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URBAN FARMING IN THE CITY OF TOMORROW

ASSESSING THE GLOBAL LANDSCAPE ON URBAN FOOD AND RESOURCE PRODUCTION WITH FOCUS ON INDOOR PLANT AND MICROALGAE CULTIVATION

MorgenStadt
City of the Future

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FOREWORD

How relevant is urban farming for food and resource production nowadays and within the current smart city discussion and the sustainable urban development? Although in Germany and Europe the topic still plays a minor role, it will make a huge contribution to global sustainability goals and a future-oriented urban development in the 21st century. Several mutually dependent trends can be identified:

- Technological progress of farming approaches: whereas in the past several hundred square meters of arable land were required to provide a city dweller with the annual supply, today modern LED technologies, hydroponic systems and multi-level structures make this possible within few square meters in a single space.

- Decentralization and resource efficiency: through automated operation and distribution processes, urban farming systems can also be operated in a modular and yet highly efficient way. The closer food production moves to the end consumer, the lower are the risks of crop failures or food waste within the supply chain.

- Decarbonisation of transport chains: an often neglected aspect of global greenhouse emissions by sector shows that global agriculture accounts for 30 percent of total emissions. A reduction of global transport chains of more than 10,000 km to ideally <10 km using electric vehicles in urban areas offers new attractive options for decarbonized food distribution.

- Re-use of and reintegration into urban environments: the transformation of our cities through systemic transitions in transport, economy or energy offer new spatial potential for the reintegration of urban farming. This can be done on unused or new free space (e.g. multi-storey car parks) enabling new spatial business models in the city of tomorrow.

In brief, a rapid technical renaissance or reintegration of food and resource production in the urban system with immense potential can be predicted. Whole cities could soon become almost self-sufficient by using roof surfaces or inner-city underground garages and make them – for example – part of an intelligent power grid. Let us, whether public or private sector, shape this future topic together!

Steffen Braun
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MANAGEMENT SUMMARY

Securing urban food and resource supply is increasingly becoming a challenge, especially in heavily populated cities with limited access to surrounding agricultural areas. Intensive cultivation practices exert pressures on soils and water resources and often rely on chemical pest control. Innovative farming approaches and technologies have been emerging to tackle such issues and bring parts of food and resource production back to the places where they are being consumed. In this context, the present study examines the existing urban farming landscape with a focus on plant-based indoor food production and microalgae cultivation as a potential resource of the future. It aims at showing the potentials of these urban farming approaches and highlighting important planning principles by bringing together a comprehensive literature research with the expertise and experience of existing farms and initiatives at a global scale.

Key aspects of this study include I) technology use, which evolves mainly around artificial lighting, sensoring, and automation processes; II) environmental performance, assessed by for example the inclusion of renewable energies, pesticide use and land scarcity issues; III) economic subjects related to investment and operation costs, as well as currently used financing models; and IV) social aspects including job creation and professional training. The analysis also highlights the importance of locally adapted and integrated system solutions and shows that both areas, plant and microalgae production, are characterized by high annual growth rates and face similar challenges (high investment and operation costs, high electricity consumption, strict legislations, costumer acceptance, and rather low prices of conventional food products). It thus provides a holistic overview on current developments and trends in this market informing cities and companies interested in gaining insights into a quickly evolving and growing sector. The study can likewise guide researchers and decision makers who are working towards a more self-sufficient, integrated and sustainable urban food and resource system.

ZUSAMMENFASSUNG

Die nachhaltige Sicherung der städtischen Nahrungsmittel- und Ressourcenversorgung wird zunehmend zur Herausforderung - insbesondere in dicht besiedelten Städten mit begrenztem Zugang zu umliegenden landwirtschaftlichen Gebieten. Des Weiteren üben intensive Anbaupraktiken und der massive Einsatz von Chemikalien Druck auf unsere Böden und Wasserressourcen aus. Vor diesem Hintergrund wird intensiv an innovativen Anbaumethoden und -technologien gearbeitet, welche diese Probleme adressieren und Teile der Nahrungsmittel- und Ressourcenproduktion wieder zurück an die Orte zu bringen, an denen sie konsumiert werden. In diesem Zusammenhang untersucht die vorliegende Studie die bestehende globale »Urban Farming Landschaft« mit dem Fokus auf a) Indoor-Pflanzenanbau sowie b) Mikroalgenkultivierung als potentielle Ressource der Zukunft.

Ziel der Studie ist es, die Potenziale solcher urbanen Anbaumethoden aufzuzeigen und wichtige Planungsgrundsätze hervorzuheben. Dafür wurde eine umfassende Literaturrecherche durchgeführt und mit dem Fachwissen und den Erfahrungen bestehender Urban Farming Initiativen ergänzt. Fokusthemen waren dabei I) der Technologieeinsatz, der sich hauptsächlich auf künstliche Beleuchtung, den Einsatz von Sensorik und Automatisierungsprozessen konzentriert; II) ökologische Auswirkungen, wie etwa die Einbindung erneuerbarer Energien, Pestizideinsatz und Flächenverbrauch; III) wirtschaftliche Faktoren einschließlich Investitions- und Betriebskosten sowie derzeit verwendete Finanzierungsmodelle; und IV) soziale Aspekte wie das Schaffen neuer Arbeitsplätze und berufliche Weiterbildung. Insgesamt wird dabei die Wichtigkeit lokal angepasster und integrierter Systemlösungen betont. Die Analyse zeigt ebenfalls, dass sowohl Pflanzen- als auch Mikroalgenproduktion, durch hohe jährliche Wachstumsraten gekennzeichnet sind und vor ähnlichen Herausforderungen stehen (hohe Investitions- und Betriebskosten, hoher Stromverbrauch, strenge Rechtsvorschriften, schwankende Kunden Akzeptanz und niedrige Preise konventionell hergestellter Lebensmittel). Die Studie bietet somit einen ganzheitlichen Überblick über aktuelle Entwicklungen und Trends in diesem Marktsegment, ermöglicht interessierten Städten und Unternehmen erste Einblicke in einen sich schnell entwickelnden und wachsenden Sektor, und informiert Wissenschaftler und Entscheidungsträger welche auf ein autarkes, integriertes und nachhaltiges städtisches Nahrungsmittel- und Ressourcensystem hinarbeiten.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

CAGR	Compound annual growth rate
CEA	Controlled-environment agriculture
CHP	Combined heat and power (cogeneration)
CO_2	Carbon dioxide
DHA	Docosahexaenoic acid (omega-3 fatty acid)
DNA	Deoxyribonucleic acid: thread-like chain of nucleotides carrying the genetic information of all known living organisms and many viruses
€, EUR	Euro, official currency of the European Union
HPS	High-pressure sodium lamps
HVAC	Heating, ventilation, and air conditioning technology of indoor and vehicular environmental comfort
ICT	Information and communication technology
IoT	Internet of things
IVAS	Integrated visualization and analysis software
KWh	Kilowatt hour
LCA	Life-cycle assessment
LED	Light-emitting diodes
MJ	Megajoule
PUFAs	Polyunsaturated fatty acids
PV	Photovoltaic system (solar power system)
R&D	Research and development
US$	The United States dollar

1 INTRODUCTION

Population growth and urbanization are leading to a higher demand for food and resources, especially in cities. Nowadays, 54 percent of the world's population live in big cities and urbanized agglomerations, a proportion that is expected to increase to 66 percent by 2050[1]. To avoid negative impacts of fossil fuel use, these resources are more and more of biological origin (especially the 4 Fs: food, feed, fuel, fibre)[2]. This exerts additional pressure on agriculture, which is already facing decreasing land availability and a loss of fertile soils. Against this background, urban farming concepts have evolved to bring parts of food and resource production back into the cities, lessen the burden of agricultural production and promote local production and supply sources[3]. Furthermore, in the effort of reducing transport distances and related logistic operations[4], urban farming approaches are increasingly being promoted by local administrations.

Especially interesting for scientific research are urban farming methods, which take place under controlled environments, such as vertical and indoor farming, or approaches, which consider new biological species and resources such as microalgae cultivation. In such cases, the use of adequate technology can help to achieve promising results such as a considerable reduction in the use of harmful pesticides, improved freshwater management and high areal biomass productivity, while maximizing taste and food value and minimizing the threat of contamination[5]. Table 1 summarizes potential benefits in this field. To tap into these, careful planning, a thorough understanding of the local preconditions, and the development and choice of adequate methods and technologies are necessary. This area undoubtedly presents very attractive development opportunities for companies producing technologies such as indoor cultivation systems, artificial lighting, sensoring, automation control, etc. At the same time, it enables cities to directly meet parts of the local food and resource demand on-site and shift towards a more bio-based and circular economy model. Furthermore, the economic viability of urban farming options is improving as potential use cases and application areas expand, and available technologies mature.

Against this background, the present study aims at providing a holistic overview of current technological advances and urban farming initiatives around the world, by assessing technological, environmental, social and economic key aspects and identifying major challenges, future trends and market outlooks. It investigates existing experiences and potentials for controlled urban and vertical farming in two main areas: 1) plant-based food production and 2) microalgae cultivation as future resource option. Thereby a focus laid on initiatives, which operate in urban settings and include indoor farming technology components.

Table 1: Potential benefits of urban farming[4–7]

Economic dimension	Promoting a bio-based economy in cities, which replaces fossil fuel based resources with renewable ones
	Generating circular economy structures results in more efficient urban logistics (against the characteristic pattern of food and resource import from rural areas and export of waste to regions outside of the city)
	Reducing transportation needs, which comes along with energy and cost savings, as well as traffic reduction
	Stimulating the local economy and creation of new job opportunities
Social dimension	Contributing to food security and accessibility: facilitation of access to food for the urban population
	Making cities a healthier place to live in (improved quality of the environment) with reduced environmental impact, due to the disruption of traditional supply chains by the creation of farms near to population centers
	Raising awareness on food production and quality (where does my food come from and how is it produced?)
Environmental dimension	Reducing the need to transform natural regions into cropland
	Maximizing resource use efficiency (e. g. vertical farms can work on less water compared to conventional agriculture)
	Reducing pollution caused by nitrates and pesticides
	Greening the city (reducing excessive runoff, increasing water treatment, improving air quality through circular production patterns)

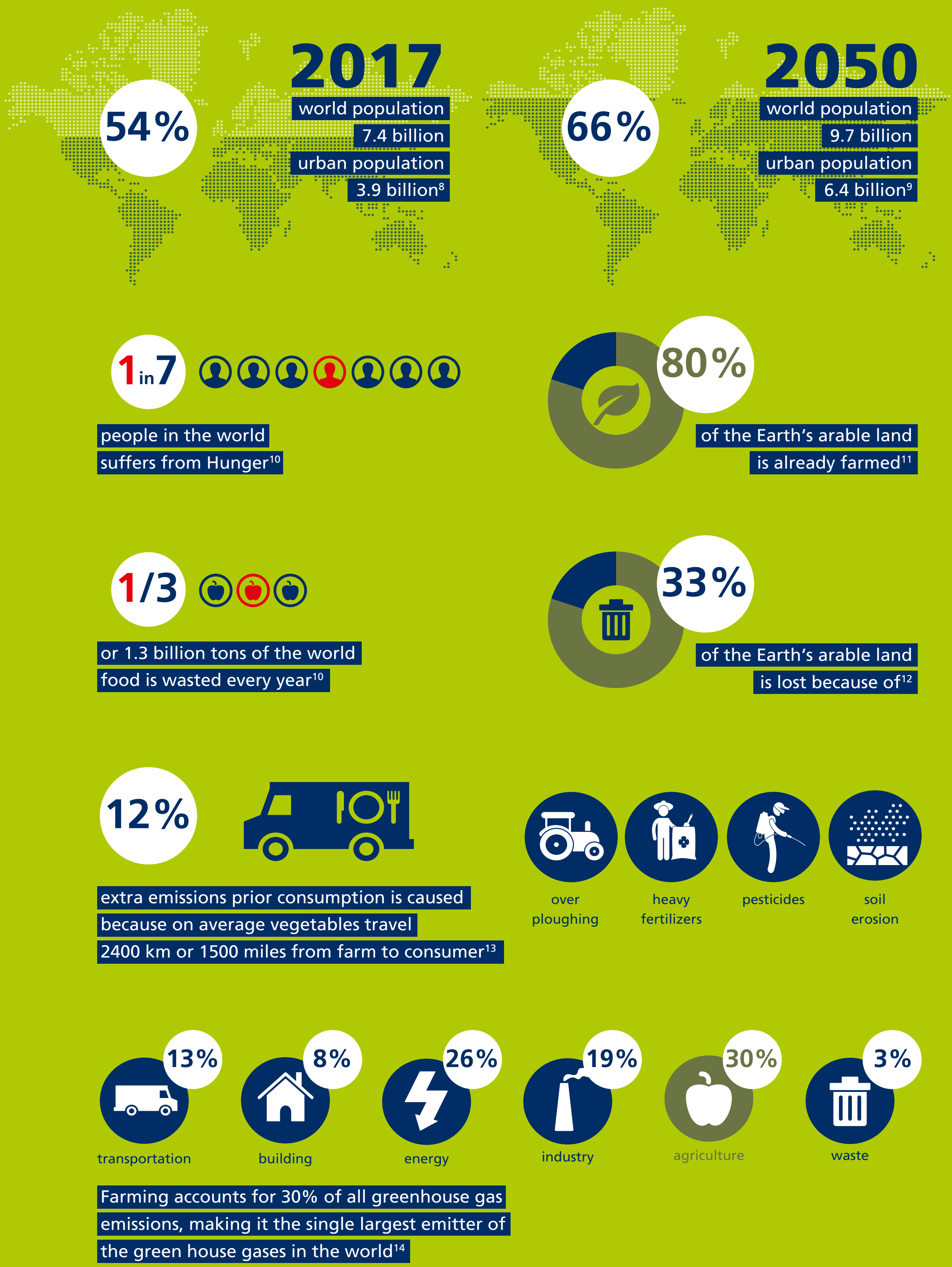
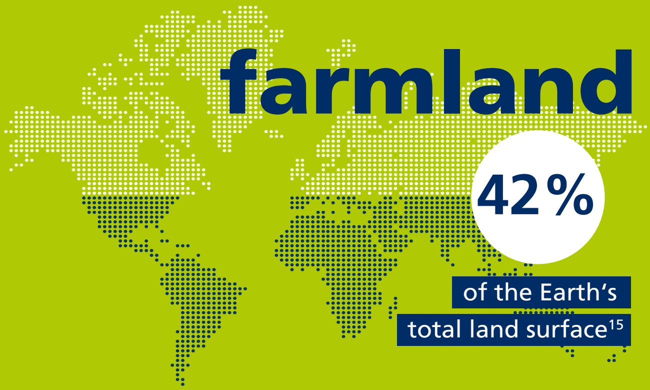
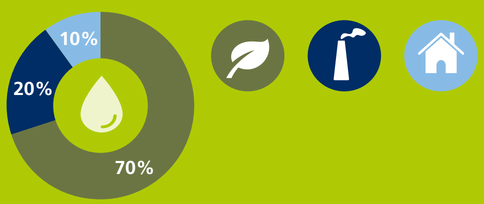


Figure 1: Fraunhofer IAO infographic on major food challenges and global trends[8–14]





70% of global water consumption is used for farming, causing rivers and lakes drying up

20% more water is required by 2050; if farming follows the traditional way[16]

80% of global deforestation is caused by farming[11]

The pesticide-rich run-off water is creating dead zones for fishing in rivers and oceans

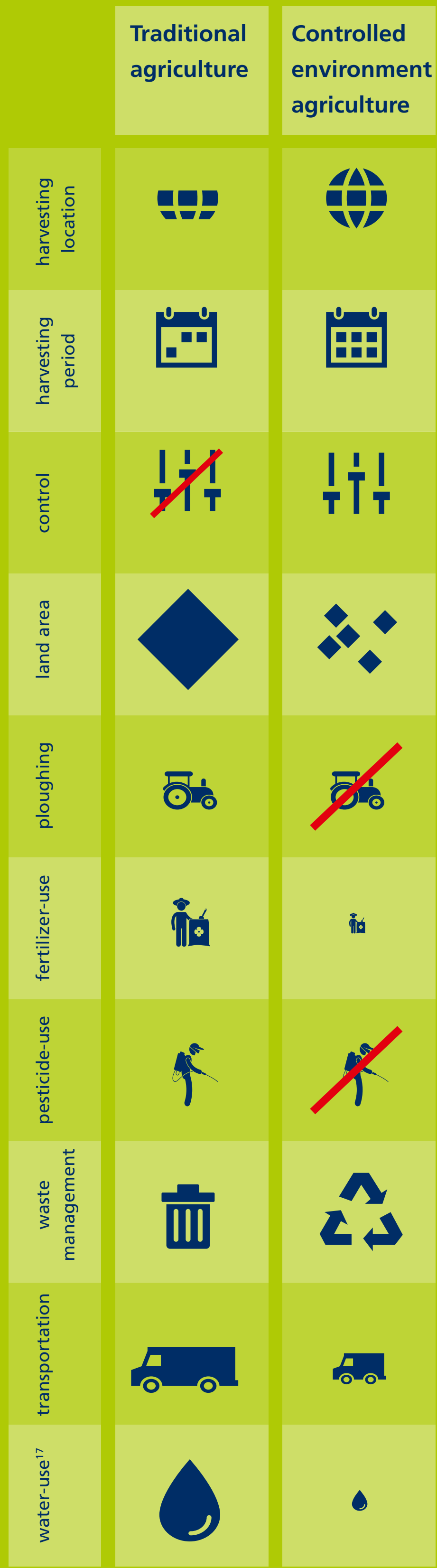


Figure 2: Fraunhofer IAO infographic on traditional and controlled environment farming practices[11, 15–17]

2 SCOPE AND METHODOLOGY

As mentioned above, this study analyzes current urban farming initiatives, where cultivation takes place under controlled or semi-controlled conditions. The identified and assessed initiatives are located within the urban spectrum and use advanced technology for the cultivation process. Most of the farms operate indoors, but outdoor farms that use innovative technologies in the production process were also included in the scope. Conventional greenhouses, outdoor farms or urban gardens have not been considered. The term "urban farm" in this study is therefore used to describe participating initiatives, which operate under the above mentioned conditions.

The study assesses two sectors, urban (plant-based) food production, as well as microalgae cultivation in closed systems. Figure 3 shows the basic outline of the applied methodology with its different research stages:

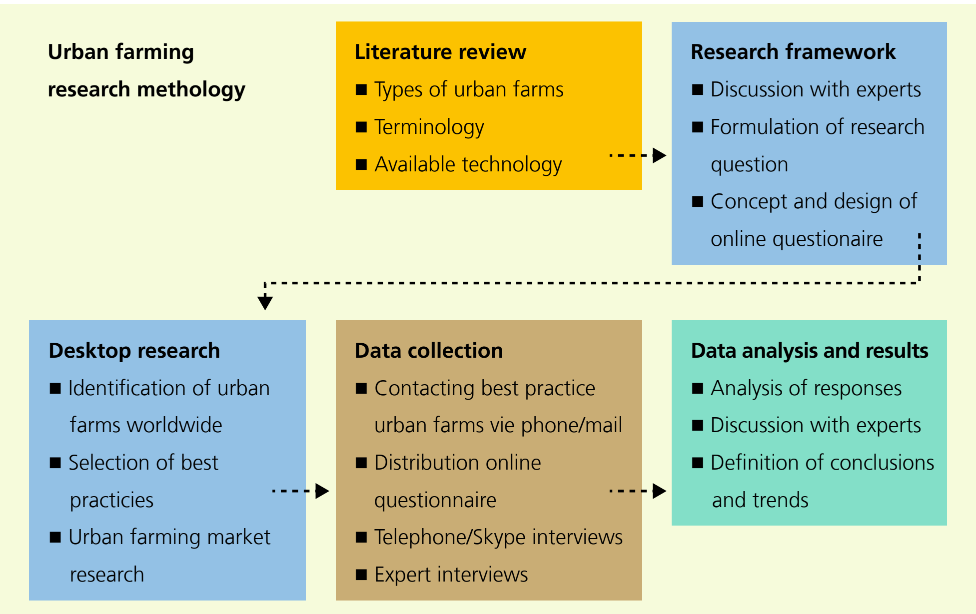


Figure 3: Applied research methodology

The methodology involved a broad literature review followed by desktop research on currently used urban farming terminologies and methods in the food and algae production sector. Subsequently, a number of case studies around the world were identified based on available online information. A research framework was defined after discussion with experts in this field, where dimensions and indicators were derived based on the revised literature and the study goals. Accordingly, a structured questionnaire was designed with 38 questions in the food and 43 questions in the algae sector. Contacts to the identified initiatives were then established via phone and mail (not all of them could be reached). The online questionnaire was forwarded to the contact person and responses were followed up through individual phone or skype calls. Thus, a series of expert interviews from the urban farming industry were carried out. A total of 39 urban farms from the indoor plant production and 53 from the algae production sector were contacted across the world. A total number of 16 urban farms producing plant-based food products and 27 urban farms in the algae production sector responded the online questionnaire (see table 2). The information received was then contrasted and matched to the findings from current literature and market predictions. Due to the lack of time and data availability or language barriers (especially in Asia) it was not possible to receive insights from all of the identified initiatives. The study thus does not claim to depict the full picture, but shows an excerpt of currently ongoing activities and approaches.

Figure 4 shows the geographical distribution of the identified and interviewed initiatives in the food production sector. As shown in the map, most of the farms were found in Asia and North America. From the 39 cases identified, 16 are located in North America (12 USA, 4 Canada), 13 in Europe (5 Germany, 3 Netherlands, 2 United Kingdom, 1 Spain, 1 Sweden, 1 Portugal), 9 in Asia (6 Japan, 3 Singapore) and 1 in Australia. It must be highlighted that the scale of production in Asian farms is usually higher when compared to the ones in America or Europe.

When looking at microalgae cultivation, most initiatives were identified in Europe (35 in total, especially from Germany, Portugal, the Netherlands and the United Kingdom), as well as in North America (12). Similarly, the large majority of respondents (22 out of 27) is based and active in Europe (6 Germany, 4 Portugal, 3 the Netherlands & others), with the remaining responses coming from North America (3), Asia (1) and South America (1). In general, especially in Nordic countries such as Sweden, Norway and Iceland, artificial lighting was a crucial asset whereas other regions also relied on natural sunlight.

Indoor plant cultivation		**Microalgae cultivation**	
Company	Country (City)	Company	Country (City)
Modular Farms	Canada (Brampton)	A4F Secil	Portugal (Leiria, Lisbon)
PlantLab	Netherlands (s-Hertogen-bosch)	Alga Pangea	Austria (Güssing)
Philips Horticulture LED Solutions	Netherlands (Eindhoven)	Algae Biotech	The Netherlands (GS Weesp)
Manticore IT GmbH	Germany (Heidelberg)	Algaedynamics	Canada
G2Gi – Indoor Farming Solutions, Lda.	Portugal (Castelo Branco)	Algalif	Iceland
Local Roots Farms	USA (Vernon)	Archimede Ricerche Srl	Italy (Camporosso)
Plantagon International AB	Sweden (Linköping)	AstaReal AB	Sweden (Gustavsberg)
LA Urban Farms	USA (Santa Monica)	Biopharmia	Norway (Oslo)
GrowUp Urban Farms	UK (London)	BioVorn (formerly known as ARAgreen)	UK (Gloucestershire)
Fraunhofer IME	Germany (Aachen)	Ecoduna / Esperella	Austria
Panasonic Factory Solutions Asia Pacific	Singapore (Singapore)	Ecologic Studio (London)	Italy (Milan expo)
Interfaith Neighbors	USA (Asbury Park, NJ)	EnerGaia	Thailand (Bangkok)
Infarm Indoor Urban Farming GmbH	Germany (Berlin)	Fraunhofer IGB Fraunhofer CBP / Subitec GmbH	Germany (Leuna)
Sostenipra. Universitat Autònoma de Barcelona	Spain (Cerdanyola del Vallès)	GICON -Grossmann Ingeni-eurConsult, GmbH	Germany (Dresden)
Green Camel	Australia	Jie Zhang & Tyler Stevermer	USA
Spread Co., Ltd.	Japan (Kyoto)	LGem	The Netherlands (The Hague)
		LusoAmoreiras, S.A.	Portugal (Lisbon)
		MINT	Germany (Berlin)
		NANOFARM, S.A.	Portugal (Lisbon)
		Necton	Portugal
		Omega Green	The Netherlands (Eemshaven)
		OneWater Inc.	USA (Indianapolis)
		Roquette Klötze GmbH & Co. KG	Germany (Klötze)
		Spirulina Mexicana	Mexico (San Miguel de Allende)
		SSC GmbH	Germany (Hamburg)
		Technological Platform for Microalgae Experimentation	Spain (Madrid)
		Xanthella	Scotland

Table 2: Geographical distribution of the initiatives, which participated in the survey

Identified initiatives – indoor plant cultivation

Identified initiatives – microalgae cultivation

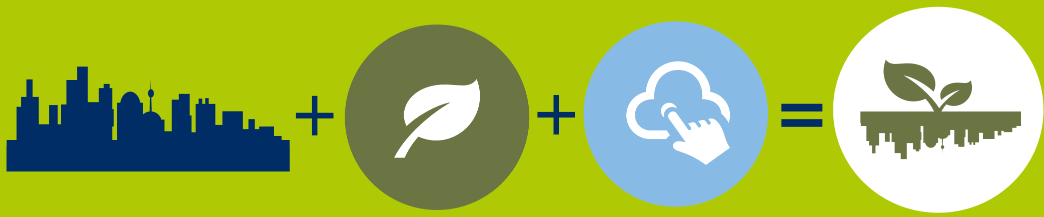
Figure 4:
Geographical distribution of the identified initiatives in the area of indoor plant cultivation and microalgae cultivation


1
1
1
1
3
1
1
1
6
1
3
1
1
1

3 IMPORTANT TERMS AND DEFINITIONS

Urban farming can be defined as the cultivation, processing and distribution of food and other products for commercial purposes[18] through crop production in urban areas, mostly to feed the local population. In recent years, the popularity of urban farming has increased due to concerns about climate change and the preservation of food security in urban areas. The effects of climate change have led to crop loss and optimal organic farming conditions have been influenced by rising temperatures and changing rainfall patterns. As agriculture contributes to 30 percent of anthropogenic greenhouse gas emissions, urban farming concepts often aim to reduce temperatures and greenhouse gas emissions in urban areas. Furthermore, the increase in urban food deserts (i.e. urban areas where access to natural, healthy food is severely limited[19]) in many parts of the world has triggered investments on urban farming methods to complement urban food needs[20].

The vertical farming model was developed with the idea of increasing the agricultural area by building the area upwards. In other words, the effective acreage for crops is increased by building multi-storey skyscrapers on the same area. It is an extension of the hydroponic greenhouse model and addresses problems related to land scarcity and overuse of soils[6]. The proximity to the consumer saves transport costs, a year-round production can be programmed on demand, and cultivation conditions can be optimized to maximize yield by fine-tuning temperature, humidity and light conditions. Indoor farming in a controlled environment also requires much less water than outdoor farming because grey water can be recycled and less evaporation takes place[6].The following infographic gives an overview of the main methods and technologies that exist when talking about vertical faming and urban farming in a controlled environment[21].



Different types of farming system based on exposure to the sun

Urban farming techniques in controlled environment

Exposed
(ex. a roof-top, open air farm.)

Enclosed
(ex. a green house; using sunlight)

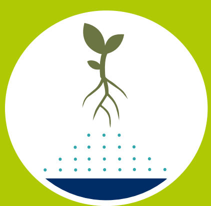
Closed
(ex. indoor farms using LED lights instead of sunlight)

Hydroponics

Hydroponic is a method of growing plants in a water based, nutrient-rich solution. Hydroponics does not use soil, instead the root system is supported using an inert medium such as perlite, rockwool, peat moss etc.[23]

Aquaponics

Aquaponics refers to any system that combines conventional aquaculture (raising aquatic animals such as snails, fish, caryfish or prawns in tanks) with hydrponics (cultivating plants in water) in a symbiotic environment.[24]



Aeroponics

Aeroponics is the process of growing plants in an air or mist environment without the use of soil or aggregate medium. Unlike hydroponics or aquaponics; aeroponics is conducted without a growing medium.[25]

Figure 5: Urban farming techniques under controlled environment[22–24]

Indoor Food Cultivation is defined as growing plants or crops exclusively in enclosed spaces and mostly on a large scale. This kind of agriculture often uses growing methods such as hydroponics and utilizes artificial lights to grow plants with the necessary nutrients and light levels. It is often used to foster a controlled environment for whatever species of plants being grown[25]. In comparison to traditional land-based agriculture, indoor urban farming advantages include more efficient use of land and resources, year-round high yield production, protection from severe weather events, enabling of food security, limited/zero use of pesticides or fertilizers, water/energy savings and lower logistical costs[26]. A large plant diversity can be grown indoors, but fruits, vegetables, and herbs are the most common ones.

Next to conventional crops and vegetables, microalgae have increasingly gained attention as new biological resource of the future. Microalgae are the most important biomass and the primary oxygen producers on Earth, but while 500,000 species are known to exist, only a small fraction is currently used. Under good growing conditions, microalgae can produce up to five times more biomass per hectare than terrestrial crops without the need for fertile soils or arable land. They can be cultivated in arid areas and, depending on the species, fresh-, sea- or brackish water can be used. Even the use of wastewater is possible in certain cases, with purification as a welcome side effect. Microalgae cultivation might also take place in urban areas and use industrial flue gases as feedstock[27].

In the urban realm, microalgae cultivation usually takes place in bioreactors which are enclosed cultivation systems, often using artificial lighting (photobioreactors). Open pond cultivation is rather found in rural areas and outskirts and were not focused on in this study. The resulting biomass contains various valuable compounds and can be harvested all year round[27, 28]. Since microalgae cultivation is a comparatively new development and often uses high-tech solutions, it still struggles to compete with mature conventional cropping systems, especially in terms of economic viability, production costs and net energy return[29, 30]. Still, the comprehensive use of microalgae and the integration of the production into urban areas and urban metabolisms – be it centrally or de-centrally - can become one of the moonshot innovations to revolutionize and add to current agricultural systems, if adapted to regional and site-specific conditions[31].

4 URBAN FOOD PRODUCTION

4.1 The urban food production landscape

More than 50 urban farms dedicated to indoor food production were identified worldwide, of which 39 were approached. For the others, no contact information was available or no contact could be established. The rest could not be reached due to the lack of updated available contact information. Out of the approached initiatives, 16 farms answered the online questionnaire and provided the basis for the analysis presented below. All of the responding farms are already in the operating phase, except for two which are in implementation/commissioning phases. Most of them use either new buildings or re-utilized infrastructure and some have been integrated into existing buildings. Among the respondents, 70 percent of the farms are in an indoor/enclosed integrated setup, two operate outdoors using aeroponics, while two are set-up in containers. In 81 percent of the farms the environment is completely controlled (temperature, light, humidity, etc.) and more than 80 percent use hydroponics as their main technology. The top products cultivated on urban farms are leafy greens (69 percent), basil (56 percent), tomatoes (44 percent) and strawberries (25 percent).

The predominant purposes of the farms are retail and direct sell, followed by research purposes. More than two-thirds (69 percent) of the farms have a distance of half a kilometre or less to the city centre and are therefore focused on customers from their neighbourhood. In some cases, the urban farms have business connections with a local restaurant, a local supermarket or a single seller who delivers the product to another location.

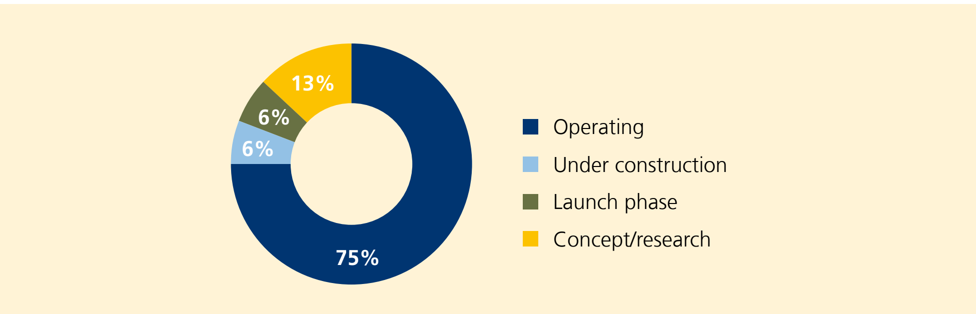
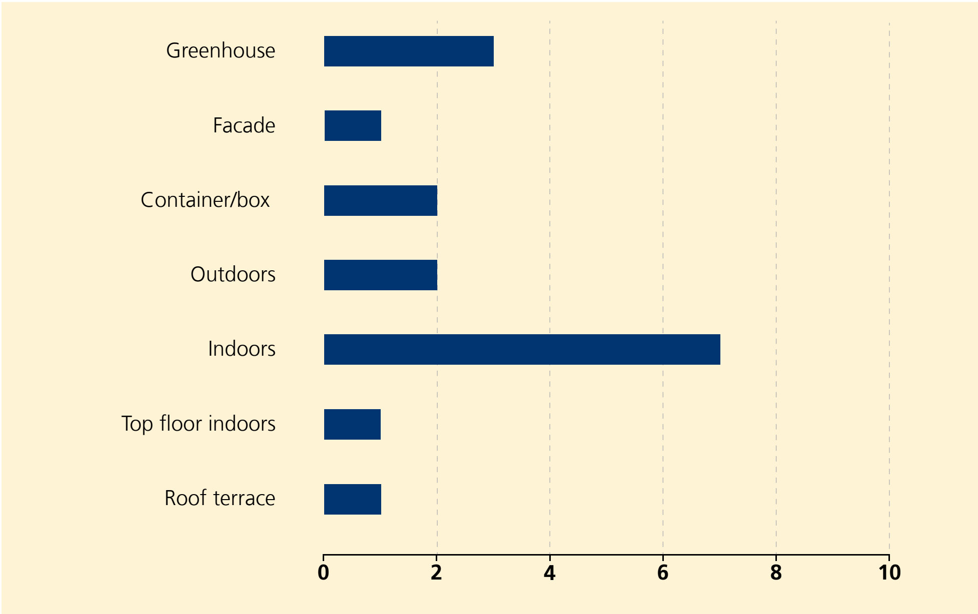


Figure 6: Stage of urban farm, n=16

Figure 7: Location of urban farm, n=16



4.2 Technologies

Urban farming is getting more efficient due to the various technological advancements, which , according to most participants, allows urban farms to be competitive against conventional farming methods. The technologies used are associated with the concept of controlled-environment agriculture (CEA). The core principle behind it is to provide protection and maintain optimal growing conditions throughout the development of the crop[32] through resource optimization such as water, energy, space, capital and labor[33]. The closed environment increases productivity and allows faster cultivation. As mentioned above, 81 percent of the interviewed farms operate in a completely controlled environment, while approximately 13 percent are semi-controlled. With regards to the farming method, all of the indoor participating farms apply hydroponics and use water as the growing medium. A quarter of them also use a solid growing media mix (soil, coconut, husk, coal, fibre, etc.) alongside with hydroponics. Farms that have an outdoor/sunlight exposed component use grow beds. Among respondents of the survey, only one farm uses aquaponics.

As for the farm set-up, participating initiatives ranged from container boxes to industrial greenhouses. Some of the industrial set-ups are new buildings that include different areas for seeding, production, cultivation, and service. However, small-space urban farms are popular as well among respondents. Ideal locations for building-integrated urban farms are roof terraces which allow the use of direct sunlight, while containers are more independent set-ups and can be easily placed in any urban locality.

The technology used has a direct impact on the output of the farms and the types of technologies applied are vast. According to the conducted survey, the most commonly used technologies are controlled irrigation, heating, ventilation, and air conditioning (HVAC), water recycling, automatic nutrients control, temperature and humidity sensors, light brightness and color controlling. Furthermore, artificial lighting could be identified as one of the core elements in modern urban farming. The survey showed that 92 percent of farms use LED lighting; most of them applying a LED mixer, followed by the white, red, far red and blue lights.

Apart from these technologies, selected urban farms are making use of more advanced and biotechnological methods for farming such as phenotyping . 2D/3D plant scanning, fermentation, vacuum infiltration and downstream processing have also been named, as well as nutrient modelling algorithms within the cloud, to monitor and predict/control the growth of microbes and conversion of organic compounds. ICT Platforms as the IVAS software are used for production planning and control.

The harvest cycle depends on the plant and cultivation method. Conventionally grown fruits and vegetables often use fertilizers and pesticides, which allow producers to get higher yields, greater pest resistance, and usually higher yields. However, as compared to conventional farming methods, in certain cases CEA achieves a shorter harvesting time for different plants. On average, leafy greens and salads grow faster under hydroponic and aeroponic controlled systems. One of the fastest growing greens is spinach: it is ready to be harvested from a seedling after around 14 to 20 days[34]. Conventional soil based cultivation takes around 35 to 40 days to be ready for harvesting[35]. Most of leafy greens and herbs (e.g. lettuce, kale, etc.) take one to three weeks after seeding to germination and two to four weeks for production. In case of fructiferous plants such as strawberries, it takes six months from seeding to final harvesting. However, hydroponic strawberries have on average 17 percent higher yield compared to the conventionally soil grown[36]. To enhance the photosynthesis process and shorten the harvesting cycle, artificial lights are chosen carefully. They provide plant species with specific wavelengths and allow photosynthesis to take place at any time. One of the resulting advantages is that although the difference in harvest cycles is not that significant, crops can be grown all year round and, depending on the demand, the production can be increased or decreased. For example, with supplemental artificial lighting and temperature controls, lettuce production can be continuous year round, with a full harvest cycle completed every 4 weeks (around 12 harvests per year)[37].

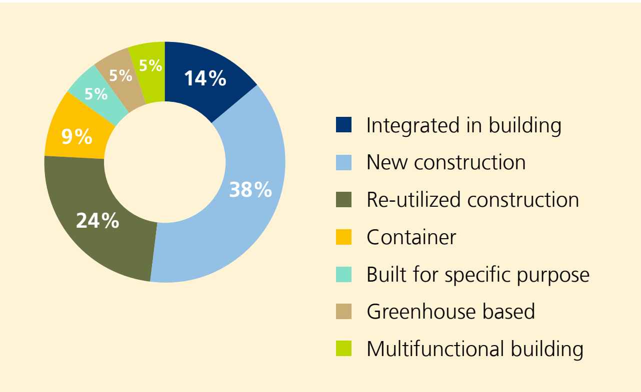


Figure 8: Typology of urban farm set-up, n=16

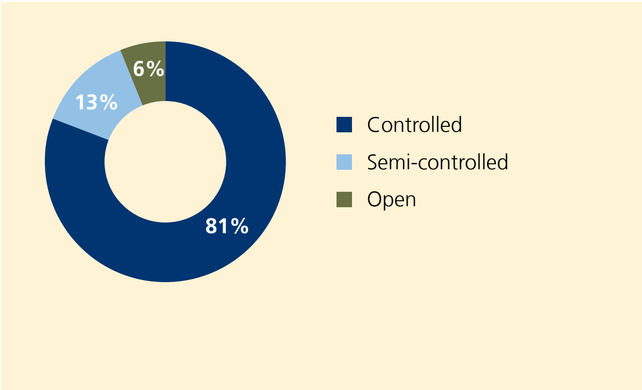
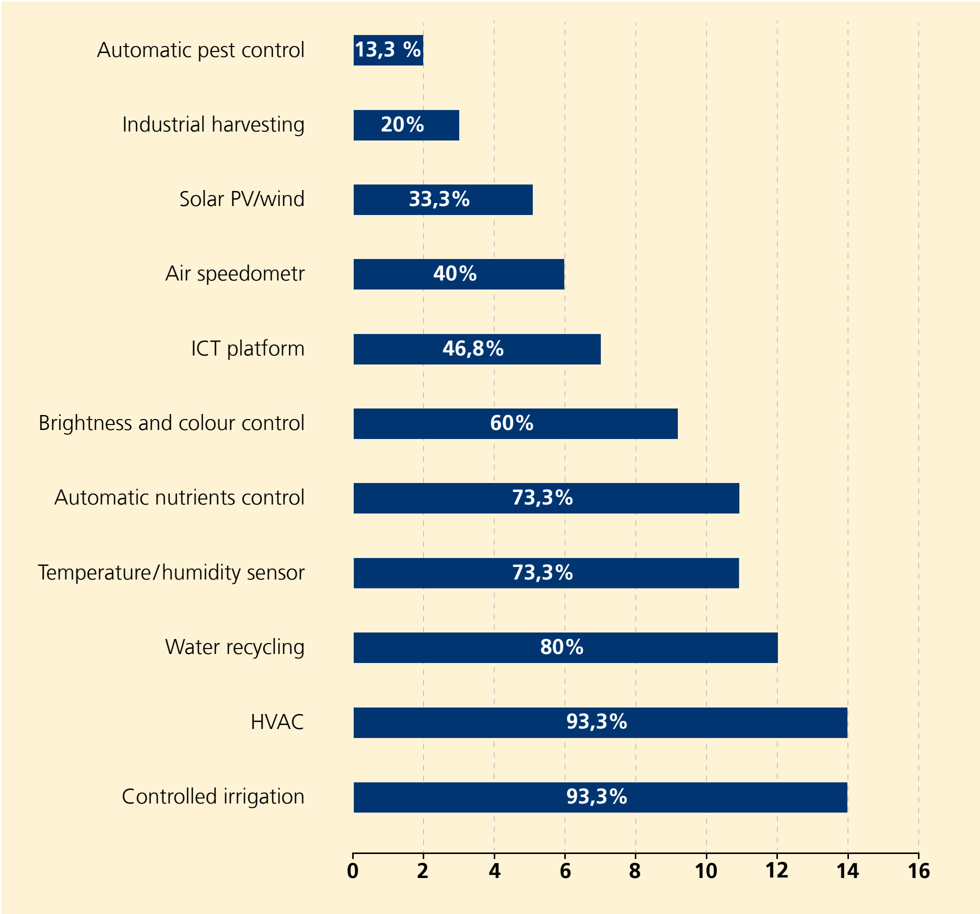


Figure 9: Controlled environment typology, n=16

Figure 10: Technology used in the urban farms, n=16



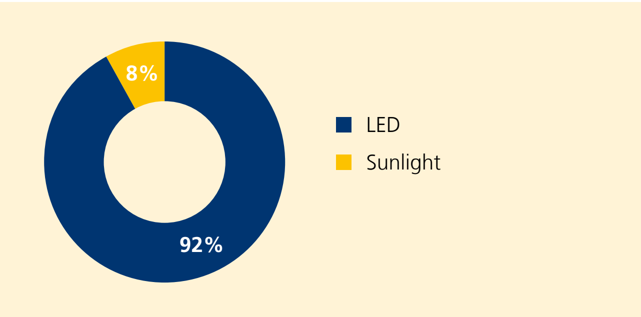


Figure 11: Artificial light use,

n=13

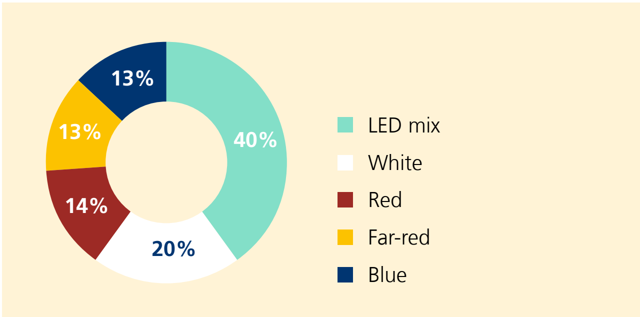


Figure 12: Led type,

n=8

4.3 Environmental aspects

The contribution of urban farming to the city's environmental sustainability should be assessed regarding the quantitative and qualitative characteristics of the urban natural resources used in the production process. Basic resources such as water and soil needed for farming are in competition with other urban needs such as drinking, domestic and industrial water use, infrastructure construction, etc[38].

Urban environments also face the problem of land scarcity, therefore the quantity and quality of land needed for a farming facility is an important factor to be considered in the analysis. According to the survey, over 50 percent of the farms use an area below 500 m^2, which is far less than an average "small size" conventional farm (about 2 ha of utilized agricultural area). Here, the vertical farming concept helps to increase the production capacity and the efficient use of space. 65 percent of the respondents indicated to operate on more than five growing layers. In the "number of layers" graphic below (Figure 14), the category "other" represents farms that use different vertical farming principle such as the growing towers produced by the company ZipGrow™.

Another impact factor is the distance from the urban farm to the initial customer. Production facilities that are located closer to its customers use less fuel for transport and thus have lower environmental impacts. For instance, "when iceberg lettuce is imported to the UK from the USA by plane, 127 calories of energy (aviation fuel) are needed to transport 1 calorie of lettuce across the Atlantic"[39]. On average, around half of the urban farms represented in the survey are located in the range of 5 km to the customer and in the range of 5 km to the city center. This is also directly related to the freshness and transportability of the products, which in this case are mostly greens, products normally highly affected by long-distance transportation.

With regard to energy, the overall demand is very variable and depends on the type of technology, the scale and the final product itself. The available literature and the results of this survey suggest that urban farms are increasingly using renewable sources of energy (mainly, biogas, wind and solar energy) to meet part of their needs. According to the survey, 78 percent of the farms fully or partially cover their energy needs with renewables, with the biggest share supplied by solar based energy. In the regions where renewable energy sources are enough to supply the grid, the practice of purchasing electricity from renewable energy suppliers contributes to reduce high capital costs for installment. Others use energy from their block, as from thermal power stations or CHP vegetable oil.

Cities are also increasingly facing problems with the disposal of wastewater and with maintaining the quality of water basins. Thus, water consumption and its efficiency are extremely important factors that should be considered. Consumption is directly linked to the size of the farm. Although the data can be very variable because of the former, our survey shows that around 37 percent of the producers consume less than 5000 l of water per year, while 25 percent use more than 50000 l per year. Also, according to the technological data presented in the previous chapter, more than 85 percent of representatives use water recycling technologies. Due to the wide consumption range identified, it is hard to make a statement or direct correlation between farm size and water consumption. It is evident that there are other factors apart from the farm´s size that have an influence on the water consumption, which would have to be analyzed.

Finally, regarding pesticides, 100 percent of all survey participants do not use any of these in their production. Still, only 20 percent of the farms are organically certified, mainly due to strict labelling rules, which do not support new technological advances[40].

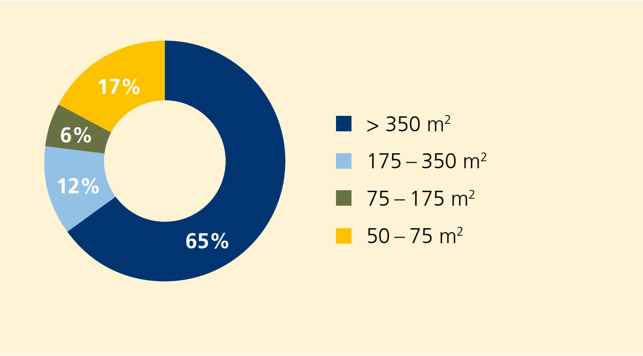


Figure 13: Size of growing area, n=16

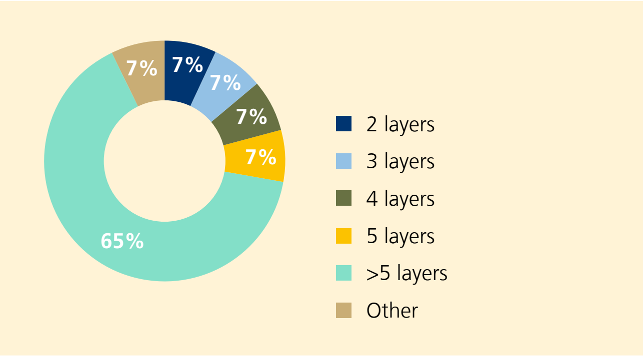


Figure 14. Number of layers, n=14

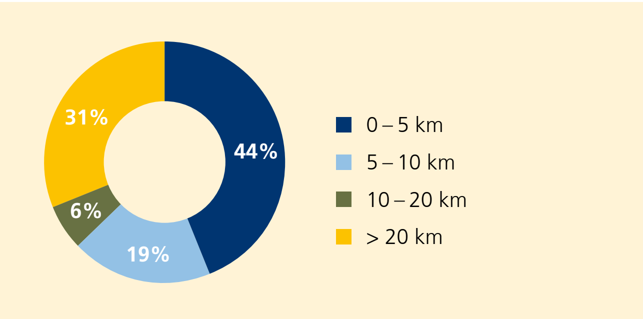


Figure 15: Distance to customer, n=16

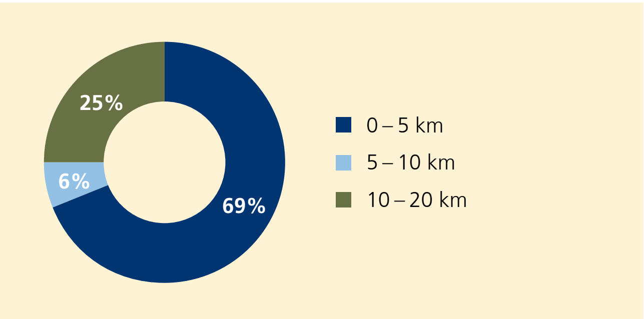


Figure 16: Distance to the city center, n=16

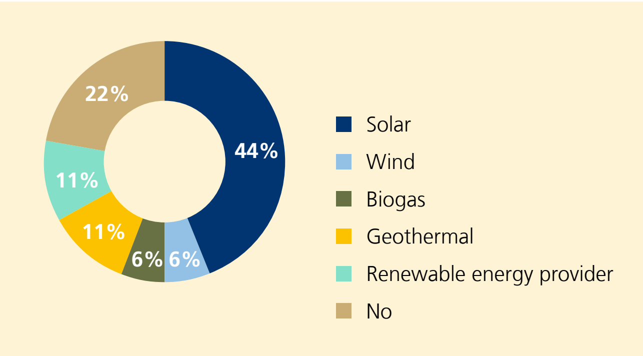


Figure 17: Renewable energy use, n=15

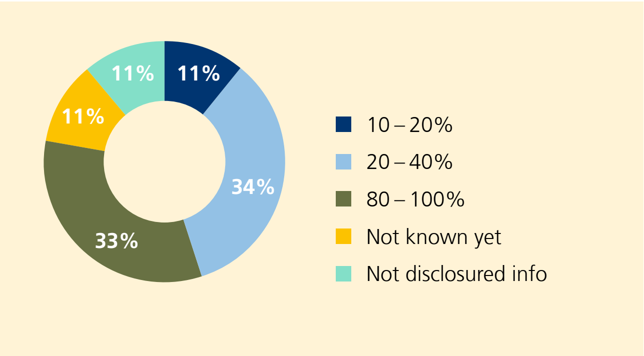


Figure 18: Renewable energy supply, n=13

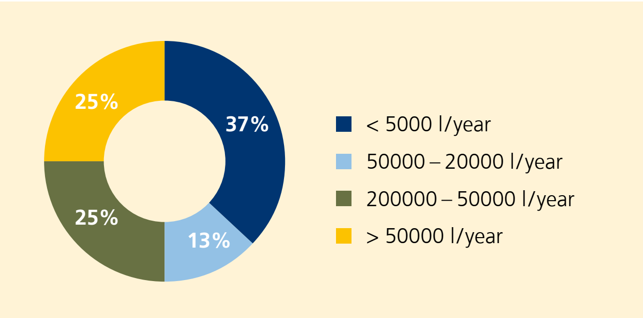


Figure 19: Water consumption, n=12

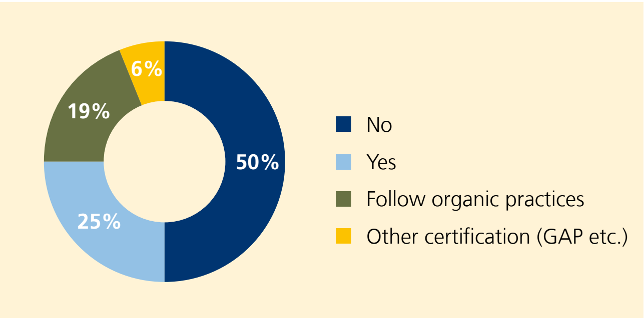
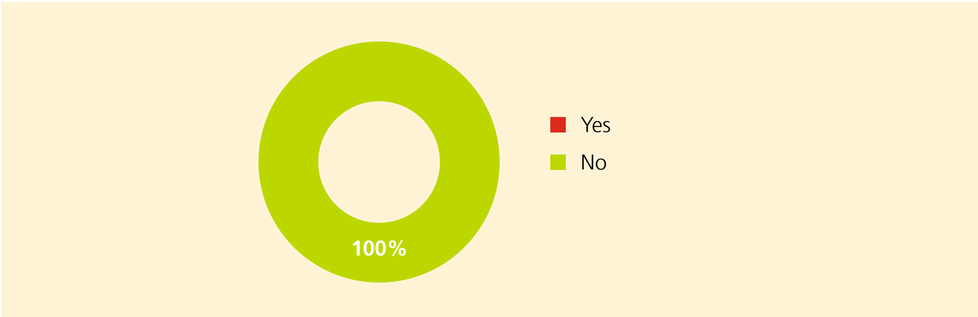


Figure 20: Organic certification, n=16

Figure 21: Use of pesticides, n=16



4.4 Economic aspects

The sustainability or ecological aspects are strictly interrelated with the economic ones. Here there are several specific factors to consider. Firstly, indoor urban farms depend on the adoption of specialized and intensified technologies. The initial investment, as well as the running costs, are quite high and the recovery period is long due to high market competition. 46 percent of the surveyed farms invested more than € 5 million as capital costs. However, survey shows that 50 percent of farms invested less than € 3,000 per m^2 (25 percent less than € 100). Around 31 percent of all respondents stated to be funded via capital investment sources as public-private partnerships and government/research funding, which is a significant share. Nevertheless, governmental support in the form of subsidies to promote initiatives that, among others, reduce the food travel distance and have in general a positive environmental impact are not existent or at least not so widespread according to survey responses and the carried out desktop research.

In general, products harvested in urban farms are often of higher quality than the ones produced using conventional farming methods. The high costs of input materials as well as initial investment may therefore be compensated by the better selling premiums obtained at the farm gate and the shorter market chain compared to conventional agriculture. This is the case for the production of high quality vegetables, condiments, and even ornamental plants, where commonly one third of the farm yield covers the running costs and generates additional income[38].

Finally, economic viability relates to the ability to not only reduce waste but to utilize or re-use by-products in the most suitable way. Here, concepts as a biorefineries – facilities that integrate biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass – should be considered[41]. This allows to generate additional income (financial or asset) and to fully use the farm's potential. The graphic below (Figure 25) shows that the most popular by-product is compost, followed by multiproduct generation in aquaponics. Further research is being carried out on means to implement sustainable recycling approaches for the generated plant biomass.

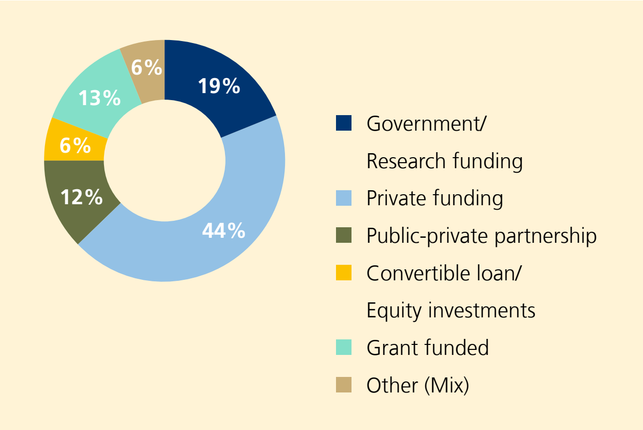


Figure 22: Model of investment, n=15

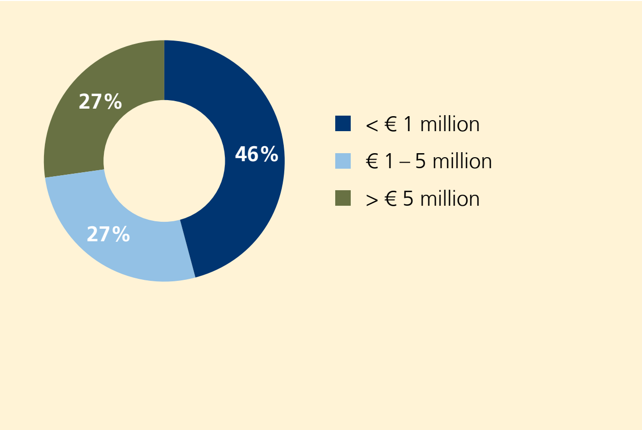


Figure 23: Capital investment, n=10

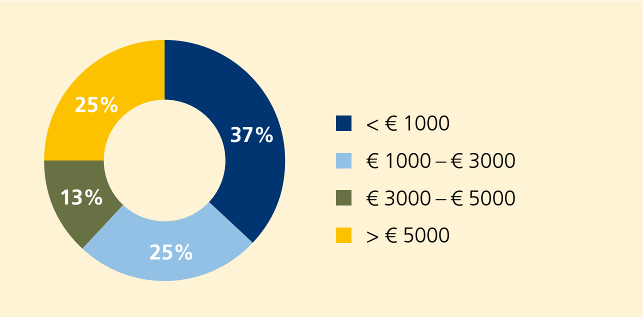


Figure 24: Investment per m², n=10

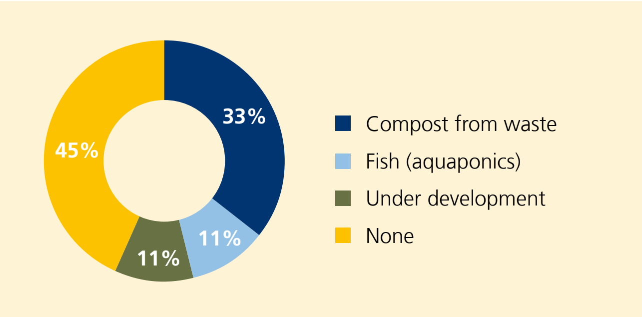


Figure 25: By-product generation, n=8

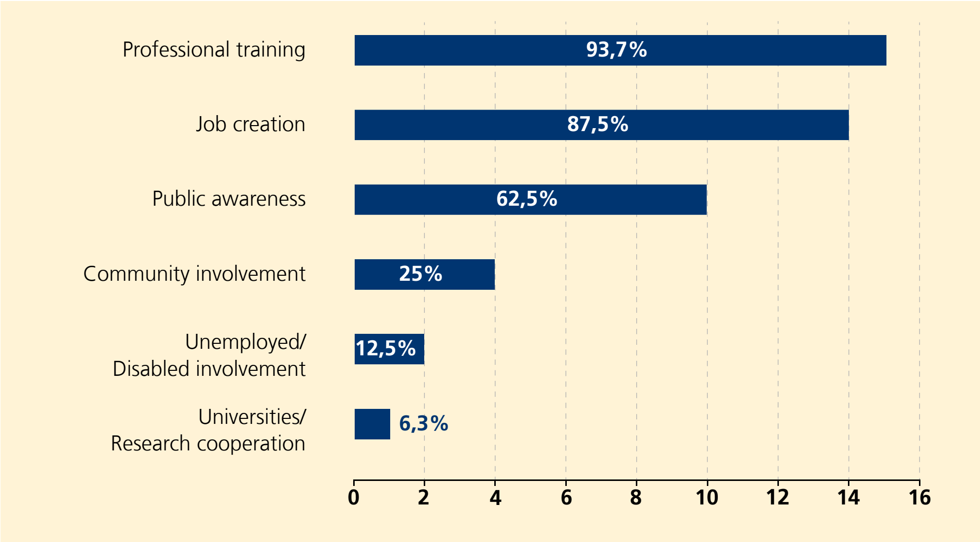
4.5 Social aspects

Urban farming can give access to land, provides a meeting point for experience exchange and educational programs, helps to improve food and health literacy etc. and plays an important role by providing opportunities to integrate local stakeholders into productive activities.

The presence of an urban farm undoubtedly increases the local awareness about growing vegetables and fruits in-house with new technologies. Almost all of the farms from our survey are involved in professional training and the creation of jobs in the local neighborhood. Still, only 25 percent involve community participation and 13 percent practice special programs for unemployed or disabled people in their farming facilities. One of the farms has created a teaching garden where local inhabitants can learn how to grow their own food in a sustainable way. This example makes it evident that urban farming goes beyond the scope of growing food and has a great community development potential, serving as an important "agent of change"[5].

The conducted survey shows that the majority of farms operate in a growing area of 350 m^2 or more with an average number of 31,5 employees; 17 percent of the surveyed farms operate on 50 to 75 m^2 with an average of 3 workers; and farms which have growing area ranging from 175 to 350 m^2 employ approximately 5 persons per farm. Those numbers suggest that the size of the farm directly correlates with the number of employed persons on the farm. However part-time contracts with working shifts can then be reflected in a larger number of workers as it is the case of one of the farms, with a growing area of 75 – 175 m^2 and 30 employees.

Figure 26: Social impact of urban farms, n=16



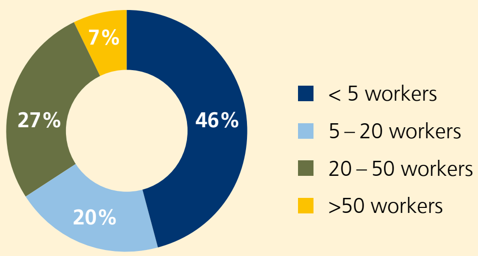


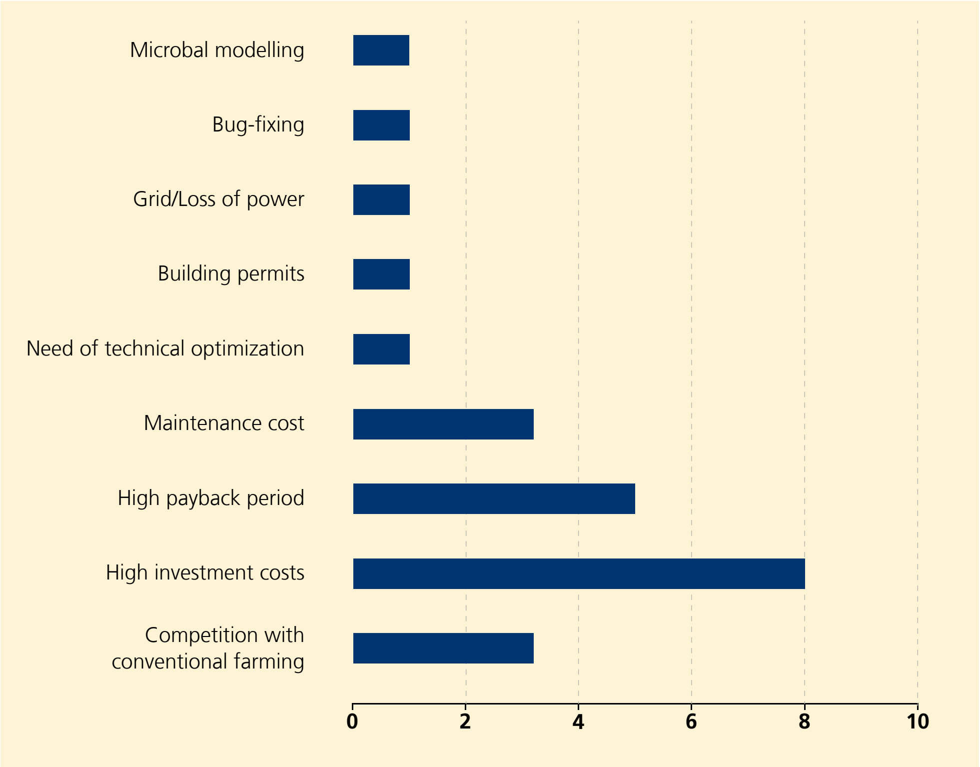
Figure 27: Number of workers, n=15

4.6 Challenges and opportunities

Most of the farmers see the elevated investment costs, the high maintenance costs and the long payback periods as one of the main challenges. They further agreed on the fact that the competition in the conventional farming market is high, as they cannot compete with the low market price of traditionally cultivated food products. Farmers mentioned that the available techniques need optimization, for instance technical problems with power grid and the loss of power/electricity. The applied technology should be able to guarantee the plants supply at all times and well-functioning pumps. The zoning and building permits have been mentioned as a further challenge, as well as the lack of governmental support. Farmers working in urban farming complain that there is not enough investment to increase consumer awareness of the positive effects of urban farming, such as on personal health and the environment. An additional issue might be the customer's acceptance for such a "high tech" food, resulting in challenges for public education, marketing and communication. In general, it is acknowledged that a higher environmental awareness among consumers would increase the demand for urban-farmed products despite their less competitive price compared to the production in the conventional agriculture. A further obstacle mentioned by the respondents is the lack of a clear business case that takes into consideration the specificities of an urban farm, identifies the right market and appropriate and efficient distribution channels.

Despite the above-mentioned challenges, around 61 percent of the surveyed farms identified urban farming as a profitable business and have plans to invest more in their projects. Some have plans to open new farms, not only in their region but also throughout the country and others are already in the implementation phase. Ongoing technological advancements (sensors, light sources, etc.) are seen as a key to increase yields and productivity rates of their facilities, which explains why respondents report an interest in further developing them. Farmers see the opportunity to use the existing facilities as showcases and incubators for new research and development in the area. One of the main opportunities identified is the increasing health awareness among citizens, the expanding demand for organic products and the growing familiarity with urban farming. As can be seen on the next graph, 81 percent of the respondents rated the sustainable future of urban farming as very promising (4,53 out of 5 points). Moreover the respondents rated urban farming for future food production and food security as very auspicious (4,61 out of 5 points). Results suggest that research should focus on the development of solutions to overcome the above-mentioned technical challenges and cities could create symbiotic systems, where surplus energy and recovered nutrients from city waste can be used. All of these measures would contribute to promote the sector and increase its competitiveness in the market.

Figure 28: Identified challenges of urban farming
n=16



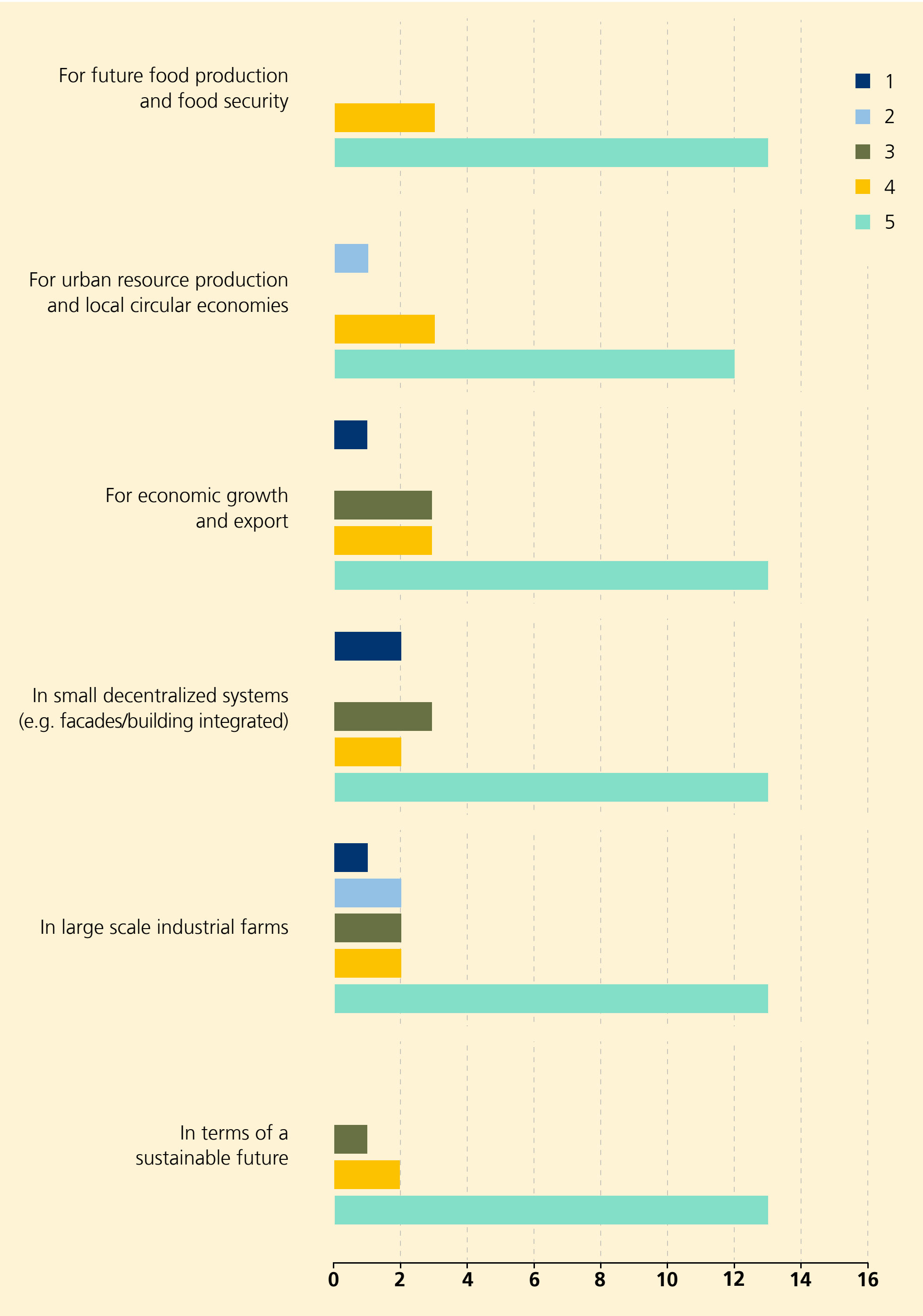


Figure 29: How promising do you think urban farming is?
n=16

1=not promising,
5=very promising

4.7 Trends

As mentioned above, the increasing acceptance of organic food is one of the determinant growth factors in the urban agricultural market. Fast-growing population, the rising health consciousness of consumers, and the increasing per capita income are driving the growth of the worldwide vertical agricultural market. There is a clear trend towards the consumption of healthy food, which constitute a major driver for urban farming since it promotes the production of organic food without pesticides, fertilizers and genetically modified organisms. Locally produced and organic food is considered as more nutritiously valuable than non-organic food that travelled a long way.

Changing lifestyles and the resulting increase of attention on a reliable crop production is driving farmers to focus on environmentally friendly production alternatives. Contrary to what has been stated by farmers in this survey, market researchs show that governments of some countries do actually promote the cultivation of organic food beyond traditional cultivation. All these factors are likely to reinforce the growth of modern agriculture and thus drive the growth of urban farming.[42]

Technology in general and the use of hardware components such as lighting, hydroponic components, climate control and sensors in the production of crops offer great opportunities for players in the urban agricultural market. The indoor farming industry is increasingly using IoT technologies as complex sensors that allow for a complete screening of the plants, which has an impact in the efficiency, but most important in the productivity of the farms[42]. Farmbots are used for automatic seeding, and are capable of planting 100 seeds in 1 minute, helping thus to reduce manual labor requirement and the overall costs. In general, urban farms working in 100 percent controlled environment have higher productivity and resource efficiency than others with less automation level. ICT platforms are used for monitoring the whole process. Further technologies are utilized for maintaining temperature, humidity, water flow, nutrients flow etc.

Additionally, LED lighting is increasingly used in the production of specialty crops grown in controlled environments. It is well known that lighting has played and will continue to play a decisive role in urban farming. The LED technology has replaced the use of direct sunlight. LED spectrums can be selected in accordance to the specific requirements. Different plants require different light spectra, and due to advancement in LED technologies it is possible to match the exact light frequency to the crop needs. This technology increases the productivity by reduced harvesting time compared to direct lights which are available only at day time. Due to LED technologies, farms can be setup in places with less sunlight, building's basements or even containers. Lighting companies, plant producers and academics are working together to advance the science and application of plant lighting, especially for high-quality specialty crops.

The market potential still depends on the design of an efficient and economical approach. It is only a matter of time before seed companies and farmers will be able to hybridize seeds that express characteristics capable of adapting to consistent and predictable environments, including special light spectra generated on vertical farms[43]. All this will help farmers to overcome the aforementioned challenges.

4.8 Market predictions

The question has always been whether the urban farming market has the prospect to keep developing or if it is a short term phenomenon. According to studies, the market for urban farming is growing rapidly. For instance the expected Compound Annual Growth Rate (CAGR) between 2016 and 2022 is of 24.8 percent, while the estimated market value is of US$ 5.80 billion by 2022[44]. In 2013 the market volume of vertical farming was € 326.5 million. A year later, in 2014, the market projection for 2020 was € 1.59 billion, while in 2015 it reached € 3.13 billion[45].

The market of urban farming appliances show similar tendencies. Reports highlight that that the market for grow lights was valued at US$ 2.50 billion in 2016 and is expected to reach US$ 5.11 billion by 2022, representing a CAGR increase of 11.86 percent from 2017 to 2022[46]. Global LED agricultural grow lights market volume was almost US$ 1 billion in 2015, and is projected to reach US$ 1.8 billion by 2021[47]. The precision farming market, which include among others bio-engineering, robotics and automation, imagery and sensors, big data, digitalization etc. is expected to reach US$ 10.23 billion by 2025. The projected CAGR is 14.2 percent[48].

Competition of the conventional agriculture market is high, due to the various less expensive alternative products available and to the still small number of market operators on the vertical agricultural market. However, the market is growing at a remarkable pace, which intensifies competition among market participants. Especially the Asia-Pacific Region and North America, followed by Europe, are showing a strong tendency to introduce solutions for urban farming as there is a constant increase in demand. Megacities and urban agglomerations located in these regions require local solutions for a reliable and fast supply of food. Hence, key market players are focusing on these regions specifically in order to expand their product offerings in the urban/vertical farming market[42].

5 MICROALGAE CULTIVATION

5.1 The microalgae cultivation landscape

Out of about 53 identified and addressed initiatives active in urban microalgae cultivation, 27 took part in the survey. Approximately 67 percent of the plants are already operating, 26 percent are in the implementation phase, and 7 percent are in the concept and research stage. The predominant purposes of the farms were direct sales, retail and trade, as well as research purposes. Other use cases included set-ups focusing on energy contracting, communal use, technical plant development, wastewater purification, as well as pure demonstration plants and technology showcases. When looking at the location of the farms, about 60 percent were located within or at city boundaries. Still, in most cases the distance to the consumer is rather high (over 30 km). On the other hand, over 30 percent of the initiatives were especially focusing on the local demand.

When looking at cultivated species and strains, most initiatives have a diversified cultivation portfolio with the most frequently mentioned species being Chlorella spp., Nannochloropsis spp., Haematococcus spp., and Spirulina spp. Main products were food additives, health and pharma products, as well as other high value chemicals. Moreover, several initiatives stressed their focus on research and technology development or on the generation of urban services instead of products, such as water purification or energetic savings. About one third of the respondents stated that biorefinery concepts and the generation of valuable side products and services were already in place. The yields of the plants ranged from 0.1 to 270 t/yr. Here a slight tendency towards implementing bigger plants with higher outputs could be recognized (Figure 30).

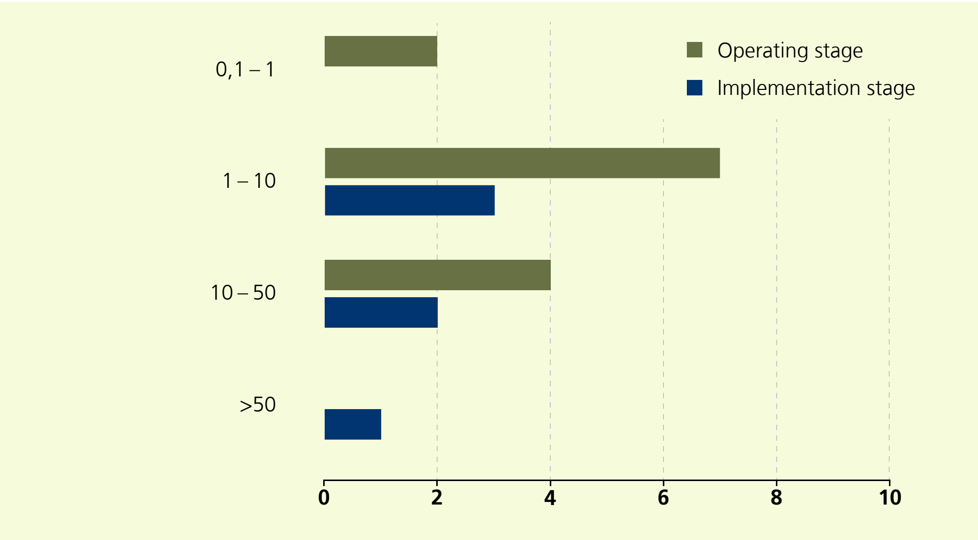


Figure 30: Yield in t/yr, n=23

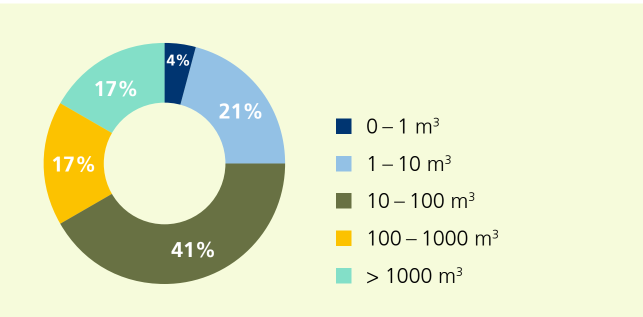


Figure 31: Scale, n=24

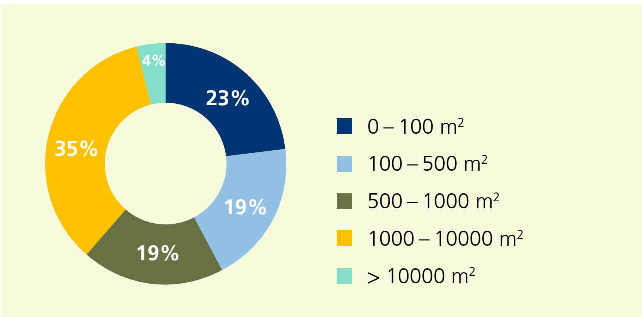


Figure 32: Area, n=26

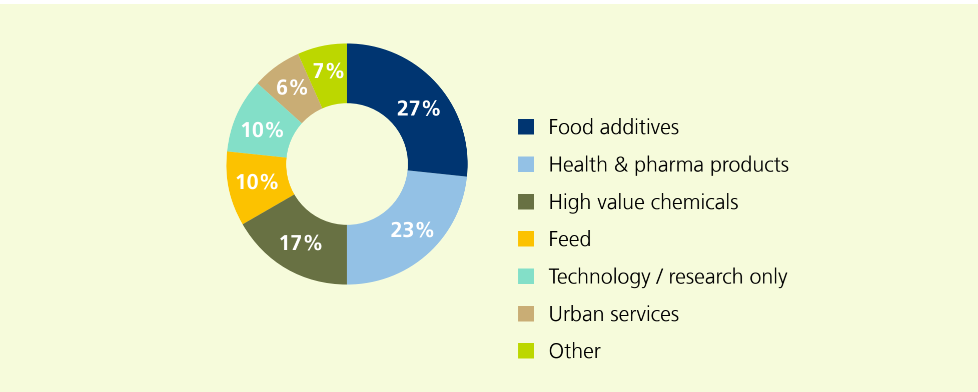


Figure 33: Main products, n=24

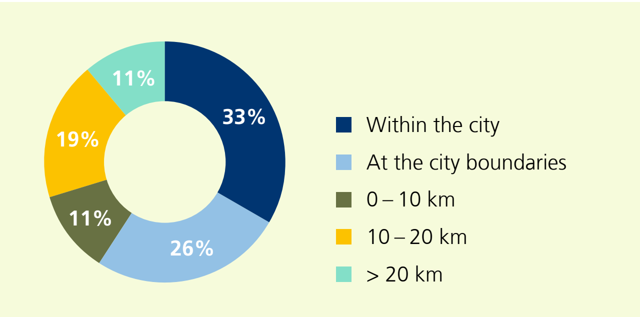


Figure 34: Distance to city, n=26

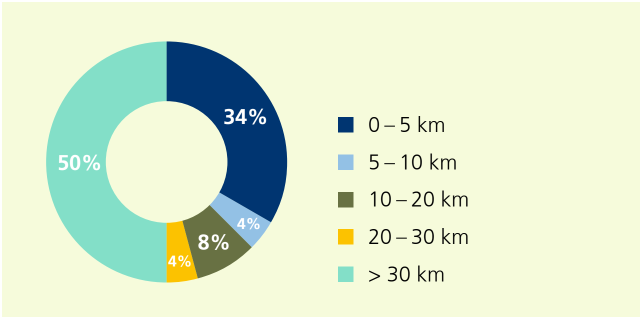


Figure 35: Distance to customer, n=23

5.2 Technology

The most frequently used cultivation technologies were tubular reactors, followed by own reactor designs. The average assumed life span was 15 years with no significant differences according to reactor types. Whilst most set-ups make use of natural sunlight, about 30 percent operate in controlled environments with artificial lighting. Additionally, 50 percent indicated that they have used or experimented with artificial lighting to optimize yields. The most common lighting technology used is LED (especially mixer and white). In addition, most initiatives use sensors and ICT for monitoring and automation processes (88 percent), as well as HVAC temperature control and ventilation systems (62 percent). The automated system functions include water recycling, fertilizing and CO_2 supply, pH control, mixing mechanisms and the compensation of weather-related temperature fluctuations. Next to technologies directly used for cultivation, many initiatives stated that energy generation and use was being addressed, e.g. via heat exchange or heat pumps. 15 percent of the participants indicated that they have on-site or integrated production of renewable energy at their plants, especially via photovoltaics and solar, biogas production or CHP installations.

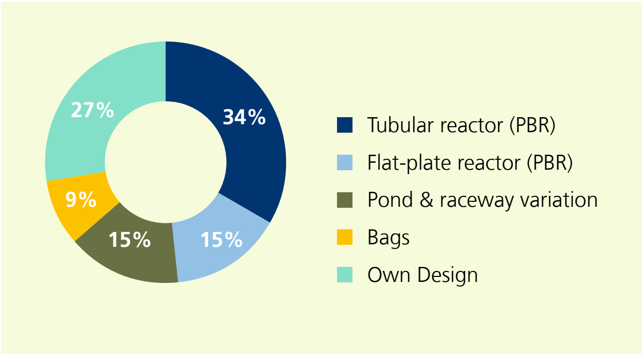


Figure 36: Cultivation technology, n=25

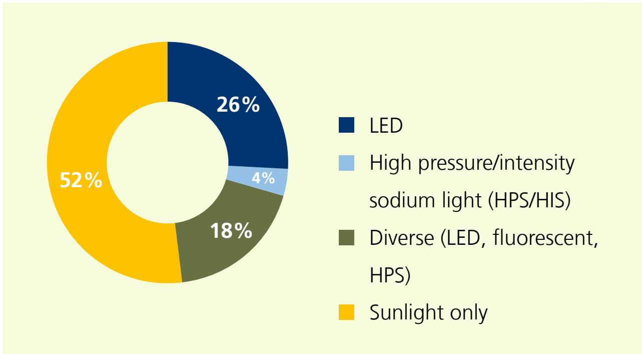


Figure 37: Lighting, n=26

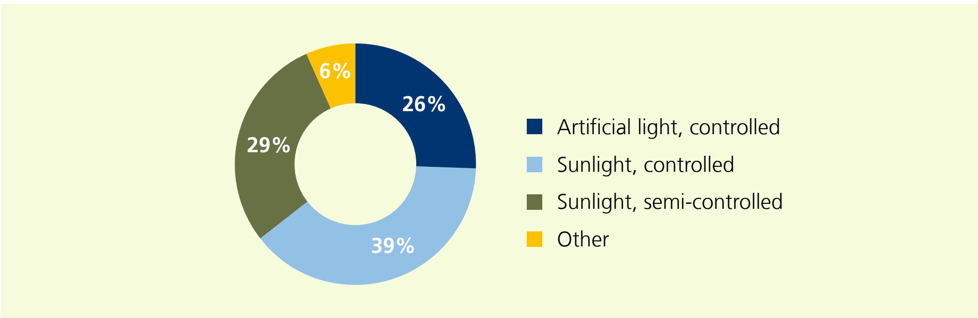


Figure 38: Farm environment, n=26

5.3 Environmental aspects

From an environmental point of view, energy and resource consumption, emissions and the use of pesticides were assessed. In most cases, data on these aspects were not monitored, not available, or confidential, leading to a rather weak data basis. Most notably, however, all initiatives reported that, similar to the indoor food farming, they are not using any pesticides in the cultivation process. When looking at electricity use per year, less than a third of the respondents provided actual numbers and the differences from plant to plant were enormous. In terms of electricity source, about 38 percent have almost no share of renewable energy in their mix, whereas about 33 percent of the farms are almost fully powered by renewable sources. Similarly, annual water consumption varied a lot from initiative to initiative with a range of 5 l to 150,000 m^3 per year. In almost all initiatives, fertilizers are added on a regular basis, including nitrogen, phosphorous and potassium as main elements. The amount of fertilizer added is often measured as medium concentration in the cultivation media or in relation to the dry biomass produced. One initiative also stated to be successfully using wastewater as feedstock with no need for extra fertilization. In terms of emissions generated, the majority of the respondents highlighted the amount of CO_2 consumed by the algae with no direct emissions but little ventilation losses from the reactor involved. However, when looking at the literature, most research and LCA studies show that high electricity use results in a rather high overall carbon and environmental footprints of algal biomass or products[30]. Here, an enhanced data and monitoring basis and more uniform assessment methods may help to identify and reduce environmental impacts in the future.

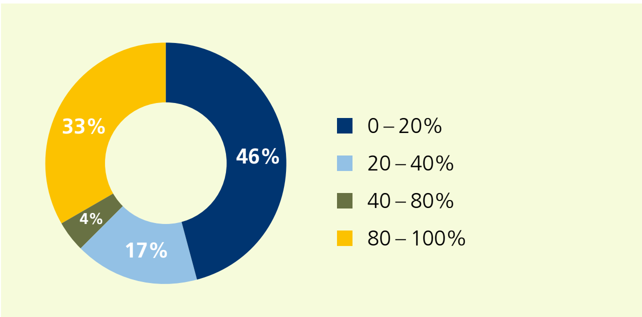


Figure 39: Share of renewable energy, n=23

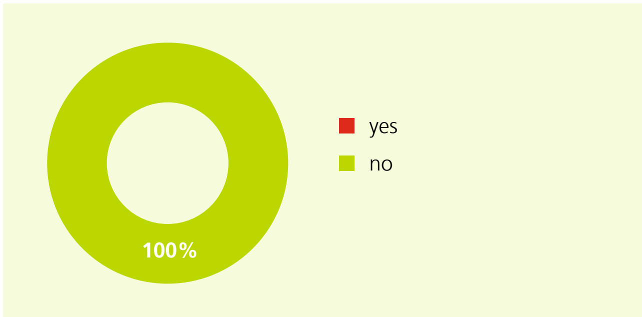


Figure 40: Use of pesticides, n=25

5.4 Economic aspects

The initial investment costs of the participating initiatives ranged between € 100,000 and € 20 million, depending on size and cultivation set-up. When looking at the investment models employed, over 50 percent of the respondents financed them out of private capital, whereas 24 percent used available government, public or research funding. Only a minority experimented with hybrid models such as public-private partnerships, project funding, crowdsourcing, etc. The indicated running costs could be estimated at 4 to 230 €/kg dry biomass. However, over half of the initiatives (especially those focused on research purposes) stated that costs were rather variable or not quantifiable. Likewise, most respondents stated that revenues and received benefits were quite hard to estimate (and some explicitly indicated to be operating non-profit oriented). When looking at the received answers, annual benefits were higher than running costs in 4 cases, whilst costs exceeded the benefits in 3 cases. Overall, profitability is one of the main challenges initiatives are currently dealing with, so access to investment capital and alternative financing strategies will be of major interest in this industry.

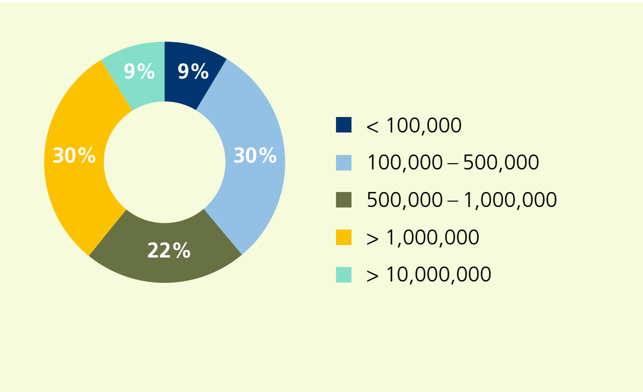


Figure 41: Initial investment (€), n=23

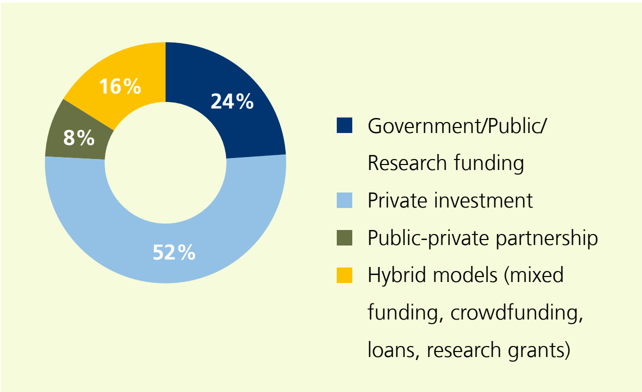
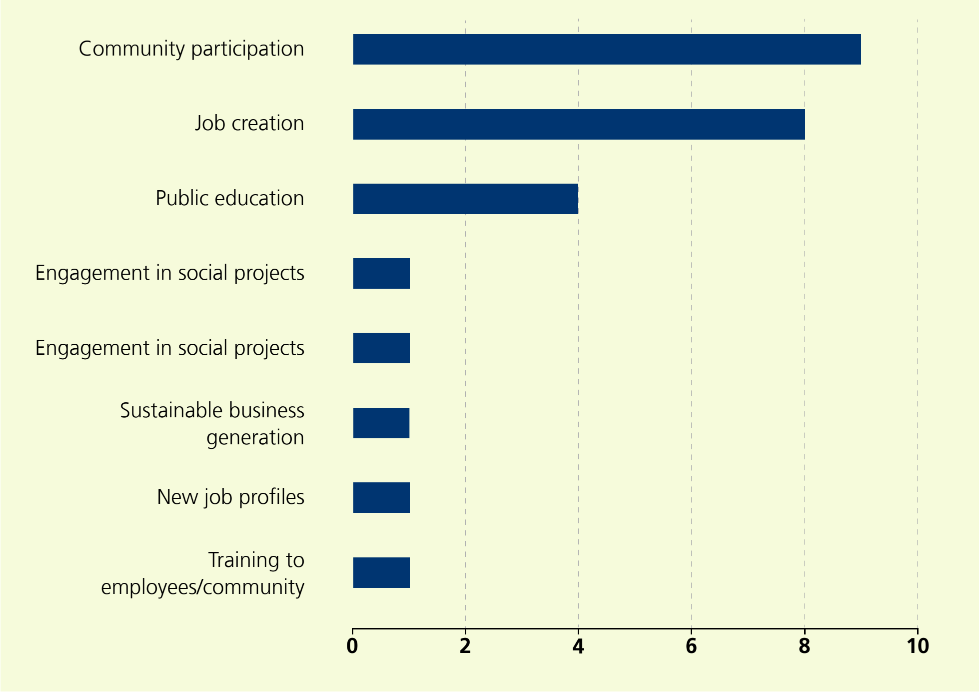


Figure 42: Investment model, n=24

5.5 Social aspects

When looking at the social aspects, most initiatives highlighted their contribution to job creation and in providing training to employees and the community. Current employment structures varied between 1 to 50 employees, depending on plant size. In general, over 65 percent of the initiatives employed 3 to 10 employees with differing profiles (e. g. technicians, managers, biologists, researchers). Other social impacts included community participation, creation of sustainable businesses and new job profiles. It was pointed out that in the emerging area of microalgae cultivation the cooperation of various disciplines and interdisciplinary education profiles play a very important role. Furthermore, direct engagement in social projects, engagement with public and university education, as well as improvement of the living environment through provision of clean water and oxygen, were named as social impacts.

Figure 43: Social impacts, n=22



5.6 Challenges and opportunities

When looking at the challenges that existing initiatives are facing, the most frequently named issues were high initial investments and high costs for development, operation and maintenance. Secondly, many initiatives stated that the prevailing unawareness and lack of knowledge concerning microalgae as potential food product and resource option is inhibiting and slowing down market uptake, as well as leading to low customer acceptance and scepticism ("the green slime obstacle"). It was mentioned that the cultural perception has to shift from generalizing microorganisms as a dangerous nuisance to recognizing their potential as future source of healthy food and resource. Furthermore, the difficulty of distinguishing between qualitatively high and inferior microalgae products and the emergence of "story tellers" that sell cheap and low quality products poses a challenge to customer trust and increases price competition. Thirdly, legal frameworks and regulations were named as inhibiting factors, especially referring to the Novel Food Regulation in Europe. Particularly smaller firms do not have the means to finance and meet the requirements of the necessary authorization processes and there is no lobby for the respective industry branch to fuel further development. The need for research and development was also stressed in terms of increasing productivity (which is still one of the imiting factors when looking at production capacity) as well as in contamination issues and quality control. Other factors mentioned, include the improvement of lighting technologies, the need for interdisciplinary-trained staff, increased downstream processing efficiency, upscaling issues, as well as the generally low prices of conventional food products. All mentioned challenges are in line with those identified in existing literature[29, 30, 49].

On the other side, several major opportunities indicate how challenges could be overcome and why microalgae production is a field of high potential: Generally, an increasing interest and level of knowledge is perceived by most of the respondents. This goes hand in hand with the ongoing R&D efforts to find higher yielding algae species and improve cultivation technologies and reactor designs which bears high potentials for future improvement. A main driver behind these efforts is the diversity of (high-value) products and components that can be obtained in microalgae production (such as astaxanthin, poly-unsaturated fatty acids, protein, lipids and various vitamins[27].

Within the urban context, the proximity to customers could present a major strategic advantage, especially with more and more customers deliberately choosing and preferring locally produced goods. Furthermore, about a third of the participating initiatives developed building-integrated solutions or made use of reutilized infrastructure or unused rooftop spaces. From a technical point of view, the integration of algae cultivation systems in smart building technologies and smart city concepts is evaluated as good opportunity. Artificially illuminated small scale plants could be an option for urban farmers to clean fish wastewater and produce certain valuable ingredients. Integration in aquaculture and other local food concepts are perceived as very promising. On the environmental and social side, especially the cut on pesticide use, high areal yields, and job creation in various discipline fields can be summarized as major opportunities in this field.

The initiative of improving the urban space and generating multiple benefits was also taken by companies developing innovative solutions that not only focus on production, such as the Urban Algae Folly, which "hosts a total of 1200 l of living cultures; absorbs 1500 g of CO_2 per day and produces 1000 g of O_2. Its ability to absorb CO_2 is equivalent to that of 24 large trees which is the amount of trees per year to cover the O_2 needs of a family. Its yearly protein production is 300 kg, which is equivalent to the protein meat of a cow. It can produce 500 g of oil per day from which approximately 75 g of biofuel can be produced, releasing up to 30 MJ of energy or 7.7 KWh. That is enough to power a British home. The Folly also shades and improve the urban microclimate and the related public realm" (quote from the questionnaire).

5.7 Trends

In general, the algae cultivation field is characterized by a high use of technology, which often leads to high energy demands. Here, the integration of renewable energy is one of the opportunities most initiatives are working and researching on. Furthermore, even though microalgae cultivation is not primarily looked at as a local supply-oriented system but rather influenced by global trade patterns and thus longer distances to the costumer, many ideas and thoughts exist on how to use microalgae to improve urban surroundings.

Figure 44 shows how promising the survey participants think microalgae is for future development. Most initiatives agree that this new farming option might be beneficial for an overall sustainable development. In terms of application areas, a tendency towards higher-priced goods (food over fuel) could be perceived. The urban context was valued as rather promising. Some disagreement could be seen in the discussion on small-scale and decentralized versus large-scale cultivation plants. In general, initiatives that are operating in small farms favour small-scale solutions whilst bigger plants favour large-scale solutions, which indicates that both options are seen by their respective investors as rather promising. Still, the majority of respondents tends towards bigger industrial farms, citing economies of scale as main argument.

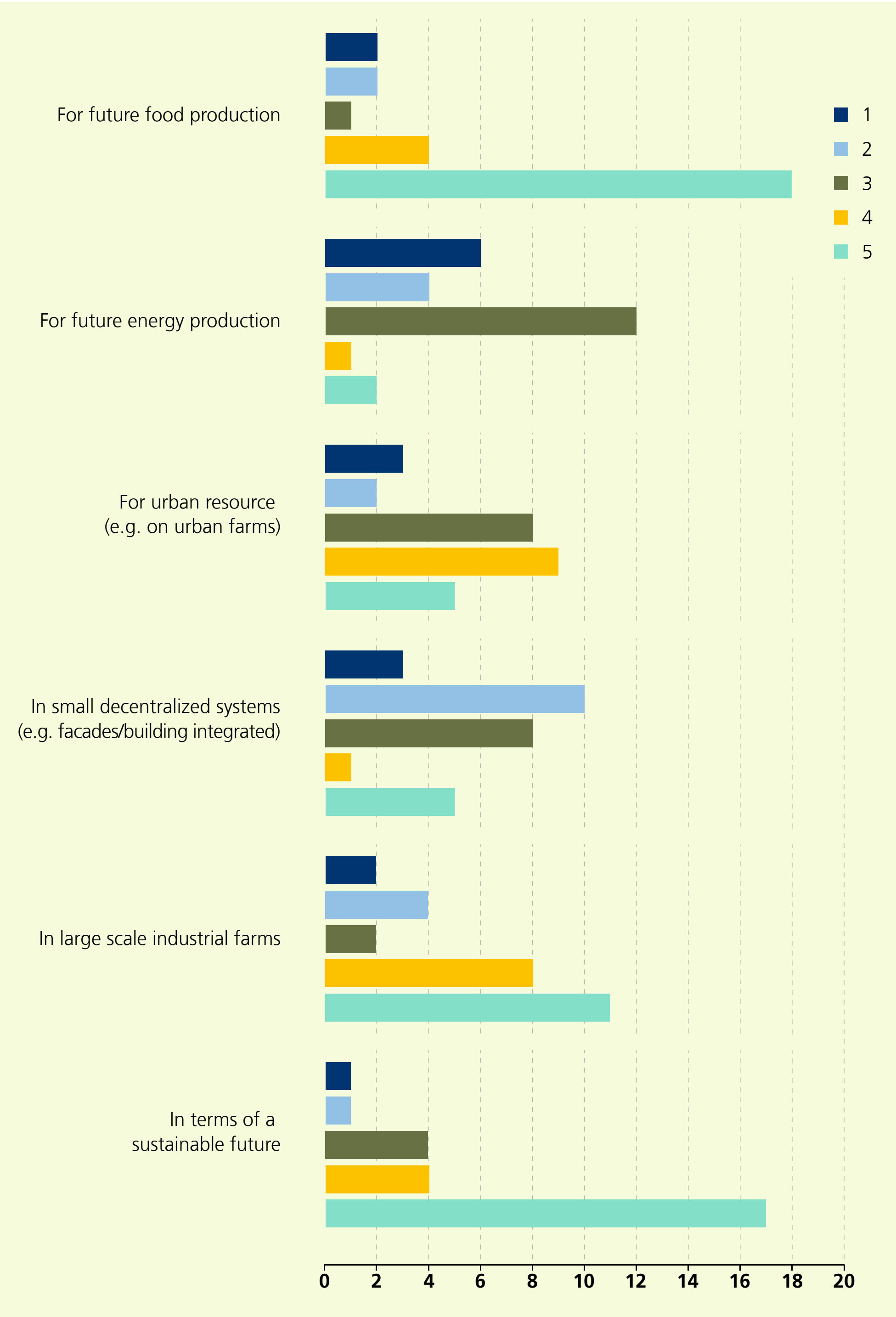
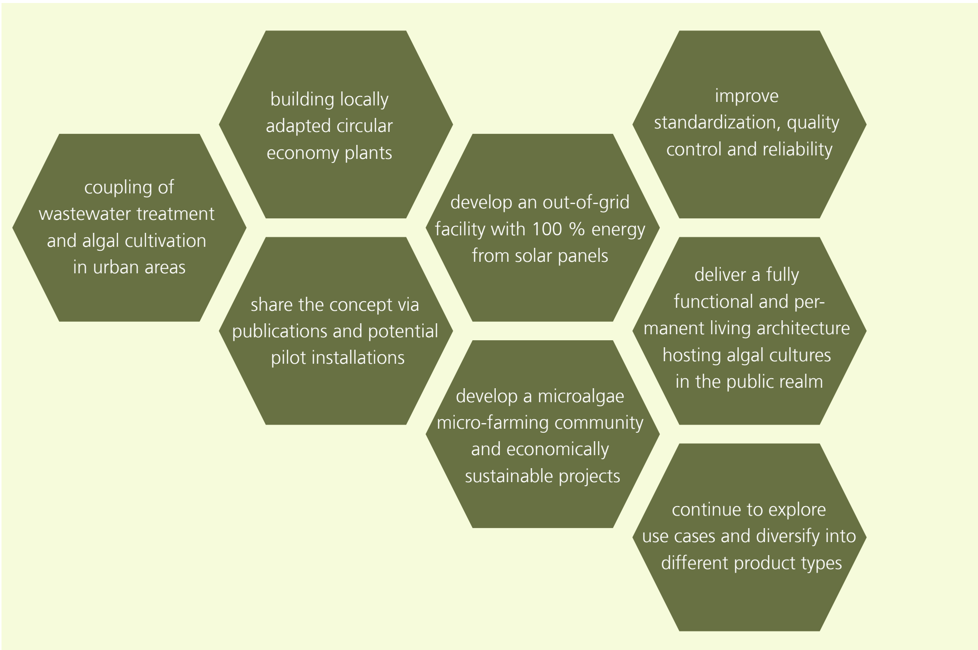


Figure 44: Evaluation of the microalgae cultivation potential, n=26

1=low potential
5=high potential

When looking at the future plans of survey participants, most indicated that they expect to grow and expand within the microalgae market, mostly via scaling up or entering new use case areas / diversifying. This trend was also identified among initiatives stating that they were increasing research and development efforts, especially in improving reactor technology, increasing productivity, lowering costs, decreasing contamination risks and optimizing / integrating downstream processing. Only one participant stated to be leaving the business. Further ideas and plans are outlined in figure 45:

Figure 45: Future plans and ideas of current microalgae initiatives in the urban context



5.8 Market predictions

Despite the various application fields and technical approaches, current production volumes are still rather low (about 9,000 tons dry matter in 2011)[49]. However, trends indicate fast-increasing growth rates and a screening of prevailing market studies suggests positive outlooks for the future:

In 2016, two different market research institutes, US-based Transparency Market Research (TMR) and UK-based Credence Research released growth forecasts for the algae market. Both predict a CAGR of over 5 percent in terms of volume between 2016 and 2024. A comparison between these reports and former studies asserts that between 2016 to 2022, 2016 to 2023 and 2016 to 2024 the CAGR is increasing successively at a rate of 5.0 percent, 5.2 percent and 5.32 percent[50–52]. In terms of volume, the algae market is expected to reach 27,552.11 tons by 2024[50].

In terms of value, product prices are comparatively high starting at approximately 30 €/kg[53, 54]. According to TMR, global algae market was valued at US$ 608 million in 2015 and is projected to reach US$ 1143 million by 2024 CAGR of 7.39 percent. The algae product market is expected to reach US$ 44.7 billion by 2013[51]. The most prominent application fields are shortly described in the paragraphs below.

It has been estimated that the largest share of the algae markets revenue stems from pharmaceutical applications and protein sales. While the former held a larger share in this segment, it will decline over the coming years and protein will increase in importance[48]. Algae are strongly present on the food additive and health supplement market. Microalgae protein for food and feed applications has been classified as advanced development, meaning a “product (or) innovation for which there are multiple location field trials and more than one proof of concept”. Still, more research and development is needed to bring it to the market[49].

In terms of volume, about 30 percent of the microalgae production is estimated to be used for animal feed. Most importantly, this refers to its use in aquaculture as microalgae is a natural food source to most aquatic organisms. However, additions to poultry or pig and, to a lesser extent, ruminant feed are also being considered and researched on[27, 54, 55]. Microalgae are also used to refine artificial animal diets since those often lack pigment sources. As an example, algae are used as natural astaxanthin source which helps in achieving the typical coloration of salmon, trout or egg yolk[56].

Another market is the cosmetics and high-value chemicals sector. Especially Spirulina and Chlorella are being used in some face and skin care products which promise anti-aging, refreshing, regenerative or sun protection functions. In some cases, where valuable molecules are present in sufficiently high amounts, their extraction is being targeted. Some obtained high value chemicals such as fatty acids (especially PUFAs), pigments (especially carotenoids) and phycobiliproteins are already being marketed as additives, food colorants, natural dyes or pharmaceuticals[57].

Due to rising concerns in the energy sector, related to fossil fuel depletion, rising oil prices and global warming, microalgae have also come into discussion as resource for biofuel production (especially biodiesel, -ethanol, and -methane). However, the required energy inputs and costs of production processes have to significantly decrease to make microalgae biofuels an economically viable and sustainable alternative[58, 59.] Especially in the aviation industry, a high CAGR of 6.95 percent from 2016 to 2024 is predicted[50].

6 CONCLUSIONS

With the rapid urbanization and the effects of climate change becoming more and more pressing on natural resources, the development of sustainable and innovative urban food and resource production approaches such as vertical farming or microalgae technology become suitable and promising options for future development. If energy consumption issues can be tackled and renewable energy integration is enhanced, the implementation of indoor farming projects can considerably contribute to climate change adaptation and mitigation by reducing the transport ways, the amount of packaging and the pressure on land. Furthermore, the absence of pesticides in their production reduces the fossil fuel use, with positive outcomes for public health and soil degradation. Moreover, it represents a very attractive option for the use and design of public spaces in the city. This is especially valid in future scenarios, for example, in which autonomous driving becomes a common practice, parking spaces are freed for other uses.

Urban farming is undoubtedly an emerging market, especially in developed countries, suffering from continued urban sprawl and loss of peri-urban agricultural land. Rather than being a short-term phenomenon, market studies indicate that urban farming has the prospect of further developing and constituting a promising market. A great market potential is especially perceived for locally adapted biorefinery strategies, the integration of innovative farming concepts in new and renovated buildings, the use of roof tops, the production of high value products (e. g. pharmaceuticals, food additives, super foods, protein etc.), and the development of sector-related technologies such as energy-efficient LEDs for the specific products.

Nevertheless, governmental programs are missing the opportunity to promote these initiatives, increase awareness and drive the transition to urban farming. Challenges such as inadequate existing rules (or lack of appropriate rules designed to foster the development of this sector) and legal issues (e. g. organic labelling and European Novel Food Regulations) need to be tackled, and more research is needed to increase efficiency, reduce energy consumption and thus ensure the economic and environmental viability of such projects. Furthermore, an enhanced data and monitoring basis on resource flows, life cycle considerations, and more uniform assessment methods may help to identify hotspots and implement continuous improvement strategies. To overcome these hurdles and push further development, interdisciplinary education and qualification profiles will be needed.

6 CONCLUSIONS

In terms of the geographical location and by considering the assessed criteria, it is likely that the wider application of urban farming will take place in small and heavily urbanized countries with limited surrounding farming land such as Japan and Singapore. Vertical farming is also attractive where demand for food is high in countries suffering from severe pollution and soil depletion, as in some parts of China and India.

Considering that by 2050, more than 66 percent of the world's population will live in cities, and that soil erosion and scarcity will limit the possibilities available to feed all people, more resources and investment must flow into indoor/vertical farming and food production. Furthermore, alternative financing strategies should be developed and tested. This will help to better prepare for the near future and ensure the transition towards a more sustainable, circular and future-oriented urban planning.

RECOMMENDATIONS

As urban farming is a promising market, further research and development is necessary to spur innovative technologies and apply locally adapted closed-loop methods to foster greener cities. Supporting regulations need to be adapted or created. This should go hand in hand not only with financial incentives to promote these ventures but also environmental awareness among the citizens.

The impacts of indoor farming vs traditional agriculture in terms of energy consumption, CO_2 balance, transport, impacts on health, positive side effects regarding air quality, reduced heat island effect, and others, should be quantified and evaluated at local scale and on a case by case basis.

Likewise, quantified information on indirect benefits such as increased awareness, the enhancement of community interaction and empowerment would help to promote urban farming, resulting in greater funding accessibility, governmental support and willingness to pay from the final customers (multi-benefit assessments).

Additional research is needed on the questions of how consumers accept integrated urban farming solutions and new products, what changes at district level have to be done, and how energy consumption (especially for lighting) can be reduced and compensated by integrated system solutions.

As mentioned above, urban farms (CEA) are still struggling with efficiency in lighting systems. Product-specific technologies have to be developed, especially for top products. Here, lighting companies could be a game-changer in the urban farming field. Specific light spectra for different plant and algae species and reduction of electricity charges are two main areas to work on. Mixed LED lighting is the favoured product by various urban farms, as it gives flexibility to grow more than one type of plant. Further opportunities can be created through LED technology innovations, enabling higher control over plant growth, greater development and concentration of phytonutrients or reduction of investment and operation costs.

Cooperation between technology providers (lighting, sensoring, water recycling, etc.), producers (different farms and initiatives), sellers (supermarket chains and retailers), restaurant chains, and academia should be established to promote research and implementation. The aim is to advance the science and application of indoor farming, especially for high value components and crops.

Additional insights are needed regarding innovative ways for the distribution and marketing of the products. Solutions such as automated food machines are a possibility, but more options should be investigated and piloted. An ICT-based platform (mobile app) can help to develop a network of urban farms, technology providers, food sellers / users and delivery providers.

More guidance needs to be available with regards to vertical farming in general. An initial assessment when considering an investment of this kind could be very helpful to support the decision making process. In this sense, an assessment framework could be developed based on the information available from existing reference projects.

Finally, modern urban planning should consider the presented trends, include green elements and foster the integration of indoor farms in buildings. Cities should promote locally adapted circular economy models and make the integration of urban farming as a component in buildings a common practice. This can become a key component in creating zero emission neighbourhoods and efficient closed systems that include water re-usage, renewable energies, waste-to-energy models and local food and resource production.

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CONTACTED FARMS INDOOR PLANT CULTIVATION

Company	Farm Name	Country	City	Website
AeroFarms LLC	AeroFarms	USA	Newark	http://aerofarms.com/
Affinor Growers Inc.	Abbotsford site	Canada	Abbotsford	https://www.affinorgrowers.com/
Bowery Farming	Kearny Farming	USA	Kearny	http://boweryfarming.com/
Bright Agrotech	Localize Farms	USA	Minneapolis	http://www.zipgrow.com/
EBF GmbH	Aquaponisches Solares Gewächshaus Neuenburg	Germany	Neuenburg	http://ebf-gmbh.de/
ECF Farmsystems GmbH	ECF Farm	Germany	Berlin	http://www.ecf-farm.de/
Fraunhofer IME	Verti Pharm	Germany	Aachen	https://www.ime.fraunhofer.de/
Freight Farms	Baltimore Maryland Urban Pastoral	USA	Baltimore	https://www.freightfarms.com/
Fuji Farm	Philips, Innovatus	Japan	Shizouka	http://www.lighting.philips.com/cases/cases/horticulture/innovatus-inc
Fujitsu	Aizu-Wakamatsu plant	Japan	Aizu-Wakamatsu	http://www.fujitsu.com/global/about/corporate/locations/worldlocation/japan/about_Aizu.html
G2Gi - Indoor Farming Solutions, Lda.	Grow to Green	Portugal	Castelo Branco	http://www.growtogreen.com/
Gotham Greens (with Nexus technology)	Greenpoint greenhouse	USA	New York	http://gothamgreens.com/
Green Camel	Green Camel ; Cobbitty Farm	Australia	Cobbitty	http://www.greencamel.com.au/farms/farms.html
Green Sense Farms LLC.	Green Sense	USA	Portage	https://www.greensensefarms.com/
Growing Underground	Growing Underground	UK	Clapham	http://growing-underground.com/
GrowUp Urban Farms	Unit 84	UK	London	https://www.growup.org.uk/
Infarm Indoor Urban Farming GmbH	Infarm	Germany	Berlin	https://infarm.de/
Interfaith Neighbors	Kula Farm	USA	Asbury Park, NJ	http://www.interfaithneighbors.org/kula-urban-farm/
LA Urban Farms	USC	USA	Santa Monica	http://laurbanfarms.com/
Local Roots Farms	Local Roots Farms	USA	Vernon	https://www.localrootsfarms.com/
Lufa Farms Inc. Groupe Montoni KUBO	Laval Farm	Canada	Montreal	http://corpo.lufa.com/en/our-farms.html
Manticore IT GmbH	aponix.eu - Erdloser Versuchsanbau	Germany	Heidelberg	https://www.aponix.eu/
Mirai Co. Ltd.	Mirai solution	Japan	Miyagi	http://miraigroup.jp/

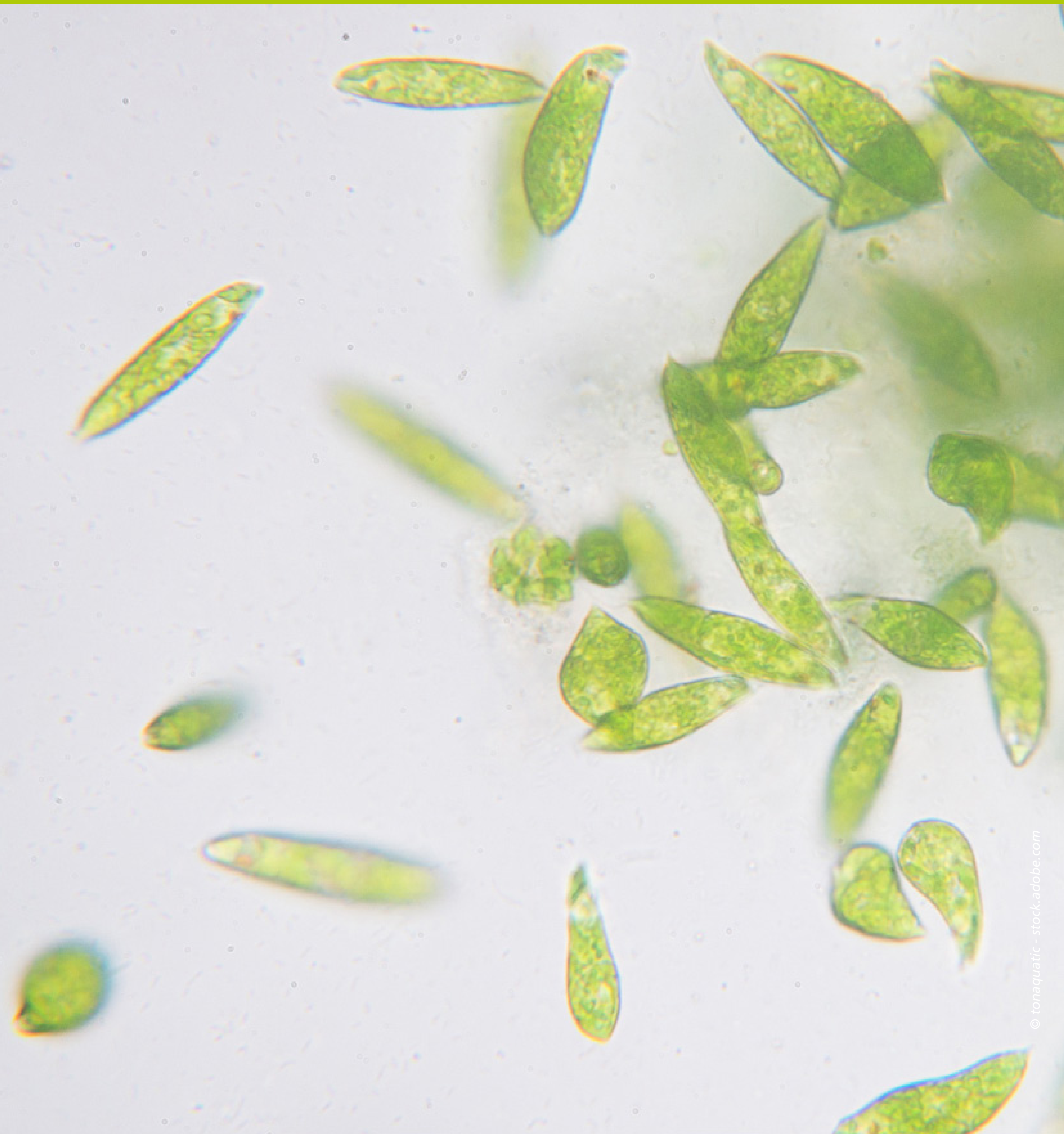
Company	Farm Name	Country	City	Website
Modular Farms	Modular Farms	Canada	Brampton	http://modularfarms.co/
Panasonic Factory Solutions Asia Pacific	Panasonic In-Door Farm	Singapore	Singapore	http://www.pfsap.panasonic.com.sg/
Pegasus Agriculture	A-Frame Oman Farm	Oman	Muscat	http://pegasusagriculturegroup.com/
Pentair	Urban Organics Hamm's Brewery Project	USA	Minnesota	https://pentairaes.com/urban-far-ming.html
Philips Horticulture LED Solutions	GrowWise	Netherlands	Eindhoven	http://www.lighting.philips.com/main/products/horticulture/press-re-leases/growwise-center
Plantagon International AB	World Food Building, Unit One	Sweden	Linköping	http://www.plantagon.com/
PlantLab	PlantLab	Netherlands	s-Hertogenbosch	https://www.plantlab.nl/
Sky Urban Solutions Holding Ltd.	Sky Urban	Singapore	Singapore	https://www.skygreens.com/
Sostenipra. Universitat Autònoma de Barcelona	Fertilecity	Spain	Cerdanyola del Vallès	http://fertilecity.com/
Spread Co., Ltd.	Kameoka Plant (1st farm) Techno Farm Keihanna (2nd farm)	Japan	Kyoto	http://spread.co.jp/en/
Sustenir Agriculture Pte Ltd	Admiralty	Singapore	Singapore	http://www.susteniragriculture.com/
Toshiba	Yokosuka plant	Japan	Yokosuka	http://www.toshiba.com/tai/
Urban Farmers	Urban Farmers	Netherland	Den Haag	https://urbanfarmers.nl/
Vertical Crop Consultants	The Farmery	USA	Durham	http://www.thefarmery.com/
Vertical Harvest Hydroponics	Urban Greens	USA	Anchorage	https://vhhydroponics.com/
Verticrop	Verticrop	Canada	Vancouver BC	http://www.verticrop.com/

REFERENCES

CONTACTED FARMS MICROALGAE CULTIVATION

Company/Farm name	Country	City	Website
A4F Secil/Lisbon Experimental unit	Portugal	Leiria, Lisbon	https://www.a4f.pt/
Alga Pangea	Austria	Güssing	http://www.alga-pangea.de/
Algae Biotech	The Netherlands	GS Weesp	www.algaebiotech.nl
Algae to Omega Holdings, Inc.	USA	Oakland Park, Florida	http://algae2omega.com/
Algaecytes	UK	Kent	http://algaecytes.com/
Algaedynamics	Canada	Mississauga	http://www.algaedynamics.com/
Algaenergy	Spain	Madrid	http://www.algaenergy.es/
AlgaeTech	USA	Cumming	http://algaetec.com.au/
Algalif	Iceland	Bogatröð	http://www.algalif.com/
AlgaTechnologies	Israel	Kibbutz	https://www.algatech.com/
Algatek	Spain	Asturias	http://algatek.co.uk/
Algenol	USA	Fortmeyers, Florida	http://algenol.com/
Archimede Ricerche Srl	Italy	Camporosso	http://www.archimedericerche.com/
ARUP	Germany	Hamburg	https://www.arup.com/
AstaReal AB	Gustavsberg	Sweden	http://www.astareal.se/
Astaxa	Germany	Ritschenhausen	http://www.algae-biotech.com/
Biopharmia	Norway	Oslo	http://www.biopharmia.no/
BioVorn (formerly known as ARAgreen)	UK	Gloucestershire	http://www.bath.ac.uk/
Blue Biotech	Germany	Kaltenkirchen	http://www.bluebiotech.de/
Culture BioSystems	USA	Coral Gables	http://www.culturebiosystems.com/
Ecoduna / Esperella	Austria	Bruck an der Leitha	http://www.ecoduna.com/
Ecologic Studio (London)/Urban Algae Folly	Italy	Milan expo	http://www.carloratti.com/
EnerGaia/Spirulina Rooftops Farms	Thailand	Bangkok	http://energaia.com/
Ennesys	France	Nanterre	http://www.ennesys.com/
Evergreen-Food GmbH	Germany	Vechta	https://www.evergreen-food.de/
F&M Photosynthetica & Microbiologica S.r.l.	Italy	Firenze	http://www.femonline.it/
Fraunhofer IGB Fraunhofer CBP / Subitec GmbH	Germany	Leuna	https://subitec.com/en
GICON -Grossmann IngenieurConsult, GmbH/ Biosolarzentrum	Germany	Dresden	http://www.gicon.de/
Jie Zhang & Tyler Stevermer/Algaevator	USA	Cambridge	http://www.jie-zhang.com/
LGem	The Netherlands	The Hague	http://lgem.nl/
LusoAmoreiras, S.A.	Portugal	Lisbon	http://BIOFAT.PT
Mial	Germany	Bad Zwischenahn	https://mial.eu/
MINT/EUREF Campus Berlin	Germany	Berlin	http://www.mint-engineering.de/

Company/Farm name	Country	City	Website
NANOFARM, S.A.	Portugal	Lisbon	https://research.ce.cmu.edu/nano-farm/
Necton	Portugal	Olhão	http://phytobloom.com/
Neste	Australia	Brisbane	https://www.neste.com/
Omega Green	The Netherlands	Eemshaven	http://omegagreen.nl/
OneWater Inc.	USA	Indianapolis	http://www.algaewheel.com/
Photonz	New Zealand	Auckland	http://www.photonzcorp.com/
Phycotech	USA	St. Joseph	http://www.algaephotobioreactor.com/
Phytolutions	Germany	Bremen	http://www.phytolutions.de/
Proviron	Belgium	Nevele	http://www.proviron.com/
Roquette Klötze GmbH & Co. KG	Germany	Klötze	http://www.algomed.de/
Sabrtech	Canada	Herring Cove	http://www.sabrtech.ca/
Solix	USA	Colorado	http://www.solixalgredients.com/
Spirulina Mexicana	Mexico	San Miguel de Allende	http://spirulinaviva.org/
SSC GmbH/BIQ Das Algenhaus	Germany	Hamburg	http://www.biq-wilhelmsburg.de/
Technological Platform for Microalgae Experimentation/Algaenergy S.A.	Spain	Madrid	http://www.algaenergy.es/en/research/
The Cloud Collective, Amsterdam, NL	The Netherlands	Rotterdam	http://www.thecloudcollective.org/en
Tomalge	Belgium	Nevele	http://www.tomalgae.com/
Wushenzhao Ecologica Development Co., Ltd.	China	Ordos City	http://www.nmshengtai.cn/
Xanthella/ASLEE	Scotland	Oban	http://www.xanthella.co.uk/
Zivo Bioscience	USA	Keego Harbor	http://www.zivobioscience.com/



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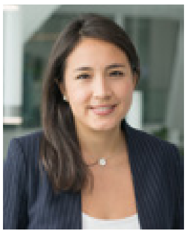

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