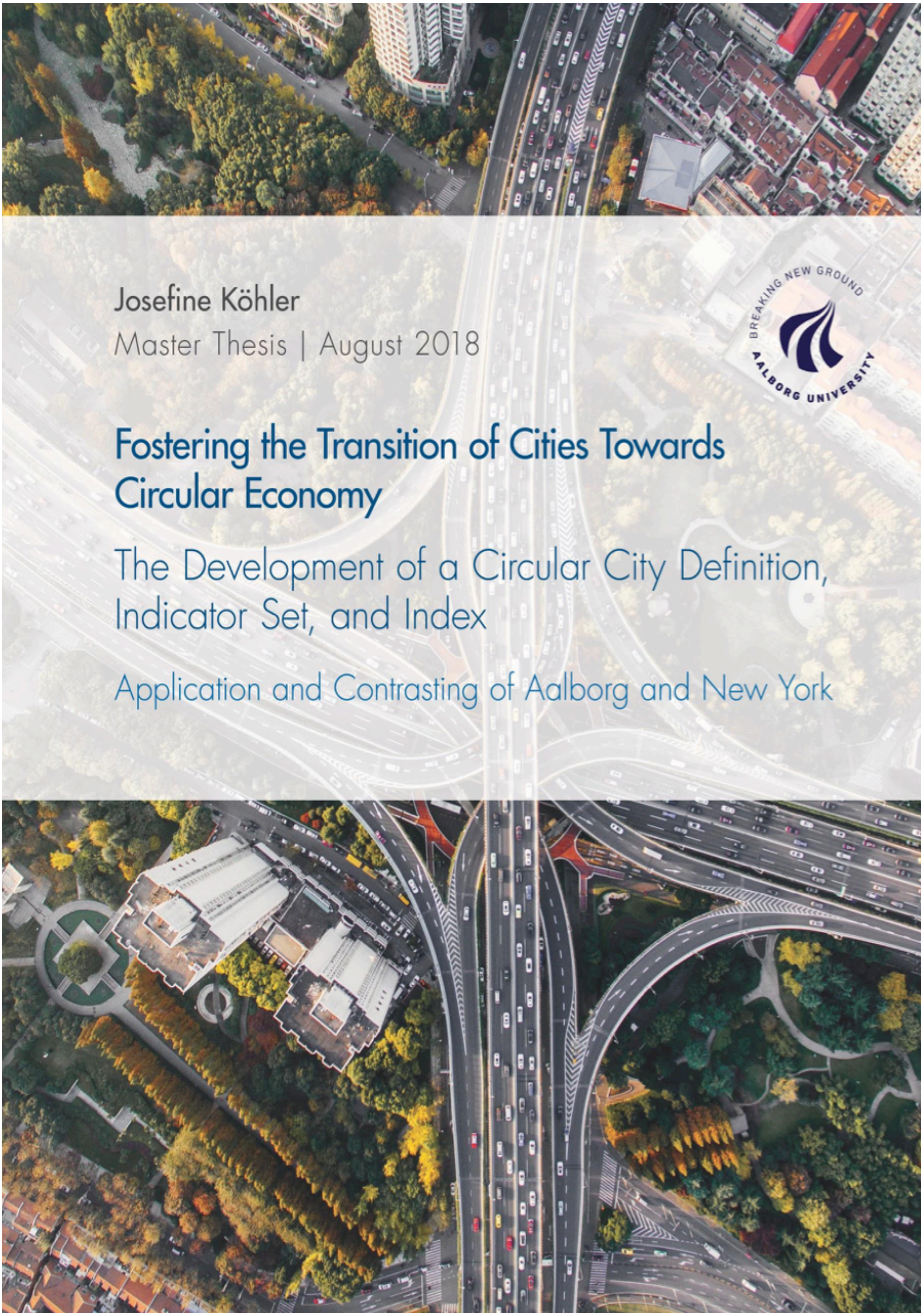

Josefine Köhler

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BREAKING NEW GROUND
AALBORG UNIVERSITY

Fostering the Transition of Cities Towards Circular Economy

The Development of a Circular City Definition, Indicator Set, and Index

Application and Contrasting of Aalborg and New York

AALBORG UNIVERSITY
STUDENT REPORT

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„The transition towards a circular economy is not limited to certain materials or sectors. It is a systemic change that affects the entire economy[.]"

„The results of monitoring should form the basis for setting new priorities towards the long-term objective of a circular economy."

European Commission

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Table of Content

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This work serves as three-fold contribution to foster the transition towards circular economy in cities. Circular economy (CE) is taken as paradigm to approach sustainable development –betterments in social, environmental and economic dimensions– throughout the complex and dynamic urban structures. Applying the concept to the city level merges two highly potential adjuvant elements to an effectively functioning urban system –a space which might generate even higher success than as so far could be reached with a circular business.

However, recent practical approaches to bring a circular city alive are in their very first steps. Transformation happens by turning the respective city into one that embraces and embeds CE. The ideal illustration represents a system where all stakeholders (businesses, the society and the government) exchange and manage urban stocks and flows (physical, social, institutional, informational and monetary) in way that results in the best overall outcome. The fundamental prerequisite is to have a common understanding of the desired state to be reached and measurements supporting precise communication and targeted action. Departing from a holistic and ideal definition of a circular city, an indicator set with 42 indicators (incl. four alternative indicators) quantifying and qualifying measurable and for a circular city relevant urban stocks and flows has been developed. It serves as basic means to capture the individual state and performance of the respective city. Those are assigned to three categories –the three striving states of a circular city– which are: the improvement of environmental regeneration by incrementally reducing material flows with CE principles which demand to cycle and to cascade materials within the biosphere and technosphere, the enhancement of social well-being that includes assurance of environmental quality, material conditions, life quality and empowering of civic participation, and finally economic quality of an economy which considers society and environment as determining elements. An index formula is finally proposed that expresses following criteria: social and environmental improvement that occurs unrestricted and decoupled from economic growth. By setting these states into relation, the index finally indicates the effectiveness of the city assessed.

Through the application of the developed circular city indicator set and index to the city of Aalborg, Denmark (DK) and New York, United States (US), the preceded conceptualization is contextualized. Both cities are frontrunners in sustainable urban development and actively approach the transition towards CE. Besides assessing the cities themselves, they are contrasted while insightful lessons learned, informing especially about the readiness of cities to measure their performance, which is extremely impeded by data inconsistency and unavailability on the city level, are demonstrated as well. Conclusions are hoped to lay the stepping-stone for further research and practical investigations in this area.

Introduction

As global challenges, such as climate change, growing population and the depletion of natural resources, intensify year-by-year, the world needs tangible concepts, which offer promising solutions and alternatives to the linear take-make-dispose way. The concept of CE has been acknowledged and identified by many international stakeholders[1] to be one of them. It has proven potential to reverse and address mentioned challenges by being successfully applied on company levels (Fortune, 2017).

As CE reaches out into social, economic and environmental dimensions, the city represents a reasonable next application level. Cities are places, where all three dimensions are concentrated and connected and therefore hold great opportunities to find and design solutions. However, cities are main contributors of global externalities, which intensify challenges within and beyond the urban boundaries. Thus, cities generate both challenges and chances representing a worthwhile setting to explore further potentials and opportunities to extent the scope of positive impact CE has brought so far to finally contribute to an accelerated sustainable development[2] in cities. Based on its three basic principles[3], the *Ellen MacArthur Foundation* (EMF) defines,

> *"[a] circular city embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative, accessible and abundant by design. These cities aim to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology. A circular city seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens, while aiming to decouple the creation of value from the consumption of finite resources."* (Ellen MacArthur Foundation, 2017b, p.7)

Such a desired state requires transformation. Cities are complex and dynamic systems and a system transformation is convoluted too, what demands two parts to be approached: First, a common understanding of what a circular city means to formulate visions and goals. It implies to comprehend the nature of urban systems, as well as the concept of CE in its whole extent. Second, a respective measurement approach enables to assess the transformational progress and to compare past or present states (Ellen MacArthur Foundation, 2015; UN Sustainable Development Solutions Network, 2015). It serves as essential tool of aligning actions to visions and changes, which need to be made to build social, human, natural and financial capital (Ellen MacArthur Foundation, 2017e).

Both parts have not yet been approached in an affiliated and consistent way. Efforts done are still quite desultory and incoherent. So are practical steps taken initiated through political decisions focussed on waste management or mobility and measurement approaches addressing other levels than a city while having a strong

[1] To name a few international stakeholder applying and addressing CE: Companies such as Dell or Levi Strauss; Networks as the CE100 initiated by the EMF; Cities, such as London or Amsterdam.

[2] "Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own need [...] to an environment adequate for their health and well-being [...] [and] to strengthen procedures for avoiding or resolving disputes on environment and resource management issues", UN (1992).

[3] The three basic principles of CE are to design out waste and pollution, to keep products and materials at their highest value within the system and to regenerate the natural system (Ellen MacArthur Foundation, 2013).

material focus, too. This research aims to contribute to fill these gaps and to foster the transition towards CE in cities.

To approach this research a holistic perspective on CE is emphasized that focalizes a redistribute, restorative and regenerative economy –an effective urban systems– as long-term goal. This demands to consider multiple aspects complimenting the focus on physical matter or material circularity[4] and the dominant motivation, occurring both in businesses and cities, of economic growth with social and environmental criteria to finally set all of them into an equally weight relationship. A further intention of this research is to base the outcomes on existing concepts and approaches, and to piece them together to a comprehensive and useful means, rather than developing something completely new and contributing to the vast plurality of sustainability frameworks. By applying the developed measurement approach, based on the established conceptual framework of a circular city, to two progressing cities, concluded lessons learned regarding data availability and supporting elements intent to foster effective and accelerated implementations of CE in cities.

The structure of this thesis is organized in this way: The literature review is composed of three parts. Chapter 1 holds a state-of-the-art of the concept of CE. It further explains the potentials of CE being applied on a city level and finally develops the comprehensive definition of a circular city illustrated in an idealistic state. Chapter 2 deals with the necessity and importance of measurements as essential element to approach transformation while it also formulates concrete expectations on metrics for a circular city. Chapter 3 introduces the 12 measurement approaches reviewed, which are sustainability frameworks and standards as well as recent approaches to measure CE on different levels. The results are organized in two parts. Chapter 4 introduces the composition of the circular city indicator set and the construction of the index while chapter 5 presents the application to Aalborg and New York. It analyzes outcomes individually for the cities, contrasts their performances and summarizes general lessons learned. This part is followed by a discussion and finally closed with the conclusion section.

[4] Material circularity defines the term of how restorative material flows are distributed and managed (Frank, 2015).

METHODOLOGY

The overall research question guiding this thesis is formulated as follows: "How can the ideal state of a circular city be formulated and how can the process of becoming one be supported by suitable measurements to make the transition towards CE more holistically and effectively?"

The research is initiated by introducing the concept of CE on its original scale –the business level– as well as the approaches to relate the concept to the city level. In this part the sub-research question of "What is the state of the art in respect to CE and CE at a city level?" is answered. Based on the review of secondary and grey literature, covering the timeline of 2013-2018 the state of the art is formulated. This includes publications from the EMF or Circle Economy, international topic related articles and case studies or strategy and policy papers of progressing cities, such as Amsterdam or Rotterdam. In addition, secondary literature from 2003-2015, about New Urbanism theory and the concepts of Urban Metabolism and Urban Ecology have been identified as holistic, tangible and acknowledged frameworks to tackle the understanding of cities and their complex nature.

This part has been paired with two activities operated during an internship from January 2018 until May 2018 at the Earth Institute at Columbia University, New York: The audition of the class "Circular Economy for Sustainability Professionals" at Columbia University supported the comprehension of CE in its whole extent. The outreach to city departments of New York, consultancies (such as Volans and Strategiq), NGOs (e.g. NYC Economic Development Corporation, NYCEDC), networks (like Circular Economy Club or Circular Economy Network) and private companies performing best practice (such as Sims Recycling) and independent agencies engaging in sustainability (such as the Environmental Protection Agency, EPA) has complimented the theoretical research with practical experiences and inputs. Based on both parts, the definition of a circular city has been developed.

The next step represents the research for measurement approaches and frameworks serving as inspirational and concrete means to compose a circular city indicator set. This has served to answer the second sub-research question of "Which indicator frameworks and standards exist and how can these inform a Circular City Indicator Set and Index?". Based on the criteria formulated within the circular city definition, 12 internationally known elements covering the business, city, national and international level, have been reviewed. Those are sustainability standards and frameworks (such as ISO 37120 or the Global Indicator Framework for the Sustainable Development Goals) supplying especially the socially dimensioned indicators while approaches addressing CE mainly provide indicators on material circularity. Suitable indicators have been chosen and directly or indirectly overtaken. To interpret the results of each indicator, they are compared to a reference unit defining an ideal state. This assigns each indicator an individual score and enables to aggregate them into three sub-indices indicating the performance in each striving state and serving as input for the circular city index. The construction of the index formula is based on the criteria of improving social well-being and the environmental regeneration while decoupling them from economic growth. In other words the best result can be achieved if all three states in highest degrees without compromising each other.

The presentation of the research's intermediate state to CE experts and research peers, at the 1st Circular Economy Symposium at the University of Exeter, United Kingdom (UK), in June 2018, has served as method of validation and reflection. The following attendance on the Circular Economy Summit, initiated by the EMF in London, served as meaningful opportunity to discuss the research and receive feedback from CE professionals, such as Ken Webster, head of innovation of the EMF.

The last step is characterized by the contextualization of the developed indicator set and index. By applying both to the cities of Aalborg and New York, the third sub-research question of "Which data exists at present and what should be measured in the future" is answered. Aalborg counts as small-medium sized, but progressive city, located in the European context while New York represents a metropolis in the United States (US). Assessing both cities on different scales and geographical contexts has been found as important in respect to economy of scales, i.e. if a larger economy holds larger potential. Data collection through the review of secondary and grey literature, covering the timeline of 2011-2018, and the outreach to city stakeholders, such as departments (as the Environment and Energy Department, Aalborg or Business Aalborg), consultancies (e.g. Minor Change Group) and regional networks (like Network for Sustainable Business Development, NBE), regional organizations (as Nordic Food Organization) or national agencies (like European Environmental Agency, EEA) served as data and information sources for the assessment.

Summarized interviews and communications can be requested.

LITERATURE REVIEW

1 Circular Economy as a Promising Concept to make Cities more Sustainable

Within the last few years, the concept of CE *"has gained tremendous momentum"* (Economy, 2018, p. 4). It became well known and acknowledged, globally and sector wide. The concept has been utilized so far amongst businesses as a practical, systemic approach to do good and to create value in all three pillars of sustainability – exemplified outcomes are increased business revenue, decreased environmental impacts and advantages for society, such as higher functionality and life quality.

Currently, several explorations are taking place around the potentials and opportunities to apply CE in cities –a place which aggregates and connects social, human, natural, manufactured and economic capitals within an interwoven system. This thesis seeks to contribute further to those explorations. Before looking at CE as it applies specifically in the context of cities, in section 1.1 it is generally discussed in order to create a common understanding by summarizing the concept and its origins.

1.1 A Summary of the Circular Economy Concept

> *„A successful circular economy holds manifold promises for meeting the SDGs [and global emission reduction targets] via a concerted and integrated action."* (Circle Economy, 2018, p. 4)

CE is conceived as a means to contribute to Sustainable Development. It addresses negative consequences of the linear economy, population growth, globalization, urbanization and climate change, striving to achieve social and environmental betterment and rebalance, while also delivering economic growth.

The global population is growing rapidly –the current world population of 7.6 billion people is expected to rise up to 9.8 billion by 2050 (UN, 2017). The middle and upper-middle class of OECD countries –with a multiple resource footprint, consuming and wasting at higher rates– will gain 3 billion people by 2025 (Ellen MacArthur Foundation, 2014). These developments will drive up the demand of food, materials, goods and services.

On the supply side, prices of finite resources rise as they become more and more scarce due to over-exploitation and the as-yet unrealized potential of recycling. Global commodity prices over all increased from 2002 until 2010 by almost 150% and prices throughout the supply chains are behaving in correlation[5]. According to the Ellen MacArthur Foundation (2014), they are forecasted to continue climbing moderately.

Factors such as uncertainty about future events, or supply disruptions, will likely lead to further price increases and volatility. This will harm economic growth as businesses and governments will be cautious and moderate about investments related to those risks (ibid.).

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[5] The calculations are based on the arithmetic average of four commodity sub-indices food, non-food agriculture items, metals and energy (Ellen MacArthur Foundation, 2014).

Some might argue that the sourcing, production and disposal patterns that society has become accustomed to since the Industrial Revolution brought higher living standards and wealth. However, others would point out that, not only are the advantages of this linear system not accessible to all, but also that the continuation of these practices has the potential to leave many critical natural resources important for industry and society such as gold, silver, iridium or indium depleted within five to fifty years (Ellen MacArthur Foundation, 2014; Circle Economy, 2018). Meanwhile the limits of growth may also be reached within the next hundred years (McDonough and Braungart, 2002).

The natural ecosystem, our planet, was once in balance, fully circular and able to regenerate, but human's interactions with nature, not accepting the planet's boundaries, have eroded this ability (Constanza *et al.*, 2012). Actions and trends related to the linear model, such as excessive resource use, mobility patterns strongly depending on cars and airplanes, or geographical changes due to artificial human infrastructures, have caused negative consequences for, and pressures on the environment, such as GHG emissions and hazardous wastes. Those consequences have evolved to such an extent that the ecosystem alone cannot compensate anymore, perceived and measurable as (the effects of) climate change. They also naturally intensify negative social consequences, such as inequality related issues. A macro-level example for social inequality is that most of the countries with low GHG emissions are acutely vulnerable to their negative impacts (Althor, Watson and Fuller, 2016). A micro-level example is that low-income households can rarely afford a healthy lifestyle (Ellen, 2015).

To close the cycle, climate change further enforces and accelerates the risks affecting economy, society and the environment, i.e. water and food supply, rising emissions and volatilities in energy and agricultural prices. According to the World Economic Forum as stated by the Ellen MacArthur Foundation (2014), most of the mentioned risks are of highest urgency. Those caused by the pressures on finite resources, are even expected to remain which will immediately affect economies and markets dealing or depending on material-based products and services.

The state of urgent imbalance between the planet and its residents, which is a mutually enforcing and dependent relationship, creates the opportunity and need for intervention by the main perpetrators: humans. The linear system, which stresses and jeopardizes the state of ecosystem and the economy, has to be changed to ensure, as it is approached in the Agenda 21, that present and future generations can meet their own needs (United Nations, 1992).

The biggest drivers of this change are businesses and industries since they directly affect and interact with global challenges. Via decisions regarding their supply chains, from resource extraction to waste disposal, they can significantly decrease their negative impacts (Ellen MacArthur Foundation, 2013). Other supportive decisions about changing business models and designing new ones could address global challenges by doing good and offering niche solutions for instance, what would imply positive contributions (ibid.).

The concept of CE has already gained momentum in businesses –starting with changing the way of doing business. It aims to trigger a positive chain reaction, reaching the society and economy, intervening the cycle of mutually enforcing negative consequences, previously discussed, striving to achieve a sufficient, resilient, intact and future proof state in all pillars of sustainability (Prendeville, Cherim and Bocken, 2018).

As an alternative way to the linear take-make-dispose pattern, CE recommends seeking to extract the maximum value from resources in use and keeping materials in their separate biological and industrial cycles, as far as it is possible. In practice, this means first of all, prioritizing regenerative resources as material inputs and second of all, making the most out of existing resources and materials, through strategies such as maintenance, cascading, sharing, reusing, redistribution, remanufacturing, recycling or recovery (Ellen MacArthur Foundation, 2013). The concept also takes advantage of technology shifts and innovations and considers how to positively influence consumer behavior in order to unlock the mutual potentials of, e.g. optimizing volume and quality ratio of goods (Circle Economy, 2018).

So, CE is a way to **rethink** the current system. To do so, the concept unites seven schools of thought, which have individually refined the concept, its principles and strategies to suggest a way for system change (Ellen MacArthur Foundation, 2017a). Those are shown in figure 1 followed by a brief introduction of each

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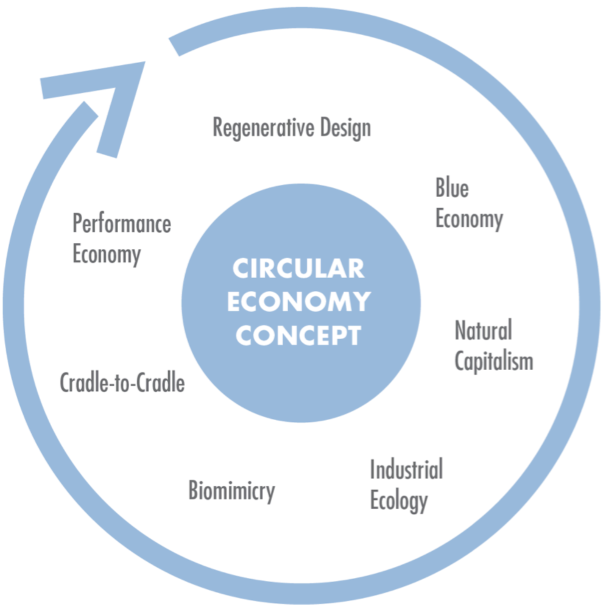

Figure 1: Concept of CE (own figure, inspired by Ellen MacArthur Foundation, 2017a).

The concept of Regenerative Design has been developed by the American landscape architect John T. Lyle and has laid the foundation of CE (Ellen MacArthur Foundation, 2017a). In his book "Regenerative Design for Sustainable Development", published in 1994, he explains **theories, designs and constructions** of regenerative and non-depleting systems living in harmony with nature. Besides suggesting practical approaches, he demands changes in policy, development strategies and consciousness to support the paradigm shift away from the linear system (Motloch, 2013). To reach a regenerative state and effective design, the development has to consider the local community and environment, while also following twelve principles (Miller, 2012). To highlight some, Lyle recommends taking nature as model and context, aggregating diversity rather than to perform isolation, seeking the optimal outcome level for everyone (the whole system), applying technology as meaningful tool, using information to replace power and shaping the form to guide the flow and manifest the process due to trans-disciplinary approaches (ibid.).

The concept *of Blue Economy has* been developed by the Belgian Gunter Pauli. In 2004, he initiated an **open-source** movement with the aim to contribute to a future open-source community (Ellen MacArthur Foundation, 2017a). He bases the concept on 21 principles, which pointing to nature, stress local solutions, focus on physics and biological systems and target the superior value generation for everyone through, e.g. **job creation** and increased equality. Those aim to shape the design of **innovative business models,** which are able to solve problems sustainably. Their products and services are supposed to be competitive on the market, to respond to basic needs, to build up social capital and to enhance living in harmony with nature (Pauli, 2016).

Within the blue economy, 200 projects have been developed so far from which 112 case studies have been compiled. Pauli puts a strong focus on making these innovative cases accessible to reach and inspire as many people as possible –he is translating the project scripts into 35 languages and even writes fables for children– to contribute to an awake and creative next generation (ibid.).

The concept *of Natural Capitalism is* represented by L. Hunter Lovins, Amory Lovins and Paul Hawken. The concept envisions an economy –already evolving through the new Industrial Revolution– where the current limiting factor, the natural capital, is economized and valued (Hawken, Lovins and Lovins, 2014). Instead of exploiting this capital up to an unrecoverable state, the authors suggest to rather take advantage of natural resources and the ecological system as it can provide nearly everything humans and living organism need. Furthermore, it can create profit and competitive advantage for businesses by **investing into social and human capital** through which innovation is finally driven (ibid.).

To do so, business models should include following four principles as the Rocky Mountain Institute (2001) summarizes: Higher resource productivity can be reached through fundamental changes in technology, design and production resulting in natural resource savings whose cost savings can be utilized for other principle implementations. The redesign of current production patterns due to nature-inspired solutions, such as closed loop systems, is supposed to either completely eliminated the concept of waste or makes waste to be used as input for another process. Shifting from traditional sale-models to “service and flow” business models, promises positive outcomes for provider and customer as the product and service can be delivered in a cheaper, more efficient and more durable way, contributing to resource productivity as well. Lastly, through the **reinvestment in the natural capital**, it can be contributed to an indirect and direct restoration and regeneration of its capacity (ibid.).

Industrial Ecology is a broad framework supporting the transformation of industrial systems, on levels of cities, regions and industrial parks towards sustainability (Lowe and Evans, 1995). The concept focuses on **energy and material related connections and exchanges** between industrial operators. In this way, waste and undesirable by-products become eliminated (Ellen MacArthur Foundation, 2017a). Respective solutions are designed by looking at nature that implies to replace the linear way of production with closed loops emphasizing cyclical flows. According to Lowe and Evans (1995), sustainable industrial systems, their operations as well as the use of inputs and outputs should be adjusted to the planet’s and local ecosystems’ boundaries. This inevitably demands the redefinition of business success depending more on ecological criteria (ibid). The concept promises with its way of operation, resulting in higher resource productivity and partnerships, competitive advantages and economic benefits.

The concept of Biomimicry takes nature as model, measure and mentor to solve human problems and contemporary challenges as the desired sustainable system already exists –namely in nature (Benyus, 2009). According to Janine Benyus, a strong advocate of biomimicry, the **natural system** should be honored not only because of its resource provision and necessary extraction, but rather because it can serve **as mentor and model** to innovate. Designing new solutions includes studying natural forms, systems, processes and strategies, while respective measurements should consider ecological standards as well (ibid.).

The German chemist Michael Braungart and the American architect Bill McDonough developed together the concept of Cradle to Cradle. It considers all types of materials as nutrients of either the technosphere, defined by the flow of industrial processes, or the natural biosphere (Ellen MacArthur Foundation, 2017a). McDonough and Braungart (2002) describe that in an ideal state, the **technical metabolism copies the biosphere** in its safe and productive processes, while in both metabolisms, it is aimed to design products which can be recovered and reutilized to prolong their life cycles (McDonough and Braungart, 2002). This is one of the three general principles derived: To consider **waste as food** and next nutrient. The second focuses on **renewable energies** as prevailing energy source. Lastly, the concept promises **value maximization** for especially human and natural systems by taking advantage of diversity, trans-disciplinary approaches and stakeholder involvement. Allover, the framework strives for reaching **effectiveness** due to generating positive impact and decreasing negative impacts of commercial and industrial activities (ibid.).

The Swiss architect and industrial analysis Walter Stahel initiated the concept around Performance Economy. In the same called book, Stahel (2010) explains one essential part of the concept is to **redesign business models and market places** into those supporting the development of human and the environment. This could include corporate environmental reporting, clean production processes and the transformation from a linear to a circular economy by implementing a cradle-to-cradle approach (Stahel, 2010). He further accounts the functional service economy as further integral part, that implies to generate **value from services** including more jobs than could be created by only selling goods. Generally, the performance economy suggests to do things right, meaning to superordinate **sufficient system solutions**, to implement virtuous loops and reversed incentives, to integrate resilience and redundancy as well as to prioritize innovation and creativity (ibid.). The concrete design of products is suggested to pursue four main goals: product life-extension, long life goods, reconditioning activities and waste prevention. These criteria promise to "*decouple wealth creation from resource throughput*" (ibid., p.3).

These sub-concepts piece the comprehensive and generic concept of CE. They all intake system perspectives, draw a strong relation to nature and set human beings first to innovate ways out of the current system.

Adopted from the performance economy, the superior goal of CE is to decouple economic growth from resource consumption while approaching the system change. The concept targets two main negative effects: waste and over-extraction of finite, primary resources. The intention is to avoid waste, imitating nature as per the concept biomimicry, while also leveraging cradle-to-cradle principles. Among other things, the outcomes of this approach would contribute to the achievements of international GHG agreements, as the way waste is disposed and treated is directly associated with the volume of resulting emissions (Circle Economy, 2018). Thus, CE has the potential to help mitigating the effects of climate change and even to reverse and solve other present challenges faced by society, economy and environment.

A further building block of CE is to design products and paradigms for a **circular performance** throughout their life cycle. This means conducting transformative changes in production and operation thinking. Products should be designed for disassembly and longevity and should not contain any substances which might be hazardous for users or the environment (Ellen MacArthur Foundation, 2014). Another example is to consider each product's waste as input for another product (either as part of the same process/organization i.e. closed loop, or part of a different process/organization i.e. open loop) in order to keep its value up as long as possible (ibid.).

The last and very essential building block is **collaboration.** The concept strongly emphasizes maintaining and increasing communication and interaction upstream and downstream in the supply chain, across sectors between business partners, businesses and their customers and between businesses and the government (Franconi, Bridgeland and Graichen, 2016). The accompanying transparency contributes to better partnerships and relationships among stakeholders, while it can also decrease individual production costs due to synergy effects (Ellen MacArthur Foundation, 2013). Collaboration enables new business models and business model innovation, such as performance or service business models. By sharing the value creation among partners and stakeholders, greater value can be derived for everyone. For instance, addressing consumers' demand more accurately, in terms of doing the *"jobs to be done"* (Christensen *et al.*, 2016, p. 3), increases the customer rates and competitive advantage, which enhances economical stability and therefore can enable and trigger further development and investments, thus growth.

An overview of the building blocks discussed is shown in figure 2 below.

Figure 2: Seven Key Elements of CE (own figure, inspired by Circle Economy, 2018).

Contribution to the UN Sustainable Development Goals

With its wide reach of positive impacts, CE plays a relevant role in implementing the Sustainable Development Goals (SDGs) as a recent study conducted by Schroeder, Anggraeni and Weber (2018) found.

The SDGs have been developed by the United Nations (UN) in 2015 and signed by 193 countries. These goals count in total 17 with 230 indicators addressing global improvements towards no poverty (SDG 1), zero hunger (SDG 2), good health and well-being (SDG 3), quality education (SDG 4), gender equality (SDG 5), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), decent work and economic growth (SDG 8), industry, innovation and infrastructure (SDG 9), reduced inequalities (SDG 10), sustainable cities and communities (SDG 11), responsible production and consumption (SDG 12), climate action (SDG 13), life below water (SDG 14), life on land (SDG 15), peace, justice and strong institutions, as well as partnerships for the goals (SDG 17) (United Nations Development Program, 2015).

By assessing the qualitative relationship between the SDG targets and CE practices, counting each target to one category, the study results that a relevant number of SDG targets can be met directly (21 targets) and indirectly (28 targets) by implementing CE in businesses, shown in the first two columns of the table below. The study also examined which targets, in their further progress, support CE practices, listed in the last column (Schroeder, Anggraeni and Weber, 2018).

Relationship	Direct Contribution	Indirect Contribution	Weak to No Contribution	Progress on Target supports CE
SDGs	SDG 6 SDG 7 SDG 8 SDG 12 SDG 15	SDG 1 SDG 2 SDG 14	SDG 3 SDG 5 SDG 10 SDG 11 SDG 16	SDG 4 SDG 9 SDG 10 SDG 13 SDG 16 SDG 17

Table 1: Targeted SDGs of CE (own table, inspired by Schroeder, Anggraeni and Weber, 2018).

As most of recent CE practices are related to a business level, thus, primarily focusing on the company's material flows, it can be argued that if the perspective of (re)designing business models would be widen to more social and environmental criteria or even if the scale of CE would be expanded to a new level, where the rather society related goals 3, 5, 10, 11 (here: category "Weak to No Contribution") and institutional and collaboration based goals 9, 13, 16, 17 (here: category "Progress on Target supports CE") are inevitably addressed, the direct and indirect contribution of CE to the SDG targets could be increased. The exact extent of this potential contribution, through an up-scaling of the CE concept, cannot be answered in this research as it is still a fairly young exploration and undefined area. However, in this work, the focus lays on how a new perspective and scale of CE can look like.

As mentioned before, areas of CE have been successfully applied in businesses and business networks as well as ecosystems; it also has proven to create a positive difference for a wider range of stakeholders beyond direct actors (Fortune, 2017). It has shown the potential to build internal capacity in its application areas from where it can increase and benefit social, human, financial and natural capitals contributing to several SDGs. These proven advantages encourage scaling CE up to an area with much higher need and potential of value creation: **the city**.

1.2 The Reasons and Potentials to Scale Circular Economy up to a City Level

Besides the success CE has already brought through a company level, a similar effect can be expected for a city level, as cities are aggregators of diverse businesses. CE implemented in cities might create an even greater value and higher positive impacts, since they also hold a stronger diversity of stakeholder and provide higher stakeholder proximity than a business or business network could ever have. This might make cities a more suitable space for CE to create momentum.

With an ongoing service, information, retail and real estate sector dominance, cities are being rediscovered as interesting places for manufacturing businesses to locate. And as *"[m]odern manufacturing is increasingly a clean, high-tech, desirable activity [...] [it] can fit into a [city] neighborhood"* (Hurley, 2017, p.1). Business models are changing –not just in the manufacturing sector where the concept of CE first gained attention. Sustainability becomes more and more important to business portfolios. Holding such innovative and sustainability oriented businesses, with ideally integrated CE strategies, might unfold even greater potentials for the city system as businesses are the most important driver for transition (Circle Economy, 2018). This makes it worth for the city to actually look closer to the concept for city specific criteria going beyond the stakeholder business.

Besides aggregating diverse businesses, which provide expertise and drive the momentum, cities also contain a growing society, resulting from urbanization, globalization and population growth. Within the next three decades, by 2050, cities will hold 75% of the world's population by 2050 (West, 2011). In other words as West puts it, over one million people will join global cities every week.

Although cities scale sub-linearly (increasing in size makes the system more efficient), as later explained more in detail, this development still causes tensions in e.g. supplying growing demands of various kinds of resources, in providing safe and sufficient infrastructures as well as in ensuring appropriate health and environmental conditions.

However, with an increasing number in population, cities can expect a more diverse and heterogenic society, naturally due to the facts of globalization and internationalization, and especially because cities are places that constantly attract the creative class. The potentials of such evolving societies represent the key to innovation that facilitates to solve mentioned tensions (Bonato and Orsini, 2018). This in turn, promises to drive the economic force of cities further up, which is already 85% of the global Gross Domestic Product (GDP) (ibid.).

The other society related aspect coming with cities, is that lessons learned show that successful steps towards CE result from the integration of the society and generally all stakeholders e.g. through fruitful collaboration and exchange (Ghisellini, Cialani and Ulgiati, 2016). So, cities represent the optimal environment, where all stakeholders come naturally together, to jointly set up and tackle a CE transition in cities.

Continuing linear sourcing, production and consumption patterns, the demand of the growing population in cities will aggravate to reach the limits of growth and depletion of natural resources, as already 75% of global resources and 80% of the global energy supply are consumed in cities today (Prendeville, Cherim and Bocken, 2018). At the same time, the urban population produces higher rates of waste, responsible for 50% of the global waste generation (Ellen MacArthur Foundation, 2017c). Waste, a source with high potential, but being left unused and treated in the wrong way can lead to negative externalities for instance in form of CO_2 emissions. Nowadays, cities already account for more than 70% of global CO_2 emissions contributing to global warming and impacting public health conditions, which mostly results from energy generation and high numbers of economies of scale working in cities (West, 2011; C40, 2018).

An alternative and more valuable way to handle waste is, as CE recommends, waste valorization. Especially in cities, where materials and nutrients are concentrated, the potential to take advantage of urban bio-cycles and industrial cycles is significantly high. For instance, global revenues generated by biomass value chains (incl. production of agricultural inputs, bio-refinery outputs and biomass trading) are estimated to be USD 295 billion by 2050[6] (Ellen MacArthur Foundation, 2017e). However, none to only a few of these materials are fed back into the biosphere so far. Cities produce approximately 1.3 billion tons of solid waste per year –half of it is organic. Recovering the organic fraction, comprising nutrients from human, animal and food waste, could replace chemical fertilizer by 2.7 times (ibid.).

Regarding urban industrial cycles, the plastic value chains could generate annually USD 80-120 billion with CE strategies. However, these values are still lost after the products' initial use (Ellen MacArthur Foundation, 2017d).

Investigations in urban waste capture and valorization can lead to savings of material and economic resources, while C02 emissions can be reduced as well. For instance, a US study found, that 10% of the electricity demand could be met by wastewater treatment plans to replace the use of finite natural resources (Ellen MacArthur Foundation, 2017d).

Thus, the necessity to change cities towards being more circular is driven by two factors: On the one hand, cities cause increasingly negative impacts –impairing environmental and life quality– pressuring local and global economies and ecosystems, while they are more and more exposed to risks related to climate change. 90% of urban areas are located in coastal areas, which make them vulnerable to i.e. rising sea levels or coastal storms (C40, 2018). On the other hand, urban areas hold major opportunities to implement circular principles due to their characteristics of large supply scales, tech-savvy workforces or high proximities between stakeholders (Ellen MacArthur Foundation, 2017e). These factors drive, facilitate and accelerate the transition. A transition that could generate positive impact and greater value than businesses could ever realize alone. The city scale allows to approach and to solve local and global challenges more efficiently and sustainably.

However, a successful circular city transition requires three factors: First of all it is crucial and fundamental to understand the city, its nature and its metabolism, which can be generalized up to a certain extent, but becomes highly individual in areas where local attributes dominantly influence. Secondly, it has to be understood as well how the concept of CE can be translated into an urban context. Lastly, for the transition itself, all stakeholders have to pull together in the same direction recognizing the mutual and common benefit, rather than perusing and prioritizing competitive behavior. The two first aspects are going to be examined within the next two sections 1.3 and 1.4, whereas the last will be taken up in section 5.4.2.

[6] To set this value of USD 295 into relation, is represents 1% of France's projected Gross Domestic Product (GDP) for 2019 or 0,33% of this year's Global GDP (Focus Economics, 2017; Statistika, 2018).

1.3 Understanding and Managing Cities: A Synthesis of Urbanism

To contribute to an understanding of cities and how to better manage them, this section synergizes some influential authors of urbanism theories who could be characterized as system thinkers. Those are: Jane Jacobs, Christopher Alexander, Geoffrey West, Dirk Helbing and Michael Batty. It is supposed to serve as explanation of a city's nature, structures and interactions to lay the ground for the next section 1.4 where the CE layer is put onto the urban system to construct the definition for the system **circular city**.

For both sections, six concepts served as inspiration to first of all, understand the system city and second of all, to define a circular city. The theory of New Urbanism has been taken as base for this section while the remaining five further shape and piece the conceptual definition of a circular city and its components.

Concepts of Inspiration		
System Definition *City*	System Definition Circular City	Sub-System Definitions Circular City
New Urbanism	Urban Ecology	Smart City
	Urban Metabolism	Doughnut Economics
	Circular Economy	Circular Economy

Table 2: Concepts of Inspiration for Defining a Circular City (own table).

1.3.1 The Nature and Purpose of Cities

The theory of New Urbanism has been chosen as it defines a holistic approach to primarily understand the city's (universal) key characteristics and to secondary suggest a new, more original and human-focused system design and management to finally achieve an overall more healthy and effective system.

The first aspect to introduce the synthesis with –what all authors explicitly agree on– is that cities are an example of complex, non-linear systems. They are junctions of numerous, organic **dynamics**. However, they reveal patterns and an intricate order that might appear chaotic without comprehension (Jacobs, 2003).

This peculiar results from interdependent **relationships** between humans, their environment (habitat) and their inventions –invention, which can be broken down to physicalities, economies and information– constructing a "mosaic of subcultures" (Alexander, Ishikawa and Silverstein, 1977) and subsystems, as Christopher Alexander would call it, or an "interwoven web" (Jacobs, 2003), according to Jane Jacobs. These relationships occur within the city itself, but also reach beyond the city's boundaries into other cities and national, even international levels and scales. These internal and external relationships, depending on the three dimensions of space and of time coupled with decisions of individuals and group of individuals, finally determine how a city is structured and functions (Batty, 2012).

On each level, mosaic or **fractal** structures are found, as these are a natural characteristic of cities. For Geoffrey West, they even represent a fifth dimension cities depend on what would give them a "signature to urban morphology" (Batty, 2008; West, 2017). Fractals have self-similarities, structural regularities, occurring in redundant, repetitive and modular form, distributed across multiple scales and levels of the urban environment, grown iteratively from the bottom in a process that can be viewed as hierarchy with a recursive nature (Batty, 2008, 2012).

The fractals are connected and hold together through human actions, interactions and transactions, characterizing mentioned relationships, emerging in and reinforced by networks, specifically social networks (Batty, 2013c). Upon resulting positive feedback loops, the urban system builds, grows and further develops around by itself and from the bottom-up (Batty, 2012; Salingaros, 2015).

According to Michal Batty (2013a), **social networks** are crucial components, which need to be intact to produce quality, value and success in cities. Regarding their potential future quantity or dimension, he speculates that in 2100 the world might be one piece, one interconnected network due to intensively growing (social) connections enabled and reinforced by digital developments (ibid).

So, humans and social networks are key and core components that lead to the purpose of cities to sustain and to connect them, and as Jane Jacobs declared, cities should ideally be places that even allow human scale and efforts to enlarge (Jacobs, 2003; Batty, 2012).

To ensure the latter, cities have to be **alive** as Christopher Alexander (1996) formulates. Living and vital structures are essential to first of all sustain and second of all to nourish humans and their development with materialities and immaterialities, such as reliable information flows, physical structures and spaces to live and to move in, provision of education, rights to participate, access to divers uses and connections (ibid.).

The most obvious way looking at cities is to study their material, physical structures (architectures, infrastructures and constructions), which are certainly mirroring local characteristics, the culture, past and present events to a certain extend. More dominantly, today, these structures are a result of forces dominating at the time of change and development –this prevalence is also found in politics and economies (Batty, 2008).

The architect Christopher Alexander sees the physical environment in a strong interdependency to the people and social networks. Cities are not just a physical manifestation (West, 2011) of social interactions; social and physical structures actually interact and reinforce each other (Batty, 2012). In 1977, Alexander developed and published the book "Pattern Language", a method to design physical environments, from buildings, streets and neighborhoods to cities. This method categorizes 253 patterns –physical structures, things, designs– and the language composed of vocabulary, syntax and grammar to solve problems individually "with infinite variety in all the details" (Alexander, Ishikawa and Silverstein, 1977, p. xxxv). The superior intention is to achieve more wholeness and coherence for humans and the world around (Alexander, 1996). The way people are integrated and interact with each other and their environment finally decides about the overall quality of the place (Jacobs, 2003). This inevitably means that people, their perceptions and feelings should be a constant in the process of designing a city as "an orderly whole" (Robert Hammond, Corey Reeser, 2017).

Another consensus of the authors, regarding the city's emergence, is that cities command a strong ability to **adapt** to local events, circumstances and environments. This is a factor not only applying for cities and social organizations, but also for organisms. Generally, the approaches studied have a strong relation to **biological** systems. Cities are about humans, built and lived by humans who are pari passu organisms, metabolisms made of organisms (Oxford Dictionaries, 2018). Thus, patterns, mechanisms and their principles of processes found in nature and biological systems, valid for already more than thousand of years, must correlate to those in cities (Jacobs, 2003). This fact enables to explain certain particularities in cities –but not all. Due to the complexity and organic dynamics, cities are not fully **predictable**; they reside in states of **disequilibria** and behave counter-intuitively and change as well as develop rather suddenly and spontaneously (Batty, 2012).

Scientific Approaches

Taking insights from biological and ecological systems as starting point to explain the nature of cities or even to plan them presents a logical approach. Respective contributions have been made by Michael Batty and Geoffrey West. They have been working on mathematical and quantitative models aiming to capture cities and their dynamics to inform decision-making about urban interactions, flows and growth.

Michael Batty has developed a mathematical approach to virtualize and interpret changes of cities over time and space. He identified **density and connectivity** as key criteria for drawing boundaries between cities, in times when cities become more and more interconnected and dependent on networks exceeding their own borders (Batty, 2013b). For instance, he has mapped interactions and flows of the UK, primarily resource flows, and has successively cut connections from a one km to 100 m distance. As a result, the ten biggest and densest clusters (urban centers) of the UK remained, whereas Scotland has been cut of completely. With this approach he has shown how essential connectivity for cities has become and how characterizing density is (ibid.).

Geoffrey West has been working specifically on **scales** of cities. In his book "Scale", published in 2017, he describes his strongly evidenced theory about scaling of biological and social organizations. After analyzing enormous sets of data and information of various cities, he concludes that physical structures in cities develop and scale like biological organisms, such as animals and humans, which proceeds sub-linearly (with a gradient of < 1, approx. 0,85). The reason for that correlation is a naturally occurring controlling network that utilizes resources more efficiently. The growth of those objects is sigmoidal, which means after a steep increase, it will level off or even stagnate (West, 2011).

Contrary, the scaling of societies, social relationships and social organizations has super-linearity (with a gradient of > 1, approx. 1,15), meaning that a city as it grows can expect higher rates of human inventions, such as crime, walking speed or wages. The course has an exponential growth. However, one of the caveats is that the system is likely to suddenly collapse at an uncertain point (ibid.).

The solution for cities to take full advantage of the combination of growth and scaling, resulting from the social and physical pillars of cities, West recommends to generate continuous and over time faster innovation cycles to maintain the growth and to prevent a collapse of the urban system (ibid.).

Businesses, the main drivers of urban economies and transitions, scale and grow in the same way as biological organizations and physical structures due to the fact that they are usually dominated by economies of scale, thus administrative and bureaucratic processes rather than social, innovative processes and the priority on research and development (R&D). That results in a stagnating growth, e.g. seen in the profit-sale ratio, which projects a failure or insolvency and the company's disappearance at a certain point of time (ibid.).

Those scientific approaches could indicate a certain universality and generic nature of cities, as they are all build by and for human beings where, as explained previously, certain patterns and mechanisms can be traced back to biological and natural systems. They can facilitate and compliment understanding processes of the present and planning processes for a more sustainable future, making cities to places where humans, the essence of cities, can flourish. Especially in times when topics around Big Data become more important in various disciplines, such approaches might become of higher value (West, 2011).

However, each city is uniquely complex in its own order and individually sensible to details what demands primarily cities to be observed, studied and analyzed individually (Helbing, no date; Jacobs, 2003).

1.3.2 How to Manage Urban Systems of Complex Order

How has this knowledge of the prevailing complexity been handled, used and integrated so far? In fact, current systems, their mechanisms and functions do rarely address the described nature of cities. Cities are developed in a simplified and homogenized way and businesses are managed dominated by price and functionality (Robert Hammond, Corey Reeser, 2017). None of both prioritize previously mentioned criteria, such as quality and vitality. Such systems are designed assuming economies of equilibria and linearities, which do neither address the nature of cities, nor their rich potentials. For instance, food is rather seen as commodity and cost related object than as a commons (Vivero-Pol, 2017). This rejection inevitable leads to the depletion of natural, economic and social resources over time enforcing or even causing contemporary global challenges (Jacobs, 2003).

This dilemma is the last aspect referred to within the urbanism synthesis. The current way of approaching city planning and doing business needs to be **reformatted**. The present system is characterized by systemic instabilities causing cascade and undesirable negative effects as well as growing vulnerabilities to global challenges; its markets become more and more inefficient while performing unequal distribution of power, resources and information through unfair conditions of one-sided value creation (Robert Hammond, Corey Reeser, 2017). A better system would intake, for instance, a systemic interaction-oriented perspective, where materials and immaterialities are equally and efficiently distributed, interactions and essential relationships are understood and engaged, solutions are designed by approaching the nature of problems, not just the symptoms, natural –including local cultural and social– dynamics are accepted and embraced in man-made structures, a system, which strives to an overall good and harmonic outcome rather than to best outcomes for only a few individuals (ibid.).

To manage and coordinate such a system, Dirk Helbing, professor in computational and social science, suggests in his book "Thinking Ahead", published in 2015, following enabling criteria.

Starting with the most important, Helbing emphasizes to let **self-organization** and further self-regulation occur. Every system –biological and social– has the natural ability to develop by itself, from the bottom up, from own forces, in an individual and unique way, usually resulting in a good, harmonic and dynamically balanced outcome. Without any effort from the outside, it happens automatically through local interactions within the spatial-temporal pattern formation (Helbing, 2015). However, Helbing stresses that this requires **regulations which frame, guide, coordinate**, thus leave enough room for a certain degree of self-regulation, rather than to control and dominate which finally hinders these natural organizing dynamics. In such a setting, the adaptability of the system and its components might initiate a restoration and regeneration of damages, back to the original, intact, healthy and most compatible functionality of its dynamics (ibid.).

As mentioned before, natural systems are built of fractural structures hold together by (social) connections and networks. This **modular** nature should be kept, to enable an organization of well-connected, repetitive, sub-systems, to first of all, make the complexity more manageable and tangible and, second of all, to prevent potential cascade effects, thus making the system more robust (ibid.).

Within this fractal and modular net, the control and power should be **distributed** in a rather **decentralized** manner in which no strict and forcing hierarchy occurs. The connectivity between different units provides the necessary infrastructure for a distributed and decentralized division of power (ibid.).

These rather structure-giving aspects should embrace **diversity** and heterogeneity on all levels and scales (ibid.). Besides the commonly known aspect of enhancing creativity and innovation, according to Helbing, diversity ensures that sub-systems stay functional while also contributing to problem solving through collective intelligence and strengthening the capacity of social capital which is crucial for economic value creation and social well-being. In this context, Helbing argues to push the unfolding of these potentials through new technologies, topics like Big Data and social networks to finally accelerate the slow pace of cultural change. He specifically suggests a participative market society and reputation platforms as promising future pathways, which are introduced in detail in his referenced book.

These criteria support managing and exploiting rich potentials in urban systems. They furthermore contribute to states of resilience –the capacity to recover quickly from difficulties– and of robustness –the ability to avoid regime shifts–, social capacity (social and human capital), efficiency in markets and places of immaterial and material distribution and lastly to growth and economic value creation (ibid.).

To reach such states aiming towards an effectively functioning city where the nature of cities is embraced and taken advantage of, and where urban structures, stocks and flows circulate in a way balancing economic, social and environmental interests to achieve a sustainable outcome, the current system has to be transformed with a strong, comprehensive and holistic approach that provides vision, tools and solutions for a better urban future, which is recommended to be circular economy.

1.4 Introducing The Circular City

Based on the understanding of the urban system, the desired transition towards CE will be compiled by introducing the circular city definition at an **idealistic state** in the following. The chosen point of departure is taken from merging the concepts Urban Metabolism and Urban Ecology. Both shape the circular city definition from two different angles. Urban ecology particularly stresses the consideration of all urban inhabitants which are besides human beings, non-human species, such as plants and animals and the environment –tying up to the previously synergized urbanism theory. The urban metabolism emphasizes the relationship between humans, cities and their environments by quantifying physical flows of exchange and accumulation.

As it finally comes to more practical approaches, those are inspired by urban case studies and organizations' efforts, such as from the EMF and the NGO Circle Economy.

Discourse to European City Agendas integrating CE in policy making

A brief discourse recognizing recent actions and efforts concerning CE on a macro-level, in European cities, shall initiate the circular city definition. The potential of CE has been identified by many policymakers in Europe as CE principles have been integrated into city agendas of i.e. Amsterdam, Rotterdam, Paris or London. Such cities have realized the strength of CE to solve and to reverse interdependent challenges related to resource depletion, climate change impacts, environmental degradation, pollution, health issues, social exclusion and to even benefit economic growth (Bonato and Orsini, 2018).

It is obvious that each city approaches the circular transition differently due to individual characteristics and circumstances, where different focuses and visions result from. However, the approaches applied can be generally identified as future-oriented, holistic, systemic, multi-stakeholder or multidisciplinary (Prendeville, Cherim and Bocken, 2018).

Their individual focuses strongly vary. While the city of London has developed in collaboration with the London Waste and Recycling Board (LWARB) a CE roadmap focusing on its *"environmental target by keeping materials and products in use for longer, re-using and remanufacturing them"* (LWARB, 2017, p. 2), Amsterdam has developed with Circle Economy, based on a Circle City Scan, the Action Agenda "Circular Amsterdam", focusing on implementing circularity in the construction and organic residual stream chain (Circle Economy, 2016). Paris aims, as stated in the "White Paper On The Circular Economy Of Greater Paris", to enhance local stakeholder collaboration and networking and to change local legislation overcoming barriers for CE (*Bio* by Deloitte, Sofies and Auxilia, 2016).

As mentioned, each city pursues an individual approach in designing its strategy considering local circumstances, which is crucial. But, there should be a second pillar to approach the change. This is a general definition of the goal, the long-term vision if not even a standardized framework as Kennedy (2007) demands, for instance.

More value gets generated if ideas are exchanged and multi-disciplinary approaches are shared amongst cities both in a common syntax. These interactions can only function with a common understanding of CE in cities which is approached to contribute to in the following with constructing the definition of a circular city.

1.4.1 Urban Ecology

The theory behind urban ecology, states that all urban inhabitants, humans and non-human species –such as bacteria, plants and animals– interact with each other and their environment. These interactions and related consequences are specifically addressed within the concept.

An urban ecosystem works under the same principles as any other natural system. According to Kirsten Parris, author of the book "Urban Ecology", published in 2016, the distinctive features, caused by the dominance of human action, represent the continuous exposure to change in a faster pace and more drastic manner due to infrastructural redevelopments, the modification of natural shapes and geochemical cycles as well as the intended or unintended introduction of new, not local species. All of those actions threaten the local ecosystem function and its resilience, the population and biodiversity of local species, and at the end of the reaction chain, the originators themselves (Parris, 2016).

Urbanization causes various interferences into the natural ecosystem and its species. A basic and ambivalent finding that Parris introduces is that humans have historically chosen places to live where the level of biodiversity is high. Those are usually located at coastal areas with a mild climate –indicating good preconditions for life. Once settled, they have been transformed into urbanized and dense environments, coming along with urban heat effects, air, water and soil pollution as well as acid rain, harming themselves and the existence of certain local species (ibid.).

Parris further explains that any species are resistant against those effects and can adapt to the urban development characterized by the artificial and changing habitat. Most are even able to profit from higher average temperatures, longer growing seasons and more accessible food. The urban effect of air and water pollution, however, balances those advantages for others and results in the dominance of pollution-tolerant species in cities. In the long run, this leads to a shift in population of local species and general biodiversity (ibid.). 8% of local species, including those on the IUCN (International Union for Conservation of Nature and Natural Resources) Red List, are threatened, while thousands, throughout human history, already became extinct. This might further influence the well-being of humans too as biodiversity in green urban spaces correlates with the psychological benefit for humans shown in a study in Parris' book (2016).

This reaction chain is reinforced through, for instance, landuses reaching from the actual city center into surrounding areas to build suburbs for housing purposes and transform forests into farmlands for agricultural purposes. Another example is the increasing activity of import and export. One externality is caused by transportation means which consume relevant amounts of non-renewable fuels, while releasing respective amounts of emissions, reaching a global level of impact.

The extent of impacts of urbanized areas has been widening within the last decades. The path of solution, the concept recommends is first of all to understand the interdependency between humans, non-humans and their common ecosystem. Second of all, it has to be examined how more livable cities, providing a beneficial and high-quality environment for humans and non-humans and how living cities, which provide space and opportunity for social interaction and community building, can be created. These intentions imply to respectively change the designing, constructing and managing cities in a way that embraces and balances biodiversity and human well-being. This makes human, social and natural capital being indispensable to be excluded from planning and assessment of a circular, effective and sustainable city. (Parris, 2016)

1.4.2 Urban Metabolism

The concept of urban metabolism was developed by the American Abel Wolman in 1965. He drew as well a relation to nature by seeing a city as organism and ecosystem whose metabolism occurs through production and consumption of organic matter, expressed by energy. Certainly, the production of an urban metabolism has to be broaden to a variety of products and services which are produced in cities, while their consumption expands to flows of energy, water, materials, nutrients and waste. These flows are supposed to be quantified and the way they get exchanged determined (Kennedy and Hoornweg, 2012; Ferrão and Fernandéz, 2013). Thus, this framework captures all biophysical stocks and flows and analyses all inputs, outputs and storages within the urban system what provides valuable insights in the resource intensity and the degree of circularity of resource flows.

The resources of water and air currently present the greatest demand in the urban metabolisms, before construction materials and developed technologies, such as electricity-driven engines, pharmaceuticals or fertilizers (Ferrão and Fernandéz, 2013). However, depending on the city's age, stage of development and cultural factors as well as local climate or population density differences in the urban cycles, scale or type may occur. This supports the necessity to develop individual strategies with a broad scope of disciplines to ensure the most effective management for the respective city addressed (Kennedy, Cuddihy and Engel-yan, 2007). Analyzing the details, but keeping the big picture perspective is the guiding principle of approaching the assessment (ibid.).

In a wider sense, according to Kennedy *et al.* (2011), an urban metabolism can be defined as "*the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste*" (Kennedy, Pincetl and Bunje, 2011, p. 1965)

That a city grows in multiple ways and scales, but especially in population size, is an implicit process of metabolism, but in the urban system, it also comes along with accumulations of urban flows to stocks. These can threaten humans, animals and vegetation residing in or even out of the city. Through accumulations of water, such as increased levels of urban aquifer, the utilization of construction materials as fill material, heat storages in pavements or nutrients (nitrogen and phosphorus) can cause common symptoms of cities: air and water pollution, flooding or urban heat (Kennedy, Cuddihy and Engel-yan, 2007).

At this point the relationship between the city and its environment becomes clear. Their state of quality and functionality strongly depend on each other. Although the urban demand is usually met through global food supply systems and international networks, examining certain synergies the city and its surrounded areas have, might be of high value. As Kennedy *et al.* point out the city's perspective, "*the vitality of cities depends on spatial relationships with surrounding hinterlands and global resource webs*" (Kennedy, Cuddihy and Engel-yan, 2007, p. 43). This resurgence could be, for instance, approached through nutrient exchanges or a common recycling system (ibid.).

The overall aim of the concept is to shift from a linear to a circular metabolism by analyzing urban material, energy, nutrient, water and waste flows, and revealing potential cascading relations and informing issues, in order to serve as base for the optimization of the current throughputs of resources. This intention contributes to find sustainable ways, which do not damage the capacity of regeneration and waste assimilation of the local and global environment. Beyond the preservation of the natural environment, the concept agrees with most of the previously introduced concepts that, as a city functions like an organism, inspiration for solutions should be taken by looking at the origins, nature that offers various opportunities to develop resilient and robust systems, (Kennedy, Cuddihy and Engel-yan, 2007).

1.4.3 The Circular City – The Effective System

To set the four guiding pieces of inspiration briefly together, a circular city represents a better system, an inherently **effective system**.

Leaning on Jacobs (Robert Hammond, Corey Reeser, 2017) to summarize the urbanism theory, the system embraces natural, social and cultural dynamics, e.g. by integrating them in man-made structures and processes, it comprises equal resource (material and immaterial) distribution and designs solutions collectively and by taking nature as model.

Taken from the Urban Ecology concept, the responsible consideration of all inhabitants –humans and non-humans– and their internal and external environment is carefully integrated in the city planning, especially the physical (Parris, 2016). Doing so, negative impacts and externalities can be reduced striving for more beneficial life conditions.

The Urban Metabolism lays the base for quantifying urban physical structures and flows. It is an example how scientific and measurement approaches can support the understanding and managing of the system. It emphasizes to take advantage of local potentials, synergies and cascading to make resource exchanges and utilizations more efficiently (Kennedy, Cuddihy and Engel-yan, 2007).

Lastly, a circular economy supplies the system and each concept of inspiration, its ideas and intentions with practical solutions. Being composed of several schools of thought with various complimenting, scalable and modular principles and practical elements, CE represents a conceptual and practical paradigm for change and tailorable solutions in cities (Ellen MacArthur Foundation, 2017a).

By internalizing CE, a city might multiply the value of what the concept has already proven on a business level while resolving negative reaction chains. The integration of the features diversity, innovation and digital technology in processes and solutions supports the necessity of continuous innovation cycles to keep the system growing (West, 2017). Components, which drive the city, such as businesses, the society or the government (the stakeholders), are encouraged to participate in the process of on-going, incremental improvement and stabilization. They are invited to collaborate and pull in one direction to shape their circular and sustainable city and achieve overall the best and harmonic outcome –an effective system.

The overall system strives towards an optimum between resilience and efficiency (=effectiveness) to reach a long-term sustainable growth in all sustainability pillars and capitals. It replenishes, nourishes and enhances development without harming or hindering anybody or anything (McDonough and Braungart, 2002). To understand and manage the dynamic nature and metabolism, interactions and relationships within the urban system are enabled by keeping the balance between observation of reality and scientific assessments based on commonly known, accessible and agreed methods. Such an approach to assess the effectiveness of a circular city is later suggested in this thesis.

Before, the following sections will introduce in detail the function of urban flows and stocks, the role of the stakeholders and the addressed capitals occurring within a circular city. All these piece together and form the conceptual framework of this thesis.

At this point, it wants to be acknowledged that the circular city definition is drawn illustrating an idealistic state in order to determine more clearly the final desired state and goal while being overall aware of potential obstacles and burdens during practical transition processes.

The circular city is understood as open ecosystem, cycling and cascading all kinds of flows, without depleting any, through the interconnected structure of the city – containing social, economic and institutional subsystems–, and its proximate environment. Whereas flows, such as of information, even go beyond the urban or region scale and connect the city to global networks.

Following five categories of urban flows and stocks shape the dynamic and complexity of the city: physical, monetary, information, social and institutional.

1.4.3.1 Physical flows & stocks

The urban metabolism framework identifies five metabolic flows: energy, water, materials, nutrients and waste. Accordingly derived, main input material flows of a circular city are energy, water, materials and nutrients processed by different sectors and actors. The output physical flows are residuals, coming along with emissions, waste and heat –potential environmental impacts.

Those flows are cycled by means of closed and open loops or cascaded within the urban system, avoiding following the linear way. Instead, CE principles and strategies are applied in order to reverse negative impacts and to create greater value. For the physical input flows, those are e.g. avoiding waste and emissions as well as valorizing residues or products at the end of their life due to downcycling or preferably upcycling.

The water flow within a circular city is cycled within the urban boundaries rather than importing water from the hinterland (Kennedy, Cuddihy and Engel-yan, 2007). After the initial use it is treated and cleaned locally to enable the re-use of fresh water or grey water for irrigating or flushing purposes.

The urban energy is supposed to be produced fully from renewable energies while it is used efficiently, avoiding leaving meaningful by-products, such as heat energy from electricity productions, unconsidered (Ellen MacArthur Foundation, 2017c).

The nutrients (organic materials) are kept through cascading within the urban bio-economy and/or its proximate environment that ideally presents the main supplier. This way, nutrients are safely cycled in and out of the biosphere, while being a source of value for another purpose before the final decomposition (Ellen MacArthur Foundation, 2017e).

Since non-organics cannot be returned into the biosphere, the materials are designed to stay as long as possible within the urban industrial cycle (Ellen MacArthur Foundation, 2017e). Their value is preserved through principles such as circular design[7], remarketing, reuse, refurbishment, repair and the avoidance of toxins. These ensure a longer initial use, while enabling next user stages.

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[7] In the new circular design guide published by the EMF, methods to design circular products are divided into understand, define, make, release categories. Further guidance and information can be found under following link: https://www.circulardesignguide.com/methods.

The physical flows have to be managed consciously, as an accumulation can become harmfully to the inhabitants. For instance, due to a functioning inner water system and the incorporation of natural water bodies into the city planning, too high water levels and flooding can be prevented (Kennedy, Cuddihy and Engel-yan, 2007). Regarding materials generally, through mentioned principles, most of them can be kept in the cycle without being directly, after their initial use, dumped or burnt where they emit emissions. For instance, to prolong the life span of the main physical structures of cites, the buildings, higher flexibility can be achieved, specifically through principles such as modularity (Ellen MacArthur Foundation, 2016). This can prevent houses of being abandoned and unoccupied if lifestyle or other circumstances change, what can keep the over all amount of construction waste low to finally contribute to the elimination of the term waste completely.

The concept of CE considered in this research goes far beyond material flows. It aims to provide prosperity for everyone, to increase livability and to achieve sufficiency and effectiveness of urban systems (Ellen MacArthur Foundation, 2017c).

> *"A circular economy is not primarily about technical materials and recycling/recovering them while moving to renewables. It is a different way to see the economy which includes the material but is not limited by it."* (Webster, 2017, p. 103)

The concept is conceived to build social, natural, human and economic capital, resulting in resilience for the city and its citizens. On a city scale, the concept does not only strive for decoupling resource consumption from economic growth, rather to decouple environmental **and** social value from economic growth.

1.4.3.2 Monetary flows

So, the next flow addressed is money and finances, which are one key information flow. *"Money is information that stimulates and co-ordinates the exchange of all things at all levels [...]"* (Webster, 2017, p. 20). It is constantly circulating within and beyond the city's boundaries and reaches into all parts of the economy to all actors of the system. Therefore, within a circular city, prices act as messages (Webster, 2017). Consequently, they reflect full costs of all goods and services to shape an effective, unhindered and adequate market. Markets, where all kinds of resources are effectively allocated and (re)distributed to provide access to basic needs and assurance of living conditions.

Monetary stocks should not exist in an extent that it only profits a few; it rather should continue to circulate within the economy, e.g. due to redistributive reinvestments or taxation (ibid.).

New Economy

The economy of a circular city is not guided by the conventional way of thinking in neoclassical terms[8], as it has happened in the past 40 years, based on even earlier

[8] Neoclassical economics is predicated on axioms assuming a stable equilibrium in the economic system or that selfish and rational behaviors (invisible hand) result in a better outcome for society. These assumptions contracting with the thinking illustrated through the New Urbanism, system or complexity theories, which understand the city as a fractal structure, a scaled living organism hold together by multiple connections and social dynamics. A linear and narrow view on economics does not serve in this context. (Helbing and Kirman, 2013),

established theories. The new economy is embedded in the society and the environment since it has the power to shape both while it also strongly depends on them. As Kate Raworth illustrates, the economy has two limiting boundaries, which are those of the planet –a biophysical and environmental ceiling– and of the society –an ethnic-social floor (Daly, 2017). However, an acting economy respects these boundaries and does not compromise meeting the needs of all.

The new economy prioritizes human goals to nurture the society to finally unfold individual and collective potentials as well as those resulting from a growing diversity in cities. It also recognizes and uses the power of the market, the relationship to the state and the core role of the families and households bringing up the next generation (Raworth, 2017). The recognition of such criteria might contribute to shape a stable, balanced and just economy. In fact, the economy is able to distribute value going "*beyond redistributive income to pre-distributive wealth*" (ibid., p. 221). It also enables, besides respecting its boundaries, to work with and within the environment to avoid further depletion and exploitation of finite resources by finding new ways, enabling regenerative design, consumption and production that finally increases environmental and social quality.

The economy in a circular city broadens the perspective from a narrow economic metric (GDP) –only focusing on economic growth– to a bigger picture with feedback rich mechanisms. It includes and addresses effectively the society and the environment to make decisions. This inevitably leads to a redefinition of success. Economic growth is not the only or most important means anymore; it is complimented by social and environmental measurements or even by aspects that cannot (yet) be captured in metrics.

Furthermore, inner and outer dynamics are considered to see the economy as embedded, interconnected and interdependent subject –rather than as so far, as isolated object– to the global context (ibid.) (figure 3). Inner, dynamic complexities or evolutionary processes as well as outer influences of other cities, such as the state and the environment, are implicated. The challenge finally lays in finding the city's part in contributing as interconnected evolving system to an overall better and whole system.

This vision also implies that there is not only one solution of how the economy of a circular city should look like. It rather emphasizes the role of local actors to find the final definition of economy than forcing it with rational control elements into a universal function. This is taken up in the next part of the section when the role of society, government and businesses is addressed.

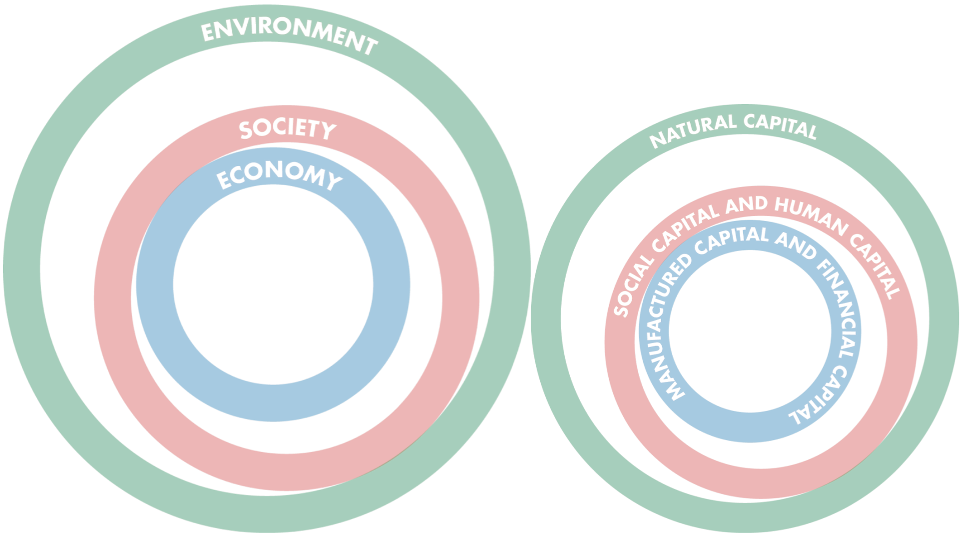

Figure 3: Embedded Economy (own figure, inspired by EMF Logo).

1.4.3.3 Information flows

The other key information flow represents the literal information. As the monetary flow, it is a leveraging component. Information in a circular city is mutually exchanged in a circulating way internally and externally. This results in valuable feedback loops that feed the stakeholders with information to facilitate and enrich their life and purpose that further enables to optimize performance and to adjust actions for a more effectively functioning system (Falconer and Mitchell, 2012).

The difference to the monetary flow is that the information flow is less tangible. However, according to Helbing (2015), this flow is extremely powerful as information is knowledge and further can generate –if managed in the right way– collective intelligence and wisdom of crowds, both contributing to the achievement of an overall better outcome with stable and efficient markets, guiding innovation and prevention of failures. This is why this flow has to be guided, managed and used wisely considering new, changing ways and technologies to unleash its full potential of more complete and effective information flows.

New Informational Connectivity

The flow of information is changing mainly due to the fact of emerging technological advancements. A circular city embraces these developments to a degree compatible for all parties and supportive for the whole system. It is taken advantage of the variety of information that becomes more transparent and tangible due to such advancements.

As the concept of a smart city suggests, information and communication technologies (ICT) and smart computational technologies ideally connect physical, social, information technology (IT), business and governmental infrastructures resulting in a more intact and effective communication and collaboration (Chourabi *et al.*, 2012). These infrastructures are responsive, accountable, transparent and open making the new form of knowledge accessible and exchangeable (Helbing, 2015).

This way, the real life or physical connections get more and more complimented by virtual connections which facilitate the information flow and increase its quantity –if not even the quality. Hence, the city becomes, besides being an interlinked and interdependent biological system, a digital network, which can leverage the collective intelligence embedded in the city (Chourabi *et al.*, 2012).

Such complimented connectivity results in richer feedback loops which help the mutual understanding of different actors, the adjustment process to each other and of products and services for each other. Thus, it optimizes and levels the overall urban system functioning. Beyond these effects, the integration of ICT contributes to various resource savings as well as global carbon savings, which are estimated to be 15% by 2020 (Falconer and Mitchell, 2012).

To reach such contributions, information and data is monitored as good and complete as possible. The information gathered feed scientific approaches, such as from West or Batty, to better understand the individual dynamics of the city and to assess what cannot be seen only with eyes, and to predict –to the extent possible– related risks. The flows also supply concrete measurement approaches to evaluate the city's measurable flows and stocks as well as its general state and progress-making. The performance can be tracked and adjusted easier to agreed goals and strategies, while respective information can be used for benchmarking purposes (Chourabi *et al.*, 2012).

As the long-term effects of digital technologies are still uncertain, practical applications are tested and evaluated in detail before their implementation (Chourabi *et al.*, 2012). However, the emerging digital network characteristic of the city is meant to generally benefit everybody due to higher information access and opportunity to connect where burdens, such as physical distance, have been before. So serve participatory digital platforms, for instance, now as global collaboration, communication or reputation systems generating higher innovation potential or helping to promote fair behavior (Helbing, 2015).

More specifically, the society accesses new opportunities in being supplied with educational and informational sources, participatory opportunities in public decision-making or problem solving concerns. For the private sector, new knowledge and know-how transfer between business partners are facilitated or beneficial interfaces to clients and the government are build. For the growing service sector, digital information and technologies can unlock opportunities to innovate infrastructure, transportation or utility services and techniques. Governmental intentions are especially facilitated due to easier, more efficient and faster bureaucratic and administrative processes (Chourabi *et al.*, 2012). Efforts gathering information which depict the dynamics of urban flows, stocks and related actors can be fostered and facilitated as well. This serves to grasp the city specific collective intelligence in order to better manage it and to build institutional flows accordingly for it.

1.4.3.4 Institutional flows & stocks

The institutional flows are of regulative and legislative nature. Due to laws, administrative rules, incentives or taxations, the urban system with all its actors and relevant activities is guided and coordinated to unlock the potentials a circular city holds. One example is the taxation of natural resources, rather than taxing labor (Webster, 2017). This would lead to more efficient consumption and higher investments in R&D searching for supplements, alternatives and innovations as resources become more expensive. Whereas, labor and employment will increase and wages would be ensured (Witzen, 2018). Such taxation also has a positive cascading effect on the society, as more services will be available this way (ibid.).

Institutional trust for instance represents an institutional stock, which reflects the effectiveness of exemplified governmental measures, of how they reflect the society and emerge in favor of a democratic system (OECD, 2017e). This is besides the institutional flow shaped and enabled by effective information flows.

1.4.3.5 Social flows and stocks

Flows directly referring to the society are those of culture, such as traditions and values, and those occurring in family households or educational institutions, including upbringing and passing on of values. These naturally vary with culture, geography and local circumstances. Respective places and institutions are encouraged and supported with all resources necessary as they have the responsibility to grow and educate the next generation (Raworth, 2017).

Contrary to physical flows, the accumulation of cared social flows (social stocks) is desired and of positive value forming the social capacity.

1.4.4 Circular City Stakeholders

These urban flows and stocks are exchanged and distributed between the circular city stakeholders which are the society, businesses and the government (figure 4). Those have to pull in one direction and manage the flows and stocks in a way that does not hinder one another instead that does enable each other's main function and purpose.

The society represents the heart of the city. The long-term purpose of the society is to sustain and develop, but also to shape and maintain its habitat. This demands to engage and to participate in local decision-making. A relevant worth mentioning sub-stakeholder of the society is academia. It provides the city with important research and knowledge inputs, such as recent insights, news and discoveries, which feed the continuously innovating and developing process (Circle Economy, 2018).

The businesses are generally the driver for action and engine of supply for daily needs, long-term projects and innovation. They produce and provide products and services to meet the demand of the society and bring ideas into action.

The government manages the society's and businesses' activities through legal frameworks –having a guiding and inclusive not controlling nature– which are complimented by organizing, planning, mediating and supportive functions. Thus, it ensures enabling conditions for the development of the whole urban system.

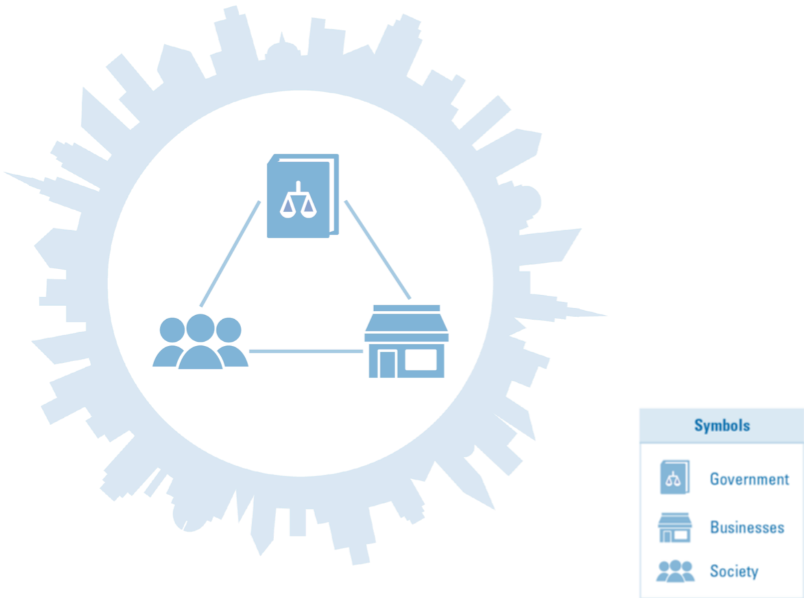

Figure 4: Circular City Stakeholders (own figure).

1.4.4.1 Circular City Society

The society in a circular city represents the core of the system, as social structures are the fundament of communities, organizations and entities, which are further the root of consumption, production, exchange and markets (Jacobs, 2003). On the one hand, depending on individual professions and personal circumstances, they influence flows and stocks in their field of reach, which can be indirectly or directly. On the other hand, they strongly depend on a sufficient distribution of physical, monetary, information and institutional flows in quantity and quality, and supported positive social flows. This distribution as a part of managing mainly lays in the government's responsibility. It is necessary to, at the minimum, meet basic needs and living standards, and beyond the minimum, to provide opportunities for individual development and learning. Both aspects are essential to nourish and to unleash the potentials lying in the collectiveness of societies and to build up social and human capital (Helbing, 2015). This addresses criteria regarding housing, education, income and employment, health, infrastructure, transportation, security, public policy, culture and general well-being.

In practice, examples of these criteria are, in accordance to the original idea of efficient markets, prices reflect true/full costs and information, so do wages. Citizens receive an income reflecting actual work done including guaranteed basic income. The society has unrestricted access to information and data through functioning communication channels and platforms, but is at the same time, protected of potential data misuse. The health and safety of every citizen is ensured due to sufficient public services, supports and insurance systems. Access to high quality education, adequate and affordable housing and transportation means is a fix to everybody while access to enough public and natural spaces for leisure and recreational purposes is provided as well.

The circular society is made of **homo socialis** as Helbing (2015) defines. This type of human is characterized by –contrary to the homo economicus[9]– making interdependent decisions, friendly and fair behavior aiming for a better outcome for everyone, self-determined and conditional collaboration. Sudhoff (2014) further describes a circular society with mutual responsibility, a strong community cohesion and sense, helpfulness in daily activities, interconnectedness and a high valuing of equality. Such characteristics of the homo socialis will form "*network minds [which] enable collective intelligence*" (Helbing, 2015, p. 59) that in turn result in the capacity to solve problems.

Due to the trend of globalization and urbanization, urban social structures and ethnical backgrounds are becoming more **diverse**. The circular society embraces this trend, welcomes multicultural and professional backgrounds, and tolerates differences to exploit a greater common and mutual benefit. These characteristics facilitate actions and projects based on sharing, collaboration and multi-stakeholder approaches. They also increase the potentials for innovation and creativity and shape a forward thinking society that comes up with new ideas and innovative, successful solutions for local challenges (Johnson and Lehmann, 2008).

To broaden the relationship to human and their environment, the society pursues a **sustainable lifestyle**, i.e. consuming consciously, respecting nature's boundaries, while avoiding certain actions and decisions with negative impacts on others and the environment. This results from corresponding system conditions, which have integrated respective principles and commandments in legislation, education, professional development and information channels for instance.

Lastly, the society in a circular city holds an **active and participatory** citizenship within a democracy and trustworthy system, which makes citizens being involved in local decision making processes (Bauwens and Niaros, 2017). The circular society is empowered and heard from the local government, what enables changes from the bottom up. Change, from those who know the city the best (Robert Hammond, Corey Reeser, 2017).

All aspects together contribute to unfold the full potential of the circular city society to flourish. With the society, so does the whole city.

Stakeholder	Characteristics
Society	The Heart of the City
	Accesses Good Environmental Quality
	Commands Ensured Living Conditions
	Has High Life Quality
	Homo Socialis
	Growing in Number and Diversity
	Pursues Sustainable Lifestyle
	Holds Active Citizenship

Table 3: Characteristics Circular City Society (own table).

[9] The homo economicus is assumed in mainstream economics such as in neoclassical economics. The term defines humans or firms as agents characterized by rational (in game theory as perfectly rational), selfish, self-regarding and competitively optimizing. To make decisions, it is furthermore presumed to access "unrealistic information of storage and capacity"(Helbing, 2015, p. 42).

1.4.4.2 Circular City Businesses

The business landscape within a circular city is wide and diverse. While manufacturing industries have been coming back into the cities, start-ups as well as established and transitioning businesses, focusing on service and performance provision, represent another growing part. Regardless what business model, following and **implementing CE principles** to the highest degree possible, is a standard. To recapitulate a few, businesses use renewable energies and resources as inputs, design their products for longevity, they valorizes waste and cycle or cascade residual products as long as possible within the industrial or biological cycles. These activities are supported by taking advantage of new technologies and innovations, which are used with best intentions for the common good and value creation.

The prior intention of circular city businesses is to come up with solutions, which optimize urban flows and stocks that further support a better functioning of the overall system. Furthermore, their priority is to meet the **local demand** first in the most sustainable way, before anything gets exported going on a long route and increasing the carbon footprint. This is why local markets and direct feedback from the society are frequently analyzed by the businesses and the government.

Besides listening to the market demand to ensure low costs and efficient supplies, businesses also take responsibility in two ways. First they support the local job market by **providing jobs and strengthen the local labor force** as well as a good working environment, finally enhancing the local workforce development. Second, they guide the market hand in hand with the institutional body. For instance, products, which harm the society and environment or are rather contra-productive for the overall value creation, are taken incrementally off the market. This makes the feedback flow to employees and consumer a mutual and positive.

The operations of circular city businesses are characterized by maintaining and extending connections to various stakeholders and disciplines, as higher value and more successful solutions and impact can be generated this way. Innovation challenges, research, **systemic and collaborative** projects –physically or virtually– could be examples where direct participation from the society, including academia, synergizing with other businesses and partnering with the government can be realized.

Businesses are the main **driver of change** and functioning in a city. Due to implementing CE principles and thinking, operating accordingly to sustainability goals and to mentioned characteristics in a collaborative way is what businesses in a circular city aim for and where they position them.

Stakeholder	Characteristics
Businesses	Driver of Action
	Part of Wide and Diverse Business Landscape
	Perform Green, Sustainable, Responsible
	Embed CE principles
	Collaborate and Network
	Participation in Local Markets

Table 4: Characteristics Circular City Businesses (own table).

1.4.4.3 Circular City Government

The government of a circular city has understood the general dynamics and complexities of the urban system, the interrelatedness and interdependency amongst its actors, sub-systems and related connections reaching beyond the city boundaries. Generic principles of cities are comprehended while local characteristics are grasped as well. This captures a comprehensive perspective on the city the government represents.

Considering Helbing's (2015) suggestions and enabling criteria, the circular city government rather coordinates and guides the system, its flows and capitals than controlling them. It leaves enough **room for the natural self-organization and self-regulation** recognizing that already simple local interactions, which occur efficiently by themselves, can create a rich variety of complex structures, properties and functions and finally can give the system a resilient structure. Meanwhile, depending on the identification of cultural mechanisms, needs and potentials, the government **balances out the interest** of economic, governmental and individual origins and ensures positive, effective interactions and feedback loops. This means, a crucial task of the government is to determine the right interaction rules and sanctioning mechanisms to **frame and stabilize** the described actions and characteristics of the society and businesses to ensure the development and well-functioning of the overall urban system (ibid.).

The government has a strong emphasis to **protect and build the social and human capital** by ensuring equality, life quality, a healthy environment and wellbeing of all citizens while a special support regards social institutions which directly build and form this capital (Raworth, 2017). Another focus is to maintain an **intact and growing local economy** through effective markets, an innovative business environment and active market participants. Beyond that, the **environmental state is protected** and equally important as the system and its actors strongly depend on the natural capital that enables life. The government makes sure through deciding on **right boundary conditions** that a mutually benefiting co-existence of several systems can occur. So are competitive or conflicting concerns between different systems and stakeholders, e.g. regarding housing and land, leveled with appropriate regulative means and practical strategies, such as specific design principles, collaborative problem-solving or ideas about shared spaces, as the concept of CE suggests.

These new focuses of the government preceded a **system change** –not minor changes in the existing system– a change in understanding, thinking and managing the city. The new paradigm is to let the system grow and be build from the bottom up while planning and managing the process from the top (see figure 5). Managing it by taking in a holistic perspective. For instance, the GDP only does not longer represents the compass of success; it has been complimented with equally important criteria describing social and environmental states. The government’s main responsibilities are to draft and implement the right boundary conditions, better decision-making, adjusted curriculums, appropriate laws and taxations, suited regulations and guiding, value-sensitive incentives which all consider and enable **CE as practical and conceptual paradigm**. For the realization processes, it implies to provide **longer and appropriate time scales** to let all stakeholders adjust to changes and to support sustainable implementation processes which finally reveal long-term success on a common level (Helbing, 2015).

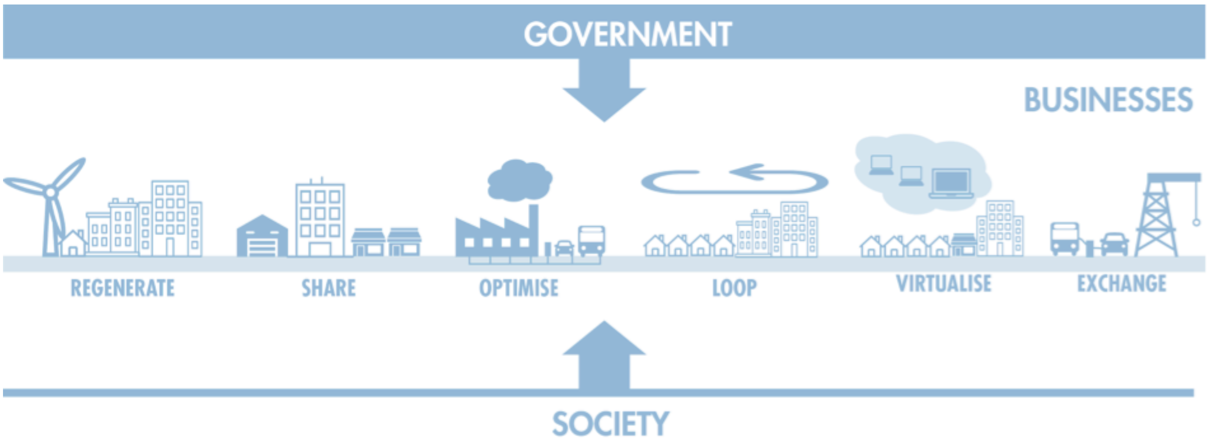

Figure 5: Balanced Top-Down and Bottom-Up Approach (own figure).

The governmental body represents a **democratic and trustworthy** instance. Thus, sources and information used and processes passed are publicly available, **transparent** and comprehensively presented. Similarly, laws, data, standards or strategy papers are open. However, the city's actors are not overloaded with information what could hinder the effectiveness of the whole system (ibid.). So, it is also part of the government to keep the big picture perspective, to zoom out, to remember the long-term goal and take accordingly action, i.e. placing and distributing the right amount of information.

Local challenges are solved **collectively**. The same applies for finding new solutions to develop the city, which is continuously approached. Different stakeholders are brought together taking advantage of multi and **trans-disciplinary** backgrounds. Businesses are as usual one part of it. Another part is academia and knowledge institutions to benefit of recent research insights. Lastly, the society is engaged and empowered to take part in processes as this actor knows the city the best and embodies a great potential of creative and innovative solutions fitting the local environment (Robert Hammond, Corey Reeser, 2017). The information for these (solution-finding) processes is generated virtually and physically to involve as many parties as possible while both **participatory effort** form the society and businesses, and **administrative investigations** from the government piece a more complete flow of information (Manabe, 2015).

Resulting ideas constructed in a process that embraces complexity and diversity are drafted, **tested** and assessed. Micro-prototypes are tested in places such as living labs, incubators and innovation platforms while macro scales are tested via simulations, time restricted and scalable.

Examples for other practices are to provide sufficient advisory services to the private, public and academic sector regarding local developments and CE and sustainability concerns. Regulations include **market-based incentives** such as supporting the dematerialization of the society, directly by guiding the market to digital sources, or indirectly, by expanding the integration of online platforms or second hand market to exchange goods and services. The effectiveness of the markets is supported **leveraging the opportunities** for participation or new investment opportunities, such as crowd funding or new loan conditions (Webster, 2017). Furthermore, the government makes sure that general CE principles, such as waste equals food and the shift towards renewable energies, are realized within the urban system, integrated in activities of the society and the businesses. This is fostered besides market-based incentives with **sanctions** for breaches. Further enabling conditions address new and digital technology, which are enabled and embedded in urban developments, such as in automation technologies or smart devices and co-producing activities, enabled through e.g. 3D printers (Helbing, 2015).

More concrete intervention approaches for specifically enhance the integration of CE, are first of all, the initiation of projects where CE knowledge is developed coupled with local needs and activities. This way, **awareness** of all stakeholders can be created. Second, business support schemes are designed to **equip** local organizations with financial means and advertise to develop innovative circular business proposals. Third, established collaboration platforms to bring all stakeholder and their interests together to contribute to a mutual understanding, while expertise and networks can be leveraged and exchanged. Fourth, respective regulatory frameworks facilitate and enable collective projects and activities between businesses, society and knowledge institutions to first of all educate sustainability and CE, and second of all to collectively develop CE projects in the city. Lastly, the government collaborates with the **national level**, to influence fiscal frameworks. This presents a lever to create incentives for CE, such as mentioned taxes on resources, lower taxes on labor, CO2 taxes, increased taxes on incinerators or landfill (Ellen MacArthur Foundation, 2015).

Stakeholder	Characteristics
Government	Understands Generic and Individual Dynamics of the City it Represents
	Guides the System, Sets Boundary Conditions for Effective Flows
	Ensures Right Conditions for Society and Businesses
	Is Fair and Transparent
	Keeps Balance between Top-down and Bottom-up
	Publishes Policy and Strategy Papers
	Has New, more Holistic Decision Criteria (e.g. complimented GDP)
	Pursues Democracy, Collective Decision-making and Solution Design
	Implements Sustainability and CE Education in Information Flows

Table 5: Characteristics Circular City Government (own table).

1.4.5 The Effect on the Capitals

If the urban stocks and flows are effectively distributed and exchanged amongst all mentioned stakeholders, all capitals, the human, social, natural, manufactured and economic –influencing directly the quality of the urban system– can be maintained, stabilized or even increased (Ellen MacArthur Foundation, 2017b).

Before the effect and relationship of the circular city flows, stocks and stakeholders on the sustainability capitals are explained, each capital is briefly defined in the following leaning on Johnson and Lehmann (2008): The human capital defines states such as health, knowledge, trust, networks, education and competence of people. The social capital refers to institutions that help to develop human capital and enable social interactions. Natural capital describes any physical flow of natural resources and the state of the ecosystem. The manufactured capital defines the structures and stocks of buildings, infrastructure or products in use (ibid.).

Finally, the economic capital does not have a value for itself; it rather represents the means of monetization of all other capitals in a message which ideally represent the true value, similarly to, as mentioned before, the monetary flows (Webster, 2017).

Relationships

All stakeholders stay in a mutual relationship with each other. Information and monetary flows occur usually between all and in every direction as these two key information flows characterize and depict the functioning economy.

The government distributes information, as well as provides rules and laws both businesses and the society has to comply with. At the same time, businesses and the society pay taxes to the government, e.g. income, consumption or property tax, but can also receive public financial supports, such as incentives, unemployment benefits or funds. The city's development processes and solutions are designed collectively in collaboration with all three stakeholders within a balanced top-down and bottom-up approach, which can be an example of well-managed information flows. So, between the government and the society, social, monetary, information and institutional flows are exchanged which mainly affects the social, human and financial capital of the city. Between the government and businesses the exchange of information, institutional and financial flow prevails. These flows primarily influence the financial and manufactured capital.

The relationship between the society and businesses is characterized by an exchange of social, financial, physical and information flows. The society demands, consumes and purchases the products and services produced by the businesses. Besides providing solutions for the jobs to be done, the businesses also provide employment and jobs for the society. This relationship essentially affects the social, human, financial, natural and manufactured capitals.

The mentioned relationships are illustrated in figure 6 on the next page in the inner three layers.

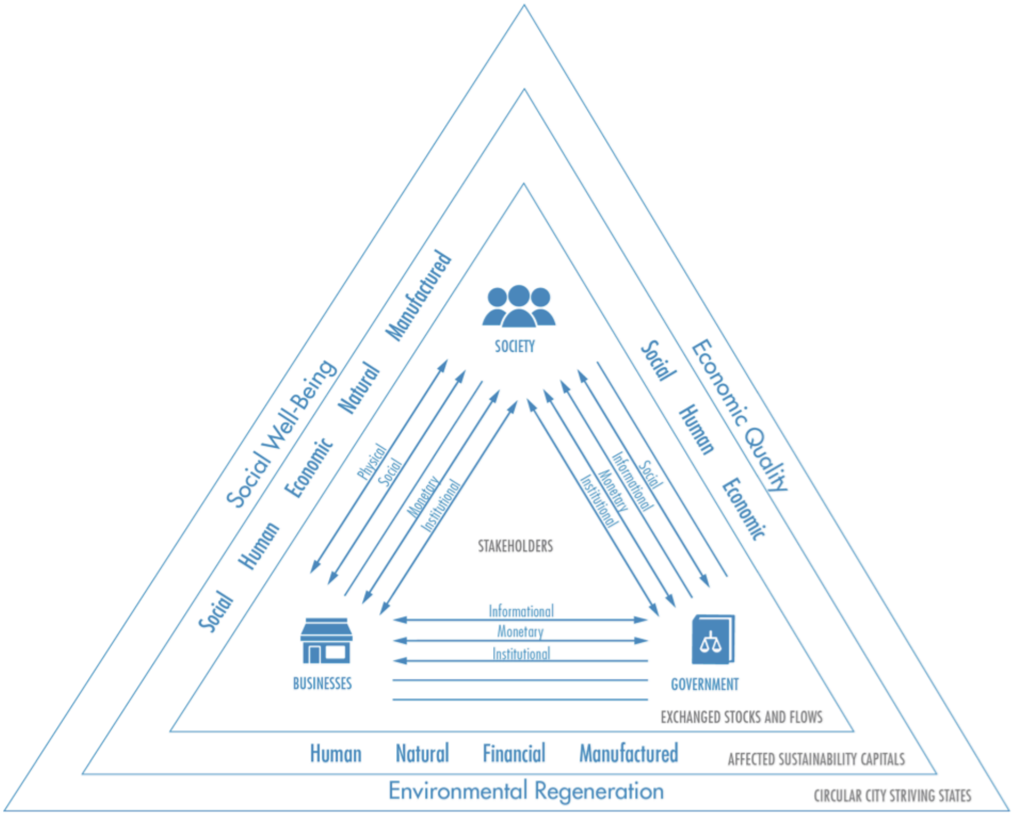

Figure 6: Circular City Triangle (own figure).

The last layer of the triangle represents the superior goal of a circular city. It shows, resulting from an effective exchange of flows and stocks between the stakeholders, affecting all sustainability capitals, the increase of the three striving states, which define and indicate the effectiveness and quality of the system:

1. **The Regeneration of the Environment.**
   Due to "cycling" physical flows, via CE practices, within the urban system and its proximate environment, the pressure on the ecosystem decreases that enables its regeneration.
2. **Social Well-being.**
   By putting the emphasis on human beings who are the root of every entity existing in a city, ensuring proper life standards and life quality and beyond, the full potential of social collective intelligence can be revealed.
3. **Economic Quality.**
   A financial growth –without defining the extent of growth at this point, as it strongly depends on the individual city characteristics– occurs in co-existence with the before-going states, which enriches it with quality. Due to a transformation of the economic system –including a new compass of success, which considers social and environmental criteria equally– a sustainable development within the city is enabled.

To sum this chapter up, after successful applications in businesses contexts, CE represents a promising path to transform urban areas into places of regeneration, redistribution and growth complying with superior and long-term goals of sustainable development. Cities have high potential to approach, solve and revert contemporary challenges to a higher degree than could be ever reached on a business level.

This hypothesis is supported by the facts that cities hold naturally enabling aspects, such as aggregating diversity of businesses and society, proximity between its stakeholders and various increasing connections. With the dynamic occurring between urban stakeholders through exchanged stocks and flows, they furthermore command and affect all capitals. Managed in an effective way, a higher positive value of the environment, economy and society can be generated.

With a combination of the right boundary conditions set by the government, participation from the society and action from the businesses enabling local, common and mutual understanding, collective envisioning and strategy design, which embraces technological development and considers CE as paradigm, local and global challenges can be addressed within the urban **transformation** towards becoming a circular city. (Bonato and Orsini, 2018).

2 The Role of Measurements in the Transitioning Process towards CE in Cities

As the term transformational change is enacted over a period of time, it is required to measure and monitor progress-making over time (BusinessDictionary, 2018). The data measured and the results assessed enable first of all, to scan the current state which can facilitate the understanding of the city, its generic and specific characteristics. Second of all, it represents a base of communication that can help to integrate and incorporate CE principles and target SDGs more precisely in decisions and actions, locally as well as nationally. As analyzed and explained in the previous chapter, CE aims for an effectively functioning system that targets sustainability and resilience in cities as long-term goals as it changes and improves the urban system's state of economy, society and environment. The transition is approached from a system perspective and happens within a continuous, incremental process. The concept of CE serves as conceptual and practical paradigm as it paves the path due to concrete objectives and visions providing ambitious yet crucial principles and strategies for the transformation journey.

To achieve the goal, to specifically determine how the state of CE in a city is and where it wants to focus on as well as to identify which elements and sectors do impede or contribute to the transformation, the *"articulation of [...] the development and [...] measurement of generally accepted indicators [...]"* (Environmental Protection Agency, 2011, p. 45) is required.

In correspondence to the last quote of the EPA, the following chapter justifies the necessity of approaching change with appropriate metrics. After introducing their function and contributions, the expectations on metrics for a circular city are formulated, followed by a brief examination of which criteria defining a circular city are actually tangible and measurable.

2.1 The Function and Contribution of Sustainability Metrics

The abilities to measure, to monitor and to assess states of sustainability on various levels and in diverse sectors for different entities is critical due to reasons, such as decision making, goal achievements and vision formulations. The foundation of these abilities represents indicators and indices (Guo *et al.*, 2015).

According to the Organization for Economic Co-operation and Development (OECD, 2010), indicators are descriptive, quantitative or qualitative variables measured either due to direct observation or derived quantities. They provide a simple but reliable means to measure achievement, in order *"to reflect changes connected to an intervention, or to help assess the performance [and progress-making] of a development […]"* (OECD, 2010, p. 25). While indices comprise aggregated indicators, from potentially more than one sustainability dimension, within a single measure, a metric defines the unit of the indicator or index being measured (Guo *et al.*, 2015).

The functions, contributions as well as applications go far beyond only measuring a certain state for **reporting** purposes. If the applied metrics are chosen wisely –in terms of comparability and verifiability– and appropriately –regarding describing criteria of the focus well enough–, they rather serve as base for **discussion and communication**. Decisions about future developments, improvements, optimizations or even changes can be made well founded. *"[…] [C]ircular economy policies need sound indicators"* (Circle Economy, 2018, p. 2) –coupled to metrics, political long-term visions and agendas could be **designed** more specifically, while their achievements and compliance can be **traced** more accurately at the same time. Disregarding of the level of the entity being assessed (e.g. business or city), capturing performance with metrics enables also to **compare** relevant variables, to disclose opportunities and risks or to weigh up alternatives. Beyond that, pilots and innovations as well as their markets can be evaluated more comprehensively. All this allows and enables an effective **benchmarking** and the identification of best practices –internally and externally.

The application of indices allows furthermore to assess the state, progress-making or performance from **different perspectives** depending on how the index and it components (made of indicators in nominator and denominator) is constructed and unfold (Environmental Protection Agency, 2011). This modular characteristic can contribute to a better comprehension, a common understanding and finally consensus as it helps to communicate in a more clear and unambiguous way.

Regardless which intention specifically drives the application of sustainability metrics, it can be generalized that it is **critical for the success** of sustainability concepts to measure progress over time.

However, sustainability related topics always come along with a high degree of **integrity and interrelatedness** of different dimensions, stakeholders and subjects. This is why it is recommended to compose a **set** of indicators covering at least the main interrelations and to simulate different scenarios of several possible cases (Schwarz and Beaver, 2002). Following results are likely to provide a picture closer to reality, avoiding one dimensional decisions and actions, rather fostering responsible decision making, considering and planning for future needs.

Sustainability indicators are usually embedded in a framework or standard with a specific focus, which is represented in a metric assortment or they are organized and aggregated towards an index or score (Guo *et al.*, 2015).

Both ways are demonstrated within this thesis, starting from chapter 3 where a review of the main frameworks and standards is given, while later on, based on this, a circular city indicator categorization, set and index are proposed.

2.2 The Necessity of and Expectations on Metrics for Circular Cities

> *"Cities […] are increasingly taking a centre stage addressing key societal, economic and environmental challenges, as all these issues come together in the urban environment. The need to measure progress in moving the needle to a circular city is therefor evident."* (Circle Economy, 2018, p. 4)

This quote summarizes the importance of metrics to measure progress-making of cities towards a circular economy, which this thesis is from now on focusing on. The necessity is represented first by the complex nature of the city and its composition of interrelated sub-systems accumulating a large amount of information and data exchanges within the urban metabolism. The application of metrics, which inevitably require accurate and reliable measurement methods and data platforms, contributes to unknot, uncover and structure urban flows and certain stocks. Secondly, metrics provide the base for effective and responsible policies, decisions and action steps addressing mentioned global and local challenges to finally target visions and agendas as well as the overall goal of sustainable development in cities.

Until now, there have only been made very few efforts in developing a framework to measure or to construct measurements to indicate CE in businesses and even less in cities –this applies at least to those which are publicly available. The first approach was done by the EMF. 2015, with the publication of the "Circularity Indicators Project", they have made a contribution to measure the circularity of material flows for products and companies (Frank, 2015). In 2017, the organization Circle Economy followed with developing the "Global Circularity Metric" that captures the material circularity of the planet (Circle Economy, 2018). In the same year, the British Standards Institution (BSI) developed a standard for implementing CE principles in businesses. And this year, 2018, the European Commission has published a small indicator set to measure material circularity and innovation on a national and EU level (European Commission, 2018).

However, implementations and practical applications of CE have neglected holistic measurement approaches so far. They either only considered material flows or completely neglected measurements and rather focused on the achievement of fast practical results. But to track future progress-making of transitioning approaches, to allow the assessment of measures or to adjust specific targets, the implementations need to be complimented with CE suitable metrics and measurement frameworks (European Commission, 2018).

To initiate the proposal of a holistic approach to measure CE in cities, the expectations on respective indicators are as follows.

First, similarly to sustainability metrics, they have to cover a broad range of criteria, aiming to form a complete picture of the state measured. The three pillars of sustainability, equally weighed, define this range reaching into social, economic, environmental and institutional fields where urban flows get exchanged and stocks are aggregated. Only by considering both the utilization of resources and the simultaneous value creation in all dimensions, the desired long-term goal of sustainability –system robustness and resilience– can be achieved (Fiksel, Mcdaniel and Mendenhall, 1999).

The concept of CE offers concrete approaches and strategies to achieve this goal and promises urban prosperity, which is restorative, regenerative and redistributive by design (Ellen MacArthur Foundation, 2017d). To recapitulate, flows and stocks are managed aiming to stabilize a self-organizing and self-sustaining urban system to finally strengthen the effectiveness of the system. For instance, the physical flows are "circulated" in a way as described in section 1.4.3 while social and informational flows are enhanced. So second, the indicators have to depict specific CE contributions, such as recycling rates or the stakeholder's participation in local decision-making or collaborations.

Third, the desired system state –the effectiveness through increasing social, environmental and economic values– is reached in a way that decouples economic prosperity from environmental and social value. So, circular city indicators have to represent on the one hand, the quantity and quality of all sustainability dimensions and their categories and on the other hand, the applied metric, which aggregates chosen indicators, should depict the decoupling criteria.

The fourth and superior condition is that the indicators comply with local, national and international goals and objectives, e.g. about GHG emission reduction, waste treatment, social equality and prosperity or preservation of natural habitat.

Lastly, the amount of indicators chosen should neither be too big or too small. A too little assortment might result in a one sided or restricted perspective, while a too large set might loose clarity or overlap in certain aspects.

The metrics should finally follow those criteria and generally draw and show relationships and dependencies between analyzed variables (Fiksel, Mcdaniel and Mendenhall, 1999). The metrical assessment itself should be conducted frequently, as ISO (2014) recommends, annually fulfilling the condition to track development over time. A frequent control will bring benefits due to resulting improvement and adjusting processes of actions and states (Environmental Protection Agency, 2011).

2.3 Status Quo: What is measured and actually measurable?

Justifying the urgency of urban transition towards a circular economy and the necessity of measuring the progress-making represents the theoretical part. To actually put these intentions into practice requires four aspects to consider.

The first aspect presents a **common understanding**. This does not only need to prevail within the city and its stakeholder, but also beyond. Particularly, in the communication to other cities, for comparing and synergizing purposes for instance, and to national and international levels where fiscal frameworks are developed, this understanding is crucial as well.

Due to the lacking second aspect of **inconsistent or not yet invented measures**, framework and standards, the first aspect can rarely be met beyond the city level (Fiksel, Mcdaniel and Mendenhall, 1999). Applying several different approaches might bring individual improvements, but the overall success, what is of even greater value, fails. Overall success demands a clear communication of what is measured and the opportunity to compare performances (Giovannini *et al.*, 2014). Otherwise, synergies are hard to be identified. Current means to measure sustainability and material circularity are numerous and lack of consistency and compatibility.

The third aspect is the **quality of data** monitoring. In many cases, required data is not documented at all**, porous** in its record or not transparent. For instance, capturing the total waste stream in NYC is a major challenge, since the commercial waste is collected by private companies which makes tracing difficult (Rosengren, 2016). Connected to this point, a competitive attitude with data, even if it would be available, the common refuse to share it impedes measuring and especially comparing results (Circle Economy, 2018).

There are gaps as well as barriers for the successful application of CE measurements in cities from different angles. This research contributes to fill and overcome those. It serves as concrete stepping-stone to support CE implementations and measurements in cities. Rather then inventing something new, it is intended to structure and organize existing frameworks and standards, where also existing approaches are narrowed down or scaled up. Thus, it is contributed to more consistency and the promising complementation of existing approaches to form a global, common and transparent base line for circular city metrics.

Despite mentioned hindering aspects to measure in practice and the approach of this research to compensate those, **not everything** what defines a circular city **is actually measurable**. Physical and monetary flows are certainly the easiest to be quantified, as common units of weight, density or currency exist.

The social and environmental criteria are partly directly measureable, but a large extent is only measurable through subjective (such as subjective life satisfaction), qualitative (e.g. air quality) or indirect metrics (such as change rate of native species or impact assessments indicators).

Similar concern applies for the institutional flow. Public trust and corruption are measurements, which can at least indirectly indicate the effectiveness of the government, how governmental operations reflect the society's values and expectations and how they favor a democratic system (OECD, 2017e).

Information is the most difficult to measure. The information flow is as yet rather impossible to measure directly, as no metrics have been developed so far. Eventually with further developments of digital technology and new assessment means, it might be possible one day to capture the flow of information.

However, as mentioned before, this research departs from a definition of a circular city at its idealistic state, but measures what is possible at this stage of time and feasible to cover within the given time period which are, as soon explained more in detail, relevant physical and economical flows as well as qualitative social and institutional aspects.

3 Frameworks and Standards Reviewed on Potential Circular City Metrics

To initiate the measurement approach of the effectiveness and progress-making of a circular city, sustainability frameworks as well as standards and recent approaches to measure the state of CE have been reviewed. They have been chosen by meeting following two criteria: global acknowledgement and application –to facilitate administrative efforts– as well as relevancy for sustainability, CE and the understanding of a circular city developed in this thesis. In this chapter, the choice and role of the chosen frameworks and standards will be explained, followed by introducing each one briefly.

3.1 Availability and Choice of Frameworks and Standards Reviewed

From 1987, with the publication of the Brundtland Report "Our Common Future", by the World Commission, the attention towards sustainability assessment and monitoring approaches has increased. Today, numerous standards and frameworks are available to measure sustainability on different levels (Banaite and Tamosiuniene, 2016).

Starting in the early 1990s, sustainability product standards and eco-labels for agriculture products have been developed and been increasing in number and sectors applied, as well as geographical levels scaled up to until today (Komives and Jackson, 2014). To give a proxy, in 2013, already 435 eco-labels have been tracked in 195 countries (ibid.).

However, from this diversity, only three levels (business, city and country) have been chosen for the sustainability focus, since they are the most relevant for the city. As explained, businesses are the main driver for economic force and momentum of change. Knowing how and what they measure contributes to a better understanding and consideration of certain indicators. The country level plays a significant role e.g. for fiscal legislations or transferring national regulation to a local city level (Ellen MacArthur Foundation, 2015).

An even smaller (micro) level is represented by the mentioned eco-labeling or sustainability product standards. These have not been considered as they are rather irrelevant for the here approached city level.

Finally, the choice of the sustainability standards and frameworks have been chosen by the criteria of acknowledged organizations of publication, which are here the United Nations (UN), Sustainability Accounting and Standard Board (SASB), the Global Reporting Initiative (GRI), the Organization for Economic Corporation and Development (OECD), the European Environment Agency (EEA) and the International Standard Organization (ISO).

Contrary to the sustainability focus, established frameworks, referring specifically to CE, are as mentioned still rare. The only official standard on CE on a business level is the British Standard (BS) 8001, published by The British Standards Institution (BSI). This standard addressed the implementation –not the measurement– of CE principles in organizations (British Standard Institution, 2017). As no indicators are attained in this standard, it has not been further considered.

One official measurement approach on a country and EU level is the Monitoring Framework for the Circular Economy, published by the European Commission (EC) in January this year. This standard will be introduced later, as it has been overtaken into the selection of standards reviewed. The same applies for the Material Circularity Project, developed by the EMF, and the Global Circularity Metric from Circle Economy. These are not competing with official standards, but they are approaches, which measure and capture the tangible circularity on a business and global level. A further reason they are considered is that they received attention and are widely mentioned in media and practice.

Except of the Monitoring Framework on Circular Economy, which also considers competitiveness and innovation, all of the other chosen standards and frameworks only consider physical flows and stocks. To fill this gap of indispensible further indicator categories –defining **all** striving states of a circular city–, the sustainability standards served to do so.

As CE has gained more attention within the last years, further research investigations and approaches in standardized measuring can be expected as this research tries to contribute to.

For instance, Banaite and Tamosiuniene (2016) introduces in their paper further young scientific approaches to measure CE which also partly consider other dimensions than only the material. However, due to the reasons that these approaches are either not assessable or on are still on a very young stage of development, it is only referred to them, instead of considering them further.

All over, from the pool of available standards, frameworks and approaches, 12 have been chosen. Their review served in three ways. First, studying the intention and methodologies provided a base and inspiration of how to construct an indicator set and an index. Second, by considering several frameworks and standards, different focuses have complimented the developed indicator set, which is intended to be comprehensive and holistic. Third, it has been examined which already existing indicators are useful for docking to the defining and measurable criteria of a circular city.

3.2 Introducing Reviewed Frameworks and Standards

After stating and justifying the choice of frameworks, standards and approaches reviewed, they are shown and organized in the table below (table 6) by superior focus –sustainability or CE– and their scale/level addressed –micro: business, meso: city and country or macro: world.

Focus \ Level	Micro	Meso		Macro
	Business	City	Country	World
Sustainability	Sustainability Accounting Standards (SASB)	China Sustainability Development Indicator System	Global Indicator Framework for Sustainable Development Goals (UN)	
	Global Reporting Initiative Standards (GRI)	ISO 3712: Sustainable Development of Communities (ISO)	How's Life (OECD)	
	ISO 14031: Environmental Performance Evaluation (ISO)	Extended Framework on Urban Metabolism (SEI)		
		Driver, Pressure, State, Impact, Response Model of Intervention (OECD, EEA)		
Circular Economy	Material Circularity Project (EMF)	*Circular City Index*	Monitoring Framework for the Circular Economy" (EC)	Global Circularity Metric (Circle Economy)

Table 6: Reviewed Standards, Frameworks and Approaches on Sustainability and CE (own table).

The as relevant identified frameworks and standards on the sustainability micro level meeting mentioned criteria are:

- The Sustainability Accounting Standards have been developed by the SASB, an independent standard-setting organization. They address public and private companies in the U.S. disclosing sustainability information for investors and the public. The standards are industry-specific and organized in 11 sectors and 79 industries including disclosure guidance, accounting standards or metrics for each sector, while the information focus lays on financial impacts (Sustainability Accounting Standard Board, no date).

- The Global Sustainability Standard Board (GSSB), an independent operating entity under the GRI, has developed the first global sustainability standards, which are still the most widely used in the world. The standards are designed with multi-stakeholder contributions and are considered to enable policy making and to meet public interests. The standards are structured in 3 universal and 33 topic-specific ones helping businesses to report positive and negative impacts on economy, society and environment in a comparable manner depending on their material topics (Global Reporting Initiative, 2016).

- The Environmental Performance Evaluation (ISO 14031) is a European Standard established by the ISO, which is an independent, non-governmental international organization. This standard supports organization to measure, evaluate and communicate their environmental performance and enables to assess it against environmental performance objectives by means of environmental condition indicators (ECIs) and environmental performance indicators (EPIs). It can be applied independently or complimentary with an environmental management system (ISO, 2013).

On the meso-city level, following four have been reviewed:

- The China Sustainable Development Indicator System (CSDIS) has been developed by the Research Program on Sustainability Policy and Management at Columbia University and the China Center for International Economic Exchanges (CCIEE). The CSDIS is a ranking system, composed of a sustainability metric framework and two indicator sets, comparing sustainability performances of Chines cities and provinces. For cities the frameworks holds 22 indicators organized in 5 categories addressing social, environmental, economic and institutional criteria (The Earth Institute and CIEE, 2017).

- The standard ISO 37120 for Sustainable Development for Communities also developed by the ISO contains an indicator set to assess performance management of city services, service provisions and life quality in a comparable manner. The set holds 46 core indicators and 54 supporting indicators, which are organized into 17 categories according to sectors and services. In addition, the standard also offers profile indicators to allow cities to identify other cities, which can be of comparison interest (ISO, 2014).

- The Extended Framework of Urban Metabolism (EUM), developed by the Stockholm Environment Institute (SEI) and the EEA, initiates the measurement approach from its origins, urban metabolism quantifying material flows and stocks, but extends it with three aspects. First, the terms sources, sinks and ecological support systems are more explicitly and specifically applied. Second, within the material flow analysis, urban patterns, drivers and lifestyles are considered as well to understand more comprehensively the system and its dynamics. Third, the extended framework suggests looking besides quantitative material flows also on quality of life. The framework finally contains 64 indicators organized in 4 categories (Minx, Ziegler and Owen, 2010).

- The Driver-Pressure-State-Impact-Response (DPSIR) framework, an extension of the Pressure-State-Response (PSR), has been developed by the OECD and EEA. With its policy focus, it aims to show the relationships and cause-effects occurring between the environmental system and human systems. Thus, it is intended to apply it as decision-making tool in municipalities. In total, it comprises 120 indicators categorized into four typologies (EEA, 2014).

The two frameworks on the meso-country level are:

- The Global Indicator Framework for the Sustainable Development Goals (GIFSDG) has been developed by the UN and the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs). The framework is a result of collaborative and consultative work with custodian agencies and national entities on international data collection. It organizes the 232 selected indicators in 17 categories according to the SGDs (United Nations, 2017).

- The framework around the Better Life Index, developed by the OECD, represents an evaluation of national well-being, thus addresses the social dimension of sustainability. It examines due to 50 indicators, the material living conditions and quality of life as well as related inequality criteria of the 35 OECD countries (OECD, 2017b).

Finally, the three approaches reviewed designed for CE are:

- The Circularity Indicators Project, developed by the EMF, is an approach to measure the performance and progress-making of products and companies (micro level) towards CE. In a thorough methodology the derivation of one main indicator measuring the material circularity is provided. This indicator shows how restorative the material flows of the analyzed entity are. It is composed of the variables virgin materials, unrecoverable waste, length of product's life and intensity of use (Frank, 2015). In addition to this indicator, it is recommended to compliment the assessment with additional impact and risk indicators. Both parts are integrated into a web-based measurement system for products.

- The Monitoring Framework on Circular Economy (MFCE), published by the EC, compliments the Resource Efficiency and Raw Material Scoreboard[10], which have been developed before. The framework suggests 10 indicators categorized into four groups: production and consumption waste management, secondary raw materials and competitiveness and innovation (European Commission, 2018).

- Lastly, on the macro level, the Gap Report published by the organization Circle Economy, introduces the metric Global Circularity Metric (GCM). As there are only a few official approaches to measure for CE, it has been included in the review. The metric considers, global material flows and stocks of minerals, fossil fuels, iron ores and biomass. Cycled materials and total material inputs are set into relation coming up with a ratio of 9.1% of globally cycled materials of those four material streams (Circle Economy, 2018).

From these reviewed frameworks, standards and approaches, for the circular city definition relevant indicators have been chosen and organized into an indicator set serving as base for the circular city index presented in the next part, the results.

[10] Both Scoreboards can be found under following hyperlinks:
http://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/index_en.htm,
https://publications.europa.eu/en/publication-detail/-/publication/1ee65e21-9ac4-11e6-868c-01aa75ed71a1.

RESULTS

Within the literature review, the concept of CE and its potential for a city have been introduced, followed by the conceptual and idealistic definition of a circular city. This was followed by the explanation of the necessity to consistently measure the state and progress-making of transition, and the formulation of respective expectations on circular city metrics. These two aspects shape the lens for the following results, partly in terms of how the standards, frameworks and approaches have been reviewed on useful indicators to be integrated and methodologies to be applied, and finally how the measurement approach in current times with its limitation has been constructed.

To measure the effectiveness and progress-making of a city towards CE with only one single metric would not be possible, as the urban system comes with a natural complexity and diverse dynamics affecting different dimensions of sustainability. Therefore various indicators have been chosen intending to capture the three striving states of a circular city. These are introduced in the following two sections, followed by the presentation of the circular city index. The last chapter 5 represents a contextualizing section where the measurement approach is applied to two frontrunner cities.

4 The Circular City Indicator Set: The Categorization of Existing Measurements

The introduced frameworks and standards differ in their target groups, focus areas and levels, while they also overlap in some aspects. However, in sum, they complement each other and finally piece the circular city indicator set.

The review serves as explanation and inspiration to depict the desired goal with a comprehensive set of indicators. Either, indicators have been overtaken directly if they complied with expected criteria on circular city metrics and were enabled by data availability, or they have been integrated indirectly by doing small adjustments, such as changing units and reference units.

From the standards and frameworks reviewed on a micro-business level, almost none of their indicators have been overtaken. They certainly address similar categories, especially in terms of resource consumption, but they generally measure more sector and function specific, which could not be used for the city level. Following, the meso (city and national) level standards and frameworks served as main sources.

4.1 The Circular City Indicator Set Categorization

The categorization of the circular city indicator set has been developed based on both the idealistic circular city definition and the necessary process of transition. As mentioned before, the effectiveness of the urban system is characterized by the three striving states: environmental regeneration, social well-being and economic quality. Resulting from the effective exchanges of information, monetary, institutional, social and physical flows, these states are expected to be achieved and stabilized over time.

To indicate these states, focus has centered on the quantitative physical flows and the monetary flow as well as on qualitative social and institutional flows and stocks. As the flow of information is impossible to capture in a sufficient extent so far, it has not been considered in the measurement approach. Within the given time period, respective material and economic stocks have not been integrated either, as their tracking comes with even higher data availability burdens and efforts for necessary detailed analyses (Bristow and Kennedy, 2013). However, making urban flows more effective directly affects their stocks as well by transforming them into stocks of circulating materials, money and information (Lehmann, 2011). Contrary, social and institutional criteria automatically consist inextricably of flows and stocks, which is why for them, flows and stocks could be considered.

The three striving states of a circular city are, as the nature of city predefines, interrelated. They affect each other and are influenced by the actions of the city stakeholders. The understanding with which this measurement approach is constructed and results are interpreted includes and considers this essential characteristic. However, it can only be mapped to a certain extent.

Keeping this in mind, each state is assigned to one or two capitals, shown in the table below (table 7). The economic quality refers to the economic capital and is indicated by the monetary flow of the city. The state of environmental regeneration is assigned to the natural and manufactured capital and further measured by the urban physical flows. Lastly, the social well-being refers to the social and human capital that are indicated by social and institutional stocks and flows.

Thriving States	Capitals	Flows & Stocks
Economic Quality	Economic Capital	Monetary Flow
Environmental Regeneration	Natural & Manufactured Capitals	Physical Flows
Social Well-being	Social & Human Capitals	Society related Flows & Stocks
		Institutional Flows

Table 7: Relation of Thriving States, Capitals and Urban Flows & Stocks (own table).

Based on this, the indicator categorization follows by sub-categorizing the flows and stocks into 35 indicator categories, shown in the next table (table 8), listed in the right column. The categorization considers both sustainability relevant aspects (natural, social and institutional) as well as CE relevant principles and criteria supporting the circular city definition.

Whereas the monetary flow is simply represented by the flow of **"Monetary Value"** circulating through the urban economy and beyond, the physical flows are, as the concept of Urban Metabolism suggests, organized in energy, water, materials – including organic and non-organics– and waste. Energy is divided into the categories describing the **"Energy Consumption"** and the **"Share of Renewable Energies"** used for the urban energy generation. Water defines the categories of **"Water Consumption"**, the **"Water Reuse"** and the **"Anaerobic Digestion"** practices. The materials are split into organic (or nutrients) and non-organics. For the nutrients, the categories of **"Food Consumption"**, **"Locally Sourced Food"** and **"Urban Agriculture"** have been chosen. The non-organic materials are composed of the **"Consumption of Goods"** and the rate of **"Locally Produced Goods"** consumed in the city. The waste flow is split into emissions and residual waste. The chosen categories are **"CO2 Emissions"**, **"Waste Generation"**, **"Waste Recycling"** rates and again the **"Anaerobic**

Digestion" practices. The indicator categorization of the physical flows represents, on the one hand, indicator groups that designate levels of consumption for water, food, materials and energy, or the generation of waste and emissions. On the other hand, they indicate specific and essential CE principles to cycle and to cascade the urban physicalities, which are the shift to renewable energies, water reuse, the application of anaerobic digestion, local and hyper-local food sourcing and production, and the elimination of waste.

The social flows and stocks are organized in environmental quality, material conditions, and life quality, which are all crucial for the society to have ensured to sustain and to further develop and to build social and human capital. The environmental quality is defined by the categories of **"Biodiversity"**, **"Air Quality"**, **"Water Quality"** and **"Noise Pollution".** The category of biodiversity has been chosen to be part of the social pillar due to two reasons. Firstly, because biodiversity in urban spaces correlates to the well-functioning of the ecosystem and ultimately to human well-being (Millennium Ecosystem Assessment, 2005; Parris, 2016). Secondly, for reasons of practicality, its unit better fits to the ones of the social flows and stocks. The material conditions are described by **"Income"**, **"Employment"**, **"Poverty"** and **"Housing Conditions"** categories. The categories characterizing the life quality are **"Transportation and Mobility"**, **"Education"**, **"Security"**, **"Health"**, **"Life Satisfaction"**, **"Social Network"**, **"Work-Life-Balance"**, **"Cultural and Leisure"** and **"Recreation".** The category of civic participation is represented by the **"Civic Engagement"** of the citizens in local decision-making.

The institutional flows hold trust and transparency characterized by the categories **"Institutional Trust"** and the degree of **"Corruption".** These two represent the relationship between the society and the government. It indicates how well the government represents the society and acts in an appropriate and democratic way. On the next page, the described categorization is organized within table 8.

Thriving States	Capitals	Flows & Stocks		Indicator Category
Economic Quality	Economic Capital	Monetary Flow	**Money**	Monetary Value
Environmental Regeneration	Natural & Manufactured Capitals	Physical Flows	**Energy**	Energy Consumption
				Share of Renewables
			Water	Water Consumption
				Water Reuse
				Anaerobic Digestion
			Materials	
			Organic	Food Consumption
				Food Locally Sourced
				Urban Agriculture
			Non-Organic	Consumption of Goods
				Goods Produced Locally
			Waste	
			Emissions	CO2 Emissions
			Waste	Waste Generation
				Waste Recycling
				Anaerobic Digestion
Social Well-being	Social & Human Capitals	Social Flows & Stocks	**Environmental Quality**	Biodiversity
				Water Quality
				Air Quality
				Noise Pollution
			Material Conditions	Income
				Employment
				Poverty
				Housing Conditions
			Life Quality	Mobility & Transportation
				Education
				Security
				Health
				Life Satisfaction
				Social Network
				Work-Life Balance
				Cultural and Leisure
				Recreation
			Civic Participation	Civic Engagement
		Institutional Flows	**Trust & Transparency**	Institutional Trust
				Corruption

Table 8: Categorization Circular City Indicator Set (own table).

4.2 Filling The Circular City Indicator Set - The Chosen Indicators

To fill the just presented indicator set categorization with concrete indicators, the following sub-sections introduce the chosen 42 indicators (incl. four alternatives if data is unavailable) by defining each, explaining the importance to a circular city and naming its original source.

Besides complying with the expectations on circular city metrics, they have been chosen by three criteria to indicate the state and progress-making of a circular city. For the economic and physical flows, they either inform about the state and market of crucial city resources and sectors, such as economy or energy consumption, or to indicate the performance of principles CE recommends, such as cycling or cascading urban resources, such as recycling waste or using its organic fractions for anaerobic digestion to produce a new product with high value for renewable energy supply. For the social and institutional flows and stocks they measure qualitative (subjective and objective) aspects essential for a society to evolve hand in hand with its government.

Ultimately, the indicator set intends to depict a picture that captures the city, its flows and stock, and the conditions for the stakeholders as a whole.

The indicator units are usually related to an ideal state based on best practice findings or recent research results. If no suitable or reliable source could be found, it has been related to the national average to at least interpret and rank the result to the national performance. This improvised solution will be taken up again in the discussion part. However, deliberatively, it has not been chosen the international average due to two reasons. First, the performance of the city is determined by its national regulations and fiscal frameworks, which both determine the potential of development. Second, comparing two completely different cities varying in culture, climatic conditions and policy based on the same international average would neglect the context, setting and eventual unintended limitations of the city. As these has not yet been developed a data platform considering those aspects, the national average serves as baseline.

If the indicator results are not weighed against an as ideal defined state or national average, they naturally and obviously indicate a state, which is either desired or undesired –such as the crime rate, which is undesired, is intended to be low, or the recycling rate that is favored, is supposed to be high.

4.2.1 The Indicator for Economic Quality

To indicate the monetary value and with it the striving state of economic quality, the Gross City Product (GCP), also known as Gross Metropolitan Product (GMP) or Gross Urban Product (GUP), has been chosen. It measures the monetary value of all goods and services produced within one year in a metropolitan area thus indicates the economic activity of the local business and industry sectors (NYCEDC, 2018). It leans to the GDP that measures the same on a national scale.

To indicate the economic quality, it is suggested to measure the change rate of the GCP. The respective metric which compares the previous fiscal year with the year of assessment is the **"GCP Growth Rate [%]"**. It is indirectly taken from the CSDIS. The framework suggests measuring the nominal GCP growth rate. But, since the real GCP is already adjusted for price changes and inflation, which all vary by country, it has been decided for the real GCP growth rate in order to facilitate the international or cross-country application.

Flows & Stocks	Indicator Category	Indicators
Economic Flow	Monetary Value	Real GCP Growth Rate [%]

Table 9: Indicator for Economic Flow (own table).

Discourse about the GDP

The appropriateness of using the GDP to measure economic development and growth has been debated for decades. The GDP reflects market prices in monetary terms and records the prevailing economic purchasing power. However, it does not capture the distribution and quality of growth, activities which cannot be monetized, or criteria addressing the society. (Agostini and Richardson, 1997)

So, the GDP by itself is certainly not a metric that could represent or measure the development of such an economy described in section 1.4, i.e. a new, more holistic economy occurring in an (ideal) circular city. The circular city or a transitioning city approaching this state needs a new and extended compass which considers the necessary embeddedness of social and environmental criteria (Raworth, 2017).

After all, the metric GDP has been chosen since it is the most widely applied means to measure economic activity. As explained previously, the economic flow circulates throughout the whole urban system as it acts as message and information. This makes it very comprehensive and difficult to capture. The GDP is an already established metric that includes personal consumption, business investments, governmental spending, as well as exports and imports; its calculations are standardized as well. Both aspects reduce parts of the administrative burden. However, it still requires some effort to apply it to the city scope. Only for the biggest metropolitan areas has the GCP been calculated so far. For instance, the company PricewaterhouseCoopers (PwC) calculated in 2009 the GCP for 151 cities by applying the filter of agglomerations of a population over 3 million (PricewaterhouseCoopers, 2009).

Another reason targets its original intention to measure the economic force within the city's boundaries –this is a fitting intention to the local thinking sustainability concepts and CE stress. A (transitioning) circular city aims to build up its own local production and purchasing force with as many local resources as possible, supplying local needs first before exporting and distributing to global markets.

Considering before-mentioned aspects, an already established economic metric – by itself too one dimensional– will extend with complimentary, equally important metrics addressing environmental, social and institutional criteria striving for a stable and sustainably growing economy. This forms the base for the later presented circular city index.

4.2.2 The Indicators for Environmental Regeneration

The following chosen indicators for the environmental regeneration address two main criteria: the incremental reduction of consuming natural resources, and the increase of specific CE applications with their productivity of cycling and cascading practices. By performing and improving in both, a desired environmental regeneration will be achieved. Applying these over at least two years, these criteria can be analyzed.

Especially in this pillar, it is explicitly mentioned again that the entire city is addresses by the chosen indicators measuring the variables: yearly consumption of energy, water, organic and non-organic materials, the generation of emissions and waste. This measurement approach understands the urban system as a whole, but refers with its unit per capita to each citizen in order to make it easier to compare and to refer to the respective reference unit.

To start with the energy flow, one indicator has been chosen for each indicator category.

The urban energy consumption is defined by the indicator of **“Total Energy Consumption [kWh/capita]”**. This metric includes the overall energy, heat and electricity consumed within the city. Applying the unit per capita, the total consumption is distributed to each citizen. This indicator is one of those quantifying an input flow of the city which is important to know about in order to be able to manage it in a more efficient way. The energy consumption within a circular city is attempted to be optimized and to incrementally be supplied by renewable energies. The metric can be an initial base to inform about the quality of transmission and housing standards, consumption patterns, the overall energy efficiency, or the effectiveness of energy regulations.

None of the reviewed frameworks, standards or approaches measures the total urban energy consumption. Those, which consider the energy consumption, address rather the building sector (ISO 37120), or the fuel of production (DPSIR framework), the GDP (CSDIS) or only to electricity (ISO 37120). However, the reviewed approaches Material Circularity Project and the Global Circularity Metric include the energy consumption from a broader perspective as well are the approach.

The second category, the share of renewable energies, is indicated by the “**Share of Renewable Energy Sources from Total Energy Consumption [%]”** and is taken directly from the EUM framework. Incrementally shifting to renewables energies such as wind or solar as main energy sources, represents an important principle of CE. This practice takes advantage of local or regional resources and removes pressure from natural resource deposits, thereby reducing their depletion. It also takes pressure from the city as it becomes less dependent on national market prices and energy imports.

Flows & Stocks	**Indicator Category**	**Indicators**
Physical Energy Flow	Energy Consumption	Total Energy Consumption [kWh/capita]
	Share of Renewable Energies	Share of Renewable Energy Sources from Total Energy Consumption [%]

Table 10: Indicators for Physical Flows, Energy (own table).

The water flow categorizes water consumption, rate of water reuse and share for wastewater used for anaerobic digestion (AD). There is only one indicator for each of these.

The first category holds the **“Total Water Consumption [l/capita]”**. This represents the total urban water consumption distributed to each citizen and is directly overtaken from the CSDIS and ISO 37120. The water flow represent the second important input flow the urban metabolism depends on. Its utilization is aimed to be optimized through efficient technologies while cycling and cascading practices prolong its lifecycle and reduce the amount of fresh water. Besides depicting the overall consumption, it can serve to imply the urban water distribution system functioning or conditions.

The **“Rate of Water Reuse [%]”** is the indicator chosen for the second category under the water flow. This rate relates to the water treatment system and indicates how closed the urban water cycle is. A closed cycle would be if wastewater were treated with a high quality output (dinking water) and were completely fed back into the urban water distribution system. Such a scenario is highly favored in a circular city. A less closed cycle would be if the water is guided into a natural, proximate water body after the treatment and if the supply of fresh water happens through regional natural reservoirs.

The last category is the **"Share of Wastewater used for AD [%]"**. It captures the amount of wastewater as treatment by-product. This is used to produce biogas or biofuel due to the biological process of AD. The remaining solid, organic matter could further be used as fertilizer if no micro-plastics remain in the matter (The Danish Environmental Protection Agency, 2017). This represents a lifecycle, a circular city prefers over landfilling or incinerating as the value of the waste product –even if it is down-cycled– is passed on and cascaded to the next use. This may even replace finite virgin resource and also saves emissions.

Both of the last indicators are inspired by CE und indirectly taken from the GCM approach, which includes the globally cycled water.

Flows & Stocks	Indicator Category	Indicators
Physical Water Flow	Water Consumption	Total Water Consumption [l/capita]
	Water Reuse	Rate of Water Reuse [%]
	Anaerobic Digestion	Share of Waste Water used for AD [%]

Table 11: Indicators for Physical Flows, Water (own table).

The nutrients or organic material flow is described by three indicator categories with one indicator each.

The category food consumption is ideally indicated by the **"Total Food Consumption [kg/capita]"**. It is indirectly taken from the EUM framework in which this metric is only considered within the breakdown of CO2 emissions.

This indicator is intended to indicate the overall consumed organic material flow that serves as food for the urban inhabitants. The indicator chosen, however, only records the consumption of human food due to data availability reasons. This compromise is not evaluated as falsified for this assessment, as farm animals represent already directly and indirectly an input for human food, through supplying products such as eggs, meat or milk. The consumption of food

Besides informing about the food demand of the local market, the food consumption might also reveal, combined with the composition of consumed food and generated waste, certain gaps that hold potential to make the urban nutrients flows more resource saving and efficient. Optimization in terms of making the most out of available resources represents here as well a common practice of a circular city.

It has been found that the consumption of food in weight units is not monitored well and comes along with insufficient data availability. Therefore, an alternative indicator is provided. The **"Total Food Expenses to Total Expenditure [%]"** measures the amount of food consumed via purchasing unit and serves as proxy for the actual consumption in weight units. As a circular city aims to achieve that prices represent full costs, this indicator can be declared as reasonable alternative. The indicator is inspired by the CSDIS framework to take the end consumer expenditure as an alternative means. Respectively, the indicator is measured based on market surveys about the consumer consumption expenditure.

The second category under the organic material flow is the **"Share of Locally Sourced Food to Total Consumption [%]"**. This indicator shows two things. First, it shows the most obvious, the amount of locally[11] sourced food compared to the total food consumption. Second and more indirect, it shows how the local, regional or even national food distribution network works, thus how much emphasis is put on supplying the city with locally sourced food. For instance, according to personal communication with Nina Harbo from the Environment and Energy Department, Aalborg, especially in smaller cities, the food distribution is managed nationally. This means that the locally sourced products get forwarded to a centralized location where it is processed and redistributed. From the CE perspective, this does not represent the preferred version, as the transportation over great distances causes a relevant amount of emissions. The ideal scenario in a circular city is to supply as much as possible directly locally and hyper-locally.

The next category is defined by the indicator **"Share of Urban Agriculture to Total Area [%]"**. It aims to indicate to what extent urban spaces and gardens are used to grow hyper-locally[12]. The term urban agriculture officially refers to growing food crops and raising animals within the urban setting (Goldstein, 2012). It usually composes community gardens, commercial and personal gardens or urban farms. Especially community and public gardens have been found to strengthen the local community, its involvement and awareness (ibid.).

As urban agriculture is still a relatively young practice for cities and dominated by private and community ownerships, it is still very difficult to capture the extent in which it is present within cities as well as its outcome (Lin *et al.*, 2017). Therefore, the indicator can only be related to the relative city area in current times, rather than to the absolute outcome, such as weight of produce and meat, which would certainly be an appropriate compliment to indicate the productivity and space efficiency.

Both of the last indicators have not been found in any reviewed standards, frameworks or measurement approaches; rather they have been inspired by CE principles and local thinking approaches to source and supply as much as possible with local resources.

Flows & Stocks	Indicator Category	Indicators
Physical Material Flow, Organic	Food Consumption	Total Food Consumption [kg/capita]
		Total Food Expenditure to Total Expenditure [%]
	Food Locally Sourced	Share Locally Sourced Food to Total Consumption [%]
	Share of Urban Agriculture	Share of Urban Agriculture to Total Area [%]

Table 12: Indicators for Physical Flows, Organic Materials (own table).

The non-organic material flow utilizes two indicator categories for each one indicator. The consumption of goods is ideally indicated by the **"Total Consumption of Goods (excl. Food) [units/capita]"**. It intends to inform about the non-organic material flow. This flow is captured with the total amount of materials, products and goods consumed by the end-consumer in physical form or through a service contract. In a circular city, consumption patterns and business models shifting towards service models in order to reduce resource consumption by enhancing product longevity and increasing their material productivity. The indicator informs besides the amount consumed, about

[11] According to the EC, there is no universal definition about the range of "local". The geographical range of sources reviewed vary between 20-100 km from the point of production (European Commission, 2013).

[12] "Hyper-local" defines an even smaller geographical range than "local". It usually refers to urban agriculture, thus food production within the cities boundaries due to gardens, in-house farming or rooftop farms (Foley, 2016).

needs, demand and interest of the society and can serve as means to optimize and adjust the market assortment and production.

Due to same reasons as for the food consumption, an alternative indicator is provided. The **"Share of Expenditure on Total Goods (excl. Food) to Total Expenditures [%]"**, as well inspired by the CSDIS framework, takes the monetary expenditure as proxy to inform about the amount (and value) of non-organic goods consumed. Since this indicator is based on monetary means, it can further imply information on the effectiveness of market prices or market mechanisms. In combination with waste indicators, inefficiencies within the value chain could be revealed as well.

The second indicator recommended is the **"Share of Goods Produced Locally to Total Consumption [%]"**. A circular city aims to produce as much as possible with local resources and by itself within a local radius as maximum. The indicator can imply the extent of initiated urban and sub-urban closed loops, which source, consume and cascade locally. So, practices such as local production and distribution are supported and prioritized while aiming to reach the highest extent possible. In turn, it also tells about the import activity on national or international markets which is less desired.

None of the reviewed standards or frameworks includes such an indicator. The main motivation has been taken from CE and its principles.

Flows & Stocks	Indicator Category	Indicators
Physical Material Flow, Non-Organic	Consumption of Goods	Total Consumption of Goods (excl. Food) [units/capita]
		Share Expenditure on Total Goods and Services to Total Expenditure [%]
	Goods Produced Locally	Share of Goods Produced Locally to Total Consumption [%]

Table 13: Indicators for Physical Flows, Non-Organic Materials (own table).

The waste flow represents the main output flow of the urban metabolism and is defined by four categories holding one indicator each. The CO2 emissions category is defined by the indicator of **"Total CO2 emissions [tons/capita]"** and captures the total urban CO2 emissions. This metric has been indirectly taken from ISO 37120. ISO recommends measuring GHG instead of CO2. However, CO2 has been chosen over GHG emissions, as the later air quality index already considers the most important categories harming human and environment.

A circular city intends to reduce its CO2 emissions as much as possible by applying e.g. clean and efficient transportation means or energy sources. The metric respectively relates to and informs about the urban energy supply, consumption and the urban transportation sector, as well as, the efficiency and environmental friendliness of general technologies applied.

The category of waste generation is indicated by the **"Total Waste Generation [tons/capita]"** and has been directly taken from the CEMF. The indicator aims to capture the total urban waste output and relates it to each citizen. A circular city eliminates the concept of waste over time. This intention results in striving for the lowest waste generation by adjusting consumption patterns and performing specific practices to divert waste from landfilling and incinerating. It will lead to a decrease of the overall amount and related externalities, such as air and water pollution.

The **"Average Recycling Rate [%]"** is directly overtaken from the CEMF and it informs about the city's effort and practices to post-decrease. The indicator averages the recycling rates of the three biggest urban waste sources: municipal solid waste (MSW), industrial/commercial waste and construction and demolition (C&D) waste (Miljø- og Fødevareministeriet, 2017). As a circular city aims to prolong the lifecycle of materials, the recycling rate is intended to be as high as possible while driving the waste generation down.

As recycling is not the only way of diverting waste from landfills and incineration plants, this indicator could be complimented by the average reuse rate or recover rate. All three rates represent the most important and common practices to reduce waste (European Parliament and Council, 2008). For reasons of data availability, however, these could not be further considered.

To address the organic fraction of waste, it is suggested to measure the **"Share of Compostables Used for AD [%]"**. This indicator was not found in any of the reviewed frameworks, standards or measurement approaches. Therefore, CE principles served as inspiration to measure the after-use of compostables. Similar as for the wastewater, the compostable organic waste fractions can be used for AD to produce biogas or biofuel while using remaining solids as fertilizer. This represents a cycle, which is favored within a circular city.

Flows & Stocks	Indicator Category	Indicators
Physical Waste Flow	CO2 Emissions	Total CO2 Emissions [tons/capita]
	Waste Generation	Total Waste Generation [tons/capita]
	Waste Recycling	Average Recycling Rate [%]
	Anaerobic Digestion	Share of Compostables used for AD [%]

Table 14: Indicators for Physical Flows, Waste (own table).

4.2.3 The Indicators for Social Well-being

The striving state of social well-being is defined by two aspects: the social and institutional stocks and flows. These hold the indicator categories: environmental quality, material conditions, life quality and civic participation for the social stocks and flows, as well as lastly, trust and corruption defining the institutional flow.

As measurement and data availability allows, a variety of indicators have been chosen. The in the following introduced indicators contribute directly or indirectly to the final performance of a circular city, however, all of them capture those criteria directly influencing social well-being. This is of importance as the definition of a circular city relies on a balanced top-down and bottom up approach. By ensuring high results in the social well-being indicators, the society becomes empowered and is more likely to participate that in turn, reinforces happiness as well (Barker and Martin, 2011). In addition, high social quality, good life and work conditions attract potential residents, such as the creative class. This part of society enhances innovation in the city, which represent an important component of CE. Hence, in this research, the quality of social well-being is understood as enabling component of effective evolvement and change toward CE. Measuring the indicators furthermore informs the government and supports to better address and involve the citizens.

Some of the indicators are measured qualitatively or subjectively via self-reports and surveys, such as general life satisfaction or the satisfaction with cultural and leisure offers. This is because factors influencing social well-being depend on the personal perception of the respondents. One aspect of appropriate city planning is involving the local society to a sufficient degree, as the priority lays on satisfying the local society's needs. This is why their (subjective) opinion counts. However, according to Van Hoorn (2007), the subjectively captured response is influenced by individual, demographic, institutional, environmental and economic circumstances. Due to this reason, the subjective metrics are complimented by objective metrics addressing those circumstances.

Under the social part, four categories define the environmental quality. The following indicators are the closest related to the before-explained indicators defining the physical urban flows. Besides indicating the environmental conditions the society lives in, which are aimed to reach highest standards, direct effects of improvements or deteriorations occurring around the physical flows can be observed as well. For instance, if the urban energy system makes progress in shifting from fossil fuels to renewable energy sources, CO2 emissions are reduced and the urban air quality will automatically become cleaner. This indirectly affects further life quality indicators such as the human health status or life expectancy.

The category of biodiversity is composed of the indicator of **"Ratio of Biodiversity Designated Protected Areas to Total Area [%]"**. It is indirectly taken from the GIFSDG, which measures the respective area from national mountain sites (indicator 15.4.1), and from the DPSIR framework that recommends assessing it on the national level. These have been accordingly adjusted to the urban scale.

The indicator measures how much space of the total city area is dedicated to protect the native vegetation and wildlife (flora and fauna). According to Lepczyk *et al.* (2018), the amount and size of green and natural areas finally determine and correlate to biodiversity. Hence, the indicator serves as proxy for biodiversity potential within the urban area.

Keeping track on the preservation of local biodiversity is crucial for the ecosystems and social development. According to the IUCN, between 1970 and 2000, the overall population of species dropped by 40% while the Living Population Index, developed by the World Wide Fund of Nature (WWF) states an average change of 58% in vertebrate population abundance between 1970 and 2012 (International Union for Conservation of Nature and Natural Resources, 2010; World Wide Fund of Nature, 2016). Generally, biodiversity is threatened by factors, such as changing climate conditions, alternation in land use and the nitrogen-carbon cycle, as well as, invasive species, which can all be observed occurring in cities (Masters and Norgrove, 2011). A metric addressing biodiversity conservation implies besides its actual state, how much the city invests to biodiversity preservation, which enriches natural areas for recreation and leisure, and finally contribute to social well-being. In a further sense, it can also connote to which extent the city succeeds in determining the mentioned threatening factors.

To get a more accurate assessment of the biodiversity stock and its development, the "Change Rate of Native Species [%]" addressing flora and fauna, as ISO 37120 suggests, could be measured additionally. However, data for this indicator has been found to be inconsistent as for instance just the change rate of a few specific species has been reported over time. Deriving available national or regional data to the city level that considers a significant larger amount of natural areas has not been seen as alternative at this point, because it does not represent the urban level at all. So, this indicator is not further considered in the indicator set.

The water quality is indicated by **"In-City Samples Meeting Water Quality Standards for Coliform Bacteria [%]"**. Most of the standards and frameworks reviewed on a city or national level, consider the water quality as an indicator, but choose another measurement unit. However, it has been decided to utilize coliform bacteria as indicating unit, as they imply the main source of risk and are easy to measure. According to the New York State Department of Health (2017), coliform bacteria are bacteria found in soil, surface water and in human as well as animal waste. They do not cause diseases or contaminations, but they indirectly indicate the potential fecal contamination and risk coming from pathogens, which are difficult to measure. Contrary to pathogens, coliform bacteria are easy to identify, though they come from the same source as pathogens. They usually occur in a larger number than pathogens, a factor which makes so useful towards determining the risk of water contamination threating the urban population (ibid.).

This indicator further implies sanitary states and quality of the city's water system that can be affected by infrastructure conditions or treatment methods.

The air quality holds the indicator of **"Ratio of Days Meeting Standard of the AQI between 0-50 [%]"**. The Air Quality Index (AQI), developed and daily calculated by the EPA, is an internationally established index reporting air quality on a national level, and also for the biggest cities. It especially focuses on health effects by considering five major air pollutants. These are ground level ozone, particle pollution, carbon monoxide, sulfur oxide and nitrogen dioxide (Environmental Protection Agency, 2016). The evaluation ranges from zero to 500, while zero indicates good air quality, 500 reports hazardous air quality. The first category of good air quality reaches from zero to 50 and indicates only little potential to affect human health and environmental conditions negatively (ibid.). Thus, the proposed indicator depicts the ratio of the days meeting the good AQI category within the year assessed.

Besides referring to the health status of the society and environment, a high AQI can also imply environmental friendly industrial activity, the diversion of waste from landfills and incinerators, clean transportation and technologies applied for heating and electricity generation.

This indicator is indirectly taken from the CSDIS. This framework suggests reaching the second level of the AQI, which represents the range of 50-100. However, as the best level of air quality should be ensured for the sake of human health and the environmental state, the targeted category for this indicator set represents the first AQI category.

For the category of noise pollution the indicator **"Ratio of Households Disturbed by Noise 7 or More Times a Week to Total Households [%]"** has been chosen. It measures the rate of self-reported noise disturbance, which can include all kinds of noise, such as neighborhood or traffic noise.

Most of the meso level standards and frameworks reviewed consider noise pollution, except for the CSDIS, the GIFSDG and the OECD Better Life framework. In those, which include noise pollution, the unit varies between relating it to traffic noise or the exceedance of standardized noise levels. According to the EEA (2017), noise pollution exceeding a level of 55 decibel (dB) for daily exposure or 50 dB for night exposure represents a threat to wildlife and human health. In cities, it is usually caused by industry or transport sectors –road traffic is the major source, followed by railway and aircraft noise (ibid.).

As noise pollution has been found being differently measured across cities or suffers of data unavailability, the alternative indicator **"Ratio of Households in 'very noise congested' Areas to Total Households [%]"** is suggested. This indicator reports those households located in very noise polluted areas based on noise levels of transportation or industries. Contrary, to the other noise indicator, which is based on subjective documentations of the citizens, this is a more objective attempt to measure and is based on scientific measurements.

However, both serve as means to capture the extent of health threatening noise pollution. Since they both capture transportation noises, which are as mentioned the major source of noise, they can imply the prevalence of electrical vehicles representing a clean thus desired mobility means in a circular city. In a further sense, these metrics can indicate to which extent the city engages in noise reducing measures or how foresighted it approaches the urban land use.

Flows & Stocks	Indicator Category	Indicators
Social Flows & Stocks, Environmental Quality	Biodiversity	Ratio of Biodiversity Designated Protected Areas to Total Area [%]
	Water Quality	In-City Samples Meeting Water Quality Standards for Coliform Bacteria [%]
	Air Quality	Ratio of Days Meeting Standards of the AQI between 0-50 [%]
	Noise Pollution	Ratio of Households Disturbed by Noise 7 or More Times a Week to Total Households [%]
		Ratio of Households in 'very noise congested' Areas to Total Households [%]

Table 15: Indicators for Social Flows & Stocks, Environmental Quality (own table).

The following indicator categories lean closely to OECD Better Life framework. If the indicators are not directly or indirectly taken from it, one of the other frameworks and standards reviewed serve as source for the chosen indicators. The latter case will be mentioned explicitly.

The next four categories define the material conditions, which are crucial to ensure minimum life standards for the urban society. Each category holds one indicator. The category of income is represented by the indicator of **"Share of Average Disposable Income to Minimum Costs of Living [%]"**. Due to different tax and market regulations, the average disposable income and costs of life expenses vary by country and region and they do not necessarily correlate with each other. The suggested indicator forms the ratio between both in order to filter these individual conditions and reveal income inequality (Knotek and Zaman, 2014). Besides the income inequality, this indicator shows how well local incomes are adjusted to market prices by the following two things: First, it is examined to what extent minimum –but socially acceptable– life standards can be met on food, cloth, health, housing and education. This factor also referred as the human right of adequate standard of living. Second, it indicates the budget by subtracting the life expenses by the disposable income with which the society could theoretically invest and participate in the local market. A circular city prefers local trades and aims to meet the urban demand with local markets first. It holds a market that supplies and represents its local participants. It furthermore holds a redistributive economy that ensures sufficient monetary resources to meet basic needs and to further enable participation in the local market.

The corresponding indicator recommended by the OECD Better Life framework is the net household income by itself. The other framework touching upon an income indicator is the CSDIS with a housing-income ratio.

The category of employment holds the indicator **"Unemployment Rate [%]"** which depicts the ratio of the part of the total labor force which is unemployed, in paid and self-employed. Unemployed people are those who report not having a job, but are able to work and have taken initiative to find work (OECD, 2018).

This indicator can imply the state of the local job market and economy, if jobs are scarce or not, and the state of the searching labor force in terms of qualification and motivation. Within a circular city, the unemployment rate is intended to be as low as possible. One promise of CE is to notably strengthen the local job market and labor force by transforming business models and creating new jobs. This indicator can respectively measure success in this field.

The category of poverty is represented by the **"Share of People Living in Poverty to Total Population [%]".** This rate, directly taken from ISO 37120, identifies the share of people living under the threshold of minimum life standards, standards which should be kept within an effectively functioning economy, as low as possible. It implies the quality of the insurance and social welfare system, which is supposed to ensure minimum life standards for people in need and unemployed. It further refers to potential income inequalities. A circular city aims to lift everybody into a financially stable situation by providing enough job opportunities, fair income levels and sufficient social welfare services.

The next category, housing conditions, represents the highest priority of the human material needs hierarchy (OECD, 2017b). It therefore influences human health, family functioning and the conduct of basic social activities. The indicator chosen is the **"Ratio of Dwellings Without Basic Facilities to Total Dwellings [%]"**. It indicates the access to safe water as well as sanitary toilet and washing facilities (OECD, 2017b). This indicator aims to inform about local housing standards and quality while it can also reveal the assurance of public services or the effectiveness of regulatory mechanisms for the private housing sector. Similar to the unemployment and poverty rate, a circular city aims to avoid high results by setting the right boundary conditions and by providing necessary resources.

A more accurate picture would be depicted by be complimenting this indicator with the healthiness of the housing environment or adequate heating standards. Due to data unavailability, however, they could not be considered further.

Flows & Stocks	Indicator Category	Indicators
Social Flows & Stocks, Material Conditions	Income	Share of Average Disposable Income to Minimum Costs of Living [%]
	Employment	Unemployment Rate [%]
	Poverty	Share of People Living in Poverty to Total Population [%]
	Housing Conditions	Ratio of Dwellings Without Basic Facilities to Total Dwellings [%]

Table 16: Indicators for Social Flows & Stocks, Material Conditions (own table).

The following indicators aim to show the life quality. The first category of transportation and mobility holds one indicator, which is the "**Trips with Green Transportation [%]"**. This indicator has not been found in any standard or framework reviewed, rather was taken from CE principles. Only indicators addressing specific mobility means, such as public transportation or car ownership (ISO 37120) has been found.

The recommended metric captures the amount of trips taken by feet, bike and public transportation. Certainly, e-vehicles or ride sharing would be as well considered as green transportation means, but data inconsistency determined to include those. Also, it is not implied that public transportation means only use renewable energy sources, but increased efforts of municipalities has been recognized in shifting towards alternative energy sources to power the public transportation sector.

Green mobility via mentioned means represent the favored version of moving within the circular city. They reduce over all CO2 emissions and increase air quality by using alternative fuels and by optimizing space and resource utilization due to especially sharing activities. Furthermore, noise pollution can be decreased as the amount of total cars would be reduced or replaced by less noisy and clean vehicles.

The choice of green transportation is incentivized and facilitated by the city. Enough alternative offers and services are provided, such as bike sharing systems, frequent public transportation, such as busses and metros relying on clean fuels, and sufficient infrastructure for walking and biking. Moreover the whole system is supposed to function efficiently by well connecting neighborhoods as well as urban and sub-urban areas and allover by keeping commuting and travel times as low as possible.

Measuring the average travel time to commute to work, as the OECD Better Life framework recommends, could indicate the latter factor. However, due to data inconsistency, especially regarding units, this indicator had to be neglected.

To capture the overall mobility and movement of the citizens might furthermore be valuable in terms of having a compliment means to measure activity and participation. But also in case, data and metric availability restricted its further consideration.

The next category concerns education and is indicated by the **"Population Holding at least an Upper Secondary Degree [%]"**. The degree of education attained has a strong influence on human well-being. It correlates with the chance to get a job and the height of wage earned while it also implies a better health status and civic participation (OECD, 2017b). Upper secondary education represents the minimum qualification to directly enter the labor market. It also provides the base for advanced training and higher education paths (OECD, 2009).

For a circular city, this means to support and build a stock of good, high and diverse education which represents a valuable source to enhance innovation, the labor force and life quality. It can furthermore influence and prevent undesirable states such as poverty, unemployment and crime. Allover, it contributes to improvement in social, institutional and economic flows and stocks.

The category of security is defined by two crime related indicators. According to OECD (2017b), the experience with crime represents the major criteria shaping the personal security. Being a victim of crime can lead to the loss of life or property, physical and metal injuries or a disruption of social functioning and the feeling of vulnerability.

The first indicator is the **“Yearly Crime Rate [incidents/1.000 inhabitants]”** of all types of crimes (incl. robberies, rapes, assaults etc.) reported within the city and related to 1.000 people.

The second indicator is the **“Annual Homicides Rate [incidents/1.000 inhabitants]”**. The act of homicide is the most extreme kind of contact crime and represents a rather one-dimensional. However, it suffers the least of unavailability and underreporting that verifies comparability (OECD, 2017b).

Both indicators together inform about the criminal potential within the urban society, the over all perception of personal security what affects interpersonal trust and indicates the effectiveness of local and national justice and police authorities.

The health category holds as well two indicators in order to give a complimenting proxy on the health status of the society, which would actually be the morbidity rate. However, measuring this rate only is still challenging as it composes various different conditions that vary internationally and impede the comparison.

The first is the “**Life Expectancy [number of years]”**. It informs about how long the average person within a society is expected to live. The calculation is usually based on age-specific mortality rates (OECD, 2017b).

The second indicator, **“Self-Reported Health Status ‘very good’ and ‘good’ [%]”** informs about the subjective perception of the individual health status (OECD, 2017b). Although the results of this indicator can vary by country due to different social and cultural aspect, this general perception on the personal health status has been chosen as it has shown to imply people’s future health care use and mortality rate (Desalvo *et al.*, 2005).

Both indicators compliment each other. They depict the local health status and can imply information about the health and insurance system of the city and the environmental quality or socio-economic criteria. As in a circular city, all of these criteria are intended to meet very high levels, a good result on health would confirm and verify this intention.

The next category is life satisfaction. It holds the third subjective indicator of **“Self-Reported Life Satisfaction, score 8-10 [%]”** and informs about the overall life satisfaction in high and very high states (score 8-10). This indicates the quality of urban life conditions from the citizen point of view. It can include aspects such as health, income, education, personal fulfillment, or social and environmental conditions occurring (OECD, 2017c). High results in this indicator are specifically desired, because a generally happy society is more likely to involve and participate into local activities and planning processes (Barker and Martin, 2011). This is very favored in a circular city as a balance between bottom-up and top-down –which leaves space for its self-organization– is pursued in order to organize the urban system as effectively as possible.

The social network category is represented by the **“Self-Reported Satisfaction with Social Contacts, score 8-10 [%]”**. This metric aims to indicate interpersonal trust to other people. According to the OECD (2017d), this type of trust is together with institutional trust of “*fundamental importance to the well-being of individuals, and to society more broadly*” (OECD, 2017d, p. 26). Trust is a prerequisite for every-day’s transaction and a requirement for all types of behaviors and policies, which maintain public goods and global commons where in turn sustainable growth is based on (OECD, 2017e). However, as it is inherently intangible, it can only be measured indirectly through its sources of surveys, self-reporting means or official statistics.

The quality of interpersonal trust or satisfaction with social contacts is indirectly influenced by personal security or educational attainment. This indicator leans towards the variable suggested by the national OECD Better Life framework: "share of people having at least one person to rely on"; however, this was adjusted for data availability reasons.

By preventing mentioning impeding factors for interpersonal trust and by enhancing at the same time common activities and community projects, the circular city builds social cohesion and empowers social connectivity and proactive citizens.

The category of work-life balance is represented by the **"Average Working Hours [hours/week]"**. The time spent at work can impact the personal health status, including stress levels, if the amount of hours spent is too high. The more time spent at work, the less is spent for leisure or personal care (OECD, 2017a).

The indicator aims to capture an optimum of working hours, which leaves enough time for leisure, recreation and personal time in order to keep long-term labor productivity high. The indicator might also imply information about the work conditions, such as employer expectation, the distribution of labor force, or from the side of the society, the motivation and attitude towards their job. In a circular city, all of these criteria are intended to be kept in a healthy balance, not compromising significantly any of the stakeholders involved, such as employer, employee or the state.

For the next category, leisure and culture, corresponding to the work-life balance, the measurement of **"Self-Reported Satisfaction with Cultural and Leisure Offers, score 8-10 [%]"** has been chosen. The OECD Better Life framework recommends measuring the time spent for leisure, but as this time can be approximately derived from the numbers of hours worked, it has been decided for the satisfaction of the local leisure and cultural offerings. Furthermore, the actual time dedicated to leisure and cultural activities can vary largely across countries. What finally matters is to provide qualitative and quantitative offerings, ones that meet the society's interests and fulfill the overall purpose to recharge, interact and enjoy the urban life.

For data availability reasons, following alternative indicator is provided: **"Leisure and Culture Offers [score]"**. It measures from an objective perspective the quantity and diversity of local leisure and culture offerings. Some cities, such as New York, capture their offerings in a score between one and ten, where ten indicates the best result. Either way, both indicators can serve as proxy to inform about the cities efforts to provide diverse and enough activities and events where people can get together and balance their work-life.

The category of recreation holds the indicator of **"Share of Public Spaces for Recreational Use to Total Area [%]".** This indicator is directly taken from the EUM framework and ISO 37120. It defines the area of urban accessible spaces dedicated to recreational purposes for the society, such as public parks, sport fields of waterfronts. These are places where social interaction, community building, physical activity and regeneration can happen, which all contributes e.g. to a better health status and life satisfaction.

In a further sense, green urban areas –dedicated to recreation or biodiversity protection–, contribute to indirect physical improvements, such as air and water purification through the natural ecosystem activity. Thus, considering more parks and recreational areas in the urban city planning leads to higher environmental and life quality, both influential aspects of the overall social well-being. Therefore, a circular city gives nature more space by considering it in the urban planning. More space efficient solutions and the embedding of nature into the land use represent possible practices.

Flows & Stocks	Indicator Category	Indicators
Social Flows & Stocks, Life Quality	Mobility & Transportation	Trips with Green Transportation [%]
	Education	Population Holding at least an Upper Secondary Degree [%]
	Security	Yearly Crime Rate [Incidents/1.000 inhabitants]
		Annual Homicides Rate [incidents/1.000 inhabitants]
	Health	Life Expectancy [number of years]
		Self-Reported Health Status as 'very good' and 'good' [%]
	Life Satisfaction	Self-Reported Life Satisfaction Status, score 8-10 [%]
	Social Network	Self-Reported Satisfaction with Social Contacts [%]
	Work-Life Balance	Average Working Hours [h/week]
	Leisure & Culture	Self-Reported Satisfaction with Local Leisure and Cultural Offers, score 8-10 [%]
		Leisure and Culture Offers [%]
	Recreation	Share of Public Spaces for Recreational Use to Total Area [%]

Table 17: Indicators for Social Flows & Stocks, Life Quality (own table).

The last category under life quality is civic engagement. It is measured by the indicator of **"Voter Turnout [%]"** as a ratio of voter participation in local elections to the total voting-age population (OECD, 2017b). It gives an idea of how the urban society involves itself with public decision-making and policy processes. A society characterized by political and civic engagement can effectively shape its environment and is highly desired in a circular city, as mentioned under the life satisfaction indicator.

A more precise indicator, describing the engagement in urban planning and management, is suggested within the GIFSDG. Under goal 11, the indicator 11.3.2 demands the "proportion of [...] civil society in urban planning and management that operate regularly and democratically" (United Nations, 2017). However, applicable data could not have been found. Various sources state that the participation of urban societies has been increasing, but without mentioning any numerical foundations. This increase can be a result of the development of digital technologies offering new opportunities to participate, such as on online platforms. This example is one main reason as analyzed by Wilson, Tewdwr-jones and Comber (2017) and represents a future means to participate, communicate and exchange in a circular city. It is hoped to be able to enhance and to capture participation more accurate in the future. This would enable to measure the participation beyond voting and also to design more effective involvement strategies to unlock the societal participation potential and commonly shape the city representing all its stakeholders.

Flows & Stocks	Indicator Category	Indicators
Social Flows & Stocks, Civic Participation	Civic Engagement	Voter Turn Out [%]

Table 18: Indicator for Social Stocks & Flows, Civic Engagement (own table).

The last category, public transparency, refers to the institutional flows and is indicated by following two indicators.

The first one is **"Self-Reported Trust in Local Government, responding 'yes' [%]"**. As mentioned previously, trust is an essential element for everyday transactions, behaviors and policies. To compliment the interpersonal trust to other people, the here addressed institutional trust occurs between the society and the government. It implies respectively the accordance of the local government operations to the society's expectations and finally indicates the local governmental trustworthiness. Thus, it plays a crucial role for policymakers as it shapes economic performance and social well-being (OECD, 2017e). Due to the fact that trust is a rather intangible stock, there is not just one understanding or definition of trust. In this context, the definition provided by OECD (2017d), is used where trust is defines by two components: competence and values that are further based on responsiveness, integrity, fairness, reliability and openness government provides and ensures.

Similar to interpersonal trust, institutional trust is measured based on official statistics on surveys and self-reports.

The second indicator addresses corruption, which is closely related to trust. The term is defined as "*abuse of entrusted power of private gain*" (Transparency International, 2017). It can occur in the private and public sector as well as in everyday life. Bringing more transparency into processes, which seem shady, ambiguous or suspicious to a third person can eliminate corrupt activities and build interpersonal and institutional trust. The measurement suggested being applied is the **"Perceived Corruption Index [score/100]"**. This index has been established by the organization Transparency International to measure how countries perform in ending corruption in the public sector by addressing policy and government. It is measured by expert assumptions and perceptions of the private sector citizens (ibid.). The score zero represents the highest corruption rate and a score of 100 represents the lowest corruption rate.

The only standard under the reviewed literature, which includes a corruption indicator on a city level, is ISO 37120. This suggests the metric "share of convictions for corruption by city officials per 100.000 inhabitant", but the metric could not be considered as it suffers of lack data availability.

Both indicators suggested addressing institutional trust and corruption. These to variables correlate with each other, but they utilize two different angles –the society perspective and sector experts' assumptions– to measure trust and transparency in governance (OECD, 2017e). This is what makes it more verifiable, as no more accurate metrics are available in these times.

The combination of activating civic participation and public transparency can be a picture of a balanced bottom-up and top-down approach, which is approached in a (transitioning) circular city aiming for the overall best and common and mutual outcomes and benefits.

Flows & Stocks	Indicator Category	Indicators
Institutional Flows & Stocks, Transparency	Public Trust	Self-Reported Trust in Local Government, responding 'yes' [%]
	Corruption	Perceived Corruption Index [score/100]

Table 19: Indicators for Institutional Flows & Stocks, Transparency (own table).

All the chosen and just presented indicators are supposed to numerically depict the desired states of a circular city. Especially the indicators of the social categories are closely interrelated, but in sum, they piece the most essential states and practices of the city which are ready to be processed further towards the circular city index presented in the next section.

4.3 The Indicator Scoring

The necessary intermediate step to utilize the measured indicators for the index is to score them, as their units and interpretation are not consistent yet. To align them, the results of the measured indicators are normalized using a reference unit as means of assessment. The scale of assessment is respectively the range between zero and one, where one is the best result.

The results of those indicators whose reference units represent an ideal state (zero or one) are turned into their decimal number. Depending on if they indicate a desired or undesired state, the numbers are either directly taken over as score (if desired state is one), or, they are subtracted from one (if desired state is zero).

Some other indicator results are scored against a specific unit. These are either best practice or research recommendations. Some have not been considered further, as no reasonable reference unit could be determined. In these cases the national averages serve as classifying means.

The economic flow, the GCD growth rate, has been related to the average ideal growth rate defined by the Federal Reserve System, the central bank of the US. According to this source, a growth between 2-3% represents a healthy and safe inclination keeping the balance between inflation and unemployment rate (Thoma, 2007). For this assessment the average of 2,5% has been applied.

Certainly, in discussing the GDP rate, it can be debated if this source, acting still in neoclassical terms, is an appropriate source. However, a stable economy with corresponding growth rates has been observed between the 2008 recession and the 2010 recession in the US (Amadeo, 2018). Some might argue that this rate is set too high; however, this research believes in the potentials CE can bring to the global economy. According to McKinsey (2014), growth rates of even seven percent might result from increased resource productivity in Europe by 2030. This represents an argument against that it is set too low. The reason why the reference unit is not set higher is because it is believed in before-mentioned historical observations.

The physical flow indicators which measure the generation of waste and emissions are intended to be as low as possible. The respective ideal state is zero. It is acknowledged that this state might never be reached; rather, this state represents an ideal scenario for both output flows from the CE point of view. However, as these indicators are measured in absolute numbers and units such as liter or tons, it is difficult to classify their performance if the results are unequal to zero. So far, there is no standard formulated so far which categorizes the performance of the whole urban system, including all its industries and sectors or considering the influence of individual city criteria. Hence, these indicators have not been scored and further utilized. However, they represent essential and informative flows and serve as base to quantify other related indicators, such as the recycling rate. For this reason, they are part of the indicator set, but do not contribute to the index result. Instead, the national averages are provided and can serve as proxy to classify and set it into context to the nation's performance.

For similar reasons the indicators addressing the consumption of energy, water, food and goods have not been scored either. These flows will always occur as they represent essential urban inputs while their final extent depends on the city's size, population and circumstances. At this point, it has been decided to not even define an ideal state, as it cannot be universalized. Again, national averages are provided, but not interpreted. For the potential next assessment for the following year, it can be considered to compare the results for waste, emissions, energy, water and materials against the city's performance of the previous year or to local goals, regarding the reduction of waste or the optimization of total water consumption for instance. Both could not be realized for the assessment in this thesis for data unavailability reasons.

To continue with those indicators of the physical flows, which are scored, address specific CE practices, these are: the wastewater reuse, waste water used for AD, locally sourced food, urban agriculture, locally produced goods, and the recycling rate. Contrary to the previous, an ideal state is formulated and value to strive to is decided on: The indicator results are intended to be as high as possible and to pursue to reach the ideal state of one.

For the social flows and stocks, the indicators on biodiversity, life expectancy, education, average working hours and the area dedicated for recreational purposes are scored in comparison with a special reference unit taken from current research outcomes, established standards or best practice, which represent the desired state. Each of these reference units are explained in the following text.

The urban agriculture indicator "Share of Urban Agriculture to Total Area [%]" refers to a reference unit based on a study published in 2018, which examines the quantitative potential of global aggregate ecosystem services of urban agriculture. Based on the analysis of remotely sensed data and published studies, Clinton *et al.*, (2018) estimated the spatial availability in urban areas of building facades, rooftops and vacant lands. From the study results it is averaged that 24% of rooftops, 10% of building facades and 6,8% are suitable for urban agriculture. Depending on the individual land use of the city assessed, these values represent the reference unit. For the assessment in this report however, these numbers have been averaged to 13,6% due to practicalities.

The reference unit for the biodiversity indicator "Ratio of Designated Protected Areas to Total Area [%]" is based on target 11 of the Aichi Biodiversity Targets[13] suggested by the Convention of Biological Diversity working under the United Nations Environment Programme (UNEP). The target suggests to preserve and manage 17% of inland water and terrestrial areas as well as to integrate it into the wider landscape by 2020 (Convention on Biological Diversity, 2011). Research literature, such as Wilson (2008) agrees that biodiversity has to be given more space in urban areas, and it is also commonly mentioned, the more in which large areas (at least continuous 10-13 hectare) and green spaces are dedicated to biodiversity preservation, the greater is the number and diversity of species. However, spatial recommendations are rarely given. Therefore, the mentioned target 11 serves as a foundation to construct the reference unit. The suggested ratio of 17% has been reduced by two thirds acknowledging the

[13] The Aichi Biodiversity Targets compose in total 20 targets addressing serving as flexible framework for regional and national biodiversity targets (Convention on Biological Diversity, 2011).

fact that this spatial suggestion has been made for the regional scale, including both urban and rural areas. The less urbanized areas around the city, such as suburbs or rural areas, provide greater opportunities to generously carry out biodiversity protection, where the 17% finally represents a realistic ratio again. Thus, for the city level, 5,6% is the reference unit as an ideal state.

The indicator addressing the state of education is scored against the graduation rate of Finland. This country is ranked having one of the best education systems in the world (Aedo, 2017). Respectively, its graduation rate of 90% in upper secondary education serves as ideal and attainable state to be reached for the whole population (OECD, 2009).

The reference unit for the life expectancy indicator represents the average life expectancy of Hong Kong, which has been ranked this year by the World Bank having the highest life expectancy at birth at 84 years (The World Bank, 2017). This value is also supported by the World Health Organization (WHO) that confirms in its report "Global Health and Aging", published in 2011, high and very high global life expectancy between 80 and 85 years (World Health Organization, 2011).

The reference unit for the indicator measuring the work-life balance refers to the average weekly working hours of Denmark. The Danish average workload ranks the best within the OECD Better Life Index (OECD, 2017d). Its 37 hours per week thus serve as reference unit.

An American study conducted in 2016, examining the relationship between the quality and quantity of urban parks and spaces and social well-being, serves the base of reference unit for the "Share of Public Spaces for Recreational Use to Total Area [%]" indicator. By conducting binary relationships assessments and regression analyses between parks and well-being variables, the study found that social well-being scores the best by 9,1% total park percentage (Larson, Jennings and Cloutier, 2016). This value represents the optimal area dedicated to recreational purposes.

The indicators on income and mobility are scored in comparison with an ideal state. The ratio of disposable income to minimum life expenses is supposed to be as low as possible assuring that with each income level minimum life expenses can be afforded. Thus, the reference unit is zero. The opposite applies for the mobility indicator. As green transportation defines the desired mobility means in a circular city, the reference unit of one represents the ideal state.

The remaining metrics measure the ratio of the best and desired state, e.g. "Self-reported Health Status as 'very good' and 'good'". These remaining metrics indicate the water and air quality, health status, general life satisfaction, and satisfaction with local leisure and cultural offers. Therefore, the indicator results strive to reach the ideal state of one. The indicator on noise pollution, on the other hand, represents an undesired state as it is measured by identifying the ratio of undesirable noise levels. Hence, the aim here is to reduce this ratio towards zero.

Unit-wise, the same applies to the rates of unemployment, dwellings without basic facilities, poverty, yearly crime and homicides. The prevalence of these states is undesired; thus, they are intended to strive towards zero.

Last to mention is the social indicator on civic participation and the two metrics of the institutional flows and stocks: institutional trust and corruption. The desired state for all indicator results is to be as high as possible, striving towards one. Although corruption is an undesired state, the perceived corruption index already ranks the highest corruption with 0 and the lowest with 100.

Having all indicator results normalized into a score between zero and one, the average of each striving state can be calculated. The respective averaged values represent the three sub-indices, which are compatible with the circular city formula: The economic quality, the environmental regeneration and the social well-being.

4.4 Circular City Index

The circular city index is designed to fulfill two main intentions. The first is to represent the measurable circular city criteria within an aggregated means, and thereby to summarize the city's state and progress-making within one single metric. This aggregated, single metric could serve as a ranking or marketing instrument. However, to understand the index result, so that the performance and effectiveness of the city can be assessed, it is acknowledged and highly stressed that this number cannot serve alone as an isolated means of indication. The final interpretation must consider at least the applied indicators and, if possible, even more detailed indicators –depending on what data and information is accessible. Considering this, both the indicator set and the index are meant to serve as an assessment base for annual performances of a single city or as a means to compare between different cities.

Second, both elements can facilitate a kick-start of communication, which ideally follows in finding synergies and enhancing the exchange of experiences, knowledge or measures to transition towards CE. They overall accelerate the process of change and serve as stepping-stones for tailored action.

The three aggregated and averaged sub-indices are set into the circular city formula as shown in the formula below.

$$Circular\ City\ Index = \frac{Social\ Well\ being + Environmental\ Regeneration + Economic\ Quality}{3}$$

As mentioned in section 1.4.3.1, two aspects define the overall goal of a circular city: first, to increase and enhance social well-being and environmental regeneration and second, to decouple economic growth from both aspects without financial success compromising their integrity.

The relation of the three striving states should not have a negative correlation nor impede each other's development. Instead they should reinforce each other and perform three-fold betterment. The index formula is constructed in a way that the highest index result can be reached if all three parameters increase towards one, with each jointly striving towards an effective urban system.

The scoring scale of the index reaches from zero to one, where zero indicates the lowest and three the highest performance in being a circular city.

Ultimately, the index serves as aspirational means leaning on the ideal definition of a circular city. It can also only give an estimate on how the city perceived as a system is performing in transitioning towards CE. For instance, the index can illustrate the extent of which a city manages to expand urban bio- and industrial cycles, and increase social and environmental quality standards, without forfeiting economic quality. However, to make any further interpretation, especially for policymakers, the results of the circular city indicators have to be taken into consideration by analyzing them and even complimenting them with more detailed indicators, such as sector specific energy consumption or waste generation –if data availability allows.

Another recommendation, leaning to ISO 37129, is to suggest the application of city profile indicators, which include background information or basic statistics about the city. This can help to grasp from where the transition is departing and how the calculated index, i.e. the city's performance, can be interpreted.

5 Application to Two Frontrunner Cities: Aalborg and New York

The presented circular city indicator set and the circular city index are based on the initial conceptualization of what a circular city means, how the urban system should function through the lens of CE. The composition of the indicator set depicts the relevant criteria for a well-functioning city, while the index aggregates the three striving states and indicates the overall performance. To finally verify this developed framework, the indicator set and index have been contextualized by applying it to the cities of Aalborg and New York. In the following sections, the cities are introduced before their performances are both individually assessed and compared to each other, finally lessons learned from the practical application are closing this chapter.

In the attached excel file, the organized and detailed evaluation of both cities can be found. This is structured as follows: The first four columns classify the indicators into addressed thriving states, capitals and urban flows and stocks which results in the overall indicator categorization in column E. Column F includes all the chosen indicators. Before the result of the indicator is found in column H, the indicators are briefly explained before. The results column is followed by the scale for which the data could be found and the data source (column I and J). The columns K and L compose the reference units against which the indicator result is weight. The next column M contains a short description of the reference unit and the importance of the indicator to a circular city. This is followed by column N providing the source of the reference unit. In column O the score of each indicator is shown while in the next column (P), the indicator scores are aggregated into the categories of the three states a circular city is striving towards. Those sub-indices are calculated to the circular city index in column Q.

5.1 Introducing the Cities Assessed

To provide an introduction to the cities assessed, both are presented by giving some basic profile information and summarizing their major efforts in sustainability and CE. On the first view, the cities of Aalborg and of New York might seem very different or even unrealistic to compare, for instance, in terms of their dimensions. However, as the following section will illustrate, they hold interesting similarities in approaching change towards sustainability and CE that in turn, verifies the success potential of different means and scales of change.

5.1.1 The City Portrait and Sustainability Efforts of Aalborg

Aalborg represents the fourth biggest city in Denmark and the regional capital of northwestern Denmark with a population of 210.316 (2016) spread over 1.137,31 km^2 (Aalborg Kommune, 2016). The politic system of the city is represented by the mayor Thomas Kastrup-Larsen (social democrat) and the city council consisting of eight political parties (City of Aalborg, 2016).

Founded by the Vikings in the 7th century, the city has a long history. Since 1800, however, the city is known as industrial city with companies such as Aalborg Portland, the world's largest exporter of white cement (Aalborg Portland A/S, 2008). The city is located directly at the Limfjord, a shallow and narrow gateway to the sea. Taking advantage of this strategic location, a big harbor is part of Aalborg as well. It represents one channel the city accesses international markets via marine transport. Beyond trading, the city frequently hosts passenger ships and ferries, enhancing the tourism sector. Other channels linking the city to the world are a motorway going south and an airport with international connections. Besides sufficient external infrastructures, the city is known as 20-minute town command one of the most accessible transportation structures in northern Europe (Invest In Aalborg, 2018).

Aalborg is turning into a knowledge city. Both the education and business sector are growing. The biggest institutions of higher education are the University College of Northern Denmark (UCN) and Aalborg University (AAU). Together, they have approx. 50.000 students, 2.500 of them are international (City of Aalborg, 2016). The business landscape has a very diverse profile, ranging from large international groups, subcontractors to niche companies being nationally and internationally competitive. In total the city holds 104.000 workplaces and 10.000 companies while 1.000 start-ups join in each year (ibid.). Today's focus sectors are sustainable energy, ICT, transport and logistics and health technology. With a growing population and the city's intention to attract even more internationals, both sectors can expect to develop and diversify.

The history of sustainability efforts goes back to the year 1994 when the Aalborg Charter has been approved with more that 3.000 signatures from individuals, NGOs, municipalities, national and international organizations, and scientific bodies (Aalborg Kommune, 2017). The charter is inspired by the Agenda 21, initiated at the Rio Earth Summit in 1992, and aims to contribute to local urban sustainable development. This was followed by the 4th Conference on Sustainable Cities & Towns in 2004 when Aalborg agreed to a list of commitments (ibid.). In 2016, Aalborg's Sustainability Strategy has been developed representing the framework for urban planning and regulation. Smart solutions, CE and shared economy are taken as means to approach the transition aiming to reach the overall goals of social development and green economic growth (ibid.). Being ranked as city with the highest life quality and the happiest citizens already shows success in the social goal (European Commission, 2016). The further progress-making is supported, besides the city itself, by two main bodies: the Center of Green Transition, which targets the citizens and focuses on civic inclusion, and the public-private cooperation, the NBE, that addresses regional-wide businesses and municipalities to share knowledge and to collaborate in sustainability related to topics (Aalborg Kommune, 2017). The annually held Sustainability Festival is a result of a partnership between all city stakeholders (municipality, businesses, NGOs, citizens and academia). It promotes local sustainability efforts, initiatives, partnerships and networks (ibid.).

As mentioned, the concept of CE serves as tool of transitioning for the city. Besides supporting public and private efforts in closing material loops addressing especially the urban waste and construction sectors, the most recent effort made is the Europe-wide circular public procurement calling for ideas to recycle and repair the furniture of a public primary school in Aalborg, instead of investing into new equipment (Circular Europe Netwerk, 2018). Moreover, the city participates in collaboration with the NBE in the project Circular Region. According to personal communication with Sebastien P. Bouchara from the NBE, the project is still in the developing phase and will officially start in the beginning of 2019. It aims to strengthen the collaboration amongst the eleven municipalities of North Jutland to find CE based solutions to approach local challenges. As each city has individual focus areas, it is considered to find synergies between different sectors, such as centralizing the recycling of a specific material.

5.1.2 The Portrait and Sustainability Efforts of New York City

The city of New York represents the most densely populated city of the US and is the capital of the State New York. Over an area of 783,86 km^2, composed of five boroughs, it holds a population of 8,5 million people (New York State Department of Health, 2016; United States Census Bureau, 2016). Since 2014, Bill de Blasio, the first democrat after 1993, represents together with the council split in republicans and democrats, the municipality.

The city has a long history too. Being initially founded as Dutch settlement (New Amsterdam) in 1626, its identity has been evolved through Native American and European influences, as well as, the American and Industrial Revolution –to just mention a few historical milestones (Lankevich, 2018).

New York is located in the northeastern part of the US. The city merges the Hudson, East, Harlem and Bronx River, and serves since decades one of the primary gateways of transatlantic transportation or import and export activities. It also represents the entry of international immigration while at the same time its population is more than one third of people born outside the US (Huffington Post, 2017).

Today, the city is internationally known as metropolis characterized by cultural diversity, tolerance and freedom, entertainment as well as, entrepreneurship. Since 1850, many companies, especially manufacturing industries, have settled in the city. Today's main business focuses are in finance, mainly represented by the Wall Street where numerous financial businesses are located, the real estate, media and advertising sector, retail, fashion as well as food industries, with a recently growing ICT, Cleantech and biotech wing (NYC, 2018).

Besides attracting companies, the divers cultural and historical offerings, such as entertainment, visual and performing arts, museums or architecture draw the attention of significantly many tourists pushing the local economy. Last year, 2017, the mayor announced that 62,8 million tourists have visited the city, which is a record-breaking number (Heywood, 2018).

Another sector, which mirrors the vast and unique dimension of the city, is education. New York City has the largest public school and higher education system in the US teaching in total more than 1,6 million students (Living Cities, 2000).

Commanding such diversity and dimension in cultural and commercial sectors, the city holds potential of changing with pace and innovation and reaching a relevant sized audience.

The first political sustainability agenda can be traced back to the year 2007, as the former mayor, Michael Bloomberg, implemented the sustainability plan PlaNYC 2030. Seeing necessity due to the ongoing population growth, Bloomberg realized to integrate environmental and social goals into the historically dominant economic development goals (Cohen, 2015). The sustainability plan includes 127 policy initiatives and ten overall goals addressing infrastructure, environment, green economy and quality of life within the city (NYC Global Partners, 2010). The plan demands to monitor frequently the performance with measurable achievements providing a clear picture of progress-making, which is respectively reported and published (Cohen, 2015). PlaNYC serves until today as the main framework for the sustainable development of the city.

Regarding specific efforts around CE, similar has been found as for Aalborg. New York uses CE as means to realize concrete goals committed to in the sustainability plan, like achieving resource efficiency due to recycling practices. The city is as well place of various networking initiatives and NGOs, such as the Circular Economy Network, the Circular Economy Club or NYCEDC, which all aim to spread the message of CE and what it can contribute to a sustainable development. Personal observation during an internship at the Earth Institute in New York, attendance and interviews with respective parties confirmed that collaboration and stakeholder engagement is key. It has further been noticed that the concept of CE becomes part of curriculums and student project outcomes serve as input for local urban development plans. This year, the mobility sector has been inspired by outcomes of the spring mid-term projects aiming to make New York City's transportation more circular. The city's infrastructure is characterizes by mass transit and divers transportation means, however, it suffers of the population growth while relying significantly on fossil fuels. This serves as great opportunity to prove the potentials of CE.

5.2 Evaluating the Cities Assessed

The evaluation has been conducted through comprehensive data research. Officially published national, regional and municipal documents have been reviewed. Various interviews with city departments, regional and national organizations complimented the data collection and verification. Both parts served furthermore to understand certain city characteristics and its individual metabolism.

2016 has been chosen as reference year for the assessment as this was the most recent year data has been found in highest degrees of quality and quantity. However, in some cases, assumptions have had to be made based on data from previous years. The earliest year considered it 2011. This applies for the CO2 emissions of New York, as this was the only year data could be found, which captures the whole city.

The scale of assessment is in both cases the municipal level. Here again, in a few cases data has been derived or overtaken from the regional, such as the GCP of Aalborg, or national level, as for instance the corruption index for both cities.

Before the results are presented, information on the population size and the total area for both cities assessed and the respective country is given while a map of the cities assessed is provided as well (for Aalborg the information has been taken from Aalborg

Kommune, 2016 while the data for New York is sourced from New York State Department of Health, 2016 and United States Census Bureau, 2016).

The following assessment focuses on the indicators measuring the performance on practices around the physical flows (striving state: environmental regeneration) as this part represents for both cities the one with the highest improvement potential.

5.2.1 Results for the City of Aalborg

Population size DK: 5.731.000 people
Total area DK: 42.924 km²

Population size Aalborg: 210.316 people
Households Aalborg: 105.158 people
Total area Aalborg: 1.137,31 km²

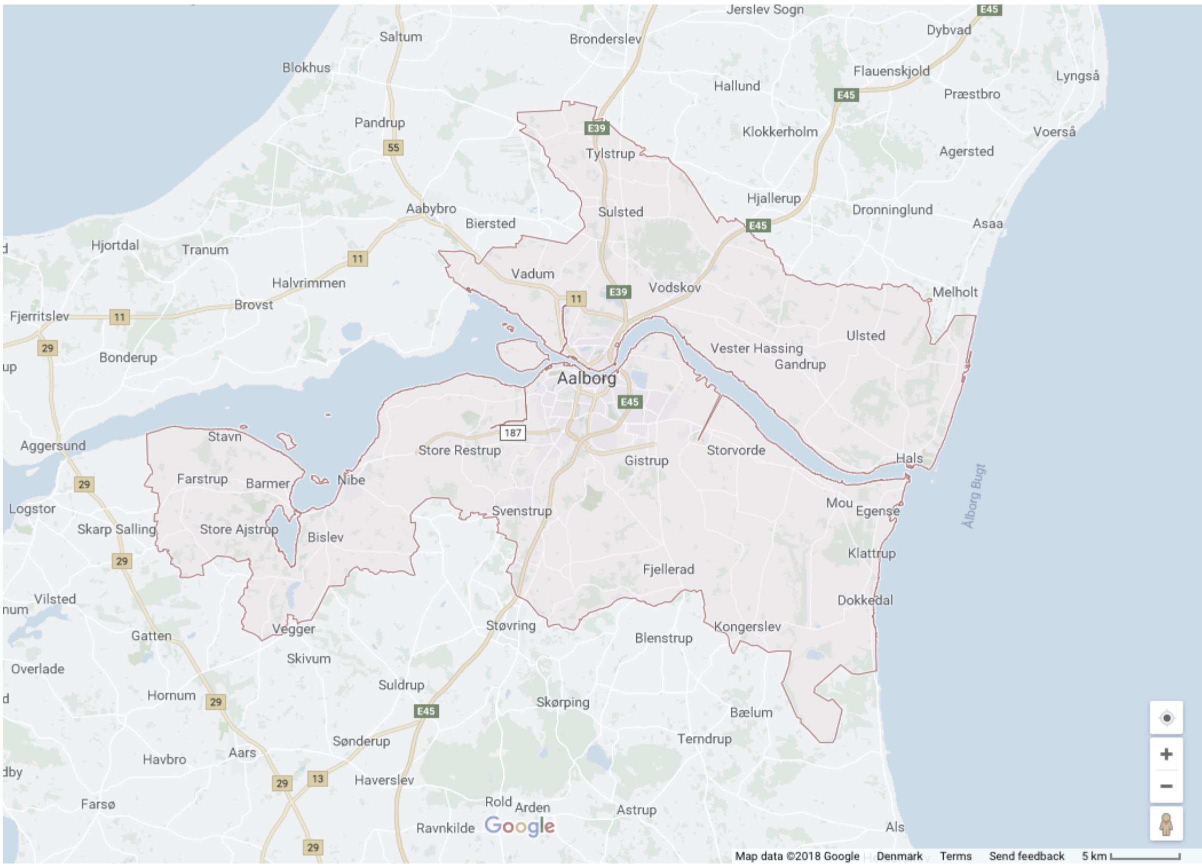

Figure 7: Aalborg City Map (Google Maps, 2018a).

As mentioned before, the indicator results on the consumption of energy, water, food, goods, CO2 emissions and waste have not been scored due to the lack of classification means, which can serve as reference unit. However, this research emphasizes that they are highly important to be monitored, especially over time. They serve as base to track, in combination with the other indicators, progress-making and might identify further potential of improvement. They quantify the main input and output flows of the urban metabolism, which are aimed to be reduced and optimized over time.

Indicators	Indicator Result	National Average
Total Energy Consumption [kWh/capita]	46.406,36	36.642,82
Total Water Consumption [l/capita]	57.057,00	56.541,00
Total Food Consumption [tons/person]	n/A	n/A
Total Food Expenses to Total Expenditure [%]	7,31%	12,14%
Total Consumption of Goods (excl. Food) [units/capita]	n/A	n/A
Total of Share Expenditure on Goods (excl. Food) to Total Expenditure [%]	50,20%	54,40%
Total CO2 Emissions [tons/capita]	12.400,00	6.822,54
Total Waste Generation [tons/capita]	2,28	1,52

Table 20: Consumption Indicator Results, Aalborg (own table).

As the table shows, the city of Aalborg has a significantly higher consumption of energy and generation of CO2 emissions than the national average. These results can be explained by considering the transportation and industry sector. For instance, Portland Aalborg, one of the biggest exporters of white cement, consumes approx. 30% of the total energy consumption of the city while it contributes in the same extent to the urban CO2 emissions (The Public Utility Companies of Aalborg, 2004). Inevitably, this negatively affects the urban air quality and level of noise pollution. On the other hand, the industry sector contributes to the economic activity of the city. According to personal communication with the Economic Department of the city, Aalborg contributes at least 40% to the region's economic activity.

The city's total waste generation is about one third higher than the national average. This can be related as well to the industry sector, but also to the increasing construction activity. The city has been realizing various housing projects to meet the demand of the growing population; industrial sites has been turning into multi-functional urban spaces to make the city more attractive, such as within the Cloud City project, or a new hospital and railway bridge are under construction as well (City of Aalborg, 2016). High construction activity contributes overall temporary to increased noise and air pollution, but finally contributes to improve the overall life quality of the society.

The water consumption more or less complies with the national average. Even though industries, such as Portland Aalborg, utilize a relevant amount of water, they can keep their total freshwater consumption low due to water recycling installations on-site (Aalborg Portland, 2016).

The calculation for the consumption on organics and non-organics has had to be based on regional expenditure surveys. Even by reaching out to the Regional Department of Development, North Jutland, verified municipal data could not be found. Comparing the numbers to the national average, no significant deviations are shown.

The aggregated results of the indicators scored lead to a circular city index of 0,57. The three striving states contribute to the index result in a distribution as shown in the following pie diagram.

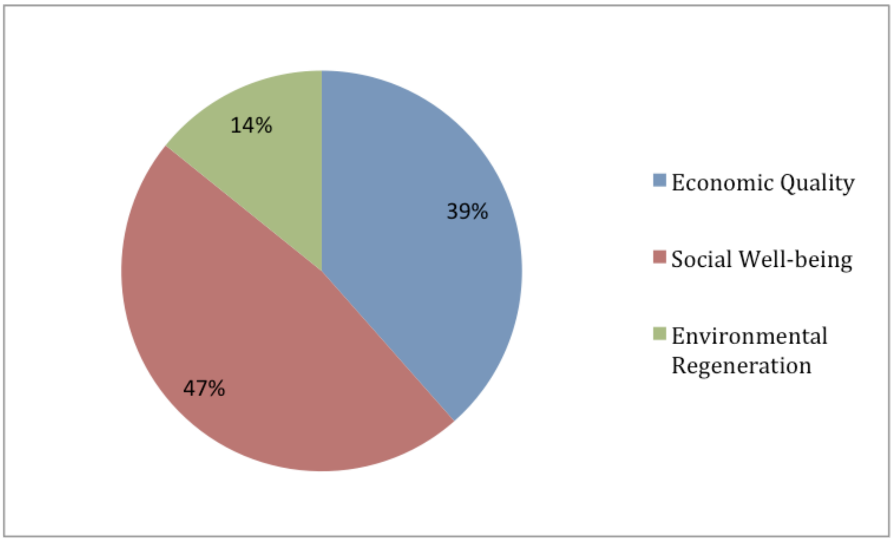

Figure 8: Sub-Indices Contribution to Index Result, Aalborg (own figure).

Assessing the GCP, it has had to rely on the regional GDP growth rate, which is 1,66%. The city of Aalborg does not measure this metric neither anything comparable what could have been used alternatively. However, considering, that Aalborg contributes to at least 40% of the regional GDP, it can be assumed that Alborg's GCP might even exceed the regional value.

The sub-index capturing those elements influencing the environmental regeneration has the lowest result. This is mainly due to results under 1%, as for the rate of water reuse, locally sourced food, the share of urban agriculture, locally produced goods and the share of compostables used for AD.

Due to sufficient ground water reservoirs, there is no necessity to treat the wastewater in such a high quality that it could be put back into the urban water system. Instead it is guided into local water bodies. By doing so their quality has been improved over time that directly affects the status of regional biodiversity.

According to personal communication with local supermarkets and the Environment and Energy Department of the city, priority has not been put so far on directly selling local food. Instead it is delivered to centralized processing facilities before the food is distributed to the vendors. Reducing the relatively short distances even across the country might not be found to result in the most relevant impacts.

To capture the amount of locally produced goods has been very difficult. Even if there are locally producing companies, it is not transparent or consistently monitored how much is directly sold in local stores. Another reason for the deterioration is that only a few businesses actually advertise with their local production. This made it difficult to grasp all locally producing companies. Finally, even if the ratio would be known, the total consumption of goods has to be available in the first place to get a result on this indicator.

Activities in urban agriculture are very small as well. According to the Environment and Energy Department of the city, the only places known of operating urban agriculture are two in areas within the city: an organic small scale cow farm in the suburb Hasseri and produce gardens in the public park Karolinelund located in the city center. However, it can be assumed that a relevant amount of urban agriculture is performed in private and community gardens, which has not been possible to capture within the given time period. During the research, further efforts from academia has been noticed. This specifically addresses food-water-energy nexus projects, which promise future investigations and innovations in this field.

The indicator measuring the organic waste used for AD counts zero, as the Danish government has prohibited this practice. This is due to detections of micro-plastics in organic waste fractions (The Danish Environmental Protection Agency, 2017). This represents an appropriate reason as the industrial and biological cycles should not be mixed. However, the long-term vision is to prevent micro-plastics entering the waste, so that the cycle can be fully closed.

Better results are represented by the renewable energy share. According to a study made by the city of Aalborg and Plan Energi, 19% or the urban energy and electricity consumption is supplied coming from renewables. Due to national goals, ongoing efforts in research institutions and the commercial sector, improvements can be expected here as well.

The recycling rate averaging the biggest waste sources (MSW, industrial and C&D waste) shows a relatively high result. The calculation has been based on local MSW data published by the municipality (44%), the recycling rate of Portland Aalborg –one of the biggest contributor to energy, waste and CO2 emissions– has been utilized for assuming the rate for the industrial sector (99%), and the recycling rate of C&D waste rests on national statistics which provide the percentage of 87%. These numbers aggregated, Aalborg's recycling rate accounts 76,67%. According to Nina Harbo from the Environmental Department, the city invest into researching about future opportunities in dealing with different waste fractions in the most sustainable and efficient way. This would also include the problematic around micro-plastics in organic waste and wastewater. Personal communication with Klaus Bystrup from Aalborg Forsyning Renovation, has furthermore informed about collaborative projects between the city and local businesses in recycling plastics for instance.

The best result of 100% is achieved for the wastewater used for AD. None of the solid waste, as by-product from the wastewater treatment, is wasted. All of it is utilized to produce dried sludge, which is further directly used on-site to produce energy to power the treatment plant.

Overall, the city of Aalborg performs CE relevant practices in wastewater, shifts towards renewable energies and recycles on a relatively high level. These are main contributions the city makes to support the environmental regeneration.

The sub-index of social well-being contributes the most to the index result. In total, its averaged indicator scores result in 0,81. This confirms and mirrors the nomination of Europe's city with the highest life quality. Throughout all categories, the city has good and very good results in the upper third. Outstanding are very low poverty, unemployment and crime rates, as well as no undesirable housing standards reported.

Potentials of improvement are seen in the categories of education and green transportation. Only 53,72% of the total population holds at least an upper secondary degree. This could be explained with demographic developments or a still prevailing dominance of training professions and a rather slow shift to more job positions requiring higher educational degrees. Nevertheless, remembering the low unemployment rate, the local labor and employment force seems not to be negatively influence by this fact, which is what finally and mainly matters. The ratio of trips made by green transportation amounts 53%. Although most of the destinations are in a 20-minute distance and according to the Environmental Department of the city, 90% of the citizen possess a bike, a relevant amount of trips –almost 50%– is still taken by car.

Reasons for this could be that almost one third of the society commutes by car to work (Aalborg Kommune, 2013). Both results contradict with the intention of being a knowledgeable and sustainable city. However, efforts observed in extending the higher education sector and attracting international students, as well as improving the infrastructure for green transportation by making mode by car less favored, promise improvements in these fields.

The results of the institutional flow –counting under the social well-being– could not be made on the city level. The metric of trust in the local government rests on data measuring the trust in the regional government. The corruption index is assessed on the national level. Both results represent good outcomes as 73% of the population trusts in the regional government and 10% of corrupt activities are assumed to occur. The long-term goal is to measure this metric on the local level, as transparency and mutual trust are crucial and enabling components to encourage the relationship between citizens and the government. To know about this number will lead to richer participation and project outcomes in urban planning.

To summarize the assessment of Aalborg, the city performs very good in striving towards high social well-being, the economic quality occurs on a moderate level reaching two thirds of the ideal growth rate while the performance in environmental regenerating activities hold the highest improvement potentials.

5.2.2 Results for New York City

Population size US:	323.400.000 people
Households US:	118.86.065 people
Total Area US:	9.834.000 km^2
Population size New York:	8.461.961 people
Households New York:	3.114.811 people
Total Area New York:	783,86 km^2

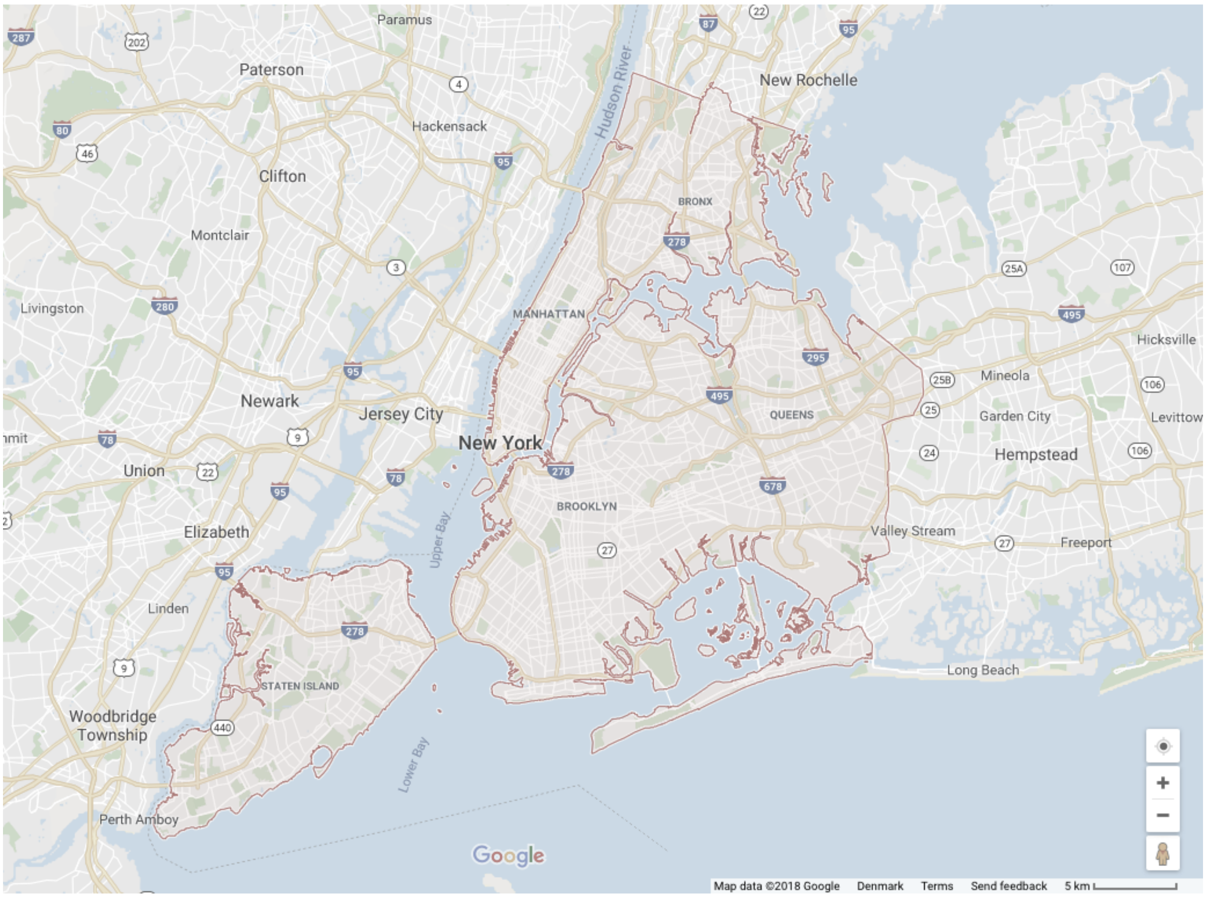

Figure 9: New York City Map (Google Maps, 2018b).

To start the evaluation of New York in the table on the next page, the unscored indicators, are shown. Those are the consumption of energy, water and materials (food and goods) as well as the generation of waste and the CO2 emissions. Similarly as in the assessment of Aalborg, the national average is provided to classify the city against the nation.

Indicators	Indicator Result	National Average
Total Energy Consumption [kWh/capita]	24.325,49	88.265,68
Total Water Consumption [l/capita]	161.656,10	1.582.500,00
Total Food Consumption [tons/person]	1.112.672,76	("Approx.") 1.000.000,00
Total Food Expenses to Total Expenditure [%]	10,70%	12,60%
Total Consumption of Goods (excl. Food) [units/capita]	n/A	n/A
Total of Share Expenditure on Goods (excl. Food) to Total Expenditure [%]	9,10%	10,60%
Total CO2 Emissions [tons/capita]	20,71	21,70
Total Waste Generation [tons/capita]	2,30	26,11

Table 21: Consumption Indicator Results, New York (own table).

Comparing the energy and water consumption, and the waste generation of New York to the national average, the results correspond and confirm the theory of economy scales, e.g. advocated by Geoffrey West, explained under section 1.3.1. As a city becomes bigger, criteria such as consumption scale sub-linearly. In New York's case, the energy and water consumed, as well as waste generation are significantly lower than the national average. This can be explained with the high density that enables more efficient use of resources. Regarding the consumption of food and goods (only taking the consumption of goods measured via the expenditure under consideration, as the national food consumption in tons, rests on a very rough assumption), as well as the generation of CO2 emissions, the city performs slightly better than the national average.

The aggregated results of the indicators scored lead to a circular city index of 0,60. The three striving states contribute to the index result in a distribution as shown in the following pie diagram.

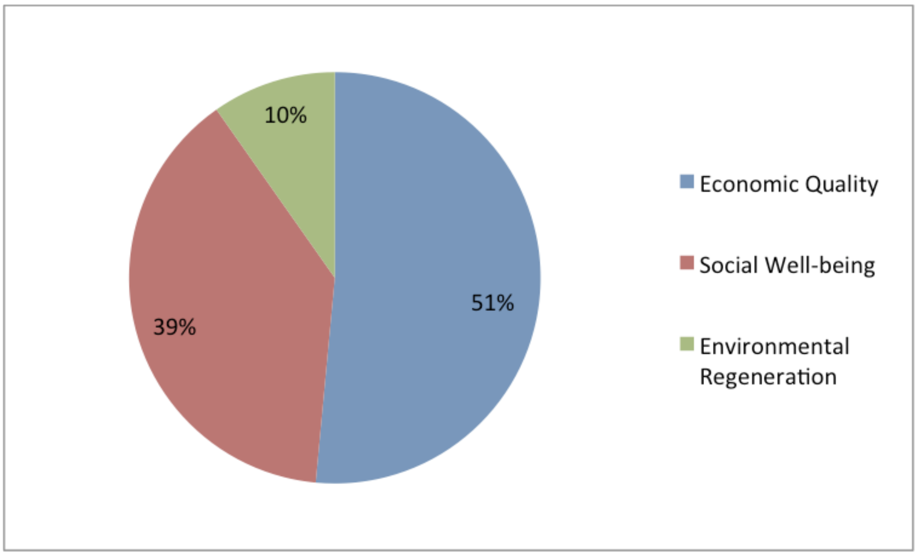

Figure 10: Sub-Indices Contribution to Index, New York (own figure).

The GCP of the city obviously contributes more than the half to the index result. The indicator scores 0,93 reaching with 2,33% almost the as ideal defined state of 2,5% annual growth. Such a result was to expect, as New York is known as center of finance and international trade, holding more than 120.000 companies within its boundaries.

The efforts in regenerating the environment due to CE practices are very weak. The indicator results count less than one percent in the share of renewable energy sources, water reuse, compostables used for AD, locally sourced food and urban agriculture.

The energy supplied by renewable energies only amounts 0,24% of the total energy consumption. This part represents electricity generated via solar photovoltaic (PV) installations. While the urban energy grid still mainly relies on fossils and nuclear energy, the state demands to reach 50% of electricity generated by renewables by 2030. This statewide goal implies to rapidly multiply PV installations within the city and to exploit the potentials for local offshore and on-land wind farms, as well as for hydropower applications (Blasio, 2014).

The same as Aalborg, the city of New York accesses sufficient and high quality freshwater and does not suffer of the necessity to fully close the urban water system loop. The drinking water of the city is supplied by fresh water reservoirs and catchments upstate. The wastewater is treated from 14 wastewater resource recovery facilities (WRRFs). After the treatment, the water is guided into the close by rivers, which has brought improvements, for instance to the once polluted Hudson River (Fisher, 2016).

The share of locally sourced food still remains very low if one puts it into relation to the total annual food consumption of NYC, which is 9,5 billion tons. The biggest public initiative engaging in the local food supply sector is GrowNYC. By distributing, e.g. on farmers markets, approx. 1.000 tons of produce from 210 statewide farms yearly within the city, local food production and consumption is enhanced (Stevens, Huber and Hurwitz, 2015).

Regarding the waste flow, the city performs moderately in extending the value of waste due to composing and recycling activities. So far, the majority of organic waste is together with other fractions, delivered to landfills. However, the initiative GrowNYC runs composting sites in all five neighborhoods where the citizens and companies can bring their organic waste while the city is also working on expanding the organic municipal waste collection as public service (NYC Department of Sanitation, 2018). Currently, 10,6% of the organic waste is composted and turned into fertilizer.

The indicator on waste recycling has been calculated based on published waste reports of the city, providing information and assumptions on MSW, industrial and C&D waste. In all three sectors a recycling rate of 30% can currently be assumed. This has been confirmed via personal communication with Kate Gouin working for the Mayor's Office of Sustainability. Further efforts of the city are in progress, especially in including the society and the commercial sector into recycling practices (NYC Department of City Planning, 2017).

The last indicator result on a very low level is on urban agriculture. Based on the electronic communication with William Lasasso from Green Thumb, one of the largest community gardening programs in the US, the total area utilized for urban agriculture can be estimated around 0,05% with potential to increase.

The highest result is achieved for the indicator on wastewater used for AD. According to electronic communication with Jane Gajwani from the Office of Energy, NYC Environmental Protection, the 14 WRRFs use 100% of the solid wastewater treatment by-product for AD. Annually, 102 million m^3 of biogas are produced of which 30% is used on-site while the remaining is flared. Current efforts are made in reducing the amount of flared biogas. Those are the design of a gas purification process to send 20 million m^3 to the national gas grid and the construction of two further cogeneration facilities.

The sub-index measuring the social well-being makes, with the aggregated score of 0,70, the second biggest contribution to the index result. The indicator results reach from moderate to very good.

Remarkably negative are the relatively high poverty rate of 19%, a high ratio between average disposable income and local life expenses of 63% and a significant low voter turn out of 10% in a local primary election.

Fighting against poverty represents for years one of the highest goals on the social improvement agenda of the city. As stated in the OneNYC plan, focusing on social improvements, the city aims to lift 800.000 people out of poverty by 2025 (Blasio, 2015). The poor relation between the average disposable income and life expenses could be explained with the high housing prices. According to the annual end consumer expenditure survey, averagely 40% of the income is spent just on housing (US Department of Labor, 2016). The local voter turn out on a local primary election only counts 10% while 62% of New York's population voted for the presidential election in 2016 (The City of New York, 2016). The participation on local elections has been decreasing since 1992 from 57% (ibid.).

On the other hand, despite its high density, outstandingly well performs the city on dedicating enough space to nature, both for biodiversity preservation and recreational purposes. Both indicators exceed the ideal state defined.

Lastly, worth-wile mentioning is the high result on education. 80,80% of the population holds at least an upper secondary degree. The strong public school system might be the reason for it. However, it also shows that education alone does not necessarily prevent poverty.

The indicators measuring the institutional flow score moderately. Both have had to be measured on the national level, as no data on a local level has been available. The corruption indicator scores moderately, stating that in 26% of public institutions corrupt activities can be expected while the indicator result on trust in the national government shows that only 32% of the population trust in the national government.

These results might imply, together with the voter turn out, that the mutual relationship between society and government seems to be hampered. However, since, both last indicators are measured on a national level and do only represent local conditions in a broader sense, no further explanations are made at this point.

To summarize the assessment of New York, the city commands a strong economic force, which can represent an enabling component of further improvement. The category addressing the regeneration of the environment has been scored rather weak, however, recent efforts promise future betterment. The social well-being ranks in the second highest quarter, but contains larger deviations between certain indicators.

5.3 Contrasting the Cities Assessed

Both cities assessed consider themselves as frontrunner and progressive action-maker in sustainable development and transitioning towards CE. Accordingly, this assessment comes up with a tight result: New York receives the index result 0,6 while Aalborg achieves 0,57. Thus, New York is ranked as the more circular city, or rather as the city closer to the ideal state of being a circular city. Although the result is narrow, both cities have their strengths and weaknesses. This section will point out and summarize the main anomalies.

Looking at the consumption indicators (table 20 and 21), economy of scale effects are confirmed by the indicators on energy consumption and CO2 generation per capita, but do not apply on those of water consumption and waste generation.

The effects are neither confirmed by the rest of the indicators, except the GCP. In the following diagram both city performances are contrasted in those indicators and indicator categories, which have been scored, thus represent the base for the index results.

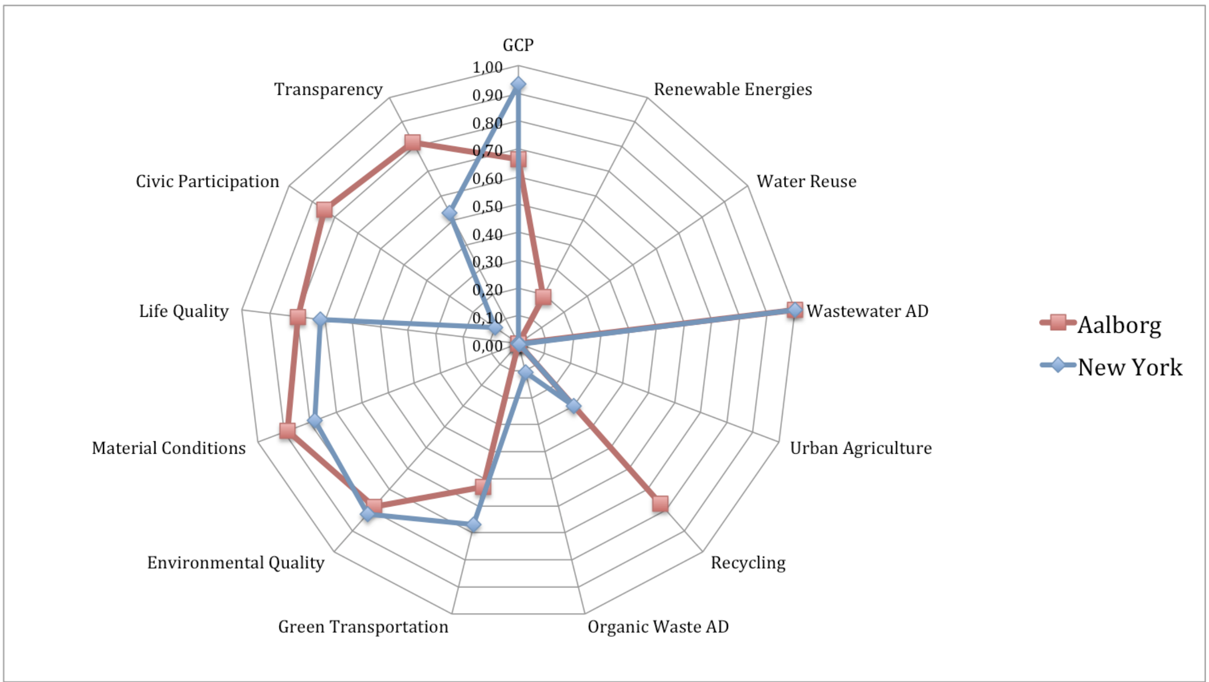

Figure 11: Contrasting Aalborg and New York (own figure).

To Start with the mentioned exception, the GCP scales in the larger city and thereby contributes to that New York almost reaches the defined ideal economic state.

While Aalborg has a lower (regional) GCP, the diagram shows that Aalborg performs constantly better in the social well-being related indicators. New York keeps up in the environmental quality, material conditions and life quality, but performs poorly on civic participation and public transparency (national).

Except of anaerobically digesting 100% the wastewater stream and making progress in recycling activities and integrating renewable energy sources into the urban energy system, both cities have low results in the physical flow indicators, which would contribute to the environmental regeneration. This part represents for both cities the one with the most and highest potentials of improvement.

New York and Aalborg perform differently in the three striving states. Aalborg holds compared to New York strengths in civic participation, public transparency and recycling, whereas New York commands a stronger economy that finally results in New York's slight dominance. However, none of them performs well in all striving states and weights them equally. Therefore, neither city can be considered as circular city.

5.4 Lessons Learned

During the application process of the circular city indicator set and index, including the collection of data, two main lessons learned are concluded in the following. One is on data availability; the other one identifies an essential element that has been observed in both cities to be supportive within the process of transitioning towards CE and sustainability: partnerships.

5.4.1 Learning on Data Availability

The initial process of composing the indicator set, has suffered more of data unavailability than the actual data collection process. Departing from the conceptualization of an ideal circular city, the assortment of the set has been determined by metrics and data unavailable. However, either through adjusting indicators or considering alternative approaches, such as using the expenditure as proxy to assess the consumption of food and goods, compromises could be found without limiting the holism of the assessment lens.

The issue around data unavailability within the process of collecting data for the specific indicators has been found as less aggravated than expected. Although there are still gaps, especially in local economic activity for Aalborg, or information on the self-reported satisfaction with the social network for New York, or for both cities in institutional related data, such as trust in local government or consumption related data, for more than 90% of the scored indicators data could be found on the city level.

However, finding and accessing the data has not been straightforward. Deviating data required verification processes through further research or contacting responsible departments while occasional lacks of data demanded well-founded assumptions. These have been made by reaching out to experts and persons in charge or by considering national statistics. In those cases, it was more difficult to approach private companies and consultancies, whereas public institutions, NGOs and regional/national departments have shown interest in this research and represent a supportive data source.

The biggest gap on data has been found on material input and output flows. Understanding the urban waste flow, its total amount and respective recycling rate, and finding respective data on its composition has been very challenging. Certainly, the waste flow is a complex matter, composed of various fractions, generated by numerous producers. However, it represents a highly valuable source, which should be captured in its whole extent to identify potentials and to manage it in a more effective way. The only more or less well-documented waste stream is MSW. The remaining components are not transparent at all. If data is published addressing commercial waste for instance, it is rather based on assumptions and inconsistent data supply. A reason for this might be that especially industrial, commercial or C&D waste, generated by private organizations, is still managed individually. Either there is no established infrastructure, which considers a common collection or a competition dominated thinking still prevails in these sectors which excludes collaborative actions with other businesses or the city as even waste could reveal sensitive information of the company's performance, not recognizing the potential of collaboration.

A similar issue regarding data availability and transparency has been recognized for the consumption of food and goods. While accurate data on consumption in units could not be found, at least the respective expenditure is documented and accessible. However, in both cases it is only published on a regional level. After contacting Niels Frederik Rottbøll from the Regional Department of Development, North Jutland, it has been confirmed that data on a city level, based on consumer surveys, exists, but is aggregated toward a regional and national level, which is what is publicly available. So, data is monitored to a certain extent, but not all of it is published.

Back to the waste flow, for Denmark, the "Waste Statistics 2015" published by the EPA captures the amount of waste of all sectors (Miljø- og Fødevareministeriet, 2017). After experiencing that data on consumption of food and goods exists on a local level, but is not published, it could be assumed that the same applies for waste. In New York's case, however, according to Kate Gouin from the Mayor's Office of Sustainability and Saami Sabiti from the NYCEDC, it is stated that this information is not captured or monitored at all. This might be connected to the scale of New York and its higher complexity.

Despite these difficulties, as mentioned most of the data supplying the indicators could be found. It has been recognized that both cities invest remarkable efforts in being more transparent and providing open data. However, regarding the pace of data collection, the process for New York has been easier and faster.

To conclude this learning on data availability, not every urban flow is sufficiently captured yet. Especially the material flow of food, goods and waste suffers of data unavailability or inconsistent communication to the public. However, especially from public department and institutions as well as NGOs efforts have been recognized to improve this state.

It is hoped that the issues on data unavailability will improve with time, that more data will be publicly available, that more data will be measured in order to enable measurements and unfold their potentials to guide decision-making.

5.4.2 Identifying Elements Supporting the Transition

Although both cities assessed differentiate in their scale and geographical context, it has been found that they have recognized the potential of partnerships and networks.

Notable contributions to achievements in CE result from various kinds of partnerships and networks in both cities. In the case of Aalborg, the NBE collaborating with municipalities of the North Jutland region, Aalborg University and local businesses, engages its members to share knowledge and tools to strengthen sustainable business development. Besides supporting practical solutions, it communicates best practice CE business cases aiming to inspire and educate about the concept and related efforts made. The most recent project addresses the city level (Circular City Region) and intends to enhance collaboration between the municipalities and businesses. The Center for Green Transition is a public-private partnership (PPP) that addresses besides the city of Aalborg and its businesses, the citizens as well. Besides offering consulting services and advice, it organizes events where all parties can come together, share innovations and know-how.

In New York many private and public initiatives has been noticed approaching sustainability practices, such as community gardens and urban agriculture. Specific CE efforts evolve through networks, such as the Circular Economy Network or the Circular

Economy Club. Both aim to merge academia, businesses, cities and the society. They provide a platform for exchange and collaboration. By holding frequent and public events, stakeholders are brought together and engaged. A recent effort is the Circular Economy Map, initiated by the Circular Economy Club, capturing worldwide all kind of stakeholders being explicitly involved in CE. Activities like this facilitate to connect to potential partners, enhance synergies and mutual inspiration.

Both cities have identified partnerships and networks as essential elements to support the transition towards CE. Those represent an effective and success-bringing tool to engage all urban stakeholders –businesses, government, and society, including academia– to spread CE knowledge and best practice amongst them, and to finally enhance collaboration and synergies. They furthermore contribute to adjust the stakeholders to each other and align their visions and help to focalize the same goal in order to pull together into one direction. By doing so, the dialogue on how to approach necessary changes –even a system change– could be shaped. Allover, networks and partnerships represent enabling settings to set up and to work out actions, as well as giving input for designing the right boundary conditions.

Combined with specific measurement approaches, such as developed in this thesis, it might even unlock more mutual potentials. Through networks and partnerships, the mentioned issue on data availability and accessibility could be leveled through collaboration and less competitive atmosphere. This contributes, on the one hand, to more accurate measurement results, which, on the other hand, result in even more tailored action steps and decision-making. It finally can foster effective progress-making based on well-founded partnerships.

DISCUSSION & FURTHER RESEARCH

This research captures the performance of a complex system, the city, transitioning towards CE. Based on a holistic definition of a circular city, the developed measurement approach aims to be a meaningful tool of transition. However, four main concerns are addressed in the following discussion section to reflect the work done and serve as base for potential future research investigations. Those relate to the specific choice of the economic and the social indicators, the unscored consumption indicators, the potential extension of the indicator set and related data availability.

During the application process, it has been found that New York has been ranked as the city which is slightly ahead in the transition of becoming a circular city. This is because it commands a stronger economic growth rate. Due to data and metric availability reasons, the economic flow in this measurement approach is only indicated by one, very broad and by itself rather one-sided, metric. Whereas the social well-being is composed of five indicator categories. The economic activity of countries and cities are so far mainly measured with the GCP/GDP as it represents a widely applied and standardized metric. Even though this measurement approach aims to compensate the one-dimensional characteristic of the GDP, it still seems to be too dominant by just being represented by one metric. Therefore, engaging into research how economic activity and quality, inclusive a respective growth rate, can be captured more holistically is strongly recommended. Until more appropriate metrics are developed, the circular city indicator set could be complimented by considering the contribution of the different urban sectors, i.e. primary, secondary and tertiary and their relevance for sustainability and CE performance.

Another note to the GCP addresses its availability on a city level. So far, it has only been measured for approx. 150 cities worldwide. Assessing at present the performance in sustainability and circular economy inevitably includes measuring the economic activity of the city. Relying on regional or national level falsifies the result as not all of the city contributions are captured. While, for instance, accounting the environmental externalities, such as CO2 emissions of the city straight, but not the direct economic contribution, does not depict an accurate picture. Therefore, it is demanded to calculate the GCP –or a more appropriate metric– for most of the cities.

The next point of discussion regards the choice and extent of the social indicators. This research argues that the social well-being in all of its dimensions contributes directly and indirectly to the potential of being a circular city. By providing a high social quality to the citizens, they become equipped and empowered to participate in the urban planning. This supports the desired balanced process between bottom-up and top-down city management. However, it is not yet proven how the measured social criteria finally contribute over time and neither is if the direct or indirect contribution dominates. Future experiences from practice will bring clarity and might demand to adjust the social indicators or take specific ones out.

Regarding the unscored consumption indicators, following wants to be discussed: The reason for leaving the indicators on consumption for the physical flows (energy, water, emissions, waste and materials) unscored, thus unconsidered in the assessment of the cities, is that no sufficient reference unit and comparison base has been found. Instead, the national average has been provided to at least classify the city performance and to quantify other indicators, such as the recycling rates for instance. To score the consumption of the city against the national average would contradict with the idea of striving towards an ideal state. National or international averages do not meet this criterion. In the future, it could be considered to score the consumption indicators against best practice data of a comparable city (e.g. matching in size, state of development or geographical conditions). During the development process, best practice city cases have been considered and researched for. However, it has been found that there are not many and those, which can be considered best practice, do not provide a consistent database yet. The most appropriate approach recommended to score the consumption indicators is to consider the performance of the previous year or locally set goals, such as reducing the CO2 emission by 5%. Again, for reasons of data unavailability this idea could not yet been realized.

As mentioned, each indicator category has suffered of data unavailability within the process of composing the indicator set. For future measurement investigations, it is hoped to expand the indicator set to an even more encompassing one. While it is now only recommended to use additional indicators and data available to understand and interpret the city's performance, future improving data availability would enable to include more indicators in the circular city index. Relevant and insightful information could be provided by indicators on electrical vehicles, the mobility and movement of the citizens, the degree of connectivity, institutional trust and transparency on a city level, the education about sustainable development and CE (SDGGIF, indicator 4.7.1), civic participation in urban planning, waste generation by sector and type of waste, the consumption on food and goods in units, outcome of urban agriculture and locally sourced food, as well as AD, economic activity generated by green and sustainable businesses, organizations applying CE practices, the development of the urban service sector, the degree of partnerships and networks across sectors and stakeholders, degree of digitalization, patents on sustainable and CE innovation or green procurement.

Due to restricted time and resources available, physical stocks could not be considered in this initial measurement approach. However, as Kennedy recommends, data capturing relevant urban physical stocks are on construction materials, water, nitrogen and phosphorus, and landfilling (Kennedy, Pincetl and Bunje, 2011).

The last aspect to mention addresses the general data availability. The application to two progressive and in sustainability and CE actively involved cities has shown that the lack of data impedes and determines the measurement. This might be due to the reasons of evolving complexity in cities, insufficient management or the lack of collaboration and effort, which could be the same reasons of why system changes are evolving rather slowly. However, this research calls for better and more accurate data availability, accessibility and monitoring, as well as transparency in information and data sources –all on a city level. Cities hold high potential of generating more momentum of change towards more sustainability and CE. To ensure effective decisions and action steps, data needs to be provided and measured in order to unlock the collective intelligence occurring in cities.

CONCLUSION

CE has proven its potential to address and reverse global challenges and to create a positive difference for a wider range than its direct actors, as successful applications on company levels show. It is expected that it can unfold further potentials and opportunities on a citywide picture where enablers, such as aggregated businesses and social diversity, proximity between stakeholders and a dynamic economy, come together. By scaling CE up to a city level and by combining it with suitable measurements, sustainable development in all dimensions and the ability of resilience within the urban system are likely to be achieved more effectively and holistically.

The development of the definition of a circular city in an ideal state contributes to the lack of understanding what CE can mean on a city level. The formulated definition demands that all urban flows and stocks (physical, social, institutional, informational and monetary) are managed in an effective –transparent and complete– way, exchanged amongst all urban stakeholders (the society, the government and businesses). The overall goal is that the three striving states (environmental regeneration, social well-being and economic quality) jointly strive towards an effective urban system.

As this research works towards developing a circular city measurement approach, this definition represents the foundation of the circular city indicator set and index aiming to measure the performance of the urban system as a whole. Supplied by 12 internationally known indicator frameworks and standards addressing sustainability and CE, the indicator set has been composed by taking metrics directly and indirectly over. Although the developing process has been determined by data availability, the final assessment of the cities, Aalborg and New York, only suffered of 10% data unavailability. Main areas lacking in data availability are waste, material consumption, economic activity, as well as institutional trust and transparency on a local level. As these criteria are essential for the overall performance of the city, it is called for more data availability on city levels.

A further finding is that both cities take advantage of the supportive elements of partnerships and networks. These have shown a facilitating and enhancing role in the process of change as they provide a setting enabling knowledge sharing and collaboration. Beyond this, these elements might represent a promising means to make the flow of information and data amongst various stakeholders more transparent and complete, thereby compensating present data unavailability issues.

Allover, this thesis aims to lay the stepping-stone for a meaningful contribution in the transition towards CE in cities. By providing theoretical and practical insights and lessons learned, it is hoped to serve as input for and compliment to recent investigations of research institutions, cities and leading organizations in this field.

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