

The Future of Vertical Farming in Agriculture

Abu Anzar Hossain, Mahafuzar Rahaman*

School of Agriculture, Swami Vivekananda University,
Telinipara, Barrackpore, North 24 Parganas, West Bengal
700121, India

*Corresponding author: mahafuzarr@svu.ac.in

Abstract

As the world population grows and arable land becomes scarce, vertical farming is emerging as a transformative approach to sustainable food production. This review explores the future of vertical farming by examining its technological foundations, economic viability, environmental impact, and potential to revolutionize agriculture. Utilizing advanced techniques such as hydroponics, aeroponics, and aquaponics, vertical farms offer resource-efficient, high-yield alternatives to traditional farming. With increasing urbanization, climate volatility, and food insecurity, vertical farming provides a promising solution to produce fresh food locally, year-round, and with minimal ecological footprint. Despite its promise, challenges including high capital costs, energy requirements, and regulatory complexities must be addressed. This paper presents a comprehensive synthesis of current literature, innovations, and global case studies while outlining research gaps and policy recommendations for mainstream adoption. The future of vertical farming hinges on technological innovation, interdisciplinary collaboration, and inclusive policies that support equitable and scalable food systems.

Keywords

Vertical farming, Sustainable food production, Hydroponics, Aeroponics, Aquaponics, Urbanization and climate change, Technological innovation and policy

Introduction

The 21st century is witnessing an unprecedented convergence of challenges in food production, urbanization, and environmental sustainability. With the global population projected to exceed 9 billion by 2050, the pressure on conventional agriculture to feed a growing and increasingly urbanized society is immense (FAO, 2020). Traditional farming practices, though historically reliable, are now struggling against the constraints of land degradation, water scarcity, climate change, and declining biodiversity. These limitations call for innovative and transformative solutions that can augment food security while reducing environmental burdens.

One such innovation is vertical farming—a technique that involves growing crops in vertically stacked layers, often integrated into urban structures such as buildings or repurposed warehouses. Using controlled-environment agriculture (CEA) systems, vertical farms employ hydroponics, aeroponics, or aquaponics to cultivate plants without soil, relying instead on nutrient-rich solutions and artificial lighting to simulate optimal growing conditions year-round. Unlike traditional agriculture, which is heavily dependent on large tracts of fertile land, vertical farming thrives in compact, urban spaces and can operate independently of external climatic conditions (Despommier, 2010).

The rationale for vertical farming lies in its potential to mitigate many of the shortcomings of traditional agricultural models. Urbanization has significantly reduced the availability of arable land, with rapid infrastructure expansion converting fertile farmlands into residential and industrial zones (Lambin & Meyfroidt, 2011). Furthermore, climate-induced disturbances such as floods, droughts, and soil erosion continue to disrupt conventional farming outputs, threatening global food supply chains. Vertical farming offers an opportunity to counter these issues by enabling year-round crop production, reducing transportation costs, lowering freshwater consumption by up to 95%, and significantly decreasing the carbon footprint associated with long-distance food logistics (Eigenbrod & Gruda, 2015; Kalantari et al., 2017).

The rationale for vertical farming lies in its potential to mitigate many of the shortcomings of traditional agricultural models. Urbanization has significantly reduced the availability of arable land, with rapid infrastructure expansion converting fertile farmlands into residential and industrial zones (Lambin & Meyfroidt, 2011). Furthermore, climate-induced disturbances such as floods, droughts, and soil erosion continue to disrupt conventional farming outputs, threatening global food supply chains. Vertical farming offers an opportunity to counter these issues by enabling year-round crop production, reducing transportation costs, lowering freshwater consumption by up to 95%, and significantly decreasing the carbon footprint associated with long-distance food logistics (Eigenbrod & Gruda, 2015; Kalantari et al., 2017).

Evolution

● Historical Overview

Vertical farming as a concept has evolved through centuries of agricultural innovation. Although the term itself was coined much later, early forms of stacked agriculture were practiced in ancient civilizations such as the Hanging Gardens of Babylon. These early techniques foreshadowed the concept of growing plants in vertically tiered structures to maximize space utilization (Despommier, 2010).

In 1915, American geologist Gilbert Ellis Bailey introduced the term “vertical farming” in his book of the same title, which envisioned underground farming structures. However, it was not until the late 1990s that the modern form of vertical farming began to take shape. Professor Dickson Despommier of Columbia University revitalized the idea by proposing multi-story indoor farms capable of feeding urban populations sustainably. His students developed conceptual designs for vertical farms, sparking academic and public interest in this futuristic model (Despommier, 2013).

Technological Advancements

The advancement of key technologies such as LED lighting, nutrient film technique (NFT), automated climate controls, and closed-loop hydroponic systems has significantly

propelled vertical farming into the commercial mainstream. NASA's experiments on growing food in controlled environments for space exploration also contributed to the development of efficient soilless cultivation systems (Bugbee, 2004). These breakthroughs have enabled vertical farms to become viable alternatives to traditional farms, especially in urban environments where space is constrained. Innovations in data-driven agriculture, including AI-driven monitoring and IoT-based environmental control, are further enhancing the precision and efficiency of these systems (Kalantari et al., 2017).

- **From Concept to Commercialization**

Vertical farming has transitioned from academic speculation to commercial reality, particularly in the past two decades. Companies such as AeroFarms (USA), Plantagon (Sweden), and Spread (Japan) have developed fully operational indoor farms that produce leafy greens, herbs, and microgreens with minimal environmental impact. These facilities are not only optimizing resource use but are also redefining the supply chain by bringing production closer to consumption centers (Benke & Tomkins, 2017).

Drivers of Vertical Farming: Urbanization, Climate Change, and Food Security

- **Urbanization and Land Scarcity**

The global urban population is expected to rise to nearly 68% by 2050 (UN DESA, 2018). This rapid urbanization is leading to the conversion of agricultural lands into residential and industrial zones, diminishing the availability of fertile soil for traditional farming. Urban vertical farms present a practical solution by utilizing underused urban spaces such as rooftops, basements, and warehouses for food production (Lambin & Meyfroidt, 2011).

- **Climate Change and Environmental Degradation**

Climate change has become a formidable threat to agriculture through erratic weather patterns, droughts, floods, and rising temperatures. In 2011 alone, the U.S. faced a \$110 billion loss in grain due to extreme drought (Martin et al., 2016). Vertical

farming, with its climate-controlled environments, shields crops from these externalities, ensuring stable production cycles irrespective of outdoor weather conditions (Kalantari et al., 2018)

Furthermore, vertical farming minimizes environmental degradation by eliminating the need for plowing, heavy pesticide use, and irrigation practices that deplete water tables. It recycles water through closed systems, reducing consumption by up to 95% compared to conventional agriculture (Eigenbrod & Gruda, 2015).

● **Food Security and Population Growth**

Feeding an additional 3 billion people by 2050 will require a 70% increase in food production (FAO, 2020). Traditional methods are ill-equipped to meet this demand without intensifying environmental harm. Vertical farming can play a critical role by producing food closer to urban consumers, reducing transport-related emissions, and offering consistent yields with reduced input (Despommier, 2010).

● **Socioeconomic Factors**

Food deserts in urban centers disproportionately affect low-income populations. Vertical farms embedded within city neighborhoods can increase access to fresh, nutritious produce while also creating local jobs in agriculture, engineering, and logistics. Moreover, by shortening the supply chain, vertical farms reduce dependency on imports and global food markets, increasing regional resilience (Thomaier et al., 2015).

Technological Pillars of Vertical Farming

● **Hydroponics**

Hydroponics involves growing plants in a nutrient-rich water solution without soil. This method offers superior control over nutrient delivery and root oxygenation, resulting in faster growth and higher yields. Commercial hydroponic farms, such as those run by Eurofresh Farms in Arizona, have proven the scalability and economic feasibility of this method (Savvas, 2003; Bugbee, 2004).

Hydroponic systems can be categorized into various types: Deep Water Culture, Ebb and Flow, Drip System, Wick System, and Nutrient Film Technique (NFT). Each system is suited to specific crops and scales of operation. Their closed-loop nature minimizes water use and nutrient runoff, enhancing sustainability (Al-Kodmany, 2018).

- **Aeroponics**

Aeroponics is a more advanced form of hydroponics where plant roots are suspended in air and misted with nutrient solutions. This system maximizes oxygen availability and is highly efficient in water usage. Aeroponic systems are particularly suited for environments where water is scarce or expensive. NASA has extensively researched aeroponics for space missions due to its minimal resource requirements (Lee & Lee, 2015).

- **Aquaponics**

Aquaponics integrates hydroponics with aquaculture, creating a symbiotic environment where fish waste provides nutrients for plant growth, and plants help filter and purify water for the fish. This closed-loop system reduces waste and eliminates the need for synthetic fertilizers. Aquaponics is especially effective in developing regions where integrated food systems can provide both protein and vegetables (Rakocy et al., 2006).

- **Controlled Environment Agriculture (CEA) Technologies**

CEA involves the use of sensors, artificial lighting (especially LED), automated nutrient delivery, and climate control systems. These technologies allow vertical farms to maintain optimal conditions for crop growth year-round. Integration with artificial intelligence and Internet of Things (IoT) platforms enables real-time monitoring and adaptive responses to crop needs, improving productivity and reducing resource waste (Benke & Tomkins, 2017).

- **Lighting and Energy Systems**

Lighting is a critical factor in vertical farming. The shift from high-pressure sodium lamps to energy-efficient LEDs

has drastically reduced power consumption while enabling precise light spectrum control. LEDs tailored to specific wavelengths can enhance photosynthesis and reduce energy costs. However, electricity remains a major operational expense, highlighting the need for renewable energy integration (Kalantari et al., 2017).

Architectural and Infrastructural Innovations

● Vertical Farming Typologies

The physical structure of vertical farms varies significantly, ranging from simple rooftop gardens to sophisticated skyscraper greenhouses. Despommier (2010) classified vertical farms into three main types: (1) retrofitted urban buildings, (2) rooftop farms, and (3) newly constructed high-rise vertical farms. Each typology presents unique architectural challenges and opportunities depending on location, scale, and intended crop diversity.

Retrofitted warehouses are a common choice for early-stage vertical farming operations due to lower capital investment and existing urban integration. These structures are often equipped with LED lighting, hydroponic systems, and environmental control infrastructure. Skyscraper farms, though costlier to build, maximize vertical space utilization and offer significantly higher productivity per square meter of land (Al-Kodmany, 2018).

● Design Considerations

Designing vertical farms involves integrating engineering, architecture, and agronomy. Important design features include:

- Modular layouts for scalable production
- Efficient HVAC systems for humidity and temperature control
- Automated irrigation and nutrient delivery infrastructure
- Optimized lighting setups for uniform growth
- Structural reinforcements to support heavy water and crop loads

These design principles aim to create an ecosystem that is both energy-efficient and productive. Smart building management systems (BMS) are increasingly used to regulate internal farm conditions in real time (Healy & Rosenberg, 2013).

- **Rooftop Farming**

Rooftop farming is a rapidly growing sub-sector within vertical farming. It utilizes the often-unused spaces atop urban buildings for agriculture. Cities like New York, Tokyo, and Singapore have embraced rooftop farming as part of their urban greening strategies (Sanye-Mengual et al., 2015). These systems improve building insulation, reduce stormwater runoff, and contribute to local food production without requiring new land.

Environmental Impacts of Vertical Farming

- **Resource Efficiency**

One of the most cited environmental benefits of vertical farming is its efficiency in resource use. Hydroponic and aeroponic systems use up to 90–95% less water than traditional agriculture due to closed-loop recirculation systems (Eigenbrod & Gruda, 2015). Land use is also minimized, as vertical farming can produce the same crop volume on a fraction of the footprint needed by conventional farms.

- **Reduced Emissions and Pollution**

By locating farms close to urban consumers, vertical farming reduces “food miles”—the distance food travels from farm to plate. This reduction in transportation significantly cuts carbon emissions associated with logistics (Wood et al., 2001). Additionally, vertical farms eliminate or drastically reduce the use of synthetic pesticides and herbicides, mitigating their environmental and health impacts.

- **Ecosystem Restoration**

The widespread adoption of vertical farming can contribute to ecosystem restoration. As more food is produced in controlled urban environments, natural ecosystems—such as rainforests and wetlands—can be preserved or even restored. Despommier (2010) argues that replacing conventional

farming with vertical systems could return millions of hectares to nature, enhancing biodiversity and carbon sequestration.

- **Waste Management and Circularity**

Vertical farms generate organic waste from plant residues, which can be composted or converted into bioenergy. Aquaponic systems offer a closed-loop nutrient cycle where fish waste nourishes plants, and plant roots filter the water. Future vertical farms are expected to integrate anaerobic digesters and renewable energy sources to achieve near-zero waste production (Kalantari et al., 2018).

Economic Viability and Business Models

- **Capital and Operational Costs**

Vertical farming involves substantial initial capital investment for construction, lighting, climate control, and automation systems. Operational costs, especially electricity for lighting and HVAC, also remain high. As a result, most vertical farms currently focus on high-value crops like microgreens, leafy vegetables, and herbs to ensure profitability (Benke & Tomkins, 2017).

Despite these challenges, technological advances and economies of scale are gradually reducing costs. Companies are now exploring solar energy, AI optimization, and precision farming tools to enhance energy efficiency and reduce labor dependency.

- **Revenue Models**

Vertical farming enterprises typically generate income through:

- Direct-to-consumer models (subscription boxes, farmers markets)
- Business-to-business sales (restaurants, grocery chains)
- Licensing proprietary technology
- Co-locating with supermarkets or residential complexes

Some farms also engage in educational services and agrotourism to diversify revenue streams. Rooftop vertical farms in schools and universities often receive government subsidies for promoting sustainability and community engagement.

Case Studies

- **Aero Farms (USA):** Operates one of the largest indoor vertical farms in Newark, NJ. Uses aeroponics and LED lighting to produce leafy greens sustainably and has attracted major investments.
- **Plenty (USA):** Backed by SoftBank and Amazon's Jeff Bezos, Plenty specializes in high-tech indoor vertical farms and has expanded to several U.S. cities.
- **Spread (Japan):** Utilizes robots and AI to automate much of its indoor farming processes, thereby reducing labor costs.

These case studies highlight both the potential and the economic hurdles of scaling vertical farming to mass production levels.

Investment Trends

According to AgFunder, investment in vertical farming technologies grew from \$60 million in 2012 to over \$1.2 billion in 2020. Venture capitalists and governments are increasingly interested in sustainable agritech, especially in urban contexts. Countries like the UAE and Singapore offer financial incentives and regulatory support for vertical farm development (FAO, 2020).

Policy Landscape and Government Initiatives

● Role of Public Policy

Effective public policy can significantly accelerate the adoption of vertical farming. Government support is critical in areas like urban zoning regulations, startup financing, infrastructure development, and research funding. Unfortunately, many regions lack coherent policies that specifically address controlled environment agriculture (CEA) or vertical farming (Al-Chalabi, 2015).

- **Urban Zoning and Land Use**

Many municipalities still have restrictive zoning laws that prohibit or limit the establishment of vertical farms in residential or commercial areas. Modernizing urban planning frameworks to include urban agriculture, green roofs, and indoor farming is essential. Progressive cities like Singapore have created “Agri-Food Innovation Parks” that blend vertical farming with high-tech R&D facilities (Sanye-Mengual et al., 2015).

- **Financial Incentives**

Some countries offer grants, tax rebates, and low-interest loans to startups in vertical agriculture. For example, the USDA provides funding through its Specialty Crop Block Grant Program to support innovation in sustainable farming. The EU has also introduced Horizon 2020 research grants for smart agriculture, including vertical farming systems (Healy & Rosenberg, 2013).

- **Education and Workforce Development**

Governments and universities play a role in building a skilled workforce for the vertical farming industry. Programs in agronomy, plant sciences, and agriculture engineering are evolving to include CEA-focused curricula. Technical training and certification programs are also needed to meet labor demands in this growing sector.

Challenges and Limitations

- **High Initial Investment**

The cost of setting up a commercial vertical farm remains a significant barrier. Infrastructure such as LED grow lights, climate control systems, hydroponic or aeroponic equipment, and automated monitoring technologies requires substantial capital. Initial investments for a medium-scale facility can range from hundreds of thousands to millions of dollars (Kalantari et al., 2017). This often restricts participation to large corporations or heavily funded startups.

- **Energy Consumption**

Although vertical farming saves water and land, it consumes considerable energy, particularly for artificial lighting and HVAC systems. LED lights must operate 12–16 hours daily to mimic sunlight, and maintaining consistent indoor temperatures in extreme climates adds further to the power burden. If not supplemented with renewable energy, vertical farming may trade one environmental concern for another (Benke & Tomkins, 2017).

- **Limited Crop Diversity**

Most vertical farms specialize in high-value, fast-growing crops like leafy greens, herbs, and microgreens. Cereals, root vegetables, and fruiting plants are generally unprofitable due to longer growth cycles and larger spatial requirements. Expanding crop diversity requires advances in lighting design, nutrient delivery systems, and growing media (Al-Kodmany, 2018).

- **Regulatory and Zoning Constraints**

In many urban areas, regulatory frameworks are not yet adapted to support vertical farming. Building codes may restrict the retrofitting of structures for agricultural use. Additionally, licensing procedures for food production, waste disposal, and water management can be complex and inconsistent across jurisdictions (Al-Chalabi, 2015).

- **Knowledge and Labor Gaps**

Vertical farming requires interdisciplinary expertise spanning plant science, systems engineering, data analytics, and logistics. A lack of trained professionals and technical education programs hampers rapid industry growth. In many regions, agronomy curricula still focus on conventional agriculture, leaving a skills gap in emerging technologies.

Global Case Studies

- **United States**

The U.S. is home to pioneering vertical farming firms like AeroFarms, Plenty, and Bowery Farming. These companies

leverage AI, aeroponics, and LED lighting to supply major retailers with pesticide-free produce. AeroFarms operates facilities in Newark and Virginia, producing over two million pounds of leafy greens annually (Benke & Tomkins, 2017).

- **Netherlands**

The Netherlands, known for its agricultural innovation, has embraced vertical farming as a way to improve food self-sufficiency. Dutch companies like PlantLab and Priva have developed closed-environment farming systems and export their technology globally. Government incentives, academic support, and public-private partnerships play a critical role in scaling innovation (Kalantari et al., 2018).

- **Japan**

Japan has adopted vertical farming to overcome limited arable land and aging farmers. Spread Co., established in Kyoto, uses robots for planting, harvesting, and packaging. Their “Techno Farm” series is a model of automated vertical agriculture, offering high yields with minimal labor input.

- **Singapore**

Faced with land scarcity and food import dependency, Singapore launched the 30 by 30 initiative, aiming to produce 30% of its nutritional needs locally by 2030. Vertical farming startups such as Sky Greens and Sustenir Agriculture have emerged with government backing and rooftop urban farms (Sanye-Mengual et al., 2015).

- **India**

In India, vertical farming is gaining attention due to rapid urbanization and climate vulnerabilities. Startups like Urban Kisaan and Future Farms focus on low-cost hydroponic solutions suitable for Indian consumers. Challenges remain around affordability and energy access, but demand is rising for sustainable urban food sources.

Future Prospects

- **Integration with Smart Cities**

Vertical farming can play a crucial role in smart city planning

by offering decentralized, hyper-local food production. It complements urban sustainability goals such as zero food miles, waste recycling, and efficient land use. Future cities may integrate vertical farms into residential complexes, schools, and supermarkets (Despommier, 2013).

- **Renewable Energy and Automation**

The future of vertical farming depends on reducing energy costs. Innovations in solar panels, battery storage, and geothermal energy can make farms energy independent. Coupling these with automation and AI will streamline operations, minimize human error, and boost productivity.

- **Crop Genomics and Breeding**

Advances in crop genomics can yield cultivars specifically optimized for vertical environments—shorter stature, faster growth, and higher nutrient content. Genome editing tools such as CRISPR may be used to develop stress-resilient, high-efficiency cultivars suitable for vertical systems (Bugbee, 2004).

- **Food Security and Disaster Resilience**

Vertical farms are insulated from climate shocks and supply chain disruptions. They offer a strategic reserve during pandemics, floods, or geopolitical conflicts. Governments may include vertical farming in national food security policies to build resilient food systems (FAO, 2020).

Research Gaps and Directions

- **Crop Expansion**

Current research focuses heavily on leafy greens. There's a need for in-depth studies on the feasibility of growing grains, pulses, and fruit-bearing plants in vertical systems. This includes testing new substrates, lighting configurations, and nutrient profiles.

- **Socioeconomic Impact**

While vertical farming promises job creation and food access, rigorous socioeconomic assessments are lacking. Research should explore its impact on employment, food pricing, land

use, and urban equity—especially in developing economies (Lambin & Meyfroidt, 2011).

- **Energy Optimization**

Energy efficiency remains a bottleneck. Studies should explore hybrid systems combining passive solar, renewable energy grids, and thermal insulation techniques to lower operating costs. Life-cycle assessments (LCA) will help measure the true environmental footprint.

- **Policy Frameworks**

Global consensus is lacking on regulatory standards for vertical farming. Comparative policy analysis can help identify best practices in zoning, subsidies, and food safety regulations. Model legislation can be drafted to guide local governments in supporting vertical agriculture.

- **Data and AI Integration**

While AI tools are increasingly used in vertical farming, data quality and algorithmic transparency remain issues. Open datasets, standardized metrics, and user-friendly AI platforms are needed to ensure widespread adoption and scalability.

Conclusion

The global agricultural landscape is undergoing a seismic transformation driven by climate change, population growth, urbanization, and dwindling natural resources. Vertical farming emerges as a viable, sustainable, and scalable solution to these pressing challenges. Through innovations in hydroponics, aeroponics, aquaponics, and controlled environment agriculture (CEA), vertical farming offers unprecedented control over food production, enabling year-round cultivation with significantly reduced water, land, and pesticide use.

This review has explored the multifaceted dimensions of vertical farming—technological, economic, environmental, and policy-related. While the benefits are compelling, challenges persist. High energy demands, limited crop diversity, and regulatory hurdles must be addressed through continued research, public-private partnerships, and policy

innovation. Moreover, scaling vertical farming in developing countries will require context-specific adaptations, cost reductions, and education programs.

The future of vertical farming is closely tied to broader societal goals, including food security, climate resilience, and urban sustainability. With strategic investment, interdisciplinary collaboration, and supportive governance, vertical farming can play a central role in reshaping agriculture for the 21st century and beyond. The shift from horizontal to vertical cultivation is not just a spatial adjustment—it is a paradigm shift that reimagines how, where, and for whom we grow our food.

References

- Al-Chalabi, M. (2015). Vertical farming: Skyscraper sustainability? *Sustainable Cities and Society*, 18, 74–77.
- Al-Kodmany, K. (2018). *The vertical city: A sustainable development model*. WIT Press: Southampton, UK.
- Benke, K., & Tomkins, B. (2017). Future food-production systems: Vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, 13(1), 13–26.
- Bugbee, B. (2004). Nutrient management in recirculating hydroponic culture. *Acta Horticulturae*, 648, 99–112.
- Despommier, D. (2010). *The vertical farm: Feeding the world in the 21st century*. Thomas Dunne Books.
- Despommier, D. (2013). Farming up the city: The rise of urban vertical farms. *Trends in Biotechnology*, 31(7), 388–389.
- Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities: A review. *Agronomy for Sustainable Development*, 35, 483–498.
- FAO. (2020). *The state of food security and nutrition in the world*. Food and Agriculture Organization.
- Healy, M., & Rosenberg, J. (2013). Urban agriculture and sustainable food systems. *Journal of Environmental Studies and Sciences*, 3(1), 12–19.

Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2017). Opportunities and challenges in sustainability of vertical farming: A review. *Journal of Landscape Ecology*, 11(1), 35–60.

Kalantari, F., et al. (2018). A review of vertical farming technology: A guide for implementation. *International Journal of Agricultural and Biological Engineering*, 11(4), 110–118.

Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, 108(9), 3465–3472.

Martin, C. L., et al. (2016). Agriculture and climate change: Challenges and solutions. *Nature Climate Change*, 6, 603–608.

Rakocy, J. E., Masser, M. P., & Losordo, T. M. (2006). Recirculating aquaculture tank production systems: Aquaponics. SRAC Publication No. 454.

Sanye-Mengual, E., et al. (2015). Sustainability assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. *Journal of Cleaner Production*, 90, 20–30.

UN DESA. (2018). *World Urbanization Prospects: The 2018 Revision*. United Nations Department of Economic and Social Affairs.

Wood, S., Sebastian, K., & Scherr, S. J. (2001). Pilot analysis of global ecosystems: Agroecosystems. World Resources Institute.