Blue-Green Systems

© 2020 The Authors
173

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

Implementing nature-based solutions for creating a resourceful circular city

Guenter Langergraber[a,*], Bernhard Pucher[a], Lena Simperler[a], Johannes Kisser[b], Evina Katsou[c], Devi Buehler[d], Mari Carmen Garcia Mateo[e] and Nataša Atanasova[f]

[a] Institute of Sanitary Engineering and Water Pollution Control, University of Natural Resources and Life Sciences, Vienna (BOKU), Muthgasse 18, A-1190 Vienna, Austria

[b] alchemia-nova GmbH, institute for innovative phytochemistry & closed loop processes, Baumgartenstrasse 93, A-1140 Vienna, Austria

[c] Department of Civil & Environmental Engineering, Institute of Environment, Health and Societies, Brunel University London, Uxbridge Campus, Middlesex, UB8 3PH, Uxbridge, UK

[d] Institute of Natural Resource Sciences, Zurich University of Applied Sciences (ZHAW), Grüentalstrasse 22, 8820 Wädenswil, Switzerland

[e] MCG Research & Innovation Sustainability Architecture/Urban Planning, Zarandona 30004, Murcia, Spain

[f] Faculty of Civil and Geodetic Engineering, University of Ljubljana, Hajdrihova 28, 1000 Ljubljana, Slovenia

*Corresponding author. E-mail: guenter.langergraber@boku.ac.at

Abstract

Resource depletion, climate change and degradation of ecosystems are challenges faced by cities worldwide and will increase if cities do not adapt. In order to tackle those challenges, it is necessary to transform our cities into sustainable systems using a holistic approach. One element in achieving this transition is the implementation of nature-based solutions (NBS). NBS can provide a range of ecosystem services beneficial for the urban biosphere such as regulation of micro-climates, flood prevention, water treatment, food provision and more. However, most NBS are implemented serving only one single purpose. Adopting the concept of circular economy by combining different types of services and returning resources to the city, would increase the benefits gained for urban areas. The COST Action Circular City aims to establish a network testing the hypothesis that: '*A circular flow system that implements NBS for managing nutrients and resources within the urban biosphere will lead to a resilient, sustainable and healthy urban environment*'. In this paper we introduce the COST Action Circular City by describing its main objectives and aims. The paper also serves as introduction to the review papers of the Action's five Working Groups in this Special Issue.

Key words: blue-green infrastructure, circular economy, nature-based solutions, resourceful cities

INTRODUCTION

Cities worldwide are facing a number of challenges including resource depletion, climate change and degradation of ecosystems. If cities do not adapt their current infrastructure and resource management, they will not be able to cope with these challenges. Nature-Based Solutions (NBS) or Green

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

Infrastructure (GI) solutions are one element that can help to achieve this transition. NBS and GI can provide mutual ecosystem services such as regulation of micro-climates, flood prevention, water treatment and food provision which are beneficial for the urban environment. To date, implementation of NBS focusses most of the time on achieving only one ecosystem service. The benefits gained for urban areas could be increased if the concept of circular economy is adopted by NBS achieving different ecosystem services and returning resources to the city.

The aim of the European Union funded COST (COoperation in Science and Technology) Action Circular City is to build an interdisciplinary platform for connecting city planners, architects, system designers, circular economists, engineers and researchers from social and natural sciences that develop systems for circular management of resources in cities. Such systems would allow cities to cope with the global challenges of resource depletion as a consequence of increasing pollution and climate change. In this COST Action, the definition of a common language and understanding across disciplines are seen as crucial success factor, while Circular Economy (CE) concepts are seen as key approach and NBS or GI solutions are seen as core elements of the toolbox.

The COST Action aims to encourage collaboration and research to test the hypothesis that '*A circular flow system that implements NBS for managing nutrients and resources within the urban biosphere will lead to a resilient, sustainable and healthy urban environment*'. The Action tests this hypothesis in five domains: built environment, urban water, resource recovery, urban farming, and society, with particular focus on their integration to provide solutions for circular cities. It is structured according to the five domains in five Working Groups (WGs).

In this paper, we firstly define the challenge and then describe the main objectives of the COST Action Circular City as well as its structure. As starting point for the common language required, we provide key definitions that we use in the Action and, additionally, we introduce the Action's five WGs as introduction to the WG's review papers that are also part of this Special Issue.

THE CHALLENGE

Our world is approaching a situation where vital resources are peaking, e.g., oil, phosphorous, water, space, while at the same time generation of pollution is growing and climate change is proceeding. Present day's infrastructure and resource management systems are not capable of dealing with this challenge. In fact, their linearity (import–use–dispose) and consumption oriented paradigm is one of the major causes for the problems that we are facing. Continuing the 'business-as-usual' approach to resources, management will cause severe problems even in areas where such problems may seem negligible at present. Wealth and well-being of coming generations will depend on our ability to adapt our economies to this challenge in the finite world in which we are living. Transforming today's cities into sustainable and resilience cities is one of the main adaptations that will be necessary. A holistic approach looking at cities from a system's perspective is needed to achieve this goal.

NBS and especially GI are introduced in the urban landscape to cope with challenges cities are facing. These challenges are urban heat islands, flooding events, treatment of waste- and runoff waters from different origins and food provision. According to the EU Biodiversity Strategy to 2020, GI could encourage a better use of nature-based approaches to tackle climate change and to improve resource efficiency, for instance through more integrated spatial planning and development of multifunctional zones that are capable of delivering benefits to biodiversity, the land owner and society at large. NBS offer a range of ecosystem services beneficial for the environment. However, NBS are often built without considering their multifunctionality. Thus, NBS only fulfil a single function with little consideration of their recovery potential of waste and water, or their positive symbiosis with other systems. NBS can provide an array of valuable services, such as clean water production, nutrient recovery, heavy metals retention and recovery, as well as production of a broad range of

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

plant-based materials. NBS are ideally energy and resource-efficient, and resilient to change, but to be successful they must be adapted to local conditions (EC 2015a). In order to achieve successful implementation and dissemination of NBS, there is a need to raise awareness on NBS, since the concept of NBS still remains vague or unknown to the larger public (Nesshöver *et al.* 2017). Furthermore, services from NBS are often considered public goods, and their economic value is often not recognised by the markets. Consequently, their true economic worth is not reflected in society's decision-making and accounts (Kinzig *et al.* 2011).

The CE philosophy based on the 3Rs: Reduce, Reuse and Recover (EC 2014; Winans *et al.* 2017), has emerged as an alternative to the wastefulness of the current linear '*take-make-use-dispose*' practices of urban areas. The principle of CE is to create a closed loop for each natural or man-made product by transforming the linear resource flow into a circular flow. It targets all kinds of industrial processes and products. Regarding the urban environment, the scale of thinking is rather global in order to address the urban metabolism as a whole, and create not only specific CE systems, but also an overall resource management system for the urban biosphere. NBS can contribute to this on a local level as they can be easily adapted and operated decentralised where the highest demand occurs. The highest benefits of NBS besides their technical initial purposes is the influence on urban micro-climate and recreation purposes for the inhabitants.

As stated by the European Commission (EC 2015a, 2015b), CE and NBS are major parts of future developments in order to provide resources and a life-friendly environment especially but not only in urban areas. This COST Action intends to establish an interdisciplinary environment for researchers and practitioners to counter hazardous impacts of mass urbanisation and linear flows by implementing NBS. The various benefits of implementing NBS now, as described by the European Commission (2015b) can be further enhanced by the approach proposed in this COST Action. NBS contribute to sustainable urbanisation, climate change adaptation and mitigation as well as risk management and resilience. When materials become waste, the net loss of natural resources is increasing leading to the depletion of our natural capital. In addition to reducing the production and spread of hazardous materials, NBS will have additional benefits on type and method of resource use, reuse and recycling based on CE principles for the urban biosphere. This COST Action develops combined approaches to implement NBS within a CE environment enhancing the benefits provided by the implementation of NBS and increasing the reuse of 'secondary raw materials' such as organic matter, nutrients and water. This approach also represents one of the key elements for the implementation of CE (EC 2015a).

State-of-the-art

While only occupying 2% of the earth's landscape, the urban environment consumes around 80% of the energy generated worldwide, while producing 75% of the global CO_2 emissions. The global material consumption has grown eight fold over the past 100 years and is expected to have tripled by 2050 (Krausmann *et al.* 2009; UNEP 2011; Koop & van Leeuwen 2017). With 75% of global natural resources being consumed in cities, an increasing scarcity of resources such as fertile land including nutrients, clean water and air as well as raw materials (metals, wood and plastics) is expected (EMF 2012). This generates more and more pressure on rural areas and natural ecosystems to secure the supply of water, energy, food as well as the removal of waste.

City managers and politicians are challenged to find new ways to meet these demands within their municipalities. With the concept of CE, all kinds of loops in the production chain, waste disposal and water reuse can be closed. CE adapted for cities can include the following principles: regenerate, share, optimize, loop, virtualize and exchange goods and energy (EMF 2015). In this context, different points of view concerning CE exist (EMF 2016), which are mainly dependent on the goals and mostly influenced by the involved stakeholders, and specifically addressing different materials. The overall approach stays the same, namely neglecting a linear resource flow where at the end of the chain is

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

the disposal by closing the loop through reusing and recycling resources within a defined system. The European Commission has adopted an ambitious CE package, which encourages actions that contribute to 'closing the loop' of product lifecycles through greater recycling and reuse, with significant environmental and economic benefits (European Commission 2015b).

Despite technological innovation and improved public awareness of the environmental impacts, the increasing trend of urbanisation will make the 50% reduction in CO_2 emission by 2050 a far-fetched target. On the other hand, present day food, energy and water systems are advancing technologically, but achieving poor results when addressing the global challenges due to insufficient communication and cross-sectorial collaboration. The challenge of urban resilience is not a single sector or discipline solution. It therefore seems crucial to invest on finding interdisciplinary solutions addressing the urban metabolism as a whole pushing the frontier of the urban biosphere (Kennedy *et al.* 2009; Dong *et al.* 2016; Fujii *et al.* 2016). The benefits of NBS and GI are demonstrated in several EU-funded projects and COST Actions (e.g. COST Actions on the Green Infrastructure approach, FP1204, and on Urban Allotment Gardens, TU1201). According to the European Commission (2015a), the emerging NBS are 'living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits'. Therefore, NBS has become a plausible concept to address the urban environmental challenges that arise as a city rapidly urbanizes (EC 2015a; Maes & Jacobs 2017).

The concept of NBS builds on and supports other closely related concepts such as the ecosystem approach, which promotes the integrated management of land, water, and living resources as well as their conservation and sustainable use (Eggermont *et al.* 2015; Faivre *et al.* 2017). Moreover, the Ecosystem Services (ES) framework is used to highlight the benefits NBS provide in urban areas (Bolund & Hunhammar 1999; Haase *et al.* 2014). These benefits include local climate regulation through air cooling (Stewart & Oke 2012), mitigation of flood risks (Ozment *et al.* 2019), air pollution control (Yin *et al.* 2011; Gomez-Baggethun *et al.* 2013) and noise reduction (Bolund & Hunhammar 1999), when implementing green spaces, parks, green roofs and green walls. Direct health benefits may include positive effects on mental and physical health through stress reduction, relaxation and general health enhancements when citizens reside in urban areas (Völker & Kistemann 2011; Hartig *et al.* 2014). Finally, the presence of green and blue spaces provides the opportunity to experience nature and to enhance public ecological knowledge and awareness of nature conservation (Lundy & Wade 2011).

Finally, an important and many times overlooked service of NBS for decreasing the ecological pressure from cities is the provision of food. Edible NBS or urban agriculture systems are crucial for closing the nutrient cycle. Safely extracted resources from domestic waste flows used for urban food production address some of the biggest challenges that we are facing today: reducing waste outputs from cities, preserving decreasing phosphorous reserves by utilizing phosphorus and nitrogen from wastewater, reducing food-related transportation distances and associated energy consumption and greenhouse gas emissions, and reducing the need for land- and energy-intensive food production systems. In addition, urban agriculture systems can have high levels of biodiversity, often exceeding that of other green spaces within the city, which has a positive effect on ecosystem services (Lin *et al.* 2015). Depending on the available space, different concepts of urban agriculture exist, ranging from traditional systems to vertical or underground farming as well as small decentralised systems like shared neighbourhood gardens (Bohn & Viljoen 2010; Thomaier *et al.* 2015; Buehler & Junge 2016). It has been shown that implementing different concepts can significantly increase the self-reliance of the cities (Grewal & Grewal 2011; Säumel *et al.* 2019) whereby the results of Wielemaker *et al.* (2018) reveal that integration of urban sanitation and urban agriculture can maximize urban self-sufficiency.

The shift towards more circular and sustainable modes of production and consumption is driving a shift towards greater energy efficiency and a smaller carbon footprint. In a CE, raw materials are

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

re-used and recycled; and new materials needed for the energy transition are produced more efficiently and sustainably. In turn, products are designed to be reusable, or to be easily repaired or disassembled, to facilitate remanufacturing and recycling (EPSC 2019).

It is time to systematize the use of NBS and the CE approach to resources management in cities by introducing changes in our legislation, resources utilization concepts, technologies, economic valuation and last but not least revision of the society's values, which is a great challenge.

THE COST ACTION CIRCULAR CITY

What is a COST action?

COST (COoperation in Science and Technology – see www.cost.eu), the longest running European framework, is a unique platform where European researchers can jointly develop their ideas and initiatives across all scientific disciplines through the trans-European networking of nationally funded research (COST 2019). COST activities are largely arranged as COST Actions. Calls for COST Actions are open, i.e. Actions can be submitted related to any scientific field.

A COST Action does not fund research. It is a science and technology network funded over a four-year duration. An Action is organised through a range of networking tools, which are performed for the purpose of supporting and ultimately achieving research coordination and capacity building objectives. Networking tools include meetings, workshops, conferences, training schools, short-term scientific missions (STSMs) and dissemination activities.

All COST activities have to be inclusive in terms of gender, age and geography. Special networking tools are available for underrepresented groups, e.g. Early Career Investigator or participants from less research-intensive countries, also referred to as Inclusiveness Target Countries.

Activities of COST Actions are coordinated by the Action Chair and Co-Chair supported by the Chairs and Co-Chairs of the Working Groups as well as the persons coordinating specific activities (e.g. STSMs and science communication). All decisions are made by the Action's Management Committee (MC). In the MC, each participating COST country can nominate two representatives. Currently, 39 countries are participating in COST and thus are COST countries. In general, activities of Actions are open to all persons working in COST countries.

For more details about COST Actions, the reader is referred to the COST website at https://www.cost.eu.

Objectives & outputs

The COST Action CA17133 Circular City provides a network for researches and practitioners from different fields: (waste-) water engineering, agronomy, urban agriculture, urban planning, architecture, energy, IT, etc., linking their fields to close knowledge gaps within the systems and scales looked at. Within this COST Action, a large number of people will be connected supporting each other and work together on finding interdisciplinary solutions to cope with the above-mentioned challenges.

The Action's objectives and outputs have been defined in its MoU. Objectives are reached with the Action's research coordination and capacity building activities, respectively. The methodology how the outputs will be delivered was not set at the beginning. Developing a common methodology is an essential part of the work in this interdisciplinary Action.

The Action's main research coordination objectives are:

- Use an interdisciplinary approach applied by the different working groups to map occurring resources within the urban biosphere, especially provided by NBS systems.
- Develop appropriate communication methods, promoting resource recovery for consumers and built up public awareness on the benefits of a closing the loop approach.

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

- Identify, analyse and report the existing state of the art of NBS implementations in the urban landscape by involving stakeholders such as city officials, urban planners and engineers.
- Identify and address regulatory, governance, financial and legal drivers and barriers for NBS implementation and use of recovered resources, and support institutional change to better regulatory governance.

The Action's main capacity building objectives are:

- Widen the field of knowledge within each working group by incorporating a joint research approach.
- Involvement of special target groups such as city official, urban planners and engineers, gender equality and involvement of underrepresented/less research-intensive countries.
- Training of Early Career Investigators (ECI) and PhD students, in the implementation of interdisciplinary approaches concerning resource recovery, reuse and coordinating resource streams within the urban landscape when developing structural measures using NBS.

A full list of objectives can be found in the Action's Memorandum of Understanding (CA17133 2018)

The Action's main outputs are (CA17133 2018):

- a review on the state-of-the-art and existing case studies,
- a catalogue of technologies for providing/recovering resources with NBS within each WG,
- a description of possible resource input provided from NBS systems,
- scientific publications including case studies, and
- a guideline on combined NBS and CE possibilities within the urban environment.

Working groups

The COST Action Circular Cities comprises five Working Groups. Each WG is led by a Chair and Co-Chairs elected by the MC of the Action. Besides members of the MC, also other persons can join the WGs. Usually individuals are members in only one WG for the whole duration of the Action. However, this is flexible as some individuals prefer to work in two or more WGs and/or switch WGs.

Even though each WG in the Circular City Action is focusing on a different subarea of the urban metabolism, it is necessary to connect the findings to define the potentials of embedding NBS in a CE. In order to achieve good interconnection between the individual WGs (Figure 1), the tasks and activities especially of the technology focused WGs are similar.

The Action's five WGs are as follows:

- WG1 Built environment: The built environment puts the main focus on the natural environment and its role in transforming to a CE system (Pomponi & Moncaster 2016). Within this working group, the NBS-CE aspect is investigated on building and settlement level with the main focus on vegetated building materials and resources to be obtained from the corresponding NBS. WG1 defines available resource streams connected to NBS within the built environment. Moreover, the aim is to identify best-practice case studies, monitor resource loops and investigate possible available resources provided by relevant NBS proposed by other WGs.
- WG2 Sustainable urban water utilisation: This working group investigates the implementation of a save and functional water cycle within the urban biosphere, where water is defined as a resource, nutrients can be harvested from wastewater, heavy metal adsorbed by filter materials contributing to phytomining and the treated water looped back for irrigation, sanitation and also recreational purposes. The resource recovery methods are established in WG3. WG2 critically appraises the established centralised infrastructure for water, furthermore, defines available resources within

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

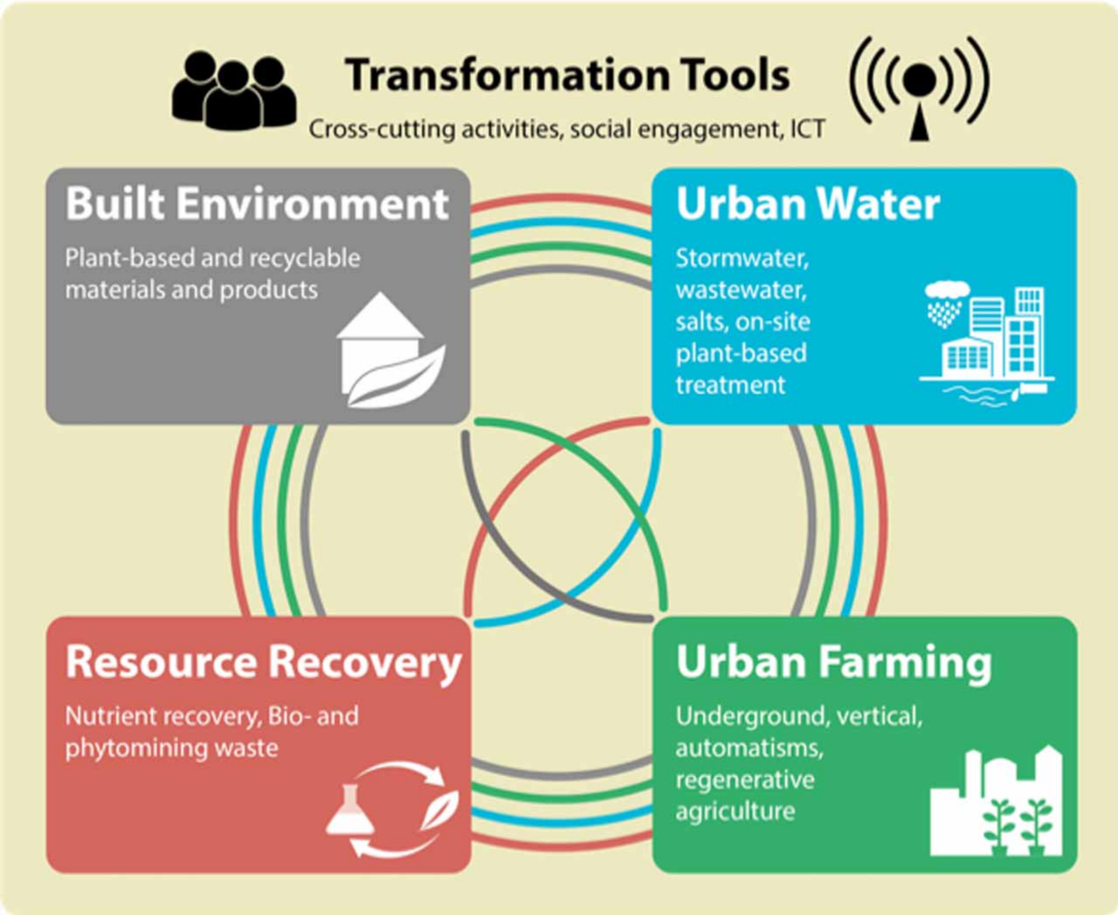

Figure 1 | The Action's Working Groups and their interrelations (CA17133 2018).

the water flow, performs risk assessment on urban water and evaluates NBS for storm water management and waste water treatment.

- WG3 Resource recovery: A significant portion of resources is lost when passing through the urban biosphere. The implemented NBS for mitigation or treatment purposes shall become sources for a variety of resources to be harvested, used, reused and recycled within the urban environment. Therefore, possible sources and implementation strategies within the urban biosphere are investigated. WG3 identifies, appraises and assesses the available resources in the urban context, like waste- or runoff water, liquid and solid waste streams, materials from the other WGs, urban pollutants, etc. Furthermore, the aim is to combine innovative NBS applications such as regenerative biological systems, phyto- or bio-mining, bio-filtration. The outcome will be the creation of new areas for urban farming, waste treatment, run-off treatment and so on.
- WG4 Urban Farming: The WG on Urban Farming focuses on the integration of resources from other working groups (water, nutrients …) into urban farming systems as well as on the resources provided through urban farming for further use in other WGs. The WG will further investigate different urban farming systems especially developed for dense urban areas (e.g. underground farming, vertical and rooftop farming) and their potential for symbiosis with other WGs (e.g.: urban farming with wastewater, urban farming on formally contaminated soil after phytomining was carried out, etc.). While the main purpose of urban farming is food production within a city, the Action pays close attention to other resources available from urban farming, usually considered waste. Furthermore, the evaluated systems will consider the amount of resources available from other WGs.
- WG5 Transformation tools: WG5 coordinates and leads the interdisciplinary activities between the WGs. For this, the 'Circular City Cell' was established. The 'Cell' is composed of members from all

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

WGs with specified tasks aimed at facilitating cross-group communication and research. The first objective of WG5 is to investigate performance-based assessment tools for measuring the impact of resource recovery and reuse cycles as well as reviewing ICT tools to facilitate the implementation of NBS. Moreover, associated barriers to the implementation of NBS on legal and stakeholder level are identified. The second objective is to develop a mechanism to translate the insights of the first objective into simplified tools and information for stakeholders. The third objective of WG5 is to establish public relations strategies and approaches to provide stakeholders with accurate, timely and satisfactory information, with the intention to maximise public engagement. Furthermore, WG5 aims promote effective knowledge dissemination and public engagement, and to suggest methods to monitor and interpret citizens' well-being and consumption trends (socio-economic preferences).

Definitions

Already during the initial discussions when setting up the Action it became clear that several terminologies are used differently in the various fields involved in the Action. To be able to communicate with a common language, the Action defined the following terms: Nature-Based Solutions, Circular Economy, Ecosystem Services, Circular City, and micro/meso/macro-scale (Table 1).

Nature-based solutions

The Action's definition of NBS is based on definitions of the EU that refer to solutions that are inspired and supported by nature (EC 2015a) and solutions that are designed to bring more nature

Table 1 | Definition of relevant terms in the COST action circular city

Term	Definition
Nature-Based Solutions	NBS are defined as concepts that bring nature into cities and those that are derived from nature. NBS address societal challenges and enable resource recovery, climate mitigation and adaptation challenges, human well-being, ecosystem restoration and/or improved biodiversity status, within the urban ecosystems. 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 discussed in WG3 Resource Recovery), as they may be needed for supporting and enhancing the performance of NBS.
Ecosystem Services	Ecosystem services are the benefits people obtain from ecosystems. These ecosystem services have strong links to human well-being.
Circular Economy	CE is defined as an economic system that aims at minimising waste and making the most of resources. In a circular system resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing energy and material loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.
Circular City	A Circular City is where we apply the concepts of CE, i.e. we manage waste, commodities and energy in smarter and more efficient ways. A Circular City results in less pressure on our environment, new business models, innovative designs and new alliances and cooperation between different stakeholders.
Micro/meso/macro-scale	In the Action Circular City - *Micro-scale* relates to household level, - *Meso-scale* relates to district level, and - *Macro-scale* relates to city level or above. When referring to the Built Environment (WG1) - *Micro-scale* relates to green material, - *Meso-scale* relates to green buildings, whereas - *Macro-scale* relates to green sites, which are parts of the city or surrounding areas of buildings.

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

and natural features and processes to cities (EC 2015c). These EU definitions were amended by incorporating solutions that use or mimic natural processes to enhance water availability, improve water quality, and reduce risks associated with water-related disasters and climate change (UNESCO 2018) and ideas from the three criteria for NBS as suggested by Albert *et al.* (2017): First, NBS need to provide simultaneous benefits for society, the economy and nature; second, the term should be understood to represent a transdisciplinary umbrella; and third, a NBS needs to be introduced gradually.

Ecosystem services

Ecosystem services are the many and varied benefits that humans freely gain from the natural environment and from properly functioning ecosystems. Ecosystem services can be grouped into four broad categories: *provisioning*, such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and oxygen production; and *cultural*, such as spiritual and recreational benefits (MEA 2005). These ecosystems services support achieving the constituents of well-being such as security, basic material for good life, health, good social relations, and freedom of choice and action (MEA 2005). NBS and treatment wetlands in cities allow to achieve multiple purposes and ecosystem services (Masi *et al.* 2018).

Circular economy

The Action's definition of CE is based on the 3Rs; Reduce, Reuse and Recover. CE is an economic system aimed at minimising waste and making the most of resources (EMF 2016, 2017). In a circular system resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing energy and material loops; this can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling (Geissdoerfer *et al.* 2017). This regenerative approach is in contrast to the traditional linear economy, which has a 'take, make, dispose' model of production.

Circular city

A Circular City is where we apply the concepts of CE, i.e. where we manage water, nutrients, commodities and energy in smarter and more efficient ways, so that minimal amount or no waste is produced. A circular city will result in less pressure on our environment, new business models, innovative designs and new alliances and cooperation between different sectors and stakeholders (Cities in Transition 2019). Alongside the *UN* Sustainable Development Goals (UN 2015) and climate objectives, the transition to a circular economy will support city leaders as they deliver against their priorities, which include housing, mobility, and economic development (EMF 2017).

Micro/meso/macro-scale

A general definition of micro/meso/macro-scale was not possible. Most WGs use micro for household level, meso for district level, and macro for city level or above. When referring to buildings and the built environment (WG1), the definition did not fit and was amended to micro relating to green materials, meso relating to green buildings, and macro relating to green sites, which are parts of the city or surrounding areas of buildings.

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

THIS SPECIAL ISSUE

The members of this COST Action hold a broad knowledge about different aspects of CE, NBS and Circular Cities. Therefore, the first step of the Action is to review, make the knowledge accessible to the society and create synergies. These review finally results in the Action's first main output, i.e. the 'review on the state-of-the-art and existing case studies'.

For the review of the state-of-the-art in the Action's five WGs, a common database is used as a starting point. This database comprises the available knowledge in the Action's network and includes information on 72 projects related to Circular City. Information on projects has been collected in the form of project ID cards from members of the COST Action and participants of the first Circular City workshop held in Vienna, Austria, from 14–16 February 2019.

Based on the information collected from the project ID cards, 29 out of the 72 projects are European funded and among these 29 projects, 16 are funded by European Union's Horizon 2020 Research and Innovation. Regarding the stage of the projects, 26 out of 72 are completed, while 11 projects are at an early stage of the project's development.

Among the 72 projects, 11 European and National projects are selected and presented. Table 2 provides an overview of the 11 projects, along with some general information regarding their funding source, their duration and the projects' scale (according to the definition provided in Table 1, 'In the Action Circular City'). Additionally, the projects' representatives were asked to identify the focus of their project based on the classification and allocation to the WGs of the Action.

The review of the state-of-the-art in the Action's five WGs is looking at the experiences available among Action members from different angles and identify what has been done, what was successful, what were the challenges, etc., and identify bottlenecks/research questions, as well as interlinkages between the WGs as basis for the future work in the Action. In the following, the content of the five WG state-of-the-art reviews is summarised:

- Pearlmutter *et al.* (2020) present the point of few of *WG1 Built environment*. NBS are discussed at three different levels: (i) green building materials; (ii) green building systems; and (iii) green building sites. Concepts of NBS and CE in the built environment are introduced and the impacts of urban development and the historical use of materials, systems and sites is examined. A series of case

Table 2 | General information and allocation to WGs 1–4 of 11 selected projects (EU H2020 = European Union's Horizon 2020 research and innovation)

Project title	Funding source	Time frame	Scale	WG 1 Built Environment	WG 2 Urban Water	WG 3 Resource Recovery	WG 4 Urban Farming
CITYFOOD	EU H2020	2018–2021	Macro	X	X	X	X
C2C-CC	European Commission	2017–2022	Macro		X		
EdiCitNet	EU H2020	2018–2023	Meso to macro	X	X	X	X
ESTIMUM	Luxembourg National Research Fund	2017–2019	Micro to macro	X	X		
HOUSEFUL	EU H2020	2018–2022	Micro	X	X	X	X
HYDROUSA	EU H2020	2018–2022	Macro			X	
Nature4Cities	EU H2020	2016–2020	Macro	X	X	X	X
Natural Water Retention Measures (NWRM)	European Commission	2013–2014	Macro		X		
proGIreg	EU H2020	2018–2023	Meso	X		X	X
Run4Life	EU H2020	2017–2021	Micro			X	
URBAN GreenUP	EU H2020	2017–2022	Micro to macro	X	X		

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

studies is presented illustrating the development and implementation of such solutions in recent years. Finally, policy instruments which can be leveraged to promote NBS and CE in the most effective manner are discussed.

- Oral *et al.* (2020) describe the *WG2 Sustainable urban water utilisation* perspective. NBS for urban water management from literature and case studies are presented and analysed. The paper identified three main challenges: (i) flood and drought protection; (ii) the water–food–energy nexus; and (iii) water purification. It is shown that NBS provide additional benefits, such as improving water quality, increasing biodiversity, obtaining social co-benefits, improving urban microclimate, and the reduction of energy consumption by improving indoor climate. The conclusion of the paper is that NBS should be given a higher priority and should be preferred over conventional water infrastructure.
- Kisser *et al.* (2020) present the state-of-the-art review of *WG3 Resource recovery*. The focus of the review is on NBS as technologies that bring nature into cities and those that are derived from nature, provided they enable resource recovery. The findings presented are based on an extensive literature review, as well as on original results of ongoing and recent research and innovation projects across Europe. The focus of the review was on urban wastewater, industrial wastewater, municipal solid waste and gaseous effluents, and the recoverable products (e.g. nutrients, nanoparticles, and energy). The implications of source-separation of waste and end-of-pipe technologies vs. circularity by design are discussed. Finally, an assessment of the maturity of different resource recovery technologies (Technology Readiness Level) is carried out.
- Skar *et al.* (2020) show the *WG4 Urban Farming* review. The scope of urban agriculture is to establish food production sites within the city's sphere through building-integrated agriculture including concepts such as aquaponics, indoor agriculture, vertical farming, rooftop production, edible walls, as well as through urban farms, edible landscapes, school gardens and community gardens. This article describes some of the current aspects of the circular city debate where urban agriculture is pushing forward the development of material and resource cycling in cities.
- Katsou *et al.* (2020) present the state-of-the-art in *WG5 Transformation tools*. A combined appraisal of the latest literature and a survey of projects provides an overview of enabling tools, methodologies, and initiatives for public engagement. Additionally, links between facilitators and barriers with respect to existing policies and regulations, public awareness and engagement, and scientific and technological instruments are described. The most promising methods, physical and digital technologies that may lead the way to Sustainable Circular Cities are introduced. The paper provides useful insights for citizens, scientists, practitioners, investors, policy makers, and strategists to channel efforts on switching from a linear to a circular thinking for the future of cities.

ACKNOWLEDGEMENTS

The work is funded within the COST Action CA17133 Circular City ('Implementing nature based solutions for creating a resourceful circular city', http://www.circular-city.eu, duration 22 Oct 2018–21 Oct 2022). COST Actions are funded within the EU Horizon 2020 Programme. The authors are grateful for the support.

REFERENCES

Albert, C., Spangenberg, J. H. & Schröter, B. 2017 Nature-based solutions: criteria. *Nature* **543**, 315. (16 March 2017), https://doi.org/10.1038/543315b.

Bohn, K. & Viljoen, A. 2010 The CPUL City Toolkit: Planning productive urban landscapes for European cities. In: *Sustainable Food Planning: Evolving Theory and Practice* (Viljoen, A. & Wiskerke, J. eds). Wageningen Academic Press, Wageningen, The Netherlands.

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

Bolund, P. & Hunhammar, S. 1999 Ecosystem services in urban areas. *Ecological Economics* **29** (2), 293–301.
Buehler, D. & Junge, R. 2016 Global trends and current status of commercial urban rooftop farming. *Sustainability* **8** (11), 1108. doi:10.3390/su8111108.
CA17133 2018 Memorandum of Understanding for the Implementation of the COST Action 'Implementing Nature Based Solutions for Creating A Resourceful Circular City'. Brussels, Belgium. Available from: https://e-services.cost.eu/files/domain_files/CA/Action_CA17133/mou/CA17133-e.pdf (accessed 30 May 2019).
Cities in Transition 2019 *The Circular City*. Available from: https://citiesintransition.eu/transition/circular-city (accessed 30 May 2019).
COST 2019 *COST Vademecum*. COST office, Brussels, Belgium. Available from: https://www.cost.eu/wp-content/uploads/2019/05/Vademecum-May-2019.pdf (accessed 30 May 2019).
Dong, H., Fujita, T., Geng, Y., Dong, L., Ohnishi, S., Sun, L., Dou, Y. & Fujii, M. 2016 Areview on eco-city evaluation methods and highlights for integration. *Ecological Indicators* **60**, 1184–1191.
EC 2014 *Scoping Study to Identify Potential Circular Economy Actions, Priority Sectors, Material Flows & Value Chains*. European Commission, Brussels, Belgium.
EC 2015a Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities. *Final Reportof the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities (full version)*; Publications Office of the European Union, European Commission, und Directorate-General for Research and Innovation, Luxembourg. Available from: http://dx.publications.europa.eu/10.2777/765301 (accessed 30 May 2019).
EC 2015b *Closing the Loop – An EU Action Plan for the Circular Economy*. European Commission, Brussels, Belgium.
EC 2015c Available from: https://ec.europa.eu/research/environment/index.cfm?pg=nbs (accessed 30 May 2019).
Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J. & Reuter, K. 2015 Nature-based solutions: new influence for environmental management and research in Europe. *GAIA -Ecological Perspectives for Science and Society* **24** (4), 243–248.
EMF 2012 *Towards the Circular Economy: Economic and Business Rationale for Accelerated Transition*. Ellen MacArthur Foundation, Cowes, UK. Available from: https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf (accessed 30 May 2019).
EMF 2015 *Delivering the Circular Economy: A Toolkit for Policymakers*. Ellen MacArthur Foundation, Cowes, UK. Available from: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_PolicymakerToolkit.pdf (accessed 30 May 2019).
EMF 2016 *Circular Economy – Schools of Thought*. Ellen MacArthur Foundation, Cowes, UK. Available from: https://www.ellenmacarthurfoundation.org/circular-economy/concept/schools-of-thought (accessed 30 May 2019).
EMF 2017 *Circular Economy in Cities*. Ellen MacArthur Foundation, Cowes, UK. Available from: https://www.ellenmacarthurfoundation.org/our-work/activities/circular-economy-in-cities (accessed 30 May 2019).
EPSC 2019 *European Political Strategy Centre*. Available from: https://ec.europa.eu/epsc/home_en (accessed 30 May 2019).
Faivre, N., Fritz, M., Freitas, T., de Boissezon, B. & Vandewoestijne, S. 2017 Nature-Based solutions in the EU: innovating with nature to address social, economic and environmental challenges. *Environmental Research* **159**, 509–518.
Fujii, M., Fujita, T., Dong, L., Lu, C., Geng, Y., Behera, S. K., Park, H.-S. & Chiu, A. S. F. 2016 Possibility of developing low-carbon industries through urban symbiosis in Asian cities. *Journal of Cleaner Production* **114**, 376–386.
Geissdoerfer, M., Savaget, P., Bocken, N. M. P. & Hultink, E. J. 2017 The circular economy – a new sustainability paradigm? *Journal of Cleaner Production* **143**, 757–768.
Gomez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPherson, T., O'Farrell, P., Andersson, E., Hamsted, Z. & Kremer, P. 2013 Urban ecosystem services. In: *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. A Global Assessment* (Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S. & Schewenius, M. eds). Springer, Dordrecht, The Netherlands, pp. 175–251.
Grewal, S. S. & Grewal, P. S. 2011 Can cities become self-reliant in food? *Journal of Cities* **29**, 1–11.
Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Lorance, E., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., Wurster, D. & Elmqvist, T. 2014 A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. *AMBIO* **43** (4), 413–433.
Hartig, T., Mitchell, R., de Vries, S. & Frumkin, H. 2014 Nature and health. *Annual Review of Public Health* **35**, 207–228.
Katsou, E., Nika, C.-E., Buehler, D., Marić, B., Megyesi, B., Mino, E., Babí Almenar, J., Bas, B., Bećirović, D., Bokal, S., Đolić, M., Elginöz, N., Kalnis, G., Garcia Mateo, M. C., Milousi, M., Mousavi, A., Rinčić, I., Rizzo, A., Rodriguez-Roda, I., Rugani, B., Šalaševičienė, A., Sari, R., Stanchev, P., Topuz, E. & Atanasova, N. 2020 Transformation Tools Enabling the Implementation of Nature-based Solutions for Creating a Resourceful Circular City. *Blue-Green Systems* (submitted manuscript for the Special Issue '*Towards Circular Cities – Nature based solutions for creating a resourceful circular city*').
Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havránek, M., Pataki, D., Phdungsilp, A., Ramaswami, A. & Mendez, G. V. 2009 Greenhouse gas emissions from global cities. *Environmental Science and Technology* **43**, 7297–7302.
Kinzig, A. P., Perrings, C., Chapin, F. S., Polasky, S., Smith, V. K., Tilman, D. & Turner, B. L. 2011 Paying for ecosystem services – promise and peril. *Science* **334** (6056), 603–604.
Kisser, J., Wirth, M., De Gusseme, B., Van Eekert, M., Zeeman, G., Schoenborn, A., Vinnerås, B., Finger, D. C., Kolbl Repinc, S., Griessler Bulc, T., Bani, A., Pavlova, D., Staicu, L. C., Atasoy, M., Cetecioglu, Z., Kokko, M., Haznedaroglu, B. Z., Hansen, J., Istenič, D., Canga, E., Malamis, S., Camilleri-Fenech, M. & Beesley, L. 2020 A review of nature-based solutions for

Blue-Green Systems Vol 2 No 1
doi: 10.2166/bgs.2020.933

resource recovery in cities. *Blue-Green Systems* (submitted manuscript for the Special Issue '*Towards Circular Cities – Nature based solutions for creating a resourceful circular city*').

Koop, S. H. A. & van Leeuwen, C. J. 2017 The challenges of water, waste and climate change in cities. *Environment, Development and Sustainability* **19** (2), 385–418.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H. & Fischer-Kowalski, M. 2009 Growth in global materials use, GDP and population during the 20th century. *Ecological Economics* **68** (10), 2696–2705.

Lin, B. B., Philpott, S. M. & Jha, S. 2015 The future of urban agriculture and biodiversity-ecosystem services: challenges and next steps. *Basic and Applied Ecology* **16** (3), 189–201.

Lundy, L. & Wade, R. 2011 Integrating sciences to sustain urban ecosystem services. *Progress in Physical Geography* **35**, 653–669.

Maes, J. & Jacobs, S. 2017 Nature-based solutions for Europe's sustainable development. *Conservation Letters* **10** (1), 121–124.

Masi, F., Rizzo, A. & Regelsberger, M. 2018 The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm. *Journal of Environmental Management* **216**, 275–284.

MEA 2015 *Ecosystems and Human Well-Being*. Synthesis, Millenium Esosystems Assessment, Island Press, Washington, DC, USA. Available from: https://www.millenniumassessment.org/documents/document.356.aspx.pdf (accessed 30 May 2019).

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauz, K., Külvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E. & Wittmer, H. 2017 The science, policy and practice of nature-based solutions: an interdisciplinary perspective. *Science of The Total Environment* **579**, 1215–1227.

Oral, H. V., Carvalho, P., Gajewska, M., Ursino, N., Masi, F., van Hullebusch, E. D., Kazak, J. K., Exposito, A., Cipolletta, G., Andersen, T. R., Finger, D. C., Simperler, L., Regelsberger, M., Rous, V., Radinja, M., Buttiglieri, G., Krzeminski, P., Rizzo, A., Dehghanian, K., Nikolova, M. & Zimmermann, M. 2020 State of the Art of Implementing Nature Based Solutions for Urban Water Utilization Towards Resourceful Circular Cities. *Blue-Green Systems* (submitted manuscript for the Special Issue '*Towards Circular Cities – Nature based solutions for creating a resourceful circular city*').

Ozment, S., Ellison, G. & Jongman, B. 2019 *Nature-Based Solutions for Disaster Risk Management: Booklet (English)*. World Bank Group, Washington, D.C, USA. Available from: http://documents.worldbank.org/curated/en/253401551126252092/Booklet (accessed 22 October 2019).

Pearlmutter, D., Theochari, D., Nehls, T., Pinho, P., Piro, P., Korolova, A., Papaefthimiou, S., Garcia Mateo, M. C., Calheiros, C., Zluwa, I., Pitha, U., Schosseler, P., Florentin, Y., Ouannou, S., Gal, E., Aicher, A., Arnold, K., Igondová, E. & Pucher, B. 2020 Enhancing the circular economy with nature-based solutions in the built urban environment: Green building materials, systems and sites. *Blue-Green Systems* (submitted manuscript for the Special Issue '*Towards Circular Cities – Nature based solutions for creating a resourceful circular city*').

Pomponi, F. & Moncaster, A. 2016 Circular economy for the built environment: a research framework. *Journal of Cleaner Production* **143**, 710–718.

Säumel, I., Reddy, S. E. & Wachtel, T. 2019 Edible city solutions – one step further to foster social resilience through enhanced socio-cultural ecosystem services in cities. *Sustainability* **11**, 972.

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., Tzortzakis, N., Chrysargyris, A., Peticila, A., Alencikiene, G., Monsees, H. & Junge, R. 2020 Urban agriculture as an innovative mechanism to secure cities a sustainable and healthy development in the future. *Blue-Green Systems* (submitted manuscript for the Special Issue '*Towards Circular Cities – Nature based solutions for creating a resourceful circular city*').

Stewart, I. D. & Oke, T. R. 2012 Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society* **93**, 1879–1900.

Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U. B. & Sawicka, M. 2015 Farming in and on urban buildings: present practice and specific novelties of zero-acreage farming (ZFarming). *Renewable Agriculture and Food Systems* **30**, 43–54.

UN 2015 *UN Sustainable Development Goals*. Available from: https://sustainabledevelopment.un.org/?menu=1300 (accessed 30 May 2019).

UNEP 2011 *Towards A Green Economy: Pathways to Sustainable Development and Poverty Eradication – A Synthesis for Policy Makers*. UNEP. Available from: https://sustainabledevelopment.un.org/content/documents/126GER_synthesis_en.pdf (accessed 30 May 2019).

UNESCO 2018 Nature-based Solutions for Water. In: *World Water Development Report 2018*. UNESCO, Paris, France. Available from: https://unesdoc.unesco.org/ark:/48223/pf0000261424 (accessed 30 May 2019).

Völker, S. & Kistemann, T. 2011 The impact of blue space on human health and well-being – salutogenetic health effects of inland surface waters: a review. *International Journal of Hygiene and Environmental Health* **214** (6), 449–460.

Wielemaker, R. C., Weijma, J. & Zeeman, G. 2018 Harvest to harvest: recovering nutrients with new sanitation systems for reuse in urban agriculture. *Resources, Conservation and Recycling* **128**, 426–437.

Winans, K., Kendall, A. & Deng, H. 2017 The history and current applications of the circular economy concept. *Renewable and Sustainable Energy Reviews* **19** (2), 385–418.

Yin, S., Shen, Z., Zhou, P., Zou, X., Che, S. & Wang, W. 2011 Quantifying air pollution attenuation within urban parks: an experimental approach in Shanghai, China. *Environmental Pollution* **159**, 2155–2163.