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CIRC4FooD: An urban food production system inspired by the circular economy

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Abstract

The environmental footprint of the current, linear food system is a key challenge that must be dealt with for a transition to sustainability -a fact highlighted in the recent Circular Economy Action Plan of the European Commission. Agricultural practices are drivers of polluting food production, while cities form critical hubs of wasteful food consumption. Urban agriculture has emerged as a promising practice for shortening supply chains while building urban resilience. The aim of this article is to present CIRC4FooD: a system for urban food production inspired by the circular economy, aiming at reducing the use of resources and the environmental impact of food production and consumption in the city. CIRC4FooD is comprised of four sub-systems: rainwater collection system, vegetable garden precision irrigation, composting system and a smart irrigation system. The latter collects data from all sub-systems, providing input to an online platform for monitoring and assistance, where the users can be informed about the growth of the vegetables and their water or fertilizer needs. The CIRC4FooD system is currently being piloted in three scales at the city of Trikala in Greece: raised beds and small municipal gardens in public space (small scale), domestic vegetable gardens (medium scale) and a city park (large scale). The expected results, apart from sustainability gains, include the optimization of the water harvesting installations and precision agriculture software, as well as the development of an integrated, circular urban agriculture system widely available to cities and citizens.

Keywords: Urban Agriculture, Circular Economy, Rainwater Harvesting, Precision Irrigation, Composting

1. Introduction

Globally, cities are drivers of resource consumption and waste production, although they cover only 3% of the planet's surface. Our planet is already predominantly urban, while the urbanization level keeps on rising. Along with urban population, the need for food and resources to cover the needs of the 4.5 billion urban dwellers steadily increases: by 2050, 80% of the food produced globally is expected to be consumed in cities. Increased urban food consumption is directly related to increased use of natural resources for production and transportation through long and in many cases global supply chains, as well as more food waste to process and eventually discard.

The linear nature of our economy and our food system is calculated to cost 5.7 trillion USD per year, while the agriculture industry is responsible for ¼ of the global GHG emissions and the degradation of natural resources. Although massive amounts of resources are required in order to produce our food, the FAO estimates that around 1/3 of it is lost in the production and logistics chain or wasted by retailers, food service providers and consumers, every year. An estimated 20% of the total food produced is lost or wasted in the EU. Amidst this landscape of incautious resource consumption in the food sector, food security is rising as an urban challenge, a paradox that was highlighted even more by the outbreak of the pandemic.

The switch to a circular food system, combined with food production in urban areas, can provide solutions for reducing the planet's food footprint while providing opportunities for healthier cities and lifestyles. In this direction, organizations like the Ellen MacArthur Foundation for the transition to circular economy have introduced initiatives for circular economy in cities and the transformation of the global food system. The synthesis report "Cities and Circular Economy for food" (MacArthur Foundation, 2013) suggests three key priorities in order to achieve circular urban food systems: local and regenerative sourcing of food, reduction or elimination of food waste, and production/promotion of healthier food options.

Urban agriculture provides major benefits in shortening the supply chain, while covering people's need for fresh food. It can support cities to produce food locally, while circular food systems such as the one presented in this study can eliminate the waste of food and reduce the use of resources like water and fertilizers through rainwater harvesting and composting. The combination of food production as circular economy action and the supply of home-grown vegetables can support urban dwellers towards healthier food choices and environmentally conscious lifestyles.

2. City coalitions for sustainable food systems

Globally, cities have recognized the importance of food policies for tackling environmental and socio-economic challenges. Inspired by related policy incentives such as the Sustainable Development Goals, the EU Farm to Fork Strategy, Circular Economy Action Plan, Water Reuse Regulation and Biodiversity Strategy, several coalitions have been formed by cities around initiatives for sustainable and circular urban food systems.

The Milan Urban Food Policy Pact is an international agreement of more than 100 cities who joined forces in 2015 for the "Urban Food Policy Framework for Action": a declaration with actions for cities who want to achieve more sustainable food systems. Similarly, at the C40 cities summit in Copenhagen in 2019, 14 cities of global importance committed to sustainable food policies, with the aim of addressing the global climate emergency. Recognizing that food is among the biggest sources of consumption-based emissions from cities, and that a sustainable diet along the reduction of food waste could dramatically reduce GHG emissions from the food sector, they committed to the "Good Food Cities Declaration". Currently, in the context of the upcoming COP26, the 26th United Nations Climate Change conference that will take place in Glasgow in November 2021, the Glasgow Food and Climate Declaration brings together local authorities for food democracy and sovereignty, putting integrated food policies at center stage of global climate change discussions.

The aforementioned city coalitions, confirm the urgent need for wide implementation and large-scale application of systems that provide integrated solutions for local food production, water management and food waste reduction through approaches embedded in the local community.

3. The CIRC4FooD system

Building on the need for applied and tested solutions to promote sustainable food production in and around cities, CIRC4Food is an integrated, circular solution for urban agriculture, consisting of four distinct systems:

1. *Rainwater harvesting system*

This system collects rainwater from building rooftops or terraces and directs it to water tanks located at ground level, where it is stored to cover the water needs of the plants. The first prototype has been developed within the Horizon2020 project of HYDROUSA (www.hydrousa.org) at the island of Mykonos. Internal sensors monitor the quantity and quality of water in the tank.

2. *Precision irrigation system*

Depending on the application type, vegetables can be planted either on the ground or in raised beds, while the size of each application varies according to the requirements and availability of space. A precision irrigation system is installed, with sensors that monitor the environmental conditions of the soil such as humidity and air or soil temperature, to ensure that the plants are irrigated sufficiently upon their needs. The first prototype has also been developed within the HYDROUSA project.

3. *Compost management system*

CIRC4FooD includes a built-in aerobic compost bin for the vegetable residues, aiming at a zero-waste process. It provides the option to supply additives in order to control and optimize the composting process. Here, the sensors monitor the conditions in the bin in order to avoid malfunctioning that may result in foul-smelling or sources of infection.

4. *Online platform for monitoring and assistance*

The data collected by the sensors installed in each system are gathered in an online monitoring platform supported by a mobile device version. The platform is accessible to all users, who can enter to monitor the conditions, growth and needs (for example water or fertilizer) of their plants. They have the option of receiving notifications in a frequency that they specify themselves. Although the system can function automatically based on the input of the sensors as well as machine learning, the interaction of the citizens with the gardens is a process that will amplify the social benefits that can be acquired through the installation of a system like CIRC4FooD and is therefore much preferable.

4. Pilot application of CIRC4FooD concept

4.1. Case study: city of Trikala

Trikala is a city of 81,000 inhabitants in northwestern Thessaly, at the central region of Greece. The city is located on a plain with 115 m of altitude, and is developed along the Litheos River, that crosses the city. The climate is Mediterranean, with very high temperatures during the summer (34.5ºC average temperature in August), while the average monthly precipitation varies from 17 mm in August to 80.2 mm in February. During the last years, the region has experienced several hazardous flooding incidents due to extreme precipitation events.

Trikala is recognized as a green and smart city, appreciated for its quality of life. The city has been awarded at European level for its sustainable mobility strategies and infrastructure (extensive bike network and walkability), while it participates in several international networks and projects for knowledge production and good practices exchange. Being an extroverted city willing to innovate, Trikala is an ideal location for installing and piloting a system for urban food production such as CIRC4FooD.

4.2. Pilot installations

The CIRC4FooD system will be installed in three variations and three different scales, small to large, in the city of Trikala. The small-scale application regards mobile raised beds that will be located at various public spaces of the city, but also small municipal vegetable gardens, to demonstrate the system and raise awareness about urban agriculture, water and circular economy.

At the medium scale, CIRC4FooD will be implemented at domestic level, at detached houses and multistorey apartment buildings. In total, the installed applications regard vegetable gardens of 30 households, whose needs will be covered by independent or shared systems of rainwater harvesting and composting.

Finally, at the large scale, the full system will be installed at the Matsopoulos Mill Park, a large-scale public space for leisure and education with various activities and hundreds of thousands of visitors each year.

The systems will be piloted for a duration of six months, with extensive quantitative data collection and targeted surveys of the users in order to evaluate the characteristics of the project and upgrade the system with the necessary configurations.

Table 1. Scales of CIRC4FooD system implementation

Application scale	System typology
Small scale	Raised beds and small municipal gardens in public space
Medium scale	Home gardens at detached houses and apartment buildings
Large scale	Public space of city park

4.3 Expected results and expansion

The main benefits from the pilot applications are expected to be at least:

- 30% reduction in water used from the water supply network
- 10% increase in the quantity of vegetables produced
- 30% reduction in the use of commercial fertilizer
- 20% of reduction in food waste.

However, numerous additional indirect benefits of the circular urban agriculture approach are anticipated. Social benefits include raising awareness about environmental, technological and food literacy, while enhancing the sense of food security through local food production, and improving diet habits with increased fruit and vegetable consumption. Moreover, circular urban agriculture is expected to lead to increased social interaction and sense of community, equity and inclusion. The expected environmental benefits include urban greening, enhanced biodiversity, reduced waste production and reduced ecological footprint of citizens. Finally, economic benefits can also be achieved due to the shortened food supply chains, as food is produced closer to home.

This range of effects and impacts of the CIRC4FooD system will be analyzed in detail, in order to identify possible drawbacks that hinder the wider acceptance and mainstreaming of the system at the level of citizens or institutions, and propose solutions to address them. At the end of the project a scalability study will explore the extension of the systems throughout the city of Trikala, presenting the benefits, the expected challenges, the interventions that should be made and the corresponding costs.

Further expected results of the project include the optimization of the rainwater harvesting installations and precision irrigation software, as well as the development of an integrated, circular urban agriculture system widely available to cities and citizens. The pilot application in the city of Trikala can provide a case study for the CIRC4FooD system to be used in more cities, or for similar systems to be designed and applied in large-scale areas.

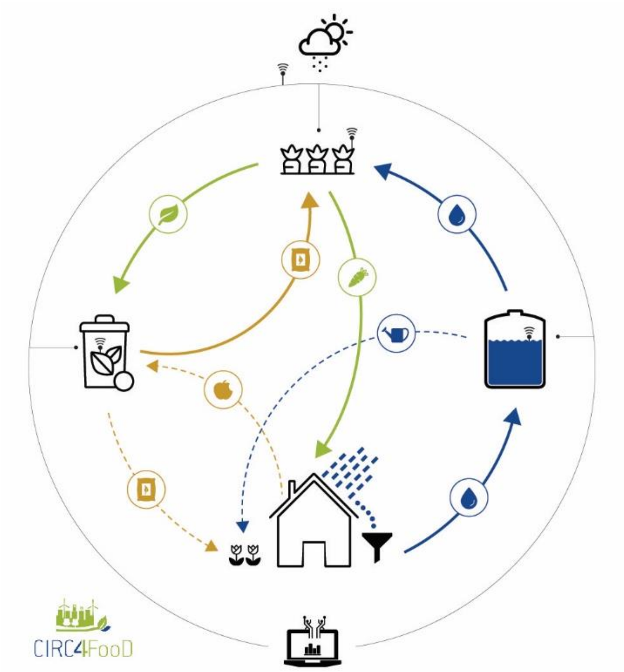

Figure 1. The CIRC4FooD system

5. Discussion

5.1. Urban agriculture as Nature-based Solution

Urban agriculture has broadly been defined as "*agricultural practices in urban and peri-urban areas, a centralized operation involving horticulture, animal husbandry, aquaculture, and other practices for producing fresh food or other agricultural products*" (Kozai et al, 2019). Although the terms urban farming and urban agriculture are many times used interchangeably, there is an underlying consent that urban farming concerns a rather market-oriented approach, whereas urban agriculture implies personal consumption and leisure or community interaction (Valley, 2018). Urban agriculture has been recognized to provide multiple co-benefits arising from the ecosystem services that urban greening entails through the production of food in urban open spaces. For this reason, it has recently been directly conceptualized as a multifunctional Nature-based Solution (NBS) (Camps-Calvet et al., 2016; van der Jagt, 2017; Artmann and Sartison, 2018; De Filippi et al, 2019; Kingsley et al., 2021).

The European Commission defines NBS as "*Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and* *seascapes, through locally adapted, resource-efficient and systemic interventions.*" (European Commission, 2015) A direct connection between the concepts of urban agriculture and NBS are the "vegetable raingardens" a category of raingardens, one of the main typologies of NBS widely implemented in urban areas. Raingardens function as bioretention facilities and are designed to reduce the runoff flow rate, total quantity and pollutant load from impervious urban surfaces.

5.2. Edible cities

The conceptualization of urban agriculture as NBS has also led to the introduction of the "edible green infrastructure" (Russo et al., 2017), "edible city solutions" (Säumel et al., 2019) and "edible cities" (Sartison and Artmann, 2020) terms, which have already connected cities around the world, joining forces to explore the real-life implementation and institutional integration of urban agriculture practices using NBS frameworks (e.g. Edible Cities Network). Sartison and Artmann (2020), considering edible cities as NBS, explore their possible contributions to urban sustainability transitions, and strategies for mainstreaming the edible city in the context of urban sustainability acceleration.

Similarly, it will be of critical importance to conceptually connect urban agriculture as NBS and the emerging edible city idea to circular economy and circular green-blue systems. Although researchers explore circular NBS for resource recovery in cities (Kisser et al, 2020; Oral et al., 2020), the value of circular urban agriculture systems as NBS, remains unexplored. Research is shared between the disciplines of urban planning, highlighting the environmental and social value of urban greening, including urban agriculture, and environmental engineering, that focuses on technological innovation related to recovery of resources such as water and nutrients. However, the combination of these two approaches has the potential to lead to holistic research frameworks as well as integrated and applied systems inspired by the circular economy, like CIRC4FooD.

5. Conclusions

The transition of cities to circular economy models plays a key role in tackling environmental and socio-economic challenges related to food systems. This article presented CIRC4FooD, an urban food production system inspired by the circular economy. Combined with rainwater harvesting, precision irrigation and composting, urban agriculture can provide a paradigm of circular, nature-based economy in cities. Although the conceptualization of urban agriculture as NBS has been established, further research on NBS and circular systems for resource recovery can support the optimization and wider implementation of integrated urban agriculture systems such as CIRC4FooD.

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