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Nature-Based Solutions for Agriculture in Circular Cities: Challenges, Gaps, and Opportunities

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Abstract: Urban agriculture (UA) plays a key role in the circular metabolism of cities, as it can use water resources, nutrients, and other materials recovered from streams that currently leave the city as solid waste or as wastewater to produce new food and biomass. The ecosystem services of urban green spaces and infrastructures and the productivity of specific urban agricultural technologies have been discussed in literature. However, the understanding of input and output (I/O) streams of different nature-based solutions (NBS) is not yet sufficient to identify the challenges and opportunities they offer for strengthening circularity in UA. We propose a series of agriculture NBS, which, implemented in cities, would address circularity challenges in different urban spaces. To identify the challenges, gaps, and opportunities related to the enhancement of resources management of agriculture NBS, we evaluated NBS units, interventions, and supporting units, and analyzed I/O streams as links of urban circularity. A broader understanding of the food-related urban streams is important to recover resources and adapt the distribution system accordingly. As a result, we pinpointed the gaps that hinder the development of UA as a potential opportunity within the framework of the Circular City.

Keywords: urban agriculture; nutrient streams; urban food systems; urban circularity challenges; resources management; urban sustainability

1. Introduction

In the face of growing concerns about resource constraints and the need to act on the global climate emergency, many countries intend to move towards a greener, competitive, and "resourceful" urban circular economy (CE) [1–3]. Food and biomass production can significantly contribute to closing of material cycling, thus maximizing the reuse of resources in the urban environment itself while reducing the need for external resource inputs (I) [4–7]. The primary production of food and biomass within the city has environmental, social, and economic benefits depending on how the nature-based solutions (NBS) are implemented. The COST Action CA17133 Circular City "Implementing nature-based solutions for creating a resourceful circular city" (https://circular-city.eu, accessed on 28 July 2021) defines NBS as "concepts that bring nature into cities and those that are derived from nature. As such, within this definition, we achieve resource recovery using organisms (e.g., microbes, algae, plants, insects, and worms) as the principal agents. However, physical and chemical processes can be included for recovery of resources, as they may be needed for supporting and enhancing the performance of NBS" [6,8,9]. This definition is used as a reference concept in the present study.

1.1. Advantages and Challenges in the Contribution of Urban Agriculture towards Circularity in Cities

Placing food production in the city offers ample potential to improve the sustainability of the urban food systems. One aspect of urban placement is the shorter distance between food-production sites and consumers or stores, enabling faster delivery and reduction of storage capacity. Short food-supply chains are easier to supervise regarding quality and origin [10,11] and can contribute to food security [10,12]. They enable reduction of response reaction times to consumer demands and adaptation of cultivation programs to the needs of consumers [10]. Shortening distances decreases the use of fossil fuels in food transportation and, consequently, decreases the emissions of carbon dioxide [13], thereby contributing to climate change mitigation. Since these and other advantages/benefits—i.e., food security, economic, social, and environmental dimensions—of urban agriculture (UA) can lead to cleaner and more sustainable cities [4], it is important to consider the environmental impacts of any urban food production.

Introducing circular processes into the city offers opportunity to increase sustainability, and in this respect, Atanasova et al. [5] formulated a set of urban circularity challenges (UCC) [6,7]. Closing of the key cycles (i.e., water, nutrients, materials . . .) as much as possible [5–7,9] optimizes the utilization of urban resources [14,15]. Addressing the UCC_3 on "Nutrient recovery and reuse" [5] comprises areas of great concern in UA, e.g., nutrient streams—especially when phosphorous (P) is involved. Furthermore, issues arise concerning resilience and resource efficiency of urban food systems towards a CE approach: security and safety, transport and economic activities, food loss and waste management, and more, especially in relation to unexpected events and/or crisis, such as the COVID-19 pandemic and its lockdown measures [16].

If implemented to a high standard, UA can respond to several of the UCC [5–7], and it will cover a range of scales—from small scale, such as domestic food growing [17], to large scale, such as in peri-urban farming. Urban agriculture addresses primarily the UCC_5 of "Food and biomass production"; however, it touches on most other UCC as well [5–7]. Its primary production sites are located within the city boundaries or in transitional urban hinterland zones. Conceptual solutions for such zoning were already suggested in the nineteenth century by von Thünen in 1827 [18] and Howard in 1898 [19] in order to improve urban sustainability and further developed in the twenty-first century, e.g., within the Continuous Productive Urban Landscape concept [20].

Urban agriculture also requires a joint adaptation of other UCC within the urban-rural nexus, such as nutrient recovery and reuse (UCC_3), urban water management and treatment ($UCC_{1,2}$), and improved energy efficiency (UCC_6) [5–7]. The geographical locations, complex networks, and individual characteristics of each UA project— including its input (I) and output (O) resources—are of great importance for the project's success. However, for many sites and designs, only limited information is available about the type and interaction of food-focused NBS and their I/O streams, such as water or nutrients [7]. These missing site-resource inventories are one of the main gaps that prevent the circularity of UA. The present study aims to address this gap.

1.2. What Does Circularity Imply for Urban Agriculture?

According to the CE concept [9,21] cities can work towards three ambitions for a CE regarding food: (1) "sourcing food grown regeneratively and locally where appropriate", e.g., implementing circular urban farming systems, such as aquaponics [7,22,23]; (2) "making the most of food" by reducing food waste and/or transforming it into new products; and (3) "designing and marketing healthier food products", such as novel plant-based proteins, as alternatives to meat and dairy.

The current global food system has a notable environmental impact. Agriculture uses 85% of global water resources [24] and is responsible for about a quarter of all greenhouse gasses released by human activity. Food system analysis reveals that natural resource use and emissions associated with modern systems can be substantially reduced by shifting towards a circular system [25,26]. The aim is to reduce resource consumption and emissions to the environment, e.g., by closing the loop of materials. Moving towards a food system that sources and produces locally will prevent the leakage of elements, such as carbon (C), nitrogen (N), and phosphorous (P) and stimulate the reuse and recycling of resources in a way that adds value to the system [5,7].

According to de Boer and van Ittersum [27], circularity in agricultural production comprises three principles: (1) "plant biomass is the basic building block of food and should be used by humans first"; (2) "by-products from food production, processing, and consumption should be recycled back into the food system"; and (3) "use animals for what they are good at", i.e., from "low-opportunity-cost feeds" to valuable outputs and products.

While 10% of the world's population lives in hunger, a third of the food produced in the world is wasted every year, together with an increasing trend of population intensification [3,28]. Edible food surpluses can be redistributed, and products that are no longer edible could be turned into new products—from organic fertilizers to biomaterials, medicines, and bioenergy, thus boosting new sources of income in the bioeconomy [4,9,29,30].

The food production in a CE minimizes or eliminates waste, emulating natural processes in ecosystems where waste is transformed into resources that feed other processes. To be safely returned to the soil as compost or fertilizer, recovered resources must be free of contaminants. This implies separate treatment of waste streams to avoid cross-contamination [21,31]. The resulting cycles can contribute to the regeneration of ecosystems, which in turn provide renewable resources and support biodiversity. Investments in implementation and efficiency improvements are necessary for long-term success in the transition from linear to circular food systems [7,32].

1.3. The Objectives of This Study

The present study addresses the significance, roles, opportunities, and threats of UA within urban sustainability and climate resilience. It places UA as a key activity of any future city that decisively impacts on urban circularity measures and, at the same time, is itself impacted by urban circularity. Aiming to understand and make visible the necessary resource streams in relation to urban food, we discuss selected UA typologies in their complex interactions with other aspects of a circular city, namely the water, nutrient, material, waste, and building system cycles as well as energy flows [5–7].

Following the framework proposed by Langergraber et al. [6] to address UCC using NBS, this research aims to:

1. Evaluate NBS units (NBS_u), NBS interventions (NBS_i), and supporting units (S_u) addressing UCC on food and biomass production [6,33];

2. Define the input and output (I/O) streams, analyzing the inputs (I) necessary for the operation and the outputs (O) generated by UA related NBS (hereinafter UA-NBS);
3. Summarize the main circularity aspects that are relevant for UA; and
4. Pinpoint the gaps that currently hinder the efficient development and implementation of UA-NBS within the Circular City framework [8,9].

2. Materials and Methods

To answer the research questions above, four elicitation workshops with a multidisciplinary team of experts were held between January and April 2021 within the framework of the COST Action CA17133 Circular City. The workshops were based on the IDEA protocol, which stands for "Investigate", "Discuss", "Estimate", and "Aggregate" [34,35]. The workshops' participants were divided into four working groups (WG) formed within the COST Action Circular City and corresponding to the sectors of "Built Environment" (WG1); "Sustainable Urban Water Utilization" (WG2); "Resource Recovery" (WG3); and "Urban Farming" (WG4) [8,9]. The total number of participants in the Circular City workshops ranged from 70 to 81, and the UA expert group (WG4) was run by 6–11 members [7]. The WG4 comprised experts in agronomy, food science, urban planning and architecture, aquaponics systems, water-food-energy nexus, agricultural water management, participatory systems, and governance (further details can be found in Langergraber et al. [6,7]).

According to the methodology reported by Castellar et al. [33] and Langergraber et al. [6], the NBS were classified into NBS units (NBS_u), differentiating between spatial units (NBS_su) and technological units (NBS_tu), and NBS interventions (NBS_i), including soil interventions (NBS_is) and river interventions (NBS_ir), following the classification of Castellar et al. [33]. The list of NBS corresponded to that extended by Langergraber et al. [6], in which supporting units (S_u) were also considered to improve the functioning of the NBS. All these units addressed at least one UCC [5–7].

During the workshops, the following questions were posed to the UA expert group (i.e., WG4 members):

- How do the NBS_u, NBS_i, and S_u contribute to food and/or biomass production?
- Which NBS_u, NBS_i, and S_u are relevant to UA?
- How is food and biomass production (UCC_5) related to the other UCC?
- What are the main I/O streams of UA-NBS?
- What are the key opportunities and challenges for achieving circularity in UA?

2.1. Identification of Nature-Based Solutions Relevant for Urban Agriculture

The following steps were taken to identify the most relevant NBS regarding UA, i.e., selected from UA-NBS, and classify them according to the urban space in which they are located (implementation):

- Evaluation of food and biomass production (UCC_5): From a list of fifty-one NBS_u and NBS_i and ten S_u proposed by Langergraber et al. [6] and based on their contribution to the UCC_5 [5], a separate evaluation regarding food and/or biomass production was made for each NBS_u/i and S_u. To have a more accurate categorization adapted to the UCC_5, the rating was based on the relevance of either food or biomass inputs (I) or outputs (O) (Table 1). Thus, the proposed categories were as follows (Table 1):
    1. Food and/or biomass production with relevant I and/or O: UA-NBS whose main purpose is food and/or biomass production or that, due to its characteristics, produce a relevant amount of food and/or biomass and/or consume it for their operation;
    2. Usable for food and/or biomass production: UA-NBS that may produce food and/or biomass, even if it is not their primary purpose, contributing to the UCC_5; and
    3. Food and/or biomass production with no relevant production levels: these UA-NBS can produce plant material or food in small quantities. They are considered as potential contributors that can be scaled up or designed for that purpose.

- Urban agriculture-related NBS-composed list: The NBS_u/i and S_u considered relevant for food and/or biomass production were those addressing, contributing, and/or potentially contributing to the food and/or biomass production (UCC_5).
- Classification according to typologies and urban space (implementation): The NBS_u/i related to UA were grouped according to the type of urban space they are associated with: (A) as urban blue infrastructure (urban water); (B) as green infrastructure (GI) in buildings (including containers); (C) as GI on buildings; (D) as GI for parks and landscape; and (E) as GI for the urban farm. NBS_u/i can be located in one or multiple urban spaces. The classification was based on the defining characteristics of the NBS, the expert knowledge of workshop participants, and literature references.
- Selection of representative UA-NBS: To narrow the list and focus on food and biomass production (UCC_5), eight UA-NBS were selected as relevant representatives to assess the I/O streams and identify circularity challenges. The selection was made according to the available references, considering that all typologies and urban spaces were covered, and upon the experience of the participants in the workshops. In order to gather information on the selected UA-NBS, a literature search was carried out using the names and synonyms given in Langergraber et al. [6].

Table 1. Marking system for urban circularity challenges (UCC) addressed by nature-based solutions units (NBS_u), interventions (NBS_i), and supporting units (S_u), following Langergraber et al. [6,7] and categorization used for food and biomass production (UCC_5).

Mark	General Category (UCC)	Food and Biomass Production Category (UCC_5)
●	Addresses directly the UCC	Food and/or biomass production with relevant I and/or O
●	Contributes to the UCC	Usable for food and/or biomass production
○	Contributes potentially depending on specific design	Food and/or biomass production with no relevant production

2.2. Linkages between Food and Biomass Production and Other Urban Circularity Challenges

An evaluation of the NBS_u, NBS_i, and S_u in relation to the UCC was conducted to identify the existing gaps and opportunities to approach circular UA successfully based on the general assessment presented by Langergraber et al. [6]. The relationships revealed whether the UA-NBS implementation facilitates addressing other UCC, i.e., an opportunity, or whether it is a challenge to be considered.

2.3. Urban Agriculture-Related Nature-Based Solutions Circularity: Input and Output Streams

To identify the gaps in resource management within circular cities, I/O streams were defined using NBS_u, NBS_i, and S_u as CE entities, following the methodology defined by Baganz et al. [36]. General I/O streams were identified by all the WG participants from the COST Action Circular City based on an interdisciplinary approach [6], and the "Urban Farming" group (WG4) was focused on those streams directly related to UA. Following the framework proposed by Langergraber et al. [6], we used a systematic approach to describe in detail the resource streams (i.e., I/O streams) participating in the food and biomass production (the food system) by means of UA-NBS [36]. By using this approach, it was possible to determine the connection between the different sectors represented by the WG and food and biomass production for better resource optimization (Figure 1) [7].

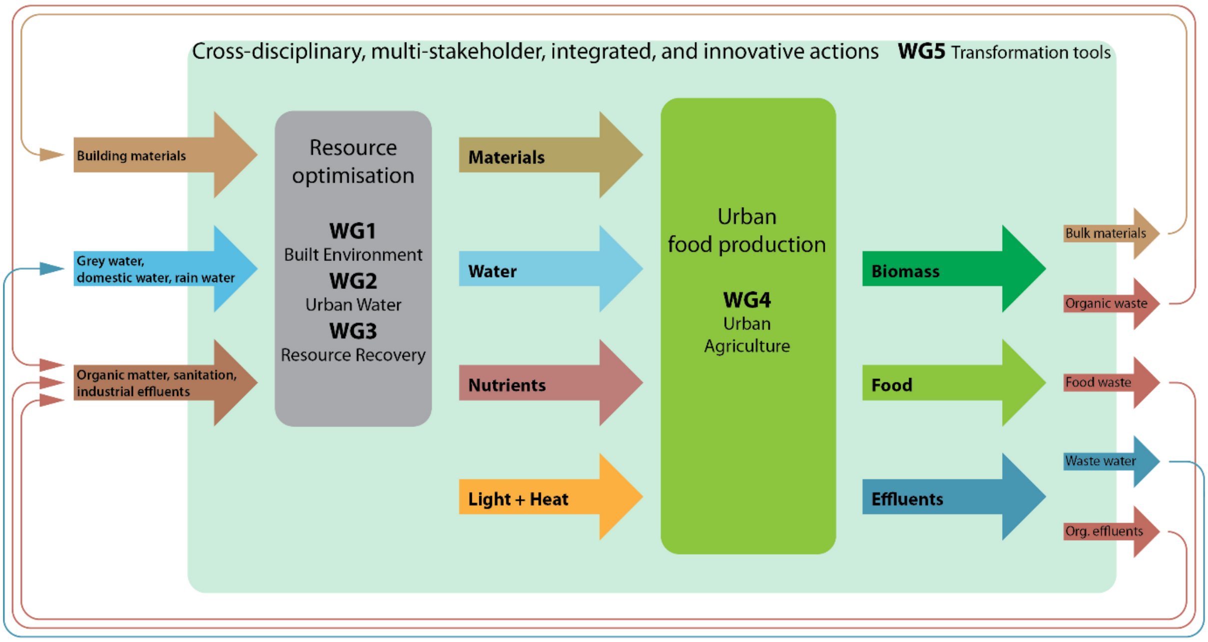

Figure 1. An urban agriculture centric view of the input and output streams studied within the working groups defined by the COST Action CA17133 Circular City on "Built Environment" (WG1), "Urban Water" (WG2), "Resource Recovery" (WG3), and "Urban Farming" (WG4) [7].

2.4. Identification of Key Challenges and Opportunities of Agricultural Nature-Based Solutions in Circular Cities

A SWOT analysis was used by the team of experts of "Urban Farming" (Working Group 4 of the COST Action) participating in the workshops to pinpoint internal (strengths and weaknesses) and external (opportunities and threats) factors influencing UA-NBS while addressing UCC, with particular attention to matter and energy flows as well as space, social, and economic effects.

3. Results and Discussion

3.1. Nature-Based Agricultural Solutions for Food and Biomass Production towards Urban Circularity

The fifth UCC proposed by Atanasova et al. [5] on "Food and biomass production" was rated separately both for food and for biomass production by using the methodology reported by [6] and, specifically for the UCC_5, following the criteria presented in Table 1, i.e., addressing the UCC_5, contribution to the UCC_5, and potential contribution, depending on specific design (see also Table 2 and Figure 2). Those UA-NBS not addressing the UCC_5 (i.e., without food and/or biomass production) are not presented in Table 2 for not being considered within the objectives of this study (related details can be found in Langergraber et al. [7]).

In total, 43 UA-NBS (i.e., 40 NBS_u/i and 3 S_u) were selected to address UCC_5 as those implemented/designed to produce food and/or biomass; the match between food and biomass production was the final rate addressing UCC_5 (Table 2, Figures 2 and S1). We propose a S_u on Chemical and biological methods (S11) to be considered as addressing UCC5, since it was not previously reported in the framework proposed by Langergraber et al. [6]. This S_u would include those enzymatic and fermentation processes involving UCC_5—mainly biomass production/transformation [37] (Table 2).

Table 2. Selected urban agriculture related NBS units and interventions (UA-NBS_u/i) and supporting units (UA-S_u), addressing the fifth urban circularity challenge on "Food and biomass production" (UCC_5) [5,6]: ● addressing the UCC_5 by food production, biomass production, and food and biomass production (score = 1.00); • contribution and o potential contribution to the UCC_5 depending on specific design (scores = 0.66 and 0.33, respectively). Empty cells are those UA-NBS_u/i and UA-S_u not addressing the UCC_5 via food or biomass production.

Classification [1,2]	(#) UA-NBS_u/i and UA-S_u [3]	Food	Biomass	UCC_5	Implementation [4]
• NBS_tu	(1) Infiltration basin		○	○	A
	(5) (Wet) Retention pond		○	○	A
	(7) Bioretention cell		○	○	A
	(8) Bioswale		○	○	A
	(9) Dry swale		○	○	A
	(10) Tree pits	○	○	○	A,D
	(11) Vegetated grid pavement		○	○	A,D
	(12) Riparian buffer		•	•	A
• NBS_tu	(13) Ground-based green facade	•	•	•	B,C
	(14) Wall-based green facade	•	•	•	B,C
	(15) Pot-based green facade	•	•	•	B,C
	(16) Vegetated pergola	•	•	•	B,C
	(17) Extensive green roof	•	•	•	C,D
	(18) Intensive green roof	•	●	●	C,D,E
	(19) Semi-intensive green roof	•	●	●	C,D
	(20) Mobile green and vertical mobile garden	•	•	•	B,C
• NBS_tu	(21) Treatment wetland		•	•	A,D
NBS_is	(23) Composting	•	●	●	C,E
	(25) Phytoremediation		•	•	B,C
S_u	(S6) Biochar/Hydrochar production		●	●	—
	(S7) Physical unit operations for solid/liquid separation		•	•	—
	(S11) Chemical and biological methods		•	•	—
• NBS_ir	(28) River restoration		•	•	A,D
	(29) Floodplain		•	•	A,D
	(32) Coastal erosion control	○		○	A,D
• NBS_is	(33) Soil improvement and conservation	○	•	•	D,E
	(34) Erosion control		○	○	D,E
	(36) Riverbank engineering		○	○	A,D
• NBS_su	(37) Green corridors	○	•	•	D,E
	(38) Green belt	○	•	•	A,D
	(39) Street trees	•	•	•	D
	(40) Large urban park	•	•	•	D,E
	(41) Pocket/garden park	•	•	•	D,E
	(42) Urban meadows	○	•	•	D
	(43) Green transition zones	○	•	•	D
• NBS_tu	(44) Aquaculture	●	○	●	A
	(45) Hydroponic and soilless technologies	●	•	●	A,B,C,E
	(46) Organoponic/Bioponic	●	•	●	A,B,C,E
	(47) Aquaponic farming	●	•	●	A,B,C,E
	(48) Photo Bio Reactor		●	●	B,C
NBS_su	(49) Productive garden	●	●	●	D,E
	(50) Urban forest	•	●	●	D
	(51) Urban farms and orchards	●	●	●	D,E

[1] • Rainwater Management, • Vertical Greening Systems and Green Roofs, • Remediation, Treatment, and Recovery, • (River) Restoration, • Soil and Water Bioengineering, • (Public) Green Space, • Food and Biomass Production, following color legend presented at Langergraber et al. [6,7]. [2] NBS_tu, nature-based solution technological unit; NBS_is, soil intervention; S_u, supporting unit; NBS_ir, river intervention; NBS_su, spatial unit [6,7]. [3] Numbered (#) according to Langergraber et al. [6,7]. [4] Typology and urban space where the rated UA-NBS_u/i would be implemented: (A) as urban blue infrastructure; (B) as green infrastructure (GI) in buildings; (C) as GI on buildings; (D) as GI for parks and landscape; and (E) as GI for the urban farm.

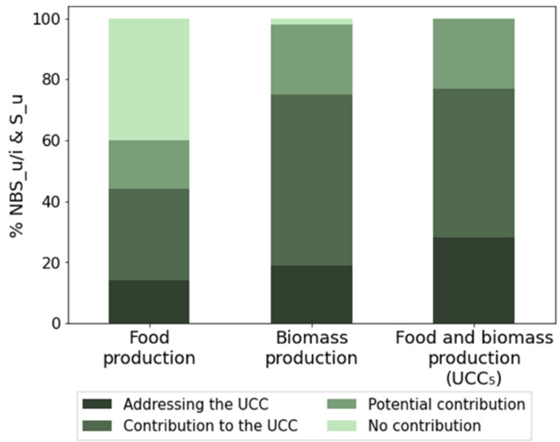

Figure 2. Colum chart representing the selected 43 NBS_u/i and S_u and categorized as those addressing, contributing, and potentially contributing to the UCC_5 on "Food and biomass production", respectively.

The selected UA-NBS_u/i and S_u were grouped within the three main groups presented in Table 1 as those categorized as follows: (1) Food and/or biomass production with relevant I and/or O, addressing the UCC_5-11 NBS_u/i and 1 S_u; (2) usable for food and/or biomass production, contribution to the UCC_5-19 NBS_u/i and 2 S_u; and (3) food and/or biomass production with no relevant production, representing potential contribution depending on specific design-10 NBS_u/i (cf. Tables 1 and 2, Figure 2) [6,7]. The later classification refers to those NBS_u/i intrinsically composed of vegetation and not primary designed for food and/or biomass production as the ones categorized for "Rainwater Management" [6,7]. However, the actions and infrastructures would be designed and implemented as food and/or biomass systems and technologies [7].

A second classification concerns to the implementation of the relevant UA-NBS_u/i and S_u according to their typology and typical urban site (Table 2). In this sense, 18 NBS_u/i were classified as urban blue infrastructure (A); 10 as green infrastructure (GI) in buildings (B); 14 as GI on buildings (C); 22 as GI for parks and landscape (D); and 12 specifically for GI as urban farms (E). Pearlmutter et al. [38] presented the state of the art on NBS in the built urban environment as the level of green building materials, systems, and sites [3]. Similarly, some of the selected UA-NBS_u/i and S_u presented in this study are classified following two of the three scales of described NBS implementation in the built environment by Pearlmutter et al. [38] at green building systems (i.e., in/on buildings' greening) and sites (e.g., parks and landscape and urban farms).

3.2. Relevance of Nature-Based Solutions Related to Urban Agriculture to Address the Fifth Urban Circularity Challenge

We highlighted and analyzed eight UA-NBS_u (*NBS_tu* and *NBS_su*) from the previously selected group of 40 units and interventions indicated in Section 3.1 as relevant representatives regarding the UCC_5 [6,7]. Among them, two belonged to the category of "Vertical Greening System & Green Roofs": wall-based green facade (14) and intensive green roof (18); one to the "(Public) Green Space" category: green corridors (37); and five to the "Food and Biomass Production" classification: hydroponic and soilless technologies (45), organoponic/bioponic (46), aquaponic farming (47), productive garden (49), and urban farms and orchards (51) (Table 2, Figure S1). The selected representatives UA-NBS_u, were clustered as both general categories on addressing and contribution to the UCC_5, with food and/or biomass production with relevant I/O and as usable for food and biomass production, respectively (Table 2, Figure S1).

Particular attention was given to describe their main characteristics and capacity for food and/or biomass production, with an emphasis on their contribution to circularity in cities, identifying potential I/O streams, and how they relate to the city's resource flows (cf. Sections 3.3–3.5):

1. Wall-based green facade (14): Wall-based green facades, as "Vertical Greening Systems", are known for their ability to mitigate urban heat island (UHI) effect and to enhance building energy savings in the urban environment, e.g., increasingly, the possibilities for crop production and wastewater treatment, particularly greywater [39–41]. They mostly consist of a modular vertical support structure with vegetation, substrate, irrigation, and drainage systems. Depending on the purpose of the system, different plants are used, with low-maintenance plants being the most common option to minimize costs. This NBS_tu can produce ornamental plants (low maintenance) as well as horticultural crops. When designed for food production, they are generally used for self-consumption and local supply (e.g., restaurants, schools, or hospitals) [42]. The yield depends on the crop/plant, type of substrate, management, irrigation and drainage systems, and the climate and orientation when it is placed outdoors. Indoor, wall-based green facades under controlled conditions at buildings or greenhouses are mostly used to produce high-yielding crops. In order to address circularity, it is relevant to characterize drainage water, which can be reused since it is rich in nutrients. Additionally, wall-based green facades can be designed as modular treatment systems when irrigated with wastewater, resembling constructed wetlands, where plant matter can be harvested and used as biomass [39,43].
2. Intensive green roof (18): Green roofs can be used to cultivate agricultural products, and their importance for this purpose has increased in recent years, as they provide additional land space in urban centers [44,45]. Intensive green roofs are characterized by a substrate depth between 15 and 70 cm, which requires more maintenance than extensive ones and allows for a wider choice of plants [46]. As an engineered structure, a green roof requires prefabricated materials to be constructed, such as protection and drainage layers, substrate, etc. Such structures may be built in residential buildings but also in commercial ones. For example, a supermarket in Brussels, Belgium (Delhaize chain), has a 360 m^2 urban farm on the rooftop for greenhouse and open-air vegetables, with a certified organic production system [47]. The aim is to control the production system and sell the products in the supermarket on the ground floor, avoiding transportation and the need for a cold chain. The residual heat from the refrigeration systems is used to heat the greenhouse, improving energy efficiency (UCC_6). Since the farm is small, and the impact is thus limited, it serves as a demonstrator of possibilities for professional UA.
3. Green corridors (37): According to Castellar et al. [33], green corridors aim to renaturalize areas along derelict infrastructure, such as railways or along waterways and rivers, by transforming them into linear parks. Green corridors can play an important role in urban GI networks and can offer shelter, food, and protection for the urban wildlife while enabling migration from one green patch to another. Back-up irrigation may be provided by reclaimed wastewater, and the biomass produced can be used for energy generation and composting. As for the vegetation planted, it depends on the site and the objectives set. Forest species, fruit trees, and fruiting shrubs or ornamental species are generally used. Lisbon (European Green Capital 2020) is an example of a network of nine green corridors that are part of the urban GI. They cover an area of about 200 ha and contribute to ecological connectivity, create spaces for UA, revalorize abandoned spaces by increasing soil permeability, and improve the connection to other NBS specialized in rainwater retention and infiltration [48]. Other cities, such as Montreal, Mexico City, Seoul, London, or Singapore, also have green corridors that provide ecosystem services to the city [49]. At each site, this NBS_su is adapted to the local context, from the use of plant species and the reuse of the available resources to the using of space according to social needs.
4. Hydroponic and soilless technologies (45): In hydroponics, plants grow in water containing necessary macro- and micronutrients that are supplied by mineral fertilizers

dissolved in water according to the plant-specific recipe. In ebb and flow systems and in grow beds, the plants grow in different media, like mineral-/rockwool, vermiculite, sand, gravel, etc., which also offer mechanical support [4,50,51]. Other soilless technologies, such as nutrient film technique, aeroponics, and deep flow technique, do not involve media. Recently, soilless technologies are being innovated by implementing artificial intelligence to learn the best way of composition of synthetic, mineral, or organic fertilizers to grow the crop, often together with artificial light in greenhouses or plant factories.

5. Organoponic/Bioponics (46): In contrast to hydroponic that relies on mineral fertilizers, bioponics is an emerging soilless technology for nutrients recovery that links (organic) vegetable production to organic effluent remediation or organic waste recycling [52]. The plants in growing media derive nutrients from natural animal, plant, and mineral substances that are released by the biological activity of microorganisms [53]. Bioponics allows closing nutrient cycles by using organic waste streams, such as urine [54], biogas digestate [55], chicken manure [52,56], and others, thus reducing the use of mineral fertilizers and the greenhouse gas emissions. Aquaponics [57] could also be considered as a form of bioponics, as it utilizes waste streams (process water, sludge) from an aquaculture. Synonyms used for bioponics are "organic hydroponic" [58,59], digeponics [60], or anthroponics [61]. Beside the source of nutrients, the key difference between organic and conventional soilless culture is the active promotion of microorganisms in bioponics to enhance nitrification, mineralization, and disease suppression and thus contribute to productivity and plant quality similar to soil-based systems [62].
6. Aquaponic farming (47): Aquaponics is a technology that couples tank-based animal aquaculture with hydroponics by using water from aquaculture for plant nutrition and irrigation. Trans-aquaponics extends this technology to tankless aquaculture and/or non-hydroponic plant cultivation. Aquaponic farming comprises both aquaponic types, whereby aquaponic farming does not imply a specific size but the fact that such this generic NBS_tu can embody both aquaponics types [22]. The NBS_tu can be established in very different setups: while aquaponics is often implemented as controlled environment agriculture, trans-aquaponics includes, e.g., pond-aquaponics [63,64], outdoor aquaponics [65,66], aquaculture using constructed wetland for sludge removal [22], and other integrated aqua-agriculture systems [67] that exploit the aquaponics principle. Both technologies are often used for food production, but aquaponics cannot be eco-certified because it exploits hydroponics and is thus not soil-based, a precondition for eco-certification—at least in the European Union. However, it is possible to meet a large city's demand for tomatoes, fish, and lettuce through aquaponic production, as shown in a case study related to Berlin [23].
7. Productive garden (49): Productive gardens are found around the world and contribute significantly to food security. Vegetables, fruits, herbs, and, occasionally, small livestock are produced in reduced spaces for the market, private consumption, or educational purposes. The productivity of urban gardens depends on climate conditions and type of crops and can exceed that of rural farms [68]; if correct cultures are selected and machine-based crop treatment technologies are replaced by manual work, it results in higher cropping density and higher biodiversity of crops to be grown together [69]. Different types of cultivation can be selected for horticultural crops, both in open fields and/or under cover.
8. Urban farms and orchards (51): Urban farms and orchards are part of the city's GI and are intended for food and biomass production. They are large enough to grow cereal crops, fruit and vegetables, and even big livestock [6]. This NBS_su can seek an economic profit or have social and educational purposes. It is common to find urban farms located in public areas and managed by a community (e.g., neighborhood). While other NBS_u are more specific, with a defined configuration, this unit encompasses a wide range of possibilities that make it very versatile. It is the

NBS_su that most resembles the rural farms, with the advantage of having the urban streams nearby to tap into. For example, food waste—which has a high nutritional value—can be used to feed animals and lower the production costs; on the other hand, treated water can be used for irrigation [27]. Within its boundaries, several other NBS can be implemented to close loops, such as composting (23) or constructed wetlands for wastewater or runoff water treatment for on-farm resource recovery and reuse.

Once the selected UA-NBS_u were analyzed individually, we compared their joint contributions to the UCC_5 (cf. Figure 3). Their contribution to food and biomass production, as defined in Table 1, resulted in scores of 1.00 (●), 0.66 (●), and 0.33 (○), corresponding to each representative NBS_u (cf. Table 2, Figure S1). Some UA-NBS_u have an important share in both food and biomass production, as is the case of productive garden (49) and urban farms and orchards (51). Other UA-NBS_u were specifically designed for food production, so the contribution to food production is higher than that of biomass, as in the case of hydroponic and soilless technologies (45), organoponic/bioponic (46), and aquaponic farming (47). However, they can also be used for biomass production [7]. In contrast, green corridors (37) generally produce large amounts of biomass; however, the capacity to produce food is lower, generally attributed to berries and fruits from trees and shrubs. If designed to include production sites (e.g., productive gardens) or specific plants, they can contribute to food production. A wall-based green facade (14) can also produce food and biomass, although its main purpose is often UHI mitigation and building energy savings. Finally, an intensive green roof (18) encompasses different types of herbaceous and shrub species, including trees, producing biomass; however, it can also contribute to food production.

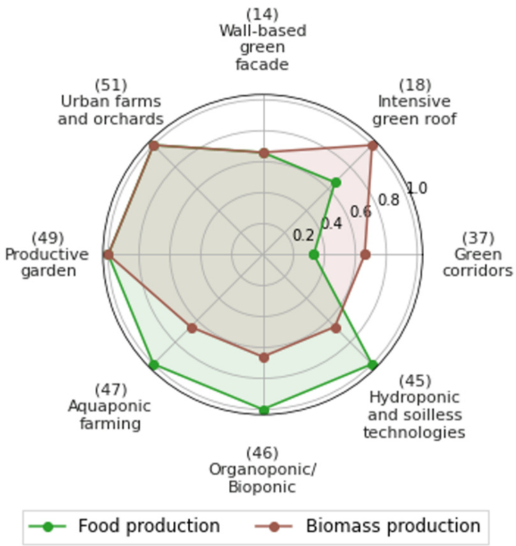

Figure 3. Evaluation for food and biomass production of nature-based agricultural solutions selected as urban agriculture representatives. Numbers of technological and spatial units (NBS_tu and NBS_su) corresponds to that given by Langergraber et al. [6] (cf. Table 2).

3.3. Interfaces between Food and Biomass Production and the Other Six Urban Circularity Challenges

The UCC on "Food and biomass production" (UCC_5) [5] seeks to close the production loop, maximizing the use of available resources while reducing the need for external resource inputs. The UA-NBS_u addressing the UCC_5 are closely related to other UCC [5–7]. Urban food production faces challenges, such as nutrient and water supply, urban planning, and energy efficiency. Conversely, the urban environment also offers opportunities for farming different to those in rural environments. Figure 4 indicates whether the implementation of UA-NBS is an opportunity to address other UCC or whether an UCC poses a challenge for food and biomass production in order to close material loops, improve energy efficiency, and make use of urban spaces.

(1) "Restoring and maintaining the water cycle (by rainwater management)"—UCC_1: Several NBS_u/i and S_u identified as relevant for the UCC_5 also address the UCC_1. The nature of the NBS_u/i, with a significant vegetation component and located in different urban spaces, such as the UA-NBS classified as "Vertical Greening Systems and Green Roofs" and "(Public) Green Space"—e.g., green corridors (37) and large urban parks (40) —, enable the restoration and maintenance of the water cycle at different scales. These NBS_u/i facilitate processes, such as water retention, infiltration, transport, treatment, and evapotranspiration [70]. The UA-NBS_su from the category of "Food and Biomass Production", i.e., productive garden (49), urban forest (50), and urban farms and orchards (51), are also relevant for the UCC_1, as they enable the same processes as the above. The implementation of these UA-NBS_u is seen as an opportunity to regulate the water cycle and not a barrier to be overcome in the sector of UA.

(2) "Water and waste treatment, recovery, and reuse"—UCC_2: NBS_u/i and S_u addressing the UCC_2 are crucial for UA, as water is a continuous input stream to most UA-NBS. In general, a minimum quality is required to use reclaimed water for irrigation and fertigation. In addition, some UA-NBS may require a certain quality depending on the crop or culture. Furthermore, the effluent water from UA-NBS, e.g., aquaculture (44) and photo bio reactor (48), needs to be treated, and for this purpose, other NBS_u/i and/or S_u, such as circular systems like aquaponic farming (47), can be implemented [71].

(3) "Nutrient recovery and reuse"—UCC_3: Nutrient recovery, reuse, and recycling is key to achieving a circular metabolism of cities [31,72]. For this purpose, it is necessary to identify and analyze the nutrient-rich flows generated in the city, such as wastewater or organic waste. Urban agriculture harnesses the recovered nutrients and keeps them in the urban system. Besides, the NBS_u and S_u from the category of "Remediation, Treatment and Recovery" [6,7] (cf. Table 2) comprise anaerobic treatment (26), phosphate precipitation (for P recovery) (S3), and ammonia stripping (for N recovery) (S4), and they are not considered as relevant for food and biomass production because they do not generate food and/or biomass to a significant extent nor require it to operate. However, they may be crucial for nutrient recovery from urban streams to be used in UA-NBS. In addition, the recovered nutrients must be able to meet the needs of crops or living organisms, considering the macro- and micronutrients required for production. It is therefore seen as both a challenge and an opportunity to recover and reuse nutrients.

(4) "Material recovery and reuse"—UCC4: Material recovery is seen as an opportunity for UA. Urban agriculture can provide a considerable amount of biomass that can be used for several purposes, e.g., building materials, soil amendment, or energy production. For example, biochar/hydrochar production (S6) and composting (23), classified as S_u and NBS_is, respectively ("Remediation, Treatment and Recovery"), can be obtained from the biomass produced in vertical greening systems and agricultural waste. Biodegradable materials, such as wood, can be used directly to build structures. One challenge would be to replace stable insulating materials, such as plastic and glass, or materials used in irrigation pipes. This could be accomplished by using recovered and/or recycled materials.

(5) "Energy efficiency and recovery"—UCC6: Mitigation of UHI effect is one of the strengths of UA-NBS in urban outdoor spaces such as infrastructure, i.e., NBS_u/i and S_u located in/on buildings, in parks and landscape, and/or urban farms. At the building scale, green roofs or vertical greening systems can improve energy efficiency by reducing rooftop and walls' surface temperature during summer, improving insulation and decreasing heat losses during the cold season [42]. On the other hand, NBS_u that include greenhouses or are located indoors may require energy to regulate

room temperature and to provide artificial lighting. However, high-yield crops or indoor urban vertical farming using hydroponics and soilless technologies (45) can substantially increase energy efficiency [73,74]. In addition, within the urban system, there is the possibility of recovering heat sources for food and biomass production that would otherwise be lost.

(6) "Building system recovery"—UCC7: An urban system is multi-stakeholder and space-constrained; therefore, the essential planning to achieve circularity is challenging. Both the design of new spaces and the retrofitting and adaptation of old ones require planning for the effective implementation of the NBS_u/i. By using UA-NBS, urban spaces can be revalorized, although the complexity of the urban system makes it a challenge for food and biomass production, as there are different ownerships, available spaces, and regulations to consider. Achieving circularity may require new approaches.

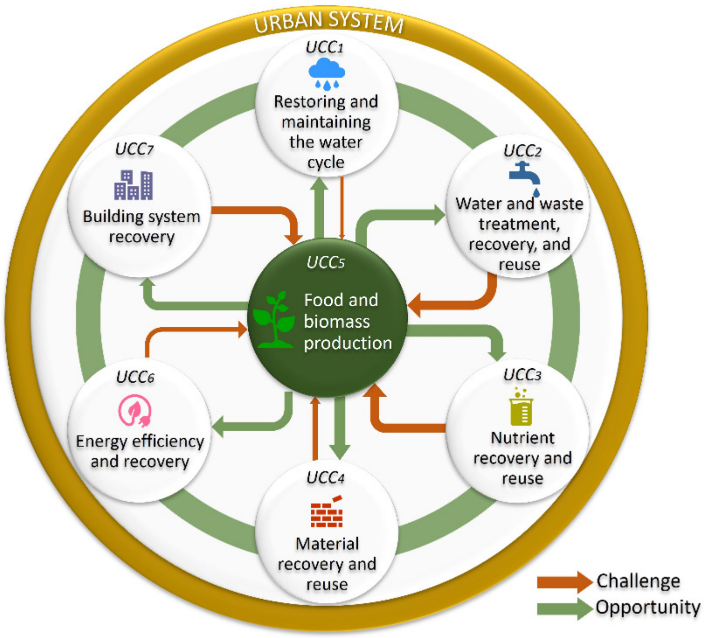

Figure 4. Relationships among food and biomass production and other urban circularity challenges described by Atanasova et al. [5–7]. The thickness of the arrows indicates the relevance of the opportunity or challenge, respectively. UCC: (**1**) Restoring and maintaining the water cycle (by rainwater management); (**2**) water and waste treatment, recovery, and reuse; (**3**) nutrient recovery and reuse; (**4**) material recovery and reuse; (**5**) food and biomass production; (**6**) energy efficiency and recovery; and (**7**) building system recovery [5].

3.4. Contribution of Input and Output Streams to Urban Circularity in Nature-Based Agricultural Solutions

From a CE perspective, UA is seen as an opportunity to counteract the linear "take-make-waste" economy [16]. Urban agriculture can be designed to minimize the need for external inputs to produce food and biomass to be consumed in the city. This emerging and inclusive approach consists of making the most of the materials and waste streams used for production, closing water and nutrient loops, and reducing discharges into the environment [7,16,75]. In this sense, circularity refers to the connection between urban streams and the streams needed in UA. From the standpoint of the NBS_u/i and S_u, an urban stream of matter or energy with the appropriate characteristics becomes an input stream. In turn, the output stream of one NBS_u/i or S_u can become the input stream of another, thus tapping into urban resources. Based on system analyses of resource streams and a corresponding streams information model to describe inputs and outputs

(I/O) [7], a practical solution to enhance circularity by concrete streams is presented (Table 3, Figure S2).

Table 3. Biomass and living organisms as resource streams related to nature-based solutions units (NBS_u) associated with urban agriculture while address the fifth urban circularity challenge on "Food and biomass production" [5–7].

<table>
<thead>
<tr><th>Stream Type</th><th>Category</th><th>Subcategory</th><th>I in UA-NBS_u [1]</th><th>O from UA-NBS_u [1]</th></tr>
</thead>
<tbody>
<tr><td rowspan="5">Biomass</td><td>Organic fertilizer</td><td>Compost
Manure (types)</td><td colspan="2">(18) (37) (49) (51) [2]</td></tr>
<tr><td>Organic crop protection</td><td>Mulch
Woodchips
Biochar</td><td colspan="2">(18) (37) (49) (51)</td></tr>
<tr><td>Food waste</td><td>Vegetables, fruits</td><td>—</td><td>(18) (37) (49) (51)</td></tr>
<tr><td>Crop residues</td><td rowspan="2"></td><td rowspan="2">(18) (37) (49) (51)</td><td>(14) (18) (37) (45) (46) (47) (49) (51)</td></tr>
<tr><td>Pruning remains</td><td>(14) (18) (37) (49) (51)</td></tr>
<tr><td rowspan="9">Living organisms</td><td>Plants</td><td>Edible
Ornamental
Seedlings</td><td colspan="2">(14) (18) (37) (45) (46) (47) (49) (51)</td></tr>
<tr><td>Algae</td><td></td><td colspan="2">(45) (46) (47)</td></tr>
<tr><td rowspan="2">Fish</td><td>Marketable</td><td>—</td><td>(47)</td></tr>
<tr><td>Fingerlings</td><td colspan="2">(47)</td></tr>
<tr><td>Poultry</td><td></td><td colspan="2">(18) (37) (49) (51)</td></tr>
<tr><td>Livestock</td><td></td><td colspan="2">(37) (49) (51)</td></tr>
<tr><td>Worms</td><td>Edible
Other</td><td colspan="2">(51)
(18) (37) (49) (51)</td></tr>
<tr><td>Insects</td><td>Edible
Auxiliary
Aquatic, larvae</td><td colspan="2">(51)
(14) (18) (37) (45) (46) (47) (49) (51)
(47)</td></tr>
<tr><td>Mushrooms</td><td></td><td colspan="2">(51)</td></tr>
<tr><td></td><td>Microorganisms</td><td>Mycorrhiza, Bacteria
Fungi
Aquatic</td><td colspan="2">(18) (37) (47) (49) (51)
(18) (37) (49) (51)
(47)</td></tr>
</tbody>
</table>

[1] I: input to NBS_u, required for its operation and maintenance; and O: output from NBS_u. [2] (#): number assigned according to Table 2 [6,7].

According to Langergraber et al. [6], the main types of input and/or output streams of UA-NBS were analyzed following the categories below:

- Biomass and Living organisms (cf. Table 3): Biomass refers to the total mass of all living organisms in an area. In a circular city, that means all organic materials derived from produced plant mass together with all microorganism and animals, important in a CE point of view [76]. Biomass is an important resource for technologies like pyrolysis—conversion of biomass to biochar—heat transfer [77], Fe2/biocarbon composite derived from a phosphorous-containing biomass [78], and several other biomass-derivate methods. Biomass concerns to materials including soil conditioners, such as wood chips or biochar; organic fertilizers, such as manure or compost; different types of organic waste, ranging from food waste to crop residues or pruning residues; and to organic crop-protection products (Table 3, Figure S2). Cultivation of plants, mushrooms, and insects may positively influence the air and soil quality. Plants take up essential nutrients from the soil; however, they can also absorb metals like lead (Pb), cadmium (Cd), arsenic (As), tin (Sn), chromium (Cr), and nickel (Ni). This makes certain plants, together with other living organisms, effective phytoremediators [79].

- Water: Irrigation water is required whenever precipitation is not sufficient. Using tap water may lead to competition with other urban users [80]; therefore, alternative water sources should be preferred. These could be subterranean water, stored rainfall water, or treated wastewater. Urban agriculture provides an opportunity to reuse (waste)water wherever it is generated, as opposed to rural agriculture, because there are no or less costs associated with transport. The use of water is minimized in soil-independent production systems with a closed circuit for water, as exemplified by Rufí-Salís et al. [14], who found daily water savings up to 40% for such systems. However, soilless systems mostly require higher energy inputs [81].
- Nutrients: Nutrient-rich urban waste for the primary production can be recycled from wastewaters of different provenance, e.g., domestic wastewater, urine, feces, greywater; wastewaters from food production, e.g., milk, tea, coffee, brewery; and nutrient-rich solid waste streams, e.g., composting, biogas, biochar. The nutrient-rich streams usually need to be subjected to one or several stages of treatment before use in UA. As Jurgilevich et al. [82] pointed out, the demand for nutrients, especially phosphorous (P), is growing drastically faster than the human population. This is coupled to large nutrient losses on one side [83] and increasing global nutrient imbalance [82] on the other. While the soils of rich countries accumulate nutrients, the soil in developing countries experience P deficit [84]. Schoumans et al. [84] argued that the European P cycle could be completely closed if imported chemical P fertilizers were replaced by P fertilizers recovered from waste streams.
- Energy: Energy flows can be optimized, too. Mohareb et al. [85] proposed co-location strategies of agricultural operations and waste streams in order to increase energy efficiency; this is the sixth urban circularity challenge (UCC_6) proposed by Atanasova et al. [5] on "Energy efficiency and recovery" that is mainly addressed. Such a strategy can be, for instance, to locate greenhouse food production next to waste heat or waste nutrient sources, such as from biogas or refrigeration equipment. Another possibility would be using phase-change technologies [86] to mediate between the locations that emit waste heat and locations that require heat, therefore obliterating the need for close proximity of these operations.

Urban agriculture must adapt the field agronomic production methods to smaller areas in urban spaces, as the available surface is restricted. Therefore, crop production in the urban environment tends to intensify in the direction of high edible biomass per surface unit, e.g., green leafy vegetables, legumes, using plants with short life cycle; therefore, annuals are preferred over fruit trees [87]. This intensification optimizes the use of soil, while soil-independent systems, either horizontal or vertical, further enable increased production rates per area. This is the case of hydroponics or aquaponic systems, where multilayer or multilevel systems can be used to enlarge cultivation surface. However, soil-based UA is more adequate for nutrient recycling, as the most used method for this process is the composting of solid organic waste [88]. The substrate to use in UA might be soil resulting from a natural process or fabricated, sometimes recurring to waste as main structural components or just as amendments from different urban waste streams [89]. Soils previously occupied with industrial facilities may have elevated toxicity levels, but several techniques can be used to overcome this problem [89,90].

3.5. Challenges of Circular City Resource Flows

The current research highlights the role of resource streams to close loops within the urban metabolism, thus creating a Circular City [4–7,36]. For two types of resource streams (i.e., food and biomass production) stream categories are shown in Table 3. Each stream is attributed as output (O) from and/or input (I) to appropriate NBS units (NBS_u); other non-NBS-endpoints, such as biogas plants, private gardens, or the "market", are also possible. With this qualitative representation, a part of a Circular City resource network could already be constructed. However, the challenges should not be underestimated, as both the qualitative and quantitative properties of the NBS_u must be matched. A good example to demonstrate possible difficulties with Circular City resource flows is NBS_u aquaponic farming (47) [6,7].

Aquaponic farming can be configured very differently internally and thus integrated flexibly within the Circular City, but that impacts input (I) resource demands and output (O) resource provisions significantly. For example, an aquaponic system that uses a combined heat and power unit may produce electrical energy instead of consuming it. Another example is the externalization of the most important internal resource stream, the transfer water, that cannot optimally supply the hydroponics. It requires targeting of the plant needs by the addition of fertilizer depending on the fish species, stocking density, and plant species [91,92]. This can be controlled since aquaculture and hydroponics are operated jointly by one operator. If aquaponic elements are split into separate units as distinct NBS with potentially different owners or operators [36], this coordination process becomes more difficult. Additionally, in extended aquaponics, the plants may grow in soil rather than hydroponically, involving another nutrient source to be considered. This concerns the qualitative side of the material flow, but the quantitative aspects of coupling can also pose problems. For example, young tomato plants need considerably less water than mature plants, but aquaculture provides a constant fish-water output. This mismatch can be countered with staggered crop production, which in turn requires a greenhouse and year-round operation [93].

But even if these problems are solved, there is still the site question, and the proposal to use the roofscape must be critically questioned due to the prevailing usage competition in cities.

3.6. SWOT Analysis of Urban Agriculture Related Nature-Based Solutions

A SWOT analysis was used to determine the strengths, weaknesses, opportunities, and threats of UA-NBS implementing the UCC_5 in practice (cf. Figure 5). Internal factors are attributes of the UA-NBS that represent either a strength or a weakness, and they depend on the objective to be achieved, in this case, addressing the UCC_5. Opportunities and threats are external factors that depend on the studied context, i.e., an urban environment with great potential for resources recovery due to the large volume of waste and wastewater generated.

- Strengths of UA are the reduction of the environmental footprint by using sustainable production methods, enabling organic certification, and increasing profitability [94] (Figure 5).
- Weaknesses identified in UA-NBS are the lack of professional experience that can lead to inappropriate use of phytosanitary products, thus aggravating pollution problems in the city. In addition, the risk of contamination is higher when treated water or materials obtained from waste are used instead of sources, such as mainstream water or freshwater. Traceability of products by means of regular monitoring and digital tools, e.g., internet of things (IoT) and blockchain technology (BCT), would facilitate both food safety and environmental risk mitigation (Figure 5).
- Opportunities include that the implementing UA-NBS as part of a sustainable bioeconomy in cities facilitates the reuse of resources stemming from urban metabolism, e.g., building materials, water, and nutrients reduce the environmental footprint of the final products [95]. For this purpose, Langergraber et al. [6,7] proposed supporting units that enable nutrients and carbon to be recovered and directed back into the system. In this regard, regulations like the recently approved European Union Circular Economy Fertilizing Products Regulation (EU 2019/1009) may facilitate the use of fertilizers that are produced in the same city, fostering circularity. Urban metabolism and industrial synergy provide multiple streams of different characteristics that can be harnessed for food and biomass production.
- Threats are, as noted above, the mismatch between the supply of nutrients and tracer elements recovered from wastewater and waste streams and the nutritional demand of crops, which can create a surplus or a deficiency [31,72], which has to be considered.

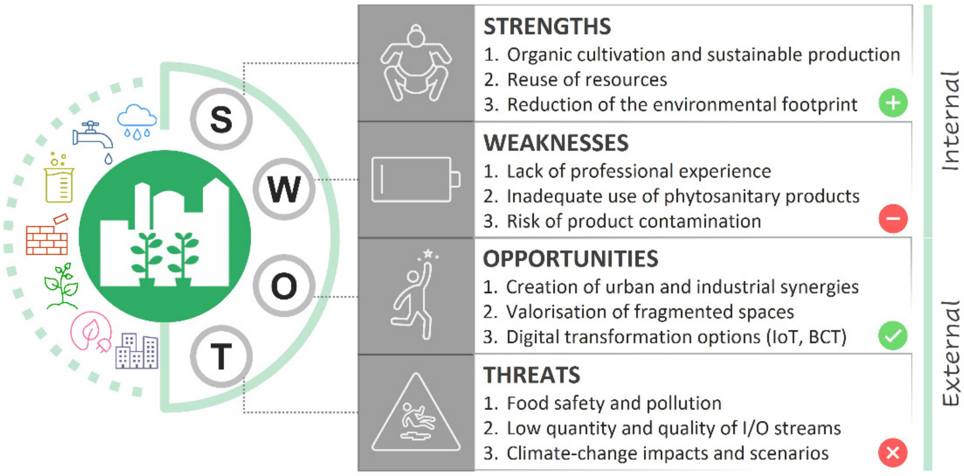

Figure 5. Strengths, weaknesses, opportunities and threats of nature-based agricultural solutions addressing the fifth urban circularity challenge to achieve circularity in cities.

The safety of food grown in the urban environment remains a concern in terms of soil, water, and air pollution [96]. Although research on the effects of pollution on UA is still scarce, there are several studies that assessed the feasibility and safety of vegetables grown in different urban spaces using UA-NBS, such as intensive green roofs (18) and urban farms and orchards (51), concluding that, in general, the concentrations of contaminants and trace metals found in the plants were below the European regulatory thresholds [97]. The following factors should be considered in order to determine the exposure of UA to pollutants in cities: (i) growing location, e.g., indoor or outdoor UA, soil-based, or soilless technologies; (ii) type of crop, e.g., leafy vegetables with a large leaf surface area are more exposed to atmospheric particles, and root vegetables are more exposed to soil contamination compared to fruiting vegetables; and (iii) soil and contaminant characteristics, e.g., ground-borne (root system) and air-borne pollution (plant above ground level) [97].

Climate change is a threat as well as an opportunity to the circularity of UA-NBS. As climatic conditions may determine the availability of resources, e.g., extreme precipitation events pose a challenge for rainwater harvesting, while even distribution of rainfall facilitates more efficient irrigation of green and productive areas, reducing dependence on external sources. Moreover, vegetated areas enhance evapotranspiration processes, which mitigates the duration of high air temperatures in cities [98]. Consideration of alternative sources may be necessary to ensure a successful operation and maintenance. Furthermore, city fragmentation and urban sprawl increase the heterogeneity of urban spaces that can be used for UA at different scales, enhancing the value of fragmented spaces (e.g., rooftops) and expanding the management options of urban areas [42]. The co-design of the UA-NBS in multidisciplinary teams would minimize uncertainty and provide insight into the city's potential.

Some circularity challenges were also recognized by Williams et al. [99] when identifying challenges to implementing looping actions, including technical constraints, linear resource systems, or the lack of circular planning and design in cities. Finally, in addition to the environmental benefits that UA-NBS provide, it is worth noting that they can also relieve societal challenges, such as food security, improved human health and well-being, sustainable urban development, or disaster-risk management [100,101].

4. Conclusions

Urban agriculture plays a key role in terms of a Circular City, as it can use recovered resources to produce new food and biomass. Thus, food and biomass production can contribute significantly towards closing the urban cycle, maximizing the reuse of resources in the urban environment while reducing the need for external resource inputs.

Greater commitment with urban agriculture would help to address urban circularity challenges. In this regard, nature-based solutions for food and biomass production contribute to address at least one urban circularity challenge. Certain nature-based solutions for food and biomass production can be circular in themselves, while others need nearby nature-based solutions or are strategically located to address other urban circularity challenges. In future, this descriptive approach can be underpinned by mathematical models, which would make it possible to support the theoretical approach with statistical data.

We analyzed how input and output resource streams related to food and biomass production are located as part of other resource streams to close the cycles within the urban metabolism, i.e., into and out of a Circular City. Design solutions geared towards closing loops, such as aquaponic farming, are targeted by urban agriculture in circular cities. A broader understanding of the food-related urban streams is important to recover resources and adapt the distribution system accordingly. For it, essential knowledge of the input and output streams is required in order to design, adapt, or couple urban agriculture-related nature-based solutions units and interventions and supporting units.

Additionally, the need for better knowledge, transversal research networks, governance, regulations, and policy strategies and dialogues to improve nature-based agricultural solutions in circular cities should be highlighted.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/w13182565/s1, Figure S1: Potential of selected representatives urban agriculture-related NBS units and interventions (NBS_u/i) to address the fifth urban circularity challenge (UCC_5) on "Food and biomass production" [5–7], according to the score range (0.33, 0.66, 1.00) (cf. Tables 1 and 2). Numbers refer to those of NBS_u/i from Table 2. Color legend refers to the categories of NBS_u/i (cf. Table 2) [6,7]; Figure S2: Overview of input and output streams in urban agriculture with focus on water.

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References

1. Halog, A.; Anieke, S. A review of circular economy studies in developed countries and its potential adoption in developing countries. *Circ. Econ. Sustain.* **2021**, *1*, 209–230. [CrossRef]
2. Nikolaou, I.E.; Jones, N.; Stefanakis, A. Circular economy and sustainability: The past, the present and the future directions. *Circ. Econ. Sustain.* **2021**, *1*, 1–20. [CrossRef]
3. Pineda-Martos, R.; Calheiros, C.S.C. Nature-based solutions in cities—Contribution of the Portuguese National Association of Green Roofs to Urban Circularity. *Circ. Econ. Sustain.* **2021**. [CrossRef]

4. Skar, S.L.G.; Pineda-Martos, R.; Timpe, A.; Pölling, B.; Bohn, K.; Külvik, M.; Delgado, C.; Pedras, C.M.G.; Paço, T.A.; Ćujić, M.; et al. Urban agriculture as a keystone contribution towards securing sustainable and healthy development for cities in the future. *Blue-Green Syst.* **2020**, *2*, 1–27. [CrossRef]
5. Atanasova, N.; Castellar, J.A.C.; Pineda-Martos, R.; Nika, C.E.; Katsou, E.; Istenič, D.; Pucher, B.; Andreucci, M.B.; Langergraber, G. Nature-based solutions and circularity in cities. *Circ. Econ. Sustain.* **2021**, *1*, 319–332. [CrossRef]
6. Langergraber, G.; Castellar, J.A.C.; Pucher, B.; Baganz, G.F.M.; Milosevic, D.; Andreucci, M.-B.; Kearney, K.; Pineda-Martos, R.; Atanasova, N. A Framework for Addressing Circularity Challenges in Cities with Nature-based Solutions. *Water* **2021**, *13*, 2355. [CrossRef]
7. Langergraber, G.; Castellar, J.A.C.; Andersen, T.R.; Andreucci, M.-B.; Baganz, G.F.M.; Buttiglieri, G.; Canet-Martí, A.; Carvalho, P.N.; Finger, D.C.; Bulc, T.G.; et al. Towards a Cross-Sectoral View of Nature-Based Solutions for Enabling Circular Cities. *Water* **2021**, *13*, 2352. [CrossRef]
8. COST (European Cooperation in Science and Technology) Action CA17133 (2018) Memorandum of Understanding for the Implementation of the COST Action "Implementing Nature Based Solutions for Creating a Resourceful Circular City" (Circu-lar City Re.Solution) CA17133; COST 044/18. Brussels, Belgium. Available online: https://e-services.cost.eu/files/domain_files/CA/Action_CA17133/mou/CA17133-e.pdf (accessed on 27 July 2021).
9. Langergraber, G.; Pucher, B.; Simperler, L.; Kisser, J.; Katsou, E.; Buehler, D.; Garcia Mateo, M.C.; Atanasova, N. Implementing nature-based solutions for creating a resourceful circular city. *Blue-Green Syst.* **2020**, *2*, 173–185. [CrossRef]
10. Pölling, B.; Mergenthaler, M. The location matters: Determinants for "deepening" and "broadening" diversification strategies in Ruhr metropolis' urban farming. *Sustainability* **2017**, *9*, 1168. [CrossRef]
11. Aubry, C.; Kebir, L. Shortening food supply chains: A means for maintaining agriculture close to urban areas? The case of the French metropolitan area of Paris. *Food Policy* **2013**, *41*, 85–93. [CrossRef]
12. Song, S.; Goh, J.C.L.; Tan, H.T.W. Is food security an illusion for cities? A system dynamics approach to assess disturbance in the urban food supply chain during pandemics. *Agric. Syst.* **2021**, *189*, 103045. [CrossRef]
13. Viljoen, A.; Bohn, K. *Second Nature Urban Agriculture–Designing Productive Cities: Ten Years on from the Continuous Productive Urban Landscape (CPUL City) Concept*, 1st ed.; Routledge: London, UK, 2014; p. 312.
14. Rufí-Salís, M.; Petit-Boix, A.; Villalba, G.; Sanjuan-Delmás, D.; Parada, F.; Ercilla-Montserrat, M.; Arcas-Pilz, V.; Muñoz-Liesa, J.; Rieradevall, J.; Gabarrell, X. Recirculating water and nutrients in urban agriculture: An opportunity towards environmental sustainability and water use efficiency? *J. Clean. Prod.* **2020**, *261*, 121213. [CrossRef]
15. Stillitano, T.; Spada, E.; Iofrida, N.; Falcone, G.; De Luca, A.I. Sustainable agri-food processes and circular economy pathways in a life cycle perspective: State of the art of applicative research. *Sustainability* **2021**, *13*, 2472. [CrossRef]
16. Food and Agriculture Organization of the United Nations, FAO. Land & Water–Circular Economy: Waste-to-Resource & COVID-19. Available online: http://www.fao.org/land-water/overview/covid19/circular/en/ (accessed on 27 July 2021).
17. Lobillo-Eguíbar, J.; Fernández-Cabanás, V.M.; Bermejo, L.A.; Pérez-Urrestarazu, L. Economic sustainability of small-scale aquaponic systems for food self-production. *Agronomy* **2020**, *10*, 1468. [CrossRef]
18. Clark, C. Von Thünen's isolated state. *Oxford Econ. Pap.* **1967**, *19*, 370–377. [CrossRef]
19. Howard, E.; Osborn, F.J. *Garden Cities of To-Morrow*, 1st ed.; Routledge: London, UK, 2013; 170p.
20. Viljoen, A.; Bohn, K.; Howe, J. *CPULs–Continuous Productive Urban Landscapes: Designing Urban Agriculture for Sustainable Cities*; Architectural Press: Oxford, UK, 2005; p. 295.
21. Ellen MacArthur Foundation. *Cities and Circular Economy for Food*; Ellen MacArthur Foundation: Cowes, UK, 2019; pp. 1–66.
22. Baganz, G.F.M.; Junge, R.; Portella, M.; Goddek, S.; Keesman, K.; Baganz, D.; Staaks, G.; Shaw, C.; Lohrberg, F.; Kloas, W. The Aquaponic Principle–It is all about Coupling. *Rev. Aquacult.* **2021**, in press. [CrossRef]
23. Baganz, G.F.M.; Schrenk, M.; Körner, O.; Baganz, D.; Keesman, K.; Goddek, S.; Siscan, Z.; Baganz, E.; Doernberg, A.; Monsees, H.; et al. Causal relations of upscaled urban aquaponics and the Food-Water-Energy Nexus–A Berlin case study. *Water* **2021**, *13*, 2029. [CrossRef]
24. Shiklomanov, I.A.; Rodda, J.C. *World Water Resources at the Beginning of the Twenty-First Century*; Cambridge University Press: Cambridge, UK, 2004.
25. Van Zanten, H.H.E.; Herrero, M.; Van Hal, O.; Röös, E.; Muller, A.; Garnett, T.; Gerber, P.J.; Schader, C.; De Boer, I.J.M. Defining a land boundary for sustainable livestock consumption. *Glob. Change Biol.* **2018**, *24*, 4185–4194. [CrossRef]
26. Van Zanten, H.H.E.; Van Ittersum, M.K.; De Boer, I.J.M. The role of farm animals in a circular food system. *Glob. Food Sec.* **2019**, *21*, 18–22. [CrossRef]
27. de Boer, I.J.M.; van Ittersum, M.K. *Circularity in Agricultural Production*; Wageningen University & Research: Wageningen, The Netherlands, 2018; p. 74.
28. United Nations, Department of Economic and Social Affairs–Population Division. *World Population Prospects 2019–Highlights, ST/ESA/SER.A/423*; United Nations: New York, NY, USA, 2019; p. 46. Available online: https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf (accessed on 27 July 2021).
29. Food and Agriculture Organization of the United Nations, FAO. *FAO Framework for the Urban Food Agenda–Leveraging Sub-national and Local Government Action to Ensure Sustainable Food Systems and Improved Nutrition*; FAO: Rome, Italy, 2019; p. 44. [CrossRef]
30. Pascucci, S. *Building Natural Resource Networks: Urban Agriculture and the Circular Economy*; Burleigh Dodds, Burleigh Dodds Series in Agricultural Science; Burleigh Dodds Science Publishing Limited: Cambridge, UK, 2020; pp. 1–20.

31. Wielemaker, R.C.; Weijma, J.; Zeeman, G. Harvest to harvest: Recovering nutrients with New Sanitation systems for reuse in Urban Agriculture. *Resour. Conserv. Recycl.* **2018**, *128*, 426–437. [CrossRef]
32. Dorr, E.; Koegler, M.; Gabrielle, B.; Aubry, C. Life cycle assessment of a circular, urban mushroom farm. *J. Clean. Prod.* **2021**, *288*, 125668. [CrossRef]
33. Castellar, J.A.C.; Popartan, L.A.; Pueyo-Ros, J.; Atanasova, N.; Langergraber, G.; Sämuel, I.; Corominas, L.; Comas, J.; Acuña, V. Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Sci. Total Environ.* **2021**, *779*. [CrossRef]
34. Hemming, V.; Burgman, M.A.; Hanea, A.M.; Mcbride, M.F.; Wintle, B.C. A practical guide to structured expert elicitation using the IDEA Protocol. *Methods Ecol. Evol.* **2018**, *9*, 169–180. [CrossRef]
35. Hemming, V.; Walshe, T.V.; Hanea, A.M.; Fidler, F.; Burgman, M.A. Eliciting improved quantitative judgements using the IDEA Protocol: A case study in natural resource management. *PLoS ONE* **2018**, *13*, 1–34. [CrossRef]
36. Baganz, G.F.M.; Proksch, G.; Kloas, W.; Lorleberg, W.; Baganz, D.; Staaks, G.; Lohrberg, F. Site resource inventories—A missing link in the circular city's information flow. *Adv. Geosci.* **2020**, *54*, 23–32. [CrossRef]
37. You, C.; Chen, H.G.; Myung, S.; Sathitsuksanoh, N.; Ma, H.; Zhang, X.Z.; Li, J.Y.; Zhang, Y.H.P. Enzymatic transformation of nonfood biomass to starch. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 7182–7187. [CrossRef]
38. Pearlmutter, D.; Theochari, D.; Nehls, T.; Pinho, P.; Piro, P.; Korolova, A.; Papaefthimiou, S.; Garcia Mateo, M.C.; Calheiros, C.; Zluwa, I.; et al. Enhancing the circular economy with nature-based solutions in the built urban environment: Green building materials, systems and sites. *Blue-Green Syst.* **2020**, *2*, 46–72. [CrossRef]
39. da Cunha, J.A.C.; Arias, C.A.; Carvalho, P.; Rysulova, M.; Canals, J.M.; Perez, G.; Gonzalez, M.B.; Morato, J.F. "WETWALL"-an innovative design concept for the treatment of wastewater at an urban scale. *Desalin. Water Treat.* **2018**, *109*, 205–220. [CrossRef]
40. Specht, K.; Siebert, R.; Hartmann, I.; Freisinger, U.B.; Sawicka, M.; Werner, A.; Thomaier, S.; Henckel, D.; Walk, H.; Dierich, A. Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agric. Hum. Values* **2014**, *31*, 33–51. [CrossRef]
41. Specht, K.; Zoll, F.; Siebert, R. Application and evaluation of a participatory "open innovation" approach (ROIR): The case of introducing zero-acreage farming in Berlin. *Landsc. Urban Plan.* **2016**, *151*, 45–54. [CrossRef]
42. Thomaier, S.; Specht, K.; Henckel, D.; Dierich, A.; Siebert, R.; Freisinger, U.B.; Sawicka, M. Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming (ZFarming). *Renew. Agric. Food Syst.* **2015**, *30*, 43–54. [CrossRef]
43. Addo-Bankas, O.; Zhao, Y.; Vymazal, J.; Yuan, Y.; Fu, J.; Wei, T. Green walls: A form of constructed wetland in green buildings. *Ecol. Eng.* **2021**, *169*. [CrossRef]
44. Walters, S.A.; Midden, K.S. Sustainability of urban agriculture: Vegetable production on green roofs. *Agriculture* **2018**, *8*, 168. [CrossRef]
45. Baganz, G.F.M.; Baganz, E.; Baganz, D.; Kloas, W.; Lohrberg, F. Urban rooftop uses: Competition and potentials from the perspective of farming and aquaponics–A Berlin Case Study. In Proceedings of the REAL CORP 2021, Vienna, Austria, 7–10 September 2021.
46. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL). *Guidelines for the Planning, Construction and Maintenance of Green Roofing–Green Roofing Guideline*; FLL: Berlin, Germany, 2018.
47. Bellamy, D. Belgian Supermarket Grows its Greens on the Roof. Available online: https://www.euronews.com/2018/07/05/belgian-supermarket-grows-its-greens-on-the-roof (accessed on 13 April 2021).
48. European Union. *LISBON–European Green Capital 2020*; EU: Bietlot, Belgium, 2020. [CrossRef]
49. Natural Walking Cities. Green Corridors–Essential Urban Walking and Natural Infrastructure. Available online: http://naturalwalkingcities.com/green-corridors-essential-urban-walking-and-natural-infrastructure/ (accessed on 21 May 2021).
50. Maucieri, C.; Nicoletto, C.; Junge, R.; Schmautz, Z.; Sambo, P.; Borin, M. Hydroponic systems and water management in aquaponics: A review. *Ital. J. Agron.* **2018**, *13*, 1–11. [CrossRef]
51. Maucieri, C.; Nicoletto, C.; Van Os, E.; Anseeuw, D.; Van Havermaet, R.; Junge, R. Hydroponic technologies. In *Aquaponics Food Production Systems*; Goddek, S., Joyce, A., Kotzen, B., Burnell, G.M., Eds.; Springer: Cham, Switzerland, 2019; pp. 77–110.
52. Wongkiew, S.; Hu, Z.; Lee, J.W.; Chandran, K.; Nhan, H.T.; Marcelino, K.R.; Khanal, S.K. Nitrogen recovery via aquaponics–bioponics: Engineering considerations and perspectives. *ACS ES&T Eng.* **2021**, *1*, 326–339.
53. National Organic Standards Board. Organic Hydroponic and Aquaponic Task Force Report. Available online: https://www.ams.usda.gov/content/organic-hydroponic-and-aquaponic-task-force-report (accessed on 28 July 2021).
54. Pradhan, S.K.; Nerg, A.M.; Sjoblom, A.; Holopainen, J.K.; Heinonen-Tanski, H. Use of human urine fertilizer in cultivation of cabbage (Brassica oleracea)–Impacts on chemical, microbial, and flavor quality. *J. Agric. Food Chem.* **2007**, *55*, 8657–8663. [CrossRef] [PubMed]
55. Lind, O.P.; Hultberg, M.; Bergstrand, K.J.; Larsson-Jonsson, H.; Caspersen, S.; Asp, H. Biogas digestate in vegetable hydroponic production: pH dynamics and pH management by controlled nitrification. *Waste Biomass Valori.* **2021**, *12*, 123–133. [CrossRef]
56. Wongkiew, S.; Koottatep, T.; Polprasert, C.; Prombutara, P.; Jinsart, W.; Khanal, S.K. Bioponic system for nitrogen and phosphorus recovery from chicken manure: Evaluation of manure loading and microbial communities. *Waste Manag.* **2021**, *125*, 67–76. [CrossRef] [PubMed]
57. Schmautz, Z.; Espinal, C.A.; Smits, T.H.M.; Frossard, E.; Junge, R. Nitrogen transformations across compartments of an aquaponic system. *Aquac. Eng.* **2021**, *92*, 102145. [CrossRef]

58. Chinta, Y.D.; Eguchi, Y.; Widiastuti, A.; Shinohara, M.; Sato, T. Organic hydroponics induces systemic resistance against the air-borne pathogen, Botrytis cinerea (gray mould). *J. Plant Interact.* **2015**, *10*, 243–251. [CrossRef]
59. Fujiwara, K.; Aoyama, C.; Takano, M.; Shinohara, M. Suppression of bacterial wilt disease by an organic hydroponic system. *J. Gen. Plant Pathol.* **2012**, *78*, 217–220. [CrossRef]
60. Stoknes, K.; Wojciechowska, E.; Jasińska, A.; Gulliksen, A.; Tesfamichael, A.A. Growing vegetables in the circular economy; cultivation of tomatoes on green waste compost and food waste digestate. *Acta Hortic.* **2018**, *1215*, 389–396. [CrossRef]
61. Sánchez, H.J.A. Lactuca sativa production in an Anthroponics System. 2015. Available online: https://www.hemmaodlat.se/research/lactuca%20sativa%20production%20in%20an%20anthroponics%20system.pdf (accessed on 28 July 2021).
62. Gartmann, F.; Julian Hügly, J.; Brinkmann, N.; Schmautz, Z.; Smits, T.H.M.; Junge, R. Bioponics, an Organic Closed-Loop Soilless Cultivation System: Management, Characteristics, and Nutrient Mass Balance Compared to Hydroponics and Soil Cultivation. 2021; (manuscript in preparation).
63. Pantanella, E. Pond aquaponics: New pathways to sustainable integrated aquaculture and agriculture. 2008. Available online: http://wptest.backyardmagazines.com/wp-content/uploads/2009/08/pondaquaponics.pdf (accessed on 28 July 2021).
64. Salam, M.A.; Asadujjaman, M.; Rahman, M.S. Aquaponics for improving high density fish pond water quality through raft and rack vegetable production. *WJFMS* **2013**, *5*, 251–256. [CrossRef]
65. Food and Agriculture Organization of the United Nations, FAO. *Integrated Agriculture-Aquac: A Primer*; FAO/IIRR/WorldFish Center: Rome, Italy, 2001.
66. Food and Agriculture Organization of the United Nations, FAO. *Small-Scale Aquaponic Food Production–Integrated Fish and Plant Farming*; FAO: Rome, Italy, 2014.
67. Zajdband, A.D. Integrated agri-aquaculture systems. In *Genetics, Biofuels and Local Farming Systems. Sustainable Agriculture Reviews*; Lichtfouse, E., Ed.; Springer Nature: Geneve, Switzerland, 2011; Volume 7, pp. 87–127.
68. McDougall, R.; Kristiansen, P.; Rader, R. Small-scale urban agriculture results in high yields but requires judicious management of inputs to achieve sustainability. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 129–134. [CrossRef]
69. Morel, K.; San Cristobal, M.; Leger, F.G. Small can be beautiful for organic market gardens: An exploration of the economic viability of French microfarms using MERLIN. *Agr. Syst.* **2017**, *158*, 39–49. [CrossRef]
70. Oral, H.V.; Radinja, M.; Rizzo, A.; Kearney, K.; Andersen, T.R.; Krzeminski, P.; Buttiglieri, G.; Cinar, D.; Comas, J.; Gajewska, M.; et al. Management of urban waters with nature-based solutions in circular cities. *Water* **2020**, *2*, 112–136.
71. Turcios, A.E.; Papenbrock, J. Sustainable treatment of aquaculture effluents–What can we learn from the past for the future? *Sustainability* **2014**, *6*, 836–856. [CrossRef]
72. Wielemaker, R.; Oenema, O.; Zeeman, G.; Weijma, J. Fertile cities: Nutrient management practices in urban agriculture. *Sci. Total Environ.* **2019**, *668*, 1277–1288. [CrossRef]
73. Avgoustaki, D.D.; Xydis, G. Indoor vertical farming in the urban nexus context: Business growth and resource savings. *Sustainability* **2020**, *12*, 1965. [CrossRef]
74. Körner, O.; Bisbis, M.B.; Baganz, G.F.M.; Baganz, D.; Staaks, G.B.O.; Monsees, H.; Goddek, S.; Keesman, K.J. Environmental impact assessment of local decoupled multi-loop aquaponics in an urban context. *J. Clean. Prod.* **2021**, *313*, 127735. [CrossRef]
75. Rossi, L.; Bibbiani, C.; Fierro-Sañudo, J.F.; Maibam, C.; Incrocci, L.; Pardossi, A.; Fronte, B. Selection of marine fish for integrated multi-trophic aquaponic production in the Mediterranean area using DEXi multi-criteria analysis. *Aquaculture* **2021**, *535*, 736402. [CrossRef]
76. Sherwood, J. The significance of biomass in a circular economy. *Bioresour. Technol.* **2020**, *300*, 122755. [CrossRef] [PubMed]
77. Li, J.-S.; Zhu, L.-T.; Luo, Z.-H. Effect of geometric configuration on hydrodynamics, heat transfer and RTD in a pilot-scale biomass pyrolysis vapor-phase upgrading reactor. *Chem. Eng. J.* **2022**, *428*, 131048. [CrossRef]
78. He, Z.; Zheng, W.; Li, M.; Liu, W.; Zhang, Y.; Wang, Y. Fe_2P/biocarbon composite derived from a phosphorus-containing biomass for levofloxacin removal through peroxymonosulfate activation. *Chem. Eng. J.* **2022**, *427*, 130928. [CrossRef]
79. Yadav, S.; Yadav, A.; Bagotia, N.; Sharma, A.K.; Kumar, S. Adsorptive potential of modified plant-based adsorbents for sequestration of dyes and heavy metals from wastewater–A review. *J. Water Process Eng.* **2021**, *42*, 102148. [CrossRef]
80. Lupia, F.; Pulighe, G. Water use and urban agriculture: Estimation and water saving scenarios for residential kitchen gardens. *Agric. Agric. Sci. Proc.* **2015**, 50–58. [CrossRef]
81. O'Sullivan, C.A.; Bonnett, G.D.; McIntyre, C.L.; Hochman, Z.; Wasson, A.P. Strategies to improve the productivity, product diversity and profitability of urban agriculture. *Agr. Syst.* **2019**, *174*, 133–144. [CrossRef]
82. Jurgilevich, A.; Birge, T.; Kentala-Lehtonen, J.; Korhonen-Kurki, K.; Pietikäinen, J.; Saikku, L.; Schösler, H. Transition towards circular economy in the food system. *Sustainability* **2016**, *8*, 69. [CrossRef]
83. Cordell, D.; Drangert, J.-O.; White, S. The story of phosphorus: Global food security and food for thought. *Glob. Environ. Change* **2009**, *19*, 292–305. [CrossRef]
84. Schoumans, O.F.; Bouraoui, F.; Kabbe, C.; Oenema, O.; van Dijk, K.C. Phosphorus management in Europe in a changing world. *AMBIO* **2015**, *44*, 180–192. [CrossRef] [PubMed]
85. Mohareb, E.; Heller, M.; Novak, P.; Goldstein, B.; Fonoll, X.; Raskin, L. Considerations for reducing food system energy demand while scaling up urban agriculture. *Environ. Res. Lett.* **2017**, *12*, 125004. [CrossRef]
86. Kürklü, A. Energy storage applications in greenhouses by means of phase change materials (PCMs): A review. *Renew. Energy* **1998**, *13*, 89–103. [CrossRef]

87. Drescher, A.W. Food for the cities: Urban agriculture in developing countries. *Acta Hort.* **2004**, *643*, 227–231. [CrossRef]
88. Goldstein, B.; Hauschild, M.; Fernandez, J.; Birkved, M. Testing the environmental performance of urban agriculture as a food supply in northern climates. *J. Clean. Prod.* **2016**, *135*, 984–994. [CrossRef]
89. Salomon, M.J.; Watts-Williams, S.J.; McLaughlin, M.J.; Cavagnaro, T.R. Urban soil health: A city-wide survey of chemical and biological properties of urban agriculture soils. *J. Clean. Prod.* **2020**, *275*, 122900. [CrossRef] [PubMed]
90. Watts-Williams, S.J.; Cavagnaro, T.R. Arbuscular mycorrhizas modify tomato responses to soil zinc and phosphorus addition. *Biol. Fertil. Soils* **2012**, *48*, 285–294. [CrossRef]
91. Suhl, J.; Dannehl, D.; Kloas, W.; Baganz, D.; Jobs, S.; Scheibe, G.; Schmidt, U. Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics. *Agric. Water Manag.* **2016**, *178*, 335–344. [CrossRef]
92. Nozzi, V.; Graber, A.; Schmautz, Z.; Mathis, A.; Junge, R. Nutrient management in aquaponics: Comparison of three approaches for cultivating lettuce, mint and mushroom herb. *Agronomy* **2018**, *8*, 27. [CrossRef]
93. Baganz, G.; Baganz, D.; Staaks, G.; Monsees, H.; Kloas, W. Profitability of multi-loop aquaponics: Year-long production data, economic scenarios and a comprehensive model case. *Aquac. Res.* **2020**, *51*, 2711–2724. [CrossRef]
94. Tokunaga, K.; Tamaru, C.; Ako, H.; Leung, P.S. Economics of small-scale commercial aquaponics in Hawai'i. *J. World Aquac. Soc.* **2015**, *46*, 20–32. [CrossRef]
95. Rosemarin, A.; Macura, B.; Carolus, J.; Barquet, K.; Ek, F.; Järnberg, L.; Lorick, D.; Johannesdottir, S.; Pedersen, S.M.; Koskiaho, J.; et al. Circular nutrient solutions for agriculture and wastewater–A review of technologies and practices. *Curr. Opin. Environ. Sust.* **2020**, *45*, 78–91. [CrossRef]
96. Wortman, S.E.; Lovell, S.T. Environmental challenges threatening the growth of urban agriculture in the United States. *J. Environ. Qual.* **2013**, *42*, 1283–1294. [CrossRef]
97. Aubry, C.; Manouchehri, N. Urban agriculture and health: Assessing risks and overseeing practices. *Field Actions Sci. Rep.* **2019**, *20*, 108–111.
98. Choi, Y.; Lee, S.; Moon, H. Urban physical environments and the duration of high air temperature: Focusing on solar radiation trapping effects. *Sustainability* **2018**, *10*, 4837. [CrossRef]
99. Williams, J. Circular cities: Challenges to implementing looping actions. *Sustainability* **2019**, *11*, 423. [CrossRef]
100. Albert, C.; Schroter, B.; Haase, D.; Brillinger, M.; Henze, J.; Herrmann, S.; Gottwald, S.; Guerrero, P.; Nicolas, C.; Matzdorf, B. Addressing societal challenges through nature-based solutions: How can landscape planning and governance research contribute? *Landsc. Urban Plan.* **2019**, *182*, 12–21. [CrossRef]
101. European Commission. Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities –Final Report of the Horizon 2020 Expert Group on "Nature-Based Solutions and Re-Naturing Cities" (Full Version). Directorate-General for Research and Innovation. Publications Office of the European Union, Luxembourg. 2015. Available online: https://ec.europa.eu/newsroom/horizon2020/document.cfm?doc_id=10195; https://op.europa.eu/en/publication-detail/-/publication/fb117980-d5aa-46df-8edc-af367cddc202 (accessed on 19 January 2021).