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Environmental Sustainability through Control Environment Agriculture

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ABSTRACT

The global megatrends of decreasing water supply, increasing population, urbanization, and unabated climate change have contributed to globally decreasing stocks of arable land per person. Under these circumstances, the sustainability of the traditional farming model based on large rural farms is likely to come under threat in coming decades. One approach for engaging with this challenging problem is vertical farming, which is based on controlled-environment agriculture. Aim of this this article was to find out the environmental sustainability through control environment agriculture for future food production. This study was conducted based on secondary sources as literature survey. Controlled environment agriculture (CEA) is a technology for plant production in environmentally controlled structures such as high tunnels, greenhouses, growth chambers, or indoor vertical farming warehouse farming. The potential benefits of vertical farming include a sustainable food-production model with all-year-round crop production, higher yields by an order of magnitude, and freedom from droughts, floods, and pests. The environmental benefits are significant, including providing healthy organic food not contaminated from chemicals. No pollution or exceptionally low pollution due to no use of pesticide, chemical fertilizer, and minimum use of water. More research is also needed that carefully assesses and confirms this environmental benefit at different locations and scales for a specific crop.

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Introduction

World food demand is increasing with the same direction while population is increasing. An emerging global problem is the long-term decreasing stock of agricultural land per capita (Benke & Tomkins, 2017). Statistics on future growth of the world population from the United Nations Food and Agriculture Organization (FAO) reveal that arable land per person is projected to decrease by 2050 to one-third of the amount available in 1970 (FAO, 2016). This decline is forecasted to continue due to the effects of climate change, the increasing geographic extent of drylands, the reduction in fresh water supply, and population growth (Fedoroff, 2015). A more complete list of prominent threats to the future supply of arable land would also include: climate change, declining fisheries (prompting a greater food burden on land-based products), increasing urbanization, rising costs of agribusiness (e.g. fertilizers, fuel, pesticides), rapidly increasing population, soil depletion, and degradation from over-farming and poor production practices (Benke & Tomkins, 2017). The growing need for more food has escalated over the last few years, and as a result, it is of vital importance to adopt more sustainable and efficient food production solutions (Avgoustaki & Xydis, 2020).

It is estimated that the demand for food will increase by almost 70%, causing food security challenges and putting pressure on the current food systems (Rosegrant & Cline, 2003). Scarcity of freshwater resources will continue to be a major limiting factor for increased food production with conventional farming practices (Foley *et al*., 2011). Traditionally, crops are produced in soil-based open field systems. Due to seasonality, environmental extremes, and soil-borne diseases, crop yield and quality varies significantly, and year-round production is impossible in most regions for most crops (Niu & Masabni, 2018). Availability of farmlands will also become a main limitation around the world, with an increasing demand for urbanization and residential development to accommodate the needs of a booming population (Alig *et al.*, 2004). Besides land scarcity, long-term land degradation is another factor that affects sustained food production. It is obvious that converting forest lands or wetlands will be undesirable because such land transformation will lead to deforestation, soil erosion, increased greenhouse gas (GHG) emission, and ultimately the losses of other essential ecosystem services (Qiu & Turner, 2013; Qiu *et al.*, 2018). Hence, to meet the world's future food security and resource demands, there is a compelling need to explore innovative farming solutions that allow the production of more food per land or water use while simultaneously minimizing its environmental footprints.

The innovated controlled environment agriculture (CEA) is a technology which has claimed to more environmentally sustainable crop production. The CEA is a technology for plant production in environmentally-controlled structures such as high tunnels, greenhouses, growth chambers, or indoor vertical farming (warehouse farming) (Niu & Masabni, 2018). The aim of CEA is to increase crop production maintaining growing conditions for optimizing plant growth and quality providing protection from pests and diseases.

This article finds out the environmental sustainability through control environment agriculture for future food production. This study was conducted based on secondary sources as literature survey.

Growing demand for agricultural production

Fundamental changes are predicted to occur in the upcoming 50 years accompanied by higher demand for food, all across the world as the world population continues to grow exponentially (Banerjee & Adenaeuer, 2014). The world population is predicted to reach an estimated 9 billion by 2050 (Despommier, 2013), and cities will be hosting about 80 % of this population (Despommier, 2011a; Islam & Siwar, 2012). Currently, there is approximately 800 million hectares of land that is designated to soil-based farming globally, which constitutes about 38 % of the total global land area (Kalantari *et al*., 2018a). Moreover, 80 % of the total arable land is currently being utilized across the globe (Ellingsen & Despommier, 2008). As the population is increasing, food demand is also increasing with the same direction. To meet the growing food demand, there is a need for utilizing more arable land for farming as swell as intensifying farming efforts that would affect global agriculture. Conventional food production indicates that the prevailing food system is increasingly associated with unsustainable practices and the respective negative environmental impacts such as land and water degradation, the acceleration of climate change or a loss in biodiversity (Specht *et al*., 2019).

A new method that could potentially meet this demand, is in designing and developing vertical farms (Despommier, 2013). In theory, Vertical Farming (VF) is an agricultural technique involving large-scale food production in high-rise buildings that enables fast growth and planned production by controlling environmental conditions and nutrient solutions to crops based on hydroponics, using cutting-edge greenhouse methods and technologies (Abel, 2010; Banerjee & Adenaeuer, 2014; Despommier, 2011a, 2011b). The proposed designs can be tested through new technologies (Despommier, 2011b), however, VF is a fairly new concept and little studies have explored the issue of integrating it in the urban context (Kalantari *et al*., 2018a). This control environment agriculture as vertical farming will meet the future food demand in cities as well as all areas of the world.

Controlled environment agriculture

Traditionally, crops are produced in soil-based open field systems. Due to seasonality, environmental extremes, and soil-borne diseases, crop yield and quality varies significantly, and year-round production is impossible in most regions for most crops (Niu & Masabni, 2018). Controlled environment agriculture (CEA) is a technology for plant production in environmentally-controlled structures such as high tunnels, greenhouses, growth chambers, or indoor vertical farming (warehouse farming) (Niu & Masabni, 2018). The aim of CEA is to increase crop production, provide protection from pests and diseases and maintain growing conditions for optimizing plant growth and quality. The environmental conditions inside an indoor CEA can be controlled precisely at desirable levels because artificial lighting is used instead of sunlight while inside greenhouses are still dependent on outside conditions such as temperature and solar radiation. Thus, manipulating light quality (or the spectrum) and light intensity to enhance plant growth and quality has become one of the most popular research fields in recent years (Niu & Masabni, 2018).

Environmental factors in CEA

Regardless of CEA type, there are five essential environmental conditions that affect plant growth and development (Niu & Masabni, 2018):

a) Temperature
b) Light

c) Carbon di oxide CO2
d) Water and
e) Nutrients

A significant number of studies were carried out more than two decades ago on controlling greenhouse temperatures for floricultural crop production. Supplemental lighting when natural light is low in winter months and low-light intensity photoperiodic lighting for flowering control have been common approaches. The rapid evolution in plant LED lighting technologies experienced in the last decade has resulted in revolutionary changes in the greenhouse and controlled-environment agricultural industry sector (Gómez & Izzo, 2018). A crop production system through control environment agriculture (as hydroponic), which resembled a deep-water culture, are illustrated in Figure 1. Within the control environment any types of crops could be produced in all season or year-round. By controlling light and temperature, it would be possible to flowering of any crop or vegetable and increase and maintain the growth.

Types of indoor control farms

The dependency of agricultural productivity on the environment may be reduced by moving plant production indoors (Specht *et al*., 2019). Indoor farming, which is based on controlled-environment agriculture, can provide optimal growing conditions to maximize the yield per growing space and enable year-round production. Indoor farming can potentially ensure stable, location-independent harvests, especially in times of climate change and increasingly frequent extreme weather events (Despommier, 2013). In indoor farming, just as in vertical farming soil-less vertical plant-production systems are preferred, as they allow an efficient use of space and resources (Banerjee & Adenaeuer, 2014). Maximum control over production methods can also reduce the use of fertilizer and pesticides and, as a consequence, reduce the environmental impact of food production (Specht *et al*., 2014).

One type of indoor farm is the vertical farm, in which plants (and animals) are cultivated on multiple levels (Despommier, 2011a). The three main techniques used in vertical farming are hydroponics, aeroponics and aquaponics, often in combination with computerized or automated systems including artificial light (Al-Kodmany, 2018). Aquaponics is an approach that combines aquaculture and hydroculture (Specht *et al.*, 2019). It enables the production of fish and leafy vegetables in cities (Love *et al*., 2015). This method uses resources more efficiently than aquaculture, as both nutrients and water are recycled (Cohen *et al*., 2018). The circulation of wastewater from the fish tank ensures fertilization of the plants and prevents nutrient discharge (Blidariu & Grozea, 2011).

Another type of indoor urban farming encompassing indoor farms is the “zero-acreage farming” (Zfarming) a concept coined Specht *et al*. (2014). Zfarming are forms of farming that do not use farmlands or open space (Milestad *et al*., 2020). This includes rooftop gardens and greenhouses, edible green walls, indoor farms and vertical greenhouses (Specht *et al*., 2014). A large proportion of forms of such farms seem to be located in North America, followed by Asia (Thomaier *et al*., 2015; Al-Kodmany, 2018).

All types of indoor control farming such as hydroponics, aeroponics, aquaponics and zero-acreage farming have the potentiality to produce more crop with less environmental impact compare to the conventional farming. In these control farming uses less land, less water, no pesticides etc. Therefore, these farming is very much environment friendly. Thus, this farming technology would ensure environmental sustainability.

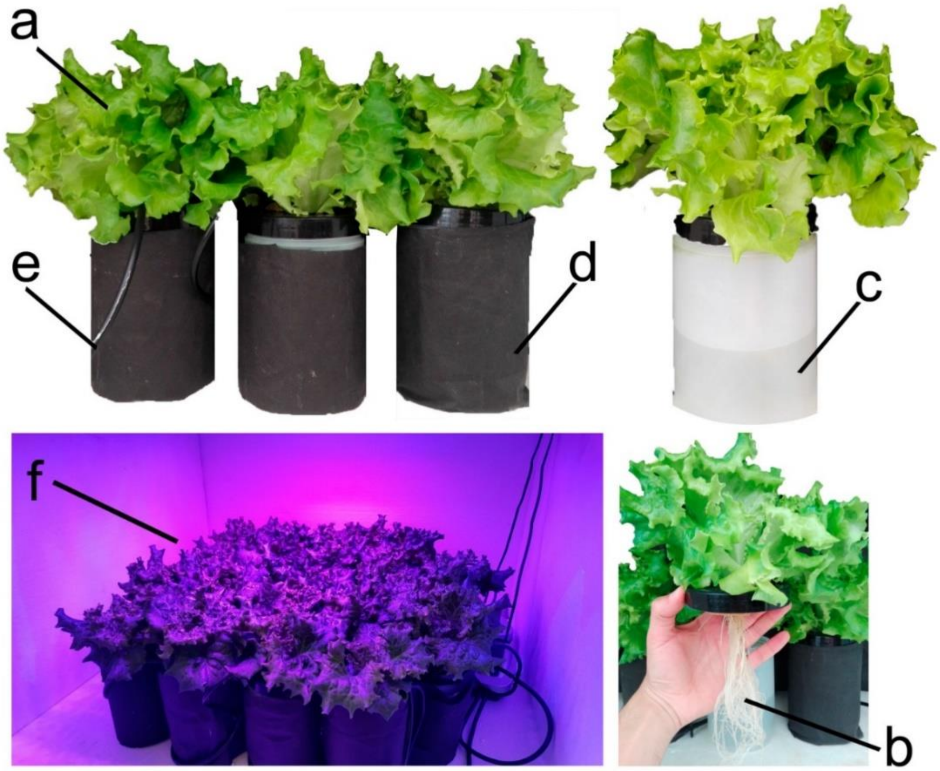


Figure 1 Images of the crop production system through control environment agriculture. Plants (a) are grown on individual deep-water culture hydroponic systems where the root system (b) floats into the nutrient solution, (c) contained in a plastic jar and (d) screened from light by a black cloth. Constant aeration of the nutrient solution is provided by air pumps and distributed to individual growing systems through tubes (e). Each light treatment is allocated to a light insulated compartment (f) of a climate controlled chamber, with white painted walls and fans allowing for air recirculation (Pennisi, Sanyé-Mengual, *et al*., 2019).

Indoor urban vertical farming

Indoor urban vertical farming (IUVF), based on controlled-environment agriculture, is another way of allowing a fresh, locally grown food production, i.e., the possibility of a year-round crop production (Avgoustaki & Xydis, 2020). The IUVF is a new promising technology that allows us to optimize agricultural production and convert it from traditional farming to an integrated urban network using the most innovative and sustainable technological achievements of our time (Avgoustaki & Xydis, 2020). In IUVF, plants grow indoors by using hydroponic methods (aeroponic or fogoponic in a few cases) and artificial lighting that simulates solar radiation (Avgoustaki & Xydis, 2020).

The vertical farming model is essentially an indoor farm based on a high-rise multi-level factory design (Benke & Tomkins, 2017). Typical features include innovative use of recycled water augmented by rainwater or water from a desalination plant, automatic air-temperature and humidity control, solar panel lighting and heating, and tunable 24-hour LED illumination (Benke & Tomkins, 2017). The LED equipment can be controlled throughout a growing season to emit a programmed spectrum of light that is optimal for photosynthesis for different types of crops (Benke & Tomkins, 2017). When coupled with regulation of temperature and humidity, the effects of seasonality can be minimized or eliminated (Benke & Tomkins, 2017). The principal design elements of a vertical farm and its derivatives are shown in Figure 2. Incorporating the IUVF it is possible to grow crop for the increasing urban people in their local areas. Thus, it will reduce the transportation cost as well as minimize environmental impact from traditional farming in the farm land.

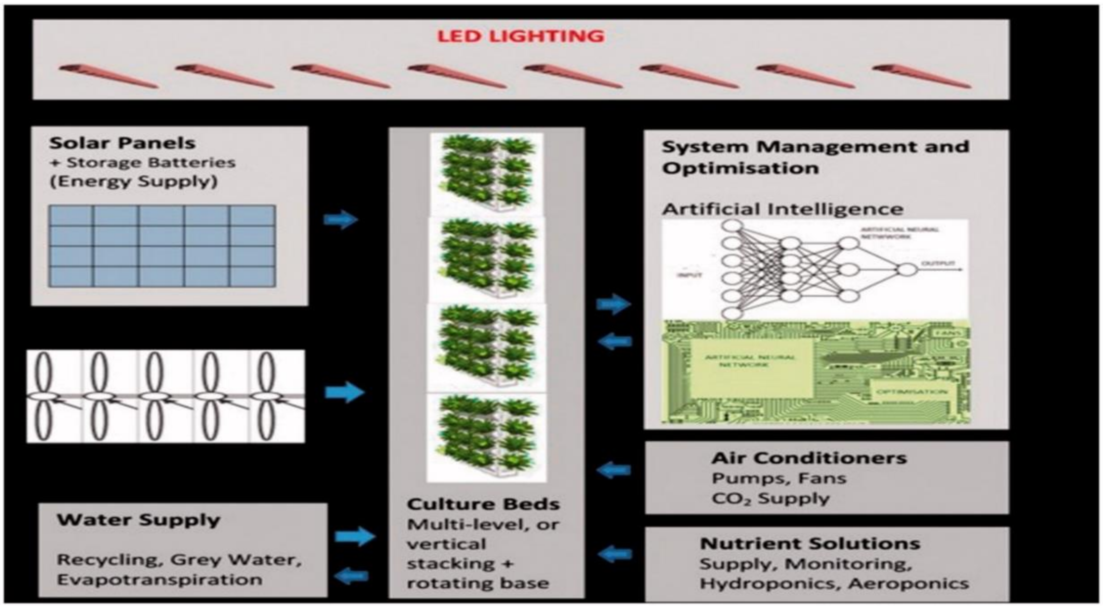


Figure 2 Components of a vertical farm, one kind of control environment agriculture, and their interactions (Benke & Tomkins, 2017)

Potentials of vertical control farming

The vertical farming model was proposed with the aim of increasing the amount of agricultural land by 'building upwards' (Benke & Tomkins, 2017). In other words, the effective arable area for crops can be increased by constructing a high-rise building with many levels on the same footprint of land (Despommier, 2011a). One approach is to employ a single tall glasshouse design with many racks of crops stacked vertically (Benke & Tomkins, 2017). It is an extension of the greenhouse hydroponic farming model and addresses problems relating to the use of soils, such as the requirement for herbicides, pesticides, and fertilizers. All-year-round production can be programmed on a demand basis, and plant-growing conditions can be optimized to maximize yield by fine-tuning temperature, humidity, and lighting conditions. Transportation costs can also be eliminated due to proximity to the consumer. Indoor farming in a controlled environment also requires much less water than outdoor farming because there is recycling of gray water and less evaporation (Benke & Tomkins, 2017). Because of these features, its wider adoption is likely to occur initially in desert and drought-stricken regions, such as some areas in the Middle East and Africa, and in small and highly urbanized countries such as Israel, Japan, and the Netherlands (Benke & Tomkins, 2017). Vertical farming is also attractive where there is a high demand for clean, green, and gourmet (CGG) food in countries that suffer from heavy pollution and soil depletion, such as parts of China (Benke & Tomkins, 2017).

The Mirai company in Japan has developed and marketed indoor multilevel farms with impressive production statistics (Benke & Tomkins, 2017). For example, one Japanese farm comprises 25,000 square meters producing 10,000 heads of lettuce per day (100 times more per square foot than traditional methods) with 40% less energy, 80% less food waste, and 99% less water usage than outdoor fields (Kohlstedt, 2015). New factories are now being planned for Hong Kong, Mongolia, Russia, and China (Benke & Tomkins, 2017). Special purpose LED lighting allows plants to grow up to two and half times faster and has decreased the cycle of days and nights with optimized temperature and humidity conditions (Benke & Tomkins, 2017). Mirai concentrates on fast-growing leafy vegetables that can be sent to market quickly (Benke & Tomkins, 2017).

Environmental sustainability of CEA

The potential benefits of vertical farming include a sustainable food-production model with all-year-round crop production, higher yields by an order of magnitude, and freedom from droughts, floods, and pests (Benke & Tomkins, 2017). The approach is compatible with water recycling, ecosystem restoration, reduction of pathogens, energy production by methane generation from com-post, decreased use of fossil fuels (no tractors, plows, or shipping), generation of new jobs for many years, and low or no requirement for pesticides (Table 1).

As the application of indoor farming technologies takes place in several regions of the world—mainly in Asian (42%), European (30%) and North American (21%) countries—the market is expected to reach a global value of 5.80 billion USD by 2022 (Pennisi, Sanyé-Mengual, *et al*., 2019). From a production perspective, indoor farming systems allow for increasing yields (up to 23-fold, as compared to traditional agriculture (Cicekli & Barlas, 2014), improved food quality (Piovene *et al*., 2015), and greater production stability due to enhanced resilience to climatic events as compared with traditional agricultural systems

(Kozai *et al*., 2015). The potential for reducing land use for agriculture is associated with both the possibility to explore the vertical dimension allowed by the use of artificial lighting (Kozai *et al*., 2015), the possibilities offered for year-round production (Kozai *et al*., 2015), and the potential reconversion of abandoned or unused buildings into agricultural systems (Gasperi *et al*., 2016). Furthermore, the environmental sustainability of crop production is increased by avoiding or limiting the use of pesticides or herbicides (Cicekli & Barlas, 2014) and improving water and nutrient use efficiency (Pennisi, Blasioli, *et al*., 2019). On the other hand, a number of questions arises on the sustainability of indoor plant cultivation with reference to energy use, particularly regarding the energy needs associated with artificial lighting (Kalantari *et al*., 2018b).

Soon, control environment agriculture will create a large income generating company minimizing environmental impact. It will ensure the environmental sustainability as well as trigger to meet the sustainable develop goals.

Table 1 Triple bottom line – potential impacts of vertical farming (Benke & Tomkins, 2017)

Category	Impacts
Environmental	• Export potential of clean, green, and food • No soil is required if hydroponics is used • Reduces fossil fuel use by employing renewable energy sources • Reduction in carbon levels
Economics	• Improved productivity • Reduced cost base for fertilizers, herbicides, and pesticides • No losses due to floods, droughts or sun damage Reduced transportation costs • No requirement for farm-rolling stock • Production can be programmed to match demand because no seasonality issues
Social	• Rejuvenation of the ecosystem Environmental sustainability • Provides employment in regional areas • Addresses social isolation in remote rural communities by providing jobs in towns • Increases demand for trade workers in construction, renovation, and ongoing maintenance • Provides new jobs in engineering, biochemistry, biotechnology, construction and maintenance, and research and development • Encourages a more holistic lifestyle where apartments and food production are localized and therefore reduces need for vehicles and transport

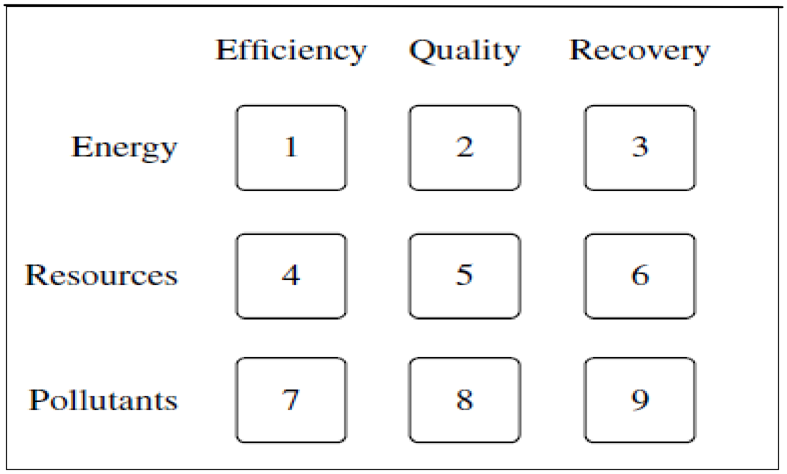
Assessing environmental sustainability of CEA

The generalized matrix strives to serve the purpose of the assessment of environmental sustainability (Figure 3). The row labels in the matrix refer to the three broad impact areas of concern to sustainability: energy, resources (materials), and pollutants (externalities) associated with a process or product (Andrady, 2015). Responsible use of energy and material resources and pollution prevention are the cornerstones of sustainable growth (Geiser, 2001).

(a) Energy: There is greatly reduced use of fossil fuels by avoiding transportation from rural zones to the urban customer base. Burning fossil fuels can be minimized by employing solar panels, roof-top wind turbines, and storage batteries. This will lead to a reduction in ecosystem carbon levels (Benke & Tomkins, 2017).

(b) Resources: In hydroponic no use of soil, and in aeroponic no use of soil and water or minimum use of water. Using recycled water and nutrients in a closed, indoor, climate-controlled environment adds to food security and can reduce or even completely eliminate the need for pesticides and herbicides.

(c) Pollution: The environmental benefits are significant, including providing healthy organic food not contaminated from chemicals. No pollution or very low pollution due to no use of pesticide, chemical fertilizer and minimum use of water. Contamination by pathogens or heavy metals will no longer be an issue as occurs in rural farming. There is scope for marketing the product in this respect. Strict hygienic practices must still be observed to minimize the risk of introduction of pathogens and biological contamination into the growing space. However, in a vertical farming situation, one can closely monitor the crop for signs of pest or disease both manually and automatically using sensing technologies. Any residual contamination can be cleaned up when the crop is harvested using strict hygienic practices.



	Efficiency	Quality	Recovery
Energy	1	2	3
Resources	4	5	6
Pollutants	7	8	9

Figure 1 Sustainability matrix for assessing environmental sustainability (Andrady, 2015)

The three column labels refer to the types of changes needed under each row category (Andrady, 2015). These are

***(a) Efficiency*:** Increasing the efficiency of use and minimizing wastage,

***(b) Quality*:** Considering the quality (of energy, materials, or pollution) in terms of minimum environmental footprint, and

***(c) Recovery*:** Reusing resources as well as waste. This in essence equates waste to a raw material removing disposal as an end of life option. This column incorporates the principles of circular economy.

These nine elements are generally stated as follows (Andrady, 2015):

Element 1: Use the minimum energy needed to manufacture, use, or dispose of products.

Element 2: Select the least polluting, preferably renewable, forms of energy.

Element 3: Capture and reuse waste energy in the same process or elsewhere.

Element 4: Use the minimum amount of material (especially nonrenewable material) to achieve the required functionality.

Element 5: Select the material with minimum environmental footprint that can deliver the required functionality.

Element 6: Reuse and recycle postconsumer products into material, feedstock, or energy.

Element 7: Minimize undesirable externalities associated with processes. Reduce air and water emissions as well as solid waste from manufacturing.

Element 8: Avoid or at least minimize the release of chemicals from processes or products, especially those toxic to humans or disruptive to the ecosystem. Avoid hazardous chemicals in products.

Element 9: Convert emissions otherwise released into the environment (such as CO2) into useful raw materials or products.

Conclusion

An increasing population, urbanization, and climate change have contributed to decreasing global stocks of water and arable land per capita. To produce more food for the increasing population environment is degrading by agricultural activities. Exploring soil, use of water, pesticide, chemical fertilizer etc. are leading the environmental pollution. Under these circumstances, more ‘sustainable’ crop production systems are needed. In other words, more food needs to be produced with less arable land and less water with a zero or minimum environmental degradation. Innovative CEA is an essential future agricultural model, and this has the potentiality to produce desirable food production minimizing environmental degradation. By the CEA environmental sustainability could be achieved. Although there are substantial potential benefits from control environment agriculture for environmental sustainability, more research is needed that carefully assesses and confirms this environmental at different locations and scales for a specific crop.

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