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Is it possible to reduce wastewater to obtain sustainable cities? Some urban experiences

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TABLE OF CONTENTS

Summary

Cities are centers for new ideas, trade, culture, science, productivity, social development, and much more. This research focuses on the role cities play in the environment, and how the misuse of resources can generate a great impact. We can assume that one of the main problems today is having a linear production and consumption system, which puts economic growth as a priority, instead of focusing on more efficient production, from an environmental point of view. In cities, complete self-sufficiency is a big concern. For food security, water, and energy, cities import resources. However, because they concentrate on a fast-growing and urbanizing population, they are essential to global sustainability.

Finding and implementing alternative solutions for more sustainable management of urban resources is a challenge that cities all over the world must overcome. There are numerous opportunities to get materials in cities. Cities can also be seen as resource reservoirs and producers of secondary resources, in contrast to linear resource-to-waste processes.

A transition to a circular economy is called for by many scientists in recent years, but there is little literature discussing the challenges of this economic model. In this research paper, the most significant limitations to this transition were researched.

The resources that are being misused are diverse, but the research will particularly focus on water. Water is one of the most important resources for human survival. Currently, 87% of the world's population (or about 5.9 billion people) have access to drinking water sources, while nearly 39% (or more than 2.6 billion people) lack basic sanitation. This is why a European project will be considered as a case study, that aims to demonstrate Nature-based Solutions for urban water treatment, storage, reuse, and reduction.

In the end, a final reflection will be made on the change needed to be successful in converting the system of consumption, and thus production. A social and cultural paradigm shift based on a "happy degrowth" would be necessary to achieve the goals of waste reduction (if not elimination).

Sommario

Le città sono centri di innovazione, commercio, cultura, scienza, produttività, sviluppo sociale e molto altro ancora. Questa ricerca si concentra sul ruolo delle città nell'ambiente e su come l'uso improprio delle risorse possa generare un grande impatto. Possiamo ipotizzare che uno dei problemi principali di oggi sia la presenza di un sistema di produzione e consumo lineare, che pone la crescita economica come priorità, invece di concentrarsi su una produzione più efficiente, dal punto di vista ambientale. Nelle città, la completa autosufficienza è una grande preoccupazione. Per la sicurezza alimentare, l'acqua e l'energia, le città importano risorse e poiché si concentrano su una popolazione in rapida crescita e in via di urbanizzazione, sono essenziali per la sostenibilità globale.

Trovare ed implementare soluzioni alternative per una gestione più sostenibile delle risorse urbane è una sfida che le città di tutto il mondo devono affrontare. Le città possono essere viste come serbatoi di risorse e produttori di risorse secondarie, in contrasto con i processi lineari da risorsa a rifiuto.

La transizione verso un'economia circolare è stata invocata da molti scienziati negli ultimi anni, ma c'è poca letteratura che discute le sfide di questo modello economico. In questo lavoro di ricerca, le limitazioni più significative per questa transizione sono state nominate.

Le risorse che vengono utilizzate in modo improprio sono diverse, ma la ricerca si concentrerà in particolare sull'acqua. L'acqua è una delle risorse più importanti per la sopravvivenza umana. Attualmente, l'87% della popolazione mondiale (circa 5,9 miliardi di persone) ha accesso a fonti di acqua potabile, mentre quasi il 39% (più di 2,6 miliardi di persone) non dispone di servizi igienici di base. Per comprendere meglio le possibilità di risparmio dell'acqua urbana, verrà preso in considerazione come caso di studio un progetto europeo che mira a dimostrare le soluzioni basate sulla natura per il trattamento, lo stoccaggio, il riutilizzo e la riduzione dell'acqua urbana.

Concludendo, verrà fatta una riflessione finale sul cambiamento necessario per riuscire a trasformare il sistema di consumo, e quindi di produzione. Per raggiungere gli obiettivi di riduzione (se non di eliminazione) dei rifiuti, sarebbe necessario un cambiamento di paradigma sociale e culturale basato sulla chiamata "decrescita felice".

«The Earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy. »

Introduction

The above quotation is taken from an essay named "The Economics of the Coming Spaceship Earth", published in 1966 by Kenneth Boulding, who wanted to set out in a clear and illustrative manner the ecological situation of the entire planet Earth, comparing it to a spaceship, which, unfortunately, possesses nothing that is "unlimited". His simple simile is intended to closely correlate a process, defined as ecological, with the economic system, which can be seen as an organism that lives within an ecosystem and from which it draws the inputs necessary for its survival. Everything that is extracted from the ecosystem must be returned to it, in the form of an output that is perfectly reconcilable with the concept of new input into the ecosystem's circle.

The transition from the cowboy economy to the spaceship economy requires considerable effort in terms of policies, resources, investments, and the ability to promote a joint global effort. This is not an easy goal, as shown by the Glasgow Cop 26, which failed to achieve a concrete commitment to stop fossil fuels: the final draft talks of "reduction", but not of abandonment, as had been hoped. Currently, cities rely heavily on other cities and the hinterlands for their material and energy needs, as well as their waste disposal[1]. The ecological footprint of cities can be used to quantify this dependence. According to numerous ecological footprint studies, cities generally surpass or "over-shoot" their bio-capabilities by 15 to 150 times[2]. Cities lack efficiency in resource utilization, which prevents them from being sustainable and they typically use resources linearly, producing waste without considering how much and how well they are being used[3]. The vast resource use and waste generation that exceeds available resources and recycling capacity are the main causes of the current urban unviability[4]. As a result, finding and implementing alternative solutions for more sustainable management of urban resources is a challenge that cities all over the world must

[1] Bai X, (2007), Industrial ecology and the global impacts of cities. Journal of Industrial Ecology, 11: 1-6.
[2] Doughty MRC, Hammond GP, (2004), Sustainability and the built environment at and beyond the city scale. Building and Environment 39(10):1223-1233
[3] Leduc W, Agudelo C, Rovers R, Mels A, (2009), "Expanding the exergy concept to the urban water cycle" in proceedings of the 3rd International Conference on Smart and Sustainable Built Environments 2009, Delft.
[4] Agudelo-Vera CM, Mels AR, Keesman KJ, Rijnaarts HHM, (2011), Resource management as a key factor for sustainable urban planning. Journal of Environmental Management

overcome[5]. There are numerous opportunities to get materials in cities[6]. Cities can also be seen as resource reservoirs and producers of secondary resources, in contrast to linear resource-to-waste processes.

To address these global concerns, a fundamental shift in the way things are manufactured and processed is required. In this Master's thesis, I will focus on the role of cities in the environment, due to their linear setting that powers the capitalist system, producing and managing the resources as the capacity of the planet to recover them were endless.

One of the one-fits-all solutions that was proposed in the last decades is the circular economy model, i.e. the modus operandi of the various actors through which everything that is extracted, obtained, or used from the environment in order to create a product, service, or energy useful for their realization, can continue to be part of the economic cycle, even after the need for which it was created and conceived has been satisfied.

It is an attitude that seeks to move the economy away from what is now known as the "linear economy", where the final output at the end of its use is discarded, and new raw materials are sought in order to produce a new one. As the spaceship gets closer and closer, the potential advantages of adopting some solutions from the circular economic model and the risks of delaying concrete commitments may be now evident and quantifiable.

Attention will be also put to recognizing drivers and barriers in the circular economy model, which is given as the new solution to every problem. I will try to understand the main difficulties, such as the lack of a proper business model for its realization, and the lack of proper information. To achieve the shift to sustainability, cities can make use of several instruments; among them, I will explain the concept of the so-called Nature-based Solutions (NBS), which could be presented as one of the main tools to face a huge number of canonic cities problems in a more sustainable way. To further understand NBS and innovations, the focus will be put also on a case study of MULTISOURCE, a Horizon 2020 European project that aims to demonstrate NBS for urban water treatment, storage, reuse and reduction. In this project, technical pilots treat a wide range of urban water, where the decision support tools are co-designed together with local, national, and international stakeholders.

[5] Cola, F., G. Recine, G. Alessandro (2005). Local New Energy Technology Implementation - Technologies Dossier. Rome, Innova Spa.
[6] Agudelo C, Mels A, Rovers R. (200), Urban water tissue: analysing the urban water harvest potential. In: Dobbelsteen, A., Dorst, M. and Timmeren, A, editors. Smart building in a Changing Climate.

1. Literature review

1.1. The circular economy in cities

Cities are centers for new ideas, trade, culture, science, productivity, social development, and much more. It can be said that usually, cities have enabled people to improve their social and economic conditions. If the after-COVID situation does not change the future trends, early 70% of the world's population will reside in cities by 2050, up from about 50% nowadays, according to the UN (2014). One of the Sustainable Development Goals[7] (SDGs) set forward by the UN is to promote sustainable cities and communities. This is the case of the SDG number 11 “Make cities and human settlements inclusive, safe, resilient and sustainable”[8]. In a world with rapid population expansion, shifting economic development, constrained planetary bounds, and climate change, it is extremely difficult to provide cities with security in terms of access to water, food, and energy[9]. Therefore, sustainable urbanization is essential for the achievement of global development goals. However, many challenges persist in maintaining urban centers as places of work and prosperity, while at the same time avoiding the damage of land and resources. Challenges posed by the urban environment include traffic, lack of funds to provide basic services, shortage of adequate housing, misuse of the resources, and decaying infrastructure.

The circular economy (CE), which serves as both a vision and a transitional mechanism for moving toward a more sustainable future, is quickly gaining traction in political and corporate debates. It has been praised as one of the answers to the climate crisis and a way to reduce the total environmental impact of economic activities[10]. Cities have stepped up efforts to hasten the transition to a more circular urban model globally[11], with CE seen as an alternative model to the unsustainable linear “take-make-waste economic paradigm”[12].

A single, all-encompassing definition of the CE is probably unachievable because it is a hotly, ever-evolving, and debated term[13]. Determining what makes a circular city is challenging because the conceptual dispute surrounding the circular model seems still unresolved. However, there are a few attempts in the literature to define a circular city to ease scholarly discussion and apply the

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[7] https://sdgs.un.org/goals
[8] https://sdgs.un.org/goals/goal11
[9] Vanham, D., (2016), Does the water footprint concept provide relevant information to ad- dress the water–food–energy–ecosystem nexus? Ecosystem Services, Elsevier, vol. 17
[10] European Commission, (2020), A new Circular Economy Action Plan. For a cleaner and more competitive Europe.
[11] Remøy H, Wandl A, Ceric D, van Timmeren A. (2019), Facilitating circular economy in urban planning. *Urban Planning, 4*(3), 1-4.
[12] Chizaryfard A, Trucco P, Nuur C. (2021), The transformation to a circular economy: framing an evolutionary view. *Journal of Evolutionary Economics,* volume 31.
[13] Korhonen J, Honkasalo A, Seppälä J. (2018), Circular economy: the concept and its limitations. Ecological Economics, Volume 143.

tenets of the circular economy model in urban settings. Starting with a short definition of a city, Grimm et al (2008) assessed that cities are concentrated centers of production, consumption, and waste disposal that drive land change and a host of global environmental problems. Several academics have investigated how the CE model's principles are applied at the city level and envisioned the idea and definition of circular cities from various angles, (e.g., Paiho[14], Prendeville et al.[15], Bolger[16] and Fratini[17]), by classifying the findings in the circular city literature into facilitators and barriers.

A circular city, according to their definition, is "based on closing, slowing and narrowing the resource loops as far as possible after the potential for conservation, efficiency improvements, resource sharing, servitization, and virtualization has been exhausted, with remaining needs for fresh material and energy being covered to the greatest extent possible based on local production using renewable natural resources" (Paiho 2020). Other definition of a circular city is done by Prendeville et al. (2018, p. 176): a circular city is "a city that practices circular economy principles to close resource loops, in partnership with the city's stakeholders (citizens, community, business and knowledge stakeholders), to realize its vision of a future-proof city." A further description of the city is given as one that "seeks to generate wealth, boost livability, and improve resilience for the city and its residents while seeking to decouple the creation of value from the consumption of finite resources."[18] According to Papageorgiou et al (2021), a city based on a circular model of development is defined as "a city that in the provision of urban service, deliberately prioritizes and practices circular economy principles to close resource loops to the greatest extent possible, to minimize the need for virgin material and energy resources, to reduce its resource footprint beyond city borders based on the principles of equitable contribution and common welfare in the transition to a circular model." The Ellen MacArthur Foundation offers the following definition: "a circular city establishes an urban system that is regenerative, accessible, and plentiful by design. This is made by integrating the concepts of a circular economy throughout all its operations. A circular city seeks to create prosperity, improve livability, and strengthen resilience for the city and its residents while aiming to decouple the creation of value from the consumption of finite resources. These cities aim to become zero waste and always keep assets at their highest value"[19]. It underlines

[14] Paiho S., et al. (2020), Towards circular cities-conceptualizing core aspects. Sustainable Cities and Society 59:102143.
[15] Prendeville S, Cherim E, Bocken N. (2018), Circular cities: mapping six cities in transition. Environmental Innovation and Societal Transitions, Volume 26.
[16] Bolger K, Doyon A. Circular cities: exploring local government strategies to facilitate a circular economy. European Planning Studies 27(11):1-22
[17] Fratini CF, Georg S, Jørgensen MS. Exploring circular economy imaginaries in European cities: a research agenda for the governance of urban sustainability transitions. Journal of Cleaner Production, Volume 228.
[18] Ellen MacArthur Foundation. (2019), Circular economy in cities: project guide.
[19] Ellen MacArthur Foundation. (2017), Cities in the circular economy: An initial exploration.

the significance of digitization while incorporating technological, economic, and social elements. The circular economy is categorized by Bocken et al (2016) as “design and business model strategies [that are] slowing, closing, and narrowing resource loops”. Here, “closing loops” refers to the reuse of materials through recycling, whereas “slowing” refers to the prolonged use and reuse of things through time, through the design of long-life items and product life extension. “Narrowing loops” is about reducing resource use associated with the product and production process[20].

A circular city minimizes resource consumption and waste in all forms, shares and increases usage and utility of all assets, and conserves and reuses resources and products, according to European Investment Bank (European Investment Bank, 2018). Among the essential components are[21]:

- Assets/products are shared/leased with end-of-life recovery
- Urban bioeconomy with organic by product/waste recovery and urban farms
- Reserve logistics to facilitate re-use, repair, and remanufacturing
- Digital tools facilitate sharing/recovery applications
- Mobility systems are clean and shared
- Production with local value loops and industrial symbiosis
- Energy production is renewable and local
- Buildings are modular, shared, and designed for disassembly

The Sustainable Development Goals of the United Nations[22], which include 17 objectives for a sustainable world, may also be used to define the circular city. The City of New York is the first city to do so[23], and following there is Helsinki, that is the second in the world but the first city in Europe[24]. The SDGs 11, 12, and 13, which focus on sustainable cities, consumption, production, and climate action, are particularly relevant to circular economy. Since the SDGs are the global goals for a sustainable future, integrating circularity into cities supports the viability of the circular city vision. Based on the definition of researchers at the Circular Cities Hub[25] established at the Bartlett School of Planning at University College London, a circular city is based on systems integration, flexibility, intelligence, cooperative behavior, localization, recycling, and renewable

[20] Nancy M. P. Bocken, Ingrid de Pauw, Conny Bakker & Bram van der Grinten (2016) Product design and business model strategies for a circular economy, Journal of Industrial and Production Engineering,
[21] Paiho S., et al. (2016), Towards circular cities – conceptualizing core aspects. Sustainable Cities and Society 59:102143
[22] United Nations. (n.d.). About the Sustainable Development Goals. https://www.un.org/sustainabledevelopment/sustainable-development- goals/
[23] The City of New York. (2018), Voluntary local review: New York City’s implementation of the 2030 agenda for sustainable development.
[24] City of Helsinki. (2019), The City of Helsinki has completed its sustainable development report to the UN.
[25] Circular Cities Hub (2017). About. http://circularcitieshub.com/about-2/.

resources. They add that resources can be cycled between urban activities in a circular city as well as “inside city regions” and that “cities can be built so that land and infrastructure can be re-used/recycled throughout time.”

During a VTT workshop[26], twenty experts from various fields (energy, food, waste, materials, business innovations, etc.) were challenged to come up with one or two terms that would define what a circular city is not. The most pertinent terms were then put to a vote by the people. The words mentioned and the weight they were given are shown in **Error! Reference source not found.**. What constitutes a circular city was the subject of a similar exercise. The outcomes are shown in Figure 2.

Figure 1 - What is not a Circular City? (Larger font size indicates higher vote count) - Source: Paiho et al., Towards circular cities – Conceptualizing core aspects, 2020. (Downloaded on September 14, 2022)

Figure 2 - What is a Circular City? (Larger font size indicates higher vote count - Source: Paiho et al., Towards circular cities – Conceptualizing core aspects, 2020. (Downloaded on September 14, 2022)

In conclusion, the VTT Researcher workshop characterized the circular city as being accountable in its actions, sustainable, holistic, and inclusive for its residents.

In Table 1, a synthesis of the definition characteristics of a circular city, based on different sources, can be found. Based on that, Paiho et al (2020) try to summarize them in a synthesis definition: “a circular city is based on closing, slowing, and narrowing the resource loops as far as possible after

[26] https://www.vttresearch.com/en/about-us/what-vtt

the potential for conservation, efficiency improvements, resource sharing, servitization and virtualization has been exhausted, with remaining needs for fresh material and energy being covered as far as possible based on local production using renewable natural resources."[27]

References	Conservation and efficiency	Reuse and closing of loops	Sharing of resources	Local production	Servitization and virtualization	Renewable resources
Prendeville et al. (2018)		x				
Bocken et al. (2016)	x	x	x		x	x
European Investment Bank (2018)	x	x	x	x		x
Ellen MacArthur Foundation et al. (2015)	x	x	x		x	
Circular Cities Hub (2017)		x	x	x		x
Number of mentions	3	5	4	2	2	3

Table 1- Main characteristics defining a circular city based on various sources

1.2. Urban metabolism

In cities, complete self-sufficiency is a big concern. For the food security, water, and energy, cities import resources. However, because they concentrate a fast-growing and urbanizing population, they are essential to global sustainability.

The biology field has influenced the idea of metabolism, which are "physiological processes within living things that produce the energy and nutrients required by an organism as the circumstances of life itself".[28] This concept called "urban metabolism" has been adapted to cities, treating them as organisms and providing an extensive framework for analyzing a city's input-output linkages with its surrounding biophysical environment.[29]

Urban metabolism is a method for measuring the total flux of resources, including their inputs, transformations, and outputs. It can be researched on a variety of scales, such as the global, national, local, and household levels. Numerous urban metabolism studies conducted over the past few decades have offered insightful data on the resource movements in and around cities[30]. In addition, urban metabolism is a foundation for both policy analysis and sustainable urban design[31].

Today, the urban metabolism is primarily linear. Cities rely on the hinterlands and other cities for their resources, importing their water, energy, and goods, and exporting their garbage[32]. As stated

[27] Paiho et al. (2020), Towards circular cities – conceptualizing core aspects. Sustainable Cities and Society 59:102143
[28] Tarr JA. (2002), The metabolism of the industrial city: the case of Pittsburgh, Journal of Urban History 28(5):511-545
[29] McDonald GW, Patterson MG.(2007), Bridging the divide in urban sustainability: from human exemptionalism to the new ecological paradigm. Urban Ecosystems 10:169-192
[30] Kennedy C, Cuddihy J, Engel-Yan J. (2007), The changing metabolism of cities. Journal of Industrial Ecology, volume 11.
[31] Kennedy C, Pincetl S, Bunje P. (2011), The study of urban metabolism and its applications to urban planning and design. Environ Pollut.
[32] Bai X. (2011), Industrial ecology and the global impacts of cities. Journal of Industrial Ecology, 11: 1-6.

by Cola et al. (2005), cities utilize these resources inefficiently, and after usage, useful by-products such as nutrient emissions to water or energy lost as waste heat, are discarded. Two fundamental issues are connected to linear metabolism. On the one hand, the high rate of resources consumption puts stress on resources availability by depletion; on the other hand, massive disposal of waste causes pollution.

Water, energy, and materials are some of the different components that make up the urban metabolism. In general, all these parts are in a linear order and simply rely on the import of high-quality resources to operate, with no harvesting or chain-wide feedback. Cities become increasingly vulnerable due to their reliance on outside factors and inefficiencies[33]. Circular metabolism, which is similar to the metabolism seen in natural ecosystems, has a low rate of consumption and involves recycling and reuse of various urban flows. Circular metabolism improves the resilience of cities while having less of an impact on the countryside and other cities.

With rankings like the Green City Index[34] or the City Blue-print[35], which tend to give high scores to western and northern European cities like Amsterdam, Copenhagen, or Stockholm, the environmental sustainability of cities has up until now been measured and communicated to the general public. Although very significant, such indices are typically exclusively based on direct urban best practices like waste collection, building energy efficiency, or water management effectiveness. They frequently ignore the fact that cities rely on resources located outside of their borders.

One of the main issues in the cities nowadays can be related to the misuse is made of the available resources. The scale of product production and consumption now is greater than it has ever been throughout human history. The rate of resource depletion has accelerated due to the world population's rapid growth, particularly in metropolitan areas, and the close relationship between economic growth and resource consumption.

One of the most important and less preserved resources in linear cities today is water. Humans, the built environment, and the ecosystem suffer irreparable harm because of global climate change, based on one of the most recent IPCC assessments (IPCC, 2018), especially for the depletion and deterioration of clean water resources. Additionally, the fast growth of urban areas, which increases the demand for water resources and disturbs the natural water cycle, highlights the significance of resilient and sustainable water management. Therefore, it is crucial that urban planning includes

[33] Cola F, Recine G, Alessandro G. (2005), Technologies Dossier Local New Energy Technology Implementation Project. Rome: Innova Spa.
[34] https://assets.new.siemens.com/siemens/assets/api/uuid:cf26889b-3254-4dcb-bc50-fef7e99cb3c7/gci-report-summary.pdf
[35] Van Leuween K., Koop S., (2015), Assessment of the Sustainability of Water Resources Management: A Critical Review of the City Blueprint Approach. Water Resources Management 29(15):5649-5670

urban water management. Additionally, decisions about land use have an impact on how water supply and wastewater systems are designed and run, as well as what needs to be done to manage stormwater runoff. As a result, whether taken separately or in conjunction with other goals, water is a crucial component of the Sustainable Development Goals of the United Nations. For instance, some of the 17 goals emphasize the importance of urban farming and call for the efficient use of resources, the restoration of the environment, biodiversity, carbon sequestration, practicable catchment management, and soil management[36].

Urban water is all the water found in urban areas, including groundwater, drinking water, sewage, stormwater, and flood overflow water as well as recycled water. Additionally, a variety of techniques can be used to address issues with urban water use, such as increasing water efficiency and demand reduction strategies, water-sensitive urban design strategies, environmental water and safeguarding natural wetlands, waterways, and estuaries in urban settings[37]. Water supply, urban drainage, wastewater treatment, and water-related sludge handling are all included in Larsen and Gujer's definition[38] of urban water management (UWM) from 1997. UWM thus encompasses the planning, building, and maintenance of infrastructure for safe drinking water and sanitary conditions, as well as the management of infiltration and stormwater runoff, the upkeep of recreational parks, and the preservation of urban ecosystems.

Despite infrastructural investments and technological advances, the water management of cities[39], in terms of both inflow and outflow, still remains a complex task, to which some new challenges have been added. Water for the public supply network must be of a higher quality than for any other sector, as it is used for drinking, cooking, showering, and washing clothes or dishes. On average, 144 liters[40] of fresh water per person per day are supplied for domestic consumption in Europe, excluding recycled, reused, or desalinated water. This quantity is almost three times the projected water needs for basic human needs[41].

When it leaves our homes, water is contaminated with waste and chemicals, including phosphates used in cleaning products. Wastewater is first collected in a special system and then treated in a designated facility to remove components that are harmful to the environment and human health. Like nitrogen, phosphorous also acts as a fertilizer, and excessive amounts of phosphates in water

[36] Keesstra S., et al, (2016), The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. SOIL, 2, 111–128

[37] http://www.bom.gov.au/water/waterinaustralia/files/Water-in-Australia-2017-18.pdf

[38] Castro, G. (1997). The concept of sustainable urban water management. Water Science and Technology.

[39] https://www.eea.europa.eu/publications/rivers-and-lakes-in-cities

[40] https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-3/assessment-4

[41] Brown, A., Matlock, M., (2011), A Review of Water Scarcity Indices and Methodologies, Sustainability Consortium.

bodies can lead to the overgrowth of certain aquatic plants and algae. This effect reduces the amount of oxygen in the water, suffocating other species. Recognizing these impacts, EU legislation has set strict limits on phosphorous content in various products, including household detergents, and thus achieved substantial improvements in recent decades.

The ability to meet all water needs for fundamental human needs, including drinking water for survival, water for personal hygiene, for sanitation, and moderate home needs for food preparation, is measured by the water scarcity index created by Gleick[42]. The following minimum amount is suggested to sustain each of these:

- The minimum for drinking water: according to estimates made using data from the National Research Council of the National Academy of Sciences, an average individual needs roughly 5 liters of drinking water per day to survive in a typical temperate climate with normal activity.
- Requirements for basic sanitation: with today's sanitation technologies, it is possible to effectively dispose of human waste with little or no water, if necessary. However, a minimum of 20 liters per person per day is advised to take into consideration the greatest benefits of integrating waste disposal and related cleanliness as well as to account for cultural and societal preferences.
- Minimum requirements for bathing: according to studies, 15 liters of water per person per day is the bare minimum required for a proper bath[43].
- Minimum amount of water for food preparation: 10 liters per person per day, which satisfies most regional criteria and meets the fundamental needs of both industrialized and developing nations.

Water demand, which is mostly influenced by population trends and socioeconomic advancements, and climate conditions, which regulate the availability of renewable freshwater resources and the seasonality of water supply, are the main causes of water shortage.

[42] Gleick, Peter H. (1996), Basic Water Requirements for Human Activities: Meeting Basic Needs. Water International 21(2):83-92.
[43] Kalbermatten, J.M, D.S Julius, C.G Gunnerson, and D.D Mara. (1983), Appropriate Sanitation Alternatives: A Planning and Design Manual. Johns Hopkins University Press.

2. The society of waste: why is the linear economy no longer sustainable?

The capitalist model based on consumerism has been regulating societies and guiding their development for decades, generating solutions that feed the patterns of living dictated by this paradigm. These models have proven to be unsuccessful, unfair, and unsustainable, and pose the need to build a more fair and inclusive society. To do this there is a need to approach the problem systemically and rethink development models so that the rights of people and the environment are placed at the center.

It seems that people are understanding just now that Planet Earth's resources are limited by nature. Natural resources, such as mineral deposits, that have their origins in earlier geologic periods, cannot be regenerated on human timescales, and therefore their reserves will eventually be depleted if consumption continues[44]. Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes[45], and the economic and social progress of the last century has been accompanied by environmental degradation that is endangering the very systems on which our future development, and our very survival, depends. Whether or not the phenomenon is caused by human activities is no longer up for debate, particularly since the industrial revolution, due to high greenhouse gas emissions (GHG). These emissions, mainly related to the industrial and energy sectors, are due to current production and consumption patterns that do not consider the limited number of resources available, and the plant's capacity to regenerate them. The mainstreaming model that governs our economic dynamics so far, is traditionally known as linear economy, which consists in:

take - make - use (or not) - dispose.

This model leads to an intensive use of natural resources and creates high pressure on the environment, with climate change and the loss of biodiversity being some of the most serious

[44] Cobo, S., Dominguez-Ramos, A., Irabien A., (2017), From linear to circular integrated waste management systems: A review of methodological approaches. Resources, Conservation and Recycling, Volume 135.

[45] IPCC, (2021): Summary for Policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

manifestations of the environmental crisis that the Planet is going through.

Figure 3 - Linear economy model - Source: Alice Abler, 2017. (Downloaded on March 13, 2022)

This kind of economic model is hugely wasteful: most of the value of the materials used is “lost” in landfills, and the products that are manufactured are constantly underutilized. This is amplified in the urban context, where significant structural debris has been found in key sectors such as mobility, food, and the built environment. For example, as assessed by the Ellen McArthur Foundation et al. 2015), in Europe, an average car is parked 92% of the time, 31% of food is wasted along the value chain, and the average office is used only 35-50% of the time, even during working hours.

“The world generates 2.01 billion tonnes of municipal solid waste annually, with at least 33% of that not managed in an environmentally safe manner[46].” Economic development has accelerated the extraction of primary materials, production, consumption, and disposal practices, increasing the amount of waste generated[47]. Raw materials are gathered from the environment and processed into final products that are disposed of at the end of their useful life under this linear model. Furthermore, the products are developed with a particular purpose and have a short lifespan.

A fundamental topic of discussion relates to the current economic system, which is based on Gross Domestic Product (GDP) and infinite growth and is therefore patently unsustainable: again, the UN, in its latest 2019 report “GSDR Global Sustainable Development Report, The Future is Now, Science for Achieving Sustainable Development”, highlights the problem and calls for the need to develop economic models with global relevance that overcome the current paradigms of capitalism[48].

The issue, therefore, goes hand in hand with a vision of development that is no longer linked to GDP growth, but to a different idea of assessing humanity's “progress” that also takes into consideration, as proposed by many thinkers, the other, seemingly intangible aspects of quality of

[46] https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html
[47] Almeida Neves S., Cardoso Marques A., (2022), Drivers and barriers in the transition from a linear economy to a circular economy, Journal of Cleaner Production 341:130865.
[48] United Nations, New York, (2019), Independent Group of Scientists appointed by the Secretary-General, Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development.

life. Living all in a world with objectively limited resources implies a radical change in thinking, not only economic but also philosophical, which seems unavoidable in the face of current phenomena. Sustainability, or living in relation to the renewability of resources, is none other than this, and in this regard, the UN 2030 Agenda is the perfect summary of it[49].

Widespread heatwaves in both the northern and southern hemispheres have been documented in 2019's climate data. In 2018 and 2019, climate change-related wildfires decimated cities and towns in California, Chile, and Australia[50]. At the same time, increasingly extreme precipitation patterns are raising the risk of both urban drought and floods[51]. Rising sea levels and other environmental problems in coastal cities have led to unprecedented environmental and social transformation[52]. Cities in Europe, South America, and Africa may experience stronger and more frequent droughts, compounding the current water scarcity and crises. Current climate change models project that the mean maximum temperature in cities worldwide would climb by 2-8°C in just a few decades[53]. The UN and the International Entities, including the IPCC (International Panel on Climate Change), have produced several qualified, in-depth, and comprehensive reports to frame the problem, indicating both possible temperatures rise scenarios and strategic areas to be addressed for mitigation and sustainability, with the goal of not exceeding 1.5-2ºC degrees increase in the Planet's average temperature. At the same time, they illustrate a worst-case scenario of 3.2°C or more increase by the end of the century, the effects of which appear truly catastrophic for humanity. As declared by the professor Maurizio Pallante on his last TedX talk in Taranto (Italy)[54], the point here is not to focus on controlling the rise in temperature with respect to the current one, but to decrease it. Achieving 1.5ºC increase at this point can be a disaster.

2.1. Urban resources management

Every year, 2,8 billion tons of organic waste occur in cities, in which urban inhabitants continuously discard large volumes of nutrients into wastewater streams via human excreta, biodegradable kitchen waste, and hygiene products, and less than 2% of nutrients contained in this

[49] https://sdgs.un.org/goals
[50] Kramer HA, Mockrin MH, Alexandre PM, Radeloff VC. (2019), High wildfire damage in interface communities in California. International Journal of Wildland Fire.
[51] Güneralp B, Güneralp İ, Liu Y. (2015), Changing global patterns of urban exposure to flood and drought hazards. Global Environmental Change, Volume 31.
[52] Newton A, Carruthers TJ, Icely J. (2012), The coastal syndromes and hotspots on the coast. Estuarine, Coastal and Shelf Science, Volume 96.
[53] Huang K, Li X, Liu X, Seto KC. (2019), Projecting global urban land expansion and heat island intensification through 2050. Environmental Research Letters, Volume 14.
[54] https://www.youtube.com/watch?v=85wQpUopIjU

organic waste are looped back of food production[55]. So far, the economy has lost around USD 23.3 billion of agricultural nutrients in human excrement[56] and additionally 100 million tons of bio-waste through the disposal of organic waste every year[57]. These nutrients are lost in the atmosphere via nitrification, incineration, landfilling, and the environment (residual nutrient loads in effluents). At the same time, Europe imports 30% of nitrogen, 71% of phosphorus, and 73% of all potassium fertilizers used[58]. Instead of being treated as a burden, organic residues could be transformed into fertilizer or nutrient-rich irrigation water that is safe for reuse, thereby returning "spent" nutrients to soils, where they enter a new lifecycle for food production. By applying currently available technologies, cities could capture nutrients from wastewater and metabolize them to produce fertilizer or soil amendment, functioning as an ecosystem, in which mutual interactions are created in a dynamic equilibrium controlled by one or more physical-chemical feedback mechanisms. This way, mineral reserves avoid their high-carbon footprints while also reducing Europe's external resource dependency.

Other than fertilizer, other resources can be recovered from urban wastewater using biological technologies: nutrient-rich irrigation water, biopolymers, alginates, cellulose, construction material, and fundamental ingredients for energy production (biogas, biofuel, electricity, heat). Wastewater treatment has the potential to shift from a burden to a profit-generating resource factory[59].

Sustainable urban development is an important challenge in a world of cities and may be the most important environmental concern in the present and the future[60]. It is critical to comprehend the workings of urban metabolic systems in order to meet this issue[61]. It can be stated with certainty that wise resource management is essential to creating sustainable cities. The complex issues we face today cannot be resolved by alone technical fixes[62]. Thus, resource management is a crucial component of sustainable development. Given the challenges that climate change will undoubtedly present, and the increased attention that cities have received over the past ten years, there has been a significant push on the part of governments at all levels to develop initiatives, innovations, and

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[55] Ellen MacArthur Foundation. (2018), Cities and the circular economy for food. https://www.ellenmacarthurfoundation.org/our-work/activities/cities-and-the-circular-economy-for-food.
[56] Jenkins, J. C. (2011), The humanure handbook: A guide to composting human manure (Joseph Jenkins Inc.).
[57] European Compost Network. (2019), Bio-waste in Europe. European compost network. https://www.compostnetwork.info/policy/biowaste-in-europe/.
[58] Fertilizers Europe. (2017), Industry facts and figures 2018. http://fertilizerseurope.com/.
[59] Ellen MacArthur Foundation. (2017), Urban biocycles. https://www.ellenmacarthurfoundation.org/publications/urban-biocyles.
[60] McDonald, G.W., Patterson, M.G., (2007), Bridging the divide in urban sustainability: from human exemptionalism to the new ecological paradigm. Urban Ecosystems 10:169-192.
[61] Decker, E.H., Elliott, S., Smith, F.A., Blake, D.R., Rowland, F.S., (2000), Energy and material flow through the urban ecosystem. Annual Review of Energy and the Environment, Volume 25.
[62] Pahl-Wostl, C., (2007), The implications of complexity for integrated resources management. Environmental Modelling & Software, Volume 22, Issue 5.

transformative changes that will assist cities in addressing the effects of climate change[63]. These measures have shown to be insufficient, thus it is obvious that decision-makers need assistance in strategizing how to stack adaptation solutions within cities that can increase resilience in the face of a multitude of potential futures[64].

Building, supplying, and sustaining cities during the current widespread urbanization takes significant amounts of resources, including energy and materials[65]. Cities are intricate, dynamic systems that are always changing. Due to their size, social structures, economic systems, geopolitical contexts, and technological evolution, they change in complex ways[66]. Additionally, they exhibit a variety of patterns, agglomeration, and fierce competition for space with other land users, needing enormous amounts of resources to operate[67]. The depletion of the resources that were closest and easiest to access may have previously prevented cities from developing[68]. The increases in urban inputs and outputs, however, have been driven by technological and infrastructure innovations[69].

As shown in Figure 4, the need for food, water, and other supplies to be stored, transported, and distributed in the newly constructed cities increased the energy requirement, having waste emissions and heat as output. The main issue of the cities today is that they are planned to generate emissions in an illimited way, without taking into consideration the impossibility for the ecosystem to regenerate them.

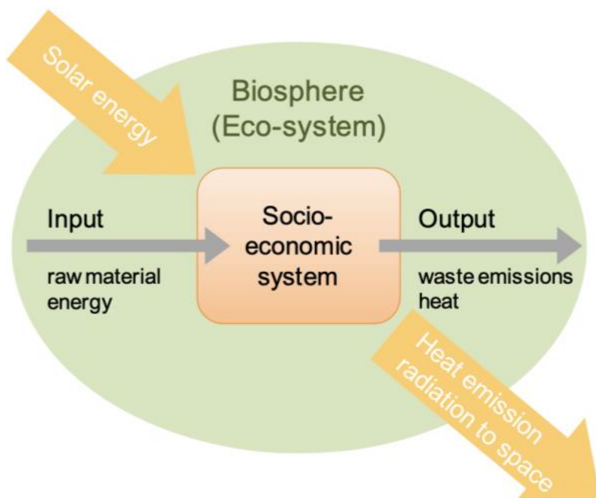

Figure 4 - Urban resources flows - Source: Institute of Social Ecology (SEC), Vienna, 2011. (Downloaded on July 14, 2022)

[63] Ürge-Vorsatz D, Rosenzweig C, Dawson RJ, et al. (2018), Locking in positive climate responses in cities. Nature Climate Change 8(3).
[64] McPhearson T, Raymond CM, Gulsrud N, et al. (2019), Radical changes are needed for transformations to a good Anthropocene. npj Urban Sustain 1, 5.
[65] Girardet, H., (2003), Cities, people planet. In: Vertovec, S., Posey, D.A. (Eds.), Globalization, Globalism, Environment, and Environmentalism: Consciousness of Connections
[66] Kennedy, C., Cuddihy, J., Engel-Yan, J., (2007). The changing metabolism of cities. Journal of Industrial Ecology, Volume 11.
[67] Batty, M., (2008), The size, scale, and shape of cities. Science 319(5864):769-71.
[68] Tainter, J.A., (2000), Problem Solving: complexity, history. Sustainability. Tainter, J.A., (2000), Problem Solving: complexity, history. Sustainability.
[69] Krausmann, F., Fischer-Kowalski, M., Schandl, H., Eisenmenger, N., (2008), The global sociometabolic transition: past and present metabolic profiles and their future trajectories. Journal of Industrial Ecology 12(5/6).

By rearranging organisms, energy, and material flows, the discovery of new energy carriers stimulated technological innovation, which in turn increased population expansion, urbanization, and domestication of entire landscapes and ecosystems[70].

Globally and particularly over the past two centuries, industrialism, the fast rise in the world's population, urbanization, and technical advancement has all contributed to growing resource demands. For instance, the ability to import resources from distance has been made possible by the development of advanced transport systems, creating a vast and intricate network of resources. At the moment, cities are heavily dependent on other cities and the hinterlands for resources and trash disposal[71]. As a result, the effects on the environment are multiplied, increasing the ecological (global) footprint of cities[72].

Cities' extensive use of natural resources, which can sometimes result in their depletion, and incineration of municipal waste have both direct and indirect effects on the atmosphere, hydrosphere, geosphere, and biosphere[73]. The carrying capacity of the global ecosystem has received decreasing amounts of attention since the industrial revolution. Ecosystem and societal collapse as a result of environmental deterioration has been discussed by Diamond (2005) and Ponting (2007). One well-known example is Easter Island, where a human culture existed between the years 900 and 1700 AD[74].

Massive environmental damage brought on by the island's indiscriminate deforestation made it impossible to make canoes and fishing nets because there weren't enough resources for cooking, heating, and construction. In addition to this, erosion also caused a diminution of the soil's quality. All of these elements contributed to the demise of the Easter Island civilization. The impact of humans on the world today is unprecedented. It has been widely understood over the past ten years that maintaining present usage rates while continuing to grow is unsustainable[75]. As a species, it must be acknowledged that, like Easter Island, the globe does not have an abundance of resources to meet all human society's needs[76].

The resource is something perpetually alive that is consumed and renewed, something that constantly harkens back to the regenerative capacity of nature. The concept of resource, moreover,

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[70] Kareiva, P., Watts, S., McDonald, R., Boucher, T., (2007), Domesticated nature: Shaping landscapes and ecosystems for human welfare. Science, Volume 316.

[71] Bai, X. (2007), Industrial Ecology and the Global Impacts of Cities. Journal of Industrial Ecology, 11: 1-6.

[72] Monstadt, J., (2009), Conceptualizing the political ecology of urban infrastructures: Insights from technology and urban studies. Environment and Planning A: Economy and Space, 41(8).

[73] Mills, G. (2007), Cities as agents of global change. Int. J. Climatol., 27.

[74] There is considerably uncertainty about the date that Easter Island was occupied (Diamond, 2005).

[75] Arrow, K., Dasgupta, P., Goulder, L., Daily, G., Ehrlich, P., Heal, G., Levin, S., Mäler, K.- G., Schneider, S., Starrett, D., Walker, B., (2004), Are we consuming too much? Journal of Economic Perspectives, Volume 18.

[76] Ponting, C., (2007), A New Green History of the World: The Environment and the Collapse of Great Civilizations. Penguins books edition.

is inspired by the more recent category of sustainability. Sustainability means identifying in the physical laws that regulate nature and in the logic of reproducibility of natural resources the constraints on the unfolding of human activities; it means making sense of a development that is no longer unlimited but constrained. This constraint would then come to define the capacity to sustain and satisfy the population and its needs, it would come to direct the demand for nature in such a way that it does not compromise its capacity for scope and in such a way that it does not alternate its capacity for renewal[77].

To answer to this need of change, a more responsible way to manage resources is needed. The sustainability of an urban configuration is strongly conditioned by the conception of the city in which nature exists as intimately and deeply connected to society. The use of technology to adapt cities to climate change has been extensively researched, and new technologies are constantly being developed and evaluated for their overall effectiveness. Capital's demand for continual development has resulted in the disruption of a complex natural cycle that has evolved over millions of years. This has caused a gap in the “metabolism” that exists between society and nature. For instance, cooling during heat waves is seen to be a health benefit but can represent negative energetic feedback due to the resource waste and the huge emission generated. Switching to systems-based heating and cooling that make use of cooling towers or district distribution can reduce sensible heat discharge and save energy[78]. Big data and internet-of-things tools are also increasingly able to provide decision-makers with real-time information so they may make better decisions about the flow and use of resources in cities.

The utilization of vegetation and blue-green infrastructure, or nature-based solutions (NBS), can supply a range of ecosystem services too, such as enhancing the environment and promoting health and welfare[79]. NBS are being used more frequently to solve issues like severe heat, drought, or flooding[80].

However, due to the fact that variations in temperature and precipitation will have an impact on green infrastructure itself, urban nature-based solutions are susceptible to many of the climate

[77] E. Tiezzi e N. Marchettini, (1999), Che cos'è lo sviluppo sostenibile? Le basi scientifiche della sostenibilità e i guasti del pensiero unico, Roma, Donzelli.
[78] Dhakal S, Hanaki K. (2002), Improvement of urban thermal environment by managing heat discharge sources and surface modification in Tokyo. Energy and Buildings 34(1).
[79] Fischer LK, Honold J, Botzat A, et al. (2018), Recreational ecosystem services in European cities: sociocultural and geographical contexts matter for park use. Ecosystem Services, Volume 31, Part C.
[80] Scott M, Lennon M, Haase D, Kazmierczak A, Clabby G, Beatley T. (2016), Nature-based solutions for the contemporary city. Planning Theory & Practice, Volume 17

concerns they are intended to address[81]. For instance, decreased water availability to maintain trees and their canopy may cause a sharp fall in transpiration, evaporative cooling, and shade cover[82]. To preserve the desired functionalities and performances while the environment changes, nature-based solutions must be managed appropriately[83]. Therefore, planning for the resilience of urban vegetation under various future climate change scenarios is necessary to guarantee that the advantages may still be obtained[84]. Although it is getting more attention from researchers and practitioners, it is still not obvious to what extent nature-based solutions can compete with grey infrastructure in terms of effectiveness and hence take its place[85].

Figure 5 - NbS in cities (green roofs) - Source: Regreen project website https://www.regreen-project.eu/nature-solutions-platform/ (Downloaded on July 18, 2022)

Social changes that motivate people to alter their behaviors and practices are the also foundation of social solutions to climate change[86]. These strategies can help people embrace and use

[81] Ward K, Lauf S, Kleinschmit B, Endlicher W. (2016), Heat waves and urban heat islands in Europe: a review of relevant drivers. Science of The Total Environment, Volumes 569–570.
[82] McPhearson T, Andersson E, Elmqvist T, Frantzeskaki N. (2015), Resilience of and through urban ecosystem services. Ecosystem Services, Elsevier, vol. 12(C).
[83] Andersson E, Langemeyer J, Borgström S, et al. (2019), Enabling green and blue infrastructure to improve contributions to human well-being and equity in urban systems. BioScience, Volume 69.
[84] Ossola, A., & Lin, B. B. (2021), Making nature-based solutions climate-ready for the 50 °C world. Environmental Science and Policy, 123.
[85] Bai X. Advance the ecosystem approach in cities, (2018), Nature 559, 7.
[86] Sheppard D. (2011), Social solutions for climate change mitigation and adaptation: cross cultural lessons from Denmark to the United States. Intersect, Volume 11.

innovative or uncomfortable measures more easily[87]. Through participation, education, and practical experience, social mobilization initiatives can reduce the perceived barriers to sustainable climate solutions and encourage action[88].

Many social solutions aim to reduce inequality and have an impact on vulnerable groups of people, including those who might have fewer resources for technological solutions (such as air conditioning), less access to cooler private or public green spaces, and less access to information for adaptation[89].

Although there may be a high level of awareness of climate risk in cities with many impoverished neighborhoods, there may not be much that can be done to protect oneself. If communities are not included in decision-making processes on adaptation and mitigation, political disenfranchisement or isolation may worsen the risks. There is a need to approach the problem systemically and rethink development models so that the rights of people and the environment are placed at the center.

2.2. Why cities are crucial for climate change mitigation

Cities must be effective, well-managed, and better at protecting their most vulnerable populations in a world that is rapidly reaching a population of 9 billion people, 80% of whom will live in urban areas by 2050[90].

According to the International Energy Agency (IEA), cities are responsible for 71% of the world's energy related GHG emissions, that were released in 2006. Additionally, cities in nations outside of the Organization for Economic Cooperation and Development (OECD) will account for 89% of this cumulative increase in CO_2 emissions between now and 2030, primarily in fast urbanizing nations like China and India[91].

The main sources of GHG emissions -coal, oil, and natural gas- provide 72% of the energy needed by cities. Even while cities use around 70% of the energy produced from renewable sources, they still account for a very small portion of the overall energy consumed.

Cities are particularly vulnerable to the effects of climate change and also contribute to it. Around 360 million city dwellers reside in coastal regions less than 10 meters above sea level, making them susceptible to floods and storm surges[92].

[87] Simon D., (2016), Rethinking sustainable cities: accessible, green and fair. Policy Press.
[88] Westerhoff L, Sheppard SR, Iype DM, Cote S, Salter J., (2018), Social mobilization on climate change and energy: an evaluation of research projects in British Columbia, Canada. Sustainability 11(22).
[89] Pelling M, Garschagen M. (2019), Put equity first in climate adaptation. Nature 569.
[90] https://www.weforum.org/agenda/2022/04/global-urbanization-material-consumption/
[91] International Energy Agency (IEA). (2008), World Energy Outlook 2008. Paris: IEA.
[92] Moser, Caroline & Satterthwaite, David. (2008), Towards Pro-Poor Adaptation to Climate Change in the Urban Centres of Low and Middle Income Countries. Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World.

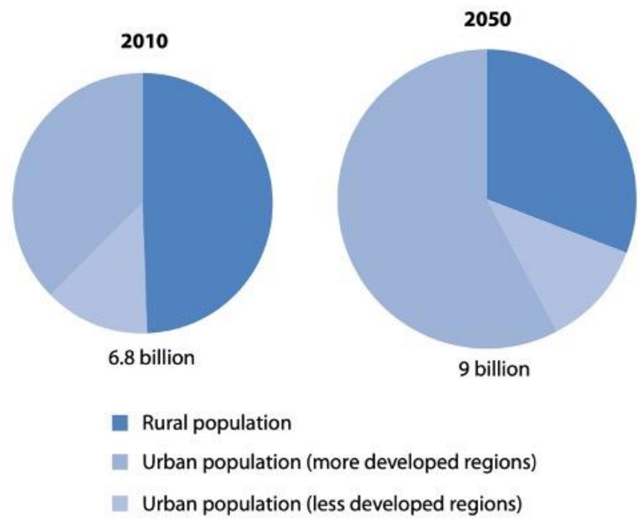

Figure 6 - Share of Urban and Rural Population in 2010 and 2050 - Source: UN 2007. (Downloaded on March 14, 2022)

They are vulnerable to increasing sea levels due to their big populations and the fact that they are situated in low-elevation coastal locations for historical and trade reasons. Cities can also be impacted by extreme weather events and altered weather patterns.

According to the Intergovernmental Panel on Climate Change (IPCC), the average sea level increased by 0.17 meters during the 20th century, and it is expected to rise by 1 meter during the following 100 years as a result of climate change[93].

The utilization of urban infrastructure is impacted by this 1-meter increase in sea level during the following century, which is significant. Large-scale electricity facilities (which are frequently situated next to water to have access to cooling water) and significant transportation systems are only a few examples of long-lasting infrastructure that are built with service lifetimes of more than 60 years. For instance, the subways, sewage systems, and bridges in big cities like London, New York, and Paris are more than a century old. Building comparable infrastructure in cities where the sea level may rise by a meter, such as Shanghai, Jakarta, Bangkok, and Rio de Janeiro, adds a significant amount of complexity to an already difficult operation.

Some larger cities will start evaluating the necessity for strategic retreat and abandonment of vital infrastructure and areas within the next ten years as greater confidence regarding the projected rate of sea level rise becomes apparent. This will result in the greatest transfer of economic wealth in human history as well as a tremendous loss of value in land and infrastructure.

[93] IPCC, (2007): Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Anomalies in climate events and patterns affect not only poor but also prosperous countries[94]. Heat waves have lately killed hundreds of people in European cities such as Paris[95]. A catastrophic heat wave killed around 70,000 individuals in Europe in 2003[96]. The ability of cities in most developing nations to adapt to climate change is crucial for the urban poor and other vulnerable groups such as children and the elderly.

Cities rely on the security of their critical inputs, which include electricity, water, and food. Climate change, which is occurring concurrently with the world's highest level of urbanization ever, will put additional strain on vital resource supply networks.

Cities may act on both mitigation and adaptation to climate change. Mitigation seeks to prevent additional climate change; adaptation entails readjusting one's life to the knowledge that some level of climate change is unavoidable. While the contrast may appear to be one of optimism against pessimism, at first sight, a successful approach to confronting climate change at the local level necessitates a combination of mitigation and adaptation. Cities are best positioned to handle climate change in an integrated approach that addresses both mitigation and adaptation at the same time.

Adaptation measures are often less expensive in the near term, but as climate change accelerates, they will become increasingly expensive and, eventually, ineffectual. Mitigation measures, on the other hand, are initially costly because they demand capital and fundamental modifications to urban systems; nevertheless, mitigation techniques are largely sustainable and result in cost savings over time. These financial implications highlight the importance of balancing adaptation and mitigation activities.

In order to be able to counteract the effects of the linear economy model and climate change, economic measures that seek to be sustainable and reduce the waste of resources have been thought of, trying to change the system of consumption to arrive at changing the system of production. This model is called circular, and it tries to be a replacement to the current economic system, trying to balance both mitigation and adaptation measures.

[94] World Bank. (2009), Development and Climate Change. World Development Report 2010.

[95] Dhainut, J-F., Y-E Claessens, C. Ginsburg, and B. Riou. (2004), Unprecedented Heat-Related Deaths during the 2003 Heat Wave in Paris: Consequences on Emergency Departments. Crit Care.

[96] World Bank. (2010), Cities and Climate Change: An Urgent Agenda. Urban development series;knowledge papers no. 10. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/17381 License: CC BY 3.0 IGO."

3. Circular economy in cities

The circular economy is currently being implemented in many different areas and places, and there is still a long way to go. In recent years, there have been many improvements, both in research and in the political framework.

Circular economy tries to turn waste into a resource by reversing the dominant linear pattern of extracting, processing, consuming, or utilizing, and then discarding raw materials, with the ultimate goal of conserving natural resources while maintaining economic growth and reducing environmental impacts (Ghisellini et al., 2016; Lieder and Rashid, 2016).

Figure 7 - How does CE work - Source: Alice Abler, 2017. (Downloaded on March 13, 2022)

Many of today's sustainable neighborhood development frameworks incorporate the ideas of lowering greenhouse gas emissions and enhancing resilience to risks from climate change. Although the initiatives for sustainable cities generally aim to improve the social, economic, and environmental conditions of the city and those who live there, they are framed in a variety of ways according to a growing list of categories, such as “eco cities”, “livable cities”, “green cities”, and “smart cities” (Holden, Li, et al., 2015).

Cities require resources just like nature, but while nature has a circular metabolism with no waste, cities have linear metabolisms that contribute to natural resource depletion.

In biology, the term “metabolism” refers to the whole variety of biochemical processes that occur within a living organism, including the conversion of food into energy, the chemical facilitation of all activities necessary for life, and the processing and disposal of waste. Cities have many functions parallel to those of a living organism: they also consume and process materials and dispose of waste. In an analysis of urban metabolism, the inputs, stocks, and outputs related to an urban area are studied in detail. It examines what drives these flows, the impacts to which they are related, and how the size and rate of these flows are projected to change over time. Beyond considering only physical flows, socioeconomic ones are also examined, such as money, data, and the movement of people[97].

Once qualified and analyzed, the urban metabolism approach can potentially maximize the efficiency of flows and reduce outputs such as pollution and waste. "Cities transform raw materials, fuel and water into the built environment, human biomass and waste" (Decker et al., 2000). Despite this analogy, the city is much more complex than an organism, so another analogy could be drawn between the city and the ecosystem.

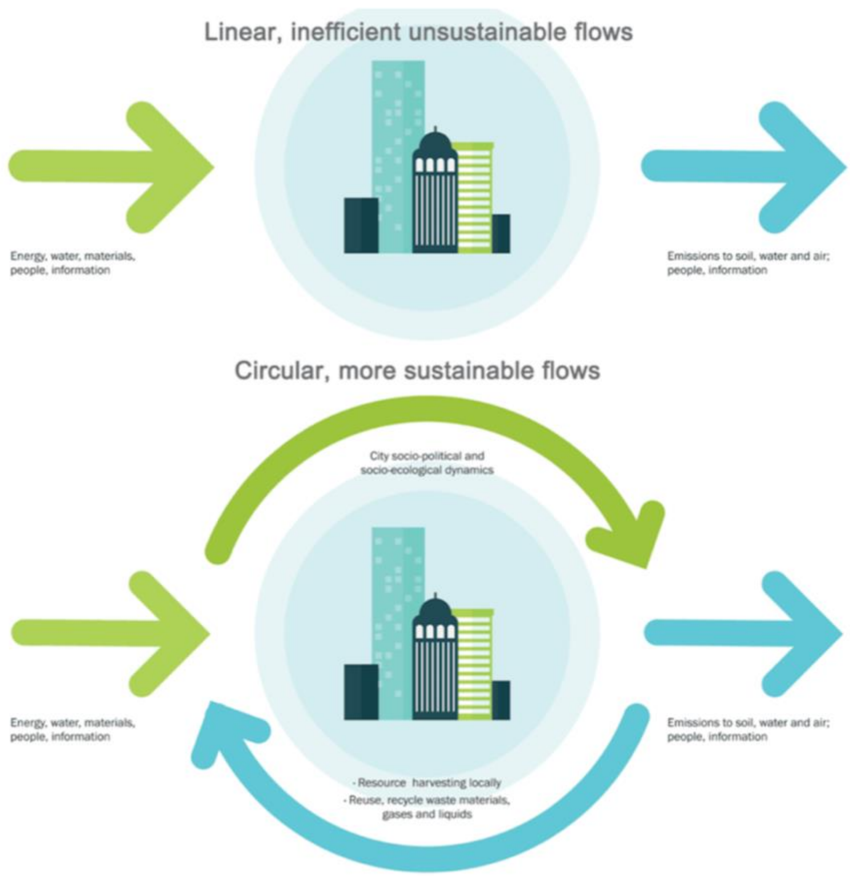

Figure 8 - Linear and Circular urban metabolism - Source: Thorpe D., Urban metabolism: viewing cities like bodies can help reduce environmental impact, 2017. (Downloaded on May 18, 2022)

[97] Eva Gladek et al., (2014), Transitioning Amsterdam to a Circular city: Circular Buiksloterham (Amsterdam: Metabolic, Studioninedots & DELVA Landscape Architects), 28.

In cities, not only the volume but also the economic value of resources reaches a peak and then declines. Food and commodities gain economic value as they move downstream along the value chain from rural production. They are at their most valuable when they reach the metropolitan consumer. When they are purchased, their value decreases, and they are eventually destroyed when they are disposed of in garbage bins and sewage pipes. When items are designed for single-use or short-term use, a bigger resource intake is required to make new products and replace waste losses. As a result of waste, the value of resources diminishes, resulting in waste management expenses and/or adverse effects on human health. The economic value of products is maintained and utilized repeatedly in a circular economy through reuse, refurbishing, repair, and in the worst case, recycling (Kisser, J., Wirth, M. 2021, p. 57).

Cities both cause and respond to modifications in biogeochemical cycles (Grimm et al., 2008). The rate of change in the world today is unprecedented. The consequences of insufficient urban resource management have emerged as a global problem given the current rate and level of urbanization and expanding ecological footprints. The availability of resources like oil, fresh water, phosphorus, and metals, as well as the disruption of natural cycles like the nitrogen and carbon cycles, are a few of these global challenges[98].

Cities both cause and respond to modifications in biogeochemical cycles (Grimm et al., 2008). As the primary resource sink in the globe, the urban system is crucial in finding answers to the challenges of global pollution and resource depletion[99]. Urban resource gathering lessens the effects on the world and boosts the resilience of cities. "Resilience is a measure of the system's robustness and power to buffer against changing situations" (Berkes and Folke, 1998, p. 12).

Consumptions per capita per year for a typical metropolis in an average industrialized nation range from 150 to 400 GJ[100] for energy and 15 to 25 tons for materials[101]. Large portions of the flows of wastewater, solid waste, demolished building materials, etc. are exported from the urban system, while other portions stay in the system as urban "stocks" as internal resource reservoirs.

When the circular principles are applied to cities in all their functions, establishing an urban system that is regenerative, accessible, and abundant by design, we can talk about circular cities. These cities aim to eliminate the concept of waste and always keep resources at their highest value, and to do so they must be enabled with innovative and emerging technologies. The circular city seeks

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[98] Boyle C, Mudd G, Mihelcic JR, Anastas P, Collins T, Culligan P, et al. (2010), Delivering sus- tainable infrastructure that supports the urban built environment. Environ. Sci. Technol.
[99] Xu M, Crittenden JC, Chen Y, Thomas VM, Noonan DS, Desroches R, et al. (2010), Gigaton problems need gigaton solutions. Ennviron. Sci. Technol.
[100] Giga-Joule
[101] Krausmann F, Fischer-Kowalski M, Schandl H, Eisenmenger N., (2008), The global sociometabolic transition: past and present metabolic profiles and their future trajectories. Journal of Industrial Ecology 12(5/6).

to generate prosperity, increase livability, and improve the resilience of the city and its citizens while aiming to decouple value creation from the consumption of finite resources[102].

The definition of the circular city integrates different but closely related and complementary elements: technological innovation, resource and energy flows, production and consumption patterns converge in a microcosm that is essentially resource efficient. Precisely because of this complexity, its impacts can be considered not only in economic and performance terms but also in environmental and social terms.

The application of the circular model in cities can bring enormous economic, social, and environmental benefits. It can foster the emergence of a:

- Prosperous city where economic productivity increases through reduced congestion, waste disposal and reduced costs, and where new growth and business opportunities can support the development of skills and jobs.
- Livable city with improved air quality and urban health, reduced carbon emissions and pollution, and better social interactions.
- Resilient city[103], keeping materials in use and reducing demands for virgin materials, working with both local and distributed production capacity, and harnessing digital technology.

These benefits can be achieved by changing how urban systems are planned, designed, and financed, as well as how they are manufactured, used, and reused[104].

A key aspect to keep in mind is that a complete urban metabolism analysis comprises more components than a simple flow analysis. It is essential to analyze the context and the agents involved, both public and private. This complete analysis will be the basis that will allow the design of the circular city project that best suits each case. It is necessary to understand that it is not possible to establish a model to follow since the reality of each city differs from that of the rest, and therefore, this process of prior study is considered essential[105]. It's also worth noting that circularity adopts a completely new and distinct way of thinking and acting, rather than simply

[102] Ellen MacArthur Foundation, (2017), Cities in the Circular Economy: An Initial Exploration.
[103] https://www.oecd.org/cfe/resilient-cities.htm (*) Resilient cities are cities that have the ability to absorb, recover and prepare for future shocks (economic, environmental, social & institutional). Resilient cities promote sustainable development, well-being and inclusive growth
[104] FEMP, "Estrategia Local de Economía Circular" http://www.femp.es/comunicacion/noticias/la-estrategia-local-de-economia-circular.
[105] Gladek, E et al., "Circular Buiksloterham", 15-16.

being more efficient. A new gasoline engine that improves efficiency by 2% or burns 10% biofuel, for example, is not a circular development, but rather a linear model improvement.

3.1. The challenges of the circular economy model

In the face of numerous studies that aim to highlight the advantages of the circular economy, like the ones done by EMF, there is a lack of evidence highlighting the possible disadvantages that may result from this shift. The need for close collaboration and interdependence between numerous stakeholders beyond traditional supply chain or network relationships within the context of the circular economy makes the social dimension of sustainability particularly pertinent (Korhonen et al., 2018; Lüdeke-Freund et al., 2019; Millar et al., 2019). Its concepts are primarily formulated from a business perspective, with equal emphasis on both environmental and economic benefits.
According to Stahel in his book “The performance economy”, social benefits are frequently underestimated. Additional industrial activities in a circular economy, such as refurbishing or recycling, require extra human labor because these procedures are rarely standardized. Often, circular economy activities are innovative and require specialized skills to be implemented. The shift from linearity to circularity can create a social issue since the jobs sought are different from traditional ones that are based on standardization and often low-skilled processes. The risk arising from this issue is that companies may decide to move production/business to other areas where such skills can be found more easily or at a lower cost. This represents one of the issues to be taken into consideration during this transition (Stahel, 2010).

3.1.1 Socio-cultural barrier

People from different cultures coexist in cities, so the beliefs, social norms, and lifestyles that people in cities embrace will be impacted by cultural diversity. Adopting pro-environmental behaviors, such as reusing and recycling goods and resources, can have varying degrees of success. The willingness of people to use resources that have been recycled, reused, or recovered will also be impacted[106].
Studies that have expressly addressed the social aspect, have argued from an instrumental perspective, addressing indicators for social sustainability such as job creation[107], worker safety[108],

[106] Crociata, A.; Massimiliano, A.; Saccoc, P. (2015), Recycling waste: Does culture matter? The Journal of Socioeconomics, volume: 55.
[107] Pedram A, Pedram P, Yusoff NB, Sorooshian S (2017), Development of closed–loop supply chain network in terms of corporate social responsibility. PLoS ONE 12(4).
[108] Devika, K. & Jafarian, A. & Nourbakhsh, V., (2014), Designing a sustainable closed-loop supply chain network based on triple bottom line approach: A comparison of metaheuristics hybridization techniques, European Journal of Operational Research, Elsevier, vol. 235.

or manufacturers' intentions to recycle[109]. The social dimension is hardly discussed in the industrial ecology discourse[110], which primarily focuses on impact assessments, like life cycle assessment (LCA) tools, with a predominately environmental and economic focus, despite the fact that sustainability is “at the heart of industrial ecology” (Ehrenfeld, 2007).

Cities serve as hubs for both manufacturing and consumption. The reuse, recycling, and resource recovery of the city's inhabitants will be influenced by their cultural values, conventions, social customs, and lifestyles. Current cultural standards pose a significant obstacle to methods that loop materials, water, infrastructure, and land. Materialism and individualism have driven economic growth and created a culture of individual consumption (such as an increase in the number of single-person households and private cars), which has an influence on resources and contributes to the production of “waste” in cities[111]. Additionally, it has contributed to the devaluation of resources that have been recycled and reused as well as the rise of the “throw-away” culture[112]. By acting in a linear fashion, current provisional systems frequently encourage this[113].

Lack of connection between city dwellers and the natural world[114] supports the dominant moral framework. The environmental effects of consumption (of materials and energy) are frequently felt distantly as a result of the globalization of services and resource flows[115]. This makes urban dwellers less aware of their environmental influence and less inclined to modify their moral standards. Additionally, a society's willingness to modify its values is diminished by a lack of awareness of resource cycles (such as those involving water, phosphorous, nitrates, carbon, etc.) and product life cycles[116].

These values are further supported by public concern over the location of industrial development or waste recycling facilities, reprocessing plants, bio-refineries, or energy facilities in residential areas. Overcoming these issues requires addressing how people value recycled, reused, and recovered resources and including them in decision-making[117].

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[109] Sushil Kumar Dey & Bibhas C. Giri (2021), Corporate social responsibility in a closed-loop supply chain with dual-channel waste recycling, International Journal of Systems Science: Operations & Logistics.

[110] Hoffman, A.J., (2003), Linking social systems analysis to the industrial ecology framework. Organization and Environment, volume: 16.

[111] Jackson, T. (2009), Prosperity without Growth: Economics for a Finite Planet. Energy and Environment, volume: 22.

[112] Cooper, T. (2005), Slower Consumption Reflections on Product Life Spans and the “Throwaway Society”. Journal of Industrial Ecology, 9.

[113] Department of Environment, Food, Fisheries and Agriculture DEFRA (2008), A Framework of Pro-Environmental Behaviours.

[114] Trevors, J.T.; Saier, M.H. (2010), The nature connection. Water Air Soil Pollut.

[115] Curtis, F. (2003), Eco-localism and sustainability. Ecol. Econ.

[116] De Flander, K. (2015), Closed Cycles - Open City. In C. Johnson, N. Toly, & H. Schroeder (Eds.), The Urban Climate Challenge: Rethinking the Role of Cities in the Global Climate Regime, New York, NY.

[117] Petts J. (1994), Effective Waste Management: Understanding and Dealing with Public Concerns. Waste Management & Research

It is necessary to address the cultural value attached to wasted (underused) resources such as looping resources and vacant land and buildings, abandoned infrastructure, and grey water[118]. It seems that waste can only be valued when it is profitable in an era of economic rationalism[119].

Lack of conceptual clarity could be one factor contributing to the missing social dimension's consideration. To advance the circular economy discourse and ensure its full contribution to sustainable development, conceptual clarity is crucial. According to Murray et al. (2017), "we can only hope to build on all three pillars of sustainability if social requirements are articulated and included in the basic formulation." In the conceptual context of the circular economy, this requires immediate attention.

3.1.2. Informational barrier

The lack of information about the circular economy is also a big barrier to this transition. The transformation of cultural values, social norms, and structures necessary to promote looping activities depend on information. Information aids in addressing the lack of public awareness and comprehension of resource cycles (water, nutrients, and materials).

Data give urban policymakers and administrators the scientific proof that change is required and that regulation works[120]. Data are also required to enable the public to become more aware of their waste creation, resource consumption (energy, water, and materials), and larger ramifications[121]. Suppliers can efficiently trade, repurpose, recycle, and recover resources thanks to technological data. However, it is a significant difficulty to compile thorough, reliable, and usable data about resources in cities. Enterprises and investors could be afraid of the risks this investment might mean. This is because the circular economy framework lacks specific guidance on how to put the concept into practice. The necessity for tailored or sectoral methods makes it impossible to provide broad guidance because the implementation of a circular economy differs greatly for different products and marketplaces (EMF, 2013). Furthermore, implementing a circular economy approach may necessitate challenging trade-offs.

Similarly, despite the recent publishing of assessment tools to analyze the circularity of organizations[122], there is currently no internationally acknowledged standardisation for circularity

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[118] Evans, D. (2012), Beyond the Throwaway Society: Ordinary Domestic Practice and a Sociological Approach to Household Food Waste. Sociology, 46(1).
[119] Hawkins, G.; Muecke, S (2002),. (Eds.) Culture and Waste: The Creation and Destruction of Value.
[120] Lacovidou, E.; Purnell, P. (2016), Mining the physical infrastructure: Opportunities. barriers and interventions in promoting structural components reuse. Sci Total Environ.
[121] Darby, S. (2006), The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering.
[122] E. M. Foundation, (2014), Towards the circular economy Vol. 3: Accelerating the scale-up across global supply chains

performance. With its transition toolset, Circular Academy[123] makes it easier for businesses to make the shift to a circular economy. To successfully restructure today's economy, however, coordination from a wide range of stakeholders would be required.

Is important that in the transition to the circular economy, enterprises do not fall into the already known "greenwashing", or misleading advertising that tries to make people perceive goods as sustainable that in fact are not. Marketing is certainly a valuable tool for communicating circularity[124]. However, unfair advertising is used to date by many companies that ride the sustainability wave while not taking part in it. This is because they have understood the growing interest of consumers with regard to the origin of the goods and services that they buy but have not yet adopted truly sustainable or circular practices.

3.1.3. Economical and financial barrier

The shift to a circular economy is also accompanied by financial constraints. There are not enough business cases demonstrating potential income. The absence of economic value in recycled, reused, or recovered resources and waste resources significantly hinder the financial sustainability of developing systems of service that permit looping processes. The lack of demand for waste or looping resources, with the possible exception of recovered energy, is the cause of the poor economic worth. Neither the price of virgin and finite resources reflects the negative externalities their use creates, nor does the economic worth of looping resources internalize the positive externalities they provide.

On the supply side, a considerable amount of money will be spent building the new infrastructure necessary to support circular actions (materials, energy, and water). This needs to be considered in cities together with vested interests and sunk costs in current urban infrastructure[125]. A step toward circularity is thought to call for extensive adjustments across the board for the entire organization, affecting every division and activity from the business models to the technical elements, and the relationship with clients, distributors, suppliers, the manufacturing system, etc.

Decontamination (materials, water, and land) and dealing with health hazards connected with recycling, reuse, and recovery (materials, water, energy, and land) increase operational expenses[126]. Future uncertainty caused by volatile resource prices (especially for fossil fuels and recycled materials) and changes in global supply networks make investment in new infrastructure systems

[123] https://www.circular.academy/toolbox/
[124] Dahl R. (2010), Green washing: Do you know what you're buying? Environ Health Perspect.
[125] Bastein, T.; Roelofs, E.; Rietveld, E.; Hoogendoorn, A. (2013), Opportunities for a Circular Economy in The Netherlands.
[126] Swickard, T.J. (2008), Regulatory incentives to promote private sector brownfield remediation and reuse. Journal Soil & sediment contamination.

riskier. It takes time for user groups to adapt to new technology, which might be risky. As a result, private investors may be less eager to invest in the necessary new socio-technical systems. However, if the true cost of using greenfield lands, virgin, and scarce resources were paid, there would be a financial basis for investing in city-wide systems that promote reuse, recycling, and energy recovery.

It could be challenging to persuade owners of a long-term system change because these changes also require time and money, and the financial linear system's rationale is centered on quick returns on investments, and cost savings.

3.1.4. Regulatory barrier

Many levels of regulation impacting resources converge in cities. The macro-level policy framework in Europe is highly defined and supportive of circular measures. The circular economy is central to the goal of a competitive Europe[127]. The Europe 2020 Strategy and the Roadmap for a Resource-Efficient Europe project back this up. However, the international policy remains sector-specific rather than integrative (e.g., the Water Framework Directive, the Energy Efficiency in Buildings Directive, and the Waste Framework Directive), and this is frequently mirrored in national legislation. This legislative structure tends to foster fragmented thinking and sector-specific techniques for managing resources in cities at the municipal level. This puts a stumbling block in the way of cross-sectoral looping operations and nexus solutions. As a result, coordinated cross-sector regulation is necessary.

Regulatory standards can be an effective instrument for assuring the quality of circular resources in both their production and performance. This gives regulators, investors, and consumers with certainty. Adoption of a publicly accessible standard with established credentials, for example, has aided in improving public awareness of grey-water reuse and assisting in the scaling-up of systems in cities[128]. Similarly, urban mining regulations have aided in the repurposing, recycling, and reuse of materials and infrastructure in cities[129]. Standards, on the other hand, can operate as a barrier to circular operations. Building regulations and conservation requirements, for example, impose governmental impediments to the adaptive re-use of infrastructure[130]. As a result, the task for

[127] Ellen MacArthur Foundation, (2015), SUN, McKinsey Centre for Business and Environment. Growth within: A Circular Economy Vision for a Competitive Europe.
[128] Wilcox, J.; Nasirib, F.; Bell, S.; Rahaman, S. (2016), Urban water reuse: A triple bottom line assessment framework and review. Sustainable Cities and Society 27.
[129] Bastien, T.; Roelofs, E.; Rietveld, E.; Hoogendoorn, A. (2013), Opportunities for a Circular Economy in The Netherlands. TNO Innovation for Life.
[130] Bullen, P. (2010), The rhetoric of adaptive reuse or reality of demolition: Views from the field. Cities. 27.

communities is to develop a set of standards that indicate the quality of circular resources. This will also contribute to increasing the economic and cultural value of these resources.

3.1.5. Political barrier

Global neoliberalism appears to have had a substantial impact on the political framework under which European cities operate. This has altered city policies, instruments, and funding decisions. It has increased the number and diversity of parties involved in resource management, altered power dynamics among important actors, and steered municipalities toward a more facilitative role in urban administration. As a result, public funding for new development (infrastructure projects) and services (waste, water, energy, transport, etc.) has been reduced.

To supply circular behaviors in cities, urban provisioning systems will require significant economic, institutional, and technical reorganization. Such a shift will necessitate long-term political support and leadership, which the current political culture of short-term, market-driven, reactive decision-making does not support.

There are regulatory systems that encourage looping actions, which should inspire public policies to support these activities in cities. Furthermore, political agendas may occasionally clash with looping measures and differ between national and local levels of government. The political case for looping activities could be created if the social, environmental, and economic advantages were be measured. Policy gaps are caused by a lack of leadership and coordination between local agencies and levels of government, which undermines policy coherence. Because the circular economy is systemic in nature, a cross-sectoral approach is required to ensure that the city rethinks urban policies and their relationship with resource efficiency holistically, going beyond the optimization of existing policies to achieve targeted environmental goals such as CO2 emission reduction. Data demonstrating the benefits would provide a strong political incentive to support these approaches.

3.1.6. Institutional barrier

To support looping efforts in cities, institutional capacity will need to be developed. New authorities are needed to develop and enforce standards for recycled and reused resources (materials and greywater), as well as to regulate circular operations[131]. Institutional mechanisms

[131] Wilcox, J.; Nasirib, F.; Bell, S.; Rahaman, S. (2016), Urban water reuse: A triple bottom line assessment framework and review. Sustainable Cities and Society 27.

that encourage new ownership models that allow for the reuse of commodities and infrastructure are critical to success[132]. Institutions that gather, share, monitor, and regulate data use are required to stimulate the recycling of material waste, land, and structures, as well as the reuse of infrastructure, commodities, grey-water, and heat[133]. In order to transform systems of provision, social practices, and lifestyles that discourage looping activities, institutions will be necessary to facilitate learning within industry, commerce, and the community[134]. Because of strong interests in conserving present methods and minimizing risk across all resource types, there will be institutional (cultural and structural) resistance to change[135]. These will have to be overcome in order for looping actions to be possible.

Nexus systems that enable integrated resource looping (especially materials, energy, and water) in city-regions confront unique institutional problems. The key issues are integrating urban resource systems and coordinating the agendas of many actors to enable looping operations. Cities contain numerous subsystems comprised of various infrastructures, urban services, and varied resource flows[136]. This adds to the technological and organizational complexity of integrating the entire system and establishing partnerships for recycling, reuse, and recovery. This difficulty is worsened by administrative fragmentation and professional silos, which impede the possibility for cross-sector resource flow integration[137]. Systemic, coordinated action across policy sectors, public and private institutional borders, and state jurisdictions is essential[138].

3.1.7. Technical and design barrier

The city can be considered as a complex socio-technical system in which infrastructure and urban shape have evolved alongside the social activities and lifestyles of individuals who live and work there. These systems do not utilize circular design or thinking. This results in a socio-technical lock-in, which strengthens linear and segregated providing systems[139]. Even if institutions supplying urban infrastructure and services are eager to use a circular design or integrated approaches, changing these infrastructural systems is essentially impossible due to the capital expense and disruption caused by such a major transition. To promote the deployment of circular

[132] Bastien, T.; Roelofs, E.; Rietveld, E.; Hoogendoorn, A. (2013), Opportunities for a Circular Economy in The Netherlands. TNO Innovation for Life.
[133] Sam Allwinkle & Peter Cruickshank (2011), Creating Smart-er Cities: An Overview, Journal of Urban Technology, 18:2.
[134] Bullen, Peter. (2010), The rhetoric of adaptive reuse or reality of demolition: Views from the field. Cities. 27.
[135] Thornton, G.; Franz, M.; Edwards, D.; Pahlen, G.; Nathanail, P. (2007), The challenge of sustainability: Incentives for brownfield regeneration in Europe. Environmental Science & Policy, Volume 10, Issue 2.
[136] Boons, F.; Spekkink, W.; Mouzakitis, Y. (2011), The dynamics of industrial symbiosis: A proposal for a conceptual framework based upon a comprehensive literature review. Journal of Cleaner Production, Volume 19, Issues 9–10.
[137] Andersson, Kim, Sarah Dickin, and Arno Rosemarin. (2016), "Towards "Sustainable" Sanitation: Challenges and Opportunities in Urban Areas" Sustainability 8, no. 12.
[138] Smith, A. (2007), Emerging in between: The multi-level governance of renewable energy in the English regions. Energy Policy, Volume 35, Issue 12.
[139] Williams, J. (2016), Can low carbon city experiments transform the development regime? Futures, Volume 77.

and/or interconnected systems (nexus solutions), citizens must establish new cultural values and social practices. One of the most difficult tasks is implementing circular and interconnected systems in cities. Of course, certain components already exist, but redesigning systems would be prohibitively expensive. It would also cause a significant disturbance. Furthermore, there is no guarantee that they will be used by the people.

The scarcity of space in cities limits the adoption of circular infrastructure or the alteration of urban form to facilitate circular actions. Pollution and environmental degradation in metropolitan areas can also make circular acts difficult. Land contamination, for example, lowers the capacity for greywater reuse and land recycling[140]. Restoration of these resources and the ecosystem services they support takes time, which can be difficult to manage in short political cycles[141]. Circular activities face several obstacles in the urban context and the existing infrastructure and layout are frequently rigid[142].

3.2. Nature-based solutions for water treatment

Water is essential for human well-being, socioeconomic development, and long-term environmental functions[143]. Water is the most important and universal resource, also including several nutrients; hence, water systems intersect with all aspects of society, industry, and the natural environment[144]. The increased stress on finite water resources has reached a catastrophic level in recent years, resulting in both diminished water availability and compromised water quality[145]. Water shortage is a major stressor in many ecosystems because ecosystems cannot function without adequate water supplies of proper quality[146]. Furthermore, global demand for water is predicted to surpass viable resources by 40% by 2030 if current trends continue[147]. As a result, the task is to

[140] Wilcox, J.; Nasirib, F.; Bell, S.; Rahaman, S. (2016), Urban water reuse: A triple bottom line assessment framework and review. Sustainable Cities and Society, Volume 27.
[141] Anderson, E.C.; Minor, E.S. (2017), Vacant lots: An underexplored resource for ecological and social benefits in cities. Urban Forestry & Urban Greening, Volume 21.
[142] Lacovidou, E.; Purnell, P. (2016), Mining the physical infrastructure: Opportunities. barriers and interventions in promoting structural components reuse. Sci Total Environ.
[143] UNEP (United Nations Environment Programme) (2009), Water Security and Ecosystem Services. The Critical Connection. A Contribution to the United Nations World Water. United Nations Environment Programme.
[144] IWA (International Water Association), 2016. Water utility pathways in a circular economy: charting a Course for Sustainability. https://iwa-network.org/water- utility-pathways-circular-economy-charting-course-sustainability/.
[145] Sgroi, M., Vagliasindi, F.G., Roccaro, P., (2018), Feasibility, sustainability, and circular economy concepts in water reuse. Current Opinion in Environmental Science & Health, Volume 2.
[146] Voulvoulis, N., (2018), Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science & Health, Volume 2.
[147] Wintgens, T., Nattorp, A., Elango, L., Asolekar, S.R., (2016), Natural Water Treatment Systems for Safe and Sustainable Water Supply in the Indian Context: Saph Pani.

meet or control the conflicting need for water while minimizing environmental harm and regenerating natural ecosystems[148].

To satisfy their water demand, many cities rely on extensive supply infrastructure to transfer water over long distances. This infrastructure approach limits the resilience of cities against the effects of climate change because the infrastructure cannot be easily or cost-effectively adapted, expanded, or repaired. In light of the increasing pressure on water resources worldwide, the integration of decentralized approaches into existing centralized infrastructure is essential for achieving sustainable, efficient, and affordable water resource management[149], increased water reuse[150], and establishing a circular water economy[151]. For example, the rigidity of grey infrastructure of waste and greywater treatment in cities makes improvements difficult to apply.

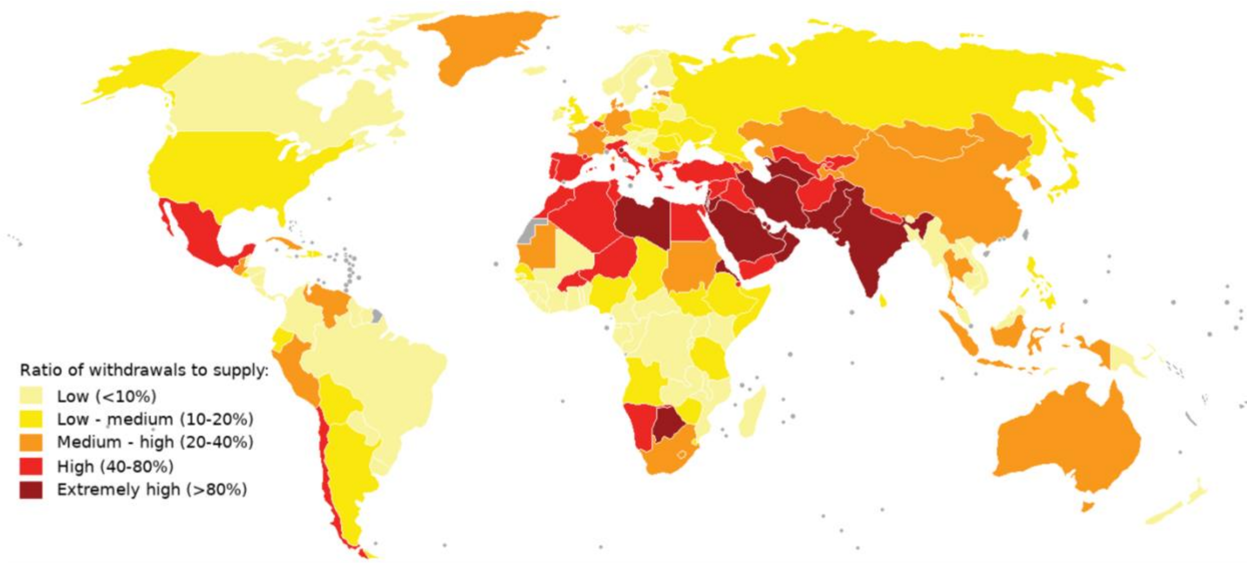

Figure 9 - Water stress per country in 2019 – Source: Sengupta S., A Quarter of Humanity Faces Looming Water Crises, 2019. (Downloaded on September 20 14, 2022)

Surface and groundwater in urban areas are polluted by point and nonpoint sources that harm the quality of life, ecology, and land values in cities. The chemical and biological hazards stemming from release of inadequately treated water (such as during extreme rain events) can no longer be ignored, especially with the increasing concerns surrounding priority substances and contaminants of emerging concern such as micropollutants and microplastics.

148 WWAP (United Nations World Water Assessment Programme), (2018), The United Nations World Water Development Report 2018: Nature-Based Solutions for Water.
149 Water Europe (2017) Water Europe Vision 2030. Brussels.
150 European Commission (2018) Regulation on minimum requirements for water reuse.
151 Circular Economy Package http://ec.europa.eu/environment/circular-economy/index_en.htm

The move to circular water systems necessitates the restructuring of water infrastructure, the use of current technological advances, and the incorporation of nature-based ecosystems into grey infrastructure (i.e., hybrid infrastructure)[152]. Existing concepts and approaches that use and enhance nature, such as ecosystem-based adaptation (EbA), green infrastructure (GI), ecosystem services (ESS), and nature-based solutions (NBS), have gained traction as they address challenges (e.g., climate mitigation and adaptation, water management, degradation and loss of natural capital, disaster risk reduction, etc.) in a more sustainable manner than conventional hard engineering. While all four ideas share the common premise of multifunctionality, NBS can be thought of as an umbrella concept for the others, with a strong solution-oriented focus and biodiversity at its core[153]. Several definitions have been used to characterize NBS to date, including those supplied by EC, 2015b, Cohen-Shacham et al. (2016), Raymond et al. (2017), O'Hogain and McCarton (2018), and Langergraber et al (2019a). They believe that NBS should be cost-effective, resource-efficient, and locally tailored. NBS are systematic actions that increase the amount and diversity of nature and natural characteristics and processes. They address numerous challenges while providing environmental, social, and economic advantages such as biodiversity, climate change mitigation and adaptation, resilience, human well-being, and so on. While CE strives to alleviate the environmental stress of socioeconomic activities, NBS has the ability to improve environmental and ecological status as well as meet human demand for natural resources.

Nature-Based Solutions for Water Treatment (NBS^{WT}) are green infrastructure components that can complement existing grey infrastructure for water, stormwater, and wastewater management in urban environments. NBS^{WT} provide improved water quality, reduced flood risks, and increased ecological connectivity, while serving as attractive components of the urban landscape, providing important ecosystem services[154] and contributing to the creation of a circular water economy[155]. The EU Research and Innovation Agenda for NBS recognize that nature-based approaches are an essential component to achieving sustainable development in urban areas[156]. Cities that want to become more climate-resilient are making it a top priority to increase investments in NBS to address the social, economic, and environmental challenges they are facing[157]. Nevertheless,

[152] O'Hogain, S., McCarton, L., (2018), A Technology Portfolio of Nature Based Solutions: Innovations in Water Management.
[153] Pauleit, S., Zo€lch, T., Hansen, R., Randrup, T.B., Konijnendijk van den Bosch, C., 2017. Nature-based solutions and climate change e four shades of green. In: Kabisch, N., Korn, H., Stadler, J., Bonn, A. (Eds.), Nature-Based Solutions to Climate Change Adaptation in Urban Areas. Theory and Practice of Urban Sustainability Transitions.
[154] Oral, Hasan Volkan et al. (2020), A review of nature-based solutions for urban water management in European circular cities: a critical assessment based on case studies and literature. Blue-Green Systems.
[155] UN-Water (2018) The United Nations World Water Development Report 2018: Nature-Based Solutions for Water.
[156] European Commission, Directorate-General for Research and Innovation, (2015), 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), Publications Office.
[157] UN-HABITAT (2018), City Resilience Profiling Tool Guide.

decision-makers still need a better understanding of what NBS^{WT} can deliver in terms of water quality improvement, risk abatement, and co-benefits, and what are the capital and operational costs of NBS^{WT} compared to conventional infrastructure options. In **Error! Reference source not found.** we can see an example of NBS^{WT} applied on an urban scale, a plant-based unisex urinal treating wastewater in an integrated vertical constructed wetland ecosystem. The treated wastewater is reused for flushing and the nutrients in urine are transformed into fertilizer.

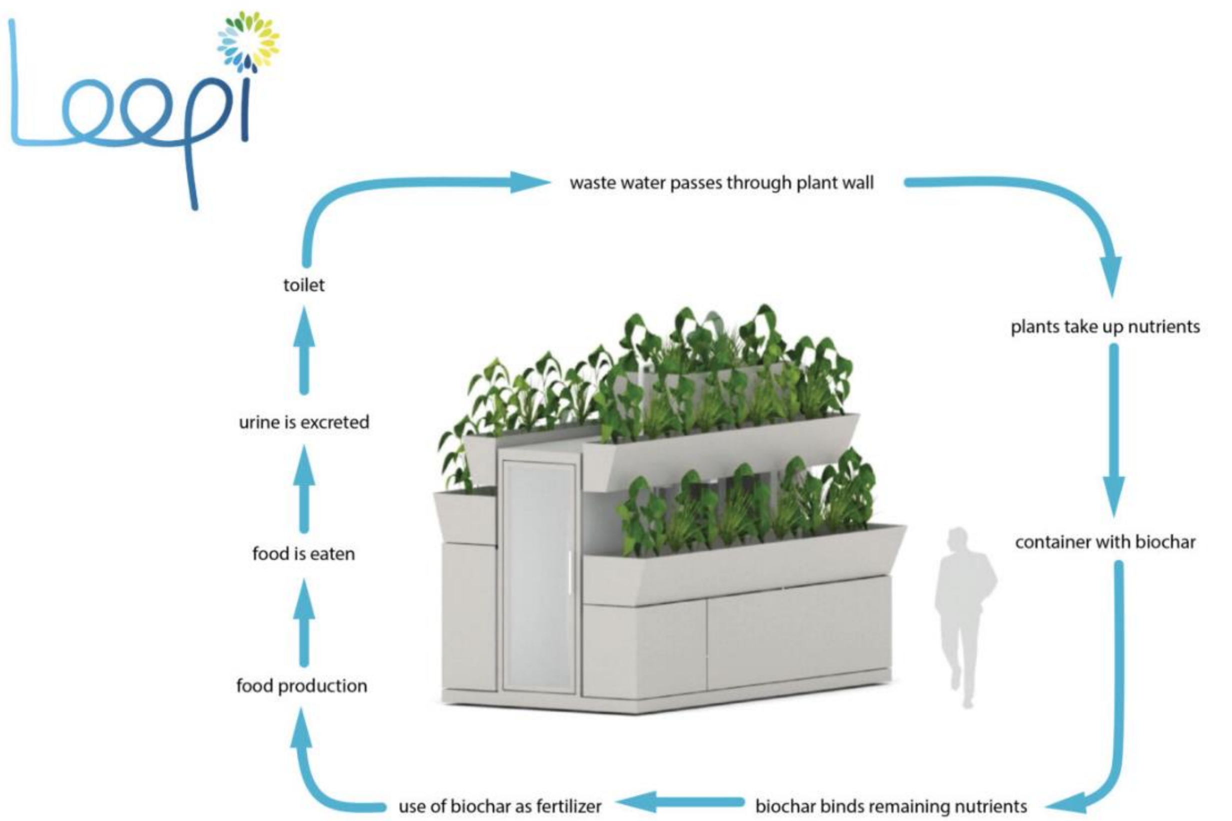

Figure 10 - Loopi Project by alchemia-nova, source: https://www.alchemia-nova.net/products/loopi (Downloaded on October 2, 2022)

Despite the recognized potential of NBS^{WT} for increasing urban resilience, there is an overall lack of large-scale integration of NBS^{WT} into urban environments, as reflected in the recent European Green Deal[158]. Decision-makers at all levels of government (particularly at local level) often simply lack the tools to conduct large-scale strategic decision-making for integrating NBS^{WT} in different geographical and economic conditions. On a technical level, there is a knowledge gap regarding the performance of these systems and their response to variations in pollutant and hydraulic

[158] European Commission (2019), The European Green Deal.

fluctuations due to climatic events such as storms or droughts. From an economic perspective, financing to stimulate rapid uptake of NBS^{WT} must look beyond private sector investment and towards spatial planning, regulation, and tax incentives[159]. Analysis of NBS-related EU projects suggests a need for new methods of co-created research that not only bring together academic researchers with non-academic local experts and a need to define a framework in which stakeholders can work together effectively and productively. The widespread uptake of NBS^{WT} is in part hindered by an inability to identify and prioritize implementation strategies on a significant scale. Improved cross-sectoral communication, stakeholder engagement, and awareness of issues related to equitable development and water are needed to accelerate the uptake and integration of NBS^{WT} into urban water cycles. In order to compete with classic water management approaches such as centralized wastewater management, NBS^{WT} must be economically feasible. Urban water management scenarios for different combinations of NBS^{WT} must be tailor-made, account for site-specific conditions and needs, and be complemented by a framework that can help private sector stakeholders formulate successful business models for NBS^{WT} implementation on a city-wide scale.

Due to the lack of a water circularity definition, this research considers the white papers of Stuchtey (2015), IWA (2016), and Arup et al. (2018) to determine what needs to be quantified for measuring circularity in water systems. Following the water, energy, and materials/nutrients routes, the three concepts of “Regenerate natural capital,” “Keep resources in use,” and “Design out waste externalities” should be reviewed.

The “regenerate natural capital” idea seeks to sustain functional environmental flows and stocks by lowering anthropogenic water use, preserving, and strengthening ecosystems, and minimizing human interactions and use disruptions.

Ecological integrity aims to reduce water and nutrient loss while increasing nutrient and water storage capacity (i.e., soil nutrient retention, soil organic matter, soil water storage).

The “keep resources in use” principle's purpose is to close the system's water and water-related material and energy loops. It can be accomplished by optimizing resource yields, energy and resource extraction, and recycling and reuse. Recirculation of resources to close loops necessitates a sufficient quantity and quality of reused resources to meet internal demands, resulting in a reduction in the number of resources extracted from nature and the amount of returning flows.

[159] European Commission (2020), Nature-based Solutions: Improving Water Quality & Waterbody Conditions: Analysis of EU-funded projects.

The “design out waste externalities” principle emphasizes both waste reduction and system economic efficiency, i.e., the costs of decreasing waste by one unit are equal to the economic and environmental benefits of having one less unit of trash. The reduction is done by taking activities to achieve the “keep resources in use” premise, while the residual waste (i.e., gaseous, liquid, and solid) has environmental consequences, hurting the “regeneration of natural capital” principle. As a result, the assessment must take into account the environmental consequences, prevent negative environmental impacts, and economic benefits and costs.

By changing existing systems and grey infrastructure, all three CE principles can be realized. While traditional grey infrastructure can be constructed to improve water reuse and resource recovery, it is not the same as the concept and paradigm of NBS. Natural processes are used by NBS, i.e., they operate with nature, whereas grey systems (infrastructure) utilize additional energy to achieve circularity. The incorporation of NBS into urban water management naturally increases the circularity of the urban water system, hence shifting urban water management towards CE.

Water in the CE should be placed without the use of needless additional energy, which would be required for the modification of the current greywater infrastructure. In particular, the application of NBS might result in the creation of new (hybrid) systems that better utilize the three principles. For example, constructed wetlands that treat road runoff will avoid water pollution, recharge groundwater, and boost biodiversity (see Figure 11). Wetland roofs will collect and treat rainwater for non-potable home usage, while also operating as a cost-effective and resource-efficient natural “air conditioning.” As a result, by utilizing their multifunctionality, NBS can aid in the transition to circular water systems.

The installation of a single NBS can provide many co-benefits connected to circularity at the same time as traditional grey infrastructure, which requires multiple mono-functional engineering solutions. Furthermore, because NBS connect nature-managed to human-managed systems, they should be considered as a critical component in identifying methodologies to holistically analyze the circularity of water systems. Any examination of water circularity can be done at three different scales: micro (single components), meso (interconnected components constituting a system), and macro (catchment, city, region, or national).

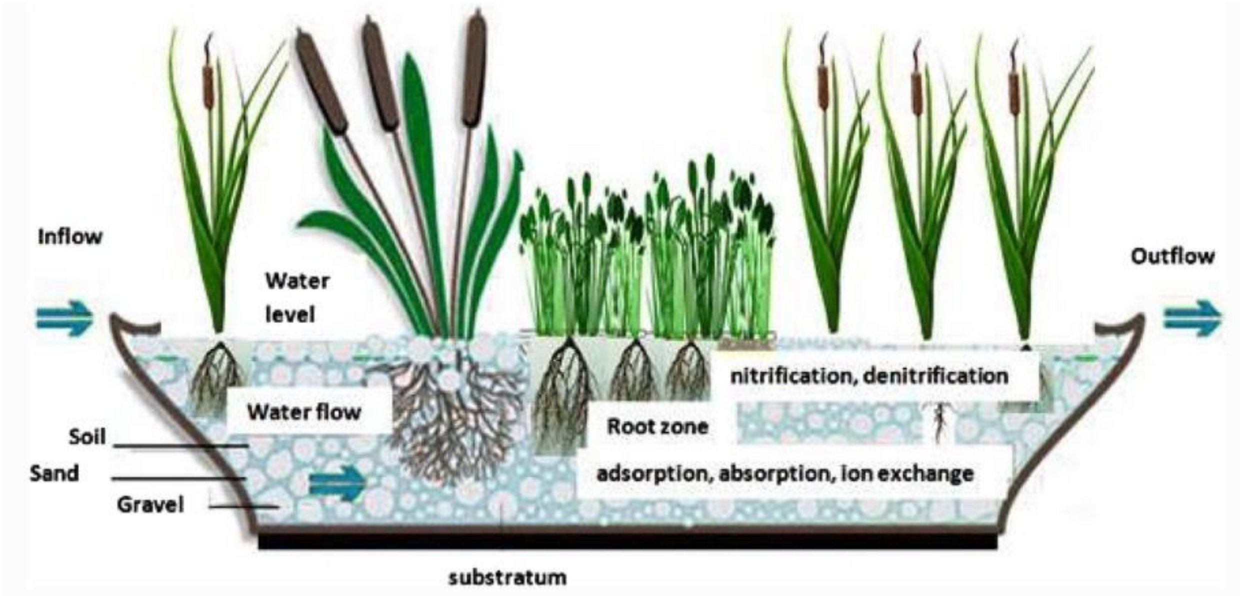

Figure 11 - Constructed wetland - Source: Kumar S., CW microcosm as sustainable technology for domestic wastewater treatment: an overview, 2019. (Downloaded on July 15, 2022)

Evaluation procedures at any scale must incorporate other scales of assessment in order to provide considerable value and become useful. As a result, the interconnections that the examined system has with other systems and scales must also be considered, by giving the information needed for the assessment at higher stages.

4. Urban water treatment in cities: urban experiences

Alchemia-nova was founded in Vienna in the year 2000 by Hanswerner Mackwitz, an eco-pioneer of the first days. After his death in 2010, alchemia-nova was restructured and led it from a 2-3 person institute to a 30-person research and innovation institute with an international profile. In 2006, they became Cradle to Cradle® partner. Ever since, they are fully dedicated to circular economy principles.

Figure 12 - alchemia-nova history timeline – Source: https://www.alchemia-nova.net/about-us/ (Downloaded on April 30, 2022)

Alchemia-nova tries to bring science to the market. Their leitmotif includes research, development, and education as well as productization, selling, and consulting of circular economy and nature-based solutions. They do so by combining and integrating 6 different research areas, which also reflect the 6 colors in the logo (see Figure 13)

Figure 13 - alchemia-nova logo from the website - Source: https://www.alchemia-nova.net/about-us/ (Downloaded on April 30, 2022)

Alchemia-nova offers different services, among them:

- Circular economy check: they examine the circularity of existing production methods, industrial processes, and supply chains. They co-develop measures to improve circularity performance. Solutions include product redesign, resource recovery, cascading utilization strategies, and re-valorization of side streams.
- Bio-based & circular alternatives: they support the development of greener products through circular process design and consultation on bio-based sustainable alternatives to non-renewable materials, based on Cradle-to-Cradle standards.
- Nature-based solutions: they offer standardized and customized solutions for plant-based water and air-purification in-and outdoors including green walls and green roofs, mitigation of heat-island effects, ecosystem restoration, and enhancing biodiversity.
- Cascading valorisation of residues: through applied biorefining and deep know-how of state-of-the-art technological developments, they conceptualize the optimal utilization of all resource flows and provide a roadmap towards the development of future-proof processes and products.
- Innovation pathways & funding opportunities: they have developed numerous innovation projects in line with cutting-edge science, matched with societal and industry needs. Their approach is always aligned with prevailing policies and framework conditions, such as the current EU Green Deal. They further assist in finding and applying for suitable research grants from the EU or national funding schemes.

Among the main projects that alchemia wrote or participated in, there are:
CATCO2NVERS[160], is a European project that aims to develop and optimize technologies that convert CO2 into different types of chemicals that can be used for many things: making plastics, used as an energy source (bio methanol), for cosmetics, or for industrial processes.
Another important project is called HOUSEFUL[161], and its aim is to develop technical solutions in combination with building-level services to be offered within the framework of closed-loop

[160] https://www.alchemia-nova.net/projects/catco2nvers/
[161] https://www.alchemia-nova.net/projects/houseful/

management models. The focus is on solutions that enable the efficient use of water, waste, energy, and material resources.

With DIVAGRI, alchemia aims to increase the productivity, income, and economic opportunities of subsistence and smallholder farmers in arid and semi-arid regions of Sub-Saharan Africa by implementing state-of-the-art, innovative bio-based solutions that will improve agricultural production, enable diversification of crops and increase added-value, create environmental, social, and economic sustainability, and generate new local economic opportunities.

Even if all these projects have interesting and innovative elements, for this research I decided to focus on another European project called MULTISOURCE, which is going to be described in the next section.

4.1 Project MULTISOURCE at a glance

The project MULTISOURCE (ModULar Tools for Integrating enhanced natural treatment Solutions in Urban water CyclEs) is a four-year project, financed by the Horizon2020[162] European funding program. MULTISOURCE has the objective to provide the knowledge, tools and business models that will enable stakeholders to conduct fit-to-purpose, large-scale planning in their city. In doing so, the project promotes circularity and sustainable development in the urban water sector and enables the widespread uptake of NbS^{WT}, storage, and reuse in urban areas worldwide.

MULTISOURCE monitors 7 distinct NbS pilots across Europe and works with four municipal and metropolitan public authorities (Lyon, Girona, Milan, Oslo are project partners) to develop a set of tools, increased evidence, as well as business models. Finally, MULTISOURCE also focuses on the applicability of its solutions to cities beyond Europe, with its consortium partners from Vietnam, Brazil, and the United States, as well as an International Advisory Board.

The main aim of the project is:

- Demonstrate the pollutant removal and risk abatement capacities of enhanced natural treatment systems, as well as the ecosystem benefits and values they provide
- Enable stakeholders in developed and developing countries, including local municipality and metropolitan areas government staff, to reduce pressure on existing infrastructure and freshwater resources by using MULTISOURCE tools to plan, finance, and implement NbS^{WT} in their region.

[162] Horizon 2020 was the EU's research and innovation funding programme from 2014-2020 with a budget of nearly €80 billion.

- Accelerate the uptake of nature-based solutions in urban water management worldwide
- Normalize social equality as an integral target of green-infrastructure and smart urban development
- Enhance cross-sectoral international collaboration among governmental staff (both practitioners and policymakers), educators, researchers, and the general public.

Figure 14 - Key components of MULTISOURCE – Source: Description of Action, 2021. (Downloaded on May 10, 2022)

The overall objective is to facilitate the systematic, citywide planning of nature-based solutions for urban water treatment, storage and reuse.

The overall concept of MULTISOURCE focusses on the intersection of NbS^{WT} with the four key areas of environment, circular economy, society and policy (see Figure 15)

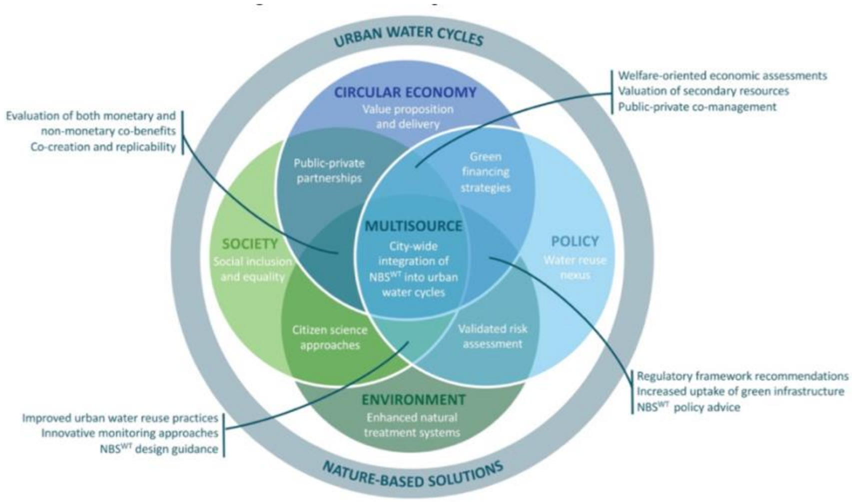

Figure 15 - Overall concepts of MULTISOURCE – Source: Description of Action, 2021. (Downloaded on May 10, 2022)

Stakeholder engagement is a key element of MULTISOURCE. Effective and inclusive stakeholder engagement methodologies will be used in the definition of co-benefits for each pilot, as well as for the development of business models and planning tools. Enhanced Natural Treatment Solutions (ENTS) are, for the purpose of this project, defined as a sub-group of NBS^{WT} that have an increased treatment capacity, lower cost, and/or smaller environmental footprint in comparison to conventional NBS^{WT}. ENTS provide primary benefits of increased water quality, water storage, and reuse, but also contribute to the creation of valuable urban habitats and provide other important ecosystem services.

Regarding the barriers above mentioned for the circular actions, on this project, they are trying to avoid these problems through research and stakeholders' active participation. MULTISOURCE will conduct a thorough review of literature on NBS^{WT} operating in outdoor, relevant conditions worldwide as well as review results from existing H2020 projects on NBS^{WT} to establish a solid knowledge base of at least 500 successful case studies, which will subsequently be integrated into the MULTISOURCE Technology Selection Tool. A secondary literature review on the nexus between NBS^{WT}, community participation and social inclusion, and gender equality is also conducted. This information, combined with data generated by the seven pilots and data shared by MULTISOURCE international partners in Brazil, the United States, and Vietnam, will provide unique insight

on the capacity and costs of NBS^{WT} for a range of polluted waters under a wide variety of climatic, socio-economic, and environmental conditions.

MULTISOURCE identifies key stakeholders and establishes and facilitates their engagement in the monitoring of the ENTS pilots and the co-design of the business models and tools, ensuring the inclusion and integration of a wide range of perspectives from local, national, and international viewpoints and from different groups of society. The project is also enabling stakeholders to perform a comparison of different urban water management scenarios, both with and without NBS^{WT}, for a selected local region, providing spatial planning information and cost ranking for different scenarios. To approach the financial barriers that usually are present in this kind of innovative action, the project will co-develop business models by local actors, involved with planning and permits, management, financing, and operations and maintenance (O&M) of NBS^{WT}. New business models will be based on cost-benefit assessment and identifying additional value, including non-monetary value, provided by NBS^{WT}. Opportunities for resource recovery will be considered in economic calculations and pricing systems, as well as other natural assets provided by nature-based solutions for water treatment. Because of the direct engagement of local, national, and international stakeholders from the start, the co-developed business models will be applicable across a variety of operational settings and regulatory frameworks. MULTISOURCE business models will assist public authorities and other stakeholders in developing strategies to accelerate the adoption and integration of NBS^{WT} in their local urban settings.

To ensure maintaining a plural and heterogeneous perspective, a number of interviews were conducted in this framework, to collect the experiences and thoughts from different European stakeholders that do and do not work with NBS. The questions (see ANNEX 2) seek to get more into the private and public stakeholders' needs and to try to understand the strengths and weaknesses of these solutions, and the general experiences they have had in their application. During our interview we also interviewed people who have never applied these solutions, to understand why, and what obstacles they find in doing so.

During the analysis of the data obtained from the interviews and the survey, we identified the different needs that the stakeholders have for the application of NBS^{wt}.

We thought that to understand how to make these solutions work, there is a need to probe into the needs of each actor, always having in mind the context where they are. The different characteristics that define different scenarios, can make even different needs evident. Instead, in our research, we found common factors present in different realities that prevent the proper application of these solutions (see Table 2).

	Urban planning department	Environment & urban resilience dept	Sewer system dept	Public water agencies and suppliers	Wastewater treatment companies	Public real estate dev.	Private real estate dev.	Architecture & landscape arch. firms	Local actors
Needs		Financing	Partner for above-ground leadership	Monetary incentive	Expertise on NBS placement, and selection	Norms, permits	Norms, permits	Norms, permits	Financing (public, community based)
	Evidence for economic efficiency /cost benefits analysis (CBA)	Costs benefit analysis	Selection of solutions	Reliable technology supplier	Financial support for initial investment	Operations & Maintenance	Operations & Maintenance	Technology experts	Appropriate management committee
	Technical expertise for selection & planning	Operations & Maintenance		More NBS knowledge		Technology experts	Technology experts	Guidance on planning process	
						Costs benefit analysis	Costs benefit analysis		

Table 2 - Needs of each stakeholder in implementing NBSWT – Source: Interviews analysis' results, 2022.

One of the current issues in common was the need of more information about these solutions:

"A lot of education is still needed. There is a lot of work to be done, especially the Involvement of citizens" (Urban development department Municipality – Italy).

"No guidelines have been provided on the long-term maintenance of these NBSs, so our personnel are learning from their experience" (Wastewater treatment company – Italy).

"I think, public awareness is key. Because if that area is accessible for the public, you really need to have them on board, because otherwise, it will not work. (...) So that's something that you need, to let them know that this is for them, that we are treating their water, that we want to close the water circle, even more. Public perception is key" (Public water agency - Belgium).

Another common issue among partners is the lack of financing. It was mentioned that public financing is currently present (for example the PNRR[163] in Italy), but this kind of economic support does not allow the projects to be *sustainable* in a matter of *time*, because when the public money ends, private financing is needed to ensure its continuity. A direct relationship was found between the lack of information about NBS and the difficulty to get investments.

*"There is still a significant barrier to nature-based solutions about investments. And part of that is because investors have got a high degree of confidence in both the cost and the benefits of what grey solutions can deliver, but they don't have a great idea of the cost or benefit that can be delivered by NBS" (*Local actor - UK*).*

"We don't really have like cost analysis comparing traditional solutions and nature-based solutions, but we're working on it. We need some studies and documents showing that this is actually cheaper, and also showing the bigger picture" (Urban development department Municipality – Poland).

The regulatory barriers are also considered a common limitation to applying nature-based solutions in cities. In cities, there are many levels of regulation impacting the resources. Regulatory standards can be an effective instrument for assuring the quality of these solutions. This ensures the regulators, investors, and consumers.

"South of Europe and Eastern Europe don't even have any regulation at all, to push or like to even allow possible solutions. And this happens in many parts of the world. On the other hand, (...) in Germany, (...), but also in China, in a more extreme way, NBS solutions are fostered by

[163] Piano Nazionale di Ripresa e Resilienza, provides a package of investments and reforms with six missions, including the Green Revolution and Ecological Transition.

the government, so you're obliged to have them no matter what. So generally, the political climate plays a major role" (Real Estate Developer – Germany).

"The lack of legislation is a huge barrier. For us to intervene in riverbeds, naturalization, for example, means to ask for a lot of permissions national government, hydrographic institutes, and so on. That's a big hurdle that we need to surpass" (Environment and urban resilience department – Portugal).

"So, one thing we had in HOUSEFUL[164] was that there was a huge amount of difficulty in obtaining permits, not necessarily for green facades, or the green solutions, but for a lot of innovativenature-basedd solutions that are involved in the project permits was a huge issue, because I mean, this is kind of a new frontier. And in many countries, the planning guidelines are very localised, so means that the planning guidelines in one city or one commune, will be different than in a neighboring city or neighboring commune. And it's a really decentralized system of planning in terms of what's allowable, what's permissible. And indeed, I think, if I'm not mistaken, one of the solutions we had from HOUSEFUL which was the home biogas solution, couldn't go ahead in one of the demo sites, because the local authority said, well, actually, as far as we can see, this is illegal within our jurisdiction, because you can't have effectively this kind of digesting system to make gas that near to residential building because the risk of explosion or whatever is too high. So yeah, there's definitely a regulatory barrier" (European Federation of Public, Cooperative & Social Housing).

The project is starting the second of four years of implementation. Several improvements and research still have to be done in order to reach every expected objective.

Nature-based solutions

One thing seems to be clear, these projects can involve a lot of innovation and development, but if they are not accompanied by new policies at the local level, with social and political involvement, they will not represent long-term solutions.

[164] https://houseful.eu

4.2. Ecological rationality: a qualitative methodology

In the framework of the MULTISOURCE project, online semi-structured interviews were conducted with 28 different stakeholders with the aim to gain an understanding of their priorities, mandates, and needs regarding nature-based solutions applied to urban water treatment.

The categories of actors interviewed were:

- 10 urban public authorities
- 9 water and wastewater agencies/utilities
- 7 public and private real estate developers
- 2 local NGOs

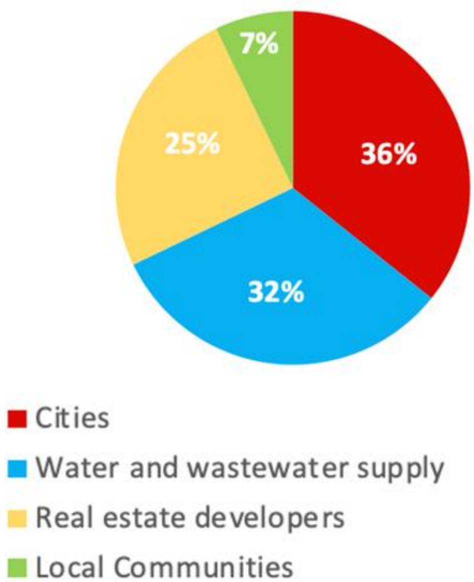

Figure 16 - Stakeholders composition - Source: interviews' analysis results. (Generated on October 30, 2022)

With the interviews, we gained qualitative information about experiences and positive or negative project development processes, with special attention to the current challenges, priorities, and opportunities that the actors face. The descriptive data analysis was done via observation and comparison of the answers. The interviews were done using the videoconference application Zoom, and were conducted in English, Italian, French, Portuguese, German, and Spanish, depending on the local language of the stakeholder. We decided to do this because we consider that communicating in the mother tongue may improve the quality of the answers. All the interviews' transcriptions have been made available on Google Drive so that they can be accessed and worked on effectively by the working group.

Stakeholders from 12 different countries were included in the interviews (see Figure 17). The latter have been transcribed and translated, and a thematic analysis was conducted on www.app.mural.co. This involved coding all the data before identifying and reviewing 10 key themes. Each theme was examined to gain an understanding of participants' perceptions and motivations. In each category, the quotes of the stakeholders were written. The information division categories for each stakeholder were:

General description
Tasks and goals
Priorities and obstacles
Opportunities and successes
Quotes
Services and NBS interested in
Attitudes towards NBS
Capacities
Needs
Roles

A survey was sent to the participants before the interview (see ANNEX 1), with qualitative information asked, to see if there was a statistically significant relationship between, for example, the kind of environmental challenges that an actor faced in their region, and the importance score they gave to the NBS that answered to that challenge.

The survey was conducted on LimeSurvey Cloud (https://www.limesurvey.org/), and the link was sent to all the participants to be answered before the conduction of the interview. The survey answers were downloaded and analyzed in Excel, allowing the creation of several charts and tables describing the results more clearly.

For the analysis, we focused in particular on the stakeholder's common priorities, roles, and needs to apply the NBS. It was also crucial to analyze the kind of partners that actors consider important to encourage this kind of solution through funding.

To do the analysis and facilitate the comparison, we put the information into tables, to also make the reading of the data easier.

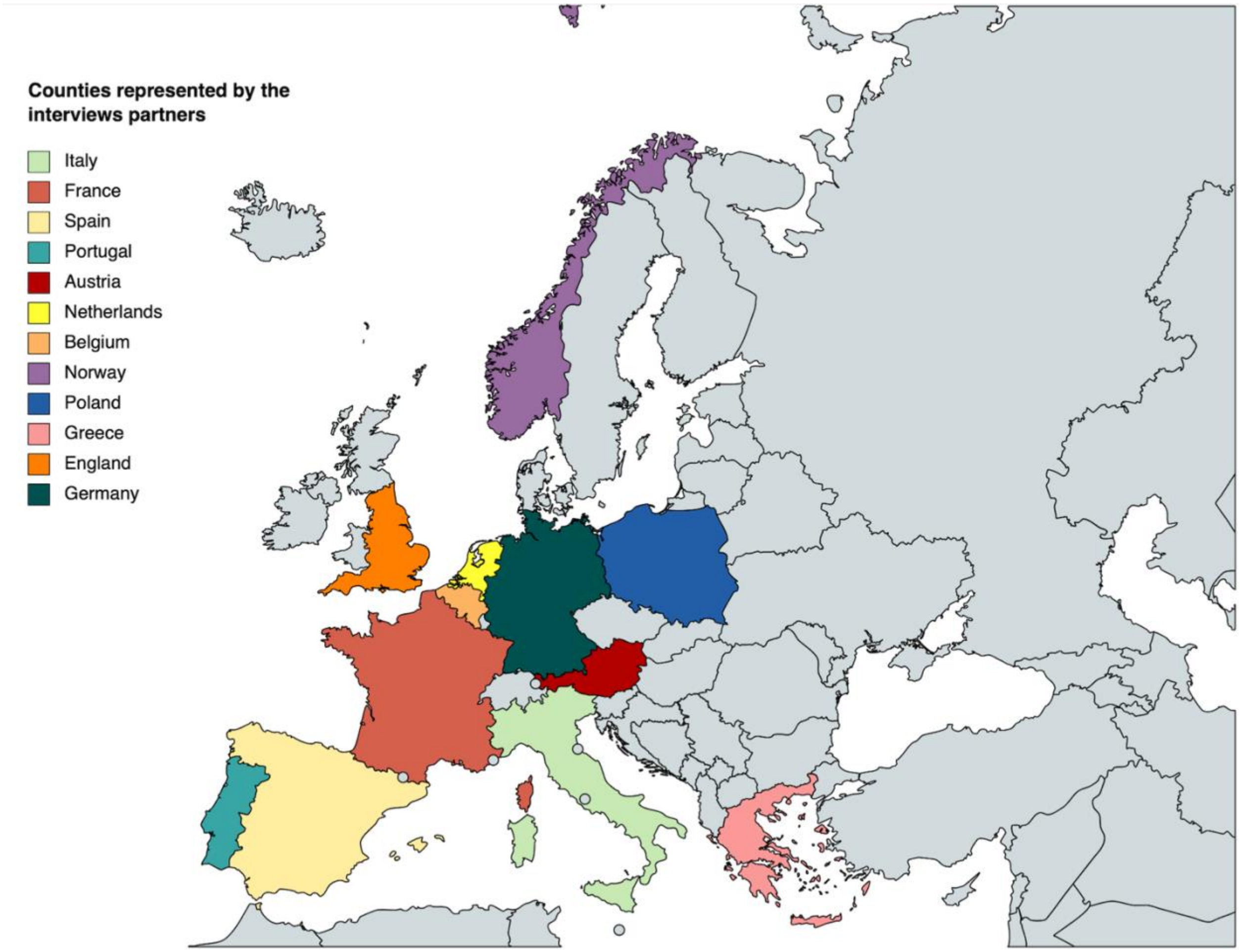

Figure 17 - Map with all the countries represented by the interviewed stakeholders – Source: interviews' analysis results. (Generated on October 30, 2022)

With all the information collected and analyzed, a white paper and a project deliverable will be written, which includes the exposition of all the research results.

Conclusion

If we want to be sustainable and build a circular economy, we will have to understand systems, and fortunately, systems thinking, and complexity awareness are spreading fast. In order to progress we need an interdisciplinary approach also within the scientific community, learning to accept complexity and the unpredictability that comes with it. Unfortunately, most organizations are still very much trapped in linear thinking, and sadly our current thinking on circularity is still based on 19th-century linear models. For example, if we would think in terms of systems, we would realize that we cannot ship trash to the other side of the planet and claim we are recycling. Before we even contemplate circularity, our production processes must become radically more resource efficient.

In terms of politics, we need negotiation, and this requires acknowledging uncomfortable facts. If we first acknowledge the challenges, we can make the circular economy a truly successful tool in building a *more* sustainable world. We are in an excellent position to make the global sustainability transition a reality as we have all the technological means we need to do so. The question is: are we using them to build a sustainable future based on well-being or well-having?

A key aspect to keep in mind is that, as it was already mentioned above, a complete urban metabolism analysis comprises more components than a simple flow analysis. It is essential to analyze the context and the agents involved, both public and private. This complete analysis will be the basis that will allow the design of the circular city project that best suits each case.

Climate change will need more professional, efficient, and strategic management of cities. Many cities throughout the world have banned the use of plastic bags, disposable cups, and bottled water. While these programs are beneficial for the social message, their environmental impact has been negligible thus far. Cities must work on methods to engage the public in more strategic interventions such as congestion charges, incentives for greener structures, premiums on residential sites requiring less automotive reliance, and the incorporation of carbon pricing into land taxes and development rights. Such broad-reaching, high-impact measures need a more thorough cultural shift to overcome established lifestyle patterns that contribute considerably to climate change.

As seen in the project MULTISOURCE, nature-based solutions can be a good substitute for the grey canonic modality, giving place to a more sustainable city. In this way, the possibility to reduce the urban presence and circulation of wastewater may be possible, because as NBS show, the nutrients found in wastewater can be reutilized for fertilizers, irrigation, or even to come back in a closed cycle to the apartments. A huge potential is present in these green technologies, but several research and pilot projects must still go on in order to find the best way to deal with the most common challenges. Lack of information and guidance, difficulties to find adequate funding, and the need for updates in the regulatory framework, are the main issues to overcome.

This shift should lead to innovation across sectors. Changes will be needed in the organization of governments, business strategies, and educational structures (which determine the supply of new products and services), as well as in civil society (the "demand" side). The third sector, which includes social enterprises, foundations, and civic associations, seems to be very active in organizing circular projects, also stimulating new demand for circular products and services, and thus opening up new market niches for innovative products. Our ultimate goal should be the regeneration of our planet through sustainability, and the circular economy is a tool to get there, but this is not enough.

As Maurizio Pallante claims during our interview (see ANNEX 3), "the circular economy, based on its definition, is a scam. Because if you think that you can put in action, a perpetual mechanism of economic growth in which every year you use the previous year's waste, if the economy must grow, the waste of year 1 will be not enough for year 2. Therefore, you cannot sustain economic growth from a circular economy."

The circular economy must be embedded in a more general project of reducing waste, thus reducing disposability, and extending the lifespan of objects. Otherwise, we are talking about a slowdown in environmental unsustainability. "Slowing down a process that has already exceeded its limits, is just prolonging the agony, not curing the disease" (Pallante, 2022).

The world economic system has become a complex machine whose ultimate goal is the creation of monetary profit, increasingly at the expense of the natural environment and the living beings that inhabit it. It is to date well known that current rates of growth are no longer sustainable. The ecological impact of our "development" is taking on disproportionate dimensions that may soon endanger the very survival of humanity. Based on my research it is now safe to say that chasing economic growth at all costs only aggravates the situation to the point of irreversibility. The future may lie in a "happy" degrowth based on the principles of equity, not imposed but individually chosen, which will bring more benefits than sacrifices.

There were several discussions about this topic, but few seem to grasp the issue seriously, perhaps because people are discouraged by the magnitude of the current crisis, and incredulous about such simple solutions that can be implemented by each individual. People still do not seem to have realized that infinite growth will never be possible in a finite world of finite resources whose indiscriminate and reckless use has severe environmental, social, and economic repercussions. The Earth has limited amounts of air and clean water, the same goes for fertile soil, plants, animals, and materials that can be extracted from its bowels. Everything is finite and enumerable. Moreover, as indicated by thermodynamics, our every action involves inevitable energy degradation. Humanity will have to awaken to these truths and will have to rethink its role in the ecosystem, not as a dominant being but as an integral part of a single living universe.

The key to transforming such a situation lies, in my opinion, in what we might call a “human revolution”. Only by starting from the individual human being, from his responsibility as a constituent element of society, a real change can be achieved. Currently, there are countless exciting technologies and solutions that can and should be used to limit the impact of our activities on the ecosystem. The crucial point for such techniques to have real effectiveness and enable a real improvement in living conditions worldwide is a change in the economic system that is no longer based solely on the market, profit, and competition, but where other values will take precedence. A necessary condition for the creation of an economic system that is not degenerative, but supportive of human life and happiness, maybe the localization of production, both material, and energy, through the enhancement of territorial resources (first and foremost the renewable sources characteristic of the place) and interregional exchanges. The emergence of neighborly solidarity, human relationships based on exchange, human warmth, friendship, the strengthening of peasant knowledge, the empowerment of the spiritual sphere, and the transmission of “know-how” and self-production are all part of this new economic-social change.

We need a decrease in consumption, a decrease (if not a total annihilation) of waste, and a decrease in the pace of life, then, a decrease in stress and chaos. We will have to enter into the perspective of living in the name of sobriety. For this reason, one of the fundamental questions to be asked individually to realize a better future will be: am I willing, and to what extent, to question my way of life, and my conception of existence on this planet?

ANNEX 1

MULTISOURCE project participants survey

Part 1: Basic Information

1) What type of organisation do you represent?

Please select the option that best describes you or the organisation that you represent:

- City / Urban public authority
- District Authority
- Water and Wastewater Utility (public/private)
- Real Estate Developer (public)
- Real Estate Developer (private)
- Community Organisation, local Civil Society Organisation
- NGO
- Property owner, homeowner
- Parks Authority
- Landscaping Company
- Other: Please specify ____

2) Is your organisation directly involved in urban water management?

Yes/ No

3) What is your organisation's main role/ scope?

Answer in a few key words and phrases (Example: park maintenance)

Part 2: Urban Water Challenges

Select the water-related challenges that affect your city:

- Water scarcity
- Declining groundwater table
- Pollution of water bodies
- Flooding
- Extreme rain events

- Drought
- Saltwater intrusion into groundwater
- Stormwater management
- Other, please specify: ______

Part 3: Benefits of Nature Based Solutions Technologies

The following list is of the potential benefits of NBS for urban water treatment such as treatment wetlands, green walls, green roofs, etc.

Please rate the importance of the following potential benefits of NBS for urban water treatment (e.g., treatment wetlands, green walls, green roofs) in your city. Rate the benefits from 1-5 in terms of how important you find them to be, 1 being not important, 5 being very important.

- Combating water scarcity by recovering water resources
- Mitigating water pollution
- Rainwater capture and use
- Reducing stormwater runoff to public sewerage systems
- Flood protection
- Greening urban spaces
- Creating jobs in green sectors
- Increasing biodiversity
- Recovering water for irrigation of green spaces
- Recovering water for agricultural irrigation
- Recovering nutrients from wastewater for agriculture
- Creating opportunities for environmental education

Part 4: Payment for services

1) Does your dept/org/company already allocate funds to NBS for any purpose?

   (yes/no; If yes, please specify which types of NBS)

2) Do you think your dept/org/company could spend money on NBS for any purpose? (yes/no)

3) Which of the following NBS would you or your organisation/dept spend money on?

- Green roofs
- Green walls

- Phytoparking
- Treatment wetlands for wastewater treatment
- Treatment wetlands for sewer overflows
- Raingardens
- Sustainable urban drainage systems

4) The following question depends on type of organisation selected at the beginning (if “other”, this doesn’t appear):

State the estimated amount of budget that should in your opinion be allocated to implement and operate (over a 10 year period) NBS projects to provide the following services. If it is a service you do not think should have funds allocated to, enter “0”.

- Combating water scarcity by recovering water resources
- Reducing sewage production
- Reducing water pollution
- Reducing the amount of storm water being treated in public sewerage system
- Creating more public access to green space
- Creating jobs in green sector
- Increasing biodiversity
- Providing water for irrigation
- Creating opportunities for environmental education
- Mitigating water pollution

Part 5: Willingness to implement

1) How much time would you spend on developing an NBS project? (in avg. hours per week)

2) Which partners would you need to implement an NBS project for urban water treatment?

3) Who should conduct the operation and/or maintenance of the new NBS?

Part 6: Optional

Are there greening projects you would like to see in your neighborhood?

State or describe any greening projects you feel could be beneficial to your community

ANNEX 2

MULTISOURCE stakeholders Interview questions

Municipalities

1. Has [city/ department name] had previous experience implementing nature-based solutions for urban water treatment?
    a. If so:

i. What types of NBS were applied, and why these? With what results?

ii. How would you characterize the overall experience of implementing this/these project(s)? (main benefits, main challenges)

    b. If not:

i. What are your initial impressions of NBS-WT?

ii. What do you think are the reasons why NBS-WT have not been implemented in your city?

2. What urban water management challenges do you think could be improved by implementing NBS? *Give examples*
3. In your view, what advantages would there be for implementing NBS-WT in your city versus traditional "gray solutions*"? What disadvantages could there be?
   (provide short definition/examples for people who are not familiar with this term)
4. In your view, what opportunities exist in your city for implementing NBS-WT? *(If question in unclear - can name examples: policies, strategies, funding sources, existing awareness, good previous experiences)*
5. What barriers do you think might hinder the implementation of NBS-WT in your city? What would you need to apply more NBS-WT?
6. Which other departments or organisations could be involved to implement more NBS-WT in your city?

(potential partnerships with other departments/ organisations/ companies/ government bodies that could be beneficial in the process of planning and implementing NBS-WT)

7. Do you have any examples of people who we could speak to?

Additional question for MULTISOURCE city partners:

Which MULTISOURCE technologies do you plan to adopt? / Which NBS-WT would you like to explore later on in the business modeling workshop? Why?

ANNEX 3

Maurizio Pallante's interview

The interview was translated from Italian to English:

1. What do you think are the major difficulties in adopting this model (Circular Economy and Happy Degrowth)?

The circular economy, based on its definition, is a scam. Because if you think that you can put in action, a perpetual mechanism of economic growth in which every year you use the previous year's waste, if the economy must grow, the waste of year 1 will be not enough for year 2. Therefore, you cannot sustain economic growth from a circular economy. The circular economy makes sense if it is accompanied by a series of initiatives aimed at reducing waste, an economy that is not aimed at growth, because if the economy is not aimed at growth, in a general theoretical sense the previous year's waste may suffice as secondary raw materials for the following year. So, if it is not framed in this way, it is simply one of many ways of using an environmentalist definition for something that is not environmentalist. If the circular economy is not framed as part of a more general project of reducing waste, and then reducing disposability, of extending the lifespan of objects, it is meaningless. However, if the goal is to slow down the lifespan of objects, to reduce the amount of waste, we are in a degrowth perspective. The circular economy is not compatible with economic growth.

If we continue to emit more CO_2 than is absorbed by chlorophyll photosynthesis, we are at a point of lack of sustainability. So, this circular economy measure is critical if it fits into that context. Otherwise, we are talking about a slowdown in environmental unsustainability. A slowing down of a process that has already exceeded limits, simply prolongs the agony but doesn't cure the disease.

Regarding the happy degrowth, after many years of hammering a value system that identifies prosperity with economic growth, it becomes difficult to talk about degrowth. Degrowth is the only way to avoid recession, this is a point that has not been understood. Because only if you direct production to the reduction of environmental impact, that is, the development of technologies that reduce the amount of matter and energy per unit of product, then it makes sense, otherwise if we do not change this mechanism, we reduce the speed at which we approach unsustainability.

It has been an anthropological mutation in Western countries that has led to identifying well-being with material well-being and forgetting the spiritual dimension because if a person has the spiritual dimension well alive, he does not devote all his energy to a value system. Economic growth is the growth of sales, and those who sell are those who make the most money. The problem is the value system on the one hand, and the productive economic system on the other.

2. How to change our tendency to consume the new? (Distrust of second-hand goods, cultural factor)

This trend stems from the fact that the identification of the concept of new with the concept of better has been installed in people's heads. If I am convinced that every new thing is better than what was there before, every time at the supermarket I will buy a new product without needing to buy it. Advertising emphasizes that something is new; they do not propose a product because it offers benefits, but because it is new.

On another hand, contemporary art has emphasized the value of novelty in itself. Now the new is not negative in itself; the positivity of something must be linked to its capacity for the future. A new thing is better than an old thing if it has more capacity for the future. Evolved double glazing is a new thing that has more capacity for the future because it allows you to maintain well-being while consuming less energy. A building from the 1960s or 1970s has less future capacity because it did not take energy consumption into account in its construction. Contemporary art has placed a value on the new in itself. “Today” has a time assessment, it does not have a value assessment. The advantage lies with those who sell, because those who can convince people that the new is better will sell more and more, because they buy more and more, and buying more and more is indispensable for economic growth, because someone may think that economic growth is linked to technological innovation that increases productivity, but if everything that is produced was not bought, an overproduction crisis would develop, overwhelming the whole economy, so the identification of the new as better is indispensable for economic growth. And dismantling this means questioning the economic mechanism in which we live. It is not simple.

2. At my work, we study natural solutions to solve problems. For example, creating closed circles to reuse water. Here, in addition to the cultural factor, there is also an infrastructure factor. For these solutions to become widespread, investment is needed. Vicious circle: if they

don't widespread these solutions, people don't trust them, but if people don't raise awareness, there are no investors. How do we get out of this circle?

It is very difficult. If I have to give a theoretical direction, it is what they call the economic conversion of ecology. Which is the opposite of what is normally said, which is the ecological conversion of the economy. And what does the ecological conversion of the economy mean? It means that the state invests in environmental technologies to make economically unviable what would not be economically viable in the market. Whereas economic conversion of ecology means investing in technologies that make it economically viable to adopt environmentally friendly technologies.

For example, the energy renovation that I am doing in my house must involve, in the first instance, reducing energy consumption, once I have reduced energy consumption, I have economic savings, as well as a reduction in environmental impact, is I can use the economic savings to invest it in technologies that reduce energy consumption. Whereas in the ecological conversion view of sustainable development economics, one exalts ecological technology because it replaces a non-ecological technology, one invests in changing the supply, when the first thing to do is to reduce demand, and only if demand is reduced at that point can I, by replacing the supply, use less energy to meet the remaining demand. I believe that only in this way is it possible to do that. I need to study designs that allow me to waste less, to increase the efficiency in which I use resources. This allows me, not only to reduce the environmental impact but also to reduce the energy bill, water bill, heating bill. And this reduction, on operating costs, can serve to amortize investment costs.

3. The slow model and circular economy in small cities are fine, but how can the Happy Degrowth model be applied in large urban cities in general?

This is not possible. The big city is the result and consequence of the linear economy, the growth economy. It is not possible to make urban conglomerates such as we have environmentally compatible. The only way to do such a thing, which is more theoretical than practical, is to dismantle big cities into neighborhoods on the model of countries. Because if I have a neighborhood where in 15 min on foot, I reach all the places and services, I can do without the car, I rediscover the relationships of proximity with people, I give value to small business... I wish that it is feasible, but I think it is very difficult. But if the urban development model doesn't change, they remain mitigations of the problem and not solutions to the problem.

Final thought:

I believe that there is a need for a change of the historical era. Theoretically, it is not impossible. In the second half of the 1700s, society and the value system changed. Either we are able to set in motion a change of civilization, or else these are remarkable interventions that are not resolving. They can mitigate but only prolong the agony, not heal the disease.

Will it be possible to heal the disease?

We must act as if it were.

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