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How can we help cities to get more sustainable through our food habits?

Edited by
Agnès Fargue-Lelièvre, Giuseppe Carlo Modarelli, Francesco Orsini and Bernd Pölling

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How can we help cities to get more sustainable through our food habits?

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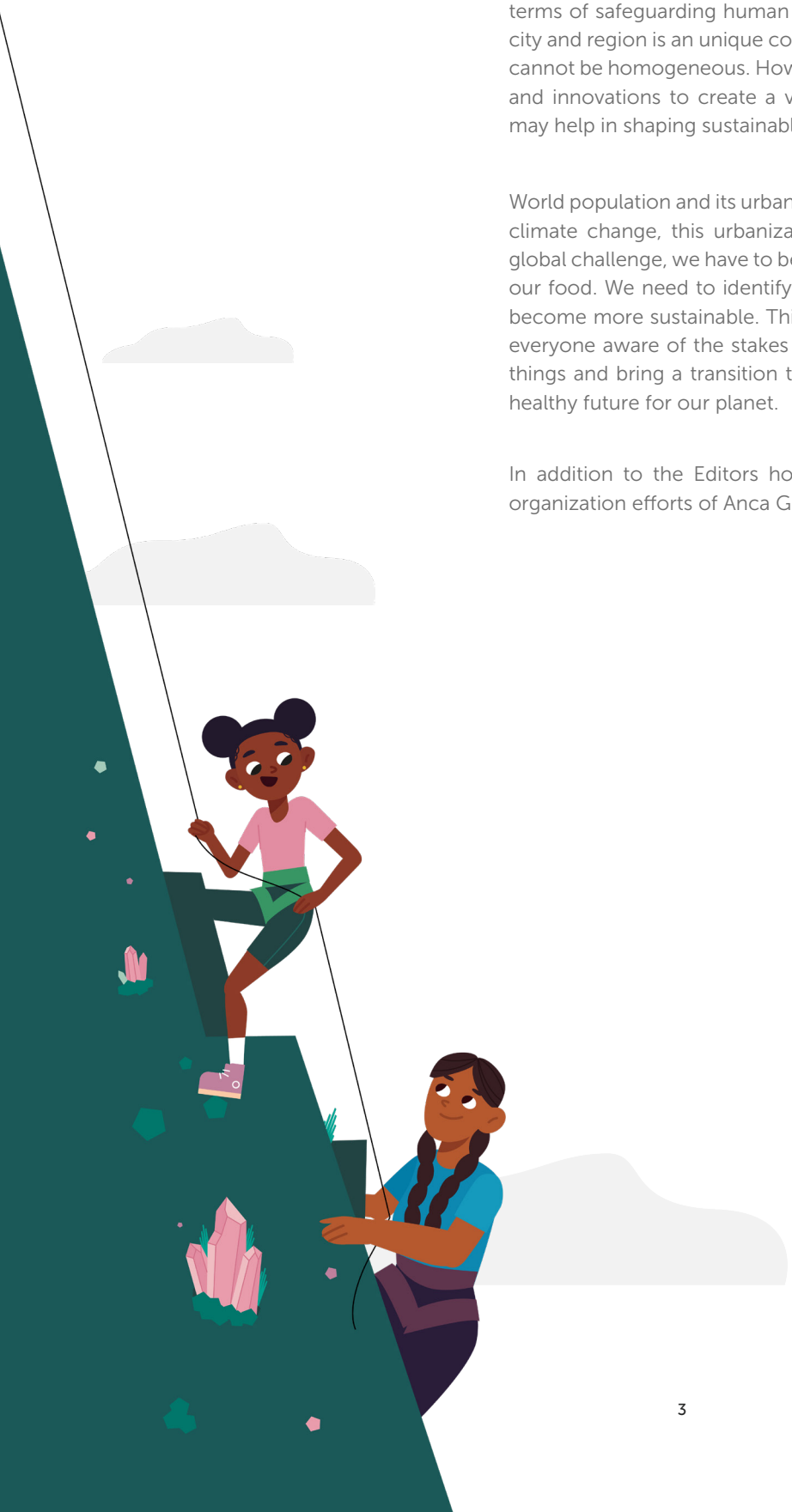
Biodiversity

About this collection

Cities rely on regional and international food production to feed their inhabitants. The food system includes everything from the production of food, its processing, consumption and waste management. Improving City/Region Food systems allows for ameliorating the sustainability of our cities, also in terms of safeguarding human rights or adapting to climate change. As every city and region is an unique context, challenges faced and solutions to answer cannot be homogeneous. However, we can learn from others by sharing ideas and innovations to create a virtuous learning loop where every experience may help in shaping sustainable future cities.

World population and its urbanization is increasing worldwide. Combined with climate change, this urbanization threatens our food security. To face this global challenge, we have to become aware of how we produce and consume our food. We need to identify innovative solutions to help our food systems become more sustainable. This means learning from each other and making everyone aware of the stakes and the ways each citizen can act to improve things and bring a transition to a more sustainable food system to ensure a healthy future for our planet.

In addition to the Editors hosting, we acknowledge the coordination and organization efforts of Anca Gheorghică.



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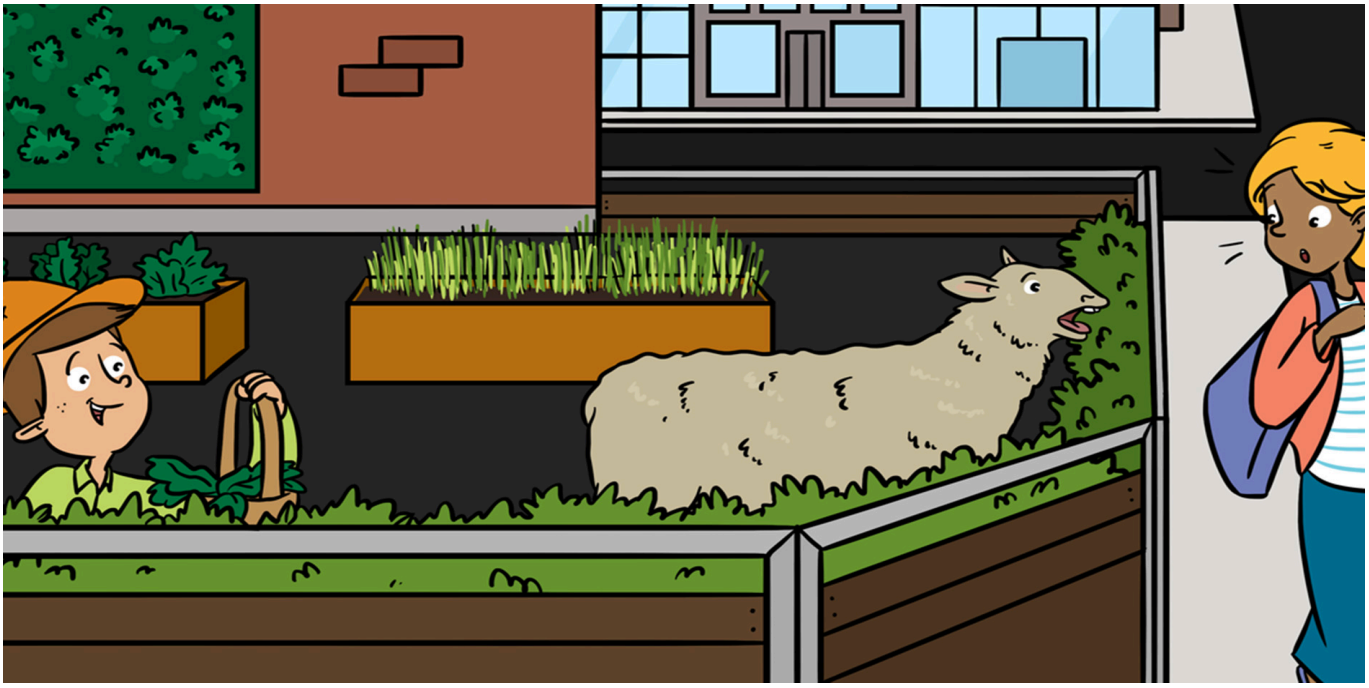

URBAN FARMS AND THEIR BENEFITS: PRODUCING FOOD IN THE CITY

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YOUNG REVIEWERS:

HOLY TRINITY

AGES: 12–13

SHOSHANA

AGE: 13

Can you imagine living in a city, while still being able to eat food that grows in your neighborhood? Agriculture has always played an important role in cities, but urban agriculture has become increasingly popular in recent years. It is a good way to provide fresh, local food for city residents and to bring nature back into cities, helping citizens to reconnect with the environment. In this article, you will learn about what urban agriculture is, some of the ways it is done, and the benefits it provides.

INTRODUCTION

What comes to mind when you think about **agriculture**? We are willing to bet that your initial thought is of the countryside, with its vast fields and meadows populated by cows and sheep. But have you ever considered **urban agriculture**? If you live in a city, there is a good chance you have walked by a location where food is being grown. Perhaps you have seen sheep grazing or even encountered

AGRICULTURE

The science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products.

rooftops with edible flowers and beehives. Urban agriculture has always happened to some extent, but it is increasing in popularity in recent years.

URBAN AGRICULTURE

The practice of farming within an urban environment, especially the cultivation of food crops for human consumption and the rearing of animals.

COMMUNITY GARDEN

It is a piece of land gardened or cultivated by a group of people individually or collectively.

URBAN FARM

An urban area (parking, ground, rooftop, balconies, etc.) used for growing crops and rearing animals.

WHAT IS URBAN AGRICULTURE?

So, what exactly is urban agriculture? This type of farming has several forms. In addition to home gardening, urban agriculture can be divided into two main types: **community gardens** and professional **urban farms** [1].

Community gardens are small urban areas where individuals come together to grow their own vegetables, enjoy nature walks, or socialize with friends (Figure 1). Typically, these gardens have specific areas for food production, alongside more "wild" spaces featuring trees and flowers. Surprisingly, community gardens can be found in every city and are likely closer to you than you might think. On the other hand, professional urban farms are agricultural businesses operating within a city. Imagine a farmer who does not have farmland in a rural area—urban areas could be good options for growing food.

WHERE CAN WE FIND URBAN AGRICULTURE?

Cities are places where it is difficult to find free space, so how do we find the room to grow food? Most cities have unused spaces, such as empty parking lots, rooftops, and vacant plots of land (Figure 1). All these areas can be used to grow a range of crops, including tomatoes, potatoes, lettuces, carrots, herbs, and even edible flowers. For instance, some urban farms repurpose old empty parking structures to grow mushrooms (Figure 2A). Animals can also be a part of the urban landscape, with certain cities allowing sheep to graze on park lawns (Figure 2B).

HOW IS FOOD PRODUCED?

We have seen that urban farming can take place in various locations, each with its own unique characteristics. As a result, urban farmers must use a range of techniques to adapt their farms to the specific type of setting. We cannot describe all of these techniques, but we will highlight a few.

The most well-known technique involves growing food directly in the ground. In these kinds of urban farms, chemical fertilizers are typically avoided in favor of nature-friendly fertilizers that enhance food quality and help the environment. However, there are instances where the soil may be contaminated, making it unsuitable for safe food production. This has caused urban agriculture to expand

Figure 1

Urban agriculture can happen in lots of different places (Figure adapted from Santo et al. [2]).

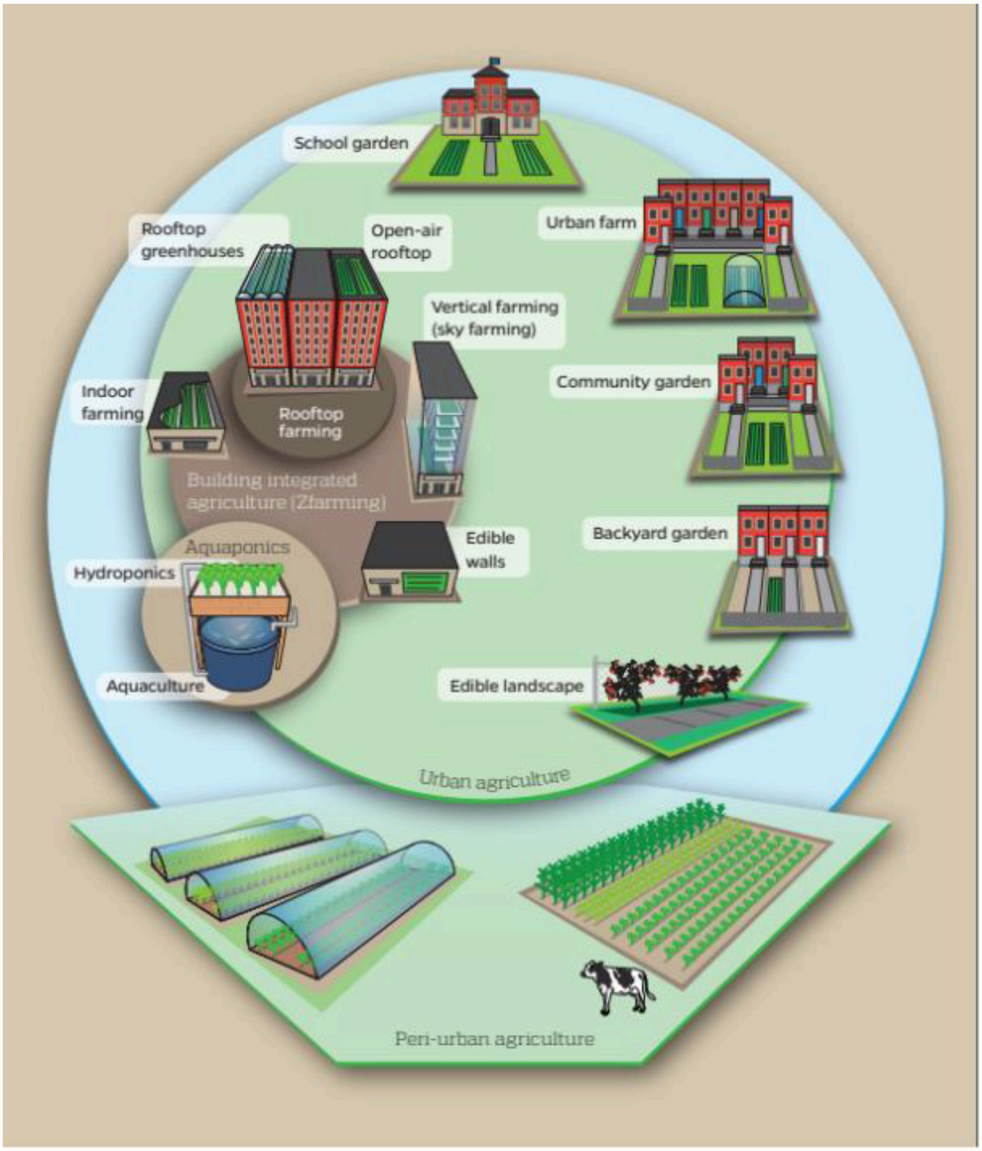

Figure 1

beyond ground-level farming. Some farms have chosen to use rooftops, while others have explored methods of growing vegetables without traditional soil at all [1]. How is this possible? Farmers use **hydroponics**, a common agricultural technique. In hydroponics, plants are placed in nutrient-rich water, allowing their roots to absorb the necessary substances for growth. Other urban farms have developed underground food production, focusing on herbs and leafy vegetables that can easily be grown in controlled indoor environments (Figure 2C).

HYDROPONICS

A process of growing plants without soil, using water to provide plants with all the necessary nutrients.

GROWING TOGETHER: THE BENEFITS OF URBAN AGRICULTURE

So now you know that urban agriculture can take several forms and can succeed in all kinds of locations. The practice of growing food

Figure 2

(A) Indoor urban mushroom farm. **(B)** Sheep grazing in an urban park. **(C)** Indoor urban farm. **(D)** Urban community garden.

in cities is becoming increasingly popular, but what advantages does urban agriculture bring to cities? While the primary purpose is certainly food production, it has other benefits, too.

Community gardens serve as ideal spaces for encouraging connections among people and helping them get involved with their communities (Figure 2D). Planting a seed and nurturing it can directly contribute to people's wellbeing. Engaging with nature acts as an anxiety reliever and can improve mood and physical wellbeing [3]. Urban agriculture also motivates people to learn about nature. For instance, understanding how a plant evolves across the seasons can help people to make healthy dietary choices [2]. Urban agriculture also creates jobs [2] and can help preserve **biodiversity**, which is good for the environment.

BIODIVERSITY

The variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable.

PROTECTING NATURE WHILE GROWING FOOD

People often think of cities as places where the natural world cannot thrive. However, urban agriculture offers a way to bring nature back to cities. The presence of plants and animals in urban areas has various environmental benefits. For instance, trees and plants can provide shade and cool the air [2]. Even a small green space placed within the heart of a city can support many kinds of plants and animals. Such green patches offer food and shelter for birds, mammals, reptiles, and

insects. Urban agriculture invites wildlife into our cities, which helps to bring nature back into our urban lives (Figure 3).

Figure 3

Aquaponics is the growing of plants and aquatic animals (like fish) in a system that converts fish poop into plant nutrients.

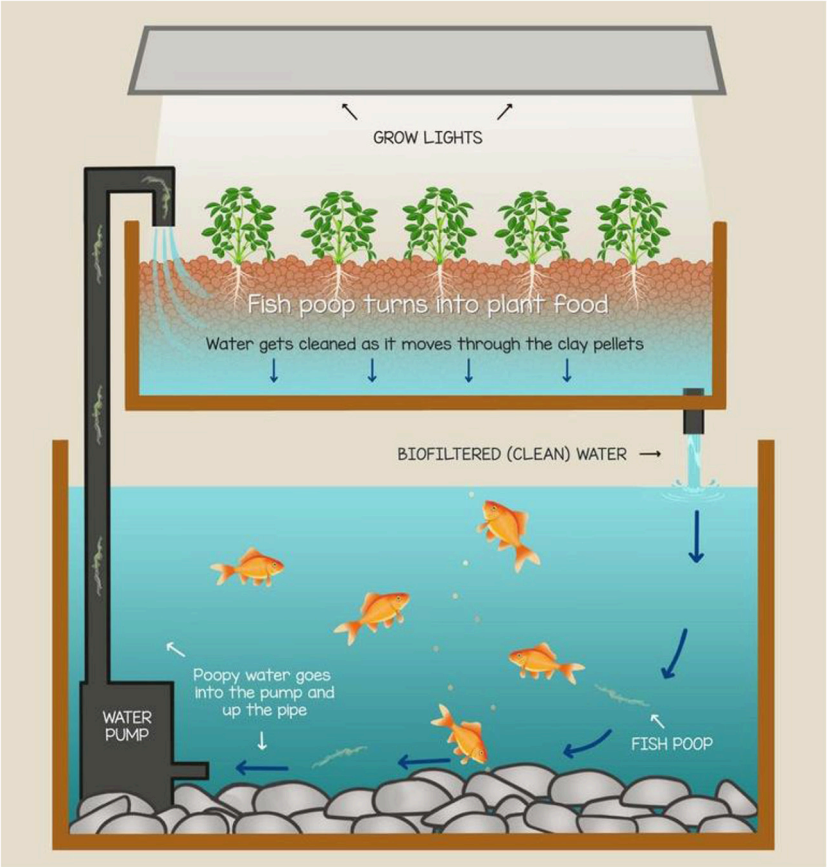

Figure 3

INNOVATION IN THE CITY

Besides providing social and environmental benefits, urban agriculture can help to create new technologies. Due to the limited space for growing plants, urban farmers must think about innovative ways to produce food. Innovation includes trying out new techniques and methods. Some urban farmers use fish poop to fertilize their plants in a system called **aquaponics**. In aquaponics, plants grow in containers with clay pellets, or another material to stabilize the plants, and water. Fish are grown in a second, connected container, and the fish poop is then recirculated back into the tank with the plants. Fish poop is a natural fertilizer and contains important nutrients like phosphorous, nitrogen, and potassium, as well as other things that the plants need to grow (Figure 3). For more information on aquaponics, see this article.

AQUAPONICS

The growing of plants and aquatic animals (like fish) in a system that converts fish poop into plant nutrients.

Many city farms have also started to offer things in addition to food, such as gardening classes, places to host events, and tours. All these activities can improve the lives of city residents [4]. All this innovation

attracts new urban farmers and people who want to take part in this movement. Maybe one day you will be one of them!

GET INVOLVED!

City residents are fundamental in urban agriculture—without them, it would be meaningless. Regardless of whether you live in a city, town, or village, opportunities to engage in growing food are never too far away. You can begin right within the limits of your own home, either by cultivating a backyard garden or even using pots on a balcony if you live in an apartment. The simple act of planting a seed and watching it grow can bring joy and raise a sense of wonder about the natural world. Look around your neighborhood or nearby park, and you might find a community garden that you can explore. Additionally, your school may have urban agriculture projects within the schoolyard. Urban agriculture is everywhere; take a walk and you will very likely discover that it has a place in your city, too.

ORIGINAL SOURCE ARTICLE

Saint-Ges, V. 2021. *Business Model des Organisations Marchandes et Productive de l'Agriculture Urbaine*. De Boeck Supérieur | "Innovations". Available online at: https://www.cairn.info/revue-innovations-2021-1-page-91.htm (accessed July 22, 2023).

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YOUNG REVIEWERS

HOLY TRINITY, AGES: 12–13

We are a science class made up of a curious group of grade seven and eight students. Our names are Kyle, Liam, Logan, Marissa, Cedrick, Olivia, Ava, Nevaeh, Audrey, Elizabeth, Olivia, Lara, Noah, Hendrick, Greyson, Jasmine, Orlando, Sara, Cassie, Marguerite, Lola, William, Sam, Kai, Preston, Xavier, Mason, and Kaitlyn.

SHOSHANA, AGE: 13

Hi I am Shoshana. I like architecture, photography and sports... very different things. What do you like to do?

AUTHORS

VÉRONIQUE SAINT-GES

Véronique earned her Ph.D. in economic sciences in 2000. From 2000–2009 her research was focused on the environmental innovations in vineyards. She is regularly asked for expert advice by people who would like to begin urban farming, or public authorities who would like to support it. Her studies concern the identification and understanding of business models of professional urban farms and their economic sustainability. Dr. Saint-Ges works with public authorities and companies to determine the ecosystem of innovations with public authorities and companies. She also teaches master's students about urban agriculture. *veronique.saint-ges@inrae.fr

HUGO DE VERGÈS

I am an urbanist coordinating a joint research unit in urban agriculture for ASTREDHOR, the French institute of applied research for plant professionals. After a master's degree in urban management and ecology, I worked in ecosystem restoration and urban ecological continuities in several organizations. With extensive knowledge in ornithology (the study of birds) and nature-based solutions, I am now focusing my research on how urban agriculture can help urban areas to cope with climate change.

EARTH SCIENCES
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A SCHOOL OF LOCAL FISH ON THE SCHOOL LUNCH MENU

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YOUNG REVIEWERS:

BENJAMIN
AGE: 10

HELENA
AGE: 12

JACKSON MIDDLE SCHOOL
AGES: 12–13

LEAF
AGE: 9

School cafeterias in the Canary Islands use mainly seafood that is imported from far-away industrial fishing operations, even though there are several nearby fishing fleets. The nearby fleets fish for tuna the traditional way, catching them one by one off of mostly small-scale fishing boats, with the hook and line technique. These boats are eco-friendly, but they tend to export their tuna—several thousand tons each year—to mainland Spain or other countries. So, in 2018, we started a project to supply local tuna and other fish steaks to about a dozen Canary Islands school cafeterias, in an attempt to reduce fish exports and imports. This is good for the environment because it decreases the amount of fuel used to move food from place to place. We hope our work will not only help school kids to eat healthier, but also improve the eating habits and health of the entire local population.

FISHING: BIGGER IS NOT ALWAYS BETTER!

Have you ever been fishing? Did you catch anything for dinner? Even if you leave the fishing to the experts, fish that live in the ocean are a major source of healthy food for people all over the world. In "traditional" **small-scale fishing**, fishermen go out in small boats, with poles, lines, and hooks, and catch fish one by one, close to the coast line. This is an environmentally friendly way to fish. The boats have fairly small motors and thus do not create much pollution, and they generally do not reject fish for being too small—so fewer fish are wasted. In contrast, large-scale, industrial fishing operations are not as friendly to the environment. They use big boats with powerful engines, so that they can travel a long way and fish anywhere in the ocean, using a lot of fuel. These fishers often use fishing methods like **long-lines** or **trawling**, which accidentally catch a lot of "extra" organisms (called **by-catch**) and can also damage the environment (Figure 1). Large-scale fishing businesses also catch so many fish that they can have a negative impact on fish populations.

Things have been hard for small-scale fishing fleets in recent times, due to certain legal restrictions and the fact that fewer young people have been choosing to do this type of work [1]. In the Canary Islands, where our research group lives and works, there is also a major port (between Europe, Africa, and the Americas) that has been the base for industrial fishing fleets for decades. This means there are readily available (but often lower quality) refrigerated and frozen seafood products being imported from all over the world.

SMALL-SCALE FISHING

Commercial fishing activities developed on boats of small size (frequently under 12 meters, habitually family-owned) that generally use simple fishing gears close to the coastline, disembarking daily.

LONG-LINE

A long fishing line up to several miles with thousands of baited hooks, which can be located closer to the sea bottom or the water surface.

TRAWLING

A large net, shaped like a cone and driven by a boat with powerful engines, that usually drags the sea bottom to catch fish, shrimps or squids.

BYCATCH

Unwanted catches of fish or other marine animals that are discarded by fishers because of their low value or because they are not allowed to keep them.

KEEPING IT LOCAL

For millennia the Canary Islands have received a special type of "tourism"—large shoals of tuna that visit every year on their traditional seasonal migrations, and that have been increasingly fished by the local, traditional fishermen from early XIX century. Many tons of tuna are caught this way but, instead of being eaten fresh on the Canary Islands, these fish are mainly shipped elsewhere [2]. We found that only a small percentage of the locally caught tuna (~15%) was eaten, fresh or frozen, on the Canary Islands, while the rest was exported overseas (Figure 2) [3]. We also found that over half of the tuna eaten on the Canary Islands is imported from somewhere else in the world. Most of the imports and exports are by air or by boat, which contributes to air pollution—including the release of carbon dioxide, which contributes to global warming.

How did this situation come about? One reason is that there are no longer any local processing companies that can produce the cuts of fish that most customers want. Also, the Canary Archipelago is one of the regions in Spain with the lowest consumption of fish

Figure 1

There are many differences between industrial fishing operations and traditional fishing methods. The traditional fishing methods used to catch tuna and other species off the coast of the Canary Islands tend to be more environmentally friendly than industrial fisheries. Artist: Marta Idaira Jiménez Sánchez.

Figure 1

products—even though the islands are surrounded by sea (Figure 2). Hard to imagine, but true.

None of this seemed to make much sense to us. So, we decided to collaborate with local schools and fishermen to see how we could change things.

START WITH THE SCHOOLS

We started our initiative, *Ecotunidos*, to promote local fish consumption—first in some schools in Tenerife and then, hopefully, to the local society of the Canary Islands. Linking up local schools with local fishing organizations was easy and exciting to do. Both sides thought getting more fish on the menu was a good idea. In the Canary Islands, most school cafeterias make their own food, and they are significant

Figure 2

Figure 2

(A) Only 9–17% of seafood consumed in the Canary Islands is locally caught (around 6,000 tons). At the same time, more than double that amount (15,000 tons) is exported. This means that most of the fish eaten in this region come from elsewhere (34,000 tons in 2017). **(B)** Much less fresh seafood is eaten in the Canary Islands (5 kg per person per year in 2021) than in other areas on the mainland of Spain (10 kg per person/year in Madrid; 15 kg in the Basque country). Meanwhile, rates of obesity and diabetes are rising in the Canary Islands. Artist: Marta Idaira Jiménez Sánchez.

consumers of other local products, including fruit and vegetables. Partnering with schools can help introduce local food producers to their communities, by demonstrating the importance of eating fresh, local foods to stay healthy.

The star products in our program are, of course, tuna and **wahoo**—especially **skipjack tuna**, which we know are plentiful in the Atlantic Ocean, so we do not have to worry about them becoming scarce. Skipjack tuna is really healthy to eat and does not contain a lot of pollutants like heavy metals, so it is ideal for kids [4]. In general, fish is important in a healthy diet because seafood products are good sources of vitamins, minerals, and **omega-3 polyunsaturated fatty acids**, all of which are needed by kids' growing bodies. We also included other, smaller fish like sardines and mackerel, depending on what the local fishing fleet brought in and what the schools found

WAHOO

An elongated and very fast swimmer tuna fish, found in tropical and subtropical seas, that may reach up to 80 kg.

SKIPJACK TUNA

A small tuna with a maximum weight of around 34 kg. The typical weight in the Canary Islands is around 5–7 kg.

OMEGA-3 POLYUNSATURATED FATTY ACIDS

Essential nutrients that perform key functions in humans associated with health benefits, especially for kids' brain and retina development, pregnant women and the elderly.

best. What better way to keep healthy and build up protein and brain power?

In the past, school cafeterias were not big consumers of local seafood products, so the change in the menu was noticeable. Cafeteria workers had to rethink school lunch menus, which was also important because the rates of obesity and diabetes among children in the area are among the highest in Spain, due to unhealthy food habits and sedentary (non-active) lifestyles [5]. Along with helping *kids* build healthier brains and bodies, our program can also be a good influence on teachers and other staff and, through the kids, the healthy-eating message can spread to their families... and hopefully even to larger parts of the population.

IS *ECOTUNIDOS* A SUCCESS STORY?

Our research team does not frequently get the chance to work with outside partners like schools and fishing organizations, so we have learnt a lot. The pilot would not have worked without fishing organizations like Islatuna and Pescarestinga, as well as the educational community; particularly, the school canteen staff. Government entities, like the Island Council (Cabildo de Tenerife) gave us their support, along with other valuable organizations such as the Association of Chefs and Pastry Chefs (ACIRE) or Ecocomedores (ICCA). Together, we have designed both menus and class content/activities for the participating schools. Hopefully, in the future, other organizations will get excited and join in too.

This project has allowed us to see what works best and to plan for bigger and better things, like bringing in more organizations and increasing the reach of the program (Figure 3).

We have come a long way since our project started in 2018. We have found ways to make life easier for school cafeteria staff who now work with local fish products like skipjack tuna, bigeye tuna, wahoo, and other local species. These schools now serve better-tasting, healthier food that is locally produced, eco-friendly, and is the same price, or even less, than the food they used to serve. We started off with 8 schools and now have 12 schools involved, with more than 2,000 schoolchildren total. The next step is to take the project to more schools and the other nearby islands, too.

WHAT IS NEXT?

We have much more work to do to transfer Ecotúnidos to other islands, including adding more schools and fishing organizations. The aim is not only to put local fish on the menu at schools, but also to

Figure 3

Our project, called Ecotúnidos, joined local schools and local fishers to bring locally caught tuna and other fish into school cafeterias. Artist: Marta Idaira Jiménez Sánchez.

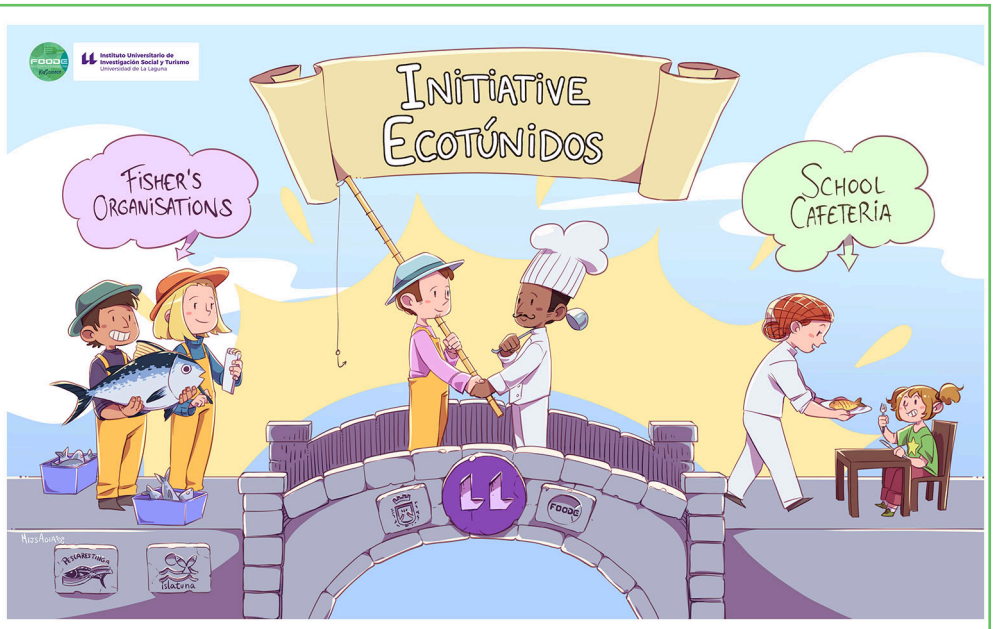

Figure 3

put it into the homes of all Canary islanders. Young kids will teach by example that local fish is best for health and for the environment.

Our fishing organizations and our schools frequently give us feedback to help us improve the program, such as creating mobile apps to make orders easier and providing training activities for cafeteria staff, for example. We continue to learn about the value of working together toward better use of our natural resources and healthier ways to care for ourselves and our environment. Do you think this kind of project could work where *you* live?

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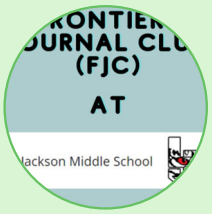
YOUNG REVIEWERS

BENJAMIN, AGE: 10

My name is Benjamin and I am in 4th grade. I love sharks and making things out of card board. I am excited about National parks and learnig new things. I hope to see more ocean articles.

HELENA, AGE: 12

My name is Helena and I am in 6th grade. I love languages. I am learning how to speak Chinese and Italian. My favorite subject is Humanities, which is basically reading, writing, and history all in one. My after school activities include swimming and playing the violin. Another favorite activity of mine is doing aerial hammock or aerial hoop. I have two cats and a leopard gecko. I LOVE traveling, and I have been to so many places.



JACKSON MIDDLE SCHOOL, AGES: 12–13

We are a group of 12 and 13 year olds that are part of the Frontiers Journal Club at our local public middle school. We love to talk about science, learn about what is going on in our world, and what we can do to make it better for all of us.

LEAF, AGE: 9

I am in the third grade, and my favorite subjects are art and science. I love observing changes in the world. I like to work as a Young Reviewer as I can observe many more changes using scientist's equipment. In my spare time, I like hiking, swimming, and riding bikes with my friends.

AUTHORS

JOSE J. PASCUAL-FERNÁNDEZ

My research is related to fisheries and coastal areas, focusing on human activities and marine resources. I was born close to the sea, and understanding these interactions has fascinated me ever since my bachelor's degree studies. Lately, my interests have focused on food sovereignty and fish consumption in the Canary Islands, as well as researching Marine Protected Areas, coastal tourism, and other issues from a practical perspective and with the intention of performing positive transformations for our everyday lives. I am currently a Professor of Social Anthropology at the University of La Laguna (Tenerife), where I have been teaching since 1991. *jpascual@ull.edu.es

JAIME RAMÓN-BRUQUETAS

I was involved in projects related to sustainable management of marine resources in Central America and worked as a volunteer fundraiser for a non-governmental conservation organization in Mexico. The experience encouraged me to study for my Ph.D. in maritime anthropology at the Universidad de La Laguna (ULL), Tenerife. My thesis focused on small-scale fisheries, fish product commercialization and collective action. Currently, I am a researcher at the Institute of Social Research and Tourism (ULL) and I am working on projects linked to local fish consumption and regulation of human activities in coastal areas in the Canary Islands. *jramonbr@ull.edu.es

RAQUEL DE LA CRUZ-MODINO
My research is related to coastal areas and heritage, focusing on the sustainable management of marine tourism and small-scale fishing activities. I love scuba diving and regularly practice many marine activities. I am also aware of food sovereignty and fish consumption in the Canary Islands. These issues are especially important to me, as my home, which is one of the poorest areas in Spain and Europe, has some of the highest levels of childhood obesity. Currently, I am an associate professor of social anthropology at the University of La Laguna (Tenerife), and I have been actively working at the Institute of Social Research and Tourism for almost 20 years.
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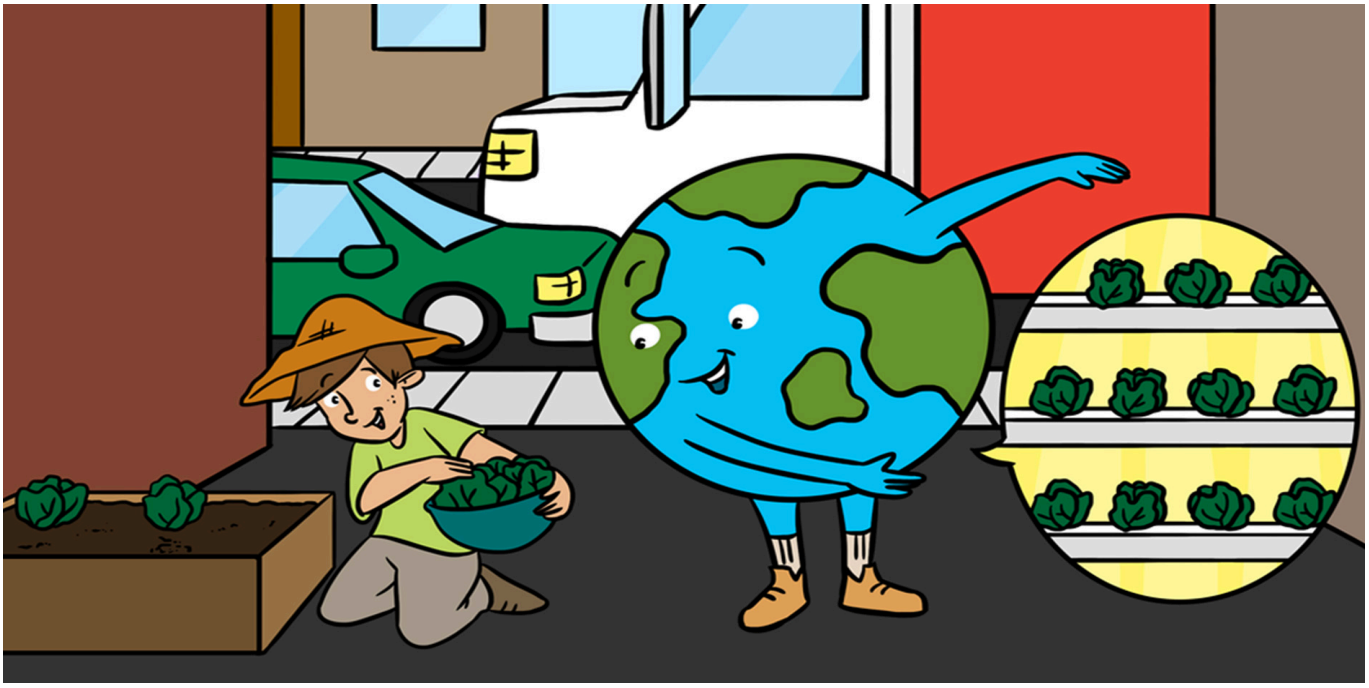

ARE VERTICAL FARMS SUSTAINABLE?

Ilaria Zauli and Giuseppina Pennisi*

DISTAL—Department of Agricultural and Food Sciences, Research Centre on Urban Environment for Agriculture and Biodiversity, Alma Mater Studiorum University of Bologna, Bologna, Italy

Today, cities are growing—taking up more space and filling up with more people. The growth of cities reduces the Earth's natural resources and the amount of land available for farming. As Earth's population grows, food production must increase so that everyone will have enough to eat. Vertical farming is a type of farming that can be done within cities, in spaces like empty buildings. In these indoor spaces, conditions (temperature, water, etc.) can be controlled so that food can be produced all year round. In vertical farms, the drained water can be recovered and reused. Lots of plants can be grown in small spaces. Despite these positive qualities, artificial lights must be used because there is no sunlight, so unfortunately a large amount of energy is needed to run vertical farms. As lights become more efficient, vertical farms can be a sustainable, environmentally friendly way to produce food.

YOUNG REVIEWERS:

ALISSAR
AGE: 14

YASH
AGE: 12

WHAT IS A VERTICAL FARM?

Today, cities take up large amounts of space on our planet, reducing the amount of land available for farming. At the same time, the huge numbers of people that live in cities use up a lot of natural resources. As the human population continues to grow, we must increase the amount of food being produced so that everyone has enough to eat. **Urban agriculture** is a type of farming in which food is grown inside cities. Urban agriculture can help to prevent hunger and it might be better for the environment than traditional farming. Vertical farming is a novel type of urban agriculture that first appeared in the late 1900s in the US, Japan, and the Netherlands. As advances in technology were made, vertical farming expanded [1, 2].

Vertical farming is a type of food-production system in which food is grown in an indoor environment where growing conditions like temperature, light, and humidity can be controlled. In cities, empty buildings or warehouses are perfect for vertical farming. Smaller vertical farms also exist for small-scale food production, for individual households, restaurants, schools, or shops, for example [3]. In vertical farms, plants do not grow the same way they do on traditional farms. Instead, they grow in trays without soil, stacked on shelves (Figure 1). This **soilless system** allows lots of plants to be grown in small spaces where the conditions can be kept just right. In a vertical farm, up to 80 g of fresh lettuce can be grown with 1 L of water. In an open field, only 20 g of fresh lettuce can be grown with 1 L of water! The amount of food grown in vertical farms can be up to 200-fold higher than in open fields [4]. This means that vertical farming can be a **sustainable** way to grow plants in cities.

URBAN AGRICULTURE

Methods for cultivating food within cities, towns, and within buildings.

SOILLESS SYSTEMS

Methods of growing plants without soil, which include hydroponics and aeroponics.

SUSTAINABLE

When a process uses resources efficiently and has a healthy relationship with the natural environment, for example recycling water or consuming less energy.

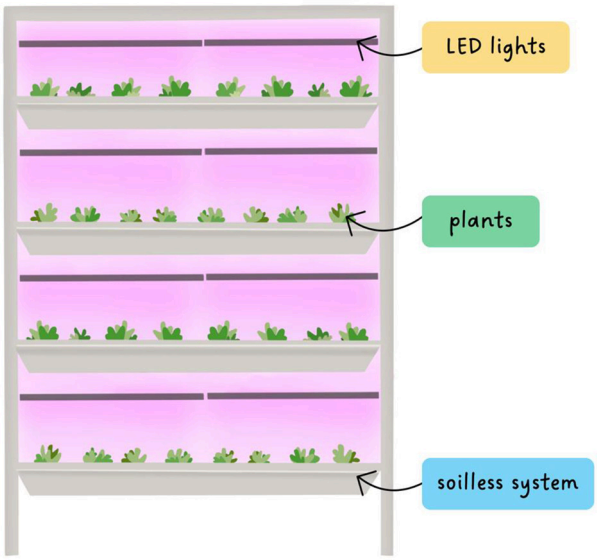

Figure 1

In a vertical farming system, plants grow in trays stacked up on shelves. These trays may have a little soil in them, to support plant growth, or no soil at all—making watering the plants very efficient. Each shelf has LED lights, and a mix of red and blue light is often used. Combined, these colors make a pinkish light that plants can use to perform photosynthesis and grow.

WHAT DOES A VERTICAL FARM LOOK LIKE?

Inside a vertical farm, you can find plants, artificial light, a water source, and a stable climate. Vertical farms use artificial light, such as the light produced by LEDs, to imitate the sun. LEDs are the most energy-efficient lights available, and they come in many colors: red, blue, green, white, and far-red (which plants can use but humans can barely see). More colors can be made by mixing LEDs. In fact, a mix of red and blue light is the most common combination for vertical farming, because those are the colors plants mainly use for **photosynthesis**—a process that is needed for plant growth [5, 6]. With LEDs, farmers can choose the perfect light recipe for each plant species, including the exact colors, the intensity of the light, and how many hours of light the plants get. With the perfect light recipe, the best plant growth can be achieved. Even though LEDs are quite expensive, their lifespan is longer than other types of lights.

As we mentioned, plants in vertical farms grow in soilless systems. The nutrients plants need are added to the water and delivered using two main types of **irrigation**. In a **hydroponic** system, plant roots are submersed in tanks filled with nutrient-containing water, either constantly or only few times per day, depending on the type of hydroponic system used. In an **aeroponic** system, plant roots are sprayed with nutrient solution, for example for 1 min between four and six times per hour, to avoid dryness. Both of these systems use less water than is needed for growing plants in soil. In either system, pots containing peat or organic sponges can be used to support the plants and keep them wet all day (Figure 2).

Through the process of **transpiration**, plants also release water through small openings mainly located on their leaves, called stomata. In vertical farms, this water can be recovered and reused for watering plants.

When plants are grown inside closed spaces, the climate can be controlled. In vertical farms, all the conditions are regulated and are independent from the conditions outdoors. For example, constant air temperature and air circulation are important. Humidity (the amount of moisture in the air) must also be controlled. Carbon dioxide can also be added inside the structure, to help plants with photosynthesis. Within these controlled spaces, plants can be grown every day of the year, regardless of weather or seasons.

In vertical farms, mainly leafy vegetables, medicinal plants, or small seedlings are grown—like lettuce, basil, or rocket. These plants are not as tall as other vegetable plants, so they can easily grow in the shelves. They also grow quickly and close together, and they do not need intense light. Lastly, they can be sold for a good price. For all these reasons, these crops are the most suited for vertical farms [3].

PHOTOSYNTHESIS

The process by which plants use light to produce the food they need to grow, together with carbon dioxide and water.

IRRIGATION

The process of applying water to plants to help them grow.

HYDROPONICS

A growing system in which nutrient-containing water is delivered to hanging plant roots as they grow inside a tank, or to plants growing in pots with soil.

AEROPONICS

A growing system in which nutrient-containing water is sprayed directly onto naked, hanging roots.

TRANSPIRATION

The process by which part of the water absorbed by plant roots is released by leaves and stems through small holes called stomata.

Figure 2

Two main soilless systems are used in vertical farms. In a hydroponic system, plant roots are immersed in water containing the nutrients plants need. Roots can be immersed for a few minutes several times per day, based on the plant's needs and growth stage. Sometimes just a little soil is used to keep plants wet and stable. In an aeroponic system, plants' roots are exposed and frequently sprayed with a nutrient solution. Plants can be supported using plastic pods and organic sponges.

Figure 2

IS A VERTICAL FARM SUSTAINABLE?

To determine whether vertical farms are sustainable, we must consider all the resources used in the system: water, energy, and space. Agriculture uses almost 70% of the fresh water available on our planet [4]. In vertical farms, the efficiency of water usage is improved compared to traditional farming, where water is often lost in the soil. In fact, a study demonstrated that vertical farms have a higher water-use efficiency for many plants, such as basil and lettuce [5, 6]. This means that the mass of plants produced per unit of water used is higher in soilless systems with a stable climate, optimal light, and reuse of transpired water.

The choice of empty city spaces for vertical farms helps natural ecosystems because less land must be used for farming. Stacking the plants on shelves means more plants can fit into a space, producing more food in a smaller area.

Unlike open fields or greenhouses, there is no sunlight in vertical farms. Lamps are the only light source, and these farms need a lot of energy. Controlling the climate within vertical farms requires energy, too. The energy use of vertical farms is one of their major limitations. The world needs new strategies to improve the energy efficiency of vertical farms. LED lamps help, because light colors and lamp heat can be adjusted to obtain the best plant growth and energy efficiency. Solar

panels may be able to provide a "green" energy solution, but further studies are needed [4].

THE FUTURE OF VERTICAL FARMS

In summary, researchers have been working hard to find the best indoor food-growing solutions for cities. Vertical farms are a good option because lots of plants can be grown in a small space, no pesticides are needed, and food can grow all year long. Farms located in cities also reduce the distance that food must travel between where it is produced and where it is eaten—and this is good for the environment, too. However, a lot of energy is needed to provide the light plants need and to control the climate in vertical farms. Reducing the energy use of vertical farms is a top priority, and more research is still needed. We hope that, in the future, growing food in vertical farms will support the world's food system in a sustainable way, helping to feed Earth's growing populations while keeping the planet healthy.

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YOUNG REVIEWERS

ALISSAR, AGE: 14
Alissar is a student in grade 9, known for her iconic portrayals of contemporary life, which have alternately been described as surreal and hyper-realistic. Widely considered to be one of Syrian's child artists, trained at the Traditional Crafts of Syria. Alissar also worked for a children's radio programme called The Argonauts, as a presenter on SY-TV's Children's Hour, and as a drawing and art talent at the National Art School and The *Martyr Basil Al-Assad School*, Damascus, the *Syrian Arab Republic*.

YASH, AGE: 12
I am a curious middle-schooler with a wide range of interests in math, science, music, tennis, geography, and building large lego sets. I love volunteering at a local animal rescue and write their monthly youth newsletter. I play the drums, and am learning to play many other percussion instruments in my school band. I am considering being a lawyer when I grow up because I am getting good at presenting a fair argument with my parents.

AUTHORS

ILARIA ZAULI
I am a Ph.D. student at the University of Bologna, currently studying aeroponic and hydroponic systems in vertical farms. Since I was a child, I have loved nature and flowers, and I also developed an interest in climate change and sustainability issues. For this reason, I decided to study biology and natural sciences, including the field

of urban agriculture. I believe that sustainable food production in cities can be the solution for the challenges our planet will face in the future.

GIUSEPPINA PENNISI
I am a junior assistant professor at the University of Bologna, in Italy. During my Ph.D. work, I studied how light can influence plant growth and metabolism, and how artificial light can be efficiently used for growing plants in indoor environment. I strongly believe that food production should take place closer to where food is consumed, which is why I have always been fascinated by urban agriculture. *giuseppina.pennisi@unibo.it

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RETHINKING HOW CITY DWELLERS GET THEIR FOOD

Claudia Wiese*, Bernd Pölling and Wolf Lorleberg

Department of Agriculture, Faculty of Agriculture, South Westphalia University of Applied Sciences, Soest, Germany

YOUNG REVIEWERS:

COLEGIO ALTOS DEL CERRO GRANDE

AGES: 11–12

COLÉGIO MAXI - MIZZOU ACADEMY

AGE: 12

Do you perhaps live in a city, or have you visited one? Cities are exciting places where there is often a lot going on. They offer a variety of job opportunities and many leisure activities, like movie theaters, shopping malls, parks, and museums. Currently, Earth's greatest population growth is happening within cities. Even though cities cover only 2–3% of the land, they consume approximately 75% of the world's energy and they produce 80% of the carbon dioxide that is released into the atmosphere. Until now, cities have not needed to grow their own food, but this makes them dependent on food sources that can be quite far away. This article will describe how urban agriculture can help cities to better deal with climate change and other environmental problems, and how this food-growing method can improve the living environments for the people in cities at the same time.

CLIMATE CHANGE ENDANGERS CITY LIFE

As you know from school and from the news, Earth's climate is changing due to human activities. Global temperatures are warming, and severe weather events are happening more frequently. Cities are especially vulnerable to the impacts of climate change, which can negatively affect the health of the people who live there. For example, most of the land in cities is covered by buildings, roads, and pedestrian pathways, mostly made of asphalt and concrete. These surfaces cause what scientists call an **urban heat island effect**. Have you ever put your hand on the asphalt at the end of a hot summer day? Even when the sun goes down and the air temperature drops, the surface still feels warm. In fact, in contrast to forests or other vegetation, these human-made materials often absorb the sun's heat and release it at night, when the air is cooler. This keeps the temperatures within cities higher than the temperatures in the countryside.

URBAN HEAT ISLAND EFFECT

When the air temperatures in the city are hotter than in the surrounding countryside, because the pavement and buildings retain heat, which makes all the surfaces very warm.

There are even more serious effects of climate change for city residents. Although rainfall is becoming less frequent, the risk of severe weather is increasing, and heavy rainfall events are on the rise. Ground that is sealed by asphalt and other human-made materials cannot take up the water the way soil can, so flooding can result. Another big problem faced by cities is how to manage the enormous amount of waste produced every single day. This waste must be taken away and, at the same time, the many goods that city residents need must be transported into the cities. All this transport in and out of cities produces a lot of greenhouse gases, including carbon dioxide [1].

The foods that city dwellers eat are produced all over the world. Before foods (or any goods that we need) find their way to a city's supermarket shelfs, they may have traveled hundreds or even thousands of miles across the globe by plane or boat, often through several countries. On the one hand, this means that we can find our favorite foods all year long. But on the other hand, cities are highly dependent on trouble-free food delivery to feed their residents. Is there anything cities can do to protect Earth's climate while also improving the lives of city dwellers? **Urban agriculture** may be the answer! [2, 3].

URBAN AGRICULTURE

The production of food within cities, to feed city residents. Includes growing of vegetables in backyard gardens and in greenhouses on rooftops. Also called urban farming.

FOOD SUPPLY CHAIN (FSC)

The path of a food product from its production, through processing, to our plates. The more stops a product makes, the longer the chain.

THE SOLUTION IS RIGHT OUTSIDE THE DOOR

One way that cities can adapt to face the challenges of the future is to shorten **food supply chains (FSCs)**. The food supply chain describes the path of a food product, from production through processing to our plates. Urban agriculture shortens FSCs by creating locations for food production within, or very close to, cities. Access to locally grown food can also be improved by encouraging farmers from the outskirts of the city to sell their goods (such as vegetables, fruits, milk, and meat) to city residents. This can both shorten FSCs and reconnect the city with its surrounding countryside. Moreover, the

farmers often receive only little money for their products, when selling it on the global food market. This puts a lot of pressure on the agricultural production and food system, especially in countries where the production requirements are high. Farmers have to produce very efficiently to be able to offer their products to low prices. Large farms are more likely to cope with the price pressure, while small family farms are more at risk to give up.

Often, there is not much land available within cities for urban agriculture—but urban agriculture can still succeed, even in the largest metropolitan areas. Smart scientists and architects can integrate agriculture into city buildings, to save space and reuse resources [4, 5]. Typical examples are rooftop gardens, where plants are grown high above the city (Figure 1). Urban agriculture tries to reuse resources like water and energy. In some cases, rooftop gardens contain greenhouses that use the heat from the building; or plants can be watered using rainwater, if there is a way to collect it.

Figure 1

Urban agriculture includes food produced in or on city buildings, including in rooftop gardens, on the walls of buildings, and even in climate-controlled spaces within buildings, where all of a plant's needs are met.

Urban agriculture can take place *inside* buildings, too. As you may know, plants have unique demands: some like a lot of sun and high temperatures, while others prefer cool and even wet weather conditions. Inside a building, the conditions are fully controllable, so that plants get the right amounts of light and **nutrients** and can grow in their preferred temperature ranges. In these controlled environments, outside weather, sunlight, and city pollution do not affect the plants. To save space, plants can be stacked on shelves, one above the other. This is called **vertical farming**. A high-rise building with many levels of vertical farming uses space very efficiently and can produce fruits and vegetables throughout the whole year, even in winter. Another option is to integrate plants into a building's walls (called edible walls) [6].

NUTRIENTS

Essential substances that a plant needs to grow.

VERTICAL FARMING

A farming method in which plants or animal products are produced on various levels, like shelves, arranged one above the other to save space.

SOIL ALTERNATIVES?

Every plant needs something for its roots to grow in, so that it can get the water and nutrients needed for its growth and development. School gardens, community gardens, family gardens, traditional farms on the outskirts of cities, and people growing a few plants on their balconies all use the most common growing substance—soil! However, the quality of city soils is often not very good and does not support the healthy growth of food plants. Soils near roads are especially poor, due to potential contamination by the pollution released by cars and trucks [7].

Soil can be replaced by other substances, such as compost, sand, or gravel. The selection of a soil replacement depends on what the type of plant being grown needs. One of the most important physical properties of a soil-replacement substance is the particle size (Figure 2). Imagine you have two bowls filled with balls—one with golf balls and the other with tennis balls. The tennis balls are obviously larger, so the bowl contains fewer of them, and the airspace between the tennis balls is greater. With soil and other growing substances, it's the same—the larger the particles, the more airspace there is in the substance. However, the water-holding capacity is reduced when the particle size is large, because water can move through the particles faster and seep into the deeper parts of the ground, where the plants cannot reach it.

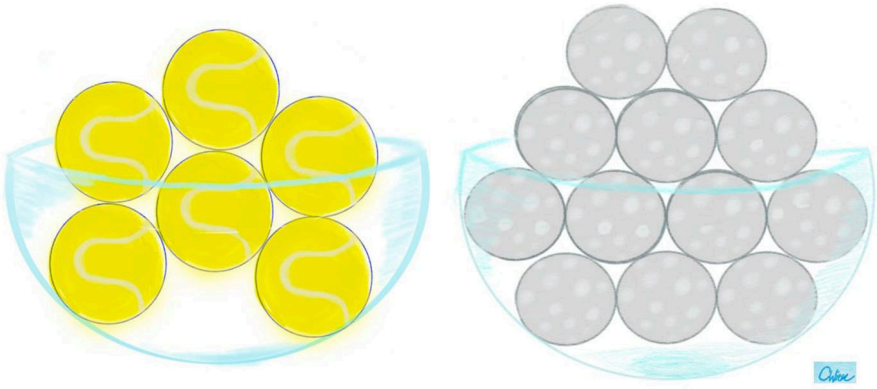

Figure 2

Figure 2

The particle size affects the properties of the soil and other substances in which plants can grow. The right cup contains tennis balls while the left cup contains golf balls. The left bowl can hold more balls and the air space between the golf balls is smaller. For this reason, the water seeps into deeper soil layers more slowly. Plants that grow on sandy soil (large particles) need to be watered more frequently in summer than those that grow in loamy soil or even clay soil (smaller particles).

HYDROPONICS

A soil-free growing method for plants. The plants receive the nutrients necessary for their growth from nutrient-enriched water.

It is even possible to produce plants without any soil-replacement substance! New technologies enable us to grow plants in water that has been enriched with nutrients. This system is called **hydroponics**. Hydroponics can also be combined with fish production, in a technique called **aquaponics**. Although aquaponics is difficult, the idea behind it is relatively simple. The fish are kept in basins, where they eat and grow. The water the fish swim in must be cleaned and exchanged occasionally. The wastewater is collected and used in hydroponics, because the fish droppings in the water are good fertilizer for plants.

The plants take up the nutrients from the water and, in doing so, clean the water. The water can then be reused for the fish (Figure 3).

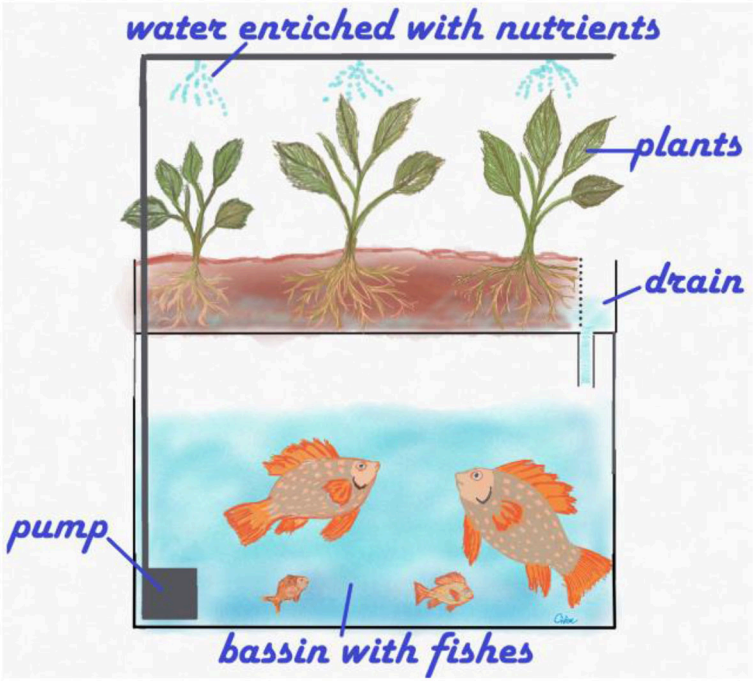

Figure 3

Figure 3

Aquaponics is a type of agriculture in which fish and plants are farmed together. The plants receive their water from the fish, which live in a separate basin below them. A pump moves the water from the aquarium to the plants. The fish droppings contained in the water serve as fertilizer for the plants. The plants also clean the water, which can then be returned to the fish via a drain.

SUMMARY

AQUAPONICS

A technique in which fish and plants are farmed together. Water containing fish droppings is used to feed plants. Plants remove the nutrients and purify the water for the fish.

In summary, producing food within cities and establishing relationships between cities and nearby farmers has many advantages—for both farmers and city residents. Even small farms that are close to cities can find a way to make money selling their products to city dwellers. Growing food within or close to cities eliminates long transportation routes and the harmful emissions that they cause. One important way to support urban agriculture is to rethink your (or your family's) food-buying behavior. Urban agriculture will only be successful if people care about locally produced food and buy it instead of buying food that was produced far away. Change begins with this slogan: Think global, eat local!

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CONFLICT OF INTEREST: 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.

YOUNG REVIEWERS

COLEGIO ALTOS DEL CERRO GRANDE, AGES: 11–12

We are 11 and 12 year old school children who despite being native speakers of Spanish also enjoy knowing English. And above all we like to learn about new thing! We are a highly dynamic, cheerful and unruly group that seeks new challenges.

COLÉGIO MAXI - MIZZOU ACADEMY, AGE: 12

For this review a small group of Middle School students within the Mizzou Academy program at Colégio Maxi worked together to complete the review. Our program is an opportunity for students to experience an American classroom experience without leaving Brazil. We had lots of fun learning about climate, weather and how the scientific process works.

AUTHORS

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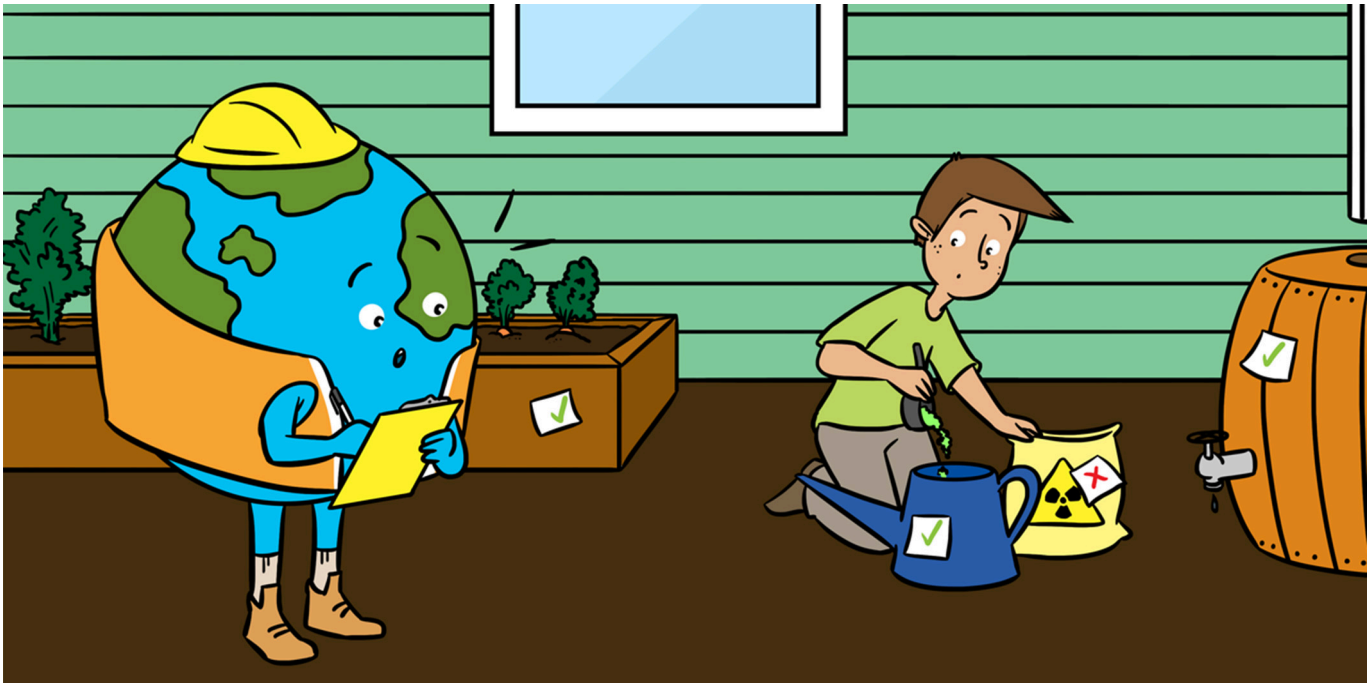

WHAT IS SUSTAINABILITY AND HOW DO WE MEASURE IT?

Agnès Fargue-Lelièvre * ***and Paola Clerino*** *

AgroParisTech Institut des Sciences et Industries du Vivant et de L'environnement, Paris, France

YOUNG REVIEWERS:

ALISSAR
AGE: 14

BENJAMIN
AGE: 8

IRENE
AGE: 8

SUSTAINABILITY

Being able to maintain a level over time. Here defined as the management of natural resources to ensure that human needs can be met today and in the future.

Today, we hear a lot of talk about sustainability and whether we can protect the planet while still living comfortable lives. But what does sustainability mean? Does it mean the same thing to everyone? Is it a new concept? What are its components and how do they interact? This article will try to answer these questions and explain how sustainability is measured and promoted in various contexts, such as farms and cities.

There are many urgent questions facing humans today. How can we make sure we will still have enough food, energy for heating, and materials to build houses in a few years' time? Can the Earth replace as many resources as humans are currently using? Can we recycle and reuse resources we have already used? If there are more and more people on Earth, will not our wastes pollute the environment? And how can we make sure everyone can earn a fair living without damaging the Earth? These questions all involve the concepts of **sustainability** and **sustainable development**. We hear the term sustainability a lot these days, but what does it actually mean? How is sustainability measured and how is it put into action?

WHAT IS SUSTAINABILITY?

SUSTAINABLE DEVELOPMENT

Development that allows humans living today to have acceptable living conditions, while also allowing those who will come after us to enjoy good conditions as well.

Sustainability has to do with making things last. When we talk about being sustainable, we mean we are trying to balance the needs of people with the impacts humans are having on the environment. We must make improvements in the way we are living so that we do not damage the Earth—that way, the people who come after us can also live good lives on a healthy planet.

The first person to ask whether the growing number of people on Earth would make it difficult to feed everyone despite technological progress was a man named Malthus, back in the 18th century! Other people also reflected on this matter and several of them came together and wrote the Bruntland Report in 1987 where the first mention was made and the first definition given of sustainable development. A major conference in Rio de Janeiro Brazil in 1992 built on this report. The countries at the conference agreed on 27 general principles to guide the development of their countries while protecting the environment. They drew up an action plan called Agenda 21, to put these principles into practice. Agenda 21 contains targets for the year 2000 and beyond like combating poverty and providing all persons with the opportunity to earn a sustainable livelihood.

Sustainable development is defined as development that allows humans living today to have acceptable living conditions, while also allowing those who will come after us to enjoy good conditions as well, by minimizing the damage that humans do to the Earth as our population grows. But this is not the only definition of sustainability—there are many definitions, depending on the topic being discussed. For instance, there are definitions of sustainable forests, sustainable cities, sustainable industries, and sustainable agriculture [1]. The United Nations Food and Agriculture Organization's definition of sustainability is: the management and conservation of natural resources (soil, water, air, etc.) through our technological and political choices, to ensure that human needs can be met today and in the future. This means protecting the environment while allowing today's societies to remain economically healthy and approved by the people [2]. All these definitions tell us that sustainability is based on three key aspects: the environment, people's daily lives, and the economy (Figure 1A).

The definition of sustainability also depends on the scale at which it is viewed: we can look at the sustainability of a single farm, a city, a large region, or the whole planet (Figure 1B). Different phenomena are involved at each level. For example, the use of chemicals that pollute water and soil could affect the sustainability of a region, but climate change affects the entire planet.

When we talk about sustainable living, we mean living a lifestyle that aims to be sustainable, by limiting our use of resources. It can

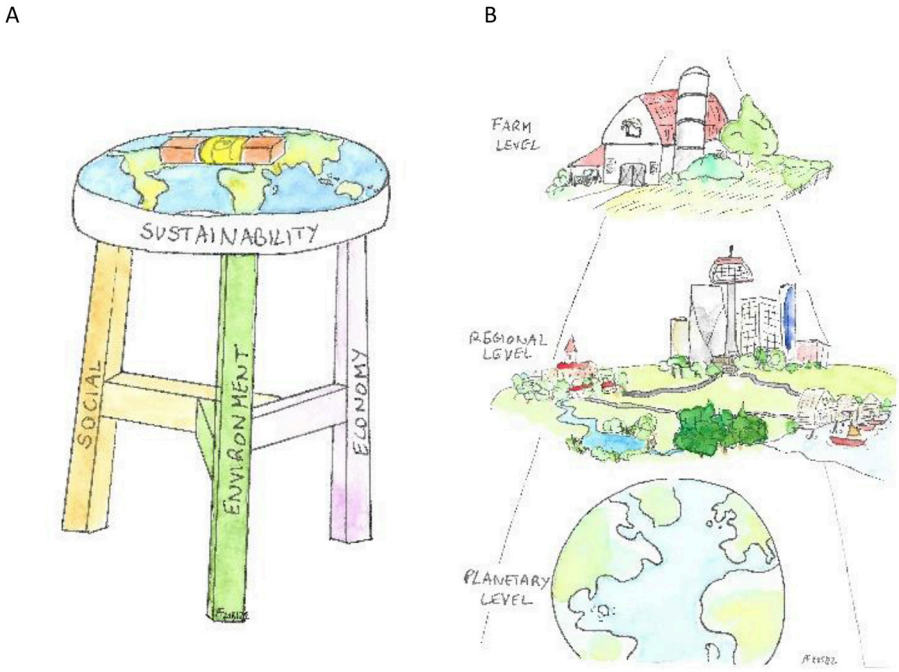

Figure 1

(A) Sustainability has three main components: the environment, people's daily lives, the economy. **(B)** The definition of sustainability differs depending on the scale we view it at—from the level of a single farm, for example, to the level of the entire planet.

imply recycling our wastes, using only rainwater to water our gardens, deciding to buy fewer things, or eating only what is produced by farms close to where we live, not on the other side of the world. This United Nations webpage can help you learn more about sustainable development and discover fun ways to live more sustainably.

EVALUATING SUSTAINABILITY

Evaluating something complex often involves trying to understand it by simplifying it. If we want to evaluate the sustainability of something, we must first define what we will evaluate (a city? an industry? a farm?), why we are evaluating it (to compare two farms? to choose the best crops to grow on a farm?), who will evaluate it (experts? groups of citizens?), and how we will evaluate it (Figure 2). The evaluation of sustainability will be different if, for example, it is done by a group of farmers comparing the sustainability of their farms to figure out how to improve their practices, or if it is done by a group of experts evaluating the sustainability of a city, to help the mayor define city policies.

CRITERIA

The standards by which something may be judged. For example, whether the price paid to farmers for their crops is fair or not.

Once we have our definition of sustainability, we must then choose **criteria** that allow us to say whether the system we are evaluating is sustainable. Let us take the example of a farm. To figure out if a farm is sustainable, we must look at all three important aspects of sustainability: environmental, social, and economic. We can ask a whole range of questions, such as: Does the farm create jobs? Does it produce high-quality food? Does it protect nature or threaten it? Can the farm produce a lot of food and provide a decent salary for the farmer, without damaging the environment? Whichever questions

Figure 2

Questions we must ask ourselves when we want to evaluate sustainability.

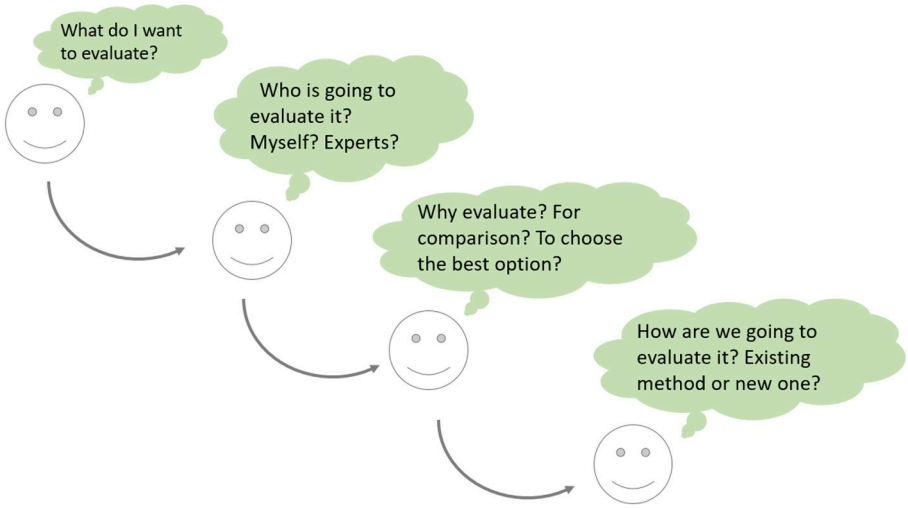

Figure 2

we choose as the criteria for our evaluation, we will need to answer them. Since these criteria are complex, we can simplify them using **indicators**. For example, say we want to focus on the criterion of whether the farm protects nature. Studies have shown that certain chemicals used to protect crops can kill bees, so we could look at whether the farm uses these chemicals. If the farm uses a lot of chemicals it will damage nature, which is not sustainable; but if the farm does not use chemicals, it will preserve nature and the farm will be more sustainable. In this case, the number and quantity of chemicals used can be an indicator of nature protection.

INDICATOR

A tool used to measure a criterion to tell whether that criterion is being achieved. For example, the number of insect species found in a farm or in a garden.

Sometimes, methods to evaluate sustainability may already exist. There are plenty of ways to assess the sustainability of farms, for example [3]. So, often there is no need to create all the criteria and indicators ourselves! However, sometimes methods to evaluate sustainability must be designed for a very specific situation, and in those cases we can create a tailor-made evaluation method by choosing our criteria and indicators. We can also decide to give more importance to some criteria than to others. For example, in a region that often suffers from drought, the amount of water a farm uses for its crops could be a very important criterion for its sustainability. Methods to evaluate sustainability can be designed by a group of experts, with the help of other people such as farmers, consumers, or nature conservation organizations.

WHAT ARE CITIES DOING TO BE MORE SUSTAINABLE?

These days, many cities want to become more sustainable to help protect our planet. In 2015, at the Milan World Expo in Italy, 100 major cities signed a pact to commit to a more sustainable food policy, and they shared their methods so they could learn from each other and improve.

URBAN AGRICULTURE

Growing crops or raising animals within or near the city. It can also include food processing, distribution or waste recycling. It can also produce flowers or pedagogical activities.

Toronto, Canada is one city that has been interested in sustainability for a long time. Toronto first established a Food Council to connect people from food, farming and community sector and make them work together to ensure access to good, affordable and sustainable food for all in 1991. In 1993, the city developed gardens where residents could produce food, on their own or together. In 2002, Toronto even set up a farm that belongs to the city. Toronto states that having shared ground-level and rooftop gardens is important for a healthy, beautiful, active city; and the city even publishes a guide to help residents garden. Indeed, **urban agriculture** improves the sustainability of cities because even more than producing food, it brings biodiversity to the city, helps diminish the heat in summer but also helps cities to look nicer and provides city residents with an enjoyable outdoor activity (Figure 3).

Figure 3

Urban agriculture improves the sustainability of cities and the living conditions of city dwellers.

Figure 3

In 2009, Toronto wanted to measure the impact of urban agriculture on its residents. The city launched a study to identify indicators to measure the benefits of urban agriculture on health, the economy, the environment, and people's social connections. The study defined 30 indicators like the number of urban agricultural projects growing native plants or the number of people trained in gardening as tools to measure the benefits of urban agriculture. Toronto used the results of the study to set public policies, to make the city even more sustainable [4]. In 2013, Toronto adopted an agricultural program to increase the number of projects all over the city and, in 2015, the city published a new guide to growing and selling fruits and vegetables in the city to answer common questions on rules, health and safety so that everyone can grow and sell healthy food.

CONCLUSION

Evaluating sustainability can tell us whether we are producing and consuming Earth's resources in ways that will allow us to live healthy lives—now and in the future—while being fair to all humans and protecting the planet. There are many tools already available to check if we are achieving our sustainability goals, whether we are looking at the scale of our own home or the whole planet. Now it is up to us to measure and promote sustainability!

ACKNOWLEDGMENTS

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CONFLICT OF INTEREST: 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.

YOUNG REVIEWERS

ALISSAR, AGE: 14

I spend summertime's swimming, riding around town, and playing in the park. My childhood was idyllic and I have many fond memories of those carefree days. I was involved in a lot of extracurricular activities, including the school band and the drama club. I am a member of some green sorority and involved in a lot of campus activities. I hope to land some small roles in independent films and commercials and do also some modeling work and being appeared in some TV shows and movies.

BENJAMIN, AGE: 8

Hi, my name is Ben, and I am 8 years old. I love Science and Math and want to be an astrophysicist someday!

IRENE, AGE: 8

Irene is my name. I adore animals and all things cute and lovely. When I grow up, I want to be a veterinarian and a teacher. I enjoy writing about anything! Dork Diaries is my favorite book, and I own the entire Dork series. When we were not fighting, I adore my younger sister. I participate in a variety of sports, including rhythmic gymnastics, tennis, swimming, and ice skating. Among them, rhythmic gymnastics is my favorite. I enjoy playing chess, but I do not get to do so often because no one in my family knows how... so sad.

AUTHORS

AGNÈS FARGUE-LELIÈVRE

I am both a teacher and a researcher in agronomy. I share my time between teaching engineering students and doing research on the working of urban farms and their impact on the city. In a previous life, I worked on crop production in rapeseed and maize and on the adoption of innovations by farmers. I am also regularly contacted by farmers and collectivities to help them develop urban agriculture. *agnes.lelievre@agroparistech.fr

PAOLA CLERINO

I am a researcher in agronomy, working on ways to assess the sustainability of urban agriculture. I study how we can define sustainable urban agriculture. I also develop tools to assess if urban farms are sustainable, with people who create and manage these farms. They can be urban farmers or people working in cities' development such as city hall employees or architects for instance. *paola.clerino@agroparistech.fr

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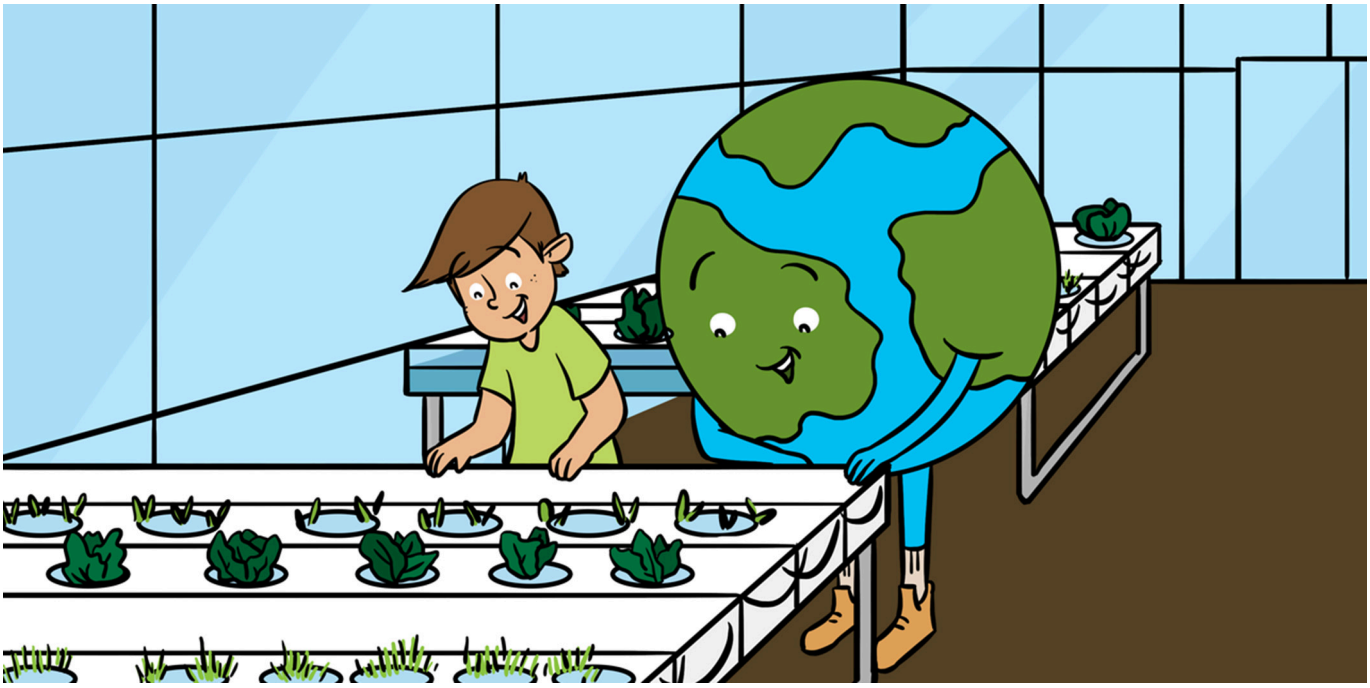

BIOPONICS: THE NEXT REVOLUTION IN SOILLESS AGRICULTURE

Lucia Vanacore * ***and Chiara Cirillo*** *

Department of Agricultural Sciences, University of Naples Federico II, Portici, Italy

YOUNG REVIEWERS:

COLLEGE HILLS ELEMENTARY

AGE: 9

Our food system is slowly becoming more environmentally friendly in response to global challenges such as climate change, the environmental damage caused by intensive agriculture, the increasing human population, and the growth of cities. Soilless agriculture, which involves growing plants without the use of soil, is a unique type of environmentally friendly food-production system. There are several soilless agriculture techniques, including bioponics. Bioponics is a new technique that aims to replace chemical fertilizers with organic or natural ones. These environmentally friendly fertilizers are recycled from plant- or animal-based waste materials, through the activity of microorganisms like bacteria. Therefore, bioponics is a sustainable method of producing fruits and vegetables, as it not only limits the use of chemical fertilizers but also conserves water and land resources and recycles important nutrients.

HOW CAN WE GROW ENOUGH FOOD WHILE PROTECTING THE ENVIRONMENT?

Our planet is facing great challenges, including climate change, an increasing global population, and the growth of cities. While the number of people who need to eat is constantly increasing, the traditional method of growing fruits and vegetables in soil can damage the planet. Traditional agriculture can remove necessary nutrients from the soil or may require the use of harmful chemicals, such as herbicides and pesticides, that can kill animals and insects. To reduce these negative consequences on the planet and to produce food that is more **sustainable**, it is important to limit the use of soil, water, and harmful chemicals, including **chemical fertilizers**. A new method of growing things, called **controlled environment agriculture** (CEA), may provide a possible solution. CEA is a form of soilless farming that is increasingly found in cities world-wide. In CEA, all types of fruits and vegetables can be cultivated within protected structures like greenhouses or tunnels, and under specific conditions of light, temperature, and humidity. CEA could allow us to use less water and fewer harmful chemicals, and to cultivate crops throughout the year instead of just during the warm seasons.

The major techniques of soilless agriculture are called **hydroponics** and **aquaponics**.

Hydroponics is a growing technique in which plants grow in a water-based solution, to which farmers add all the nutrients the plants require to grow. This form of agriculture uses materials like sand or clay balls to support the plants' roots while they grow in the water solution.

Aquaponics is a growing technique that combines hydroponic plant farming with **aquaculture**, which is fish farming. In this form of agriculture, plants grow in the water where the fish live, and all the nutrients necessary for plant growth are provided by fish instead of farmers. Indeed, thanks to the activity of microorganisms, these nutrients are created from fish poop and from the food the fish do not eat (Figure 1).

BIOPONICS: A SOILLESS AGRICULTURE SYSTEM THAT USES NATURAL COMPOUNDS AND MICROORGANISMS ACTIVITY

Bioponics is another type of CEA, in which plants derive nutrients from natural compounds. These compounds are plant-based (for example, corn steep liquor or sugar cane molasses), animal-based (for example chicken or cow manure) or mineral-based (for example granite dust or glauconite) natural substances released into the growing system

SUSTAINABLE

Something that people can use in the present without compromising the possibility for next generations to access it in the same way.

CHEMICAL FERTILIZERS

Fertilizers created by the chemical industry specifically to help crops grow better and produce more food.

CONTROLLED ENVIRONMENT AGRICULTURE

Innovative form of soilless agriculture in which fruit and vegetables can be cultivated within protected structures, such as greenhouses or tunnels, and under specific condition of light, temperature, and humidity.

HYDROPONICS

Technique of growing fruit and vegetable in the water instead of soil. All nutrients the crops needed to grow are put into water by farmers.

AQUAPONICS

Technique of growing fruit and vegetable that combines hydroponics with aquaculture. Plants grow in the water were fish live. All nutrients the crops needed to grow are provided by fish.

AQUACULTURE

Farming of aquatic organisms, such as fish, shrimps, and algae in the fresh water or sea water to produce seafood.

Figure 1

Controlled environment agriculture (CEA) involves the use of protected structures like greenhouses in which to grow plants without soil. Hydroponics is a type of CEA in which plants grow in the water to which farmers add all the nutrients they need to grow. Aquaponics is a type of CEA in which plants grow in combination with fish; all the nutrients they need to grow are provided by fish. Bioponics is a new type of CEA in which all the nutrients the plants need to grow come from natural compounds that are released into the water by microorganisms activity.

BIOPONICS

Technique of growing fruit and vegetables in the water instead of soil. All nutrients the crops needed to grow come from natural compounds that are released into water by microorganisms.

Figure 2

Picture of a bioponics system. Starting from left, color brown indicates the biofilter tank where the microorganisms transform the organic compounds like animal poop into simple molecules that are usable by plants; color light blu indicates the water recirculating tank that allows nutrients to be adequately diluted into water; color green indicates the growing tank where fruit and vegetable can grow.

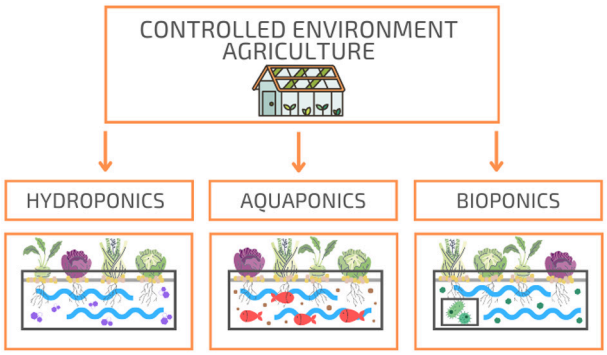

Figure 1

by the activity of microorganisms like bacteria, which transform these compounds into simple molecules that are usable by plants [1].

Bioponics also helps plants to grow due to the addition of beneficial microorganisms to the growing area. For example, a helpful type of fungi, called **mycorrhizal fungi**, can be added to plants, which then colonize plant roots. Mycorrhizal fungi create a formidable barrier against dangerous, disease-causing microorganisms called pathogens, so they protect plant roots while also aiding nutrient absorption and boosting plant growth. Therefore, in bioponics, microorganisms are very important, and their activity is essential throughout the food-production process.

Generally, a bioponics system consists of a tank called a biofilter tank, in which the bacterial activity takes place. In this tank, the animal- or plant-based organic compounds are transformed by the bacteria into plant-available forms of nutrients. A pump moves the nutrient-containing water into a water recirculating tank, which allows nutrients to be adequately diluted into water. The water recirculating tank is connected to the growing tank, where the fruits or vegetables are grown (Figure 2).

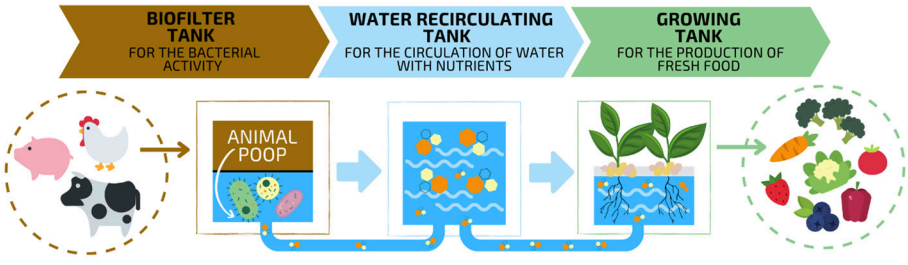

Figure 2

ADVANTAGES AND CHALLENGES OF BIOPONICS

Bioponics has environmental, economic, and social advantages. First of all, nitrogen and phosphorus are the major nutrients in the

MYCORRHIZAL FUNGI

Beneficial fungi that associate with plant roots. The fungi protect the roots from dangerous microorganisms and the fungi and plant provide each other with necessary nutrients.

chemical fertilizers used intensively in traditional agriculture, and the excess use of such fertilizers has negative consequences on nature, such as contamination of groundwater, waterways and soil that can negatively affect life cycles of beneficial microorganisms and animals [2]. Therefore, feeding plants with nitrogen and phosphorus generated from organic or natural compounds is a major environmental advantage of bioponics. Using organic or natural compounds to generate plant food also has economic advantages. For example, in developing countries, most chemical fertilizers must be purchased from other countries, which increases food production costs. Organic fertilizers, on the other hand, can be made anywhere in the world. This means that bioponics could reduce the cost of growing food in developing countries. In terms of social benefits, bioponics can strengthen bonds between people by promoting direct contact between farmers, local markets, and consumers. Local farmers can provide fresh and nutritious food while also creating opportunities for purchasers to socialize and cooperate.

Despite these advantages, bioponics has also several challenges. For example, because it contains living microorganisms, a bioponics system is fragile and can easily stop working properly. Therefore, managing these systems requires a great deal of knowledge and effort. Another challenge is that organic compounds, unlike chemical fertilizers, may be deficient in certain essential nutrients needed by plants [3]. For example, pig manure is low in potassium, which is important for plant health. Finally, because various types of animal manure are used as a natural source of nutrients for plants, it is important to be aware of potential risks to human health caused by the presence of heavy metals like lead, copper, or zinc. For example, chicken manure is often contaminated with high amounts of copper and zinc. These elements can accumulate in edible parts of plants and, when humans eat a lot of them, stomach aches can result [4]. Further food-safety research is needed to fully understand the possible health risks of bioponics.

In summary, bioponics could be a more sustainable soilless cultivation system than hydroponic one.

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YOUNG REVIEWERS

COLLEGE HILLS ELEMENTARY, AGE: 9

We are a group of 3rd Grade GT students at College Hills Elementary School in College Station, Texas. It is a Dual Language, Title I campus with a long history. We are a diverse group of friends who love to learn, tackle hard challenges, and have fun. We love to eat sweets, fruit, and anything with sugar. We learned about many scientific topics while reviewing this article and had fun sharing our thoughts. We would like to do it again!

AUTHORS

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CAN FARMERS EARN MONEY BY FARMING IN OR NEAR CITIES?

Claudia Wiese*, Bernd Pölling and Wolf Lorleberg

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YOUNG REVIEWERS:

DAVID
AGE: 12

DEREK
AGE: 15

JAMES
AGE: 9

As you probably know, most farms are found in rural areas, far away from big cities. However, when food is grown near cities, it can make cities more sustainable and prepared for the future. Moreover, it even offers business options for farmers in the outskirts of the cities as well as for newcomers and start-ups producing food in the city centers. Short food-supply chains and well-known origin are only some of the benefits. New technologies like aquaponics can go hand in hand with traditional farms. Both complement each other and enhance local food production. Nevertheless, local food production needs to be economically viable to be sustainable and prosper in the end. This raises the questions: Is it possible to run a successful and sustainable farm near—or even within—a city?

While local food production is good for the people living in cities [1], it is not always easy for farmers who grow food near cities to earn enough money to keep their businesses running [1, 2]. Farmland is limited and expensive near cities because cities keep growing, and

they compete with farmers for land. Moreover, much of the farmland is not owned by the farmers, but leased.

CHALLENGE: ECONOMIES OF SCALE

Competition with larger farms can be a big problem for small farmers. Imagine you are a wheat farmer. When summer comes and your grain is mature, you are happy to use your harvester to reap the fruits of your work. Because your farm is small, you can afford only a small harvester. As a consequence, the harvest takes you quite a long time, and your machine needs a lot of fuel. This means that you will have high **production costs**.

PRODUCTION COSTS

Amount of money that a farmer has to pay in order to buy all the necessary supplies to grow food.

Meanwhile, the farm next door is twice as large as yours. That farm is also selling wheat, but their machines are larger, more powerful and fuel-efficient (Figure 1).

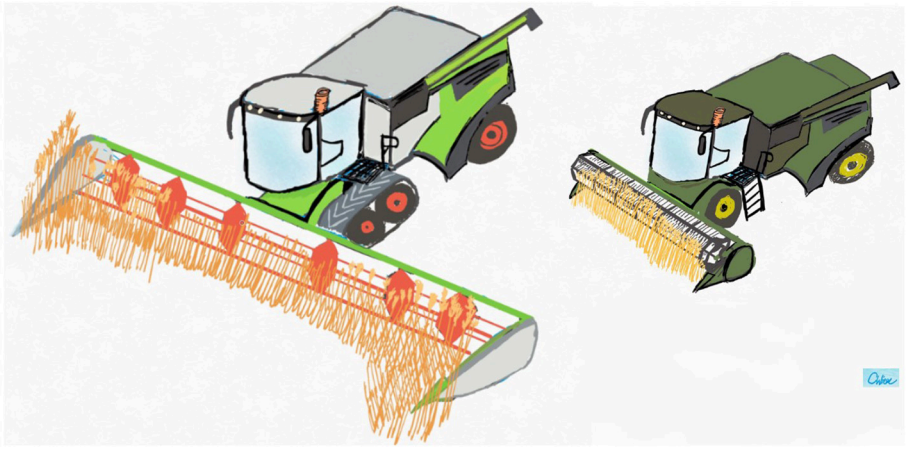

Figure 1

Larger farms generally have larger machines, which can harvest crops faster and are more fuel efficient. This is an example of an economy of scale—larger farms often have an easier time making a profit than smaller farms do.

Figure 1

The larger farm needs less time for harvesting and therefore saves money on fuel and working time. The larger farm can also get higher prices per unit when selling its products, because they can offer larger amounts. They also spend less on farming supplies, like seeds and fertilizer, because they can buy supplies in bulk. This financial difference between large and small businesses is called **economy of scale**, and it means that larger farms or companies can have financial benefits due to their size [3].

ECONOMY OF SCALE

Cost benefits that can be achieved due to the size of a company. Large companies can save more money and become more cost-efficient than small companies can.

Because farming is a very competitive business, many farmers try to enlarge their farms to take advantage of economies of scale. They also try to be as efficient as possible to save costs. When customers pay low prices for food, those prices do not always cover all the costs that farmers spend to produce food. Small farms must often shut down for this reason.

CHALLENGE: PRICE PRESSURE

All farmers are under pressure to grow crops cheaply, which is known as price pressure [4]. For example, have you ever wondered why you can buy blueberries in winter, even though they only grow during the summer in many climates? In winter, blueberries must be transported long distances from South America or South Africa, to supermarket shelves across the world. The long transport routes are harmful for the environment, and the growing practices can be less environmentally friendly in certain countries. The growing practices required for farmers in Europe have very high standards compared to the rest of the world. This is good for the quality of the products, the environment, and the working conditions of the growers. But high standards also mean higher production costs. Countries that do not worry as much about protecting the environment or paying fair wages to farm workers can sell their food at lower prices—and some stores choose their products mainly based on prices. Therefore, farmers in places like Europe, where standards are high and **sustainability** plays a key role, sometimes face difficulties selling their products because other countries can produce food more cheaply.

SUSTAINABLE

Describes food production that does not harm the environment, and in which the workers have good working conditions and are paid a fair wage.

HOW DO FARMERS NEAR CITIES COPE?

Researchers found out, that farms have developed three different ways (cost leadership, differentiation and diversification) to cope with low prices. The first way is called "cost leadership." In order to cope with the price pressure, farmers try to increase the size of their farm even more. Their farms grow and offer only one or very few different products, to make sure that they are able to offer large amounts. Simultaneously, these farms try to improve and optimize their farm organization and activities as much as possible. In order to save money. This **business strategy** is not applicable for every farm in every region. Especially when farmland is rare, like in cities, this strategy does not work anymore.

BUSINESS STRATEGY

Measures undertaken to achieve the desired development of the business and secure its stability.

Farmers along the fringes of cities use two main strategies to cope with the many challenges they face: differentiation and diversification. Both strategies build on an important **location advantage** that these farmers have—being close to lots people, the city dwellers! If farmers can adjust their businesses to the needs and wishes of city dwellers, they will not be as affected by global food prices. This can be good for both the farmers and the consumers. When farmers and customers can directly interact with each other and develop a relationship, and the customers begin to like and trust the famers and their products, then the price of the food is no longer the only reason the customers purchase it.

LOCATION ADVANTAGE

Imagine you want to sell lemonade. You could choose a stand opposite a school or along a lonely hiking trail. Surely the school, would be more favorable.

DIFFERENTIATION—STAND OUT FROM THE CROWD!

DIFFERENTIATION

A business strategy that involves offering customers something unique that they will not get elsewhere.

Differentiation means being unique—different from other producers [3, 5]. But how can farmers differentiate their farms from others? And how can they build good relationships with their customers? The quality of their products can be the starting point. Some vegetable species have a great taste, but they need more time to grow and the yield is smaller compared to more frequently grown species. This is especially the case for tomatoes and strawberries (Figure 2). If small farmers grow unique, good-tasting fruits and vegetables, they will have an advantage over large farmers that choose the fast-growing but less tasty varieties.

Figure 2

To compete with larger farms, small farms can try the strategy of differentiation, meaning they can offer unique or better quality fruits and vegetables than larger farms can.

Figure 2

Another way for farmers to differentiate is to farm less common or exotic breeds of livestock (animals). Ostriches are a good example of an exotic animal that can be raised on a farm. Did you know that one ostrich egg is the size of 24 chicken eggs? Quails lay very small eggs. To replace a chicken egg, you need 10 quail eggs. This is a clear example how exciting and diverse food can be!

Farmers can also differentiate by providing superior living conditions for their animals. Chickens running across green meadows and warming their feathers in the sun are beautiful to look at and are a real selling point. However, building nice living spaces like stables is expensive, and farmers cannot keep as many animals if they give their animals more space. This means production becomes more expensive for these farmers, which is why they have to charge more for their products.

FOOD-SUPPLY CHAIN

Describes the path of a product from production through processing to the consumer. The more intermediate stops a product makes from the farm to the dining table, the longer the food-supply chain.

However, small farmers often sell directly to customers, either in small shops on the farms or at farmers' markets, so the **food-supply chain** is shorter [6]. A food-supply chain describes the path of a product, from production on farms through purchase by customers. The more partners that are involved in food-supply chains (farmers, traders, processers, transport companies, packaging, wholesalers, supermarkets, consumers, etc.) the less money from the sales price ends up in the farmer's pocket (Figure 3). Therefore, the farmer makes less money the longer the food-supply chain becomes. Consequently,

farmers can earn more money when they sell directly to customers, although those farmers have higher costs for production, processing, and selling of food.

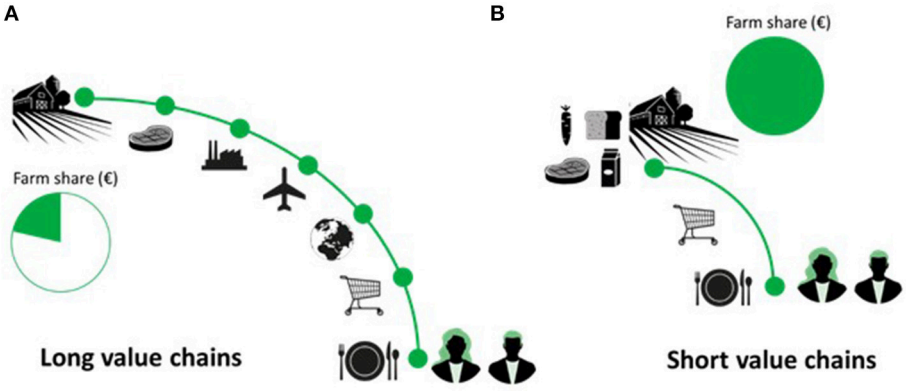

Figure 3

(A) When farms are far from their customers, the food-supply chain is long. When this happens, farmers make less money when the food is sold to consumers (see "farm share" pie chart) because the profits are spread out over all the partners in the chain. **(B)** When the food-supply chain is short, there are fewer partners, and the famer ends up with a larger profit.

DIVERSIFICATION—DO NOT KEEP ALL THE EGGS IN ONE BASKET!

The idea of **diversification** is to make a farm less dependent on selling food, by finding ways to earn income from other activities [7]. Some farms offer holiday activities for families, particularly those who live in cities and are searching for things to do in nature. Other farms keep horses and offer riding lessons, which city dwellers also enjoy. There is a lot to see and learn about agriculture and farm life, so some farmers open their gates for school classes, while some choose to open a café or restaurant on the farm. As you can see, agriculture can not only produce food, but it can also make life more colorful and diverse for city dwellers. However, this only works if farmers earn enough money to keep their farms running.

DIVERSIFICATION

A business strategy that involves offering new products and services in addition to food production, such as holiday activities for families, riding lessons, and open a café on the farm.

SUMMARY

Let us think again about the wheat we discussed at the beginning of this article. While most rural farmers sell their wheat into long supply chains, differentiated and diversified farms might do something different. Differentiated farms might process the wheat into bread that they can sell in their on-farm shop, while diversified farms might offer baking events to teach people about all the steps between harvesting wheat and making bread. Both options create memorable experiences for customers and help customers form connections with farmers.

So, coming back to the initial question of whether a farmer can earn money by producing food in or near a city, the answer is: Yes, but...! To be successful, farmers near cities must adjust their businesses appropriately, to meet the needs and wishes of city dwellers. Doing so can result in many advantages for both farmers and the city dwellers.

ORIGINAL SOURCE ARTICLE

Pölling, B., Sroka, W., Mergenthaler, M. 2017. Success of urban farming's city-adjustments and business models—Findings from a survey among farmers in Ruhr Metropolis, Germany. *Land Use Pol.* 69:372–85. doi: 10.1016/j.landusepol.2017.09.034

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CONFLICT OF INTEREST: 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.

YOUNG REVIEWERS

DAVID, AGE: 12

I am David, and I would like to have a three bros farm when we grow-up with our little brother Peter.

DEREK, AGE: 15

Hi, I am Derek, and I currently live in Vancouver, Canada. I love science, but outside of that, I can be found staring at a map, trying to wrap my head around math problems, desperately attempting to memorize ancient vocabulary moments before a test, or hitting the buzzer far too late in quiz competitions.

JAMES, AGE: 9

I am James, and I would like to have a three bros farm when we grow-up with our little brother Peter.

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FARMING ON TOP: ROOFTOP AGRICULTURE FOR HEALTHY CITIES

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YOUNG REVIEWERS:

FDR-HB_ PERU IGEM TEAM

AGES: 14–17

The world is facing many problems nowadays, including a growing number of people living in cities, many of whom often do not have easy access to fresh food. To solve this problem, it is necessary to develop a new kind of agriculture that provides city residents with food security while also protecting the environment. Rooftop agriculture could be a solution. Rooftop agriculture is a type of urban agriculture, in which food is grown on the tops of buildings. Rooftop agriculture can have many benefits. For example, it can reduce the extreme heat in the city during summer, it can help to decrease urban poverty, and it can help people to socialize more. In addition, rooftop agriculture can even benefit the buildings themselves. Rooftop agriculture is becoming more popular across the world, thanks to these benefits. We hope it will become an important part of the sustainable cities of the future.

KEY POINTS

- Researchers have found that the interest in rooftop agriculture has been increasing across the world.
- Most examples of rooftop farms are in developed countries, whereas there is still not much rooftop agriculture happening in less-developed countries. This is unfortunate because it is often more common for people in less-developed countries to have difficulty finding and affording enough food. If rooftop agriculture were increased in these countries, it could help with the food security of the people living there.
- Rooftop agriculture can also improve the wellbeing of building residents, providing them with opportunities to socialize and help with gardening, which many find enjoyable.
- If rooftop agriculture developed for innovation purposes increases, new technologies will be developed that will increase the amount of food that can be grown and sold to city residents.
- Local food production can reduce the pollution and additional expense associated with trucking food in from the countryside.

WHAT IS ROOFTOP AGRICULTURE?

The world's cities face many problems nowadays. For example, the urban population is growing quickly and climate change is affecting storms management and causing excessive heat. As a result, food is often difficult for poorer populations to access, as well as for certain groups, including immigrants and older people, which are often socially excluded. **Urban agriculture**, which means growing food within cities, can help to reduce these problems. In fact, urban agriculture can provide many benefits to a city. For example, it can reduce the excessive heat that builds up in cities during the summer, it can create small communities of people that allow for improved social interactions, it can help small businesses to grow and make money, and it can help guarantee **food security** to decrease a city's reliance on food that is transported in from the countryside.

URBAN AGRICULTURE

The cultivation of food within or close to the city.

FOOD SECURITY

The ability for all people to have access to food.

ROOFTOP AGRICULTURE

The cultivation of food on the rooftops of city buildings.

HYDROPONIC

Describes the cultivation of plants in water, without soil.

In most cities, there are only a few empty spaces with soil to grow plants, which is an obstacle for urban agriculture. Luckily, the cultivation of crops on rooftops, called **rooftop agriculture** [1], can help to overcome this problem (Figure 1A). In rooftop agriculture, plants are grown in a soil-filled container or soil-free **hydroponic** systems. The amounts of water, soil, or other resources needed for rooftop agriculture can vary greatly, depending on the cultivation system and the types of plants grown. For example, a hydroponic system uses zero soil but lots of water, whereas only 20 cm of soil may be needed to grow small plants (e.g., lettuces) if soil-filled containers are used (Figure 1A).

Figure 1

(A) Rooftop agriculture in containers filled with soil. **(B)** An open-air rooftop garden on top of a housing complex in Bologna, Italy. This rooftop farm was created for social integration.

Figure 1

Rooftop agriculture can be good for the buildings, too. For example, plants can help to insulate buildings from extreme temperatures, thereby reducing the amount of energy needed for heat and air conditioning, as well as the pollution produced by the heating and cooling processes. This also lowers the costs to heat or cool the building. Rooftop agriculture can also reduce noise pollution from the city and protect the roof from sun, rain, and wind.

TYPES OF ROOFTOP AGRICULTURE

We can classify rooftop agriculture in various ways (Figure 2). First, we can distinguish two types of farming: rooftop greenhouses, which are rooftop farms with protective structures covering them, and open-air rooftop farms, which do not have protective structures. Rooftop greenhouses protect crops from conditions like cold and wind, and they allow cultivation during the winter. However, open-air rooftop farms are easier to construct and less expensive. For this reason, open-air rooftop farms can be used in places where there is less money to spend on urban agriculture.

The buildings used for rooftop agriculture can be of two types. Buildings can be monofunctional, which means they are used *only* for plant cultivation. In this kind of building, plants can be grown

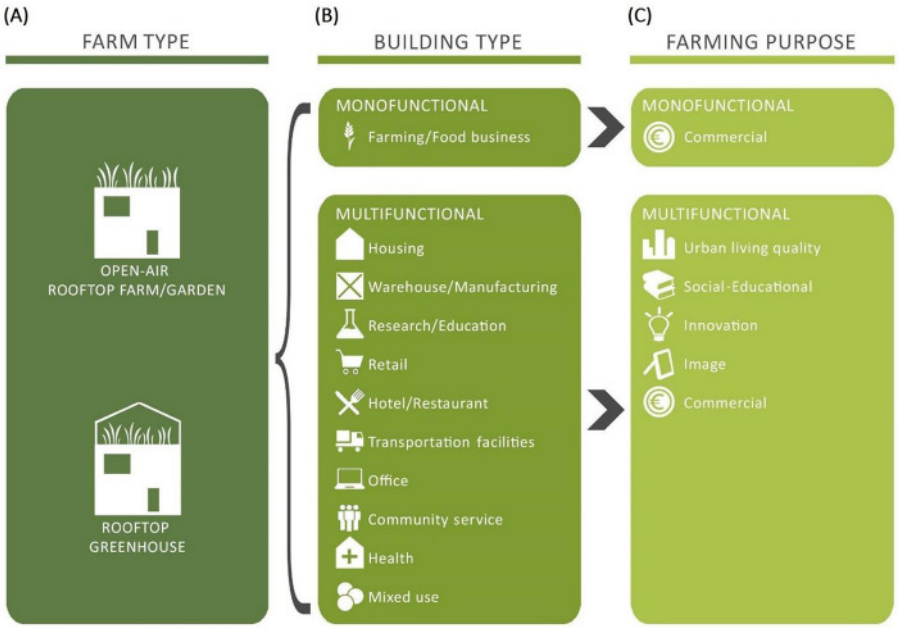

Figure 2

(A) Rooftop agriculture can be classified according to whether the farm is open-air or covered by a greenhouse. **(B)** Rooftop agriculture can occur on buildings that serve only for food production (monofunctional) or on top of buildings with other purposes (multifunctional). **(C)** Rooftop farms can be created to meet various objectives.

inside, too. Multifunctional buildings have more than one function. These buildings can be houses, supermarkets, schools, or hospitals, and the rooftops are the only cultivated part. Any type of building with a flat rooftop can be used for rooftop agriculture, but there are important considerations. For example, engineers must ensure that the added weight on the roof is safe for the building, and emergency exits, and protective railings must be present, for the safety of those using these gardens.

Rooftop farms can be created for various purposes. There are five main objectives of rooftop cultivation. Some rooftop farms are created to improve *urban living quality*, such as to give people a place to relax and enjoy nature. Others are created for *social-educational* purposes, such as to help different groups of people interact with each other, or to teach people about gardening (Figure 1B). Some rooftop agriculture is established for *innovation*, in which they create new technologies. Sometimes rooftop agriculture is used to improve the *image* of a building, making it more beautiful. Lastly, *commercial* rooftop farms are those created to make a profit [2].

ROOFTOP AGRICULTURE IS GROWING!

Rooftop agriculture is gaining popularity across the world, thanks to its benefits. Researchers have been working to understand the worldwide development of rooftop agriculture (Figure 3). By searching articles and websites, researchers counted 185 examples of rooftop agriculture across the world. Most of this rooftop agriculture is found in North America and Europe. South America has the lowest number

Figure 3

(A) Over the years, rooftop agriculture has become increasingly popular across the world. **(B)** Each black dot shows an example of rooftop agriculture identified by researchers. You can see that North America and Europe have the greatest concentration of rooftop farms.

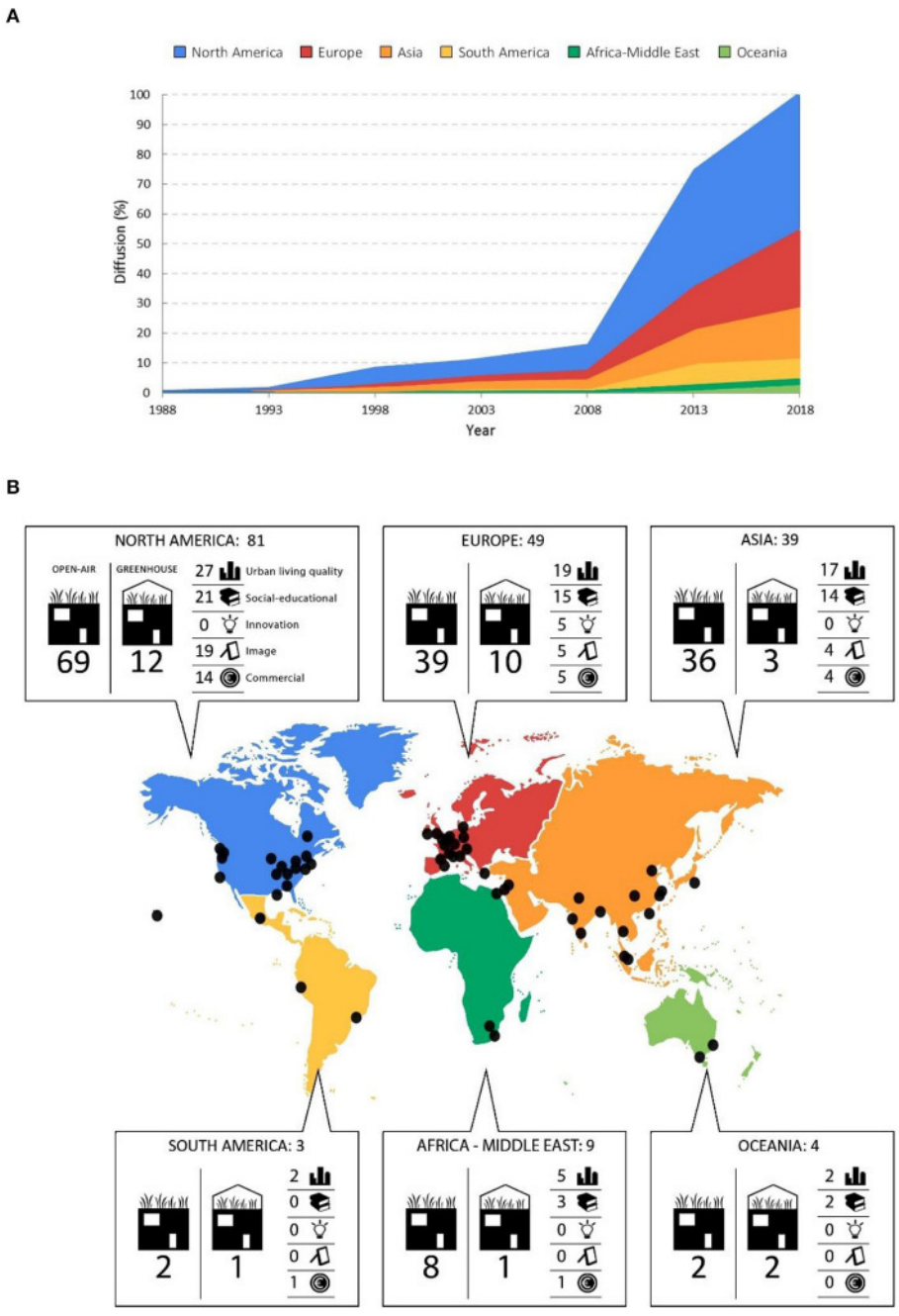

Figure 3

of examples. In total, there are 5 times more open-air rooftop farms than there are rooftop greenhouses. Urban living quality is the most common farming goal on every continent. Europe is the only country with innovation as an objective. The first example of rooftop farming was seen in the 1980s, but the number of rooftop farms did not reach a peak until 2010. Most rooftop farms are on the tops of schools and houses.

For all these reasons, rooftop agriculture could help to improve the world's increasingly crowded cities and the lives of the people living there. Rooftop cultivation is the future of the cities.

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YOUNG REVIEWERS

FDR-HB_PERU IGEM TEAM, AGES: 14–17

We are a synthetic biology team with the international Genetically Engineered Machine (iGEM) in Lima, Peru. We are the only high school team in Latin America and are proud of our work with creating a detector for cadmium using bacteria. Most of us are second language learners and the age range of our group is 14–17 years old. We love GMOs!

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Elisa is a Ph.D. student and agronomist. She grew up in the countryside. Since she was a child, she has loved nature and agriculture. For this reason, she decided to study agriculture. Urban agriculture is the focus of her research. In fact, she believes that it is important to reconnect citizens with nature. *elisa.appolloni3@unibo.it

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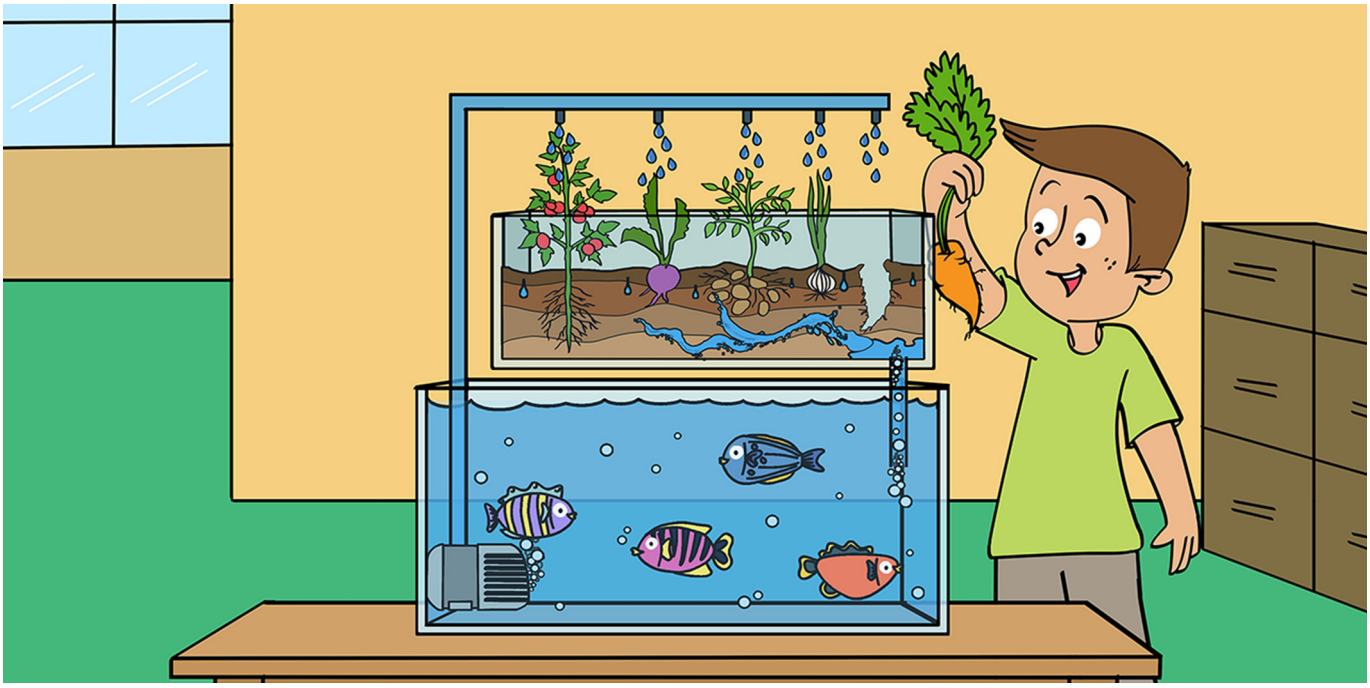

AQUAPONICS: A PROMISING TOOL FOR ENVIRONMENTALLY FRIENDLY FARMING

Roberta Calone * ***and Francesco Orsini***

DISTAL—Dipartimento di Scienze e Tecnologie Agro-Alimentari, University of Bologna, Bologna, Italy

Nowadays, agriculture must face a new challenge: produce more food with fewer natural resources. To achieve this goal, scientists are testing a technique called aquaponics. Aquaponics was introduced many years ago by ancient Chinese and Mexican populations. In aquaponics, fish and plants are farmed together. How is this possible? Bacteria change the fish poop into nutrients useful for the plants. The plants take up these nutrients and clean the water, which can then be reused to farm the fish, and the cycle restarts! Aquaponics allows farmers to obtain two products at once, and to recycle the same water many times. Almost no wastewater is released into the environment! Aquaponics systems can have different sizes and do not need soil. They can be installed in both outdoor and indoor environments. Big aquaponic systems are used for commercial purposes, while small aquaponic systems can be used for urban farming—growing food within cities.

YOUNG REVIEWERS:

CHERYL
AGE: 9

PRICE
AGE: 14

PROVIDENCE
AGE: 10

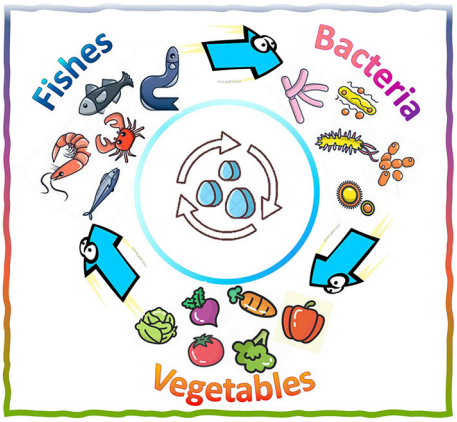

Figure 1

Figure 1

Water cycle within an aquaponics system. Bacteria convert the fish poop into nutrients that are good for the plants. The plants' roots take up these nutrients, and in doing so, they clean the water. The purified water is reused for fish farming. In this way, we obtain a closed water cycle, in which the same amount of water continuously flows. Water flows from the fish to the plants, and then back to the fish, and so on!

WHAT IS AQUAPONICS?

The population of the world is increasing rapidly, and there is not enough food to feed this growing population! Scientists have an important mission: they must find a method for producing more food without stressing the environment. Traditional farming techniques damage the environment in many ways. They harm natural resources and pose health risks to humans and wildlife. A technique called aquaponics could be a solution to this problem. The "aqua" part of this word comes from aquaculture, which is the practice of raising fish, shrimp, algae, and other seafood. The "ponics" part comes from hydroponics, which is the cultivation of plants in water, without soil. Aquaculture and hydroponics can exist separately, but when we combine them, we obtain aquaponics!

Aquaponics is a miniature version of a natural ecosystem. It works the way Mother Nature normally works in every aquatic environment! First, in aquaponics, we put the fish to work. By working, we mean eating and pooping. This results in water that is rich in nutrients—yes, the fish poop! Then, bacteria come into play. Bacteria convert the fish poop into a perfect fertilizer for plant growth. The plants take up this fertilizer with their roots and, in doing so, also clean the water. The clean water is reused for farming the fish (Figure 1). The cycle restarts!

In an aquaponics system, fish, plants, and bacteria work together as a team. This teamwork allows farmers to obtain two food products, fish and vegetables, using the same amount of water that would normally be used to obtain just one product. In this closed cycle, water is not wasted—the wastewater released into the environment is almost zero [1]!

Figure 2

Aquaponics has been used for about 1,500 years in China, where rice was grown in flooded paddy fields (top). In Mexico, the Aztecs produced vegetable on floating gardens called chinampas (bottom).

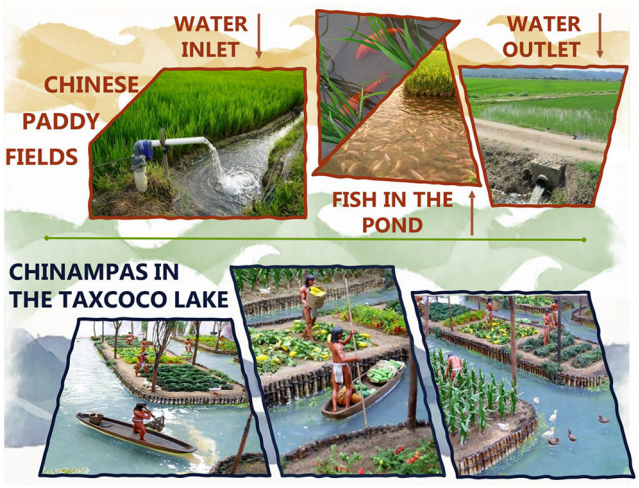

Figure 2

AQUAPONICS, PAST AND PRESENT

PADDY FIELDS

A flooded field used to grow rice.

The idea of aquaponics is quite old. The first forms of aquaponics were used about 1,500 years ago, in South China, Indonesia, and Thailand. The farmers there grew rice in **paddy fields** that also had fish in them. The fish poop served as fertilizer for the growth of the rice plants (Figure 2).

Five hundred years later, a population in central Mexico invented another form of aquaponics. This population, known as the Aztecs, created a big empire. The capital of the empire, called Tenochtitlán, was built on the shores of Lake Texcoco. In that wetland, the Aztecs did not have fertile lands to cultivate their food. For this reason, they built gardens floating in the lake, called chinampas. These floating islands were made of mud and dried plant residue. On the chinampas, farmers cultivated maize, squash, tomatoes, and other crops. The plants could take up nutrients from the lake water, which was rich in fish poop.

Although the concept of aquaponics is ancient, it was not until the 1970's that scientists rediscovered its potential. Nowadays, aquaponics is becoming quite advanced, and it provides a sustainable solution for agriculture, that will reduce the use of natural resources. Aquaponics uses up to 90% less water than traditional agriculture [2] and the plants grow much faster [3]! Aquaponics also reduces pollutants coming from the use of tractors and field chemicals [4].

Aquaponics systems can be installed both outdoors and in indoor, greenhouse-like environments. Indoors systems can allow food to be produced throughout the year! This is a great advantage in areas where the climate is not favorable for agriculture, for example, places with low temperatures, short daylight, and an absence of rain or freshwater for irrigation.

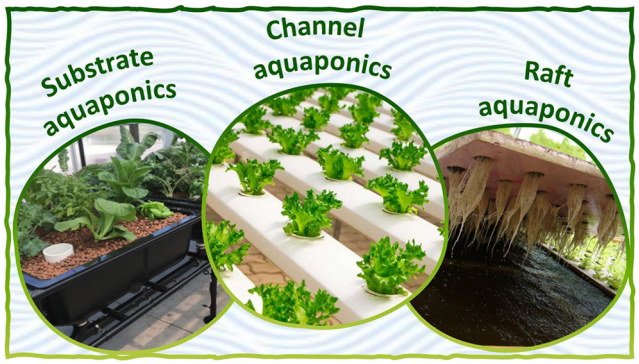

Figure 3

Figure 3

The three main aquaponic systems. Substrate aquaponics has a soil-like substrate to help plant growth. In channel aquaponics, the plants are placed within pipes that have nutrient-rich water running through them. In raft aquaponics, the plants are placed on floating rafts with their roots reaching down into the water for nutrients.

TYPES OF AQUAPONICS

There are three main aquaponics systems in use today (Figure 3). In **raft aquaponics**, the plants are grown on floating rafts. The rafts float in tanks filled with the wastewater from the fish culture. The plant roots dip into the water where they can absorb the nutrients from the fish poop. This method is most appropriate for small plants like salad greens, basil, spinach, chard, and others. In **substrate aquaponics**, the plants grow in a substrate that mimics the soil. This substrate sustains the plant roots and helps the bacteria to filter the water. This kind of system is suitable for all types of plants, but it is most often used for cabbage, broccoli, onions, fennel, carrots, tomatoes, peppers, cucumbers, beans, peas, squash, and melons. Last, in **channel aquaponics**, the wastewater from the fish flows through narrow pipes with holes, into which the plants are placed. The roots dip into the stream of water within the pipe, where they can uptake the nutrients from the fish poop. This growing method works well for plants that need little support, such as strawberries, leafy greens, and herbs. The pipes can also be placed vertically to save space.

There are many fish species that can be used in aquaponics systems. These systems can incorporate large, small, edible, or ornamental fish, it depends on the ultimate purpose of the system. The most common species of fish in aquaponics systems are tilapia, bluegill, catfish, carp koi, fancy goldfish, shrimp, and pacu.

RAFT AQUAPONICS

System in which plants are placed in holes drilled in rafts. The rafts float within tanks filled with fish wastewater. Plant roots dip in the water where they absorb nutrients.

SUBSTRATE AQUAPONICS

System in which plants are placed in holes drilled within pipes where continuously the fish effluent water flows. The roots dip into the water stream, where they can uptake the nutrients.

CHANNEL AQUAPONICS

System in which plants are placed within a substrate that mimics the soil. This substrate also contains bacteria that help the plant to uptake nutrients from the fish wastewater.

BENEFITS OF AQUAPONICS IN CITIES

Nowadays, there is a growing interest in small-scale aquaponics systems. These systems can be located within cities; for example, they can be located in parks, urban gardens, buildings, houses, courtyards, and on rooftops. Introducing small aquaponics systems into cities can bring many benefits. Aquaponics can provide a large variety of organic and seasonal fresh produce. These vegetables are environmentally friendly because they have a reduced

transport footprint—they do not need to be transported far before reaching our tables. Urban aquaponics systems can also encourage social initiatives. For example, they can promote **cohousing** and educational workshops, both of which provide people with a greater chance of meeting their neighbors. Aquaponics can also provide a shelter for birds and beneficial insects, which increases the city's **biodiversity** [5]. Last, urban aquaponics can help to create jobs for people in cities.

In summary, aquaponics is a circular soilless production system. It allows producing fish and vegetables together with the same amount of water, helping to save water. By participating in aquaponics, people can learn more about the lives of plants and fish. They can become more aware of how the foods they buy in grocery stores have been produced. This is especially important for younger people in cities and suburban areas, who are at risk of losing touch with the farming world. And one more important thing—participating in aquaponics is also a lot of fun!

TRANSPORT FOOTPRINT

Greenhouse gas emissions from transportation (trucks, airplanes, railways, etc.).

COHOUSING

Communities in which people have their own residences but share common spaces such as rooftops, courtyards, and balconies.

BIODIVERSITY

Set of all living forms that are on Earth—plants, animals, insects, fungi and micro-organisms, and their habitats.

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CONFLICT OF INTEREST: 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.

YOUNG REVIEWERS

CHERYL, AGE: 9

Hi, I am Cheryl. I have a cat named Delilah and two little sisters called Tanya and Alice. I live in a small city of Canberra. I am sometimes pretty shy and sometimes pretty cheeky. I absolutely love icecream especially "Cookies 'n' cream." Love you all.

PRICE, AGE: 14

Price loves making up stories and has also written a book (Ms. Wasteson and the waste empire). She enjoys gymnastics, athletics, volleyball, and basketball. She is brave and bouncy. Price also enjoys quality time with family and is very creative. At her school, she is part of a "green team" that works to protect the environment. She likes debating and has a passion to study and become an activist against social injustices.

PROVIDENCE, AGE: 10

Providence is the youngest amongst her three sisters. She is playful and bouncy. Providence is curious, talkative, and likes asking many funny questions, that leaves others laughing. She loves making new friends and traveling. Providence loves science experiments. During this process, she may destroy, repair or recycle some household items. As part of this adventure, Providence repaired a spoilt speaker. But after weeks of action, she modeled the speaker wires into skipping ropes. She is passionate about music and sports including volleyball.

AUTHORS

ROBERTA CALONE

I believe that we can take inspiration from nature to change the way we produce food. Most current farming techniques are strongly dependent on natural resources. Current agriculture needs a lot of land, water, and energy. This is seriously threatening the environment. Agriculture also produces a lot of pollutants that pose health risks for humans and animals. My research in aquaponics arises from the urgent need to improve food-production systems. Aquaponics is an ancient food-production system, forgotten for many centuries. Aquaponics allows us to increase agricultural productivity while reducing the use of natural resources. It is a circular system with almost zero waste. I started my research in Germany, as a university student and I am now continuing to study this topic for my Ph.D. at Bologna University. I am also in collaboration with some aquaponic farms in northern Italy. *roberta.calone3@unibo.it

FRANCESCO ORSINI

I was always intrigued by how a traditional sector like agriculture could accept and integrate innovation. We always think of farming as a rural activity, even though most of the world's population lives in cities, and innovative technologies for plant cultivation in highly urbanized environments are available. After taking part in community farming projects in African, South-East Asian and Latin American cities, I started to perform research on urban agriculture in Italy and Europe. Today I teach urban agriculture at Bologna University and coordinate research in an EU project called Food Systems in European Cities (FoodE).

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EARTH AND ITS RESOURCES
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THE IMPORTANT ROLES OF URBAN AGRICULTURE

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YOUNG REVIEWER:

AYAT

AGE: 9

The growing urban population, climate change, and the scarcity of natural resources are major world-wide challenges. In the coming years, we must ensure that more food is available to feed Earth's growing population. We need to reduce the pressures that agriculture places on the Earth. Urban agriculture, which means growing food in cities, evolved throughout human history. Urban agriculture promotes local and sustainable food systems. Agriculture in cities is good for the environment, the ecosystem, and the climate. Urban farming brings communities together and it improves the health of citizens. There are many good reasons for farming in the city!

WHEN DID URBAN AGRICULTURE BEGIN?

The growing of plants by humans, called agriculture, started at the very beginning of civilization. After agriculture took hold, the constant movement of civilizations that was necessary for hunting and gathering was no longer needed to obtain food. Therefore, humans settled in villages. The first documented examples of urban agriculture

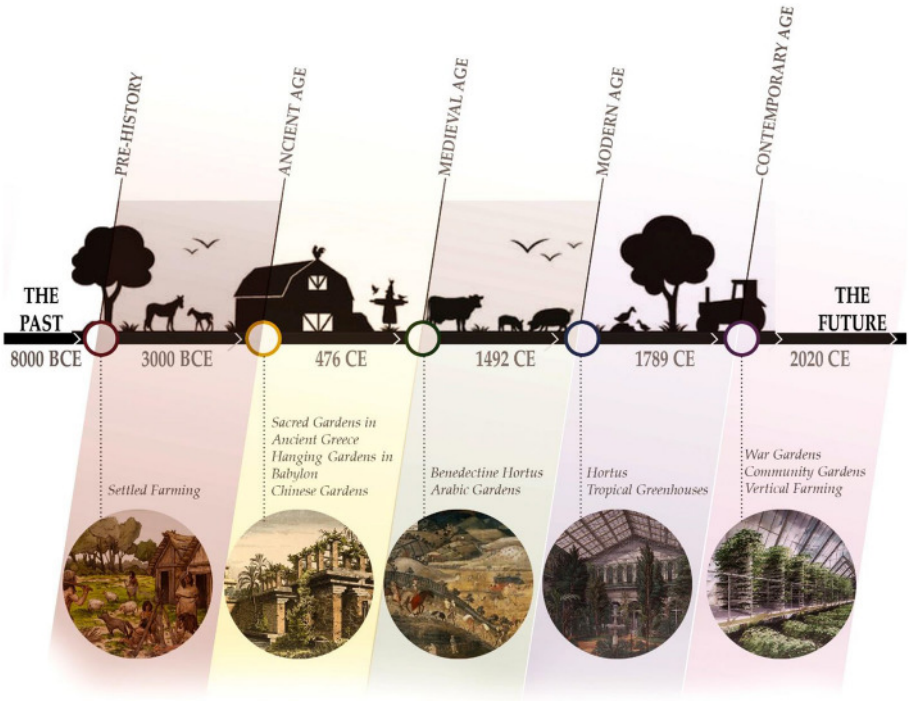

Figure 1

History of urban agriculture, from 8000 BCE (before the current era) to 2020 CE (current era).

(the growing of food within cities) include the hanging gardens of Babylon and the sacred lands of Greek cities. The health benefits of gardening were studied in Chinese gardens more than 2,000 years ago. Similarly, Arabic gardens combined beauty with other sensory experiences, such as smells and odors from aromatic plants, flowers for visual attractiveness or sounds by including plants that would attract birds and other fauna. Gardens were often places people went for their spiritual and mental wellbeing. In the Middle Ages, kitchen gardens, called hortus, appeared. In Benedictine monasteries, food was produced and processed by monks. In the Modern Age (from late 1400), the villas of wealthiest in Northern Europe had exotic plants in their tropical glass greenhouses. During the Industrial Revolution, factory workers also started gardening. These gardens both produced fresh food and provided places for workers to relax and reduce stress. Urban gardens were also promoted during war times, to provide cities with fresh vegetables. In recent years, urban agriculture has been associated with advances in society and technology (Figure 1). We can say that agriculture has contributed to the growth and development of urban cultures throughout human history!

URBAN ECOSYSTEM

Any ecological system located within a city or other densely settled area. It can also refer to the greater ecological system that makes up an entire metropolitan area.

ARE URBAN ECOSYSTEMS SUSTAINABLE?

First, what is an **urban ecosystem**? An urban ecosystem includes all the living organisms and non-living components of the urban environment, and it considers all their interactions and connections.

Figure 2

The urban ecosystem. About 50% of people currently live in urban environments and this percentage will continue to grow into the future. Urban environments can have serious impacts on Earth's environment, including a large contribution to climate change and the successive abandonment of rural areas. Besides, cities cover land with an impermeable layer of concrete that limits water flows during rainfall, causing floods, and accumulate heat during warmer seasons, resulting hotter than the surrounding countryside (Urban Heat Island effect).

SUSTAINABILITY

All those practices that can guarantee that humans can successfully provide for their needs without compromising the natural, social, and economic environments where they live.

RESILIENCE

The capacity of an ecosystem to respond to a disturbance by resisting damage and recovering quickly.

SOIL SEALING

The process that occurs when soil is covered with impermeable material (asphalt, concrete, etc.). It is an irreversible process linked to construction in cities.

A **sustainable** ecosystem is one that allows for multiple species to live and interact in the long term.

Today, half of all people on Earth live in urban settings. By 2050, two thirds of the global population will live in cities (Figure 2). All these people will need food daily! Food for people living in cities is generally produced elsewhere—it normally comes from farmers in rural areas. When an ecosystem does not include all its necessary components, the ecosystem may be considered incomplete. An incomplete ecosystem can have a high environmental impact. For example, additional energy must be used to transport fresh food to cities and store it there. Incomplete ecosystems also have lower **resilience**, which means their capacity to stand stresses. For example, when a crisis occurs (such as a pandemic or a war conflict), it may be difficult for people in cities to find food.

In highly dense cities, the urban ecosystem is at risk. For example, in urban environments, much of the soil is often covered by concrete or asphalt. This is called **soil sealing**, and it can prevent water from being absorbed by soils. When intense rain occurs, soil sealing often results in flooded cities because the rainwater cannot enter the soils. Cities can also be significantly warmer than surrounding rural areas, due to

Figure 3

Urban agriculture has many benefits for the climate, for city-dwelling people, and for the local ecosystem.

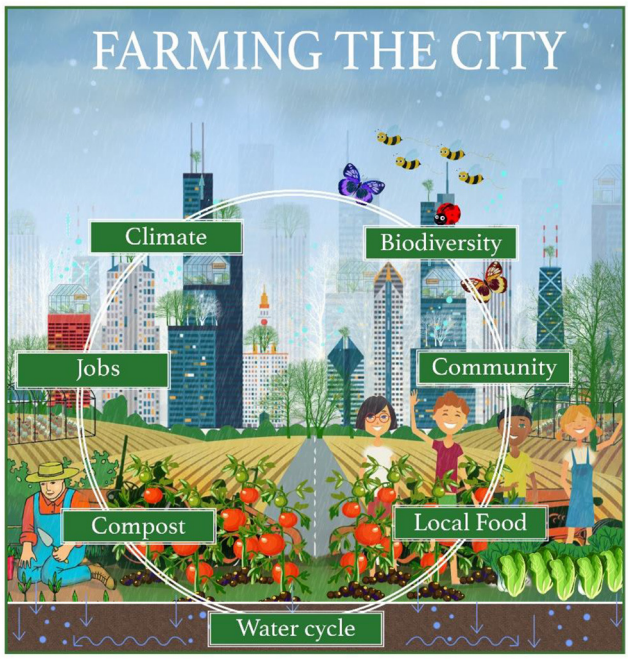

Figure 3

URBAN HEAT ISLAND

An urban area that is significantly warmer than its surrounding rural areas due to human activities.

BIODIVERSITY

All living creatures that exist in an ecosystem. Biodiversity keeps Earth's environment in balance, so it is important to preserve it.

human activities. These warm cities are called **urban heat islands**. Just imagine a city as an island of heat, floating in the cool sea of the surrounding countryside!

When green spaces and parks are limited in urban environments, **biodiversity** is also at risk. People who live in cities generally have limited access to nature. All these factors tell us that the presence of plants within a city serves multiple functions for the urban ecosystem!

CAN URBAN AGRICULTURE MAKE OUR CITIES MORE SUSTAINABLE?

Urban farming may help with a city's environmental, social, and economic challenges. Plants can improve the Earth's climate by reducing heat during the warm season, and they can retain water during intense rains, reducing the risk of floods. Urban gardens and parks can provide shelter for birds and beneficial insects, which helps to preserve urban biodiversity. A lot of organic waste, for example fresh food residues, is produced in cities. Organic waste can be turned into compost and used in urban gardens. Also, used coffee grounds may be collected from bars and restaurants—these are great for growing mushrooms.

The health of city citizens who are involved in urban gardening often improves. These city dwellers generally have more diversified diets and eat more fruits and vegetables, which are rich in vitamins and

minerals. These foods are good for our health! When people engage in urban gardening, their sense of belonging to the local community is increased. Citizens benefit from meeting their neighbors and they may bond with new people. Urban agriculture may contribute greatly to a city's **food security**. Food security is guaranteed when all the population have sufficient access to food to satisfy their needs. Urban gardening could potentially fill a city's needs for fresh fruits and vegetables [1].

FOOD SECURITY

The condition where all the population has access to a sufficient quantity of affordable, nutritious food.

Today, urban agriculture projects are increasing worldwide, and they are creating new jobs (Figure 3). Some restaurants only use locally produced food. Other successful examples of urban agriculture include school gardens and cooking workshops that use ingredients grown in the city. Urban farms also become places where technological advances can happen. For example, plants can be grown inside closed rooms and using artificial light, as is the case for **vertical farms**, which are enclosed cultivation systems where plants are grown in multiple layers, supplied by artificial lighting [2]. Also, rooftop farms and greenhouses are commonly found in the cities of North America. All in all, we can say that farming in the city is a way to create a more sustainable and livable environment for the world's growing urban population!

VERTICAL FARMS

A building in which plants are grown in multiple layers or levels, generally supplied with artificial light.

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YOUNG REVIEWER

AYAT, AGE: 9
I love drawing, painting, playing chess and reading books. My favorite books include "the secret garden" and "the wonderful wizard of Oz," and anything and everything about Dinosaurs. I like nature and frequently go out hiking to observe the beauty of nature and take notes and make sketches in my notebook.

AUTHORS

FRANCESCO ORSINI
I was always intrigued by how a traditional activity like agriculture could accept and integrate new technologies. We always think of farming as a rural activity, despite the fact that most of the world's population lives in cities, and that new technologies for growing plants in city environments are already available. After taking part in community farming projects in African, South-East Asian and Latin American cities, I started to research urban agriculture in Italy and Europe, and today I teach urban agriculture at Bologna University and coordinate research for the EU project Food Systems in European Cities (FoodE). *f.orsini@unibo.it

MICHELE D'OSTUNI
I am a Ph.D., student at the very end of my doctorate path. As an architect, I decided that my mission is to bring nature back into cities. In my own style, I

am always looking for new technologies that can improve human life in urban environments. During this research I discovered the concept of urban agriculture, and I decided to develop my knowledge about this amazingly fascinating subject. I then became president of a non-profit organization called BiodiverCity that fosters urban farming initiatives in Europe, and I was involved in the organization of the UrbanFarm International Student Challenge. *michele.dostuni@unifi.it

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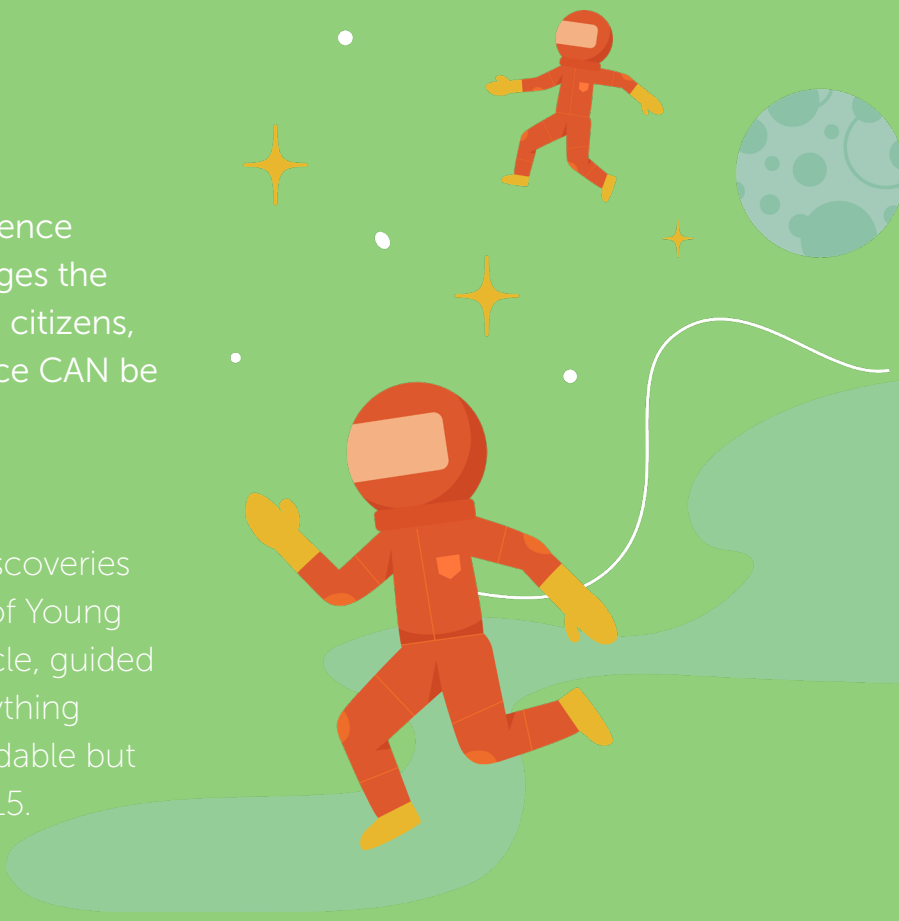

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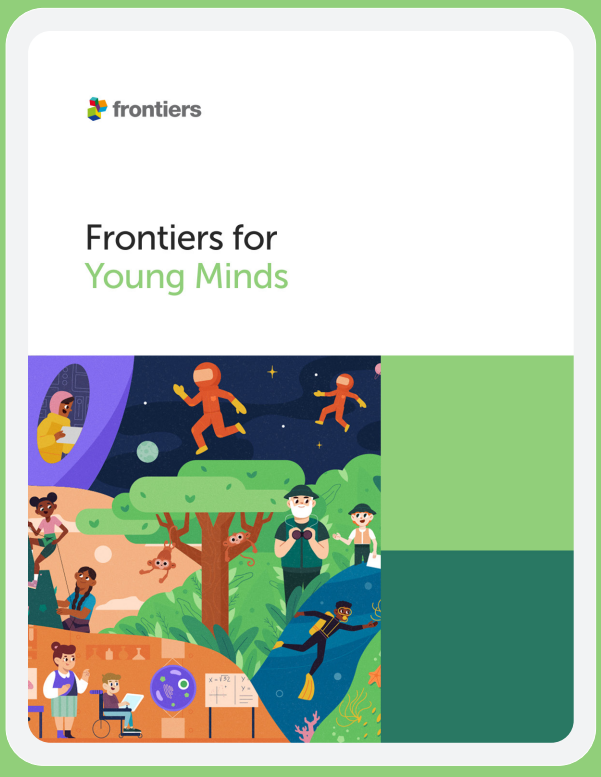

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