One Earth
Commentary

Vertical Farming and Cultured Meat: Immature Technologies for Urgent Problems

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Vertical farming and cultured-meat production have the potential to contribute to the reduction of negative environmental impacts of agriculture and improve global food security in the future. However, the technologies are still at early stages of development and thus cannot help with the urgent problems we face.

Introduction

Global food systems face an immense challenge: to secure healthy and sustainable nutrition for a growing and increasingly affluent population under the conditions of dwindling land availability and worsening climatic conditions. A 25%–70% increase in global crop supply is needed by 2050 to meet the projected demand for food.[1] Currently, food systems are far from sustainable: they are responsible for a quarter of global greenhouse gas (GHG) emissions, of which 60% can be attributed to livestock production alone.[2] Together, agriculture and livestock production also contribute approximately 85% of nitrogen and 90% of phosphorus emissions, 80% of land-use change, 70% of water use, and 80% of biodiversity loss—they are pushing planetary boundaries to their limits.[3] If we don't implement drastic changes in the way we produce and consume food, and in the absence of transformative solutions, the consequences for the environment and human health will be dire.

Many are looking to technology to provide the answers, and vertical farming and cultured meat (also known as *in vitro* meat, clean meat, artificial meat, laboratory-grown meat, or cell-based meat) are dominating the headlines. Vertical farming refers to indoor plant production in multiple vertical space-saving layers with the use of hydroponics or aeroponics and LED lights, although direct sunlight can also be utilized in some cases.[4] Cultured meat is produced by the cultivation of animal cells in a bioreactor in nutrition medium via cell-culturing technologies familiar in the medical industry.[5]

Both technologies have seen significant investment by venture capitalists over the past decade, such that 25 cultured-meat startup companies have emerged since 2010. Whereas vertical farming is already used in commercial-scale production around the world, cultured-meat production is still at the development stage, although some startups claim commercial availability of their cultured meat products in as little as 2 years' time. Given the current state of the art and the magnitude of challenges that need to be overcome, these estimates are at best overly optimistic and at worse misleading. The main challenges in cultured-meat technology include the development of low-cost animal-ingredient free growth medium for the cell culturing and the design of bioreactors for large-scale production.[5] The speed of development depends on a number of factors, such as the amount of financial investment and the ability to attract the appropriate expertise and talent away from existing, established fields. These challenges, combined with a lack of transparency from startups, mean it remains impossible to predict the exact time of market entry. This would also depend on what could be considered (and what would be acceptable) as a cultured-meat product. The first product is likely to consist of only a small percentage of cultured animal cells mixed with other ingredients. Cultured-meat products that would have a higher percentage of cultured animal cells and would be closer to conventionally produced meat products in terms of texture and nutritional value would take substantially longer to reach the market. It is highly unlikely that we will receive a cultured steak on a plate any time soon.

Environmental Impacts and Resource Use

The feature that makes both vertical-farming and cultured-meat technologies desirable as a sustainable option is their controlled environment. These systems provide the possibility to adjust the production conditions and avoid emissions more efficiently than in outdoor farming systems.[6] For instance, in conventional farming systems, plants often use only approximately half of the nitrogen applied to croplands, and the remainder is lost to the surrounding environment.[3] Vertical-farming and cultured-meat technologies can considerably reduce nutrient emissions because the water and nutrients can be recycled in the system. Closed production conditions in vertical farming also enable a reduction in the amount of chemicals used to protect plants and therefore also a decrease in the environmental and human health issues caused by pesticides.

Vertical farming also uses water much more efficiently. Water is so effectively circulated within the system that water loss is limited to that embodied within the crop biomass. Graamans et al.[7] estimate that a vertical-farming system uses as little as 4% of the water needed to produce the same quantity of lettuce in a greenhouse in the Netherlands. The water-use efficiency of cultured-meat production depends on the source of nutrients used for the cell culturing and the design of the bioreactor system. A prospective study estimated that cultured meat could have a 96% lower carbon footprint than beef and an 82% lower footprint than poultry.[8]

Vertical farming helps to reduce land use because plants are produced in multiple vertical layers. The estimates for land-use requirements for cultured-meat production vary from less than 1% to 5% of that needed for conventionally farmed beef and from 3% to 50% of that needed for poultry depending on the assumptions regarding the source of nutrients used for the cell culturing.[8,9] Because of the lower land-use requirements, both systems could free up a significant amount of agricultural land and reduce the pressure to convert forests into additional agricultural land, helping to protect biodiversity and sequester carbon. However, these benefits would not be an automatic consequence; policies that give incentives for sustainable land use would be needed. Introducing a new product to the market does not magically erase established farmland, upon which millions of people's livelihoods depend.

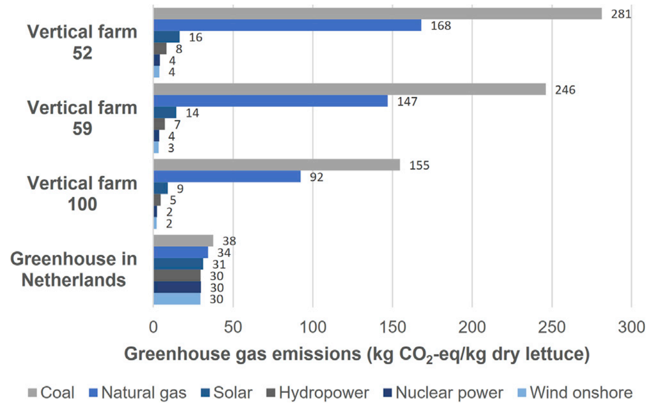

Figure 1. Greenhouse Gas (GHG) Emissions of Vertical Farming
GHG emissions of lettuce production in vertical-farming systems with various levels of LED-light efficiency (52%, 59%, and 100%) are compared with those in a regular greenhouse in the Netherlands when alternative sources of energy are used. Source: Hallikainen[11] calculated GHG emissions on the basis of the energy use of the systems as reported by Graamans et al.[7]

We shouldn't, however, get carried away. The environmental prospects of the emerging technologies are not necessarily entirely positive. Both vertical farming and cultured-meat production require higher amounts of energy than agriculture and livestock production.[7,9] In vertical farming, LED lights replace direct "free" sunlight, and energy is used for controlling temperature and humidity. Graamans et al.[7] have shown that lettuce production in a vertical-farming system in the Netherlands requires approximately three times more energy than greenhouse production, and 60% of that energy is consumed by the LED lights, 30% is used for cooling, and 10% is used for heating. The energy efficiency of vertical farming could be improved through the development of LED light technologies and optimization of their use, e.g., providing only the right light wavelength that the plants need.[6]

In cultured-meat production, energy is needed for producing the ingredients for the growth medium and for running the bioreactor (e.g., for temperature control, aeration, and mixing processes). Current estimates show that the industrial energy requirements for cultured-meat production might be larger than what is needed for conventionally produced meat.[9] However, those estimates have high uncertainty because the development of cultured-meat technology is still in its early stages, mainly at a laboratory scale, and it is not possible to obtain data directly from the large-scale production facilities. Laboratory-scale experiments provide indicative data only regarding the possible cell yield levels, but it might not be possible to extrapolate those results linearly to large-scale production systems. Because the large-scale bioreactors for cultured-meat production have not yet been tested, the current energy-use estimates for large-scale production systems are based on modeling with many assumptions regarding the growth-medium components and bioreactor design, and therefore the energy efficiency might be substantially improved from the current estimates. For instance, the production of Dulbecco's modified Eagle medium (DMEM), which is commonly used as a nutrient source in cell culturing, requires a relatively high amount of energy, especially for the production of synthetic amino acids.[9] Therefore, the energy requirements for cultured-meat production could be reduced by the replacement of DMEM with alternative ingredients. There would also be potential to improve the energy efficiency of the bioreactor heating and cooling through the use of enhanced heat integration.

Therefore, in the context of sustainability and particularly climate-change mitigation, the benefits of both technologies depend on the energy source used. The main sources of GHG emissions from agriculture are methane emissions from ruminants' enteric fermentation (39%) and emissions from fertilizers and manure applied to fields (33%).[10] In vertical farming and cultured-meat production, the GHG emissions are mainly related to energy use, and therefore the source of energy is key to determining the quantity of the emissions. Figure 1 shows that the GHG emissions of lettuce production in vertical farming systems can be reduced by 2 orders of magnitude through the use of wind energy instead of coal. Similarly, in cultured-meat production, GHG emissions can be substantially reduced by low-emission energy sources. In a world with 100% renewable energy, the energy requirements of both technologies could be a moot point, but even then, it is far from clear whether the capacity of future alternative energy sources would be sufficient to cover the increased demand associated with full-scale commercial versions of these technologies.

Prospects of Improving Food Security

The projected future effects of climate change on food productivity are mixed. However, although over 50% of crop-yield reductions in some tropical regions could be offset by a more than 50% increase in the high latitudes,[12] an increase in issues with pests, pathogens, water supply, and soil degradation is likely to hinder the net benefits. Food security and the resilience of food-production systems, particularly in regions increasingly exposed to higher temperatures and drought, are therefore a real concern. The closed production conditions in vertical-farming and cultured-meat systems have the potential to enable us to produce food throughout the year regardless of the prevailing climate conditions. Such closed systems are more stable and predictable than open fields, where crop yields can vary substantially from one year to the next and must be continually rotated to ensure healthy soils. The controlled conditions also help to reduce chemical contamination, diseases, and pest outbreaks, including animal-borne diseases, such as bird flu and mad cow disease. Thus, both vertical farming and cultured-meat production have the potential to improve food safety and the resilience of food production in the future.

However, are claims associating these technologies with food security really justified? The commercial applications of vertical farming mainly focus on the production of leafy vegetables, herbs, and berries, which provide only 6% of global calories.[10] Stable crops, which contribute 45% of global calories,[10] are lacking from these enterprises. This could be explained by higher production costs in vertical-farming systems, making it more profitable to produce higher-value crops. But the bottom line is that vertical farming is unlikely to contribute to a major share of the global calorie supply. However, studies have shown that climate change can have substantial consequences for human health as a result of the negative impact on the yields and quality of fruits and vegetables.[13] Therefore, vertical farming could provide a solution for mitigating those health issues by enabling the nearby production of perishable fruits and vegetables in places where the environmental conditions are undesirable for outdoor agriculture.

Technology for cultured-meat production, on the other hand, could have the potential to contribute to the improvement of food security through the provision of a stable, resilient, and sustainable protein supply. The ingredients for the nutrition medium could be transported longer distances as dry powder, so agricultural land is not necessarily needed close to the production facilities. However, the slow speed of the development of the technology and uncertainty regarding consumers' willingness to accept the cultured-meat products are likely to prove major obstacles in terms of gaining wider benefits from the technology. The broader health benefits of the technology are also likely to depend on the format of and marketing surrounding the product and its versatility as an ingredient.

Transformative Solutions or Cash Cows?

Both technologies are currently predominantly based in high-income countries, but in theory, both vertical-farming and cultured-meat technologies could have the potential to also benefit lower-income countries, especially people living in cities. Fresh vegetables and meat would provide important micronutrients and proteins that could improve the nutrition of malnourished people and potentially diminish the environmental footprint of conventional farming approaches. However, the high investment and production costs are likely to hinder the possibilities for utilizing these technologies in these regions, where one could argue they are most needed. A major issue in achieving this target during the near future is related to the funding structure of the technologies and the motivations behind their development. Public funding bodies have granted relatively little resources for the development of these technologies, whereas private investors have stepped in at the relatively early stages.[14,15] The lack of public research regarding the technologies slows the speed of development because the results of the research carried out in startup companies are not available for other technology developers. Furthermore, the motivations of the private companies are not necessarily in line with improving global food security and could focus more on high profits and the targeting of more affluent markets. Increased public funding might accelerate the development process of these technologies and improve the likelihood of gaining wider societal benefits from them.

The majority of the food consumed globally is produced in agricultural fields. Therefore, the main focus on improving the sustainability and security of food systems should be on the sustainable development of existing farming practices and the promotion of the transition toward healthy and sustainable diets. Novel technologies, such as vertical farming and cultured-meat production, could very well have a role to play in improving the sustainability of food systems in the future, but the technologies are not yet ready for helping with the urgent problems we face.

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