frontiers in Sustainable Food Systems

PERSPECTIVE
published: 04 December 2018
doi: 10.3389/fsufs.2018.00084

# Technology for Sustainable Urban Food Ecosystems in the Developing World: Strengthening the Nexus of Food–Water–Energy–Nutrition

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Smart integration of technology can help create sustainable urban food ecosystems (UFEs) for the rapidly expanding urban population in the developing world. Technology, especially recent advances in digital-enabled devices based on internet connectivity, are essential for building UFEs at a time when food production is increasingly limited on a global scale by the availability of land, water, and energy. By 2050, two-thirds of the world will be urban—and most of the net world population growth will occur in urban regions in the developing world. A food crisis is looming, with the developing world ill-prepared to sustainably feed itself. We identify 12 innovative technology platforms to advance the UFEs of the developing world: (1) connectivity—information delivery and digital technology platforms; (2) uberized services; (3) precision agriculture (GPS, IoT—Internet of things, AI—artificial intelligence, sensing technology); (4) CEA—controlled environment agriculture, including vertical farms; (5) blockchain for greater transparency, food safety, and identification; (6) solar and wind power connected to microgrids; (7) high-quality, enhanced seeds for greater yield, nutrition, climate, and pest resistance; (8) advanced genetics, including gene editing, synthetic biology, and cloud biology; (9) biotechnology, including microbiome editing, soil biologicals, cultured meat, alternative proteins to meat and dairy; (10) nanotechnology and advanced materials; (11) 3-D printing/additive manufacturing; and (12) integration of new tech to scale-up underutilized, existing technologies. The new tech-enabled UFEs, linked to value-chains, will create entrepreneurial opportunities—and more efficiently use resources and people to connect the nexus of food, water, energy, and nutrition.

**Keywords: FWEN, nexus, technology, value chain, sustainability, developing world, urban food ecosystems**

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***Edited by:***
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***Specialty section:***
*This article was submitted to Nutrition and Environmental Sustainability, a section of the journal Frontiers in Sustainable Food Systems*

***Received:*** *23 August 2018*
***Accepted:*** *20 November 2018*
***Published:*** *04 December 2018*

***Citation:***
*Davies FT and Garrett B (2018) Technology for Sustainable Urban Food Ecosystems in the Developing World: Strengthening the Nexus of Food–Water–Energy–Nutrition. Front. Sustain. Food Syst. 2:84. doi: 10.3389/fsufs.2018.00084*

## INTRODUCTION

Smart integration of technology can help create sustainable urban food ecosystems (UFEs) for the rapidly expanding urban population in the developing world (Orsini et al., 2013). Technology, especially recent advances in digital-enabled devices based on internet connectivity, are essential for building sustainable UFEs at a time when food production is increasingly limited on a global scale by the availability of land, water and energy. By 2050, two-third of the world will be urban—and most of the net world population growth will occur in urban regions in the developing world (UN-DESAPD, 2018). Yet the developing world is ill-prepared to feed itself: agricultural production in West Africa remains anemic—its population is doubling in 20 years—and two of the six largest global cities will be in West and Central Africa (UN-Habitat, 2014; FAO, IFAD, and WFP, 2015). In the developing world, there is chronic underuse of mechanization, basic fertilizer, and irrigation inputs—and adaption of modern agricultural and food technologies needed for sustainable intensification (Binswanger-Mkhizea and Savastanob, 2017; see **Appendix 1** in the Supplementary material).

More than a billion people live in developing world slums—which could double by 2030. Furthermore, the poorest urban households spend 60–80% of their income on food (Reardon, 2016). A food crisis is looming, exacerbated in coming decades by the impact of climate change, bulging youth populations, large migrations from rural areas to cities—and inadequate infrastructure, education, and economic opportunities (Chatterjee, 2015; Hamm et al., 2018). Current UFEs in the developing world are inefficient and critically inadequate to meet the challenges of the future (van Ittersum et al., 2016). This could have catastrophic economic, social and political consequences.

## TECHNOLOGY KEY TO SUSTAINABLE URBAN FOOD SYSTEMS (UFES)

A new path forward for UFEs needs to be found. The advancement should include increased productivity and environmental sustainability that links rural, peri-urban, and urban producers and consumers and increases overall urban region food production (Addo, 2010) (**Figure 1**). Connecting food production and distribution to urban and peri-urban markets has many advantages. Road systems are better with closer proximity to markets, reducing problems with perishability, and unreliable electricity for refrigerated storage (cold-chain). These regions and markets favor high-value (cash), nutrient-dense crops (vegetables and fruits), which require smaller acreage, and are more profitable per square meter than agronomic crops such as rice, corn, and wheat (Davies and Bowman, 2016). This creates market niche opportunities for smallholders, many of whom are women (FAO, 2011a). New technologies, coupled with new business models and supportive government policies, can revolutionize and create more resilient and productive UFEs for the twenty-first century. It will generate opportunities for entrepreneurs to create many new businesses and jobs.

These new UFEs also will create unprecedented opportunities for smallholders to progress from subsistence farming to commercially producing niche, cash crops (horticulture), and animal protein (poultry, fish, pork, insects) (McCaffrey, 2012; Davies and Bowman, 2016). There will be new opportunities within cities in creation of "vertical farms" and other controlled environment agricultural (CEA) systems as well as production of plant-based and 3D printed foods and cultured meat (Benke and Tomkins, 2017; Chadwick, 2017; Simon, 2018). Uberized facilitation of production and distribution of food will reduce bottlenecks and provide new business opportunities and jobs. "Off the shelf" precision agriculture technology will increasingly be the new norm, for smallholders to larger producers (Kite-Powell, 2018).

Rapid growth of urban markets is providing opportunities for new entrepreneurs and young people who have technological, business, and interpersonal skills—to build food production and distribution businesses based on new technologies (Reardon, 2016). These new entrepreneurs do not necessarily need a college education—but rather the ability to continually retool and keep up with technology and market opportunities. Moreover, technology is making UFEs exciting for young people to develop successful businesses that will enable them to "take ownership," innovate, make money, and have meaningful careers. And it involves more than developing apps. Rather, the challenge is understanding weak links along the value chain and exploiting innovative use of technology to create new businesses.

Middle class consumers in the developing world have greater disposable income and want better, safer, fresh, healthy, *sustainably produced* food—including more protein-rich meat, poultry, and fish (Burlingame and Dernini, 2012). They also desire new services to facilitate merchandising, purchasing, and delivering food to their doorsteps. Urban consumers are also seeking more convenient food for consumption. This creates new product and market opportunities for producing nutritionally fortified, processed food (Darton-Hill et al., 2017).

These opportunities can also extend to rural and peri-urban regions where technology can eliminate drudgery. A subsistence farmer's life of hoeing weeds and carrying jerry-cans full of water to irrigate does not attract young entrepreneurs. They quickly see the "Red Queen dilemma" of *Alice in Wonderland*: running just to stay in place and never advancing. Technology can enable rural, peri-urban, and urban producers to have better market and income-stream opportunities by servicing larger urban markets (UN-SD, 2017). Technology that enables smallholder producers to increase productivity without increasing labor—is critical to food security for UFEs. This includes integrating technology to enable smallholders to rise above subsistence and become commercially successful.

New urban and peri-urban market opportunities also are being created in the developing world by supermarket chains (Walmart, Carrefour, Pick-N-Pay, Shoprite, Tesco, Metro, Pingo Doce, etc.). They are looking for locally-sourced, high-value fruits, vegetables, flowering plants, and animal protein to service rapidly growing urban populations. Walmart and its local affiliate, Hortifruiti, for example, have small-farmer-direct programs with strict product standards servicing larger cities in Central America (Anon, 2018a). New technologies and business models are making such synergistic relationships increasingly viable.

The next generation UFEs, part of Agricultural Revolution 4.0 (see **Appendix 1** in the Supplemental Material), will be integrated with the larger collaborative economy that is connected by digital platforms, the cloud, and the internet of things, and powered

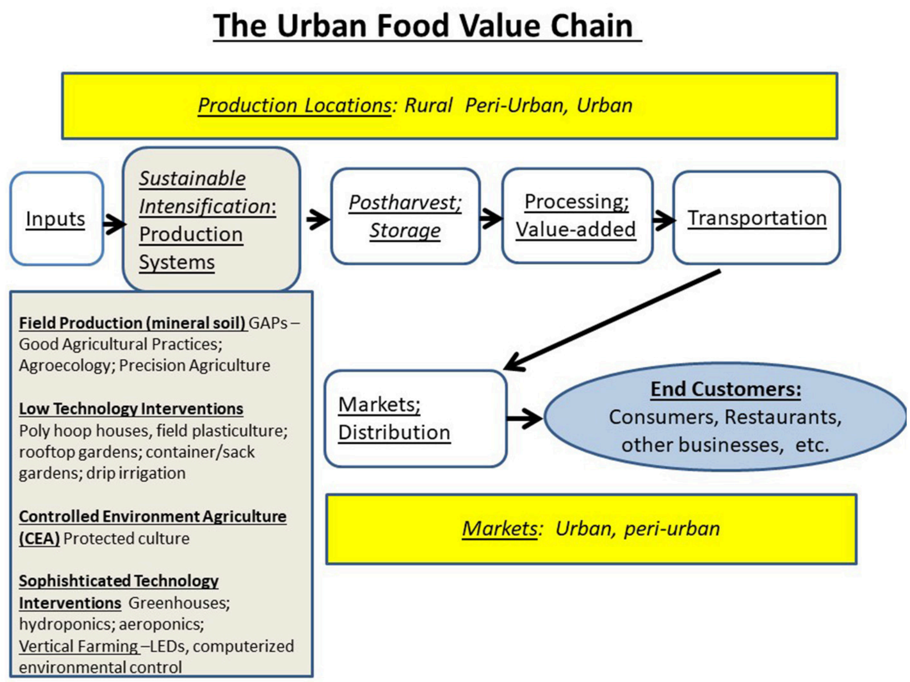


**FIGURE 1 |** The urban food value chain nodes from rural, peri-urban, and urban producers to servicing end customers in urban and peri-urban markets.

by artificial intelligence (De Clercq et al., 2018). The new tech-enabled UFEs will more efficiently and effectively use resources and people to connect the nexus of food, water, energy, nutrition, and human health. This will also contribute development of a circular economy that is designed to be restorative and regenerative—minimizing waste and maximizing recycling and reuse to build economic, natural, and social capital (Anon, 2018b).

We have identified 12 innovative technology platforms to advance the food ecosystems of the developing world that include: (1) connectivity: information delivery and digital technology platforms; (2) uberized services from producers to consumers; (3) precision agriculture (GPS, IoT—Internet of things, AI—artificial intelligence, sensing technology); (4) CEA—controlled environment agriculture, including vertical farms; (5) blockchain for greater transparency, food safety, identification; (6) solar and wind power connected to microgrids and storage; (7) high-quality, enhanced seeds for greater yield, nutrition, climate, and pest resistance; (8) advanced genetics, including gene editing, synthetic biology, and cloud biology; (9) biotechnology, including microbiome editing, soil biologicals, cultured meat, alternative proteins to meat and dairy; (10) nanotechnology and advanced materials; (11) 3-D printing/ additive manufacturing; and (12) integration of new tech to scale-up underutilized, existing technologies—such as efficient drip-irrigation with new precision soil sensors and solar-electric pumps—allowing both "on" and "off-grid" usage; "packaging technologies" (**Figure 2**).

The tech-enhanced UFEs will make on-farm production more resilient and more closely tied to urban food systems. It will also create off-farm opportunities in the value chain, including food production in cities and serving customers with new goods and services. Technology can enable transformation of UFEs, from expanded production in cities to more efficient and inclusive distribution and closer connections with rural farmers. See **Appendix 2** in the Supplementary material, which includes currently available, soon-to-be available, and prospective commercialized technologies for creating more sustainable UFEs in the developing world. Examples are as follows.

## CONNECTIVITY FOR INFORMATION, LEARNING, AND MARKETS

Connectivity, from simple cell phone SMS communication to internet-enabled smart phones and cloud services, is providing platforms for increasingly powerful technologies that are enabling development of a new agricultural revolution. Internet connections currently reach more than 4 billion people, about 55% of the global population (Kemp, 2018).

Smart phones are often the first and only computer available to a producer or a consumer in developing countries. It becomes their gateway to the world, from accessing relevant business and weather information to participating in on-line learning and acquiring data on their health. All of this can radically transform a family's economic and educational opportunities. More than 2 billion people actively use Facebook, which is often a platform for conducting business. Indonesia, a developing country, is the fourth largest Facebook user, while India has twice as many users


**FIGURE 2 |** Twelve innovative technology platforms to sustainably intensify urban food ecosystems (UFEs) of the developing world.

as the United States. Some 48% of Kenya GDP flows through mobile money (M-Pesa) and 31% of eCommerce comes from mobile devices (Munda, 2017). More sub-Saharan African adults (12%) have mobile money accounts compared to just 2% global usage (Lewis et al., 2016).

These information and communications technologies (ICT) connect food value-chain actors, from producers to consumers, with just-in-time data; enhanced good agricultural practices (GAPs); mobile money and credit; telecommunications; market information and merchandising; and greater transparency and traceability of goods and services throughout the value chain (Ekekwe, 2018; USDA, 2018). The smartphone and basic cell phones using SMS have become the one-stop-shop for a smallholder to place orders, gain technology information for "best management practices" (BMPs), and access market information to increase profitability (EPA, 2018). Hershey's CocoaLink in Ghana uses SMS text and voice messages with cocoa industry experts and smallholder producers (Anon, 2018c). Digital Green is a low cost, technology-enabled communication system in Asia and Africa to bring needed GAPs and BMPs to smallholder farmers in their own language and dialects through filming and recording successful farmers within their own communities (Harwin and Gandhi, 2016). MFarm is a mobile app that connects Kenyan farmers with urban markets via SMS messaging (Solon, 2013). Farmerline and AgroCentral use mobile and the web as part of their business model in Africa to connect farmers with the services they need (Anon, 2018d). This includes weather forecasts, market prices, and GAPs.

The internet currently remains slow and expensive in parts of Africa, affecting the ability of Africans to use the web and connect globally. However, advances such as the Google Go app will make it easier to browse the web. The app will be available in 26 sub-Saharan African countries, and will function on Android devices that have low storage capability and slow, unstable connections, including 2G networks. The app includes voice recognition for searches, instead of typing - enabling literate literate and semi-illiterate users; it can switch between languages, including Swahili (Dahir, 2018).

To further enhance Wi-Fi, while increasing their bottom line: Google Station is a free, public Wi-Fi service in Nigeria, India, Indonesia, Thailand, and Mexico. Essentially Google partners with local service providers for infrastructure and locations and offers a cloud-based platform and devices to provide and manage the Wi-Fi hot-spots (Kazeem, 2018). Google is also building fiber-optic networks through *Project Link* to help local internet service providers and mobile operators provide faster broadband in the developing world. Furthermore, Google is partnering with telecom operators in Kenya to launch *Project Loon* to connect users to the internet using solar-powered, high-altitude balloons. Facebook also has internet access projects in Africa, including Express Wi-Fi and Free Basics (Kazeem, 2018).

## UBERIZED CONNECTIVITY FOR A COLLABORATIVE ECONOMY

Uberized services can advance development of the UFE across the spectrum, from rural to peri-urban to urban food production and distribution. These facilitators—using mobile devices and mobile money transactions, and connected to the cloud for on-demand goods and services for producers, value-chain actors, and consumers—can strengthen the many weak links in the UFE. This includes uberized: planting and harvesting equipment; transportation vehicles; cold-chain facilities for temporary storage of perishable product; and "cloud kitchens" that produce fresh meals to be delivered to urban customers, enabling young people with motorbikes, and cell phones to become entrepreneurs or contractors delivering meals to urban customers.

Uberization of the UFE can begin with rural producers. "Custom harvesting" (renting) farm equipment creates business-to-business (B-to-B) opportunities for the developing world. Mechanization and automation are vitally needed to reduce drudgery, increase efficiency, and enhance profitability. Hello Tractor is an example of a custom harvesting company and is the "Uber" of small, 2-wheel tractors (Otufodunrin, 2017). It is a business platform of entrepreneurs operating in Africa and Central America. Smallholders use their cellphones to contract with Hello Tractor for tractors to plow and harvest their fields, track when they will arrive, and make mobile money payments. Hello Tractor uses smart tractors linked to the cloud with a GPS antenna and international SIM card for remote monitoring.

The global trend in urban regions of using mobile phones to order food delivery is spreading to the developing world. Just as Airbnb owns no hotels but provides more than one million "hotel rooms" and Uber owns no taxies but provides urban mobility in hundreds of cities, GrubHub has no takeout restaurants; it supplies restaurant food to over 10 million customers in more than 1,300 cities in the US and the UK. Online food-delivery platforms are increasing efficiency, expanding choice, and convenience, allowing customers to order from a wide array of restaurants with a single tap of their mobile phone (Hirschberg et al., 2016). Africa has a number of local, indigenous, on-line-delivery services, from SoupDirect and EasyAppetite in Nigeria to FoodCourt in Rwanda. In India, food delivery apps, including Google's Aero, Uber Eats, and Indian startups such as Swiggy and Zomato, are competing to gain market share (Kashyap, 2017). The Indian online delivery market is composed of aggregators and cloud kitchens where chefs prepare food at a physical outlet. The congestion of India's roads has created another down-stream, business opportunity to service Indian consumers who do not want to cook at home, but do not want to get stuck in traffic going to a restaurant.

About a third of the world's food goes to waste, often because of appearance; this is enough to feed two billion people (Royte, 2016). The businesses "Imperfect Produce" and "Imperfect Picks" use market opportunities to reduce food waste by creating a service of marketing and distributing "ugly food" (Helbig, 2018). Such services supply consumers with cheaper, nutritious, tasty, healthy fruits, and vegetables that would normally be discarded as culls due to imperfections in shape or size. Services supplying "ugly food" utilize land and resources more efficiently. Companies source directly from farms and deliver produce to customers' doorsteps for 30–50% less than grocery store prices. Farmers sell more produce, down-stream service/delivery jobs are created, and consumers have access to more affordable, healthy, and nutrient-dense food. Similar models could be used in the developing world.

## PRECISION AGRICULTURE AND CONTROLLED ENVIRONMENTAL AGRICULTURE (CEA)

UFEs production systems rely not only on field-grown crops, but also on production of food within cities (Hallett et al., 2016).There are a host of new, alternative production systems using "controlled environmental agriculture" (CEA). These range from low-cost, protected "poly hoop" houses, greenhouses, and roof-top and sack/container gardens, to vertical farms in buildings using artificial lighting (FAO, 2011b; Black, 2018; Coffman, 2018). Many vegetables, greens, herbs, and flowering plants can be commercially grown in containerized or trough/tubing systems using "synthetic" high organic media as a solid substrate or in aeroponic and hydroponic environments, which require no media support. Vertical farms enable year-round production, regardless of weather, which will be an increasingly important with global warming (Esposito et al., 2017). LED lighting provides 24/7 production with the optimal amount of light quality and quantity for specific crop production requirements (Kozai et al., 2016). Sensors and robotics provide the root system with the exact pH and micronutrients. Such precision farming can generate yields 200–400% above normal field production (Blomqvist, 2018). In addition, vertical farms *reduce land and water* usage by as much as 95%, and energy usage by 50% (Esposito et al., 2017). Although vertical farming has great potential in the developing world for the production of selected greens and vegetables for urban markets, it is generally not cost-effective for producing all agricultural products, such as field crops, fruits, and nuts.

## BLOCKCHAIN TECHNOLOGY

ICT technology can now address gaining access to credit and executing financial transactions, which has been an especially persistent constraint for smallholder producers. The Gates Foundation has released an open source platform, Mojaloop, to allow software producers, banks, and financial service providers to build secure digital payment platforms at scale (Galeon, 2017). Mojaloop software uses more secure blockchain technology to enable urban food system players in the developing world to conduct business and trade (Tapscott and Tapscott, 2016). The free software reduces complexity and cost in building payment platforms to connect smallholders with customers, merchants, banks, and mobile money providers. These digital financial services allow smallholder producers in the developing world to conduct business—without a brick-and-mortar bank.

Blockchain is also important for traceability and transparency requirements to meet food regulatory and consumer requirement during the production, post-harvest, shipping, processing, and distribution to consumers (Helmstetter, 2018). Urban consumers and regulators are expected to require more product information and labeling from listing the sustainable production system utilized, chemical applications, GMO status, handling, and transportation. Combining blockchain with RFID technologies also will enhance food safety (Costa et al., 2013).

## ENHANCED GENETICS, BIOTECHNOLOGY, AND NANOTECHNOLOGY FOR SUSTAINABLE INTENSIFICATION OF UFEs

*CRISPR* is a promising gene editing technology that can be used to enhance crop productivity while avoiding societal concerns of GMOs (Servick, 2016; Regalado, 2017a; Rotman, 2017). The technology allows genes to be added and deleted, much like using word-processing software, but does not incorporate "foreign" genes (utilized in GMO-produced plants and animals)[1]. CRISPR can accelerate traditional breeding and selection programs for developing new climate and disease-resistant, higher-yielding, nutritious, biofortified crops, and animals. It provides a pathway for plant and animal breeding that is more reliable, cheaper, and faster than traditional methods.

Post-harvest losses of perishable fruits and vegetables during harvest, transportation, and delivery to consumers can be as high as 50% in the developing world (Kader, 2005). Plant derived coating materials, developed with nanotechnology, can reduce waste, enhance freshness, nutrition, extend shelf-life, and transportability of fruits and vegetables (Rowland, 2017). The nanotechnology coating could significantly reduce post-harvest crop loss in developing countries that lack adequate cold-chains (refrigeration). New post-harvest technologies using nanotechnology and packaging materials can dramatically enhance shelf-life, nutrition, and reduce unacceptable food losses (Flores-Lopez et al., 2016; Helmstetter, 2018). Nanotechnology is also used in polymers to coat seeds to increase their shelf-life and increase their germination success and production for niche, high-value crops (Davies et al., 2018).

Just as humans have a gut microbiome, plants have a root microbiome that offers much potential in integrated pest management (IPM) systems for increased plant resistance to environmental and pathogen stress (Fitzpatrick et al., 2018). These rhizosphere microorganisms (bacteria, beneficial fungi) can enhance plant nutrient uptake, drought resistance, and signaling important to plant development (Fitzpatrick et al., 2018; Ingham, 2018). The Earth Microbiome Project is just beginning to address how to better utilize these rhizosphere organisms (Gilbert et al., 2014). This could lead to a new, environmentally friendly, naturally produced, biological fertilizers, herbicides, fungicides, and pesticides (Davies et al., 2005).

IPM can increase vegetable and fruit yield while reducing chemical usage (Parsa et al., 2014). Furthermore, the use of IPM can be enhanced by portable, hand-held, genomic sequencing technology, available in Africa and other developing regions, to identify in the field beneficial root microbiome organisms, plant pathogens, or food contaminants (Craighead, 2009; Regalado, 2017b). For example, there are portable sequencing devices, the size of USB sticks that are connected to a smart-phone that is in turn connected to the cloud to stream data in real time. It enables cost-effective, "lab-in-the-hand" genomic sequencing without requiring a physical lab and elaborate equipment to be located in the developing country where the devices would be used.

Sustainable intensification of agriculture is smart agriculture that uses agroecology, inorganic, and organic farming, and IPM through judicious use of chemicals, including fertilizers, and pesticides (Altieri, 1992; Garnett et al., 2013). Organic agriculture alone is insufficient to feed the world, although it is an important part of the matrix of different agricultural production systems. Many of the newest pesticides are very targeted to specific pests, not harmful to the ecosystem, and enable beneficial, predatory insects to thrive. Good agricultural practices (GAPs) imply smart use of chemicals, pesticides, and fossil fuels that are environmentally and economically sustainable. According to Wilcox (2011), a world without inorganic, chemical usage is neither "greener" nor sustainable.

## TECHNOLOGY FOR IN CITY PRODUCTION OF PLANT-BASED FOODS, CELLULAR AGRICULTURE, LAB-GROWN MEAT, AND 3D PRINTED FOOD

Lab grown meat, plant-based meat substitutes, and the technology for 3-D printing food may radically change where and how protein and food is produced, including in the cities where it is consumed (Card, 2017). There are a wide range of innovative food alternatives to traditional meats that can supplement or offset the need for livestock, farms, and butchers. The history of innovation is about getting rid of the bottle neck in the system, and with meat, the bottleneck is the animal. Finless Foods is a new company trying to reduce use of fish by replicating fish filets (Lamb, 2018). Rather than giving up the experience of eating red meat, technology is enabling marketable, attractive plant-based meat substitutes, and lab-grown meat that can potentially drastically reduce world per capita consumption of animal-produced red meat. It turns out that current agricultural production systems for "red meat" have a far greater detrimental impact on the environment than automobiles (Weber and Matthews, 2008; Ritchie et al., 2018).

There have been significant advances in plant-based foods, like the "Impossible Burger" and "Beyond Meat," that can satisfy the consumer's experience and perception of meat (Kummer,

[1] While there is much disinformation about genetically modified crops (GMOs), they are no less safe than sustainably produced plants and animals using traditional systems. CRISPR uses modern biotechnology without introducing "foreign genes"—hence the end-product is a non-GMO. There is no ethical justification for not incorporating CRISPR technology with traditional breeding and selection systems to speed up the introduction of drought, disease, and climate-resistant, biofortified crops, and animals that are essential for sustainably feeding the world. Humankind has been genetically modifying plants and animals, which was critical for the first Agricultural Revolution. The mule is a cross between a donkey and a horse. None of the original parents of corn, rice, wheat resemble today's modern genotypes. The commercial banana is a clonally produced, sterile triploid, and the modern apple is clonally grafted on dwarfing rootstock.

2015; Calderone, 2016). There have also been major advances in "growing" real meat in labs using animal cells.

To eliminate the inefficiency in raising animals for slaughter—scientific teams and startups are developing laboratory produced meat for animal-free burgers, chicken, turkey, and fish to create new sustainable, commercial industries (Card, 2017). In the future, "clean meat" can be produced starting with muscle stem cells from live cattle, using what is called "cellular agriculture" (Shapiro, 2018). Several startups, including Memphis Meats, are pioneering "clean meat" or cultured meat, ranging from beef to chicken. Cells of live animals can be cultured in urban "breweries" that subsequently reduce the use of land, water, and greenhouse gas emissions by more than 90%, and produce significant health benefits (Zaraska, 2016). These meat-producing breweries could become nodes in UFEs throughout the world.

3D printing or additive manufacturing is a "general purpose technology" that is being used for making everything from plastic toys and human tissues to aircraft parts, buildings, and on-demand replacement parts—which are badly needed in the developing world for tractors, pumps, and other equipment (Campbell et al., 2011). Catapult Design (https://catapultdesign.org/) 3D prints tractor replacement parts as well as corn shellers, cart designs, prosthetic limbs, and rolling water barrels for the Indian market. 3D printing also can be used to convert alternative ingredients such as proteins from algae, beet leaves, or insects into tasty and healthy products that can produced by small, inexpensive printers in home kitchens (https://foodink.naturalmachines.com/) (Chadwick, 2017). The food can be customized for individual health needs as well as preferences.

Acceptance of these plant-based, lab-grown, and 3D printed foods, will require changing diet choices through education, marketing, and developing affordable, tasty, plant-based substitutes through technology. This is not only critical for environmental sustainability, but also offers opportunities for new businesses and services.

## DEVELOPING NEXT GENERATION URBAN AND RURAL PRODUCERS AND PLAYERS—INTEGRATING NEW WITH UNDERUTILIZED TECHNOLOGIES

The key to advancing UFEs will be educating, developing and mentoring a new generation of urban producers and value chain players (Christiaensen, 2017; Townsend et al., 2017). They will not necessarily have grown up on a farm but rather learned their trades within the growing UFEs. They will be part of the collaborative economy connected to digital platforms, artificial intelligence, the cloud, and the internet of things (Lohr, 2015; Ray, 2017). The new UFEs will connect producers, horticulturists, agronomists, plant biologists, distributers, traders, marketers, urban planners, nutritionists, chefs, educators, food processors, computer programmers, engineers (chemical, mechanical, electrical, environmental), and social scientists. As an example, MIT's OpenAg is committed to developing a new generation of farmers (England, 2017; Ferrer et al., 2019). It is doing so by targeting schools. "I want kids to see agriculture as an exciting field where they can innovate, explore, and make a real impact on their communities and on the world," OpenAg founder Harper says; "Creating an exciting technology platform that inspires students to innovate and explore is our best bet toward a better future of food."

There are niche market opportunities in Africa for farmers to service urban markets with high-value, vegetable crops. But lack of access to credit and insurance, low-quality seed, lack of technical assistance, and direct links to markets limit the ability of smallholder farmers to become more commercially successful. Efforts to address this problem include Amiran, which is a commercial greenhouse supplier in Kenya. It has developed Amiran "farmer kits "to improve the livelihoods of smallholders." It is a micro-niche, "packaging technology" approach—using technology for producing high-value horticulture crops with smallholders linked to markets http://www.amirankenya.com/agribusiness2/agribusiness-afk/imp-afk-2 (Chao-Blasto, 2014). There is also support from the Kenyan government, and commercial banks in Kenya supply low-interest loans and reinsurance that is used for micro-insurance of production inputs (e.g., high-value horticulture seed, greenhouse materials, drip-irrigation, chemicals, etc.). The $4,000 micro-loan package is to be paid off over a period of several seasons, based on the high-value vegetable crop cash flow.

The Amiran program targets young producers and technologically savvy entrepreneurs (both from on- and off-farm) who are 35-years-old and younger. They are required to contribute 10% collateral, so they have "skin in the game." The vegetable production system utilizes low-cost, insect-screened greenhouse structures, outdoor drip irrigation and high quality (hybrid) seed. There is access to trainers, pest-certification, and assistance to forge direct links to markets. These technologies are appropriate for urban, peri-urban, and rural producers in the developing world for servicing urban markets with high-value, horticultural product.

Modern UFE technologies—can help smallholder farmers create viable businesses. This includes developing business-to-business (B-to-B) down-stream opportunities, linked to markets. For instance, custom seed propagators of high value vegetable and floriculture crops can raise seedlings to the "plug stage" in seedling tray systems—and sell them to producers/farmers (Davies et al., 2018). While it is more expensive for farmers to buy the "plugs" rather than propagate their crops, the seedling plugs assure farmers they will have successful crops that will be of high quality, and be produced more quickly to meet market demands. Amiran has a partnership with Plantech to supply seedling vegetable plugs to its growers who transplant them and finish off the crop (de Nijs, 2016). In Vietnam there are also custom propagators of grafted vegetable seedling plugs with greater yields and pest resistance. This is another B-to-B technology, selling directly to farmers to transplant in their fields, and CEA- hoop-house tunnels to grow and "finish off" marketable vegetable crops.

Less than five percent of the African agriculture is irrigated. This is a recipe for disaster. You cannot reliably grow quality vegetables and fruits without irrigation, which becomes even more critical with the impact of extreme climate change. "Packaging technologies" such as solar pumps with precision soil sensors linked to the cloud will greatly enhance the effectiveness of efficient, low-cost, drip irrigation systems. These systems can be used in both rural and urban production systems. Packaging UFE technologies that are linked to value chains (markets) is critical for sustainable food production.

For Africa and much of the developing world, food security and moving out of poverty will be dependent on a second Green Revolution. This entails sustainable intensification, biodiversity, biotechnology/molecular biology, development of climate-resistant high-yielding crops, better adaption of current and future technologies that enable GAPs, uberization, and a platform-connected "internet-of-food-things"[2](Anon, 2018e; Shaw, 2018). This will require a diverse-group of entrepreneurs along the value chain from production to servicing consumers. Providing urban and peri-urban markets with high-value niche crops and services offers great opportunities for smallholder entrepreneurs and for meeting world food security and nutritional requirements. Technology is the platform to better connect the nexus of food, water, energy, nutrition, human health, sustainability (environmental, economic, societal), and smart policy—and to do so in a way that is scalable, affordable, and sustainable.

## WAY FORWARD: BUILDING TOMORROW'S INTEGRATED UFES

Technology alone will not solve the developing world's challenge of creating the next generation sustainable UFEs. The "elephant in the room" hindering progress is development and enforcement of smart policies on land use, land ownership, trade, entrepreneurship, credit and market access, cooperatives, transparency in government, rule of law, education, eradicating illiteracy—and country-wide investment in agriculture, all-weather roads, and reliable electricity (Mengoub, 2018). There also needs to be *local capacity building* and *mentorship* for scaling up technology deployment (Yeboah, 2018). Successful UFEs cannot rely on a "top-down," master-plan approach. Rather, it is critical to encourage and support development of a "bottom-up" collaboration that integrates local knowledge and ideas with technology that is linked to value-chains (markets). The interconnectivity of UFEs technologies will better enable local entrepreneurs to adapt and grow their businesses.

What is needed is a holistic, comprehensive approach that utilizes the powerful new tools and innovative business models to build UFEs that connect rural, peri-urban, and urban food production, processing, distribution, and consumption. They must be economically, environmentally, and socially sustainable, and supported by government policies and civil society. This will require a multi-discipline path linked to value-chains and dependent on sound policy and transparency (trade, land-ownership, access to finance, markets), information delivery, and GAPs (Reardon, 2016; Anon, 2018c; Yeboah, 2018). In short, a "package approach" that leads to entrepreneurship and new opportunities. UFEs will be increasingly enhanced by use of artificial intelligence, growing data streams, blockchain, Internet of Things, drones, and robotics—all of which are dramatically improving in capabilities. The cost of these and other exponential technologies is also falling, often exponentially, which will increase their availability in the developing world and overall potential for a "better, cheaper, faster, scalable" approach to development—including development of UFEs (UN-CTAD, 2018).

[2]Rajiv Shah, the former Administrator of USAID and current head of the Rockefeller Foundation, observed that some of the greatest leaps in human progress have not come from *just* new technologies—but by applying those technologies locally. There are underutilized technologies, which if digitally connected, could have a dramatic impact on the food ecosystem.

## AUTHOR CONTRIBUTIONS

The authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication. FD and BG collaborated in conceptualizing how technology platforms, linked to value-chains, can revolutionize the urban food system in the developing world. FD wrote the original draft with multiple inputs from BG.

## ACKNOWLEDGMENTS

The authors thank Andrea Lazenby, journal development specialist, and guest editors, R. Lawford, R. Mohtar, J. Engel-Cox, and M. Schweitzer, for the invitation and their assistance to submit a manuscript for publication in the Nutrition and Environmental Sustainability Specialty Section of the *Frontiers in Sustainable Food Systems*.

## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2018.00084/full#supplementary-material

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**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.