Review Article

VERTICAL FARMING: WAY FOR URBAN FOOD SECURITY

ABSTRACT

Agriculture plays a vital role in supporting the world's population, but it faces challenges like declining water availability and ecological problems caused by concentrated traditional farming. As cities grow and demand for food rises, there is a need for new agricultural methods. Vertical farming is an emerging technology that offers a promising solution to the challenges of global food security. Its controlled conditions eliminate the need for excessive fertilizers and pesticides, resulting in significantly increased yields compared to conventional farming. As the world's population continues to grow and urbanization increases, the demand for food in cities rises, making smart urban-vertical farming an attractive option. The technology's efficiency in land and water usage, along with reduced transportation and storage costs, enhances its economic viability. Moreover, regions facing threats from soil degradation and water scarcity, can benefit from vertical farming's potential water savings of up to 95 per cent and land productivity twice as high as traditional agriculture. The global vertical farming market is projected to grow, offering a promising tool for sustainable food production and resilient urban environments. Vertical farming presents a novel approach to address the challenges of food production and sustainability in the coming decades, fostering a balanced coexistence with nature while meeting the needs of a growing global population. By embracing vertical farming alongside other sustainable agricultural practices, can meet the global food security in future.

Keywords: Vertical farming, Food security, Sustainable agriculture, Controlled environment agriculture, Climate change.

INTRODUCTION

Climate change is perceptible through a rise in mean temperature and increased frequency of extreme rainfall events in the last three decades [6] Anonymous., (2020). This causes fluctuation in production of major crops in different years. Economic losses of climate change in agriculture through natural disasters are rising globally, and the agriculture sector is highly vulnerable to these disasters. According to the United Nations Office for Disaster Risk Reduction (UNISDR, 2018) disaster-hit countries experienced direct economic losses to the tune of US $ 2908 billion during 1998-2017 [23] (Srinivasa Rao, *et al.*, (2019). Of the total losses, 77 per cent were due to climate related disasters. Climate change impacts are more pronounced in the agriculture sector during recent years. Climate and agriculture are intensely interconnected with global processes. Even a small change in climate affects agriculture adversely leading to decrease in the production rate. Assessment of the effects of global climatic variations on agriculture is imperative to adopt farming and to enhance agricultural production [27-28]. Adaptation strategies with improved farming techniques/practices can potentially decrease the vulnerability of adverse impacts of climate change. The greatest vulnerabilities are seen in areas of sub-Saharan Africa, South and Southeast Asia, where millions of people are likely to face greater risk of food insecurity as a result of climate change by the 2050s [5] Anonymous (2016).

Agricultural production is experiencing increased pressure to generate higher yields due to rise in global population and thereby increase in demand for food. The United Nations in 2015 projected that by 2050, the global population is predicted to reach 9.7 billion, with 70 per cent of people living in urban environments [8, 21] (Banerjee & Adenaeuer (2014); Ramanath Jha, 2022). Additionally agricultural land is continually being lost through the expansion of urban areas and infrastructure development potentially leading to shortages of farmland. This scale of change may necessitate the investigation of novel food production methods as both the amount of and yield achievable from conventional farming of agricultural land is limited [17-20]. Researchers and innovators have been looking beyond traditional farming as a way to feed everyone while having less impact on our land and water resources. A new, more innovative method of food production is desperately needed. Vertical farming is one promising alternative that consists of plants stacked vertically in tall built environments, usually in urban hubs [4] Anil Kumar *et al.*, (2020). This method of farming uses less than one percent of the land which conventional agriculture does and consumes one percent of the amount of water.

Vertical farming is therefore defined as cultivation and production of crops/plants in vertically stacked layers and vertically inclined surfaces. The idea behind vertical farming is to increase crop yield by farming upwards rather than outwards to reduce pressure on traditional agricultural land. Vertical farming encompasses a range of growth systems of different scales, users, technologies and purposes. It is particularly suited to the cultivation of a wide array of plants, such as vegetables, fruits, herbs, and even flowering plants.

Fig. 1. Techniques of Vertical Farming

Source: https://www.usda.gov/

In a physical layout, the plants are vertically stacked in a tower-like structure. This way, the area required to grow plants is minimized. The growing medium for plants in vertical farming is either soil or soilless. Instead of soil, aeroponic, hydroponic and aquaponic are used as the growing medium (Fig. 1). The soil media vertical production system utilizes locally available materials such as sacks, nets, polythene tubes or containers to grow crops. The other requirements are the soil itself, organic manure and water. The soilless growing medium adopts three technologies: aeroponic, hydroponic and aquaponic. Hydroponic technique uses water containing mineral nutrient solution to grow food. Conversely, in aquaponic vertical farming, fish production is integrated with plant production utilizing hydroponic system designs. However, instead of fertilizing plants with an aqueous solution which is comprised of all essential nutrients, plants are alternatively fertilized with nutrient-rich fish water that has been filtered, converted to nitrates, and supplemented for limiting nutrients deficient in aquaponic systems. In aeroponics, there is no growing medium and hence, no containers for growing crops. In aeroponics, mist or nutrient solutions are used instead of water. As the plants are tied to a support and roots are sprayed with nutrient solution, it requires very less space, very less water and no soil. In all production systems a combination of natural lights and artificial lights is used to maintain a perfect environment for an efficient growth of the plants.

THE HUMAN RIGHT TO FOOD IN THE WORLD

Humanity made a significant advancement after World War II in relation to human rights. The Universal Declaration of Human Rights of 1948 states that human rights are the rights that all human beings have by the simple fact of being born and being part of the human species, that is, human beings are subjects of and with rights. Article 25 of the Declaration states that "every human being has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing, medical care" and other essential social services that guarantee a dignified life for people.

The Human Right to Adequate Food (HRAF) is, therefore, the right of all people and people to have physical and economic access, on a regular, permanent and free basis, directly or through financed purchases, for sufficient and adequate food, in quantity and quality, in accordance with cultural traditions, ensuring their physical and mental fulfillment so that they can achieve a dignified life. By stating that food must be adequate, it is understood that it is appropriate to the context and cultural, social, economic, climatic and ecological conditions of each person, ethnicity, culture or social group. The understanding of adequate food, unavoidably, refers to the relationship between food and nutrition. When stating that a person eats properly, it is understood that he has daily access to food in sufficient quantity and quality to meet the basic nutritional needs of his life and health (https://www.ohchr.org).

It was then adopted by General Assembly of the United Nations, on December 19, 1966, the International Covenant on Economic, Social and Cultural Rights. It is a worldwide pact. This Pact came into force in 1976, when the minimum number of adhesions was reached, that is, 35 nations. The right to food was confirmed in article 11, when it affirmed "the right of everyone to an adequate standard of living for himself and his family, including food, clothing and housing". In this way, this right came to be treated as a fundamental human right, without which one cannot discuss and access other rights.

In 1999, with the broadening of the debate and the need to advance in the implementation and operationalization of the HRAF, the UN Committee on Economic, Social and Cultural Rights approved General Comment, which defines three fundamental obligations of countries in relation to the realization of the HRAF, namely: respect, protect and promote, the latter also includes the obligation to provide.

By 2050, the world population is expected to be approximately 10 billion people. To feed all these people, food production will have to increase by 70 per cent and to support the extra production it will need 40 per cent more water and 50 per cent more energy, according to the Food and Agriculture Organization of the United Nations (FAO). By itself, this challenge of increasing the productivity of existing food production systems already puts enough pressure on global food security. But the pressure increases when other difficulties are added to these numbers, such as: climate change, reduction of carbon emissions from agricultural activities and environmentally adequate production systems (https://www.refworld.org).

Currently, the problems related to global warming are already evident on all continents. The rise in temperature tends to increase the pressure on water resources, with an increase in climatic fluctuations, with long periods of drought or, even, the expansion of rainy seasons, both associated with the presence of environmental disasters (fires, landslides, storms etc). Another point worth mentioning in this challenge refers to the negative impacts caused by diseases, pests and weeds that are also included in this account. When we talk about reducing carbon emissions in agricultural production systems, associated with increased productivity, we talk about changes in the production system and the adoption of technological and innovative productive strategies that contribute to productive results.

For these changes to have positive results, it is necessary to take into account the local cultural characteristics related to the way of life of each local population group. The changes must offer inclusive solutions that guarantee support for small farmers and respect the choices of large producers. The production of food in urban spaces is one of the alternatives that can contribute in a sustainable way to this great global challenge. These are new possibilities of production in spaces still little explored, involving people who traditionally have no contact with food production and who can, through urban agriculture, become sensitive to this issue that involves the future of the entire humanity.

Vertical farms or vertical gardens for food production also contribute to the reduction of the individual environmental footprint, as it avoids the displacement of food over long distances made, in general, by means of transport dependent on fossil fuels. In addition, the safety of the quality of the food that will be consumed by that particular family group also becomes a reality, because in addition to saving financial resources with the purchase of food, vertical farms can contribute to the consumption of organic foods that respect the productive seasonality of ecosystems.

IMPORTANCE OF VERTICAL FARMING

Vertical farms are very powerful concept in part because they do not require soil to yield crops. Research has showed it is possible to produced experimental plants under 100 per cent LEDs (Expansion) with no negative outcomes on plants. Vertical farming can allow crops to be grown at all times throughout the year, as it is not weather dependent. Vertical farming can reduce transportation cost as there is no import of crops from another region [1] (Abdelfatah & El-Arnaouty, 2023). The basic advantage of vertical farming is that, minimal requirement of water as its used in a controlled manner. For example, even the greywater from office can be used as irrigation efficiently [8] (Beacham *et al.*, 2019).

One of the sustainable farming practices – vertical farming that could play a key role in mitigating global food security in the current uncertain world. It addresses the recent development of vertical farming with advanced precision monitoring and controlling system by the Internet of Things (IoT) applications. It also provides information about the opportunities and challenges of vertical-urban agriculture and how urban agriculture meets economic, social and educational needs [20] (Oh & Lu., 2022). Vertical farming has a scope to create huge employment opportunities and it has provided new opportunities for architecture and urban designing. Urban designers have attested to the importance of making cities green, healthy and safe. The layers of atmosphere can be used effectively in vertical build ups. Less CO_2 emissions and pollution by decreasing reliance on coal burning power plants and transportation and implementing renewable-sources of energy. Crops will be protected from harsh weather conditions and disturbances like typhoons, hurricanes, floods, droughts, snow and the likes. Food production as well as food transport will not be affected. Crops will be consumed immediately upon harvest since there is no need to transport them to far-off places, hence, the spoilage will also be lessened [19] (Naskoori, *et al*., 2021). Vertical farms have the advantage that allows them to generate bio-waste as bio-product during the process of edible biomass production. According to the cultivation system that plants grow in (hydroponic, aeroponic or aquaponic), the opportunity to farmers to collect easily all the by-products after the harvest period such as leaves, roots with fibers, stems, or even damaged vegetable and fruits and use it as well waste is offered. Based on study conducted by [2] Adenaeuer (2014), the bio-waste that is collected and used in indoor vertical farms was 2443 metric tons per year and with daily plant wastes that are collected for the indoor farms of roughly 8.11 tons.

Indoor vertical farms save 100 per cent of the pesticide use in their interior by maintaining the culture area clean and insect-free. Because of the application of close loop irrigation systems and of the collection, recycle and reuse of the water vapor that plant leaves transpire, indoor vertical farms can reduce up to 95 per cent the water consumption. Furthermore, the use of closed loops can decrease up to 50 per cent the fertilizer usage since it is feasible to recirculate and reuse the nutrient solution. Significant land reduction up to 90 per cent can be achieved with the application of indoor vertical farming, due to the important increase (more than 10 times) of the annual productivity of crops per unit land area. Yield variation can also reduce by 90 per cent because of the constant monitoring and control of the crops and the lack of influence from the outdoor environmental conditions [7] (Avgoustaki and Xydis., 2020).

A novel type of farming cooperating with innovative technology is Indoor vertical farms which belongs to provide the safest, higher quality and most fresh and nutritious groceries. Different customer studies that investigated customer opinion on different agricultural methods show a more skeptical belief concerning novel technologies on food production [12] Foley *et al.*, (2011). More specifically, people perception with technological innovations in agriculture are associated with high risks for food production presenting low expectations on the provided benefits of technology used [22] (Sparks *et al*., 1994). On the other hand, under a customer research conducted by [11] Jürkenbeck *et al*. (2019), it is noticed that consumers seem to present a high acceptance on indoor vertical farming concerning the offering sustainability and the high ecological footprint.

Food safety and traceability of products is another important factor highly relevant to indoor vertical farming. Even if it does not provide a 100 per cent safety for consumers, despite the fact that crops grow in a controlled environment protected by wildlife, animals, birds and insects, it upgrades the safety and security feeling of the products than those that grow in open field. In order all this increased food demand to be met, it is necessary to produce 70 per cent more nutritious and fresh food. However, at the same time, land experts such as agronomists and ecologists, already warn of the growing shortages in agricultural land, necessary for sufficient food production [3] (Al-Kodmary, 2018).

COUNTRY SPECIFIC VERTICAL FARMING

Vertical farming could work in different kinds of countries like Kenya, India, Brazil and in Switzerland which have different climates and vegetation and also the amount of existing water variants between the countries.

In South Africa for example, the land for agriculture is very limited due to lack of water and heat. So vertical farming has become very popular. For many years, there has been a drought in the world, but in Africa it is especially hard. Yet, they still need crops and they still grow food on the soil to survive. With the new technology of vertical farming, there is a promising outlook on food and crops. This promising outlook is due to the water consumption reduction of up to 95 per cent when they produce with vertical farming instead of normal farming methods. So vertical farming allows them to grow more crops from the water they do have available for use.

In Kenya there are also some vertical farm productions with the positive aspect, that they require little maintenance and are more easily accessible to the elderly and the disabled.

Also, in Africa people are more likely to move into cities. So, more food will be needed in cities like in Johannesburg for example. Vertical farming would make the food accessibility possible because the growing crops would happen right there were they are used. There still needs to be done a lot of research on the vertical farming technology and also, it's disadvantages. Also there has to be a calculation with the cost that vertical farming brings with it.

Fig. 2. Vertical farm in Africa

The number of vertical farms in Europe as also in Switzerland remains small, but the sector is increasing rapidly. For example, there was a pilot project near Zurich at the end of 2021. It was said that the future would show whether vertical farming would also take off in Switzerland. In Switzerland, there is no water scarcity compared to Africa. Switzerland has many springs and associated rivers and lakes. But Switzerland is a very small country and strongly influenced by the Alps. As a result, little land is available for agriculture and Switzerland is dependent on imported goods [10] Butturini & Marcelis (2020). Almost 85 per cent of the population lives in cities, which is why vertical farming is possible here, as in Africa, to meet the demand for food. However, there is also a need for more research into consumer needs. Because a conversation with a farmer showed that the demand for normal agriculture is still there (Fig. 2).

"Vertical farming companies have arisen in all of the main Brazilian metropolises," says Italo Guedes, a crop and soil scientist at Embrapa. In the last three years there has been an increased demand for information about vertical farming and the opening of several farms in Brazil. Brazil has abundant land resources and vegetable production is more strongly limited by climatic conditions than land availability. Tropical regions present significant challenges to vegetable crop production, especially with the increased frequency of extreme weather events.

Brazil's green belts are located in proximity to urban centers, but this production model may already be exhausted and is clearly under threat. By bringing vegetable production indoors, Brazilian growers can avoid the climatic challenges of growing in a tropical region while bringing food production even closer to the consumers. Vertical farms will play an important role in Brazil in reducing post-harvest losses of vegetables and in increasing the local consumption of fresh, nutritious food by the urban population. These farms also consolidate concepts of bio-economy and circular economy. The growth of agriculture in a controlled environment makes clear the need for investment in science and technology for sustainable agriculture.

Agriculture in India is constantly threatened by land degradation, desertification, and extreme weather conditions such as floods and droughts. The population in India is increasing rapidly. It is predicted that India will have up to 25 per cent more population in 2036. The vegetation in India is similar to that in Africa or Kenya. Above all, the droughts are causing problems for the farmers. In addition, more and more people are moving to cities, where the pressure for food increases.

Fig 3. Vertical farm in Sao Paulo, Brazil

Source: https://www.autodesk.com/

However, building a vertical farm in India can be difficult as the country still suffers from frequent power blackouts, which can lead to catastrophic losses if not solved immediately. Also, there are a lot of costs that come with the production of vertical farming. Clearly, some of India's chronic problems like messy food supply overuse of pesticides and unemployment can be solved to some extent. However, the huge cost of infrastructure for a large-scale farm is a major hurdle for implementing vertical farming in India to be the next big thing.

ECONOMIC BENEFITS OF VERTICAL FARMING

Vertical farming has shown promise in delivering more produce with fewer resources, but it is currently a long way from safeguarding global food security. The scale of vertical farming is relatively small, occupying only about 30 hectares worldwide, and profitability remains a challenge due to high energy costs associated with artificial lighting and climate control [15,17] (Krista Stark., 2019; Jack Payne., 2021). However, as the world's population continues to grow, the costs are expected to decrease, especially in developing regions where food security is a pressing issue. While it's uncertain if sufficient funding will make vertical farming mainstream, it is likely to become one of many tools used for sustainably increasing food production, alongside hydroponics, crop rotation, and cheaper urban agriculture methods. Vertical farms can be placed at different positions in the food chain, for example, at the distributor or retail sites [13] Gerrewey *et al.*, (2022). Urbanization, a global trend with 55 per cent of the world's population residing in urban areas, is projected to lead to further growth in urban settlements as rural populations decline by 11 per cent in 2030 [20] (Oh and Lu., 2022). To address the increasing demand for food in cities, smart urban-vertical farming has emerged as a prominent solution. By providing controlled and optimal growing conditions, such as precise temperature, humidity, CO_2, and lighting levels, urban agriculture tackles societal, environmental, and economic challenges related to food security. This approach shortens growing cycles, increases plant density, and enhances harvest yields. Additionally, urban agriculture's accessibility reduces energy and costs associated with transportation, distribution, and storage, while also lowering the carbon footprint of food crops.

The most important factor that makes vertical farming economically viable, however, is the controlled conditions under which it functions. Unlike traditional agricultural production, the external environmental conditions that impose further costs on farmers have a very limited effect on vertical farms [24] (Van Delden, 2021). For example, the need for fertilizers and pesticides (and the ensuing costs thereof) would be almost entirely eliminated because the crops would not be open to the elements and would thus be inaccessible to pests. The effects of seasonality are also diminished due to internal regulation of temperature, humidity, and access to light and water, conditions can be fine-tuned to optimal levels. This results in a large increase in production rate, sometimes producing crops at yields 530 times greater than would be produced on conventional farmlands of the same size. Additionally, control of nutrient levels and ambient temperatures will optimize the rate of plant growth and increase its nutritional value. For example, at the vertical farm Vegata Farm in Tokyo, lettuce that would have taken at least 60 days to grow in the field only takes about 40. The combination of higher yields and more efficient production rates help balance and even counteract high capital expenditures.

Agri-production in India is constantly threatened by soil degradation, desertification, and extreme weather conditions such as floods and droughts. As a result, alternative farming methods such as vertical farming are becoming more popular. Water consumption in vertical farming, for instance, can be reduced by 95 per cent. This could prove crucial in a country where 84 per cent of its total available water goes for irrigation purposes. In addition, India has a history of severe droughts that have been attributed to a drop in agricultural production of 20-40 per cent. Due to the closed environment and controlled lightning, the land productivity of vertical farming is twice as high as traditional agriculture. Taking additionally into account that only 0.25 ha on which the farm is built are needed, the total yield increases 516-fold compared to traditional agriculture through stacking the production. In total this leads to an estimated production of 3,573 tons of edible fruit and vegetables. The vertical farming produced 13.8 times more crops, calculated as a ratio of yield (kg Fresh Weight) to occupied growing floor area (m^2). The global vertical farming market size was valued at USD 2.23 billion in 2018, and is projected to reach US $12.77 billion by 2026, growing at a CAGR of 24.6 per cent during the forecast period.

The optimum use of vertical space increases productivity. For instance, 1-acre indoor vertical farming space is equivalent to 4-6 acres of outdoor space [11] (Ciceklia and Barlas, 2014). Vertical Farming has the potential for sustainable progress to produce food or related services in urban areas. The goals and future vision have been planned with the purpose of generating sustainable cities around the world. To create a city context where most of human food needs are met by self-production and recycling and reusing drinkable water would not be far-fetched since the required technologies are already available. Where there is strong enough motivation and adequate social pressure, prospective eco-city can be actualized soon enough. Commitment to achieve the goal of sustainable agriculture and to create eco-friendly environment within our community must be strengthened by the adaptation strategies [25] (Petrovics & Giezen, 2022).

TABLE 1. SWOT ANALYSIS

Strengths	**Weaknesses**
• Control of the ideal endo-climatic conditions for each cultivated plant • Ability to cultivate at high productivity scale	• High cost of implementing • Need to control the environment, water quality and seeds

• Reduction of water consumption and possibility to produce in small spaces • Reduction in the use of inputs, fertilizers and pesticides • Food can be produced all year regardless of the seasons	• Demand for cutting-edge technologies and automation in addition to trained employees • Daily system monitoring • Complete dependence on electrical energy sources
Opportunities	**Threats**
• Teaching and training of people • Sale of products that contribute to the feasibility in urban spaces • Raise awareness among consumers about the need to remunerate organic products in a differentiated way • Create startups and events that promote the popularization	• Prejudice of people with food that is not produced in a traditional way • Limited market opportunity • Need for research and innovation

Source: Author's contribution

CONCLUSION

Agriculture is one of the activities that play a main role in supporting humans in the world. However, the availability of drinking water is declining, but most of the available freshwater is already used for agriculture. On the other hand, the recent environmental approach caused by concentrated traditional farming approaches that contribute to the ecological problem has been overlooked. Agriculture still plays a very significant role in many cities. It causes thousands of acres of forest land to be plowed up, sacrificing thousands of acres of land. Industrialized nations, annually, use more than 20 percent of the fossil fuels for agriculture. Farming has become more centralized during the last few years. Developing high-tech farming systems are the results of the energy sources and new methods of farming. Moreover, overpopulation of cities needs new agricultural methods so as to bring conventional farming inside cities. A single technological strategy cannot be a panacea to the ever-growing food production system. Instead, there is a need for a mixture of multiple techniques to guide us towards the 21st century green revolution.

Vertical farming is an emerging technology, which aims to increase crop production per unit area of land in response to increased pressure on agriculture. It is one of the greatest interesting examples of something new that may contribute to these answers. Vertical farming has the potential to significantly increase food production while reducing the environmental footprint of the agricultural sector by reducing land, water, chemical, and fertilizer use and increasing overall efficiency. While the environmental benefits are well documented, the economic feasibility of vertical farming is the key barrier. However, there are large upfront costs associated with vertical farming, the economic benefits associated with increased efficiency and decreased resource use tied with its increased sustainability clearly outweigh these costs.

It appears that the concept of the vertical farm in the city center of urban areas could solve a lot of real issues related to food production and environmental degradation. Then no harvests would fail by severe weather phenomenon like droughts, floods, and hurricanes, etc. Hence, the vertical farming makes a sustainable city environment that encourages the people to live there for the safe and healthy environment, cleaner air, safe drinking water, safe usage of public liquid waste, new employment chances, and less abandoned lots and constructions. Vertical farming has the benefit of a seasonally wet and warm weather. They can easily minimize cooling and heating water, use of indoor temperature and artificial light and also. Sustainability of city Building Integrated Agriculture has a plentiful number of natural resources such as long hours of sunlight and enough water from daily rain to cultivate.

The number of technologies provided for decreasing the agricultural effect on the earth as well as oceans is restricted although it helps to sustain the increasing human population. From our perspective, Vertical farming is among the few novel paths to fully delve into the following 10 to 20 years particularly if we really aim to live in a balance with other living organisms and not to threaten their life or ours. The land productivity of vertical farming is twice as high as traditional agriculture. Yields are approximately 20 times higher. Operating and capital cost savings over field. High level of food safety

Optimally, vertical farming is required to be cheap and affordable, resistant and securely operable. If these conditions are met in a dynamic, all-inclusive research program, farming in cities can supply food for 60 per cent of the population who reside in cities by 2030. Vertical farming has the potential to be successful under proper conditions. It simultaneously helps to reduce poverty, adds to food safety, and increases contextual sustainability and human well-being. Vertical farming is an efficient tool that can supply food to cities sustainably and help urban areas survive overpopulation in a matter of providing food. Further research is essential to determine how and where emerging technologies, such as vertical agriculture, can be integrated into local food systems [14] (Glaros, *et al*., 2024). Adopting integrated policy-making approaches can help address potential trade-offs across various sustainability dimensions, identify "blind spots," develop more robust sustainability indicators, and facilitate trade-off analysis.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declares that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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