact is greater in vertical farming that in conventional farming. Liu et al. (2022) conducted a study that evaluated the environmental impacts of vertical farming for vegetables, in the Japanese province of Miyagi where this alternative agricultural technique has been utilized in a post-disaster scenario. Japan is commonly subjected to natural disasters of all kinds, since typhoons to tsunamis. Of the entire country, the province of Miyagi was one of the most severely damaged by the tsunami and nuclear accident that followed the Great East Japan Earthquake, back in 2011. Liu et al. (2022) claims that over 15.000 HA of fertile land was substantially damaged which means about 12% of the total farmland of Miyagi with the aggravating factor that the reuse of these lands was compromised due to contamination by sea salt and radioactivity.

Japan is highly dependent on food imports to match its citizens' food demands. According to Liu et al. (2022) the food self-sufficiency rate in Japan have been decreasing from 73% in 1965 to 38% in 2017 which means a national production capacity downgraded from 86% in 1965 to 66% in 2017, far below most developed countries. This implies that countries like Japan, which depend on other countries to meet their food needs, are actively exporting major ecological impacts to these countries but that implies that their supply from abroad may not be guaranteed. If some of the countries with the best self-sufficiency rate reduce their food exports in order to ensure domestic food supply, will result in increasing food prices, meaning that any change on food imports/exports will have a major impact on the global food supply. In order to avoid it, a plan, known as "The food, agriculture and village basic plan in Japan", was suggested in 2018, on the basis of the need to increase self-sufficiency based on caloric requirements to 45% and to raise production capacity to 75% by 2030, pointing vertical farming as one of the most efficient ways to achieve it.

Liu et al. (2022) highlighted the importance of local produced food, especially in post-disaster periods where the supplies get compromised due to the damage on the road system. Vertical farming was then set as a regional rehabilitation program to rebuild Miyagi's agriculture, trying to mitigate the damage to all the locals. A vertical farming project has begun in 2014 in Ishinomaki, in Miyagi Prefecture, with paddy and chrysanthemum production while in Natori, in Miyagi Prefecture, was focused on cultivating wheat and soybeans as a part of the "Tohoku reconstruction" project (Figure 5). Later on, the world's largest artificial light vertical farm with LEDs was established in Tagajo, in Miyagi Province, where it is estimated that 10.000 lettuce plants can be harvested per day, making the country's productivity much higher than it was. (Source: Kajima Website)

In 2020, over 85% of the tomato (Figure 6) and strawberry market, between 60 to 70% of the cucumbers, bell peppers and asparagus were already represented by vertical farming crops, demonstrating that this technique is widely spreading around the country. Although, Liu et al. (2022) emphasize that despite the trend in recent years it is still not possible for vertical farming to replace the conventional methods of farming. At the moment, the crop variety suitable for cultivation is still quite limited, and vertical farming techniques need further development.

Figure 5 - Tohoku Reconstruction, 2014
Source: Tohoku University Website

Figure 6 - Tomatoes Produced by Urban Agriculture on Tohoku Reconstruction
Source: Tohoku University Website

3.4.2 European Context

Berlin, Germany

The modern busy lives demand fresh products to be available all year, despite some varieties may be seasonal and/or produced across the world. The result is a food system focused on high quantities, low prices. Thus, aim to efficiency over quality so that it is possible to ensure sustainability and traceability.

From November 1st, 2016 to April 30th, 2018 the EU-funded INFARM (The vertical farming revolution, urban Farming as a Service) project reflected an emerging need for greatly nutritious locally grown food, potentially free of herbicides and pesticides. Also, refers to the lack of accountability in the current food system. The answer relies on vertical farming, which grows food in vertically stacked layers under monitored conditions, using technological tool, such as light-emitting diodes (LEDs) that mimic sunlight effects. INFARM takes the concept even further by employing its smart modular farming units in multiple places around the city.

INFARM is already operating more than 50 farms (Figure 7) across Berlin in supermarkets, restaurants and distribution warehouses. Beyond the in-store farms, INFARM has successfully installed and powered up a large-scale seedling plant and logistical support system that enables the continued operation of all farming units, enhancing its potential success towards creating an urban farming network in Berlin, that will eventually make the city closer to self-sufficiency in its food production sector. (Source: Cordis Website)

Figure 7 - INFARM Facilities, 2016
Source: Avi Bohbot Website

Sweden

Back in the summer of 2018 the Swedish food supply was significantly affected by droughts, jeopardizing national food resilience. Martin and Molin (2019) identify Sweden as a country with an increasing dependence upon food imports and significant fossil fuel inputs in the agricultural sector. It is then clear to say that to enhance food supply in a changing climate, new technological innovations and farming techniques are needed.

Therefore, it will be very important to find solutions for enhance food resilience and food security, such as vertical farming in controlled environments, less affected by climate changes. Some key factors for the environmental performance include electricity demand, growing medium, location and packaging material. For example, replacing plastic pots with paper pots can mean large reductions in greenhouse gas emissions on its own, while massively reduce the impacts and resource depletion. Furthermore, by replacing gardening soil for fibrous by-products, it is possible to reduce significantly the environmental impacts.

There is already a well settled vertical hydroponic farming by Grönska in Stockholm (Figure 8), producing around 60.000 plants per year. This type of method can grow a variety of leafy greens and herbs which are incorporated in the regional market, being sold to local supermarkets and distributors enhancing the national economy and food supply (Martin & Molin, 2019).

Figure 8 - Vertical Hydroponic Farming in Stockholm, 2018
Source: Grönska Website

Oslo, Norway

According to Gustavsen et al. (2022) the Norwegian city of Oslo has been experiencing, over the last decade, an increasing enthusiasm on urban agriculture having already resulted in a development of green spaces, and cultivation opportunities has been prioritized. There is already in motion a strategy for urban agriculture called "Sprouting Oslo", developed by the Oslo Municipality's Urban Environment Agency and running from 2019 to 2030. The plan is to provide subsidies to various urban agriculture projects around the city, increasing knowledge and to spread urban agriculture activities.

A plan like this is expected to have major impact on the city's environment by making it more resilient and well prepared for the climate adaptation challenges that lie ahead. One way to do this is through subsidies that also work as motivation to be open minded and become these new ideals and new agricultural techniques.

According to Gustavsen et al. (2022), urban agriculture also have a commercial type of approach that includes vertical farming and aquaponics, ideal for urban areas with lack of space (Figure 9). In accordance to this author, an online survey indicates that the overwhelming majority of the people already identifies urban agriculture as an important tool for the city environment, and that about 50% of the sample is willing to pay between 5 EUR and 50 EUR worth of taxes per year for vertical farming purposes.

Other part of this urban agricultural strategy has to do with the habitats and wildlife. Beyond financing cultivation tools, these subsidies should be used to build beehives and hen houses, for example. This is uncommon and often difficult to implement on vertical farming but, when possible, it should not be overlooked as it is a very important part of the natural environment, for example, because of the importance of bees in pollination processes.

Figure 9 - Sprouting Oslo, 2019
Source: Edible Cities Network Website

Belgium, France and Luxembourg

Born to work and support the emergence of rooftop greenhouses in urban areas, aiming to reduce CO_2 emissions, the GROOF (Greenhouses to Reduce CO_2 on Roofs) is a European coaching project that, as of September 2020, already included 10 rooftop greenhouse projects. 4 of them are located in Belgium, 1 in Luxembourg and 5 of them are from French cities. GROOF's expertise covers 4 essential skills for the efficient development of a rooftop greenhouse: construction, energy exchange, production

techniques and economic model. For one year, this coaching program helps project leaders through personalized advice and coaching days to help them enhance the project effectivity.

- Belgian Projects
    - Green(s)pote (Brussels) – Supported by Les amis de l'Entrepote, this project is represented by a greenhouse designed to supply a restaurant located just under the farm;
    - Pousses & Vous (Brussels) – This project consists in pedagogical projects in primary and secondary schools, turning their students into garden keepers.
    - Novacitis (Liège) – An old carpentry store in the city of Liege has been converted into a rooftop production area alongside a cafeteria, a local grocery store, and a food processing unit, all of which create synergies through each other.
    - Les Petits Poucets (Namur) – This project seeks to grow and then sell healthy, fresh produce to the residents of the city. In addition, it provides educational training programs for potential project leaders.
- French Projects (Source: Liège Université Website)
    - J'habite mon Jardin (Tours) – Working as a tool for social integration, this project was created by Tours Habitat and combines community farm with an area for leisure and group activities;
    - ISA/Yncrea (Lille) – Aims to build the first European demonstrator of food and agriculture for the city of tomorrow;
    - Culina Hortus (Paris) – Developed by Cueillette Urbaine, seeks to build France's first aquaponic and bioclimatic greenhouse farm on the roof of a building located in Paris.
    - Symbiose (Nantes) – This 400 square meter project, adapted the roof of an already existing habitacional building into a rooftop greenhouse;
    - Toits Vivants (Arcueil) – Led by Axone Promotion, the project features a multifunctional development of an urban greenhouse and a community vegetable garden located on the roofs of residential buildings.
- Luxembourg Project
    - Adhoc Habitat Participatif (Kirchberg) – Community rooftop greenhouses

Liverpool, England

Under the leadership of The Mersey Forest, via Community Forest Trust and funded through the EU Horizon 2020 project Urban GreenUP, a living green wall appeared on the exterior of St Johns Shopping Center, in Liverpool. Filled with more than 14.000 evergreen plants, this wall attracts bees as well as other pollinators to enhance its process so that they can help make the city center greener and more environmentally sustainable. (Source: The Mersey Forest Website)

With 65 meters of length, this wall is one of the longest in the United Kingdom. It was constructed as part of a project which aims to increase the urban green spaces. So they can work on improving air quality while supporting the citizens' health and wellbeing.

Those in charge for the project claim that a wall like this, not only has climate and air quality advantages, but also could be responsible for an increase in biodiversity, which is also a decisive factor in climate adaptation. 17 different plant species make up this wall (Figure 10), carefully chosen according to the potential efficiency of both the air-enhancing capacity and the pollination process.

Figure 10 - Urban GreenUP, 2020
Source: Liverpool BID Company Website

The Table 7, presented next, condenses the above information in order to provide an easier interpretation of the data.

Table 7 - Summary Table of Projects and Initiatives of Vertical Farming for Climate Adaptation

Vertical Farming Projects for Climate Adaptation					
Project Name	**Date**	**Location**	**Context**	**Objective**	**Benefits for Climate Adaptation**
AeroFarms	2004	Newark, United States	Indoor Vertical Farms	Overcoming Arable Land Shortage	Reducing Use of Water Reducing Use of Pesticides and Other Chemicals
Seoul Urban Agriculture Visions	2012	Seoul, South Korea	Vertical Farms	Avoid Potential Food Shortages	Overcoming Resource Scarce Overcoming Space Scarce Enhanced Efficiency of Resource Usage
Tohoku Reconstruction	2014	Japan	Vertical Farms	Overcoming Floods	Overcoming Space Scarce Enhanced Efficiency of Resource Usage

INFARM	2016	Berlin, Germany	Indoor Vertical Farms	Locally Grown Food	Reduced Supply Chain Water Conservation Food Security Reduced Gas Emissions
	2018	Stockholm, Sweden	Indoor Vertical Farms Using Hydroponics	Overcoming Droughts	Food Resilience Food Security (Avoiding Importations)
Sprouting Oslo	2019	Oslo, Norway	Outdoor Greening Areas	Increasing Green Public Spaces	Enhanced Water Cycle Carbon Sequestration Improved Air Quality Sustainable Public Places
GROOF	2020	Belgium France Luxembourg	Rooftop Greenhouses	Rooftop Greenhouse Coaching	Reduced CO_2 emissions Improved Air Quality
Urban GreenUP	2020	Liverpool, England	Living Green Wall	Increasing Green Urban Areas Improving Air Quality Increasing Biodiversity	Enhanced Pollination Air Quality Improved

Based on the sample presented above, there are some pertinent considerations to mention.

In fact, it is notorious the preference for indoor solutions in the case of northern European countries that aim for efficient agricultural production. In these countries there are some examples of outdoor farms, but they are directed towards greening purposes only. This fact is easily related to the climate in these countries, often marked by very variable conditions between seasons. In this sense, it is reasonable or even necessary to go for this type of solutions in order to try to make them effective, protecting them from the most aggressive weather conditions.

On the other hand, in countries that are naturally more prone to natural disasters, such as droughts or floods, building the crops in height makes them less susceptible to relevant damage. However, the

method that is most convenient for the location and crop in question can be chosen based on the objectives that are set.

This confirms what was stated before. This method is quite adaptable to different scenarios, different scales and different objectives. In each one, there should be a case study in order to evaluate the different options and deliberate on the most appropriate one.

3.5 SYNTHESIS

First of all, it is important to characterize the scenario that is currently being faced. The forecasts obtained by scientific studies help to measure the problem and, at the same time, to enhance the suitability of the proposed solutions. The direct relations between the food system and the climate are highlighted, seeking to mitigate the lack of widespread information pointed out as one of the main obstacles to the efficiency of the measures adopted, or even to the conception of these same measures.

Subsequently, after knowing the problem, it is important to outline a strategy to tackle it. This action should be broad, covering the several spheres of action, at a detailed scale as well as at a macro scale. The role that vertical agriculture could play in climate adaptation, food supply, safety and quality is established. It should make the best possible use of the main advantages that this method provides: Low Resource Requirements, Invulnerability to the Weather, Water Cycle Enhancement, Temperature Regulation, Carbon Sequestration, Minimized Damage due to Natural Disasters and Non-seasonal Production.

The analysis and comparison of projects already implemented around the world helps to evaluate the type of exploitation used, as well as the repercussions that its advantages have achieved. What went well and what went wrong, what happened as expected and what came as a surprise, could be prevented in the future projects. As one of the main influencing factors is, besides the support infrastructure, the location, it is important to make a broad and diversified analysis not only between different cities and countries, but also between continents.

This collection of information should now be condensed so that it is more easily accessible and so that parameters for implementing these ideologies and techniques can be established.

4

STRATEGIES TO PROMOTE VERTICAL FARMING IN URBAN AREAS

4.1 Introduction

Once the concept is presented and the influence it can have is understood, it is important to put it into practice. For this, it is important to have a support platform that, among other things, provides a series of tools and incentive mechanisms and guidelines for a more efficient use.

This is the purpose of the this chapter, which begins by presenting the results of a review and analysis of existing policies. Subsequently, based on this same information, some criteria for the implementation of this agricultural practice and its requirements are established. A manual of best practices is also prepared, highlighting several scenarios to be taken into account when implementing such a system. Finally, a review of existing support strategies, from regulations to monetary support, is presented.

4.2 Policies and Strategies for Urban Agriculture and Vertical Farming

4.2.1 Urban Agriculture

Over the years, several questions have been raised about urban agriculture by members of the European Parliament. Earlier this decade, some of them asked the Commission to identify what has been done to support, encourage and fund city farm initiatives in Europe. Others urged the Commission to indicate specific measures that have been put into practice, in order to promote the role that urban farming could play in feeding urban residents in the future, being part of the plans to reform the EU's agricultural policy. Later on, in 2015, the Commission got probed to clarify its position on Urban Agriculture and Peri-Urban Agriculture and to identify good practice examples in order to foster them (Source: European Commission Website). In 2017, all this growing pressure about the topic had a real impact when the Parliament's Committee on Agriculture and Rural Development (AGRI) agreed to conduct a study that would seek for evidence about this method's potential and would enlighten on different actors that could take action in the development of Urban Agriculture, along with the implications for future policies at different levels.

The results of this study helped to clarify the Commission's position about Urban Agriculture, showing that this method has a recognized potential positive influence on the urban environment, depending on the farming practices adopted.

As a result of all this, some of the most relevant policies currently influencing the food landscape in Europe are:

- **Common Agricultural Policy (CAP)**

Launched in 1962, the Common Agriculture Policy (CAP) appeared half a decade after the establishment of the European Economic Community (EEC), in Italy, and after the agreement for the integration of agriculture policies, pressured by France.

Despite the initial discussion that CAP was arguably a production-oriented policy, featuring vague objectives and proposals without much effectiveness, the reality changed after the removal of internal barriers and food price regulation. By this stage, the policy had two well-defined and innovative objectives: ensuring food security and creating a safe food market, either for farmers and consumers. From then on, a series of protection and regulation policies began to appear, which also intended to regulate the internal competition, making it fair so that it can generate a stable income for the producers.

A second policy revision happened at the early 90s, in which free market and environmental related measures started to influence CAP development. Trade barriers were further decreased in favour of the free market zone with the removal of national food quality regulations within members (Source: European Commission Website).

Meanwhile, the environmental impacts due to agricultural activities were seen as externalities. Proposed measures exclusively targeted the improvement of farming systems through ecological production techniques which could generate profit for farmers.

While maintaining the position in relation to the objectives that founded it, this policy is more refined nowadays. The measures it proposes act to maintain the market between the Member States of the European Union through some agricultural subsidies and development programmes in the sorrounding areas. Main goals are:

- Raise agricultural yields through the spread of technical advancement;
- Ensure a fair standard of living for the farming community;
- Balance between different markets;
- Ensure the availability and accessibility of food.

Despite the EU rural development policy did not include any specific measures for urban farms during the period from 2007 to 2013, they could already be supported in the framework of that policy. This could happen ever since they were located on land that fulfills the respective eligibility criteria established by the State Members. In August 2012, the Commission also confirmed that support to urban farms was available according to CAP ideals, as long as the eligibility conditions were fulfilled. The Commission has also acknowledged that urban farms could contribute to the objectives of sustainable development in the surrounding area, assuming that the principles of sustainable farming were put to practice (McEldowney, J., 2017 - European Parliamentary Research Service).

- **European Green Pact**

The connection between healthy people, societies and planet places sustainable food systems at the center of the European Green Pact - the EU's strategy for sustainable and inclusive growth - which aims to enhance the economy, improve people's health and quality of life, and protect the environment. (Source: European Commission Website)

The European agricultural and food system, supported by the Common Agricultural Policy, is already a world standard according to food safety, quality and supply, and nutrition. Henceforth, it has to be able to become the worldwide standard in terms of sustainability. The transition to a sustainable food system can provide benefits for the environment, health and society, and provide more equitable economic gains.

The EU's goals are:

- "ensure food security in the face of climate change and biodiversity loss;
- reduce the environmental and climate footprint of the EU food system;
- strengthen the resilience of the EU food system;
- lead the global transition to competitive sustainability from farm to fork."

The European Commission has set a package of legislative proposals to make the EU's climate, energy, transport and taxation policies appropriate to the goal of achieving a reduction in net greenhouse gas emissions of at least 55% by 2030 compared to 1990 levels. More information on the implementation of the European Green Pact.

4.2.2 Vertical Farming

In vertical farms, all the factors of growth, which include light, temperature, humidity, CO_2 levels, ventilation, water, and nutrients, can be managed and optimized. At the same time, weeds, pests, and diseases can be eliminated, and the use of water and fertilizers can be greatly reduced. While there are already some regulations, codes and/or guidelines in motion for agriculture support, quite often municipalities, districts and even whole countries do not address the specific issues associated with vertical farming either to support it or to guide the construction of associated facilities (Despommier, 2009).

Thus, it is assumed that policies directed at urban agriculture end up being equally addressed to vertical agriculture, since the latter is an example of application of the former. However, it is expected that specific measures for this type of agricultural technique will start to be thought out and implemented. It is even necessary that this happens, so that this method can be disseminated and applied in a correct way.

4.3 Towards the Implementation of Vertical Farming

4.3.1 Criteria (requisites) for the implementation of Vertical Farming

According to Despommier (2009), vertical farming can be suitable for most cities in the world. Although its operations, that include labor, energy and supplies needed to grow and harvest the crops, can be expensive, and a suitable location can be challenging to find, especially in urban areas with high prices per square meter, an appropriate planning can ensure profit while providing important services to the surrounding communities. The future perspective is bittersweet, since it is expected that with the increasing use of these agricultural systems and techniques, their production cost will go down. On the other hand, in many locations they still suffer from a lack of institutional, financial, and technological support, all important in this process. Despommier (2010) also states that planners and decision-makers sometimes lack knowledge on the subject, making the innovation scenario less likely and complicating the transfer of information about vertical farming and its real benefits to local communities.

When well planned, vertical farming can make efficient **structural** use of urban spaces, being the main purpose of a new urban structure or being able to give new life to previously vacant warehouses and/or rooftops, for example. The suitability of a particular site or building that can be converted into vertical farming systems depends on:

- Time availability – How long a property is available
- Area – How much space is needed
- Location – The property whereabouts

The possibilities for designing a container are almost limitless. From the most rudimentary, such as recycled bottles, to the most evolved and adapted to the most recent cultivation and irrigation techniques. This will be the primordial point, since good drainage is essential. A poorly calibrated drainage system can dictate the failure of the process by itself, because the roots of most plants rot in excessive moisture (Source: CityZen Project Website).

The next step is to choose the soil to be used. This depends on the design of the vertical garden and the kind of plants you intend to cultivate in it. For high hanging containers, well-rotted compost is advisable as it is lighter and easy to moisturize. For bigger pots, a mixture of enriched soil and compost is recommended. It is recommended to use enough rotted manure to avoid burning plants. The containers should then be filled with potting soil up to 5 cm from the border of the pot if it is straight, or up to 7 cm if it is sloped, as the compost tends to be flushed out during the watering process.

Furthermore, when choosing a crop to grow through the vertical farming method, two major **economic** categories need to be taken into consideration:

- Grow technical challenges – The ability to design and operate a vertical farming system that cultivates the selected crop.
- Marketability – Expresses the commercial competitiveness of the products grown in a given system.

Vertical farming operations foster a sense of transparency and a desire to be involved with their clients and local communities. It makes them uniquely positioned to deliver the needed solution to the existential urban and social challenges that communities all around the world face every day. This method allows a high level of control over crop-production practices, which ensure that farmers can maximize resource-use efficiency while mitigating the negative **environmental** impacts (Al-Kodmany, 2018).

On the other hand, Lubna et al. (2022) claim that commercial businesses need to be competitive and strategic in order to succeed. Growing this high-yielding, fast growing and low production cost crops in areas with adequate marketing potential will have a major importance in order to vertical farming operations prevail. Branding and consumer education are two important business tools that should not be overlooked, since they are crucial to develop a loyal customer base and to spread the ideals.

Planning can be very important in integrating vertical farming to tackle climate changes, as it can act at multiple scales. From a macro scale point of view, planners can help on the possibility to use urban wastelands to be reused, creating new spaces of quality and environmentally friendly. In parallel, through planning, new urban public spaces can be created, responding to the site's needs and aiming to the project's environmental objectives. Additionally, it can allow to do a large-scale design of the city’s greenspaces, even considering some scattered vertical farms as well as it can complement the functional and spatial structure of the urban fabric with multifunctional production and service centers with vertical farms.

At a medium scale planning can integrate multifunctional urban farms into public spaces with multi service and community production according to its wants and needs. This way it would be possible to strength the design process with additional vertical greening spaces, enhancing the community well-being and the urban environment.

Moreover, at a micro scale it can allow to create multi-functional buildings, integrating vertical eco-farms into office buildings, residential buildings, commercial buildings, tourist and recreation service buildings, for example. This would also open up the possibility of interactions between buildings like these, promoting their connection and creating new green urban spaces (Zaręba et al., 2021).

Good Practice Manual

Lubna et al. (2022) says that in order to succeed, a vertical farm has a variety of challenges to understand so that they can be overcome. Choosing a crop that can be grown profitably and safely is crucial in order to prosper a vertical farm. The inherent complexity of the farming system requires a cohesive team and task delegation: from seedling to harvesting during all growing season, similar to traditional farming methods, it needs constant monitoring, from the maintenance of the growing system to pest control, knowing that vertical farms have the advantage to year-round operate which can be challenging to manage. Therefore, it is advisable to have a systematic collection of data as well as its processing and analysis; so that these processes can occur smoothly and effectively, in order to make a continuous management of production and allow the determination of possible ways to optimize the farming strategies. It can be advantageous for operators to focus on cropping systems used in conditions identical to their own to avoid fruitless investments, since depending on the type of crop grown there will be several types of systems to choose from, knowing that each cultivation system has its own unique advantages and disadvantages that should be considered during the design phase of the vertical farm. Nevertheless, some of the most successful systems use some form of hydroponics, due to its ability to minimize the weight added to the existing structure and maximize the efficiency of water and nutrient use through its horizontal multiple layer system, stacked vertically (Lubna et al., 2022). Operators team should deliver fresh and climate-controlled air, nutrient solution and lighting to each layer of the system which is normally facilitated by an electric, plumbing and air-conditioning departments that make up a vertical farm network.

Once a crop and cultivation system has been selected, it is time to care about pest management. An integrated pest management program should be part of the vertical farm project or it will certainly have a hard time, due to pest-related crop failure. Since vertical farms are normally operating indoors, on contained and controlled spaces, the pests can only come from the outside, either on personnel and/or seeds, in the air or in the water. Air showers, coveralls, air filtration, water control and seed sterilization are just some of the good measures that can be adopted in order to avoid pests from reaching the interior of the facility. Although, it is not realistic to think that this will never happen, so there must be a proper management in the interior of the compound to avoid crop losses, starting from efficient environmental control to avoid humidity buildup and condensation which can both enhance fungal growth. This must be a proactive strategy, reacting to an outbreak cannot be fast enough to prevent crop fatal damage (Roberts et al., 2020).

Labour is, by far, one of the highest cost due to vertical farming operations since they are labor intensive and lack widespread automation, especially when compared to conventional farming. While waiting for significant technological advances, the operators will have to rely on human labor. Since these farms will be able to operate all year round, a local labor force is preferred since seasonal hiring will not be frequent. Although these type of farms are usually located in urban areas which will result in an easy

access to a large amount of local labour; on the other hand this same labor will probably be unskilled and therefore require education and training (Lubna et al., 2022). Beyond that it is highly advantageous for the operator to create a workplace culture with open communication so that employees can receive more information and learn faster while acting as an open line of communication for any issues on the farm, potential inefficiencies, and areas of work that need the attention of a more experienced farmhand. Moreover, workspace culture should be managed to minimize turnover, since when it happens at a high rate it can interrupt the optimization process. All in all, a well-trained and cohesive local labor force is the key to successfully run a vertical farm, since it represents a significant source of institutional knowledge through collective experience of work.

Data collection and environmental monitoring are crucial to vertical farming system optimization, of yields and energy efficiency that increase economic viability of vertical farming. These systems have the advantage of being highly controllable, which may be enhanced by data-driven decisions. Data collection could be extensive and related to both environmental parameters (like the air temperature, root-zone temperature, CO_2 concentration, nutrient concentrations, water flow rate, light intensity among others) and the actual plant growth (including observations from plant fresh weight, shoot length, leaf colors, for example). Monitoring of these parameters must be done at all times so that the crops can prosper and be homogeneous (Bhowmick et al., 2019).

4.3.2 Mechanisms and Tools to Support Vertical Farming Solutions

The influence of land use restrictions extends further than zoning and building code ordinances. This also explains most of the regulatory challenges confronted by vertical farmers. This is because both the zoning ordinances and building codes do not permit determined uses and structures depending on the given situation. Therefore, each situation must be carefully designed and evaluated (Simpson, 2020).

It is notable that the current regulations urgently need updating and clarification. Originally, zoning was based on uses and building restrictions that were ambiguous, both in definition and ambit, for farming purposes. The situation has not improved much (at least not significantly) since the ambiguities of the current policy make it either hard or impossible to predict how vertical farms will be handled from one urban area to another.

It is clear that a use-based regulatory scheme is an effective manner of achieving an improved public health, safety and welfare. However, it is important to recognize that some spaces, structures and/or activities will be incompatible with each other. It is then clear that this type of regulation can just ~~as~~ easily act as a barrier to the development of urban agriculture. This will be of special concern in places without any form of urban agriculture, or where the limited provisions that do exist are vague (Simpson, 2020).

Regarding vertical agriculture, knowing that a certain vertical agricultural structure can fit into a given list of possible occupancy groups, it assumes remarkable importance. Mainly because it will determine the maximum height and number of floors, the zone where a vertical farm can run, and whether crop processing is allowed at a given location.

Overall, estimates are that about 11% of the total budget value is due to the cost of material such as seeds and nutrition solutions. Vertical farms require a lot of energy, especially in those cases which artificial lightning is the only source of light for the crops. Furthermore, energy prices can represent 50-70% of the revenue of the farm. Whatever are the goals of the farm, the budget should be set accordingly. The European Union has already a subsidiary section for projects related to (urban) agriculture. This support is given through the European Agricultural Guarantee Fund (EAGF), that primarily **subsidizes**

income support for farmers and market measures. In 2019, the total amount of investment was already around €44 billion (Source: European Commission Website), as represented on Figure 11:

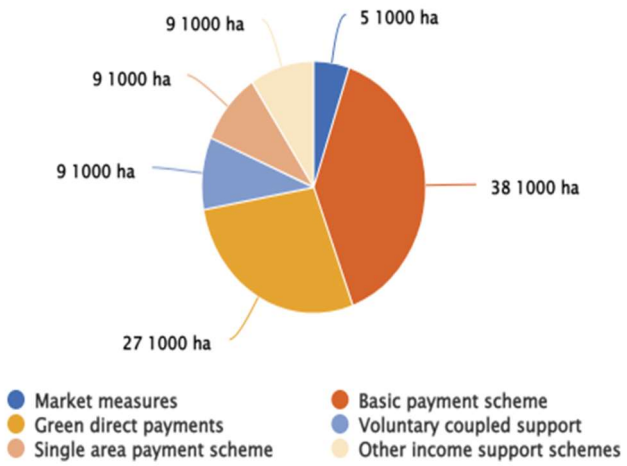


Figure 11 - EAGF Spendings, 2019
Source: European Commission

The main concern lies in the fact that it is noticeable that these measures, although varied, are still not specifically aimed at the subject of urban agriculture, let alone vertical agriculture. It is assumed that they encompass them, because they are agricultural manifestations, but the suspicion remains that they could be more practiced and more efficient if there were already directives directly related to the matter and its potential.

4.4 Synthesis

For these ideologies to be disseminated and their methodologies be implemented, it is essential to have broad and capable support from regulators. Thus, it is essential that there is a set of policies directly aimed at the implementation and monitoring of these types of cultures. Only then can codes of conduct for urban and vertical agriculture methods be established. The literature review carried out throughout this work allowed us to characterize the current legislative panorama and, based on it, identify some parameters that should be addressed, and which are not yet.

The issue of urban agriculture has been addressed in the European Parliament for several years, trying to identify what has already been done, in order to be able to deliberate what could be done in the future. Over the years, this issue has gained strength and has resulted in the emergence of new entities especially dedicated to the effect. This is the case of the Parliament's Committee on Agriculture and Rural Development, which has already conducted several studies to assess the potential of these methodologies and to highlight the various actors who should act. All this has resulted in concrete legislation for agriculture, such as the Common Agricultural Policy and the European Green Pact. Although they were conceived in different years, both share the ambition of making agriculture more efficient and sustainable as well as affordable for everyone. This ideology has already resulted in several targets set for the coming decades ranging from reductions in greenhouse gas emissions to balancing the various markets for agricultural products.

One issue to address is the fact that vertical farming itself is not yet subject to sufficient policies so that it can be widespread. There are many factors to be taken into account for such a culture in order to be efficient, and it will only spread if it succeeds in doing so effectively.

Therefore, a series of criteria/requirements that should be fulfilled in the implementation of a vertical farming project are established in this document. In order to make it really useful, an analysis was made at all scales: from the moment it is designed, to the moment it is implemented; to the management and maintenance. This strategy took into consideration the practical effects that this technique may have on the agricultural market economy but also the effects it will have on the environmental level, as well as the necessary structural support. Combining all this, a best practice manual was compiled, dedicated to complementing the information and standards that are not yet available in a legislative form. In addition, tools and mechanisms to support the practice of vertical farming are pointed out so that these practices can be implemented.

It is pertinent to detail next the specific case of Portugal, the characterization of the current situation and the forecast for the near future.

5

APPLYING SOLUTIONS OF VERTICAL FARMING IN THE PORTUGUESE CONTEXT

5.1 INTRODUCTION

The strategies presented above should be evaluated for each scenario, in order to design the most appropriate solution for each context.

In the following chapter, the Portuguese panorama in this matter is detailed. First of all, it is important to characterize the current scenario. Evaluate the measures already implemented, the existing projects and the way this matter has evolved.

Subsequently, we detail the roles that vertical agriculture can play in the country's climate adaptation, the existing policies and the work that still needs to be done.

5.2 THE PORTUGUESE CONTEXT

5.2.1 OVERVIEW

All over the world – Portugal included - people have been adapting to the climate conditions that have been changing. The way of living and the activities performed have been also changing accordingly, to make best use of the positive aspects and to protect themselves from possible climate related threats and hazards. But the planet's climate is changing, and the Mediterranean basin is among the regions where this change is being most noticeable. These changes will affect, for example, the average temperature and precipitation values and - just as importantly - the frequency and intensity of extreme weather events such as heat waves or droughts. Climate change is, therefore, a threat that needs to be tackled in a structured way if we are to prevent its effects and to reduce its risks and possible losses.

The influence of recent extreme weather events, such as heat waves, droughts, floods, and forest fires, illustrate the significant vulnerability and exposure to climate variability of many ecosystems and human systems. In Europe, these harsh events already have remarkable influence on multiple economic sectors, as well as adverse impacts on society and health. Portugal is one of the European countries with the greatest potential vulnerability to the impacts of climate change. Most recent scientific studies claim that the southern region of Europe is one of the areas prone to be most affected by climate changes. Action is needed now to avoid the impacts and the costs, associated by adapting our societies and economies to this matter. The costs of inaction are higher in the medium and long term, and may reduce mitigation and adaptation options in the future. Besides, they can even jeopardize the success of

interventions aimed to limit the global average temperature increase to no more than 2°C over the pre-industrial average. This political challenge, endorsed by Portugal and the European Union, is a long-term challenge. In fact, it is mandatory to have global emission reductions programmed for the long term - at least in a horizon up to 2050 - in the order of half the current values, so that humanity can be on a path compatible with that goal. (Source: *Resolução do Conselho de Ministros nº56 de 30 de julho – Estratégia Nacional de Adaptação às Alterações Climáticas* (ENAAC 2020)).

In the 2030 horizon, emissions reduction target has been set for the European Union of, at least, 40 % compared with 1990 and a renewable energy target of 27 %. Portugal has already had a Climate Change Strategy, which has framed the development policies on this subject. In 2004, the National Program for Climate Change was approved and later revised in 2006 and 2008. Portugal was a pioneer at a European level in the adoption of a National Strategy for Climate Change Adaptation and innovated in the establishment of the Portuguese Carbon Fund as a financial instrument to act in the climate change area. With this policy framework, Portugal has successfully met its national climate change objectives under the Kyoto Protocol, essentially through the reduction of GHG emissions in all sectors of the economy.

Although vertical farming has benefits directly related to the objectives stipulated by the above standards, Portugal cannot be pointed out as one of the main drivers of this type of agricultural technique. Therefore, the expressiveness of this type of projects and, consequently, their influence on climate change, is still low. Many factors may be at the root of this issue, from the high investments it implies to the changes it means in the daily life of the building and of those who inhabit it. In fact, the cultural issue cannot be discarded since this is a practice that breaks with most conventional and, in the case of some countries, traditional methods. It is possible that a certain herb or fruit, very characteristic of the gastronomy of a certain country, has more difficulty in being cultivated by this agricultural method. Consequently, it may negatively affect its acceptance and limit more widespread implementation. On the other hand, Portuguese urban areas are not so numerous and do not present high densities in comparison to other countries and, consequently, more plagued by the phenomenon of scarcity of cultivable area. Therefore, the need to find new agricultural techniques and to make the most of the available area for cultivation is not yet part of the daily life of Portuguese citizens, nor of the governmental agenda.

One of the few experiments was developed by Benis et al. (2017), who applied three hi-tech urban farming scenarios in Lisbon:

1) Polycarbonate Rooftop Greenhouse;
2) Vertical Farm integrated on a reinforced-concrete building with windows and skylights integrated on the top floor;
3) Completely opaque Vertical Farm on a reinforced-concrete building with no penetration of natural light on the ground floor.

Global Warming Potential resulting from data related to water, transportation and operational energy of these three case studies were compared to two other cases:

a) the existing supply chain for tomato;
b) a hypothetical rudimental and unconditioned rooftop urban farm.

Results point the rooftop greenhouse and the top floor vertical farm to have the best overall environmental performance, reducing greenhouse gas emissions by half and by a third in comparison with the existing supply chain for tomato production. By enabling this preliminary evaluation of alternative farm locations and properties, the workflow provides the user with drivable information for early-stage assessment of Building-Integrated Agriculture projects (Benis et al., 2017).

5.2.2 PORTUGUESE PROJECTS

Nevertheless, there are already some manifestations of it in greening projects mostly without agricultural production, but which are, even so, the first steps to be taken on this path in search of greater sustainability in national agricultural production:

Project: Upfarming

With the awareness of the ever-present reality of the never-ending growth of urban population and the complications that this may imply both in urban life and in the inhabitants' wellbeing, besides the predictable inherent climate crisis, Upfarming was born. The patented system of agricultural production that Upfarming has created guarantees productions up to 10 times higher, using about 50% less labor and energy, and, above all, with a 90% reduction in water use. With a wide range of products (Figure 12) that can be produced through these infrastructures, it is pertinent to state that it can be adapted to any location and/or community.

Figure 12 - “What We Grow”, Upfarming

Figure 13 - "Our Solution", Upfarming

With a completely Portuguese origin and already patented innovations (Figure 13) for the implementation and production in vertical farms, this organization aims to alert to the alarming situation that is increasingly likely unless techniques like this are implemented.

It should be noted that all products needed for the maintenance of the system are of natural origin, excluding any kind of synthetic or genetically modified material, which helps to make the organic character of the whole system prevails. The use of these types of products for pest control, for example, is replaced by the use of other techniques using mechanical or biological means. In addition, the Portuguese identity and market are enhanced in that the seeds are, as far as possible, preferably bought from domestic producers and the production of the system is directed, from the outset, to buyers in the immediate vicinity of the system (Source: Upfarming Website)

All permits and construction details are handled by their own architectural team. Upfarms are built in a matter of days. The ultimate goal of the organization is to spread out their ideas and systems like this to help prevent the imminent climatic crisis, from coaching sessions to patented systems to put vertical farm to practice, from self-production systems to food supply a restaurant nearby. To make these structures more able to community engagement, Upfarming mentions they can synergize their vertical crops with outdoor kitchen, dining and community relaxion areas in order to make it a place of learning, collaboration and wellbeing.

Project: Food4Sustainability

This non-profit association is dedicated to the innovation in sustainable food production. Its concept and approach based on circular production systems was developed through a collaborative process with relevant national and international stakeholders and experts as part of Building Global Innovators (BGI) in collaboration with the municipality of Idanha-a-Nova (Portugal). It involved several partners from the EIT Digital, Climate KIC and EIT Food networks. Their main objective is solving complex, large-scale problems in biobased food systems for climate resilience while dramatically reducing CO_2 emissions, through an extended network of partners, team members and support teams to help the environment reap its benefits (Source: Food4Sustainability Website).

Their strategy embraces:

- Circular Economy;
- Sustainable Agriculture;
- Endogenous Assets and Ecosystem Services;
- Functional Nutrition;
- Entrepreneurship and Innovation.

Their work consists on testing and implementing new approaches to food production systems. This goes from the development and testing emerging approaches and technologies for sustainable intensification of food production, empower farmers to adopt cutting-edge solutions in sustainable agricultural practices and to provide education and experimentation to other communities of interest and disseminate techniques on how to achieve higher yields in selected crops through specialized teams. As a result, their aim is to have a significant impact on various value chains in terms of:

- CO_2 avoidance;
- No usage of chemicals;
- Sustainable intensification - land use optimized;
- Water preservation and environmental care;
- Efficiency throughout the entire value chain in the food industry.

Today, food4security has already several projects and partners that have joined in the search for a more sustainable environment:

- EIT Food GROW Workshops - Grow Workshops are educational discussion sessions on emerging trends and technologies in the area of sustainability in the agricultural sector;
- RIS PDS - Feel Local Portugal - Contemporary workshop aiming to develop and strengthen communication between producers and consumers (short supply chain);
- SFT-EDIH: Smart sustainable farms, foods and trade (European Digital Innovation Hub) - They are the digital innovation hub for the agri-food sector, a single point of access for the digitalization of the sector, from farm to fork;
- biolog - This platform gathers all organic operators. It promotes the sharing of contacts, knowledge and sustainable practices;
- InovFarmers.MED - Improves value chains through innovative business models for small farmers;
- InnovPlanet Summer School - A unique and intensive immersion in cutting-edge methodologies and methods to achieve sustainable agriculture with a particular emphasis on the relevance of digital processing and the implementation of smart agricultural technologies;
- transForm - Valorizes industrial waste through innovation in the production of organo-mineral fertilizers for forestry;

- Green Protein: Planting the Food of the Future - With the "Green Protein: Planting the Food of the Future" report, the aim is to promote a gradual transition to an agriculture and food system based predominantly on vegetable protein, thus contributing to reducing the ecological footprint of the Portuguese and mitigating the impacts of climate change;
- SAL - Semente AmbientaL - The SAL - Environmental Seed project aims to implement and test, through a pilot project, the future program of consumption and healthy eating habits in all school education cycles in the Idanha-a-Nova region;
- Sustainable Agriculture - Testing, implementing and disseminating new approaches to agri-food systems and their value chains to achieve economic, social and environmental sustainability is their goal;
- Highly Qualified Human Resources - Food4Sustainability aims to put Portugal at the forefront of circular food production systems with low carbon emissions and reduced water use within 5 years.

5.3 The Role of Vertical Farming for Climate Adaptation in Portugal

5.3.1 Main Policies of Climate Adaptation in Portugal

Nowadays, public policies on climate change are embedded in a number of sectoral policies in Portugal, namely, at the level of agriculture, industry, mobility and energy. Therefore, it is important to highlight the influence of certain instruments, such as the National Action Plan for Energy Efficiency, the National Action Plan for Renewable Energies and the Program for Electric Mobility in Portugal, to reduce emissions. After remarkable growth during the 1990s, national emissions decreased in the early 2000s, and more recently, particularly after 2005, national emissions have declined largely due to the increase in renewable energy sources and energy efficiency.

The maturity reached by the climate policy at the national level thus allows us to consider moving towards a more proactive planning approach, aimed at enhancing the participation and promoting accountability of the several sectors, with the objective of integrating climate policy into sectoral policies. With the second period of compliance with the Kyoto Protocol underway (2013-2020), in view of the climate policy goals and guidelines established at the international and community levels for 2020, 2030 and 2050, as well as the option for a development strategy based on green growth, it is considered that there is a political opportunity to review the climate change strategy outlined in 2001 and adapt it to new circumstances in terms of vision, guidelines, goals and instruments (Source: *Resolução do Conselho de Ministros nº56 de 30 de julho – Estratégia Nacional de Adaptação às Alterações Climáticas* (ENAAC 2020)).

The challenge of combating climate change and adapting to its effects has determined a political response at an international and community levels that tends to be more comprehensive and demanding. In line with these guidelines, Portugal has been applying climate change measures that have ensured that the objectives set out in the first commitment period of the Kyoto Protocol have been successfully met.

CLIMADAPT.LOCAL

Adapt.local prioritizes to the following areas:

- driving local adaptation;
- building technical skills;
- fostering peer-to-peer education.

Accordingly, they assume as main objectives for the four-year period 2018-2021:

- Stimulate local adaptation to Climate Change, encouraging Portuguese municipalities to develop this policy in their framework of action and raising awareness among many actors for the need to promote measures, actions and interventions - technical, regulatory and financial - that facilitate the action of local authorities;
- Facilitate the exchange of experiences between municipalities, strengthening current practices and the development of new solutions, extending local adaptation experiences to more municipalities;
- Promote the capacity building of municipalities, namely of elected officials and technicians, in the field of adaptation to climate change at the local level;
- Manage and expand the information system to support capacity building on climate change adaptation developed under ClimaAdaPT.Local.

The proposed Action Program for the four-year period 2018-2021 aims to structure the operational framework of adapt.local in this period, following the term of office of the Coordinating Council, elected in November 2017, defining, based on the institutional model adopted and the mission and objectives assumed by its constituent entities, the actions that should be developed and its main features (Source: Adapt.Local Website).

In this context, the Program aims at fulfilling the mission of adapt.local, namely to initiate in Portugal a continuous process of elaboration of Municipal Climate Change Adaptation Strategies (EMAAC), increasing the capacity of Portuguese municipalities and other entities, public or private, to incorporate adaptation to climate change in their policies, planning instruments and interventions.

For this purpose and having as reference the experience of implementation of the Action Program for the year 2017, the following Strategic Priorities (SP) were defined:

- PE1 - Dynamize local adaptation to climate change in Portugal - aims to develop actions that contribute to the recognition of the importance of local adaptation to Climate Change and to its dynamization, both at the local government level and through the creation of instruments and support measures;
- PE2 - Reinforce the notoriety and recognition of the added value of local adapt.local - aims at designing and maintaining external communication tools and developing mechanisms that allow the promotion and expansion of the network, as well as the integration of new members (municipalities and other entities);
- PE3 - Promote capacity building and network learning - seeks to deepen and broaden the capacity building of municipalities - elected officials and technicians - in adaptation at the local scale and to continue to promote the improvement of the municipalities' ability to incorporate adaptation to climate change in planning instruments and local interventions.

5.3.2 Scenarios and the Role of Vertical Farming in Portugal

According to multiple research papers, Southern Europe and the Iberian Peninsula are some of the European regions that are potentially most exposed to the effects of climate change, facing potential increases in the frequency and intensity of droughts, floods, flash floods, heat waves, rural fires and erosion.

The **reduction in annual precipitation**, its higher variability and the consequent variation in the flow regime will reduce river flows, affect the recharge of aquifers and will dry out the sources of essential rivers in the Iberian Peninsula for some periods of time. These changes may result in water quality

problems, intensification of extreme events, such as droughts, and increased pressure for desertification. Furthermore, increasing biodiversity loss associated with irregular ecosystem structure and dynamics, enhancing the degradation of the quality of surface and underground water resources. Nevertheless, the territory will remain vulnerable to flooding events, due to the predictions of an increase of the duration of heavy precipitation events.

The **new temperature and precipitation regimes** associated with climate change imply:

- heatwaves can occur more often, and their duration and intensity can increase;
- an increment in the number and intensity of major rural fires;
- extreme, unforeseeable, intense, and localized meteorological events.

Besides this tendency for heatwaves to become more harsh, frequent and to happen over bigger extensions, it is also claimed to change their seasonal distribution. Although heatwaves are normally featuring of the spring and summer, this phenomenon is expected to assume equal occurrence in the autumn. (Source: *Agência Portuguesa do Ambiente* - APA)

The coastal zones are particularly vulnerable to **coastal erosion** and coastal overtopping with many remarkable and severe effects. The results of coastal erosion and overtopping are especially enhanced by the characteristics of the anthropogenic occupation of the territory's coastline that significantly increases the risk of socio-economic costs of climatic events. Even though the uncertainty, the sea level is expected to be 0.5 meters higher by the end of the 21st century, possibly reaching values in the order of 1 meter above the level registered back in 1990. The rise of the water level can also increase the risk of saline contamination of coastal aquifers, estuaries, and the final stretches of rivers, impacting some water supply systems.

The main priorities for adaptation should be (Source: *Resolução do Conselho de Ministros nº56 de 30 de julho – Estratégia Nacional de Adaptação às Alterações Climáticas* (ENAAC 2020)):

- Reinforce resilience and national abilities in terms of adaptation;
- Ensure Portugal’s engaged participation at the international level in terms of compliance with agreements, negotiations and collaboration;
- To engage society in the challenges of climate change, promoting individual and group initiatives;
- To encourage research, innovation and knowledge generation on climate change and develop a knowledge basis to support the elaboration of public policies;
- Enhance the effectiveness of information, reporting and monitoring systems;
- Ensure effective governance conditions and ensure the integration of climate objectives in the different sectoral spheres.

Thus, climate change scenarios anticipate a remarkable increase in meteorological conditions prone to large areas across the Iberian Peninsula, namely the entire territory of Portugal. Therefore, it is urgent and of particular importance to be aware of these impending problems in order to deliberate the best strategy to combat them or at least minimize their effects. The practice of vertical agriculture can and should be one of the solutions to be considered. As already mentioned, it is a particularly energy-efficient method, safeguarding much of the waste that is characteristic of conventional farming methods. Noteworthy:

Temperature Increase

The most severe climate scenarios for Portugal expect that the temperature increase may reach +5°C in 2100 to a minimum, average and maximum temperatures, especially during summer and in the Portuguese interior areas (Figures 14 and 15). The warmer temperatures are reflected in an increase of very hot days, especially in the southern interior areas and more frequent heat waves, especially in the north-eastern interior areas (Source: *Instituto Português do Mar e da Atmosfera* (IPMA)).

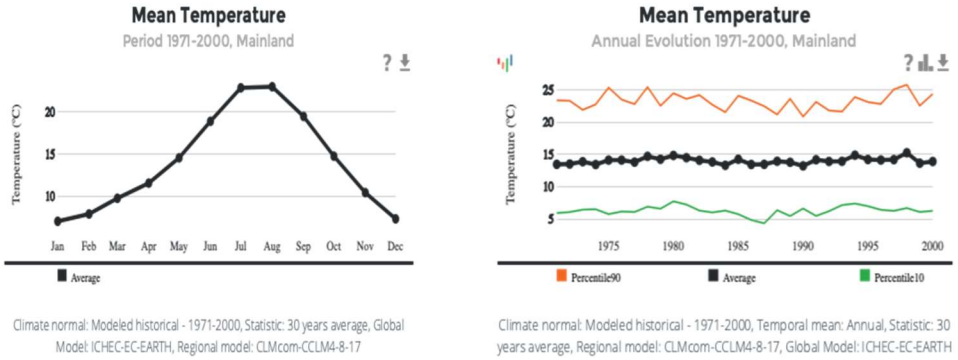


Figure 54 - Mean Temperature Evolution 1971-2000
Source: IPMA

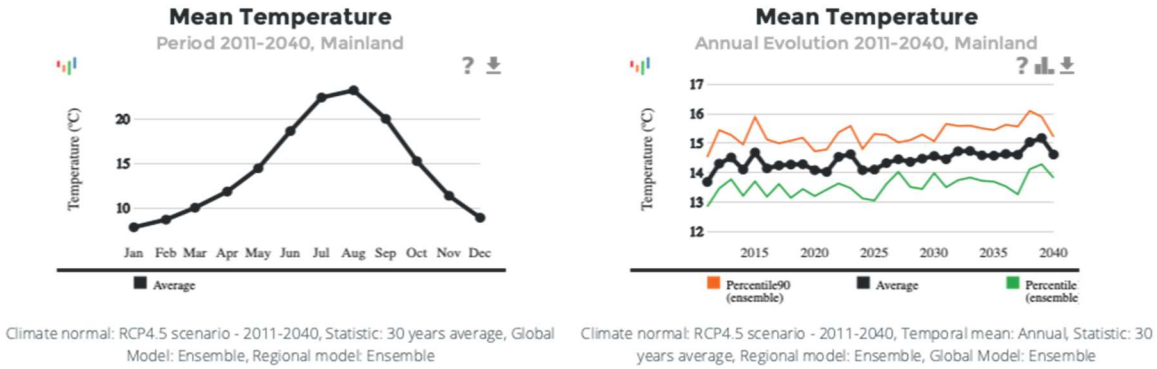


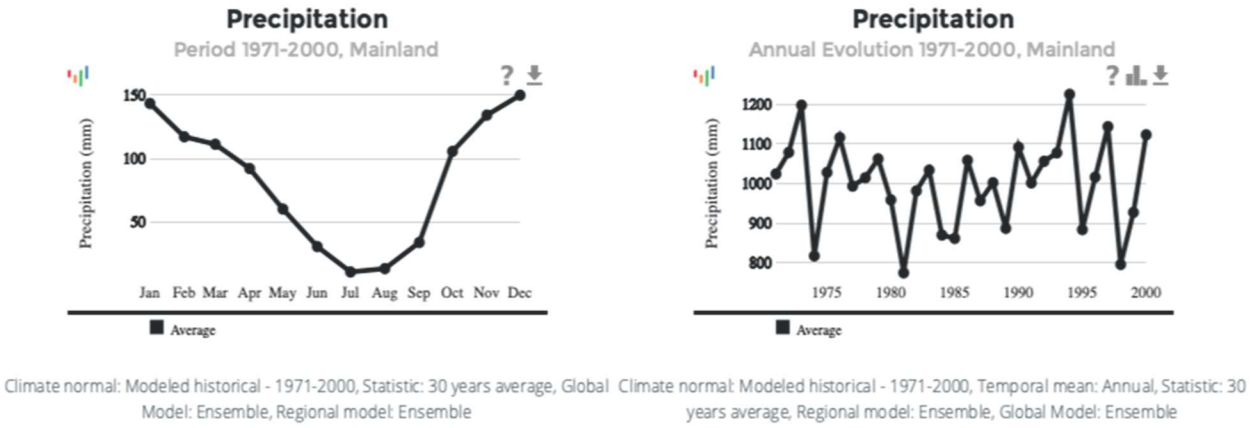
Figure 15 - Mean Temperature Evolution 2011-2040
Source: IPMA

In this sense, the inclusion of vegetation in urban buildings will be of particular interest as it can be used to its full potential in terms of building climate control. The use of greenhouses installed on rooftops will be especially efficient, as they combine all the functions of climate control with the production of basic foodstuffs for their consumers. This makes it possible not only to increase energy efficiency related to production, but also to enjoy the benefits related to reducing or eliminating the need for transportation and inherent greenhouse gas emissions.

Precipitation Deregulation

Even tough precipitation patterns are usually more unpredictable, they are also expected to diversify in the near future, with significant reductions in annual values worldwide, with values between -10% and -50% until the end of the century (Figures 16 and 17). Furthermore, extreme precipitation events will predictably be more frequent through a reduction in days with low to medium/high precipitation. Thus, it is expected to happen an increase in the seasonal variability of precipitation and the expansion of the

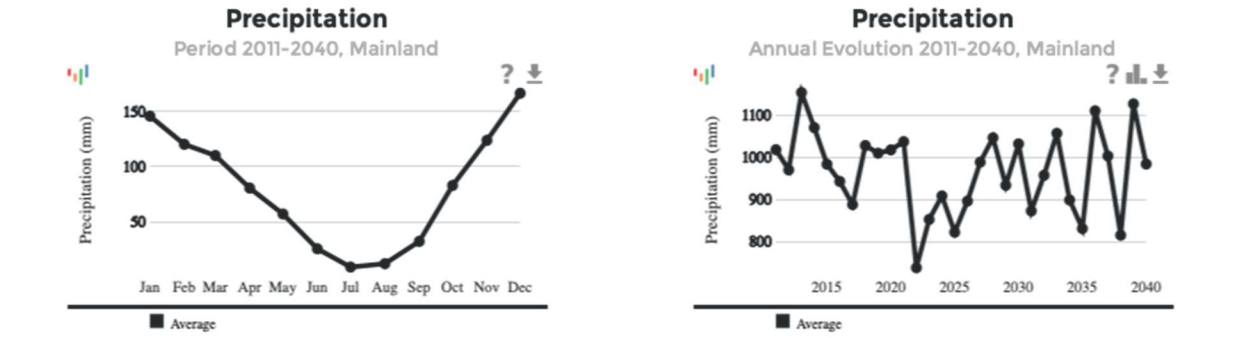
dry season from summer to spring and autumn. Therefore, all the conditions will be met for an increased probability of prolonged droughts (Source: *Instituto Português do Mar e da Atmosfera* (IPMA)).



Climate normal: Modeled historical - 1971-2000, Statistic: 30 years average, Global Model: Ensemble, Regional model: Ensemble

Climate normal: Modeled historical - 1971-2000, Temporal mean: Annual, Statistic: 30 years average, Regional model: Ensemble, Global Model: Ensemble

Figure 16 - Precipitation Evolution 1971-2000
Source: IPMA



Climate normal: RCP4.5 scenario - 2011-2040, Statistic: 30 years average, Global Model: Ensemble, Regional model: Ensemble

Climate normal: RCP4.5 scenario - 2011-2040, Temporal mean: Annual, Statistic: 30 years average, Regional model: Ensemble, Global Model: Ensemble

Figure 17 - Precipitation Evolution 2011-2040
Source: IPMA

Against this background, the ability of vertical farming methods to reduce water use and, above all, to increase the efficiency of water use may have a significant contribution. The vertical arrangement of the crops is decisive for the design and efficiency of irrigation systems. Moreover, the fact that they are concentrated in an area and not dispersed over several hectares, allows greater and better monitoring, which will speed up the process of detecting any leaks, and their resolution.

Space Management

One of the great advantages of this agricultural technique is that it makes the most of the available area. This can also be especially useful in the management of the urban area and its surroundings. If on the one hand the need for transport can be reduced by placing the crops in urban buildings, on the other hand this allows the storage facilities related to the sector to be thought out and located in a more strategic way. In a medium/long term this could mean more efficient land-use planning and alertness to the consequences of climate change-related erosion.

5.4 SYNTHESIS

The need to increase awareness of climate change issues is widespread throughout the world, Portugal included. It is, in fact, pointed out as one of the most vulnerable countries to the impacts of climate change, both in economy, health, and social spheres in general. This is due to the assessment that the southern part of Europe is one of the most susceptible to problems derived from climate change.

Therefore, it is especially urgent for a country like Portugal to be aware of this problem and really start to tackle it. There are, of course, targets for the reduction of emissions and energy consumption set by the European Union to be met by 2030. Although Portugal does not yet have enough representations of these methodologies in order to multiply them throughout the territory, it has already been working on this subject for several years. This is evident in some experiments already done to evaluate the farming scenarios in Lisbon, for example.

There are already some examples of projects with considerable size and concrete results, and others are already planned for a near future. We highlight, as examples, the cases of Upfarming, a Portuguese company completely dedicated to the practice of vertical agriculture (mainly indoor). The emergence of associations such as Food4Sustainability, a non-profit organization, will be essential in the future for the proliferation of both awareness of the problem and the goals to be achieved, through a dedicated and personalized strategy for this purpose.

In this sense, it is once again important to clarify Portugal's position on this issue at the political level. As it happens in a European context, agriculture is the target of specific policies and standards; nevertheless, vertical agriculture is still not properly detailed. Although this is a manifestation of agriculture it should be taken on its own in order to make it more efficient, more widespread, and thus more feasible and affordable.

Portugal has already been implementing some measures for climate adaptation with the creation, through the Kyoto Protocol, of ClimAdaPT. This program establishes specific measures for this theme, with proposed objectives for the coming years.

However, there is still work to be done. Particularly in Portugal, a country that is predicted to be one of the most affected by climate change, such as the deregulation of annual precipitation, new temperature and precipitation patterns. The predicted increase in the average annual temperature, as well as the reduction in average annual precipitation are two big worrying factors that will certainly cause damage unless they are really addressed and mitigated. It is easy to conclude that special attention should be given and addressed with concrete policies and measures, to these situations, now more than ever. Besides all the impact on the climate, these changes will also influence the switch in the basis of survival, the support of everything, the soil. If today there is a concern about the lack of arable space, consequences of this kind could lead to the extreme of erosion and degradation of soil properties.

6
CONCLUSIONS

6.1 General Conclusions

The conclusions presented in this chapter can be divided into two key points: those that refer to the focus of the study, namely how urban agriculture and, in particular, vertical agriculture present themselves as potential tools for urban planning; and the potentially determining role that vertical agriculture could play in climate adaptation. Parallel to these, some conclusions about the theoretical concepts and their conceptual and normative approach are also presented.

The scarcity of arable land is a growing reality, and the problems related to food availability for a growing world population are already alarming and will get worse. The majority of the world's arable land is already in use today. However, the subsistence of a growing population that is increasingly concentrated in large and dense urban centers, far from farmland, cannot be guaranteed.

It is already agreed that urban agriculture is important in urban environments, due to its capability to combine the ability to increase the existing area by growing crops much closer to consumers. Thus, it is possible to combine increasing agricultural production with the advantages inherent to reducing energy use. In fact, there are already several policies and strategies to encourage it. However, there is still a long way to go for vertical agriculture. Despite the fact that its innovative layout allows more efficiency per unit of area, there is still no specific regulation or strong incentives to implement this method or even to monitor it. This reduces the efficiency of the implementation of the method and its dissemination.

Vertical Agriculture implies several approaches and each one should be evaluated correctly so it can be efficiently adapted to the concrete situation. This method has many advantages for climate adaptation, but there are also many limitations and disadvantages. Accordingly, there must be an analysis and subsequent monitoring in projects that incorporate these methods so that they can fulfill their potential, avoiding negative (direct and indirect) impacts without compromising the benefits.

In Portugal, the implementation of these methods is still scarce, but there is a potential that should be explored, and that should be duly inserted in strategic policies, through financial incentives or even in a regulatory framework. The population's awareness of environmental problems is urgent. However, it is extremely important that this process is accompanied by comprehensive and cohesive legislation so that measures can be properly designed and projects can be developed correctly.

Based on the findings described and the results of the previous chapters, some recommendations for future work are suggested.

6.2 RECOMMENDATIONS

The measures proposed in the previous chapter result in recommendations for the study of these issues.

Firstly, it is suggested that a detailed analysis should be made of the study area in question and its surroundings. Thus, identifying the best way to implement these ideologies, through an adequate methodology based on its needs. There are benefits common to all types of vertical farming and urban agriculture in general, but there are some that are associated with a particular crop type that should be considered.

If there is proliferation on a sufficient scale for its effects to have a significant expression in the climate sphere, it is necessary to improve both the encouragement of the practice and the normative legislation of these agricultural techniques. Although agriculture as a whole has already extensive legislation, this methodology is still not dealt with on its own and, as such, its lack of detail and follow-up is a natural consequence. However, it is considered essential that this reality changes, in order to spread the knowledge.

Finally, the promotion of an extended study at the time of each submitted project, which is easy to understand for the general population, is suggested. This measure has as main objective to make known these techniques that are still, in general, little known and consequently little practiced. This way, it would be possible to evaluate the resulting impacts from the application of this same project in that specific area and its surroundings. There will be the possibility of verifying other locations for its implementation, too. Taking into account the benefits for all parties, such a tool could raise the awareness of the general public on these issues; both on the problems faced by agriculture today and how urban agriculture, in particular vertical farming, could help combat them, as well as on climate change and how these techniques can help to tackle it.

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Legislation

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