Nature based solutions for circular urban food systems

Towards circular urban food systems

The linear character of the current global food system requires a transformation towards more sustainable, circular food systems (Groot et al. 2020; Stelwagen et al. 2021). Improved sustainability in food systems can be achieved by adopting and incorporating a circular approach in production, consumption and waste management. A circular food system is characterised by the optimized use of resources and reduction of food losses by transformation of waste streams into useful inputs for other processes, such as (local) food production. These optimizations in the food system target not only nutrient flows but also the interacting energy and water systems. Water, for example, has a key role in the food system for irrigation, whilst energy is for example essential for cooling during transport and storage (Bellezoni et al. 2021). Hence, circularity in food systems entails "efficient use of land and closing the water, nutrient and carbon cycles to minimize resource loss and environmental degradation" (Groot et al. 2020) (figure 1). Cities have (at least) a threefold role in such circular food systems: they are centres of consumption, waste generators as well as productive spaces.

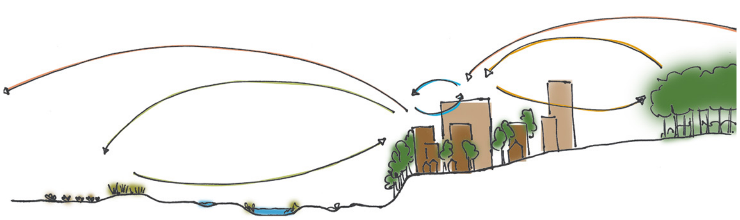

Figure 1. Circularity in food systems entails closing resource cycles; partially these cycles can be closed inside a city and partially such cycles connect cities with areas outside their boundaries. (image by the authors)

1.1 Cities as centres of consumption

When we think about the position of cities in the food system, cities are foremost centres of food consumption (Stelwagen et al. 2021). Indeed, with the emergence of cities (3000 BC) (Agudelo-Vera et al. 2011) also the geographical separation of food production and consumption arose. By 2018, cities were home to 55% of the world's population and this is projected to increase to 68% by 2050 (UN, 2019), implying *urban* food demands will continue to grow.

Cities concentrate not only consumers but are also home to a large number of retail outlets, with noticeable geographical differences in terms of the prevailing types of outlets. Whereas supermarkets are the main access point of food in The Global North, food retail in The Global South is characterised by a mixture of formal and informal retail outlets – including local markets, wholesalers and supermarkets (Battersby and Watson 2018; Timmer 2017). The majority of food purchases in East Asian and Latin American cities are by now from "modern retail establishments", especially supermarkets (Timmer 2017). In Africa the rapid emergence of supermarkets is still ongoing, and although supermarkets are by now an important part of the food retail environment, local markets and traders remain an important source of food (Battersby and Peyton 2016).

1.2 Cities as waste generators

With the large amounts of food being consumed in cities, also large amounts of waste are being generated. Both retail and consumers are associated with considerable food waste levels. In high-income countries, waste at retail level is foremost a result of retail being inclined to sell homogeneous and "perfect" produce. Also in lower-income countries waste at retail level can be significant, yet for different reasons such as inadequate protective packaging, temperature and humidity control. It is, for example, estimated that 0-15% of fruits and vegetables are waste at retail level in all regions of the world, except for sub-Saharan Africa where this number is as much as 35% (FAO 2019). Food waste at the consumer side is also significant, and besides high-income countries also emerging economies are increasingly facing this issue. Indeed, "the higher the household wealth, the more food consumers waste" (FAO 2019). Another nutrient-rich output flow at the consumer level is human excreta, which is currently predominantly seen as a waste. Yet, scholars argue that human excreta management should be reframed as part of food and farming systems as to highlight the potential contribution of human excreta-derived nutrients as nutrient source in a circular food system (Harder et al. 2020). Finally, cities also generate waste with food system activities upstream of consumption and retail, including at food processing and food production. The food processing industry is of particular interest as the nutrient-rich waste streams generated by the food processing industry offer various applications in for example food, medicinal, and skincare products (Osorio et al. 2021).

1.3 Cities as productive spaces

Finally, cities can also be seen as locations for food production. Food production in urban areas is increasing, especially in rapidly growing cities of the Global South. According to Bellezoni et al. (2021), in some eastern and central African cities nearly half of all vegetables and maize consumed by city dwellers originate from urban agriculture. Whilst urban agriculture has as a common denominator that farming takes place in the urban environment, urban farming initiatives are very diverse. Urban farming differs for example in terms of type of growing space used (including mobile systems as well as soil-, building and water bound forms), level of technology application (e.g. for soilless cultivation, water management, fertilization, lighting and pest management) and involvement of the urban population and professionals (ranging from private and community gardens to professional local food farms) (Skar et al. 2020).

2. Opportunities for Nature Based Solutions in urban food systems

Nature Based Solutions (NBS) are key elements in urban contexts. Their contribution to support, not only biodiversity but also human conditions, is being increasingly considered (Mendes et al. 2020). NBS appeared as a concept in the years 2000's and brought attention to proactively managing nature towards improving urban ecosystem services and benefitting from them (Cohen-Shacham et al. 2014). NBS allows finding solutions to tackle multiple challenges, within different dimensions (Raymond et al. 2017). These challenges can be related to environmental dimensions, such as climate resilience or water management, but also to economic and social dimensions, ranging from green economy to planning and governance issues. Hence, it is argued that the combination of the multiple benefits from NBS provide viable solutions for urban global change adaptation (Roebeling et al. 2021).

The specific benefits and co-benefits provided by NBS in urban food systems depend on design factors, local conditions and the scale of the project, and include (Zareba et al. 2021):

- reducing the urban heat island effect;
- improving the quality of outdoor and indoor air;
- reducing noise;
- restoring the natural water balance in urban areas;
- improving the energy efficiency of buildings;
- protecting the building structure against UV radiation and temperature fluctuations;
- multiplying harvests in urban areas and improve the quality of agricultural products provided to urban residents;
- creating opportunities for local citizens to meet, increasing the sense of community;
- providing room for biodiversity;
- improving aesthetics; and
- providing greater accessibility to recreational areas.

Abovementioned benefits, in turn, lead to associated health benefits (temperature; air pollution; noise; recreation), avoided costs (health; flooding; energy; infrastructure) and increase in property values.

2.1 NBS for circular food systems

Various urban food system activities provide opportunities for the implementation of NBS in supporting transitions to a more circular urban food system. As the urban environment is highly managed, NBS that rely upon the (better) usage of existing ecosystems and involve only minimal or no intervention - so-called intrinsic NBS (Groot et al. 2020) - are hardly to be found in cities. Hence, NBS in cities are foremost inspired in nature. That is, the NBS involve "the creation of new ecosystems and/or the use of new technologies copying ecosystem functionality to sustainably increase service provision" (inspired NBS) (Groot et al. 2020).

So far, the following opportunities for NBS stand out:
- **NBS for urban food production**
- **NBS for resource recovery**

As shown in figure 2, these NBS play a role in different parts of the food system. Whereas NBS for food production address consumer loops, NBS for resource recovery address primarily pre- and post-consumer loops. In the following sections we discuss these different sort of NBS and provide examples of implementation of these NBS in the Netherlands.

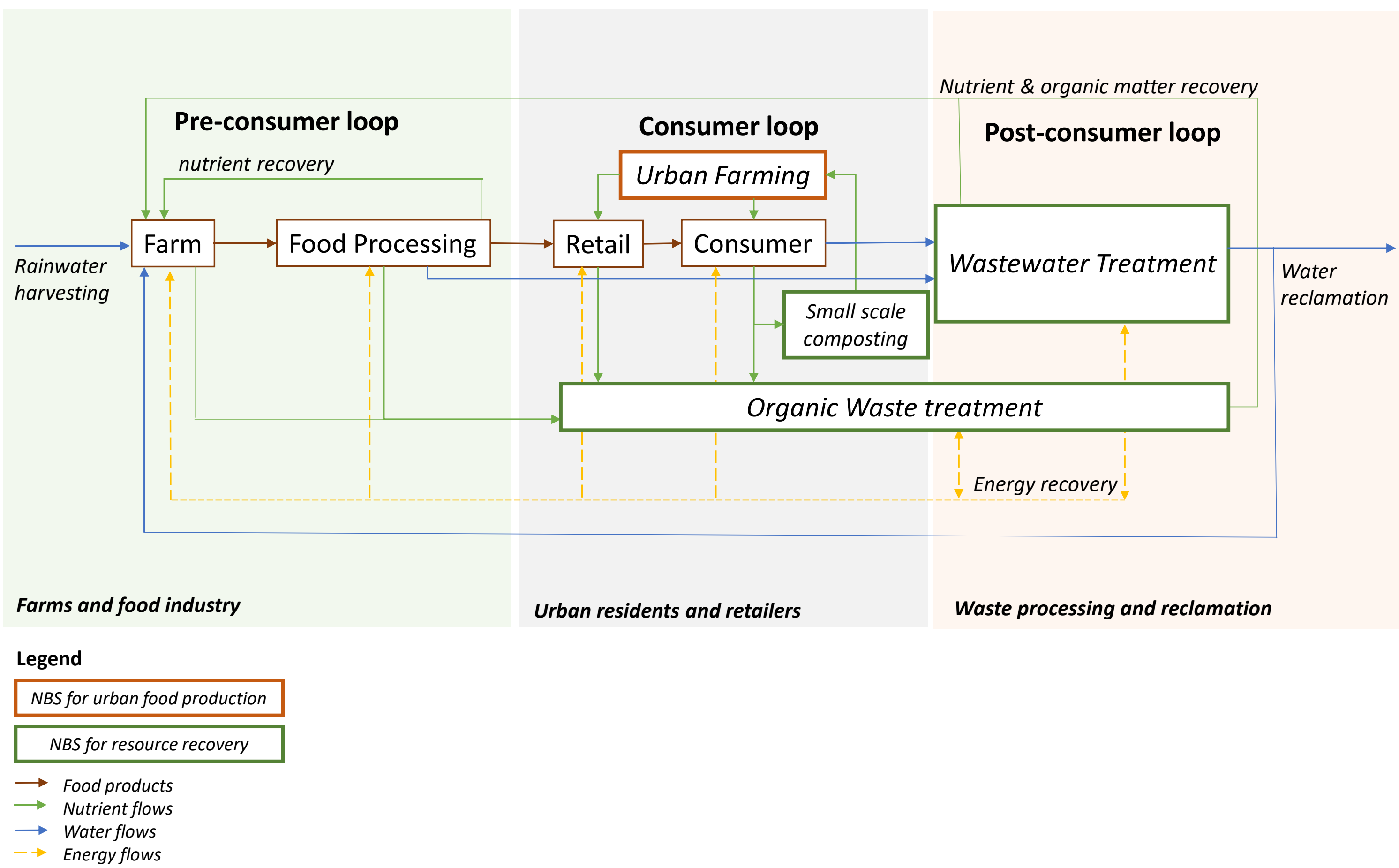

Figure 2. The opportunities for NBS in the urban food system. (image by the authors)

2.2 NBS for urban food production

Urban agriculture as strategy for urban resource circularity is based on the premise that production (and retail) of food within geographical proximity of the consumer, in the city, results in short travel distances. In this view, such NBS contribute to efficiency with energy and material savings that result from avoided transport, packaging and cooling due to the shorter distance between production and consumption (Bellezoni et al. 2021; Zwart and Wertheim-Heck 2021). NBS for local food production can also play a role in a more circular system as a receiving element for recovered water and nutrients from waste(water) streams (Canet-Marti et al. 2021). This is also the case in urban farming concepts that specifically rely upon a closed-loop design, including for example aquaponic systems (Skar et al. 2020).

Urban agriculture can take many forms. To differentiate systems of urban farming, the distinction between no-tech, low-tech and high-tech systems can be used (Snep et al. 2020). No-tech NBS urban agriculture includes for example private vegetable gardens and orchards, and food-forests or ‘Tiny-Forests’. Urban farming on rooftops is characterised as low-tech. Because of its location and separation with natural groundwater, certain levels of technology are necessary to manage water -both during drought and peak rain events to protect the crops and the building underneath. High tech vertical farming systems stack the indoor production of fresh (leaf-) produce and often rely on soilless technologies, which realize considerable savings on land surface requirements (10-20 fold), water usage (a few % of normal agriculture), minerals and phytochemicals, but rely 100% on technological water and lighting solutions (Snep et al. 2020).

2.3 NBS for resource recovery

NBS for resource recovery entail solutions that bring nature into cities and “technologies that are derived from nature, using organisms as principal agents if they enable resource recovery and the restoration of ecosystem services in urban areas” (Langergraber et al. 2020). These NBS can be used to recover nutrients, water and/or energy from solid food waste streams, dairy and food industry wastewaters and from municipal wastewaters (human waste).

Circular farming concept: Rotterzwam

Rotterzwam is a company which offers kits to private home owners and businesses to grow oyster mushrooms on waste coffee grounds (figure 3). Next to mushroom growing kits they have also developped a wide array of related products (vegetarian foods based on oyster mushrooms) and services (training and workshops for people and businesses). This concept does not reduce the amount of coffee waste, but inserts a new step in better utilising the nutrients and energy present in coffee grounds close to where coffee is consumed, before the leftovers go to the composting plant. This circular model fits in the consumer cycle of organic matter, in which the mushrooms are either directly available to consumers or via local retail when grown in small businesses.

Figure 3. Rotterzwam oyster grow kit.
(image courtesy of Rotterzwam)

No-tech NBS for urban food production

Since 2019 the AmsterGaard Foundation has been active in creating miniature food-forests, which is an example of a no-tech NBS. Movable hexagonal planters (figure 4), made from recycled local wood,

Figure 4. AmsterGaard food forest: a movable planter, maintained and harvested by local residents.
(image courtesy of AmsterGaard)

are used to create string-gardens of these planters in the dynamic city center of Amsterdam, in the densest, most paved and underground crowded locations (utilities). This allows the creation of small 'edible oases', that are cared for by locals, increasing the sense of community, increasing biodiversity and improving liveability with positive effects of urban green (such as urban cooling and stress reduction). In 2020 vermicomposting was added as a service (see 2.2), creating valuable compost for the planters with kitchen cuttings from and by the locals, without the need of in-depth technical composting knowledge.

Figure 5. The rooftop farm at Dakakker in Rotterdam.
(image https://www.dakakker.nl)

Low-tech NBS for urban food production

Project Dakakker is a 1.000 m2 rooftop farm in Rotterdam city center where vegetables and (edible) flowers are grown since 2012 (figure 5). The system is built with 30-40 cm of arable specific lightweight urban farming soil on a standard 40 mm drainage board. The food produced can be eaten in the on-site restaurant, and the edible flowers are harvested and sold to restaurants in the area. Due to the deep soil, this rooftop is known for its high soil- and flying insect biodiversity. The roof is operated by one professional rooftop-farmer, supported with manual labour from local volunteers. The incredible enthusiasm of locals to volunteer in this project has resulted in a waiting list for volunteers to be invited to work on the roof. Next to producing food, the project also has societal impacts such as community building and re-connecting city dwellers with nature and their source of food.

High-tech NBS for urban food production

Since the first Dutch high-tech company GrowX started in Amsterdam in 2018 (figure 6), vertical farming has seen worldwide initiatives, for example in Dubai (12.000 m2 by Crop One) and Japan (Philips Lighting, Innovatus, Delicious Cook and Spread). In the US, AeroFarms, Oasis Biotech (20.000 m2) and Plenty Unlimited known vertical farming produce providers. They market specifically towards the zero-pesticide usage in growing their crops. From a resource point of view, the high energy consumption rates in vertical farms, which are 365 days a year operational, is still a limiting factor.

Figure 6. An indoor vertical farm by GrowX, Amsterdam; a highly efficient, crop production system. (image courtesy of GrowX)

Composting and anaerobic digestion are commonly used processes to recover resources from flows of solid food waste, including the biodegradable fraction of catering waste, as well as vegetable, fruit and allotment waste (Kisser et al. 2020). Composting refers primarily to aerobic processes that oxidize organic matter into an end product, compost, that can be used as fertilizer and soil improver. When the composting process makes use of worms, this is called vermicomposting (Hullebusch et al. 2020). Nutrients in organic waste can also be converted by applying insect larvae, that transform this waste into high-value end-products such as food supplements, fish feed, feeding for poultry and pets, fertilizer and biogas (Hullebusch et al. 2020). Anaerobic digestion is a process where different groups of microorganisms break down organic material, in the absence of oxygen, and convert it into energy (biogas) and nutrients in a recoverable form. Anaerobic digestion can also be used to treat domestic wastewater streams and wastewater from the (dairy) industry (Kisser et al. 2020). Other NBS that can be used to treat liquid food waste streams include photobioreactors, which rely upon organisms such as microalgae to recover nutrients from wastewater, and constructed wetlands that mimic natural wetlands to treat wastewater. Constructed wetlands can, for example, be used to recover nutrients from nutrient-rich wastewaters from food processing plants (Hullebusch et al. 2020; Kisser et al. 2020).

3. Enablers and disablers for NBS implementation

The multidisciplinary approach needed to foster NBS, requires robust mechanisms of knowledge transfer between academics, practitioners, and civil society. Yet, NBS suffer multiple incorporation difficulties already observed in other environmental concepts (Hansen et al. 2015). Some of the key socio-institutional, biophysical and hybrid (both socio-institutional and

Decentralized anaerobic digestion

DeSah in the Netherlands has developed a Decentralized Sanitation and Recovery Concept as a circular, source separated wastewater treatment system. The system relies upon anaerobic digestion with a so-called UASB reactor, amongst other technical installations. System inputs include the wastewater flow from vacuum toilets, which reduce water usage with 90%, and food waste that comes from grinders in the kitchen and is transported in waste water. Recovered resources include energy in the form of biogas and heat, nutrients in the form of the fertilizer struvite, and reclaimed water. The DeSaH concept is suitable as compact and local treatment solution, in high-rise buildings, remote areas and areas where the sewer system is at its maximum capacity (Kisser et al. 2020).

Nutrient recovery with composting

Composting is the most well-known form of biological waste processing. Food and garden biological material is being collected in the Netherlands from households and businesses and transformed through aerobic composting to reusable compost for soil quality enhancement and fertilization. In the Netherlands, 1.5 million tons of waste was processed into compost and marketed from this stream (RWS, 2021). Arable farming, open field horticulture and tree cultivation are the main buyers of the compost. About 75 percent of the produced organic waste compost goes to these sectors. Next to this type of controlled, large-scale composting of vegetable, fruit and allotment waste, composting also occurs on smaller scale levels up to the household level. Such composting initiatives are characterized by a shorter cycle from organic waste to application of the end-product.

Figure 6. Home composting of kitchen waste.
(image https://www.appeltern.nl)

biophysical) barriers to and enablers of NBS are the following (Sarabi et al. 2019; Voskamp et al. 2021):

• Barriers for successful implementation and uptake of NBS include uncertainty regarding implementation processes and effectiveness of NBS, inadequate financial resources, path dependency of organizational decision making, limited space/land and time, institutional fragmentation and inadequate regulations.

• Enablers for successful implementation and uptake of NBS include partnership among stakeholders, effective monitoring and valuation systems for implementation processes and benefits, knowledge sharing mechanisms and technologies, economic instruments, plans, acts and legislations and, finally, education and training.

The scientific discourse on NBS is still struggling to deliver specific planning, governance, and institutional recommendations that can embed these solutions in the decision making process and in specific planning tools (Mendes et al. 2020). The incorporation of NBS in the urban agenda is essential to move towards a more sustainable planning approach. Furthermore, the incorporation of these concepts in policy and planning instruments, such as municipal master plans, in a clear and comprehensive way, is an essential move forward that must be promoted by both social and environmental scientists (Zwierzchowska et al. 2019).

4. Research directions

Cross-scale food strategies

When aiming for more circular urban food systems it is important to acknowledge that the urban food system cannot be seen in isolation from the transboundary, global food system it is embedded in. The urban system heavily relies, and will keep relying on, the import of food that is produced outside city boundaries (Hullebusch et al. 2021). Yet, urban food systems can potentially facilitate large-scale sustainability transformations (Hebinck et al. 2021). A key challenge is thus to formulate cross-scale strategies for a more circular food system that tap into this potential and at the same time acknowledge that urban food flows only partially take place in the urban environment itself, and, in part, resource cycles must be closed higher up in the production chain and outside the city boundary.

Distribution of ecosystem services and values

Little is known about the actual performance and ecosystem services supply of NBS; how are multiple impacts, cost and benefits distributed over time, space and stakeholders? What is needed to realize optimal ecosystem services provision and to minimize the negative impacts of NBS for urban food systems, for example on food safety, water quality, and water and energy usage?

Smart, place-specific NBS strategies

We need to enhance our understanding of which combinations of NBS need to be made for optimal functioning and ecosystem service provision of these solutions. Smart combinations include for example urban farming and rainwater harvesting NBS that enable capture, storage and reuse of rainwater for plant irrigation. Likewise, the effect of context-specific city characteristics (economic, political, geographical etc. context) on succesful implementation and functioning of NBS must be understood. Integrated concepts and place-specific, spatial strategies for implementation and management have to be developed.

Inclusive transition

In the context of planning processes, the concept of NBS has also been associated with concepts such as co-design and co-management, where the role of stakeholders becomes central (Dennis et al. 2019). The involvement of various stakeholders along a truly participatory and multidisciplinary process is, however, still rarely adopted (Raymond et al. 2017). How to make the transition towards circular food system a truly inclusive transition? What are appropriate implementation and management models for NBS?

Common language

Finally, a common language needs to be sought that enables researchers with various background (social, economic, environmental, technological, ...) to work jointly in a truly interdisciplinary approach on NBS for urban food circularity challenges. Multiple definitions of NBS exist; these should be acknowledged and embraced in future NBS research.

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Funding was provided by the Ministry of Agriculture, Nature, and Food through the Knowledgebase Program 34: Circular and Climate Neutral;[KB-34-007-010], Program 35: Food Security and Valuing Water; [KB-35-007-002]