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Urban agriculture: boon or bust?

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URBAN AGRICULTURE: BOON OR BUST?

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Heads of lettuce in Taiwanese controlled-environment farm YesHealth iFarm - ©Association for Vertical Farming

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Agriculture needs a revolution to be able to feed 9 billion people by 2050 within planetary boundaries. Urban agriculture (UA) is heralded as a solution, but can it deliver? To answer this question, different types of UA need to be discussed with their distinct advantages and limitations, particularly differentiating conventional open-air extensive farming from high-yielding Controlled Environment Farming (CEF). The former is too low yielding to support food production in a meaningful way but can enhance community, provide education services, psychological value and improve local environmental conditions – particularly if applied on urban rooftops. This kind of farming is rarely commercially viable but offers significant societal value. Business models could range from being offered as public services to being cross-subsidized through attached commercial operations. Distinct from this, some forms of CEF may provide substantial contributions to food outputs in years to come, as CEF can be expected to grow significantly, driven by inherent efficiency advantages over current food value chains. However, it tends to be highly capital- and knowledge-intensive and will likely develop at the fringes of cities due to economic considerations. As such, it is a form of peri-urban agriculture (PUA) and could become part of a peri-urban circular economy for food.

INTRODUCTION

The green revolution of the 1950s has been one of the greatest successes of humanity: immense gains in agricultural yields have been achieved and it is estimated that half of the world's population is alive as a direct consequence of synthetic fertilizers[1]. Adding the invention of pesticides and antibiotics also allowed us to produce food with a level of output productivity and reliability never previously imagined. Still, by 2050, humanity will need to feed 9 to 10 billion people. This will require expanding food production by about 50% compared to today's levels[2].

However, the global food system is far from "sustainable" and further expanding food production becomes increasingly challenging: few productivity gains are being realized while pressure on fertile land is increasing. We are indeed "mining soil" – at a rate of an estimated 25 billion metric tons per year globally, and since topsoil regenerates only slowly, it is essentially a fossil resource and possibly the only one we cannot substitute. Moreover, climate change is expected to negatively impact yields of key crops such as wheat and rice through warmer climates and add to problems of soil erosion. It may also exacerbate eutrophication, which is already wreaking havoc in ecosystems around the world.

1 Our World in Data (2017). How many people does synthetic fertilizer feed? https://ourworldindata.org/how-many-people-does-synthetic-fertilizer-feed, Accessed April 18, 2019

2 Food and Agriculture Organization of the United Nations (2018). *The future of food and agriculture. Alternative pathways to 2050.* Rome.

In this context, urban agriculture (UA) has been receiving lots of attention in recent years, and is often heralded as a key building block in a sustainable food future. Its proponents highlight benefits of short transportation distances, visions of integrated living and food systems, and community-building opportunities. Additionally, drastically more efficient production and fantastically high yields seem possible. Added to this, claims of opportunities for integrated production and waste disposal solutions, or production of custom-designed foods, are often heard. Could UA offer an answer to all our problems?

CONTEXT: THE CHALLENGE OF FEEDING THE WORLD, A BITE TOO BIG TO CHEW?

Today agriculture uses 70% of all freshwater and 50% of all fertile land and causes around 25% of all man-made CO_2 emissions. It is also linked to catastrophic biodiversity loss especially through land conversion and pesticides. As a result, humanity has extinguished 60% of global species over the last 50 years alone. Agriculture thus contributes substantially to the transgression of at least four of the nine planetary boundaries – those criteria that define a safe operating space for human existence – defined by the Stockholm Resilience Institute. The challenge is to square the human needs of billions of people without irreversibly creating ecosystem conditions that humanity has not seen in all its existence – ones that will most likely be unfit to support our civilization[3].

As pointed out in the report “Cities and the Circular Economy for Food” published by the Ellen MacArthur Foundation and SYSTEMIQ in early 2019, currently the global food system creates societal costs of an estimated $5.7 trillion annually – or two dollars for each dollar spent on food[4]. Of these costs, $1.6 trillion are due to production-related health issues: $200 billion from air pollution caused by agriculture (an estimated 20% of particulate ambient air pollution, causing 3.3 million premature deaths per year, comes from agriculture). Exposure to pesticides creates social costs of an estimated $0.9 trillion, $150 billion of which in the EU alone. Overuse and poor management of antibiotics in the food system contributes significantly to antimicrobial resistance, causing an estimated $300 billion of damage in lives lost and additional healthcare. In particular, this last issue is set to increase drastically if no action is taken.

Clearly, just optimizing the current “food system” – ranging from production of inputs through farming, distribution, processing and consumption to managing waste – will be insufficient to surmount these challenges. There will not be one single way to solve these problems. We will need to both drastically improve our current ways and develop new ones. A new agricultural revolution is needed, creating in effect a regenerative, circular economy of food – one where production is compatible with healthy natural systems, where waste and pollution are designed out, and materials are used optimally.

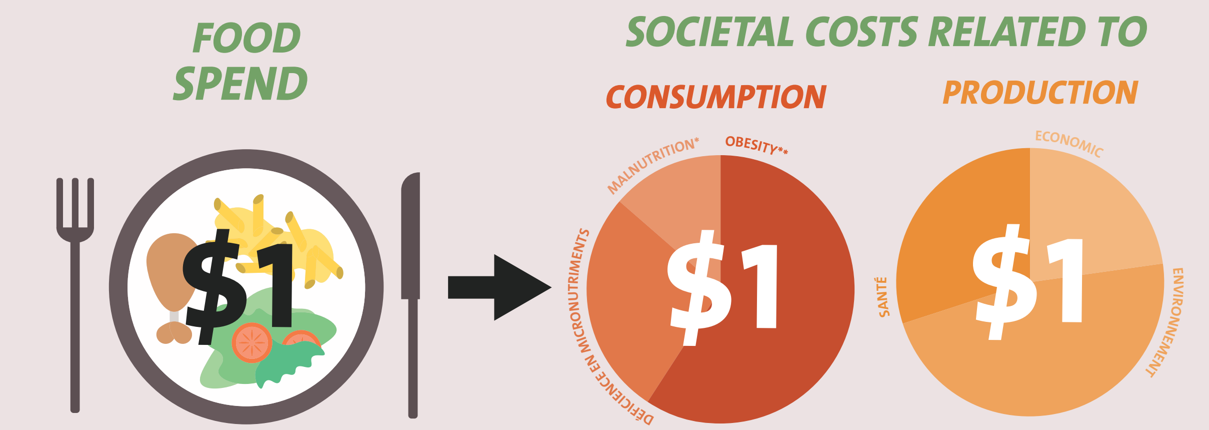
Yet many well-intended efforts to make farming more benign have proven to be less than successful by various metrics. In fact, recent meta-studies investigating effects of organic farming paint a mixed picture at best of its environmental footprints[5]. In the meantime, more symbiotic ways of farming are being explored, ranging

3 EAT-Lancet Commission on Healthy Diets From Sustainable Food Systems (2019). *Healthy diets from sustainable food systems*

4 Ellen MacArthur Foundation (2019). *Cities and the Circular Economy for food*

5 Clark, M., and Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letter 12*

Total costs of the global food system as per the Ellen MacArthur Foundation (2019)



*Excluding obesity; **Due to diet
Based on *Cities and Circular Economy for Food* analysis – for details see Technical Appendix.
Source: https://www.ellenmacarthurfoundation.org/assets/downloads/Cities-and-Circular-Economy-for-Food_280119.pdf

Figure 1

from conservation and regenerative agriculture to agroecological and syntrophic farming approaches. While showing enormous potential, such concepts are yet to be defined and studied thoroughly. So far it seems that their success is highly context-specific and often fails to transfer or scale. Taking them to mass market has suffered from ideological debates in the past. Clearly, more work is to be done to unlock alternative farming practices' potential for the food system at large.

URBAN AGRICULTURE – HYPE ONLY?

Among those alternative practices, UA appears more hype than truly disruptive at closer inspection. As far as data goes, there is little reliable evidence that farming in cities represents a significant contribution toward global food needs. There have been claims that UA is practiced by over 800 million people and provides up to one-fifth of the world's food. However, the bulk of the empirical evidence for such claims dates back to estimates from the early 1990s, and refers mostly to conventional small-holder, backyard farming[6]. Not only has the world changed dramatically since then, with likely only a few residents of Beijing or Delhi still growing a significant part of their own food, it would also appear that there are significant downsides to such farming practices (such as soil contamination and poor efficiency) with limits to scaling them meaningfully.

More recent estimates of the potential of UA are much more modest. One recent study estimates its maximum potential global contribution to food production at around 1-3% of global annual food production[7]. SYSTEMIQ's own estimates directionally confirm this, although our analyses indicate that this mostly consists of vegetables.

Vegetables, as important as they are for a healthy diet and long-term health, are not what feeds the world: proteins and calories are also urgently needed. But due to lower yields these are simply not profitable to produce in an urban environment. In the case of animal protein, beyond sheer cost considerations, there are other good reasons for moving production away from human settlements. These include hygiene, logistics and nuisance from odors and noise.

In the majority of cities, it may be difficult to secure the amount of land needed for substantial urban farming at reasonable prices. It would be hard to envision plots of vacant land large enough to sustain farming on a meaningful scale in a medieval Italian city, or a sprawling megacity in an economy in transition. Furthermore, due to local regulations like zoning laws, legal concerns including ownership and hygiene regulation, and competition for uses, even small areas may be difficult to secure in many cities.

CO_2 emissions of the EU food system: shares of the value chain steps. Logistics contribute only marginally

*including fertilizer inputs
Source: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC96121/ldna27247enn.pdf

Figure 2

Lastly, UA has been heralded as a solution to many environmental problems related to food. In particular, shorter transportation distances have been associated with lower carbon footprint, food packaging and food wastage. There seems to be evidence that, particularly for perishable goods like watery vegetables, less produce goes to waste if grown near its point of consumption. However, since produce still needs to be transported, a significant reduction in packaging should not be expected through more local production. And finally, since only a minor share of the carbon footprint of foodstuffs is due to transportation, the proximity argument appears to be largely moot: according to some studies, in the European Union, only around 5% of CO_2 equivalent emissions in the food system stem from transportation activities, while two-thirds come from agricultural processes themselves[8]. So, the appeal of UA appears to be spoilt. Or is it?

URBAN AGRICULTURE: NOT FEEDING THE WORLD BUT NOURISHING CITIES DIFFERENTLY

Maybe the question needs to be phrased differently. What if focusing on yield constraints and satisfying people's hunger from UA misses the point? What if urban agriculture was less about feeding cities, and more about nourishing them in different ways by improving urban environmental quality, enhancing climate resilience, and providing community spaces.

There are nowadays different types of food production that have been discussed in the context of UA, each of which has vastly different properties and as such must be viewed distinctly:

- Expansive urban agriculture (including backyard and rooftop farming)

6 Smit (1996). Urban agriculture, progress and prospect: 1975–2005. The Urban Agriculture Network (TUAN). Cities Feeding People Series, Report 18

7 Clinton et al. (2018). A Global Geospatial Ecosystem Services Estimate of Urban Agriculture. *Earth's Future*, AGU100.

8 European Commission Joint Research Center (2015). Energy use in the EU food sector: State of play and opportunities for improvement. *JRC Science and Policy Report.*

- Covered urban agriculture (greenhouses, including rooftops)
- High tech vertical and indoor farming (including container and warehouse farms)
- Aquafarming (controlled environment fish production)
- Aquaponics (combining fish rearing with one of the above for symbiotic effects)
- Insect farming (growing insect protein based on biomass, including potentially biowastes)
- Molecular agriculture (lab-grown meat and microbial production of essential components such as oils, vitamins and protein).

We propose here that only the first one, expansive UA, will have a significant role to play in cities (and to an extent its close cousin, covered UA), but through environmental and social services rather than food production. All other forms listed, while likely set for exponential growth due to economic drivers, would naturally gravitate toward the fringes of cities and thus constitute forms of peri-urban, rather than urban, agriculture. Instead, discussing them under the umbrella of "controlled environment farming" (CEF) is advisable to clarify the discussion. We will argue why.

On a theoretical level, this argument conforms with the model of the Isolated State formulated in 1826 by agronomist Johann Heinrich von Thünen. In this model, agricultural activities are located around a theoretical city in concentric rings. Each commodity's distance to the urban center is determined by profitability of production. Input variables include land prices, production and transportation costs, and sales prices. This simple model shows that while vegetable farming can be profitable near cities, animal husbandry and crop farming are only feasible further away[9].

Clearly, this simple model does not describe reality in its complexity. Also, conditions have changed dramatically since the time of von Thünen's writing, particularly due to huge reductions in transportation costs and the invention of refrigeration. Most recently, efficient lighting that enables indoor plant growing further changed the equation. Still, one key variable remains unchanged: the cost of land. In most cases, the marginal added benefit of shortening food transportation distances by placing production within cities will not justify the substantial premium that is placed on space. Considering the razor-thin margin most farmers operate on today, only vacant lots could qualify temporarily for UA. This can be observed in the USA where UA experienced a revival only after the real-estate crisis of the 2000s. That von Thünen's thinking is still up to date is exemplified by the work of the Amsterdam Institute AMS. When designing food systems for the Almere planned city, the institute explicitly referred to the principles of the von Thünen model.

Even for the highest-yielding forms of CEF, this rule holds; also, even those efficient modes of production would need logistics for inputs, intermediaries (e.g., packaging) and delivering outputs. Given the complexity of urban logistics, this is another argument against placing CEF in cities. Lastly, such capital-intensive operations benefit especially from economies of scale, something that is challenged almost by definition in dense urban centers. Questions of regulation such as zoning would add to commercialization costs. Only the most sought-after and most perishable products would ever justify this additional effort. So, while high-end restaurants may grow their own micro-greens in the future, it is unlikely that you will buy your potatoes from a container farm behind your apartment complex.

At the same time, both expansive and covered forms of UA tend to be low yielding and labor intensive, a far cry from highly optimized large-scale farming. As such, they would not be able to compete on price for food crops. But UA has additional benefits to providing food, including social and environmental services. If placed on rooftops, UA can reduce the climatization needs of buildings in a similar way to green roofs. Studies have found significant reduction of cooling needs in summer and heating needs in winter. Like green areas and extensive green roofs, UA can help reduce the urban heat island effect, and reduce stormwater run-off by between 60 and 100%. It can thereby retain water, improve the local microclimate and make cities more resilient to extreme weather events. In a reality of accelerating climate change, such functions will increasingly be vital for urban living. Areas of UA can also absorb and neutralize air pollutants, improving urban air quality[10]. Given that outdoor air pollution is listed among the top five contributors to the global burden of disease[11], this is no small feat.

The Von Thünen model, simplified: costs of land increasing with proximity to the city

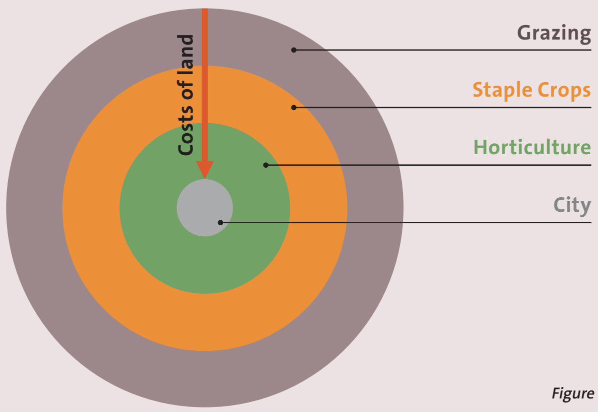


Figure 3

9 See for example: O'Kelly, M. and Bryan, D. (1996). Agricultural location theory: von Thünen's contribution to economic geography. *Progress in Human Geography 20*, 4

10 Michigan State University (2019). Benefits of Green Roofs. http://www.greenroof.hrt.msu.edu/benefits/index.html, Accessed April 18, 2019

11 Institute for Health Metrics and Evaluation (2018). Findings from the Global Burden of Disease Study 2017. Seattle. http://www.healthdata.org/sites/default/files/files/policy_report/2019/GBD_2017_Booklet.pdf

A last (but by no means least) ecosystem service relates to insects and pollinators. As insect populations have dropped by up to 40% over the last 50 years across the world[12], UA could throw a lifeline to these vital parts of our ecosystems (as part of larger and decisive action to protect biodiversity). In sum, UA can provide several valuable ecosystem services in urban centers that help build healthy cities.

The same study that found potential global UA food production of up to 1–3% of global food outputs per year estimates the value of ecosystem services of urban farming: by the authors' estimates, global urban vegetation suitable for urban agriculture is estimated as being worth $33 billion per year in total. This includes energy savings of up to 15 billion kWh, nitrogen sequestration of up to 170,000 metric tons, and avoided stormwater run-off of up to 57 billion cubic meters. In a scenario of "intense UA implementation," these services plus pollination, climate regulation, soil formation, and biological control of pests could be worth $80 billion to $160 billion annually[13].

An equally important benefit of UA may be of a social and psychological nature: shared gardens are an opportunity for local community building and creating a sense of purpose and belonging to neighborhoods. In some Chinese cities, UA is being used as a means to soften the cultural and emotional transition from a predominantly rural to highly urbanized society. This helps to create or perpetuate narratives of cultural continuity and equality between rural and urban areas. As such, UA can contribute to maintaining or strengthening social fabric. Additionally, UA can function as a platform for intergenerational exchange to foster cultural heritage and inclusion of the elderly. Meanwhile it can provide opportunities for non-market employment. For the large swaths of people that are expected to be pushed out of structured labor by automation, this may become increasingly important.

UA can also be used as an educational tool for schoolchildren and adults alike. It can thereby support understanding of natural systems and increase support for environmental policy in the long term. A greater appreciation of how food is grown might help incentivize people to lower food wastage (although arguably also risking conveying a somewhat romantic picture of agriculture).

Lastly, there is extensive evidence for the psychological benefits of both green spaces and outdoor recreational activities, both of which UA can contribute to. While applicable to the wider population, in some cases this is even being used in therapeutic approaches. In Japan, "forest bathing" has been part of the official national health program for decades due to its proven benefits to health. In some cities, such as Guelph, Ontario, so-called "healing gardens" are used to help former cancer patients to recover from their illness and treatment.

As argued above, rarely would expansive UA be profitable through food production. Integrating other functions into an urban environment – such as using UA as meeting space or event location – could help finance it, but even then it would likely operate on a narrow margin. As such, UA must likely either be operated for specific applications, such as the healing gardens of Guelph, or as an entirely non-commercial community-driven project.

One more way that UA can support business is what has been dubbed the so-called "shower head approach" in China. After the boom of shopping malls in many Chinese cities, much like in the west, online shopping has been putting pressure on retail in the Middle Empire. Creating green, recreational spaces on roofs provides those businesses with a way to incentivize people to visit. After being conveniently shuttled onto the roof, people are funneled through the shops floor by floor, with the hope that their hunger for shopping can be stirred; it's a modern form of trickle-down economics that might actually work. As such, UA is cross-subsidized by increased sales revenues from attached shops, and co-financed through integrated restaurants, cafés and the occasional gardening class. Food production has become a side element.

Given their potential for ecosystem and social value creation, UA facilities could also be considered a public service and as such be (co-)financed through public funds. However, being dependent on public funds and policy limits the scalability of UA. If negative externalities such as air or noise pollution were priced into other economic activities, further private investments could be attracted. However, a key prerequisite would be a widely accepted way of assessing UA's environmental and/or social value creation. One framework that proposes such a multi-capital assessment is that of Circular Economy. As such, a Circular Economy for Food could help promote UA.

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CONTROLLED ENVIRONMENT FARMING: NOT URBAN BUT SET TO GROW AND IMPACT

In contrast to the UA approaches described above, CEF-like vertical farming, aquaponics and molecular agriculture are conducted indoors and under controlled conditions separated from the outside world. Consequently, they do not require natural sunlight nor fertile soils, making it possible to implement them within buildings or even underground. They are highly input efficient and

12 Sánchez-Bayo, F., and Wyckhuys, K.A.G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation 232*

13 Clinton et al. (2018). A Global Geospatial Ecosystem Services Estimate of Urban Agriculture. *Earth's Future*, AGU100

City Garden farm on the rooftop of Jinqao shopping mall in Shangai - ©Nannan Dong, Tongji University

high yielding, setting them apart from "conventional" urban farming. Accordingly, they provide little to no environmental and social services.

CEF is becoming possible principally due to recent technological innovations like LED lighting, cheap sensors and machine learning. As such, various types of CEF have received significant attention in recent years. Corporations including German and Dutch lighting producers Osram and Philips dedicate divisions to their development and scaling. Venture capitalists and investors have started paying attention, too. For example, in 2018 U.S.-based vertical farming operator Plenty secured $200 million of venture capital and the backing of Amazon founder Jeff Bezos[14].

However, as argued above, such practices should not in fact be considered urban agriculture. Not only do they have, by design, little interaction with their surroundings and as such are not dependent on their location being urban, but also, at commercial scale there is little incentive to place these types of food production in urban centers due to costs of space and logistics. Locating those facilities in proximity to cities at logistically efficient locations makes more sense economically, allowing them to service nearby consumption centers flexibly. Therefore they could be categorized as peri-urban agricultural solutions (PUA). So discussing CEF under the umbrella of UA appears misleading and to the detriment of optimal support for both UA and CEF/PUA.

One reason for the hype and mixing of CEF and UA may be the possibility of placing container farms in nearly any location, making them icons of the technological developments of CEF in recent years. However, once technology continues to mature, they will likely remain a niche phenomenon or laboratory-type test beds due to limited economies of scale, as controlling units and climate control are key cost factors in high tech agriculture. Costs per unit of harvested vegetable have been estimated at four to ten times higher in container farms than conventional greenhouse farming, which can be expected to limit their commercial viability in the long term.

At the same time, CEF has the potential to significantly alleviate the ecosystem pressure compared to conventional farming. An industry-commissioned study conducted by KPMG, a management consulting firm, finds net positive socioeconomic effects of indoor vertical farming of €322 million annually compared to conventional farming for lettuce in New York City. These benefits are composed of substantially higher yields, 98% water saving, 23% reduced food losses and 60% reduced fertilizer needs. Additionally, 99% lower land usage and 7,000 metric tons of CO_2 emissions avoided are monetized in the study. Benefits are counteracted through economic losses from reduced job creation[15].

However, water, land and nutrient efficiency are not key differentiators in all regions of the world. Conversely, the comparatively high energy needs of CEF have raised criticism (and caused economic troubles). In fact, like-for-like energy demand of CEF has been found to be up to 10 times higher than that of greenhouses, and multiple factors higher than that of outdoor agriculture. Consequently, the use of renewable and other low-carbon energy sources like waste heat is paramount to rein in the carbon footprint of CEF.

Currently, the bulk of usual agricultural climate impacts do not stem from direct energy consumption. Rather, what dominates the CO_2 footprint are N_2O emissions from biochemical soil processes, land conversion, and upstream energy inputs particularly in fertilizer production. This last one alone contributes at least 3% of global CO_2 equivalent (CO_2e), as it is based on the energy-intensive Haber-Bosch process[16]. If, however, CEF were conducted with carbon-neutral energy sources, its reduced footprint of other sources of CO_2e could render it more climate friendly than conventional farming.

While the climate impact of CEF is therefore manageable and can indeed be positive, costs may not be. Since a lot of technical development is still taking place in the field, CEF is very capital and knowledge intensive. As a consequence, few CEF companies have been able to sustain operations for long. Those are typically able to offset the high capital and energy intensity with superior benefits tailored to local conditions. These include extreme climatic conditions (such as in desert climates in the UAE), unusually cheap energy (such as in Iceland with virtually free heat and electricity), or exceptionally high premium on space (such as Tokyo or New York City). In all those places named, successful CEF have been operational. For example, Tokyo-based

14 Bloomberg Technology (2017). SoftBank Vision Fund Leads $200 Million Bet on Indoor Farms. By Selina Wang, July 19, 2019. https://www.bloomberg.com/news/articles/2017-07-19/softbank-s-vision-fund-leads-200-million-bet-on-indoor-farming, Accessed April 18, 2019

15 OSRAM (2018). The value proposition. https://www.osram-group.com/en/innovation/value-proposition, Accessed April 18, 2019

16 Zhang, S. (2017). A chemical reaction revolutionized farming 100 years ago. Now it needs to go. *Wired magazine*, Science. https://www.wired.com/2016/05/chemical-reaction-revolutionized-farming-100-years-ago-now-needs-go/, Accessed April 18, 2019

Innovatus has been delivering 12,000 heads of lettuce per day from the fringe of the city into its urban center since 2015.

Business models for vertical farms remain nascent and risky for the time being, with more economies of scale and both technical and agronomical learning to be done before a wider range of produce becomes economical

While in principle most vegetables and pulses are amenable to CEF, companies have so far focused on highly perishable, high-value produce such as leafy greens, herbs, and some berries (and marijuana). Reasons for this include short growth cycles, with some CEF operators claiming to achieve up to 60 harvest cycles per year. Those lead to low specific energy requirements, rapid adaptability to demand and lower risks of contamination or pests damaging the crop. Moreover, losses are minimized should something go wrong along the way: one spoilt harvest due to pests or poorly adjusted inputs is less of a risk if your crop takes only a week to grow. Other favorable conditions are that, with leafy vegetables, large parts of the crop can be sold, the high market value of the produce and big potential in efficiency gains compared to conventional methods.

This suggests that business models for vertical farms remain nascent and risky for the time being, with more economies of scale and both technical and agronomical learning to be done before a wider range of produce becomes economical. Whether inherent advantages can be economically sustained for crops where a smaller fraction of the plant can be sold as food remains to be seen.

For insect farming, moving from small-scale, labor-intensive operations to large-scale industrial production proves difficult as well. Not unlike animal breeding, insect farmers need to consider the health of their breed and optimize systems accordingly. For scaling and commercialization, still more development is needed. This type of CEF may be the most compatible with the philosophy of circular economy, as insects such as crickets and black soldier fly larvae can be raised on a broad range of organic feedstocks including biowastes. This is also its key economic advantage: being able to utilize low-cost feedstock or even be paid for disposal can add to its bottom line.

Aquaponics, meanwhile, could provide a highly input-efficient mode of fish production. For those systems, symbiotic effects of plant and fish production in a closed loop system promise multiple benefits regarding water purification, feed and fertilizer inputs and multiple revenue sources. What sounds good on paper often leads to challenges in real life: the comparatively high complexity of such systems can lead to unfavorable economics much as for hybrid vehicles. Price premiums for guaranteed zero-contamination, zero-antibiotic fish might be able to offset those downsides.

Lastly, of all the solutions discussed, molecular agriculture might deliver the largest impacts in all dimensions of sustainability if it replaces beef and fish meal. Those solutions are the most nascent, in many cases barely beyond laboratory status. Consequently, costs are still high. For example, Maastricht-based Mosa Meat – the company that famously produced the first stem-cell-based burger for an infamous €250,000 – aims to commercialize its product at a price nine times that of its conventional equivalent. In the long run, however, the company expects production costs to drop below those of livestock meat. They base this on the belief in economies of scale and substantial upstream efficiency advantages compared to conventional beef production. Given the obscene inefficiencies in producing beef today, this prediction seems credible. Whether other, more trophically efficient types of meat like pork or chicken could be replaced by cultured meat in an economically and environmentally meaningful fashion remains to be seen.

In summary, the various forms of CEF promise a range of benefits compared to current production methods but, in most cases, still lack the maturity or economics to penetrate the mass market. For the foreseeable future, major hurdles include energy requirements and capital costs. The associated cost penalty may be offset in the medium term by substantial efficiency advantages, additional revenue streams and premiums for better ecological and health performance compared to conventional produce. The extensive use of waste and renewable energies is a *sine qua non* for this scenario, but in itself could enable an abundance of food once further cost reductions for renewable energies are realized as expected. That way, various types of CEF can be expected to grow significantly over the decades to come and, as opposed to UA, contribute meaningfully to global food supplies.

CEF conceptualized as part of a peri-urban food system, reconnecting cities with their surroundings

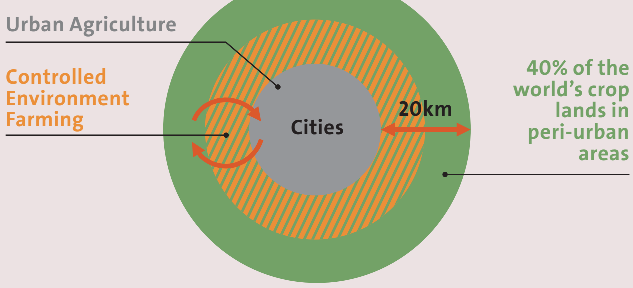

Figure 4

Exhibition of the Taiwanese YesHealth Farm model
© Association for Vertical Farming

GOING FULL CIRCLE. CONNECTING URBAN AND PERI-URBAN AGRICULTURE IN A CIRCULAR ECONOMY FOR FOOD

Already today, 40% of all cropland is located within 20 km of cities[17], largely due to the historical location of cities in fertile lands. This means that a large share of value added in the agricultural sector takes place here. Consequently, this needs to be considered when promoting UA. As cities sprawl, these croplands are the first to be threatened by land conversion, putting local communities and fertile soils at risk. At the same time, urbanization has led to an increase in the urban-rural dichotomy regarding income along with cultural attractiveness. By becoming part of this peri-urban agricultural landscape, CEF could help reconnect peri-urban communities with urban centers culturally, through material flows, and economically. While providing fresh produce for cities nearby, it could provide income to those peri-urban areas that have been under economic pressure for years. By using inputs much more efficiently, CEF could also benefit urbanites by lowering agriculture's impacts on air and water quality, as well as relieving freshwater stress. CEF projects could also recycle and upcycle nutrients from urban organic waste flows and thus contribute to a more productive, circular use of organic matter.

Until now this has remained unprofitable in most cases, and no regulated market exists for the resulting fertilizer products. Lacking clear standards and labels, it is difficult for (potential) producers to demand the premium they would require to offset the additional costs[18]. Given this lack of standardized market and limited experience with such innovative fertilizer products, using them constitutes additional costs and risks to CEF operators. Thus, upcycling of nutrients needs to be developed separately so that standardized controlled quality is available. Once this is achieved, the high levels of purity – for example, in recovered phosphorus fertilizers – would suit the selling points of CEF (guaranteed low contamination, environmentally friendly) and justify premium prices. This would support the creation of a more symbiotic relationship between cities and their surroundings – a peri-urban circular economy for food.

17 Ellen MacArthur Foundation (2019). *Cities and the Circular Economy for food*

18 Yara (2019). Veolia and Yara partner to propel European circular economy. https://www.yara.com/corporate-releases/veolia-and-yara-partner-to-propel-european-circular-economy/, Accessed April 19, 2019

CONCLUSION: FAST FORWARD TO 2039. A FUTURE-PROOF CIRCULAR FOOD SYSTEM BASED ON URBAN COMMUNITY FARMING AND PERI-URBAN HIGH-TECH AGRICULTURE

In a world experiencing ever more regular and more extreme climate shocks, where many ecosystems have become unstable due to rapid biodiversity decline, high-tech and regenerative agriculture have been boosted by governments and business alike. Agricultural inputs are used more efficiently than was the case in the 2020s, thanks to precise live measurements and largely automatized farming methods. Deep agronomic understanding helps to use natural and mechanical remedies for pest control, having rendered synthetic pesticide use all but obsolete. Governments put high premiums on protective measures for the remaining flora and fauna, while land grab has been largely stopped at least in the developed countries like the EU, Indonesia and China by means of draconian penalties for infringements.

In cities, many rooftops and open spaces are used as means to grow vegetables locally while providing recreational space, and to buffer the rare but intense rainstorms and to reduce temperatures in the scorching hot summers. Children learn about the history of natural ecosystems and past farming practices here. Starting from elementary school, they are educated about the reasons for moving away from the inefficient, environmentally destructive and morally problematic ways of producing meat in the early 21st century. Luckily, after becoming mostly uneconomical compared to novel production methods, such practices lost economic importance and thereby political support; ultimately, they were outlawed. Nowadays, most meat products are grown in-vitro and printed from substrate to the specifications of the consumer. Only subsistence farmers and the most affluent eat meat produced through slaughter or hunting.

Fish, on the other hand, are produced indoors at industrial scale. While ethical concerns about this are being discussed in public, the consensus is that it is the far better alternative to the deep sea fishing that almost led to oceanic ecosystem collapse. Insect farms provide high-quality protein to the fish farms, all the while converting by-products from agricultural activities into valuable plant nutrients.

Meanwhile, most vegetables are being grown in large automated facilities on the outskirts of the cities. They are produced on demand and delivered same day to people's doorsteps. The few inputs they require are provided largely from urban waste streams, ranging from water to substrate and vital plant nutrients.

This retraction of agricultural activity from natural ecosystems into controlled environments has thus helped fill the gap to feed the world population and stop ecosystem collapse – just about.