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Intelligence-Driven Urban Internet-of-Things Ecosystems for Circular, SAfe and IncLusive Smart CITIES

D2.1: Circular Economy models for smart city assets

Abstract: This deliverable defines IoT-enabled circular business model design with focus on exploring how Cities can create new forms of value and achieve scale while transitioning to a circular business model enabled by IoT technology (exploring linkages between service and business model design), and digital strategies for service business models (including public services) by analysing the role of digital resources as enablers of city service business models. The deliverable also describes the initial trust and reputation models based on the user models identified, and finally develops a model that captures the digital strategies employed by Cities in a service context and explain the contributions these strategies create.

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1 Introduction

1.1 Circular Economy (CE)

The **tragedy of the commons,** coined by economist William Forster Lloyd back in 1833, is a situation in a shared-resource system where individual users, acting independently according to their own self-interest, behave contrary to the common good of all users, by depleting or spoiling that resource through their collective action [1]. Although this theory was developed more than a 150 years ago to study unregulated gazing on a common land (finite resource), it can be easily realised that this paradigm can be extended to essentially cover a number of contexts in the modern economy. In fact, this principle is highly relevant and topical. Today's linear economy where the technological advancements enabling the human kind to cheaply extract, exploit, use and dispose of materials at high rates is reaching its physical limits. We have reached a pivotal moment in the history of our planet, where the linear economy approach, combined with the steadily increasing population has started to reveal the signs of a planet in fatigue and decline. Circular Economy attempts to offer a remedy:

A circular economy is one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times [2]. It distinguishes between technical and biological cycles as an attempt to minimise leakage and wastage.

Learning from nature that recycles and upcycles its "waste", CE is built on the premise that every material can be reused in a way that the natural capital can be regenerated and restored. Figure 1 captures this in the so-called CE "butterfly" system diagram, showing the mirrored relationship between the biological and technical cycles.

Quite obviously, a practical and pragmatic approach in implementing CE is a non-trivial task. Following the research in IDEAL-CITIES, it is argued that the two key ingredients in attaining circularity and achieving sustainability are **technology** and **people.** In the course of this project the focus is on these two factors where they are systematically studied and it is explored how these can act as enablers in the context of an urban environment.

1.2 Data-driven CE

Smart, or data-driven Circular Economy is the utilization of reactive, adaptive, autonomous or collaborative objects and systems for economic and environmental value creation and appropriation through closing material and energy loops, minimizing natural resource depletion and restoring natural biospheric balances [3]. The paradigm of Circular Economy directly challenges the so far established linear economic model, where resources are transformed into products that at the end of their life-time are disposed of as waste.

The notion of Circular Economy was first popularised during the 70's but mainly through a material sciences perspective. Indeed, the initial approach heavily focused on innovative material that would be highly recyclable and "eco-friendly"; such as plastic. However, as consumerism continued gaining ground, it soon became apparent that such an approach was inefficient and fragmented. The reason was that it did not truly enable the transition to a circular economic paradigm but rather the introduction of recycling loops towards the end of the produce-consume-dispose line. Several efforts have been made in order to increase the efficiency of the recycling process, both from a technical (e.g. improving the efficiency of recycling and reclaiming processes) and a business perspective (e.g. studying business models that would provide clear incentives for exploiting waste). However, these efforts still did not address the core nature of the problem.

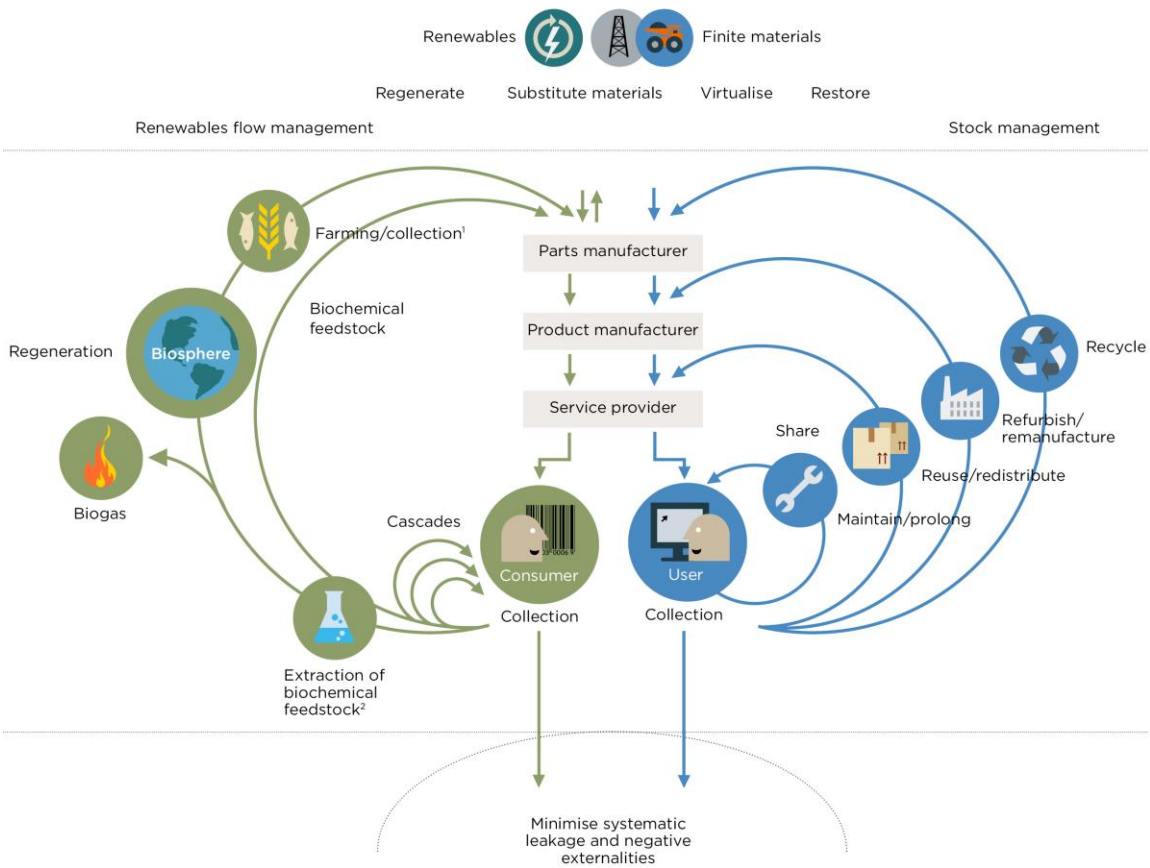


Figure 1: CE system diagram [4]

The notion of Circular Economy is being revisited in the last few years under the light of recent technological advancements. Innovations, particularly in the domain of ICT, allow us, nowadays, to collect and process very dense data - dense both in space and time - of high granularity and fidelity. This data can then be mined in order to extract multi-dimensional information that help the fine-tuning of processes, as well as decision making.

Internet of Things (IoT) is a technological paradigm that provisions the generation and exchange of data among machines over the Internet. The paradigm refers to a suite of technologies - ranging from sensors and actuators, to embedded microprocessors and microcontrollers, to low power wireless networks and light-weight communication and application protocols - that underpin the seamless and massive integration of everyday objects and machines to the Internet. The scope of this integration moves well-beyond remote control and automation; it also covers the ability of the machines to dialogue with each other and to some extent make decisions and adjust their operation based on data and information received from other machines and systems. Finally, another important aspect of IoT is its key role in bridging the gap between the physical and the digital worlds, thus paving the way towards cyber-physical systems. While sensors enable digital systems to collect data from their ambient environment and to monitor physical processes, electromechanical and electronic actuators enable digital systems to act upon their environment, thus closing the loop.

IoT is an underpinning paradigm enabled by recent and ongoing technological advancements, that already transforms the way we understand and interact with "computers". Other paradigms with an equally profound impact are Artificial Intelligence and Machine Learning, Robotics, Distributed Ledger Technologies and Next Generation Wireless Communications such as 5G and Multi-access Edge Computing, to name a few. These technologies work in synergy and interlock with each other, forming a new technology-lead environment that supports broader socio-economic paradigms, such as Circular Economy.

Indeed, the ability we now have to track individual smart assets, to collect dense spatiotemporal data from systems and machines and to (a great extent) automatize their behaviour and reaction, enable us to revisit Circular Economy from the angle of a Data-Driven methodological approach. Such an approach not only further promotes the digitization of processes and decision making, but also greatly facilitates interoperability among heterogeneous systems and therefore the development of cross-vertical use-cases.

1.3 Circular Economy Business Models

Ideal-Cities include the paradigm of Circular Economy aiming to contribute to the optimization of resource utilization and the extension of the lifecycle of the IoT – enabled devices through intelligent assets management. This alternative economic model focuses on maximizing what is already in use along all points of a product's lifecycle, from sourcing to supply chain to consumption to the remaining unusable parts for one function and their conversion back into a new source for another purpose [5].

Circular Economy aims to replace the end-of-life concept with restoration, promote the transition to the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, with the objective of the elimination of waste through the superior design of materials, products, systems, and, within this, business models [6].

The circular economy model also seems to be the path to slow down the climate change process and to reduce greenhouse gases emissions, thus, preserving the environment by:

- using renewable resources to equilibrate the non-renewable resources demand,
- eliminating waste by improving the reuse in each operation on the value chain during the manufacturing process having products designed from the start to reuse and,
- using biological ingredients in the manufacturing process that can be safely returned to the biosphere.

These principles allow establishing four sources of value creation to implement instead of the linear economy model [6]:

1. *The power of the inner* circle refers to the durability of the product and the ability to reduce the need to be changed in reuse, refurbishment and remanufacturing. The faster it returns to use, the higher the potential savings on the shares of material, labour, energy, and capital embedded in the product.
2. *The power of circling longer* is related to maximising the number of consecutive cycles (reuse, remanufacturing, or recycling) and the time in each period.
3. *The power of cascade use* refers to the diversification of the reuse in all phases of the value chain
4. *The power of pure circles* is related to the fact that the use of uncontaminated material in manufacturing increases the stream of collection and redistribution efficiency while maintaining quality.

The circular economy aims to change the mind-set from consumption to a new and more resilient behaviour concerning the way to see the product, the customers and the business where durable products are leased, rented or shared wherever is possible.

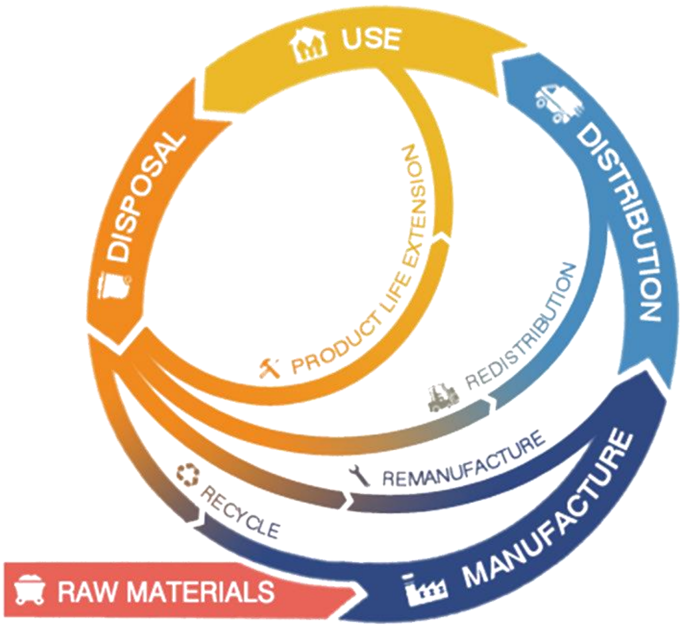


Figure 2 The Circular Economy Cycle

1.3.1 Business models

The business models applied to circular economy aims to harness the utilisation of already existing resources avoiding as much as possible the extraction of natural resources. The models propose actions in all phases of the value chain and are related to measures as reducing waste, that allows the shift from selling products to selling integrated products and services that deliver value in use [7], broadening the consumption and remanufacturing (Figure 2). The work carried-out by Lacy and Rutqvist [8] distinguish five typologies according to a business-centric perspective:

- Circular supply chain: Right from the start
- Recovering and recycling: making a history of waste
- The product life-extension Business Model: Products that are built to last
- The sharing platform business model: Sweating Idle Assets
- The product as a service business model

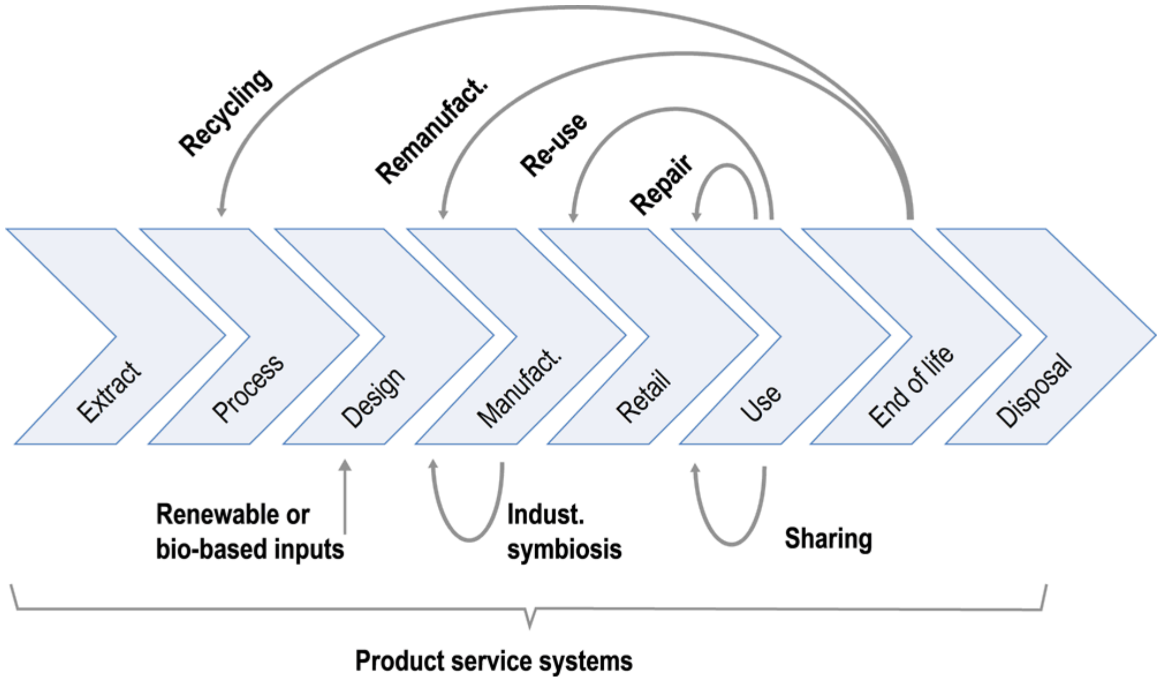


Figure 3 Impact circular business model n the linear economy (Source: OECD Report, 2018)

1.3.2 Circular supply chain

The circular supply chain is based on the use of bio-based materials instead of traditional materials inputs. Using these new inputs and adopting strategic sourcing decisions, companies can reduce the environmental pressures in the supply chain using materials that will not become waste. For apply this model, the market demand for new green products should be ensured because higher prices might be applied for the latest products. Another aspect to consider is the availability to obtain bio-based, renewable or recovered materials that at the same time, should satisfy or surpass the quality of the traditional materials. Finally, the cost of new materials should also be affordable and easy to implement because companies will unlikely adopt models which might increase their production costs significantly.

1.3.3 Recovering and recycling

Due to the competitive market and raw materials becoming more expensive due to overexploitation, the companies are searching how to reuse the by-products resulting from the manufacturing of their products along with the value. This model aims to foster material reuse and maximises the economic value of product return flows, which awake the interest of companies producing large volumes of by-products that can be reclaimed and reprocessed at a reasonable cost [8].

The challenge of adopting this model is to ensure that the unit cost of the product, including the revalorization process of the recycled materials, should not increase the price compared to the use of traditional materials. The by-product has to fill the quality requirements, which sometimes are difficult to achieve. The availability of by-products will also play an important role to ensure the provision of the materials, especially in regions with low population and consumption. Finally, the price of transport will also have an impact on the implementation and vary due to the nature and quantity of material required.

1.3.4 Product life-extension

Companies adopted the model focused on volume production, which encourages consumers to replace frequently the product. This model creates products that can be used once and then renewed for a new product or just discarded, causing a significant amount of waste that is also difficult to reuse. This business model is related to improving life span of the products while proposing innovative ways for upgrading the product without the need to change it each time a new feature is available. In this model, the durability, functionality and quality are the value of the product

Thus, before discarding a product, the model proposes different ways to put the product back to the market again as refurbishing, take-back/trade-in/buy-back to remarket, upgrade, refill and repair. The challenge is to design products that can be easily upgraded or dismantled to recover the different parts.

1.3.5 Sharing model

This business model is related to the sharing economy and provides a platform to connect product owners with individuals or organisations that would like to use them. Rather than accepting that products sit idle, the platform boosts their productivity by allowing co-access or co-ownership [8]. This business model is the result of the development of new technologies as the internet, mobile phone applications, etc. that facilitate communication and connection between people. For the owners of under-utilised assets, the use of platforms provides an opportunity to earn additional income [9]. The challenges of adopting the business model are related to the critics to the influence on the broader economy and the need to approve of new legislation.

1.3.6 Product as a service

The business model proposes that the companies retain the ownership of the product, and the performance is more important than the product itself. The services that the companies can offer adopting this model vary from the maintenance through design, use, reuse, remanufacture and recycling [10]. The main feature is the close collaboration developed with the customer, which instead of being a consumer becomes a user of the service. The main forms of monetisation can be divided into four typologies: the pay for the use which specifies the user pays for metrics such as kilometres driven, etc. The rent and leasing allow to the user to buy contractual rights for a limited period, short and long term respectively, and finally, the performance agreement in which the service involves a specific result.

The main challenges in adopting this model are related to the expansion of the market and the full digitalisation of the service. If the service is not fully digitalised, a physical presence will be needed to work with the users. On the other hand, the full digitalisation might cause a disconnection with the users who continue feedback will help to improve the services.

1.4 Smart Cities

The literature contains a plethora of attempts to provide a definition of a “smart city”; the International Telecommunication Union (ITU) alone in a recent survey captured over 100 definitions for the term [11]. Although the term is currently and continuously evolving, it is clear from the most recent work that in order to characterize a city as being "smart" would require to assess it over a number of features or dimensions. Furthermore, it seems that there is no one-size-fits-all definition of a smart city. This should not be a surprise as cities have different priorities, agendas and face different and potentially diverse challenges. In any case, the main driver for injecting "smartness" in a city is about sustaining a development and equitable growth. Such driver is the common denominator of all definitions of smart cities (Table 1) which essentially refer to offering a good standard of quality of life and services to its citizens.

Table 1: Definitions of a smart city

Year	Definition
2000	A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens [12].
2006, 2008	Territories with a high capacity for learning and innovation, which is built in to the creativity of their population, their institutions of knowledge production, and their digital infrastructure for communication [13].
2007	A Smart City is a city well performing in a forward-looking way in these six characteristics [economy, mobility, environment, people, living, governance], built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens [14].
2012	Smart cities have a high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output oriented planning systems, creative activities and sustainability oriented initiatives [15].
2013	The term "smart city" is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring urban infrastructure for environment protection and reduction of CO2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators, whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital [16].

Although these definitions revolve around sustainable development, another theme that emerges and becomes more visible in the later years is the human aspect and more specifically, citizen participation.

In spite of the ambiguity characterising the term, one can identify the core notion of a smart city to lie in the use of modern and state of the art ICT for improving the efficiency and ameliorating the quality of management processes and services of a city with the aim of improving the quality of life of citizens. As aforementioned, how this abstract aim translates in concrete implementations is dependent upon the environment and the particular challenges each city faces.

However, these monolithic and relatively succinct definitions of a smart city are an oversimplification of the essence of the city, which cannot capture the sheer complexity and the many facets that make a smart city. Cities themselves are sometimes seen as an organism or a system comprising of many parts that interact with each other to serve a number of purposes and functions, resulting to a display of certain behaviour on both a macro and micro level. As such, the research community has attempted to address this by introducing smart city definitions that include a set of dimensions (see [14], [15], [17], [18], [19]); besides, even some of the definitions in Table 1 do consider dimensions in one form or another. Using different planes enables the possibility to study different aspects of a city by selecting a focus on a particular dimension, but at the same time acknowledges the interdisciplinary nature of the problem domain. Studying the various smart cities dimension approaches, one of the most mature and comprehensive definitions is the one by Chourabi et al [20], which is summarised in Table 2

Table 2: Dimensions of a smart city

Dimension	Description
Management and organization	A project is influenced by such managerial and organizational factors as project size, managers' attitudes and behaviours, and organizational diversity
Technology	A smart city relies on computing technologies applied to critical infrastructure components and services, but technology can either improve citizens' quality of life or contribute to the digital divide.
Governance	Included are processes, norms, and practices that guide the exchange of information among the various stakeholders and their leadership, collaboration, communication, data exchange, partnership, and service integration.
Policy context	Included are the political and institutional components of the environment.
People and communities	Individuals and communities affecting and affected by implementation of a smart-city initiative can involve participation and partnership, accessibility, quality of life, and education.
Economy	Economic inputs to and economic outcomes from smart-city initiatives include innovation, productivity, and flexibility.
Built infrastructure	Availability and quality of technology infrastructure involve wireless infrastructure and service-oriented information systems.
Natural environment	Included are sustainability and good management of natural resources.

European Commission in its report "Analysing the potential for wide scale roll out of integrated Smart Cities and Communities solutions" [25] presents the results of a comprehensive study of 300 examples of Smart Cities initiatives across Europe. The analysis has identified the commonalities among the corresponding Smart Cities and

Communities initiatives and have taxonomized those according to the sector they referred to:

- Real-time road user information
- Enhancements of public transport
- Traffic monitoring, management and enforcement
- Smart technologies for the built environment
- Sustainable districts
- Place making
- Smart city platforms
- Intelligent city services
- Smart grids.

The taxonomy indicates that the initial efforts for developing smart cities has been mainly focused on the verticals of transport, building and space management and energy. While these verticals are key in improving the function or even the revenue of a city, they do not directly address the immediate needs of citizens.

In fact, the same report presents elaborated findings on the most common reasons why Smart City and Communities initiative have failed across Europe. The report concludes that cases of failure can often be tracked back to *a lack of attention to the needs of users*, which is independent from the technological development of solutions. The report further notes that *designing solutions starting from the citizenry is possibly the most relevant lesson that can be learnt from past experiences*. The key lessons learnt on a failure of Smart City and Communities integrated solutions, as identified by the report, are:

- *Inability of solutions to integrate with the urban dimensions* that their success depends on. In particular, this risky element has been recognised when designing and developing solutions without the sufficient involvement of the citizenry and – in several cases – of the political-institutional authorities. This involvement has rarely been constant throughout the project duration; most often it has been focused on the initial phases only.
- Despite a strong vision on how SCC solutions had to evolve and integrate with the urban environment in the long-term, a common *inability to translate the long term orientation into a coherent action plan* strongly contributed to limit the chances of success of the cases analysed.

It is worth noting that the technological dimension was hardly an issue at all.

Based on these findings, Ideal Cities identifies as main drivers in its approach a) supporting sustainable and equitable growth and b) citizen's participation and engagement.

1.5 Cyber-Physical Systems and Socio-Technical Systems

From a systems thinking perspective, a city can be viewed as a complex system that is continuously evolving, with its "elements" continuously and coherently organised and connected in order to perform a particular set of functions or purpose. As in any approach for defining, studying and analysing a system, the appropriate level of abstraction needs to be established. While it is important to highlight Meadow's assertion that "self-organizing, nonlinear, feedback systems are inherently unpredictable [so]. . . we can never fully understand our world, not in the way our reductionist science has led us to expect." [26], in the case of modern smart cities a systemic analytical approach can be seen as a pragmatic approach in appreciating the "wicked problems" [27] that the underpinning technical, cultural and social structures display.

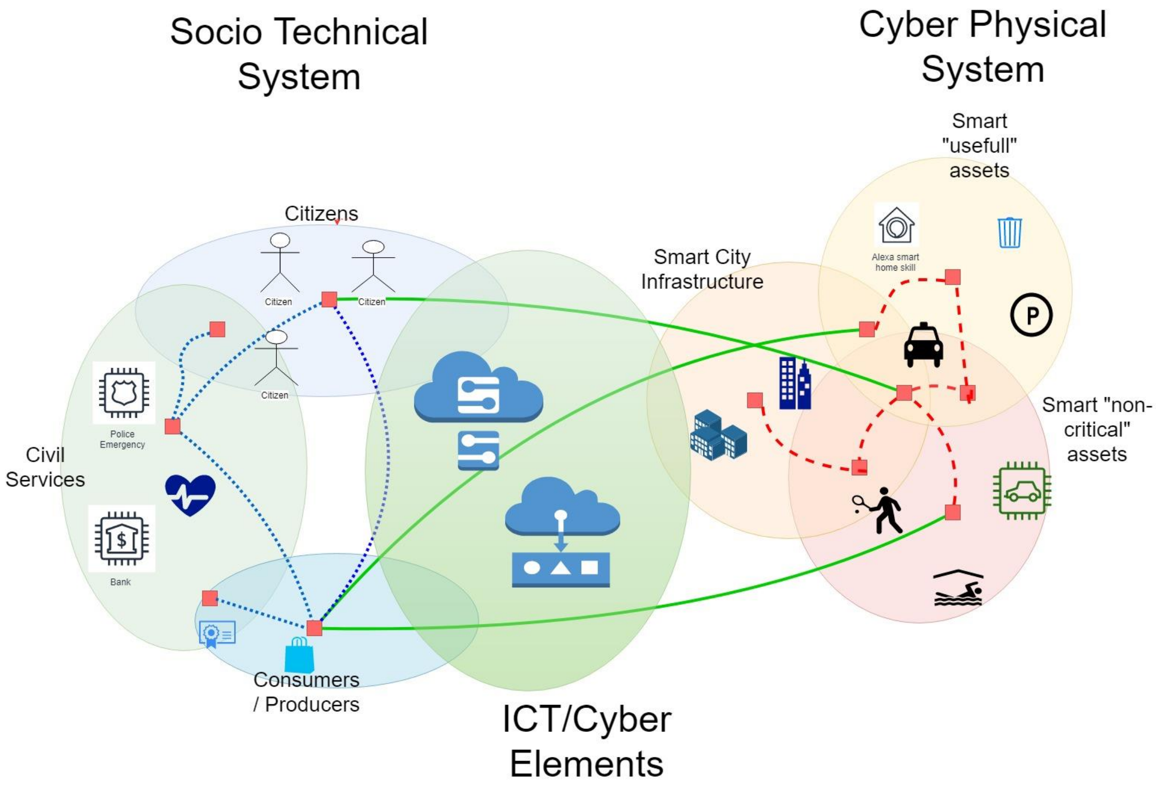


Figure 4 IDEAL-CITIES view of a smart city as a system-of-systems consisting of a Socio Technical System (STS) and a Cyber Physical System (CPS). The various actors interact within their respective scope

In the case of IDEAL-CITIES, a smart city is viewed as a system of systems comprised of a Socio-Technical and a Cyber-Physical system (STS and CPS). If these two systems were represented in a Venn diagram, the overlapping area would include the pure ICT/Cyber elements. On the STS side, lie the users - or human assets – who interact with the city infrastructure in meaningful ways, expecting to receive services or contribute to the city's functions. Human interaction is realised by exchanging information both through the physical and the cyber plane. In addition, the humans may interact both with each other and with the city's smart infrastructure.

On the CPS side lie all the physical devices – or potentially intelligent assets – that interact with the city's ICT infrastructure services such as fog and edge computing nodes. These intelligent assets can have varying levels of "importance" in the system, assuming different roles and offering services of different levels of criticality. A first distinction could be between the Internet of "useful" Things, which are the devices that are required for keeping the city running (e.g. traffic sensors, actuators), and the Internet of "non-critical" Things, that are part of a smart ecosystem and interact with other components, offering “nice to have” functionality such as supporting leisure related activities (e.g. gadgets, and general purpose wearable devices).

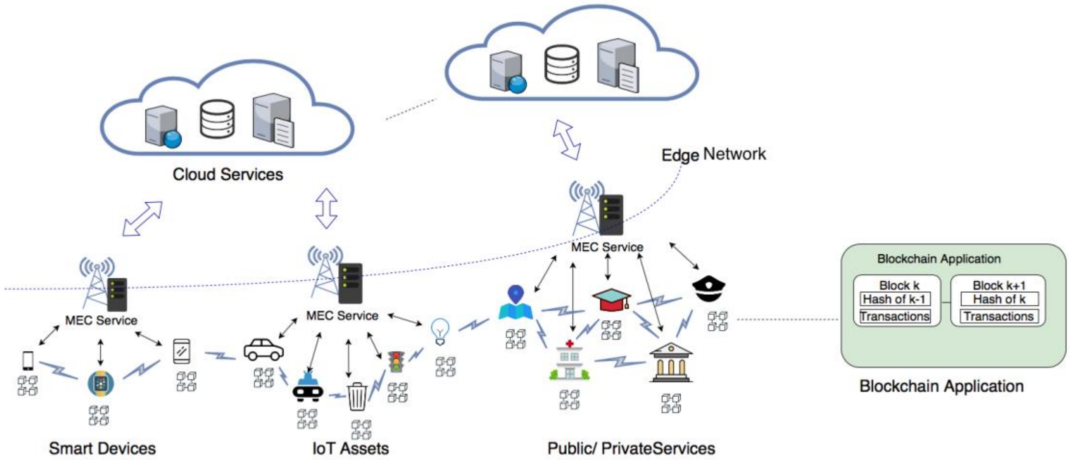


Figure 5 Edge Computing nodes as storage enablers of Blockchain ledger for IoT networks in a smart circular city.

Both types of assets - human and IoT - interact through the physical and the cyber plane, by exchanging information. The human nodes, which mainly correspond to citizens, are producers and consumers of data and information, the so-called “prosumers”. Through crowdsensing and crowdsourcing methods, the information can be topical, relevant, accurate and available even within given strict timeframes, giving the opportunity for fine-grained decision making in real-time. This decision making activity can be supported by AI capabilities that in turn have the capacity to control and modify the physical world conditions. For instance, an environment control system for a smart building can monitor a certain set of environmental parameters (e.g. temperature, humidity, luminosity), recognise the level of occupancy of a specific area, as well as the level and type of activity of the occupants and adjust ambient conditions accordingly. In addition, all transactions could be captured and ledgered, so that the respective and involved partied would be compensated appropriately.

A high level example of a systems thinking approach is to consider a technological framework with the core components mapped to an entity where:

- Internet of Things will **sense**,
- The Edge will **react**,
- Artificial Intelligence will **think**
- Blockchain will **remember**.

A prime example of this approach has been presented by A. Damianou et. Al [28] in their proposed architecture that enables blockchain applications to run over IoT cyberphysical systems in the context of smart circular cities. In their approach, ICT/Cyber elements, such as Edge computing infrastructure, allow for city assets and services to be managed and monitored via blockchain applications. The various technologies work in synergy with each other following the aforementioned analogy, thus enabling the seamless and secure exchange of information among distinct sectors and services. This flow of information among the various actors and systems of a smart city is the main function that underpins the effective adoption of circular principles.

1.6 Data-Driven CE in an Urban Ecosystem (Circular Cities)

It can be argued that a smart city should be the epitome of sustainability since any deviation from this would entertain scenarios of dystopic futures. Circular Economy may provide the ends whereas ICT may provide the means. In other words, the purpose for a city to become "smart" is to reach a state where sustainable and equitable growth is achieved. Many cities embarked on a journey to become smart and soon realised – and in some cases through failures as presented later in this report – that the end goal was to address sustainability challenges, even in the case where this was not explicitly envisaged from the outset. At the same time City Councils are realising that a key to finding a solution to the sustainability challenge is data; "Data is the new oil" is a statement attributed to mathematician Clive Humby back in 2006 and was rehearsed by The Economist in 2017 with the post titled "The world's most valuable resource is no longer oil, but data" [29]. Quite ironically, oil representing the old linear economy that was primarily driven by non-renewable energy sources such as fossil fuels were used to illustrate the value and importance of data in the modern world. Embracing information technologies and their capabilities in producing and consuming data, it can be seen as a natural consequence that CE would really need to be data enabled or alternatively data-driven to be able to deliver what it evangelises.

Achieving circularity however cannot be solely down to a city's transition to a smart one. The city would essentially need to truly be transformed. In order to achieve this, there will need to be a set of relevant requirements, Key Performance Indicators and a maturity model to capture the structure of the roadmap towards sustainability. Sustainability and Circularity can only be realised at the higher levels of maturity, when all city's assets (people and technology) converge and serve this goal.

A maturity model will help in establishing the stage(s) or CE readiness of a city against the set of agreed dimensions a smart city is comprised of. To date a few research initiatives and studies have proposed maturity models or the so-called readiness guides, see for example the ScottishCitiesAllience [30] or the Smart cities Council [31]. Currently, the focus of these models is on the transition of the city to being smart, rather that being circular, which is indirectly captured in some cases under the sustainability dimension or goal. The maturity models may also have varying levels of stages and of course dimensions. In the context of IDEAL-CITIES and provided that the main purpose of a city is to adopt Circular Economy models, the adopted maturity model is comprised of the following stages [32]:

Stage 1. The **Instrumented City**: this is the first stage of the transition, where the city embeds constellations of sensors and devices on the physical infrastructures (e.g. bridges, street lights, gas pipes, the grid). At this stage the devices perform basic tasks for specific purposes. A typical example is the smart energy meters installed at the households. At this stage, there are no capabilities of information exchange between constellations of different purposes. The stakeholders use the intelligence gathered primarily as an advice source.

Stage 2. The **Connected City**: this is the stage where connectors between the different constellations are in place. Such added capability at this stage only does not necessarily involve any actual exploitation or systematic utilisation of the available data. The stakeholders are still concentrated in consuming the data within their respective sector or domain, despite the increased heterogeneity and availability of the data.

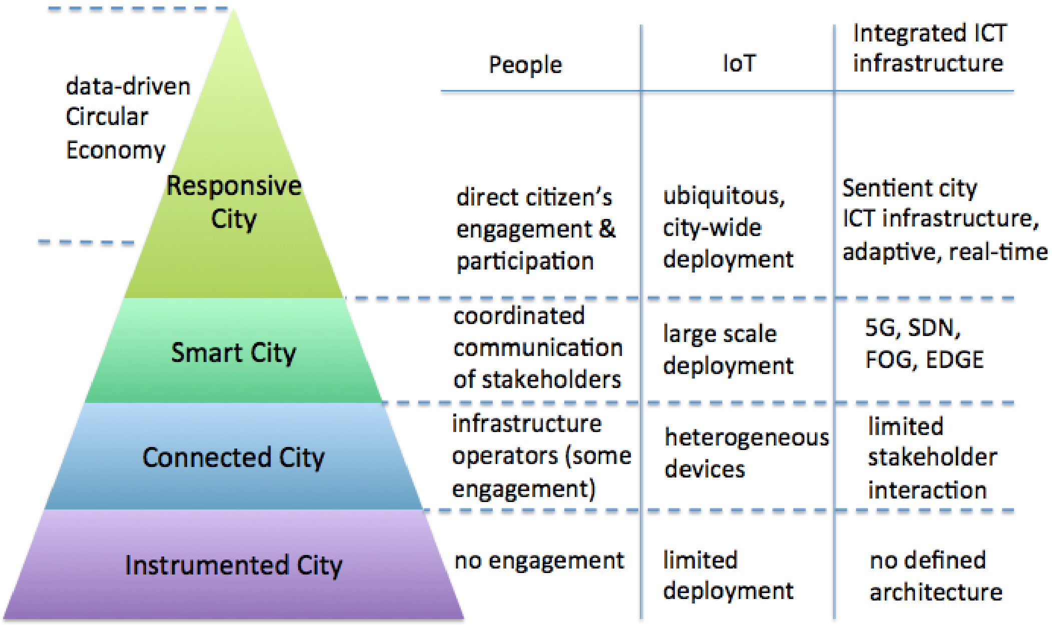


Figure 6 Maturity stages for a data-driven CE ready city

Stage 3. The **Smart City**: this refers to the stage where all assets are fully interconnected and actionable information is available to the stakeholders who can reach high levels of situational awareness. The main volume of the activities is performed in the city's "back office" operations. Infrastructure operators, utility and service providers can perform intelligent processing and the local government stakeholders can perform global processing and maintain an overview of the city's operations.

Stage 4. The **Responsive City**: This stage could be considered as the city's "self-actualisation" level, in line with Maslow's hierarchy of needs. A Responsive City is a state where the humans, the intelligent assets and the rest of the components are in complete sync, where the information is available in real time and in an appropriate, accessible format. Through collaborative decision making, the assets and infrastructure will dynamically adjust to cater for short term and ad-hoc needs of its citizens; the city can infrastructure can trivially handle exceptions; through predictive analytics and proactive computing the city can anticipate changes and respond by corrective actions, making sure that the finite resources are available when needed and waste is virtually eliminated. In essence, the city has reached the ultimate level of sustainability.

The four maturity stages against the dimensions are depicted in Figure 6.

2 Current landscape of smart cities

2.1 Smart city initiatives

At the time of writing, there are over 200 smart city initiatives across the globe. Of these, at least 40 have a CE agenda. It is worth noting that not all circular cities necessarily define themselves to be also smart as they may have a lower maturity level in adopting and implementing smart city infrastructure components. Unsurprisingly, in these cases many have identified data availability to be among their challenges.

In the following sections an indicative sample of pioneering smart and circular cities is presented.

2.1.1 Amsterdam

Table 3: Amsterdam – Key data

Population [33]: 1,140,339	Area: 219.3 km^2
CE Achievements [34]:	• Roadmap on circular buildings • Housing • Value Chain network • Living labs

- Smart city investment commencing year: 2009
- CO_2 Emissions (metric tonnes) [35]: 4,471,000
- Waste Recycled [36]: 27%
- Consumed Renewable Energy [37] 5.8%

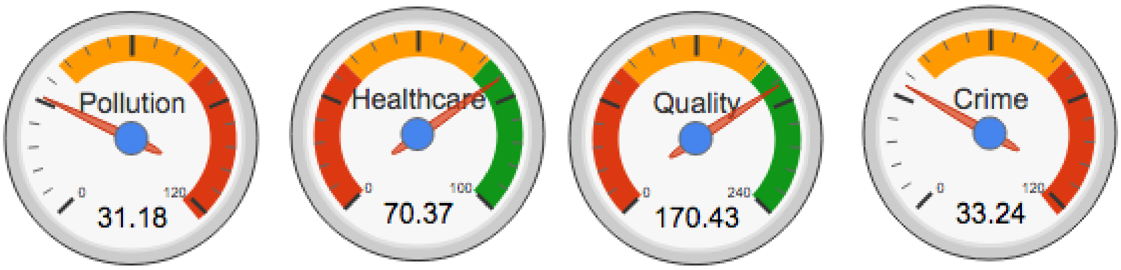


Figure 7: Amsterdam – Pollution, Healthcare, Quality of Life and Crime indexes [38]

- 1 CCTV camera per 3,900 citizens [39]
- Key challenges: City’s bridges and canals, flood warning
- cities in motion index rank:3

Accommodation: AirBnb listings: 19,619 [40]

Availability: 26.4% Estimated occupancy: 19.8%

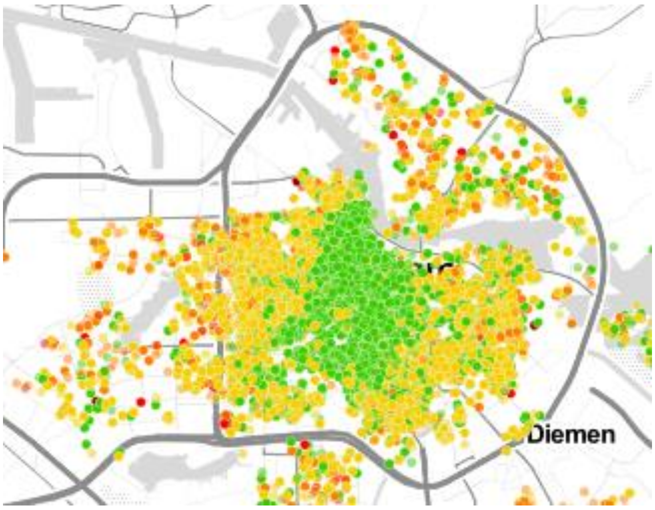
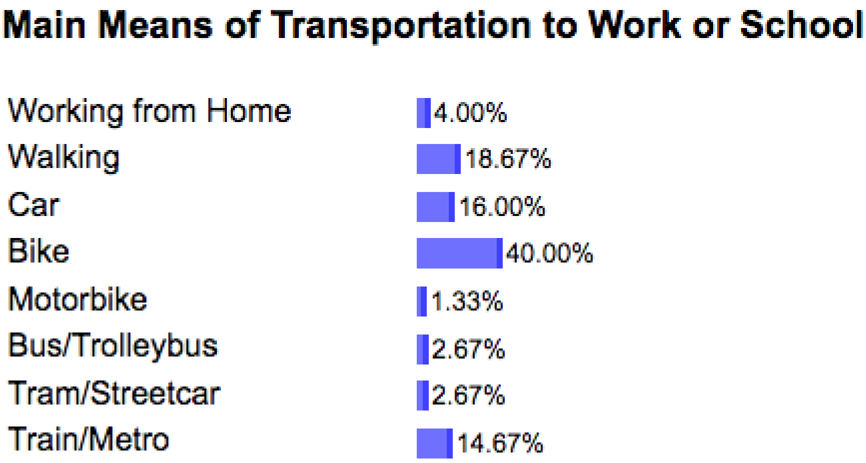


Figure 8: Tourist's feelings map [41]

Transportation: Cost of one way ticket: 3.00 Euros[42]



Amsterdam's transformation into a smart city started in 2009. The fundamental first step (Smart City Step 1) was a meticulous recording of 12K datasets, across 32 departments of the city, a task that was proven to be of a little short-term payoff. Despite public expectation for immediate breakthroughs and rapid changes, there are too many steps required for a stable and effective development. Amsterdam's Chief Technology Officer, Ger Baron, highlighted an aggravating element in the fact that "every company that comes here and tells us how it works, they're wrong because they don't have a clue how a city works…there is a big difference between how people think it works and how it works"[43]. Continuous experimentation with pilot projects and increased input from citizens are the first steps towards a functioning smart city [44]. This dedicated effort laid the foundations for what led to April 2016, when the city won Europe's Capital of Innovation Award by the European Commission.

In 2014, Amsterdam was one of the first 20 cities that the World Council of City Data (WCCD) certified with the international standard (ISO 37120) on Sustainable Development of Communities – Indicators for City Services and Quality of Life [45]. The ISO 37120 is a set of 100 indicators, categorized under 17 Sustainable Development Goals (SDGs), developed using the Global City Indicators Facility (GCIF) framework [46]. Two years later, WCCD has announced its partnership with the Dutch Central Bureau of Statistics (CBS). In addition to Amsterdam, another three certified Dutch cities (Rotterdam, Eindhoven, and Heerlen) facilitate the CBS city-level data. 60% of the ISO 37120 standard's indicators are collected and reported by CBS [47].

By this moment, Amsterdam's smart city initiative has created more than 80 pilot projects across the city that cover a variety of need for the citizen's and tourist's everyday life (Smart City Step 2). Step 2 consists mainly of laying the necessary infrastructure and enabling technologies. The stakeholders of the projects come from the public and the private sector. Examples of applications stem from usual smart city projects such as waste management, parking, energy or even projects particularly tailored to the city's needs, like flood alerts due to Amsterdam's characteristic geography. With the docking areas and the Johan Cruijff ArenA being two of the main deployment areas, an important number of projects is going through the implementation phase.

Amsterdam Smart City (ASC), the innovation platform of the Amsterdam Metropolitan area categorizes the projects into six verticals: Digital City, Energy, Mobility, Circular City, Governance and Education, Citizens & Living. The subjects touched by those verticals are spread across smart mobility, smart living, smart society, smart areas, smart economy, big and open data, infrastructure, and living labs. In a city like Amsterdam, where much of the infrastructure is from the Reformation Era, adaptations must take place to ensure the capital's roads, housing, services and quality of life improve. At the same time, cities must become more sustainable to avoid increases in air pollution and further contributing to climate change [48]. The city aims not only in improving the lives of its residents and visitors but also in providing with an unseen transparency by making the city's data open source; along with providing advanced ICT and digital infrastructure.

The future of Amsterdam's smart city initiative (Smart City Step 3) holds an increased role for Amsterdam's people and communities. Enabling technologies need to be adopted by and ran by the public. No matter how effective a city's administration is, nothing can be compared with the direct intervention and incident response from a concerned community. Data transparency and e-governance aims to the increase of society's democratization and turn Amsterdam into the first completely open source city. Schemes like Repair Cafes and apps like Verbeterdebuurt help the people of Amsterdam to highlight their everyday problems and suggest improvements. Amsterdam's residents are actively participating in testing various projects, such as energy saving technologies [49] and mental health initiatives.

Amsterdam has embraced the concept of circularity since 2015; the first city in the world to develop a vision and roadmap for circular economy [50]. Taking advantage of the city's high-level ICT infrastructure, the project developers managed to deploy a wide network of sensors and actuators that enabled the necessary technical backbone for data driven projects around the city's premises. Examples include street lights that only switch on in the presence of cyclists or cars, or office lighting that only turns on when an employee's mobile phone is detected [51]. The existence of a number of platforms and frameworks allow the exchange of information between projects and developers.

Amsterdam's resources also expanded significantly with the acclamation of its citizens' and tourists' potential. Crowdsourcing and crowdsensing are two vital elements in the city's effort to achieve its goals. By acclaiming the massive data produced by its people and also managing to involve them, actively, in numerous projects, Amsterdam has become a living lab that produces its own motivating power on the road to becoming a model Smart City with circular economy characteristics.

One successful example is the city's approach to measuring air quality. Back in 2013, expanding its 11 existing stations was a project that faced significant cost and scalability issues, in order to meet the existing demands [52]. The officials took a different approached and launched the Amsterdam smart citizens' lab. The lab provided the citizens with the necessary equipment and expertise to build their own low-cost sensor kits and take measurements for temperature, humidity, light, sound, carbon monoxide, and nitrogen dioxide, also teaching them how to upload the measured values.

Social Urban Data Lab is a state-of-the-art project built by developers using acquisition, enrichment, integration, analysis and visualisation of big urban data [53]. Social Glass is one of the project's outcomes that utilizes real-time data analytics and forecasting to create a "reflection of the human landscape". The use of machine learning on models created by the combination of word meaning analysis and relationships leads to determining the condition, mood, desires and emotion of the public. The successful depiction of the city's mood is the result of cross-referencing the results from the analysis with geolocation and other municipal open data and the establishment of patterns. Social data from local events or daily incidents like traffic jams are examples that trigger Social Glass and create alerts by people responses for other people to use.

Those examples prove the claim that circular economy is not another approach in effective recycling [53]. CE extends in a variety of social instances and aims to improving humanity's well-being in area that are of equal importance to waste management. As seen in the Amsterdam smart city platform [54] the majority of the projects are in the implementation phase, testing applications and improving their operation in real-life(time) scenarios.

2.1.2 Berlin

Table 4: Berlin – Key data

Population [55]: 3,556,792	Area: 891.1 km2
CE Achievements [56]	• The Berlin Public Procurement Act • Decree on the application of regulations for environmentally-friendly purchases and order placements for deliveries, construction work and services • Living labs

- Smart city investment commencing year: 2015
- CO2 Emissions/head (tonnes):4.9 [57]
- Waste Recycled [58]: 44.2%
- Consumed Renewable Energy [59]:22%

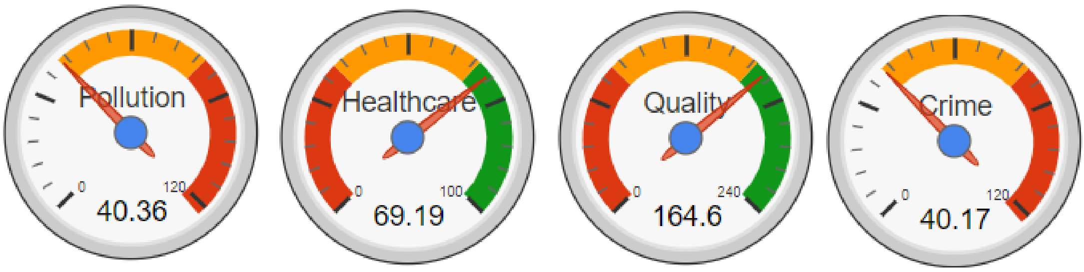


Figure 9: Berlin – Pollution, Healthcare, Quality of Life and Crime indexes [60]

- 14.765 surveillance cameras [61]
- Key Challenges: Increase cooperation among stakeholders, social integration of Berlin's new residents, increase productivity, Industry 4.0, security.

Figure 10 Cities in motion index rank: 9

Accommodation: AirBnb listings: 22,552[62]

Availability: 26.4% Estimated occupancy: 28%

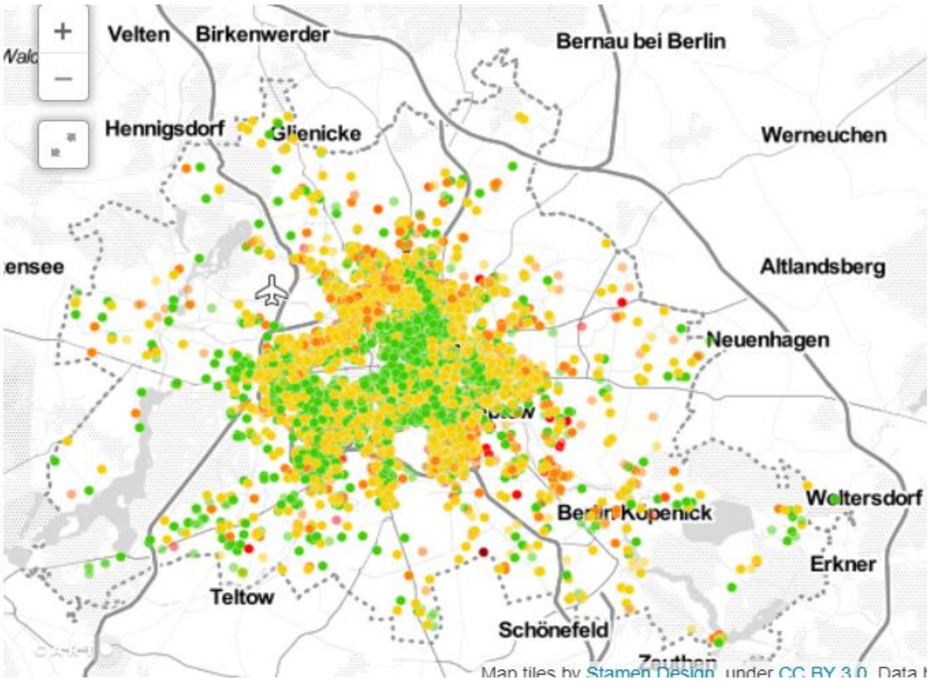


Figure 11: Tourist's feelings[63]

Transportation: Cost of one-way ticket: 2.80 Euros [64]

Total percentage of citizens walking, cycling or taking public transport to work: 54.8%[65]

Berlin started the process of transforming into a smart city as soon as its officials realised the drastic changes that will reshape the city's life. By 2030 the population of the city will have been increased by 250.000 new residents [66]; a thing that will require important reconsiderations in everyday matters like traffic management, resources management etc.

The number of challenges that arise with this fact cover a wide area: the growing city, the aging city or the city in the midst of structural change, all require inter-disciplinary and inter-departmental approaches, if solutions are to be found. The Smart City approach aims to find solutions to the ecological, social, economic and cultural challenges faced by Berlin through the use of intelligent technologies [67]. Without changing its face and identity, Berlin needs to create the essential conditions that will aid in achieving the goals set by its smart city initiative. Despite the fact that the first initiatives began at earlier dates, in April 2015, the Berlin Senate decided on the Smart City Berlin Strategy. Among its objectives, the strategy included the expansion of the international competitiveness of the Berlin-Brandenburg metropolitan region, the increase of the resource efficiency and climate neutrality of Berlin by 2050, and the creation a pilot market for innovative applications [68].

Berlin.de, the city's official portal, breaks down the city's smart city goals, with further analysis, into to the following [69];

- A reduction in the use of finite resources; the establishment of the use of renewable energies; an increase in resource efficiency and the climate neutrality of Berlin by the year 2050

- A minimisation of the negative side-effects of living in a densely populated urban environment, such as environmental pollution, stress-related illnesses or a diminished feeling of personal safety
- The further development of the international competitiveness of the capital city region of Berlin-Brandenburg; an increase in economic strength and the creation of jobs
- The creation of a lead market for innovative applications
- Further networking on a regional, national and international level
- A strengthening of the resilience of urban infrastructures
- The long-term securing and optimising of public services through public administration, municipal enterprises and social bodies
- The strengthening of a transparent decision-making culture in public administration
- An increase in the quality of life and location
- An increase in opportunities for greater social participation [70]

The list of goals could be considered long, but Berlin takes assistance from its years of experience and competence in urban transformation gained from the eras after 1945 and 1990 and the rich ecosystem created by more than 100 co-working places, innovation labs and accelerators, the 500 new start-ups that are funded each year, the manpower provided by more than 30.000 graduates each year and powerful partners like Cisco, Siemens, Bosch, Daimler, BMW etc. [71].

Berlin started the process of becoming a smart city with the use of its developed ICT network; mobile Internet, LTE, RFID, NFC, WLAN and a wide range of communication hardware, actuators and sensors. A high-performance wireless and wired broadband infrastructure with comprehensive coverage for every cluster of the city, is the backbone for the future smart city of Berlin [72]. The city officials were engaged in dialogue with political stakeholders in city, state and European level to secure the necessary conditions for seamless development. After establishing connection with the appropriate political factors, the city officials initialised an effective promotional campaign that reached a number of private partners of significant importance that is highlighted by the names mentioned above.

At this stage, the smart city projects in the city of Berlin extend from projects originating from the usual smart city areas of research (e.g. traffic management, smart housing, smart grid) to areas that cover issues of governance and citizen's protection along with industrial concepts. The Open-Data-platform has been online since 2013 and offers transparency in public administration and the production of smart city apps [73]. Berlin targets the implementation of Industry 4.0 innovations that will utilise new materials and will boost the industrial production [74]. The city officials have recognised that the effort for creating a city based on smart concepts requires a dedicated approach in cybersecurity; on 17th December 2014 the federal government passed the bill for increased security for IT system called "Erhöhung der Sicherheit informationstechnischer Systeme" [75]. According to the bill, the affected organisations are obligated to inform the authorities for any cyber-attacks.

The continuing progress and the development of the strategic plan is highlighted by collaboration between Berlin and Cisco; the two sides partnered in a deal that will allow

Cisco to invest $500 million in the city's projects [76]. According to the press release of the collaboration [77], the fields of interest and investment will cover areas like telemedicine, security operation centres (SOCs) and Intelligent networking infrastructure. The platform designed, openBerlin [78], will improve the city's security and decrease the response times in cases of emergency and act as the bridge between partners with different background.

With the aforementioned background, Berlin has all the required prerequisites that will allow the city to adjust to the future of smart cities and improve further. One of its major targets is to be completely aligned with all the obligations that come along with the Paris agreement; with the Berlin Energy and Protection Programme [79], the target is to create a CO_2 free urban environment. In order to optimize the current plans, the authorities plan to increase collaboration between all the stakeholders from every involved sector. Increasing the involvement of citizens in the projects is also another objective for the city, creating an ongoing dialogue that will help the current projects to reach their full potential, with the use of platforms like mein.berlin.de [80].

The future plans for the next steps in the smart city project are interconnected with the circular economy projects in Berlin. The utilisation of such projects will provide with a significant effort to transform the city from a consuming city with no production units to an organisation that will encourage production across areas such construction, food and agriculture, textile, materials, and recycling [81]. Social integration is another vital part of enabling circularity. The future incoming residents should become an integral, accepted part of the Berliner society and a number of actions and project aim to that purpose. "Skilful and intelligent urban management and the inclusion of stakeholder groups can ensure the social participation of everyone. Berlin is a melting pot of the most diverse range of cultures, religions, ethnic groups and age groups. The city fosters and preserves the potential which lies in this diversity, and is constantly evolving. Innovative services will be beneficial and accessible barrier-free to all people, irrespective of their level of education, income or age" [82]. Platforms like [83] and [84] promote citizens' contribution and awareness in projects regarding food production, textile industry, energy, construction etc.

2.1.3 Copenhagen

Table 5: Copenhagen – Key data

Population [85]: 1,333,888	**Area: 178.46 km²**
CE Achievements [86]:	• New technological solutions for waste management • Promotion of dialogue and action to recycle • Embrace circular principles • New jobs and materials for industry

- Smart city investment commencing year: 2012
- CO2 Emissions (metric tonnes) [87] : 1,450,358
- Waste Recycled [88]: 45%
- Consumed Renewable Energy [89]: 43% from wind power

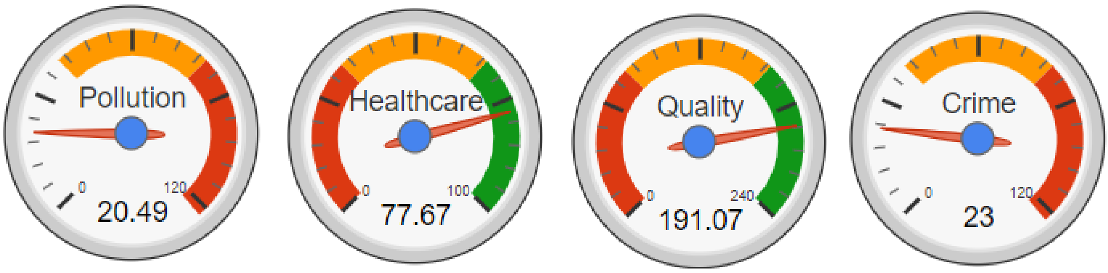


Figure 12: Copenhagen – Pollution, Healthcare, Quality of Life and Crime indexes [90]

- 433 CCTV camera systems with various numbers of cameras [91]
- Key Challenges: Health, Green growth, Traffic Management, Cooperation between stakeholders

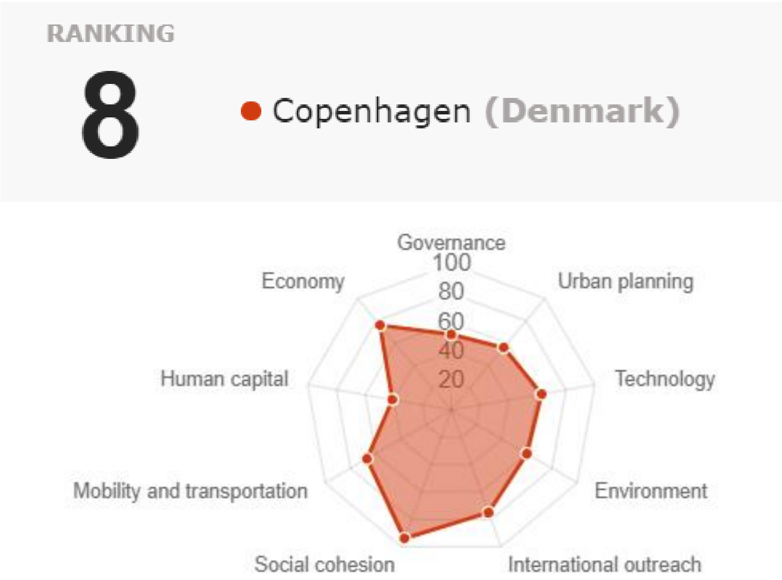


Figure 13 Cities in motion index rank: 8

Accommodation: AirBnb listings: 26,016 [92]

Availability: 23.4% Estimated occupancy: 14.1%

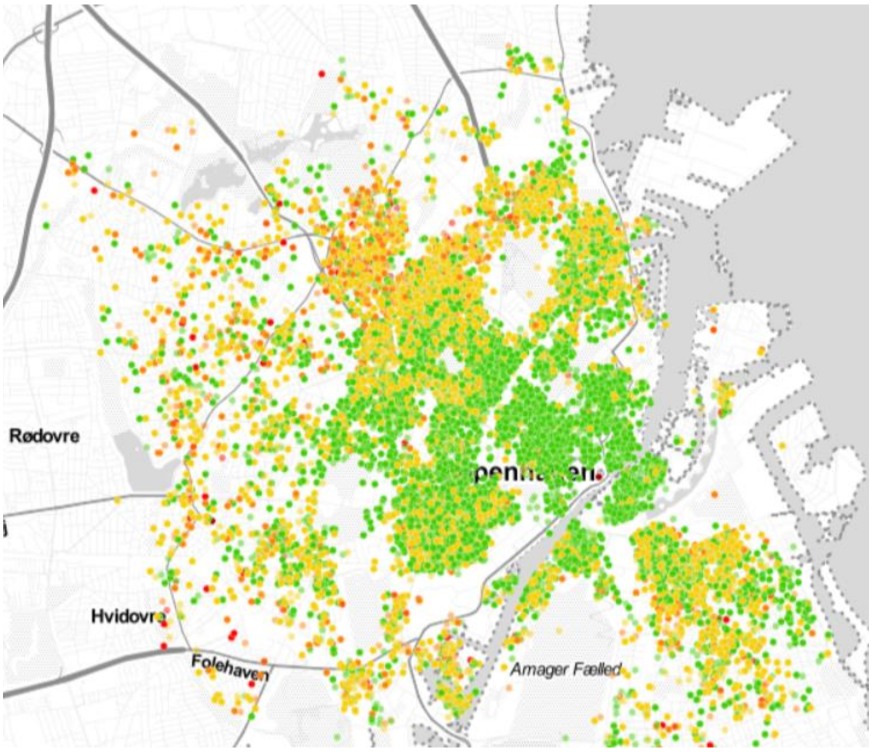


Figure 14 Tourist's feelings [93]

Transportation: Cost of one way ticket: 24.00 kr (2.27 Euros) [94]

Total percentage of citizens walking, cycling or taking public transport to work: 68%

Copenhagen is one of the leaders in the race towards the full adaptation of the smart cities' paradigm in Europe. The capital of Denmark has managed to receive a series of awards [95] and acknowledgement due to its committed efforts and multifaceted approach on creating an ideal smart city that would be in position to set the example for other initiatives not only across Europe but also across the world. The first steps towards transforming into a smart city date back to 2012 [96]; since that day Copenhagen has managed to get closer to its main goal; becoming the first carbon neutral city until 2025 [97]. For the achievement of this target, Copenhagen is changing its management of energy production and use, the traffic systems and its emergency incident responses [98] in order to optimize the output of the city's productive force and manage its waste.

Initially, Copenhagen was an typical European industrial city [99]; the decision of becoming smart was based on the goals for an increased quality of life and growth in a greener city [100] that focuses also on health, smart citizens and smart learning which requires increased use of data driven technologies and the active involvement of citizens. This dedicated effort, not only in Copenhagen but also in other Danish cities, distinguishes Denmark as one of the leading European nations in smart city initiatives [101]. At this moment, Copenhagen possesses a core of enabled services that can be taxonomized in the bellow sections [102]:

- Big Data city flow
- Asset tracking
- Sensor Platform

- Cost efficient data connection

This core of services has led to a number of highlights, according to Copenhagen connecting [99]:

- 11-32% optimized traffic flow
- 2,4 million car hours saved
- 30,7 million driven kilometers saved 1.7 million L fuel reduction
- 5.5 million m3 water consumption reduction
- 180.000 ton CO2 emission reduction
- 50% reduction in bike thefts
- An increase in tourism by 1%
- Job creation €104 million

The swift accomplishment of milestones can be credited to the ICT infrastructure of the city along with the fact that Copenhagen realised immediately that the operation of living labs and the adoption of open data policies would be able to accelerate the progress of the projects involved in building an exemplary smart city [103]. Those corroborations assisted in overcoming a number of challenges like the need to attract talent and investments in the area in order to make Copenhagen attractive for stakeholders [104] and build the four main focus areas for development;

- Health and welfare technology growth
- Green growth
- Creative growth
- Smart growth

With the aforementioned areas of focus and the targets for carbon neutrality, zero waste disposal and smart governance, Copenhagen has allocated resources to creating and applying circular economy models. Copenhagen plans to become resource efficient and the Regional Growth and Development Strategy of the Capital Region of Denmark has set a goal of being resource efficient, with at least 80% of its waste being recycled by 2035 [105]. Copenhagen has decided to tackle with the issues of consumption, production capacity, reduced cost and waste management by relinquishing the traditional methods of production and process and becoming smarter with the acclamation of Big Data, Internet of Things, digital sharing economy platforms, BlockChain and robots in aspects of production and the city’s daily life [106].

The government and city officials have acknowledged the challenges and the difficulties of establishing a circular economy model. One of the major issues, access in relevant data is something that entails risk and cost for businesses. Therefore, the officials are planning to support analysis of public and private data for business development. The circular economy agenda is also being continuously promoted with the use of platforms like Gate21 [107] that offers information about the city’s living labs. The agenda is also embedded in the curricula of primary and secondary schools as well as in refresher and vocational training [108] to emphasise the importance of circular economy for the future of urban areas and establish it as a significant part of the citizens’ lives.

Citizen involvement is a big wager for every city that aims to become smarter. The future steps for Copenhagen require even more increased citizens’ involvement in the city’s governance. The collective knowledge of the crowd is a key element for the development of Copenhagen and any other city. Governance solutions must become less 'top-down' and more horizontal to induce collaboration and networking between stakeholders and produce feedback and data [109].

Giv et praj [110] is an example of a feedback app that allows citizens to report graffiti, damaged roads or signs, or full litter bins to the authorities in order to take efficient and instant action to remediate the inconveniences caused by those situations. The app also offers information to user that reported any issues regarding the necessary repairs and response time.

Citizens, private, public sector need to be also able to cooperate effectively and harmoniously. The previously mentioned Copenhagen Connecting is a project from the Copenhagen Solutions Lab, which is built for project collaboration. It offers an open access platform for data-collection and aggregation [111]. Copenhagen Connecting will collect anonymised real-time data from Wi-Fi access points from a variety of Wi-Fi-using devices to monitor the vehicular and pedestrian traffic in the city. The collection of data will be used to optimize traffic flow and limit congestion, minimizing the CO2 emissions [112].

2.1.4 Barcelona

Table 6: Barcelona – Key data

Population [113]: 5,541,127	Area: 101.9 km^2
CE Achievements[114]:	• 10 years of experience in Living Labs • Participation in 9 CE FP7/H2020 projects

- Smart city investment commencing year: 2011
- CO2 Emissions/head (tonnes) [115]: 2.07 (in 2017)
- Waste Recycled [116]: 36%
- Consumed renewable Energy [117]: 2%

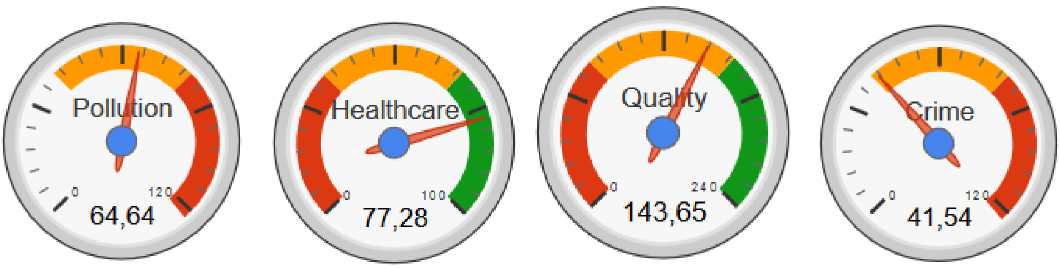


Figure 15: Barcelona – Pollution, Healthcare, Quality of Life and Crime indexes [118]

A network of web-cameras provides information about the state of the beaches, the mountains, the traffic, the weather, and some of the city's monuments [119]. Moreover, 2.700 IP cameras has been installed across the TMB's (Transports Metropolitans of Barcelona) metro and bus lines network [120], and another 70 in train station platforms [121]

- Key challenges: Urban growth and migration, urban environment improvement, healthcare, elder care, and education.

Figure 16 Cities in motion index rank: 28

Accommodation: AirBnb listings: 18,302 (http://insideairbnb.com/barcelona/)

Availability: 67.1% Estimated occupancy: 27.8%

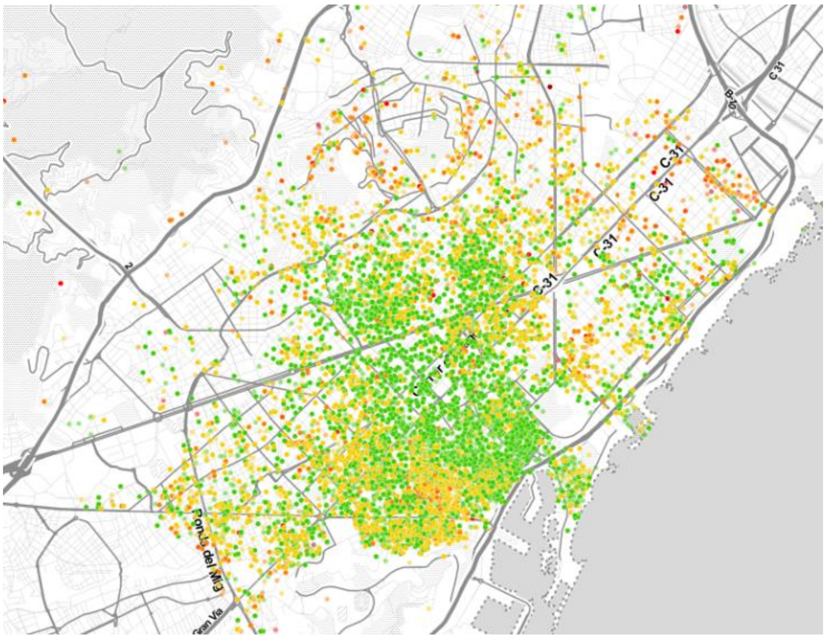


Figure 17Tourists' feelings [122]

- Transportation: Cost of one way ticket: 2.15 Euros [123]
- Total percentage of citizens walking, cycling or taking public transport to work: 71% [124]

2014 was the year when the European Commission officially recognized Barcelona as a Smart City. The city took the first place in the European Capital of Innovation (iCapital) contest for introducing the project “Barcelona as a people city”. However, we could say that the story of Barcelona becoming a Smart City starts back in the 1990s when the city authorities in collaboration with other organizations were planning and investing on an ambitious plan of the city’s transformation. The integration of Information and

Communication Technologies (ICT) like optic fibre networks, sensor networks, and Wi-Fi mesh networks was the key element to develop a sustainable and green city that promotes innovation, access to information, and collaboration among citizens, public administration and academic institutions in order to improve the efficiency of public services and life quality. In 2000 the project 22@Barcelona emerged; the project was designed to target in long-term the urban, economic, and social innovation of an industrial area called Poblenou. With various initiatives in this area, the 22@ project became a hub of cutting-edge tech companies, start-ups, universities, research and training centres which contributed in the Smart City model development.

In 2011 the mayor of Barcelona, Xavier Trias, was elected and just a year later he formed a team known as **Smart City Barcelona** to lead of the Barcelona Smart City program; that was the moment the initial development began. The team identified 12 use cases for intervention: environment, ICT, water, energy, matter, mobility, nature, built domain (public and private), economy and Laws, information flow, open government, and public and social services. Based on these areas, 22 programs initiated encompassing 200 projects [124][125].

1	Telecommunications networks	12	Citizenship
2	Urban Platform	13	Open Government
3	Smart Data	14	Barcelona in the pocket
4	Smart Light	15	Smart Garbage Collection
5	Energy self-sufficiency	16	Smart Regulation
6	Smart Water	17	Smart Innovation
7	Smart Mobility	18	Health and Social Services
8	Renaturation	19	Education
9	Urban Transformation	20	Smart Tourist Destination
10	Smart Furnishings	21	Infrastructure and Logistics
11	Urban Resilience	22	Leisure and Culture

Figure 18: The 22 programs[126]

The objective of this end-to-end strategy was to impact almost every urban service. To accomplish that, all key stakeholders from the public and private sectors, as well as the academia, had to harmonically cooperate. The massive scale of the city's technological infrastructure served as a backbone for integrated IoT systems. Different types of sensors deployed across the city provided real-time information about traffic, parking availability, water and energy consumption, waste disposal, noise, and air pollution [127].

Barcelona initially approached the Smart City concept with top-down initiatives, which partially failed to involve citizens in the innovative processes. However, in 2015 the new Chief Technology and Digital Innovation Officer of Barcelona evaluated the achievements of the previous strategy and set new goals [128]. The main objective of the new strategy was the creation of a data-centric digital economy with direct involvement and collaboration with citizens in data collection and management, as well as decision-making on local issues. Moreover, but equally important in that strategy, was the protection of the citizen's data and the concession of digital sovereignty to them [129].

Until 2014 Barcelona, along with other Spanish cities, faced serious Air Pollution problems by failing to meet the EU air quality standards since their enforcement began in 2010. In order to overcome these issues, and as part of an ongoing effort of the government, on the 27th of September 2014 the "Air quality action plan" (AQAP) with Horizon 2020 was approved [130]. The Plan targeted the promotion of public transportation, electric vehicles, active mobility, and citizen awareness among others. The successful results can be seen from the publicly available real-time measurements that GAIA air quality monitoring stations provide [131]. Moreover, it is important to mention that citizens are an integral part of this process, since they can contribute with valuable data (air composition, temperature, light intensity, sound levels, and humidity) by using the **Smart Citizen Kit** [132]; a successful project introduced in 2013 and currently deployed in the cities of Barcelona, Amsterdam and Manchester. Another project, "Barcelona's Superblocks" [133] which is directly related to the mobility sector, is designed to be highly influential regarding the reduction of CO2 emissions by 2030. The city's commitment to climate change can further be seen through the "Climate Plan" [134], according to which, Barcelona will be a carbon-neutral city by 2050.

The partnership between citizens along with the public and private sectors provide companies with a great opportunity of having direct access to real-life testbeds for their services and products, while simultaneously supporting innovation across the city's premises. The physical spaces where these experiments take place are known as Living Labs (LL) and according to the European Commission: "Cities as Living Labs, increasing the impact of investment in the circular economy for sustainable cities" [135]. Barcelona is to be considered a pioneer across the European Network of Living Labs (ENoLL), having 10 years of experience in Living Labs maturity and coverage, and participation to EU FP7/H2020 projects that focus on circular economy at the city level. Library Living Lab, iCAT Digital Living Lab, and Barcelona Laboratori are some examples followed by the most recently announced (9 January 2018) 5G Open Lab [136] which classify the Catalonia in the first place of the global 5G ecosystem.

The philosophy behind Open Data projects is to create and/or increase databases with new data sets collected, not just by businesses and public administrations, but also by the assistance of citizens. Sentilo, CityOS, DECODE, and Decidim are examples of open-source platforms for data collection, data analysis and easy access to the data from everyone, as data availability is important for creating solutions. The capital of

Catalonia, in the context of the Smart City concept, is focusing on the government's transparency, while investing on the interconnection of citizens, businesses, universities and administration.

2.1.5 Paris

Table 7: Paris – Key data

Population [137]: 2,206,488	Area: 105.4 km2
CE Achievements[138]:	• General assembly on the circular economy • Mobilisation of the city's actors; public, private, institutional and academic sector • Production of academic work on circular economy to act as guidelines for other cities

- Smart city investment commencing year: 2013
- CO2 Emissions (metric tonnes) [139] : 5,195,663
- Waste Recycled: 82.7% [140]
- Consumed Renewable Energy: 2.3% [141]

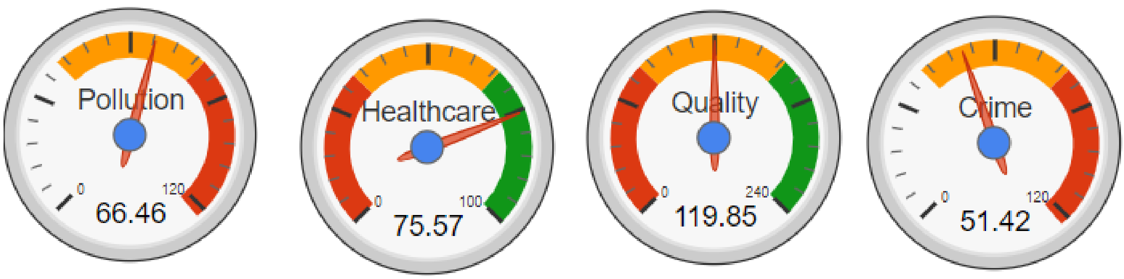


Figure 19: Paris – Pollution, Healthcare, Quality of Life and Crime indexes [142]

1 camera for every 3,600 citizens [143]

Figure 20 Cities in motion index rank: 4

Accommodation: AirBnb listings: 59,881 [144]

Availability: 28.2% Estimated occupancy: 25.3%

Figure 21 Tuorists' feelings [144]

- Transportation: Cost of one way ticket: 1.90 Euros [146]
- Approximate percentages of citizens walking, cycling or taking public transport to work [147]: 50% walking, 5% cycling, 75% public transportation

Paris started the first initiatives to become a smart city in 2010 [148], when the first innovative projects began. Like any other metropolis, the capital of France, was facing a series of challenges that were compromising the daily life of the residents and the environment of its urban areas. The main challenges [149] that Paris is still trying to overcome are the following;

- reduce inequalities and enhance social cohesion
- reduce air pollution
- the Seine River and related risks: flood, low water and the rarefaction of the resource
- enhance the capacity of the city against terrorist attacks
- improve territorial governance in order to foster resilience
- integrate in all public policies the topic of climate change adaptation and mitigation

Despite those challenges, in a densely populated area with added massive of tourists daily, the city has managed to produce a solid plan. Its dedicated efforts have managed to bring success in the involved project that also led to awards like the Commission award as the most innovative European city in 2017 [150].

For the successful outcome of the city's transformation, Paris is improving supporting infrastructure such as 4G/5G network and 400 free, publicly available Wi-Fi hotspots. The city also wants to invest further on the Internet of Things and the deployment of wireless sensors and actuator networks (WSANs) [151] [152]. One of the first issues that required immediate addressing, was transportation. Paris is redesigning its transportation network in order to become less motorised and to ease its traffic flows. Those outcomes can be accomplished by encouraging the use of public transportation[153] and cleaner modes of transportation (e.g. bicycles, car sharing, carpooling), expanding the bike path network [154] and the charging stations of electric vehicles [155].

The Parisian authorities were of the first to value the significant contribution of the use of open data and the involvement of citizens to the future of the smart cities. Simple collaboration between private and public sector is not enough. Data-driven urbanism and the utilisation of participatory data (from crowdsourcing) support the prioritization of choices and clarify decisions to promote greater flexibility and agile approaches. This approach has enormous potential by meeting the expectations of citizens who want to be more involved in urban programs and by improving the areas where they live [156].

The potential and the promising first results are building a new digital culture for the citizens and have convinced the city staff to adopt new skills and tools for data analysis and participation strategies that would assist them in benefitting from the massive amounts of date that the city produces [157]. Beside the civil sector, the importance of open data is recognised by the industry of tourism which is a vital part of the French capital's economy [158] For that reason, the Welcome City Lab, an incubator for start-ups is working on application for tourism that will work under a smart city frame. Applications like "Sortir Toot Sweet!" can inform the tourist on events and deal close to her/his location, based on customized tastes and wish lists.

The vision of Paris for a smart city does not stop in open data policies and citizen involvement. Since July 2017, the city has adopted a circular economy strategy that will last until 2020 [159] and will build a framework for various projects emerging from the following areas [160]:

- Development and construction
- Reuse and repair
- Support for local actors
- New consumption patterns
- Public procurement

The plans for circular economy are not related only with waste or energy management, pollution and traffic issues [161], they involve projects that reduce the social, financial inequalities and offer a new vision for governance and transparency that will build a strong relationship between the city's officials and the citizens. For the successful accomplishment of the aforementioned objectives the city has focused its efforts around the following pillar strategies [162]:

- Strategy I: Encourage and support economic players
- Strategy II: Innovate and experiment
- Strategy III: Scale up and establish momentum in the region
- Strategy IV: Change attitudes and practices
- Strategy V: Involve local authorities, businesses and citizens
- Strategy VI: Create a network linking players
- Strategy VII: Change legislation

A characteristic example of ambitious projects that embrace the values of circular economy is the construction projects designed by the architect Vincent Callebaut and his team. The plan involves the building of towers equipped with all the necessary accoutrements that will be able to provide eco-friendly solutions for water, power and food production independence [163]. The communal areas of the projects will allow the interaction between their residents, through various actions that increase their social cohesion, quality of life and health standards without affecting the city's identity [164].

For the further progression of the efforts in the smart city front, the municipality encourages the social innovation and collaboration between stakeholders by developing innovation labs like the Paris Region Lab [165]. The mission of the lab is to act as mediator between community services and innovators by offering the required means for tests and surveys in real life situations and its experience that both from the city staff's and the private sector's point of view. The innovation labs are enriched by the support of the research brought by universities; the development of co-working places and processes between students and start-ups will implement a Circular Incubator, that will incorporate universities in the stakeholders of the construction of a new, smart Paris.

2.1.6 Brussels

Table 8: Brussels – Key data

Population [166]: 1,191,604	Area: 161.38 km2
CE Achievements [167]:	• Identification of flaws and challenges • Link between private and public sector • Online platforms for the stakeholders • Multilevel support for businesses

- Smart city investment commencing year: 2013
- CO_2 Emissions (tonnes per head) [168]: 3.91
- Waste Recycled [169]: 42.8%
- Consumed Renewable Energy [170]: 4.8%

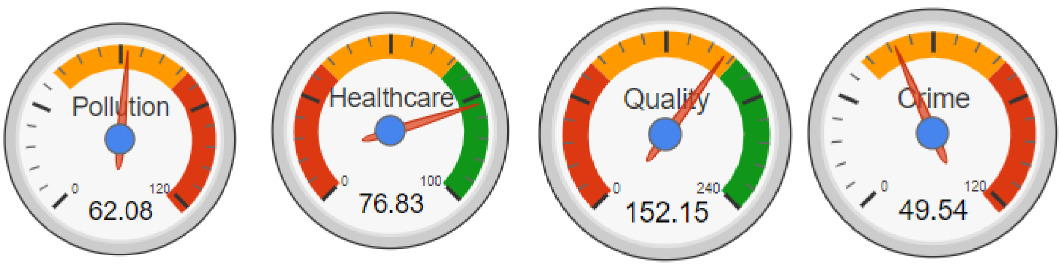


Figure 22: Brussels – Pollution, Healthcare, Quality of Life and Crime indexes [171]

- 55,000 surveillance registered cameras [172]

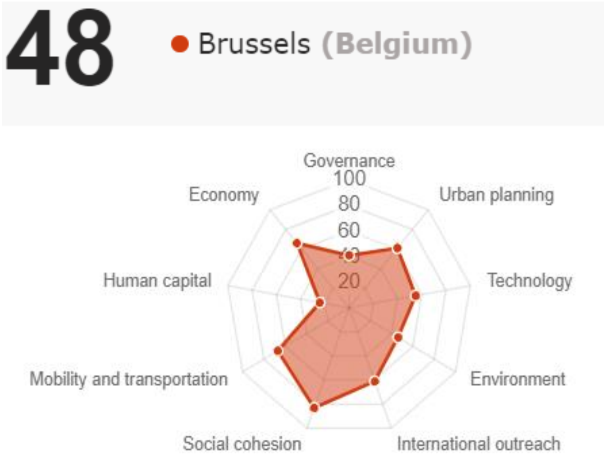


Figure 23 Cities in motion index rank:48

Accommodation: AirBnb listings: 7,420 (http://insideairbnb.com/brussels/)

Availability: 44.5% Estimated occupancy: 26.5%

Figure 24Tourists' feelings [173]

Transportation: Cost of one way ticket: 2.10 Euros [174]

Total percentage of citizens walking, cycling or taking public transport to work [175]: 45% public transport, 4% walking, 2% bicycle

Brussels, being the capital of Belgium and also the capital city of the EU, would not be left outside the European race for the formation of a smart city. The city has hosted a number of events regarding the creation and the operation of smart cities [176] and also operates its own initiatives in order to transform its current status to a new, resilient and self-sustainable environment.

In 2013, the city officials set the foundation for a five year strategic plan (2014-2019) [177] that will be able to build a new, smart Brussels and focus on seven key areas:

- Integration of data and services
- Development of a generic model for speciality applications
- Establishment of a shared CCTV platform
- Develop the Regional Data Centre
- Sixth State reform at IT level
- Development of a regional digital map
- Development of IRISnet, the lightning-fast telecom network

Development around those areas is facing a number of challenges that need to be treated and overcome. During that effort, BRIC [178] identified the following challenges [179] and implemented a number of applications, services and projects to address them:

- A region connected to efficient telecommunications networks
- A sustainable region with reduced footprint
- An open region with new services and publicly available data
- A safe region with an effective, diverse security system

The platform brussels.be highlights nine projects for the future of Brussels [180] as a smart city. It can be seen that the city invests particularly in the area of governance and open data by promoting participation in projects and offering the necessary provisions in terms of data access and ICT infrastructure. Another area is the citizens' daily life that is being enhanced through projects that involve municipal administration, waste and resource management, revamping of urban areas to address traffic and allow extra spaces for various events and actions.

Like in many other examples, the city officials are trying to increase the participation of citizens in those projects, along with improving cooperation between the various stakeholders. Innovation centres and platforms like Uraia [181] focus on building the relationships between academia, the public sector and private investors in order to offer resilient solutions for the projects and training for high value technology posts.

The result of these processes is the establishment of the conditions that allow and intrigue the participation of citizens and social groups in the aforementioned projects. Their involvement and the massive data produced are essential to the concept of smart cities. The profit for the city's residents is the improvement of their daily lives in public sectors like health, education and safety or the mitigation of social gaps or equalities. The smart city project and its social contribution is a strong marketing tool for the capital of Belgium, especially after the attacks the city has suffered and helps in the restoration of the people's lost sense of security and confidence [182].

A characteristic example of that process is the mobile application called "CitizenMap" [183]. After the 2016 attacks, Molenbeek, a start-up incubator under the Brussels smart city program, organised a hackathon dedicated to first aid and emergency services. The stakeholders of the drafting were a number of IT developers, the local red cross and the fire and emergency services. The collaboration led to the development of the application and was based on open data about the location of defibrillators in the city.

The tests have been executed as part of living experiments; proving that the values of collaboration and crowdsourcing as parts of the daily life in smart cities.

Brussels has all the prerequisites for the next step towards the cities of the future; incorporation of the smart economy concept. From March 2016 [184] the Brussels Regional Program for a Circular Economy has been adopted by the local authorities. The use of the program focuses on three key points that affect the city of Brussels:

- Transformation of environmental objectives into economic opportunities.
- Relocation of the economy to Brussels in order to increase the local economic indicators for the inhabitants.
- Creation of employment.

The circular economy is widely embraced by the local authorities; 3 regional ministries, 15 public administrations, regional advisory committees and almost 60 stakeholders between NGO's and private businesses [185] build projects divided into 4 strategic areas:

- cross-functional measures (a regulatory framework that aids the setup and operation of enterprises)
- sector-based measures (construction, resources & waste, trade, logistics, food);
- territorial measures
- governance measures (cooperation between administrations).

Be Circular - Be Brussels is one of the key measures of the Brussels Regional Programme for a Circular Economy (BRPCE) that seeks to guide and accelerate Brussels' transition to a circular economy model [186]. It operates as a service for the enhancement of cooperation between stakeholders and as a service for private initiatives that seek expertise or funding, giving them the opportunity to make use of all the advantages that the BRPCE has to offer.

One of the strong assets for the success of the program is the Belgian policies on the acceptance and use of open data. In state level, Belgium is one of the highest ranking countries regarding the openness of data [187], an attribute that has been extended to the capital's policies and operations. Brussels offers a variety of platforms that offer datasets in order to simplify access to data. DataStore.brussels is one of those platforms and aims to become an aggregator of information and data produced by the local public organisations and their partners [188] after the integration of other existing platforms.

The value of open data is highlighted by applications like mobility [189] [188] as well. Mobility is an open data platform that offers services for the effective transportation through the city. Real time data manage traffic for people travelling to or from work and school. The platform offers the ability for reporting incidents to assist those who plan trips or to inform authorities in order to handle them accordingly.

Brussels is a city that perceives the value of the smart city potential, not only for the promise of addressing the usual issues that burden a modern city (e.g. pollution, energy, traffic, health). The city is dedicating resources in order to offer its residents the chance for better employment conditions and social cohesion, proving, again, that each city has its own reasons that lead to the adoption of smart city solutions.

2.1.7 London

Table 9: London – Key data

Population [190]: 9,176,530	Area: 1,572 km2
CE Achievements [191]:	• Circular economy route map (Environment, Food, Textiles, • Electricals, and Plastic) • Increased SME profitability • Better Waste management • Reduced CO2 emissions • New jobs, services, and products

- Smart city investment commencing year: 2013
- CO2 Emissions/head (tons) [192]: 4.66 (in 2017)
- Waste Recycled [193]: 33,1% (in the period 2017/2018)
- Consumed renewable Energy [194]: 0,05% (in 2016)

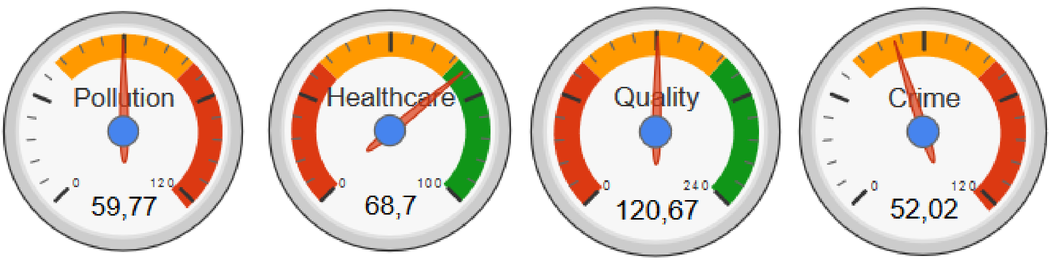


Figure 25: London – Pollution, Healthcare, Quality of Life and Crime indexes [195]

- 627,707 cctv cameras around the city, 1 camera for approximately every 14 people [196] .
- Key challenges: The size and diversity of the city

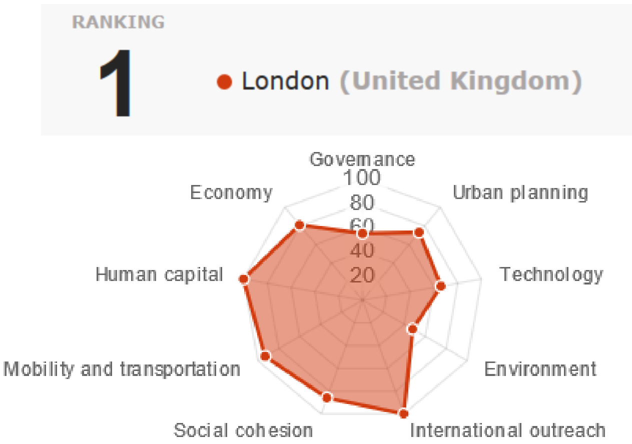


Figure 26 Cities in motion index rank: 1

Accommodation: AirBnb listings: 77,096 (http://insideairbnb.com/london/)

Availability: 41.8% Estimated occupancy: 23.6%

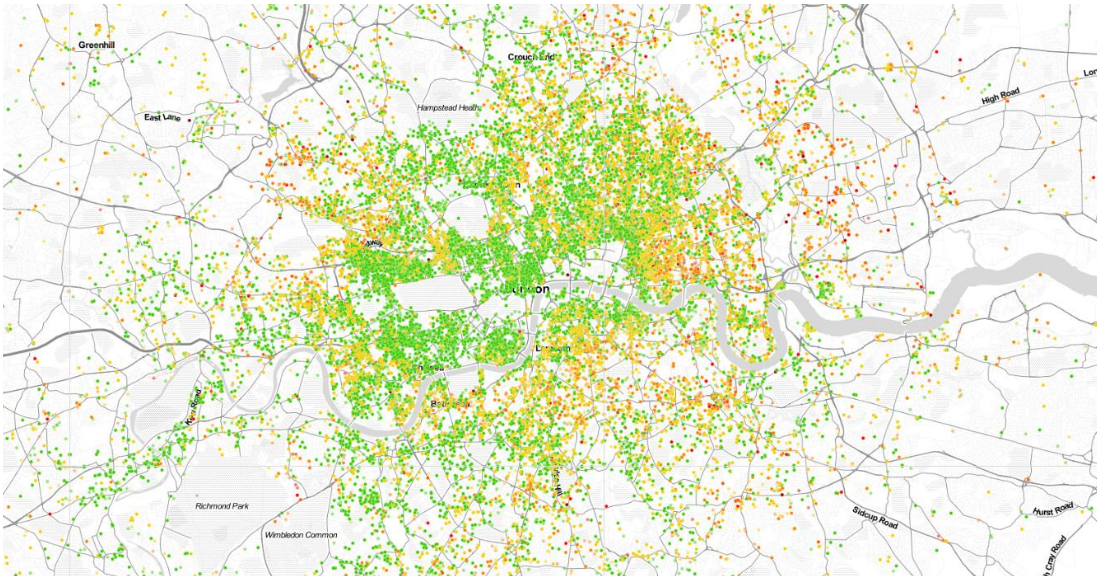


Figure 27 Tourist’s feelings [197]

Transportation: Cost of one way ticket: 2.50 GBP (2.00 Euros) [198]

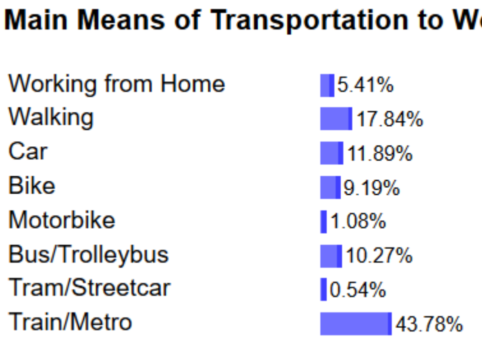


Figure 28 Means of Transportation [199]

The city of London has a very interesting historic background regarding the first step towards the city’s “smart” part. Back in 1854, the physician John Snow collected data in person and used them in order to prove his theory on what was killing the Londoners at that period [200]. With this ground-breaking approach for the time, Snow managed to solve a problem that killed hundreds of people. So, even while technology is not a part of this story, it is still made clear that the people and the data related to them belong to the core of what makes a city “smart” and not technology by itself. Nevertheless, at the time speaking, the era of Internet of Things (IoT) is on the rise and along with that, various other technological systems are now available to play a supportive role in the smart cities’ innovations.

Willing to improve citizens’ lives, the public administration of London had to make a drastic choice. Under the Greater London Authority (GLA), in 2004, the first **London Plan** [201] was published. It is about a strategic plan focusing on the economy, the environment, transportation, and social aspects in order to create an integrated framework for the overall development of London. Since then, the plan is continuously being monitored and updated, as it is also used as a guideline for every smart technology that is now being incorporated into the city’s new developments. In December 2013 the **Smart London Plan** [202] was formed by the municipal authorities who wanted to ensure, through the best use of experts (academia, business, and public administration) and technology, that London will remain one of the most competitive and sustainable cities in the world.

The 2013 Plan delineated seven different ways in which the inventive power of information and technology could be utilized to serve the city and improve Londoners' lives.

The seven key themes:

- Londoners at the core
- Open data access
- Leveraging London's research, technology, and creative talent
- Brought together through networks
- Enable London, adapt and grow
- City Hall to better serve Londoners' needs
- Offering a "smarter" London experience for all

Engaging Londoners, enabling good growth, and working with businesses were the three overarching workstreams to deliver Smart London.

The plan was updated in 2016 [203] and 2 years later, the new vision of a smarter and better-connected city was presented through the new roadmap **Smart London Together** [204]; one of the seven outstanding proposals of the "WORLD SMART CITY AWARDS 2018". The endgame was to establish London as the Smartest city in the world and the **Cities in Motion 2019** [205]is one of the proofs that the goal was met. A decisive role in this achievement was played by the formation of the following 5 missions.

- More user-designed services
- Strike a new deal for city data
- World-class connectivity and smart streets
- Enhance digital leadership and skills
- Improve city-wide collaboration

However, there are still challenges that accompany such ambitious goals and those are the following:

- Put people first and respect diversity through the process of designing digital services or adopt technology.
- Lead in data innovation while also building trust and transparency in how public data is used.
- Become better connected and open to new technologies in the built environment.
- Strengthen digital leadership in public services and enhance the digital skills and understanding of citizens.
- Make city-wide collaboration and tech partnerships better, in order to design and share what works for citizens across public and community services.

In order to overcome the aforementioned challenges London invests in disruptive technologies and innovations [206] like Artificial Intelligence (AI) / Machine Learning, Automation, Virtual / Augmented reality, Internet of Things, Data Analytics / Smart Technologies, 3D printing, and Distributed Ledger Technology / Blockchain.

Willing to improve transparency and accountability in government through constant public engagement and city-wide collaboration, London created the **London Datastore** [207] in 2010; a free open-data sharing portal that is now hosting more than 700 datasets that can be accessed from citizens, the government, academia, companies and tech developers. From that point forward London is considered as a good example for a lot of urban communities around the world. Examples of the available information and statistics include population estimates, house prices, number of international visitors, and crime rates among many others. After datastore was propelled, about 450 mobile applications were created. Furthermore, the data help the strategy makers in dissecting the best potential outcomes of development in various areas. The **London schools Atlas** [208] is another success story which can help the parents and experts engaged with procedure of school arrangements and so forth. Moreover, since 2016, the focus is on a wider set of city-data (Private data, commercial data, crowd-sourced data, and sensory data) as it can be used for better data-driven innovations and public services [209]. Transport for London (TFL) and its Unified API also makes a great use of open data providing feeds from Tube and Bus station locations and routes to London's air quality and atmospheric emissions [210]. By looking into the future, London uses the new **City Data Analytics Programme** [211] as a structure in order to develop a web of linked data stakeholders like the 33 London boroughs, academic institutions, the government, fire services, businesses, and TFL with common purpose and standards.

Circular economy is another area where London has set high goals. The city started to explore how it could become the capital of circular economy since 2015 [212]. In contrast to Paris and Brussels, London approached the definition of circular economy from an economic perspective predicting a net benefit of £7bn every year and 12000 new jobs in relative areas by 2036. However, the transition to a CE could also be environmentally beneficial and supportive in order to make London a zero-carbon city by 2050 [213], with energy efficient buildings, clean transport and clean energy.

In 2008 the London Waste and Recycled Board (LWARB) was formed; a governmental entity which co-funded three programmes towards London's CE transformation. Those are, the Circular London [214], the **Resource London** [215], and the **Advanced London** [216]. The objectives of these programmes were the following:

- To enhance the collaboration between public and private sector and international partners.
- To provide with support the city's waste authorities.
- To support SME businesses with advisory services and investment guidance towards to the city's transition to a circular economy, while also contribute to meeting the goal of zero waste to landfill by 2026.

The focus areas for action (built environment, food, textiles, electricals, and plastics) were identified in the context of **London Waste & Recycling Board** [217]. Two years later, **London's circular economy Route Map** [218] was published; an action-oriented document developed upon the previous one in collaboration with relevant stakeholders. The route map outlines 50 actions in total in order to provide the city with sustainable and profitable solutions to the challenges formed by its growth.

What is equally important, according to the route map, is that the local authorities should play a key role through the hole process by helping to raise awareness. A good example is when nine of the London's boroughs joined a food waste campaign [219] to promote healthy eating, prevention of food waste, and recycling of unavoidable food waste. Barcelona, Brussels, and Milan are three of the seven EU cities that also joined the programme; a fact that highlights the positive impact of the programme across the EU.

To be a worldwide innovator in this segment and benefit from both the economic and environmental advantages of a low carbon circular economy London invests in the contribution and the collaboration of businesses, academia, and citizens.

2.2 Circular Cities Hub

The Circular City hub is an interdisciplinary instituted by the University College London (UCL) in association with the Ellen MacArthur Foundation. The hub's main function is to bridge the gaps between academics, and stakeholders from public and private sector in order to apply the results produced by research on the governing, management, design and development of cities directly and effectively [220]. Its operation is extended to a number of countries; in a workshop held on 22 September 2016 the participants (coming from universities and enterprises across Europe) elaborated on the challenges of enabling circular economy and the city plans of Amsterdam, Bristol, London, Peterborough, Paris and Stockholm[221].

Increased and facilitated collaboration between stakeholders along with assessment of the projects' operation in the cities' daily life are a common challenge for every city that has ongoing smart city initiatives. Innovation hubs like the Inclusive City hub [222] and the online Seoul Sharing Hub [223] produce and share research for smart city solutions among their interconnected partners in their respective locations. The Circular Cities hub objective is to absorb the experience and the information of the involved partners and produce outputs for the advantage of every involved partner.

The hubs develop programs in areas of interest that involve research themes such as the following [224]:

- Urban planning
- Social interaction, inclusion and participation.
- Governance and business models
- Sustainability
- mobility, local pollution and micro climate
- Resource depletion and climate change

The outcome of the research can be used as guidelines not only for the partners of the hub but also every other city that aspires to become smart and resilient by applying scalable initiatives that are able to change the function of sites from a district to international level [225].

3 Indicative smart city projects and use cases

3.1 Transport

Transport is a representative vertical to showcase the need and use of data-driven CE concepts. A smart IoT based infrastructure strategically placed for example in traffic lights or road crossings can detect the presence and intended movement of the visually impaired or otherwise mobility-challenged person will take actions to alert the surrounding traffic, while at the same time notifying the person when it is safe to proceed. An example could be smart traffic lights switching to red to stop the traffic, embedded LED lights in footpaths or zebra crossings flashing when an impaired person is nearby, or smart signposts emitting audio signals informing the person if it safe to cross the road. In a similar fashion, electronic doors can be opened, elevators can be called or ramps can be extended when the impaired person is in close vicinity. Coventry Council has gone one step further by introducing public access areas that are shared by both pedestrians and vehicles. As in this case there is no distinction between a pavement and a road, existing solutions to help the visually impaired citizens such as tactile paving are not suitable. A potential solution would be to have smart Belisha beacons that would conventionally give priority to pedestrians who are nearby; it's location information as well as information supporting situational awareness could be offered through BLE (low energy Bluetooth), or even millimetre wave 5G that will "lock on" the visually impaired citizen via a device (smartstick, smartphone, etc.) and guide them towards the beacon, providing them also feedback in an appropriate form to let them know when it would be safe to move towards a certain direction.

A study on smart transport on urban environments was conducted in Bournemouth [226]. Four cases were analysed, namely cycles, buses, emergency services and parking. An overview of the requirements and key architecture components is presented in the following table:

Table 10: Smart transport on urban environments: requirements and key architecture components

Proposed Cyclist Architecture	Proposed Bus Architecture	Proposed Emergency Services Architecture	Proposed Smart Parking Architecture
• Sigfox IoT sensors for cyclists on the road • VMS display to alert drivers • Built in sat navigation techniques to display cyclist • Setup of sensor includes ability to enter emergency contact	• Sigfox IoT sensors on buses in Bournemouth • Ability to see real-time information of buses in a central location • Mobile application to access real-time with functionality of payment	• Sigfox IoT sensors within emergency vehicles • Pre-empted traffic light changes based on location and speed of vehicles. • Route modification based on traffic and congestion	• Sigfox IoT sensors for parking spaces • View nearby car parks and assess availability • Mobile application whereby users can reserve spaces across Bournemouth • Instant ticket if car parks in a reserved space

- Bournemouth using 5G networks on 3.5GHz and 26GHz (mm Wave).
- Use IoT sensors, which have coverage over the entire project scope.
- Ensure any IoT equipment used is standardised and can be integrated across all components to seamlessly communicate efficiently.
- Enhance fast network connectivity in order to effectively transmit information to and from IoT devices.
- Provide a resilient network with disaster recovery where appropriate.
- Must be kept up-to-date regularly with any upgrades, patch management and correct vulnerability management tools.
- Security and privacy must be fundamental to the project and ensure that customer data through any technologies built is forefront.
- Provide integration with surrounding local companies (e.g. Council for ticketing parking fines) reliably.

Figure 29: Cyclist collisions in Bournemouth 2011-5 (Bournemouth Borough Council 2017)

Cyclists was a particularly interesting case for Bournemouth; although cycling provides a solution for traffic, congestion and urbanisation, Bournemouth has been renounced as the second most dangerous area for cyclists in 2013 [227], and 2015, statistics found there were 21 causalities in Bournemouth to cyclists, which is increasing year-on-year within the area. Figure 29 shows the cyclists collisions in Bournemouth, showing the extent and seriousness of the problem. Lack of safety was deemed to be one of the primary concerns and barriers to adopting such means of transport.

Naturally, better cycle lanes are expected to decrease the number of accidents, but from a smart city perspective there were a number of solutions that can also contribute to a safer transport environment. Specifically, through the integration of both IoT sensors as well as crowdsourcing and participatory sensing applications, cyclists can be integrated into an intelligent transport system (ITS). 5G and Sigfox can allow instant-time communication signals from the sensors to the traffic alerts, meaning no latency or interruptions that can put the cyclist in danger. With the integration of VMS platforms and in-mobile or satnav applications, the technologies can provide road users with full awareness. The high level cyclist architecture is show in Figure 30 below. Sigfox sensors have the ability to be deployed on bicycles, motorbikes, and other PTWs (Powered Two Wheelers), which may be fitted onto the handlebar for instance. Location can be sent through to any mobile via the application within 2-10 seconds. The Sigfox sensor will gather information, including location and speed, sent via 5G networks through both 3.5GHz and 26GHz, and using edge computing, connectivity will provide real-time and a resilient network. The state of the device will be collected via the Cloud to provide data analytics for security and privacy management. Upon purchasing the device, SOS Emergency details can be set up via mobile devices, allowing seamless integration to contact relevant person(s) upon the state of the device detecting an accident, improving safety of using a TPW and decreasing waiting time for emergency services if necessary.

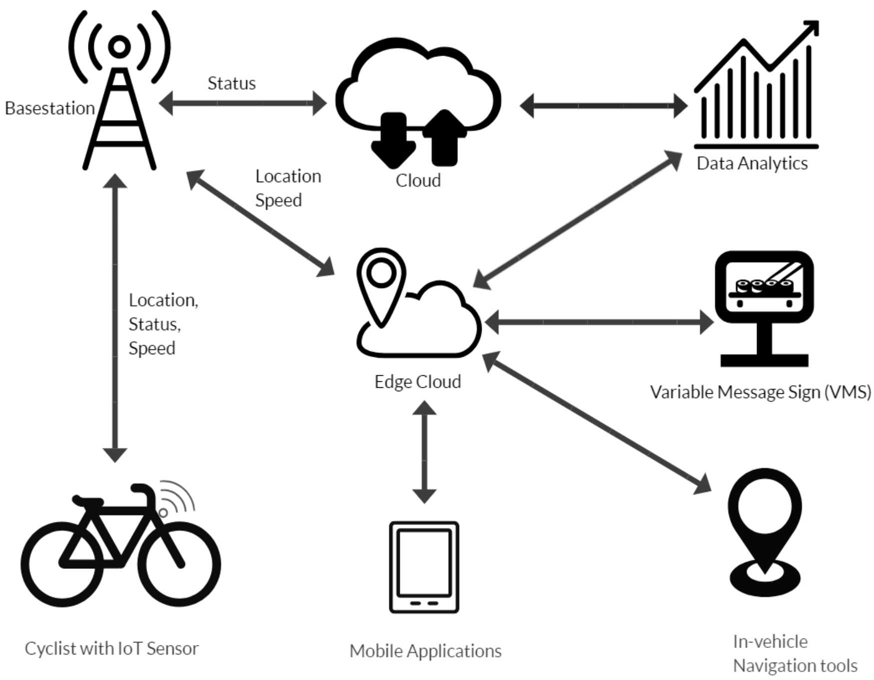


Figure 30 Example cyclist architecture

Following the ingress of the cyclist's data, these can by further used to enrich crowdsourcing applications such as Waze (Figure 31)

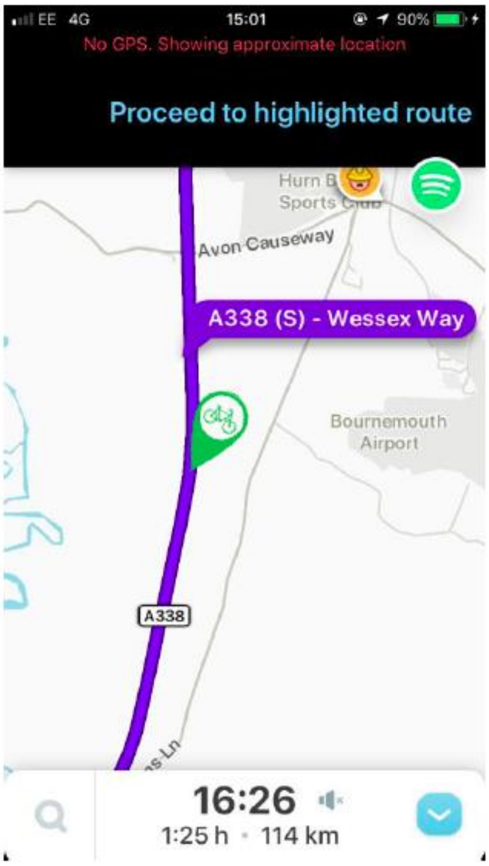


Figure 31 Waze application enriched with cyclist's data

IoT and 5G can also improve quality of bus services. Travelling via bus routes enhances ability of communities to protect the environment providing a low cost solution. However, users find that information fallacy is a major flaw, therefore information must be readily available when they need. Sensors deployed on buses, allowing real-time information via 5G and edge components to collect location, speed and bus status. Similar to the cyclist's scenario, status updates will be sent to the cloud for analytics collect information upon a breakdown or accident to inform the relevant authorities. Edge technologies can collect the location and speed to ensure limits are adhered to, and allow exact positioning of buses to update users via a mobile application and at bus stops. Research by Paulley et al. [228] found users are more likely to wait for transport if they are aware how long they will need to wait, ergo alleviating possibility of stress or anger.

Alongside real-time of the location, the mobile application can enhance the ability to plan customer routes, making journeys more adaptive for transport needs. The use of a payment gateway through distributed ledger technologies using local cryptocurrencies or smart contracts will transform the way buses take payments. The payments can include the use of Quick Response (QR) codes through in-house payment opportunities, or other decentralized internet banking schemes.

3.2 Healthcare

Smart city technologies are expected to introduce a breakthrough to healthcare. By integrating healthcare services with the transport vertical, the quality of care offered can be of significantly high quality, with minimum times when responding to incidents.

An example Healthcare/Transport high level architecture for emergency services is outlined in Figure 32.

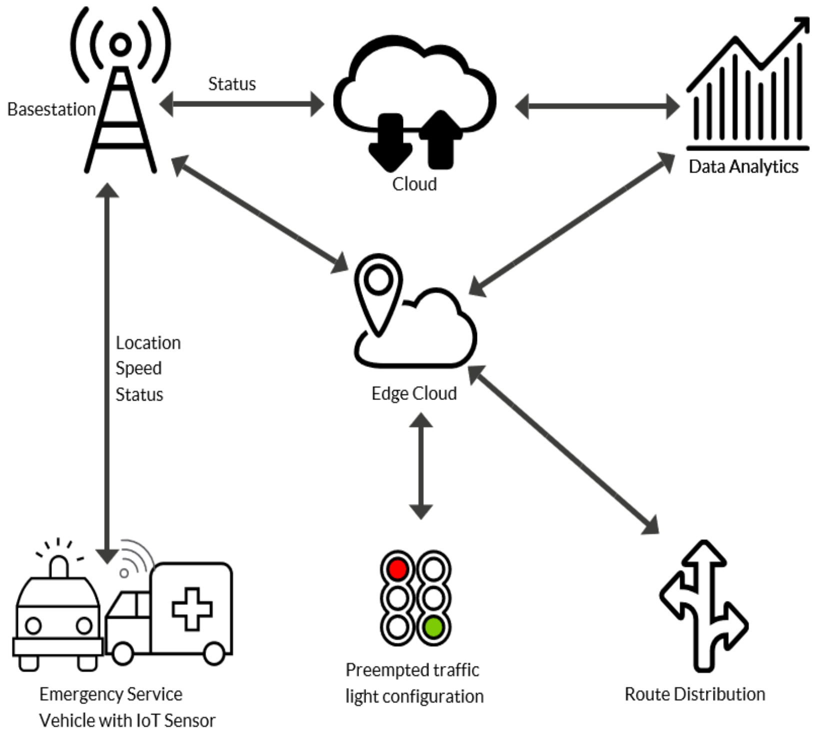


Figure 32 Emergency Services Architecture

This scenario uses IoT to reroute vehicles and pre-empt traffic lights for safety and decreased travel time. Each emergency vehicle is fitted with an IoT enabled sensor and extracts information including location, speed and status. As with all transport scenarios, the status consists of alerting relevant parties upon a possible accident or breakdown. Location and speed will be extracted via 5G and edge technologies to send real-time alerts to traffic signals, enabling a red light in all directions and creating on the fly emergency lanes allowing emergency vehicles to pass through traffic safely and securely. However, this relies on real-time and low latency equipment to work simultaneously to avoid accidents. To ensure a safe and secure network for emergency vehicles, traffic lights have the ability to provide pre-emption for upcoming vehicles to ensure safety across the junctions for emergency services, surrounding vehicles, cyclists and other TPW, and also pedestrians.

The above case can be also triggered from a wearable sensor or medical device. Two representative use cases are as follows:

1. Citizen with heart condition. IoT pace makers and defibrillators can detect if the patient is potentially going into cardiac arrest. In this case the location of the citizen will be disclosed to the health services system. The emergency services scenario can

be triggered by identifying the closest available ambulance and by pre-empting the traffic lights and creating an emergency lane.

2. An alternative and auxiliary participatory service can be the so-called Nearest Doctor Problem (NDP) [229]: In areas with of a high tourist activity or during events that attract high volumes of visitors and tourists, local healthcare services are always stressed. The Nearest Doctor refers to the need to quickly identify a doctor near an incident who will be qualified and agrees to attend to the incident. At the same time, since the doctor may be on holidays, both their (location) privacy and availability need to be captured. In a privacy preserving setting, a doctor can have an agent on their mobile device that will respond only if the doctor is available. Upon their availability, a privacy calculation can be performed in a way that the location and identity of the closest doctor will be revealed, whereas the identities and location information of all other doctors will be kept private. In addition, blockchain technologies can be used to certify the qualifications of the doctor and capture their involvement in the incident handling so that this can be used later for billing, housekeeping, etc.
3. According to the World Health Organization, most people can expect to live into their 60s and beyond. By 2050, 1 in 5 people will be 60 years or older [230]. Healthy Ageing is a key concept referring to the development and maintenance of the functional ability that enables wellbeing in older age. In turn, Functional ability is determined by the person's intrinsic capacity (the combination of all the individual's physical and mental capacities), relevant environmental factors, and the interaction between the two. Environmental factors include policies, systems, and services related to transport, housing, social protection, streets and parks, social facilities, and health and long-term care; politics; products and technologies; relationships with friends, family, and care givers; and cultural and social attitudes and values. In today's urban environments, the environmental factors are not adequately tuned to deliver Healthy Ageing to its fullest extent, due to limited resources and other potentially competing priorities and agendas. The problem is exacerbated in Cities and Boroughs such as Bournemouth and the general Dorset area, as they have a high demographic in aged citizens.

This case aims to offer a high Healthy Ageing standard through the use of IoT, 5G, SDN core technologies offering situation awareness, personalised services, predictive analytics and alerts in order to allow early interventions to heath risks and events such as falls. Through continuous monitoring via the wearable devices, the patient's gait and posture will be measured and analysed. An authorised carer will have access to the patient's data summarised and presented on a dashboard. Changes in gait and posture could provide early warning signs of a fall incident and depending on the assessment and severity classification, different actions could be triggered (from informing a family member, booking a visit, to alerting a professional expert and carer). In the event of a fall being detected the system would alert the call centre and provide information on the patient, their location as well as the location of potential alternative carers in the vicinity of the incident. By focusing on the preventable injuries class, the proposed solution if deployed on a wide scale is expected to lead to the reduction of healthcare services visits.

3.3 Tourism

Tourism is an interesting domain as it can be considered a horizontal activity, encompassing, the built environment and transport, healthcare, leisure, education and of course energy and environment. Cities that preferred and popular tourist destinations attracting significant number of visitors are good test beds for studying how a circular city can perform under high stress conditions. A high density of city visitors is known to have a direct impact on [231]:

- Housing prices due to the increase of tourism-oriented flats/rooms and new hotels in specific urban areas;
- Hospitality, cultural and retail services for visitors, competing with and displacing resident-oriented services and facilities;
- Air quality due to the additional transport needed to accommodate the tourists (coaches; private vans; cruises and aviation);
- Waste production;
- Noise pollution;
- Access to water and energy resources;
- Pressure on public services.

An extreme case of an overwhelming flow of visitors is that of Santorini island in Greece. Being among the top tourism destinations worldwide, the island of Santorini with population of under 16 thousand attracts over 2 million tourists annually.

On the other hand, tourism is a source of income and can significantly contribute to the GDP. As such, integrating sustainability into tourism is a necessity.

From a data centric view, one could consider that the core element of the tourism domain is the point of interest, POI. At a minimum, a POI is essentially a location (geographic coordinates) which is enriched with contextual information. Traditionally, a POI referred to a monolithic or singleton description of a specific and constant purpose (e.g. gas station, hotel, restaurant, etc.). In an ICT, data-driven world however a POI may be enriched by a wealth of attributes that can also be allocated dynamically different purposes and functions, in line with the CE paradigm. An address can be a residential home but can also become a hotel for a certain period of time (e.g. Airbnb). Depending on the states of the POIs the tourists (and local citizens) could make informed decisions on their visits and short term plans.

Indicatively the following use cases can sketch how a smart city can assist in delivering added value to tourism and hospitality sector:

1. Efficient parking. Parking has always been one of the challenges both for residents and visitors of a city. Even hotel-owned car parks are in many cases not large enough to serve their customers so they come at a relatively high price. A tourist who is arriving to a particular destination could specify the respective POI on the vehicle’s SATNAV system and whether they wish to park close by. They can specify their preferences, e.g. whether they prefer any trade-offs with the price and distance from the POI, as well as any accessibility requirements; these could have been declared at a much earlier stage upon creation of their particular profile. The visitor’s vehicle would then engage in a bidding process in order to identify and

reserve the preferred spot which can be a private parking space. The starting time would be dynamically adjusted according to the visitor's ETA which will be known by the vehicle. Upon agreement, a smart contract will be instantiated, the information will be logged on a distributed ledger and the minimum payment will be made. Upon departure, the contract will be completed and any outstanding payment will also be made seamlessly.

2. Supporting the visually or physical mobility impaired citizens and visitors. Technologies and solutions for assisting a visually impaired person to navigate through the city are available for many decades now, guide dogs being a good example. Visually impaired citizens are particularly confident on following a routine route. Visitors however, or citizens who wish to follow another route may struggle. To make things even more challenging, exceptional events (e.g. obstructed paths, or a more dynamic event such as fire, riot, or potentially hostile people along the path) do not always reach the impaired citizen in a timely manner. In this case, appropriate technologies can allow the pedestrian to sketch the complete context of their surroundings. These technologies could be crowd density, temperature, obstacle sensors that can be seamlessly integrated in the city's furniture. At the same time, particular furniture such as smart benches could report their occupation status.
3. Supporting the local economy through the provision of short-term incentives. Through data mining and analytics, the areas that are undervalued or under visited can be enhanced by participating in incentive schemes with direct advertising of special offers. A system can offer alternatives for lunch or coffee, again based on the preferences of the user – by showing the availability and capacity of a place in real time. Such service does not necessarily refer to restaurants and cafes but also public spaces (e.g. parks) and nearby shops to get food or other supplies if desired. This is particularly beneficial and can relieve an area's stress during events that cause overcrowding.
4. Enhanced educational activities. Many trips are of an educational nature (e.g. school trips) and have predefined plans. In such case the designated POIs can support enhanced experiences (e.g. through augmented reality) and even assessment of the students or visitors. A building for example could be tied with historical information and architecture references but also links with other disciplines such as sciences; civil engineering for example demonstrating the physics and static analysis of the building.
5. Real-time recommender systems. The use of real-time acquisition sensors provides the opportunity for mining knowledge from the user's data while they navigate in the city. This knowledge can be used for providing an enhanced interaction experience with the city through the appropriate recommendations. A recommendation, for example, will not be based only on the current location of the visitor and the nearby surroundings. The overall experience and emotions of the visitor will be captured using the corresponding devices and the surrounding can also change through the actuators installed in the appropriate smart objects. Moreover, the system can go beyond conventional recommendations by bringing together people that can enjoy activities in engaging manner. The latter would be feasible using inertial sensors of the everyday object visitors might be using, such as mobile phones, smart cameras etc.

6. New forms for sustainable tourism. Increasing the attractiveness of destinations to tourists, includes strengthening the development of sustainable tourism, within new forms. Sound is one of the crucial elements that tourists are immersed to “sense” the tourism destinations. It forms the tourists’ experience. The nature and effect of the auditory element affects their experience and evaluation of destinations. Soundscapes offer opportunities for the development of sustainable tourism. A new form of tourism (sound tourism) has emerged and based on travelling to places with unique acoustic characteristics or unique soundscapes (such as soundwalks and sound safaris). Apart from visual stimuli, acoustic stimuli play important role in the perception of landscape. Sound is a significant feature of the landscape and functions with other landscape components, supplementing its image with new component. Sound impacts the quality of landscape and shapes its character. Soundscapes are important elements of natural and cultural heritage, very sensitive to changes associated with the development of civilization. They are also very significant distinguishing feature of places and regions. Every environment has its own unique sounds. Soundscapes are carriers of content, associations and symbolism. Soundscapes can stimulate the growth of tourism as the discovery of new soundscapes has been a new challenge to contemporary culture. The need for the ecology of tranquillity as a subdivision of general ecology is recognized. The ecology of space also calls for preserving a soundscape. The urban environment is going through significant changes in the acoustic layer of a landscape. The omnipresent traffic noise (and its noise levels) makes the acoustic layer monotonous. A soundscape constitutes an enormous potential attraction for the development of sustainable tourism and can increase the attractiveness of both environmentally valuable and culturally unique areas. Drawing special attention to soundscapes as a part of the resources of urban (and rural) areas can help raise the public awareness of the beauty of tranquillity (the sounds of nature). Tranquil areas need to be protected due to the opportunities they offer for tourism, recreation and sustainable development. Sound tourism relying on soundscapes as the basic component of touristic attractiveness is consistent with the sustainable development concept because discovering the acoustic variance of landscape can not only contribute to the protection of the natural environment against noise, but also bring numerous benefits in the social and economic sphere.

3.4 Energy

Energy is a vital part of the smart city paradigm and a vertical that will be one of the major challenges for the future of the urban areas and the earth as a whole. The modernisation of the electric grid through smart grid enhancement technologies [232] will allow the better integration of new technologies, the adoption of zero-emission projects and practices and offer the following advantages to consumers and producers as well [233]:

- Energy savings through reducing consumption
- Better customer service and more accurate bills
- Fraud detection and technical losses
- Reduced balancing cost
- Increased competition

- Levelling of the demand curve (Peak reduction)
- Reduction of carbon emissions

Therefore, smart grid is a two-way flow of electricity and information that will be capable of deploying networks for sensing, monitoring, and dispersion of information to monitor everything; from power plants to customer preferences in real time in order to balance the supply and the demand at the device level [234] [235].

The complete implementation of smart grid and the delivery of its benefits exceed the realisation of physical infrastructures. New business models and practices, new regulations, as well as more intangible elements such as changes to consumer behaviour and social acceptance [236]. This would require the involvement of diverse stakeholders engaging in different forms of cooperation which also provide a number of opportunities as presented below.

3.4.1 Peer to peer energy trading

Peer-to-peer (P2P) energy trading is a model allowing producers and consumers to trade electricity directly, alleviating the man in the middle, which in that case is the grid. Consumers that generate excess energy would be able to market their unneeded energy for an extra income. On the other hand, consumers that require this marketed energy would be able to pick the source of supply [237]. The fact that this surplus comes mainly from solar panels or wind turbines [238] would also offer an important boost to local green energy projects.

The charging of the electric vehicles is a paradigm that would be the driving force in the establishment of P2P energy trading; their batteries are able to store the energy surplus and make a potential sell, when deemed profitable[239]. Toyota is the first car manufacturer to conduct a P2P energy trading pilot that will use electric vehicles as a power supply [240]. The system will use an electricity trading agent, powered by artificial intelligence that could place orders to buy and sell electricity according to real-time power consumption data and forecasts [241].

Not only in the case of P2P energy trading but also in the case of the electric grid in total, blockchain would be the enabling technology which attributes could assist in the transformation of the traditional grid to smart. The main advantages, enhanced by the blockchain technology are:

- decentralization of trust,
- increased security,
- increased resilience,
- increased transparency,
- increased scalability,
- less bureaucracy
- increased computational capacity [242].

3.4.2 Light as a Service

Managed services can appear in many shapes and forms. A great example of a circular economy model is circular lighting, pioneered by Philips [243]. The so-called end-to-end circular lighting service model reduces waste to the minimum through managing the entire luminaire lifecycle. Starting from the manufacturing of the IoT enabled light bulb which adheres to circularity by design principles, it is constructed in a way that it can be easily assembled and disassembled in a closed materials loop. The circular principles themselves are realised by traceability, serviceability, recycling, upgrade options as well as parts harvesting. The service offered by the luminaire (light) is measured and the customers can be billed accordingly.

This model can trivially be scaled to a city level and through appropriate data governance models and information sharing relating to this service provision the main stakeholders (LaaS provider and the local authority) can effectively optimise the use of resources; through data analytics the customer will be always receiving the light matching their needs. In addition, this can be done without the need to invest in new hardware upfront. In addition, the data analytic capabilities can support predictive models by measuring the performance of a luminaire in real-time and raising alerts when a particular device's performance deteriorates or reaches its end of life, so that it can be recycled or restored.

3.4.3 Ship to grid

Ship to grid is an on-demand energy service deployed in the port of Amsterdam. When moored in a harbour, the ships might remain idle for days, having though still to operate their engines and consume a significant amount of fuel. During their stay in the harbour, the ships can reduce energy cost and CO_2 emissions by connecting to one of the 200 shore power stations that acclaim green energy. The service is activated by the captain of the ship who will be able to activate a connection with the shore power station by entering his personal code. The connection is deactivated by logging off or plugging out at the connection point and the cost of the consumed energy will automatically be transferred from the vessel's account [244].

The increasing adoption of the smart grid paradigm in urban areas and the energy production of countries attracts the inevitable attentions of cyber-criminals. The attacks on the Ukrainian power grid [245], the threat of Stuxnet and a number of various indicated threats require increased cyber security awareness and the improvement of human factors [246] for the successful implantation of reliable smart components that would offer to the population of the smart cities all the aforementioned advantages

3.5 EU Projects and initiatives

3.5.1 IOTA

IOTA is an open-source distributed ledger that is being built to power the future of the Internet of Things with feeless micro transactions and data integrity for machines [247]. Unlike the blockchain technologies that other cryptocurrencies use, in order to submit a transaction to the IOTA ledger, the user must verify two other previous transactions. The concept of IOTA addresses the transaction fees and scalability issues, addressed by other cryptocurrencies and is also in position to enables transactions between machines [248].

As a result of IOTA's properties and function, IOTA foundation is investing in the prospect of smart cities and a number of relevant projects. The collaboration with communities like Hackster.io [249] and other stakeholders, like the participants of the

+CityxChange proposal [250] offers the IOTA the opportunity to become the main transaction handler for smart city devices in the following fields of:

- Smart mobility
- Smart energy
- Smart buildings
- Smart districts

3.5.2 SYNCHRONICITY

Synchronicity is the first attempt to deliver a Single Digital City Market for Europe [251]. It enables an ecosystem for the IoT-enabled smart city solutions stakeholders that allows them to innovate and openly compete. The market place offers a number of services, like the use of identified interoperability points, integration of heterogeneous platforms and devices, along with the ease of participation on the market.

The project involves 33 partners from 9 European countries and 1 from South Korea [252] providing with citizen-centred services for cities, citizens and businesses in the following areas:

- Climate change adaptation
- Mobility as a service
- Non-motorised transport
- Increase of citizen engagement in decision making
- Reduction of noise and air pollution

3.5.3 BIGIOT

The BIG IOT project is a Horizon 2020 funded project that focuses on bridging the interoperability gap between the existing heterogeneous IoT frameworks [253] and creating a unified ecosystem. Its goal is to create an unified API for the participating projects and a marketplace that the stakeholders would be able to acclaim in order to gain access to valuable resources for the IoT applications and monetise their assets [254].

Interoperability and heterogeneity are two important challenges in creating a smart city environment [255], rendering the BIG IOT project a promising venture for the future of the smart cities. For this reason, the project is tested with the use of 8 IoT platforms in three European areas; Barcelona, two German cities (Berlin, Wolfsburg) and the region of Piedmont in Italy [256].

The projects tested in the aforementioned areas target the fields of interest regarding the environment and the smart mobility. Each area has the following projects;

Region	Project
Barcelona:	• Traffic Detectors • Parking spot sensing • Air quality sensing • Noise detection • Bike sharing data • E-charging stations

	• traffic information centre tool, smart parking app, green route planning
Berlin, Wolfsburg:	• Public Transport • E-mobility • Smart Parking • Multimodal routing information • Real time crowd management • On-street information panels for traffic related news
Piedmont:	• Road traffic monitoring • Smart parking • Environmental pollution monitoring • Bike sharing stations • Bike navigation • Route planning with consideration of current air pollution

3.5.4 CE-IoT

CE-IoT is an H2020 project whose objective is to build an innovative framework that allows the optimized interplay between the paradigm of Circular Economy and the IoT; this interaction can lead to better and improved adaptation of the IoT products to the concept of CE and its needs [257]. In order for the IoT to become the key enabling technology for the CE, the project aims to adopt circular-by-design IoT architectures to maximize the utilisation of their resources and properties in order to build new circular-by-design IoT ecosystems [258]. The framework covers business, technical and legal aspects in order to achieve the pervasive use of IoT implementation in the CE environment.

The project has 5 participants from the EU and builds a framework suited for e-waste management and recycling. The pilot system offers a supply chain; combined with a monitoring framework with machine learning techniques and smart sensing, it allows prediction and decision-making policies [259]. The outcome of this process is a recycle-rewarding system and green computing policies, built for ICT organisations in order to reduce energy consumption and gas emissions for the stakeholders.

3.5.5 CE Stakeholders platform

The European Circular Economy Stakeholder Platform is a virtual open space which aims at promoting the European circular economy agenda. The platform operates as place for dialogue among stakeholders and communicates activities, information, and good practices, relevant with the circular economy [260].

The platform [261] offers tools like online forms and discussion forums that assist its users to engage in dialogue with the other stakeholders and remain updated about the news in the field of circular economy. With actions like the 2019 Circular Economy Stakeholder Conference [262], the partners have the opportunity to work on the issues and challenges for the transition to a circular economy and its implementation in national, regional and local level.

3.5.6 Urban Data Platform

The Urban Data Platform [263] is a joint initiative of the Joint Research Centre (JRC) and the Directorate General for Regional and Urban Policy (DG REGIO) of the European Commission. The platform has captured data for all EU countries across 12 dimensions/indicators which are presented through dashboard visualizations. Specifically, the Urban Data Platform provides:

- A territorial dashboard, showing the key indicators per region, country, metropolitan area, city
- Trends, presented as overviews on various territorial scales
- Thematic analyses, in an attempt to analyse the data gathered
- A strategy board, to present the strategic directions of the EU regions

At the time of writing, the strategy board contained 95 strategies with a circular economy theme, distributed as shown in Figure 33.

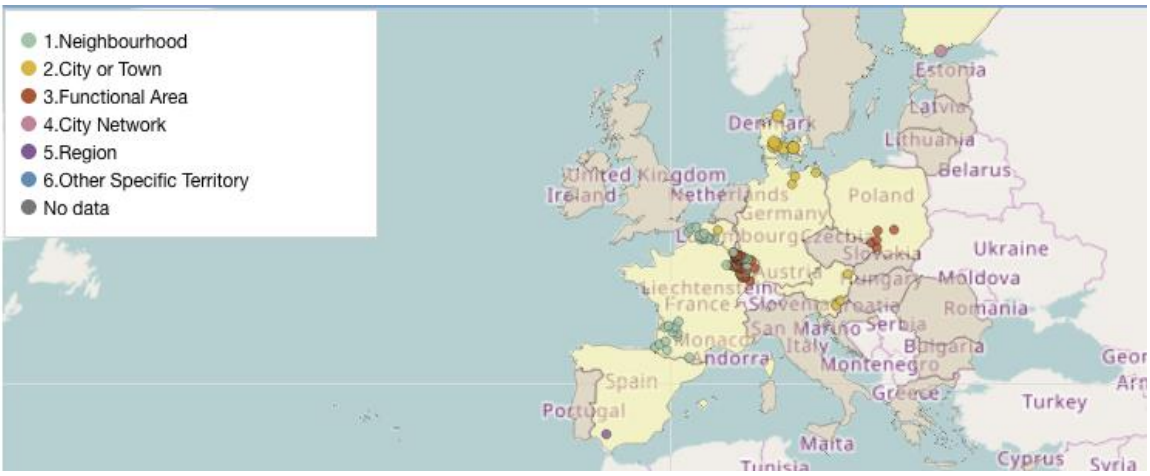


Figure 33 Circular Economy strategies [264]

4 Technological enablers

4.1 Affective computing

Affective computing aims at giving some emotional skills to machines in order to bring human-computer interactions closer to human-human communication [265] [266]. With the smart urban environment being an interactive area where people and machines collaborate, interact and coexist, affective computing can be used for providing emotional context in the individual or social interactions, having reached a level of maturity, as reflected by the number of emerging applications in domains such as computerized learning [267], entertainment [268], and therapy [269]. Recent approaches contextualising affective information in smart cities, integrated affective information towards analysing the geographical behaviour of individuals [270]. In the same line, other approaches proposed an open definition of for a computational sustainability platform able to speed the development of application and the integration of different modules to support the acquisition of data and its use for models and workflows inside environments [271].

As far as processing and modelling affective states is concerned, most of previous research in emotion/affect recognition has focused on the analysis of emotional behaviours like facial expressions, speech, body gestures and postures [272] [273]. Computational modelling has been used for the study of casual factors of emotion for human–computer and human–robot interaction. The use of behavioural and physiological signals towards identifying emotional states has emerged in the last decade. The common signals selected to be analysed originate from the mostly autonomous peripheral nervous system (heart rate, breathing rate, electromyogram, galvanic skin resistance, skin temperature), or from the central nervous system electroencephalograms. Recent attempts which study the correlation of the emotional responses with the physiological signals in a group setting had indicated that some emotional experiences are shared in the social context [274], whereas others were focused on analysing arousal values and galvanic skin response while movie watching [275]. Regardless of the modalities employed, the assessed emotions are either a set of basic emotions (often anger, sadness, disgust, joy, happiness) or assessed continuously in the valence (ranging from unpleasant to pleasant) arousal (ranging from calm to aroused) continuous space.

Identifying dynamics in human-human interaction involves capturing the coupling among different modalities, along with the synchronisation of the multimodal signals of multiple people. Many different synchronization measures have been employed lately to process physiological signals. One such possible synchronization measure is for instance the Pearson correlation coefficient (Spearman's rank correlation coefficient) that can quantify linear correlations between pairs of signals. Another approach to synchronization originates from information theory. Signals can be regarded as a collection of random variables which represents the evolution of a system over time. In this context, a basic similarity measure is mutual information or Kolmogorov – Smirnov distance that can be used as a similarity measure between distributions of signals. The first concept of synchronization came from the rhythm adjustment of oscillating objects[276] . Research was shifted soon to natural and social sciences. In social sciences interpersonal synchrony consists of three components: rhythm, simultaneous movement and smooth meshing of interactions. One important step was made by [277] to introduce generalized synchronization of coupled chaotic systems. In [278] the authors proposed that a level of the periodicity score can measure the amount of pattern repetitions in signals.

In order to successfully model emotional states in human-human interaction and, later, express those emotional states, a number of research questions that bring IDEAL-CITIES beyond the state of the art arise on the fields of signal acquisition, processing and modelling of affective states, as well as on the integration of the semantic information such as: How to capture the coupling of multimodal signals of multiple persons, how to perform online learning for updating the corresponding emotion models, how to successfully render the corresponding emotional states. From a signal processing point of view, the synchronous capture of multimodal signals of various natures, of different spatial and temporal dimensions is a challenging task. This discontinuous stream of affect information will be processed using a new generation of data mining algorithms that can handle appropriately missing and multidimensional data. Further, the developed algorithms will account for robust modelling of the relationships among different physiological and behavioural modalities, as well as with different context data and other sources of information.

The aforementioned activities will enable better modelling of the affective states, as well as understanding and interpretation of their cognitive structure [279], [280], [281], [282], [283]. Emotions significantly overlap in real-life situations. To address this challenge, the developed models will go beyond the state of the art by learning the common structure of different types of emotional and affective states. Knowledge of this structure may lead to better generalization performance on emotion/affect recognition. Multitask learning will allow learning the common features shared among different emotions [284], [285], as well as incorporating information from multiple sources that can be indicative for the affective state of an individual at a given time. Multi-label learning approaches will also be developed to account for the fact that at a given time, more than one emotion rely on the human brain, [286]. One of the biggest challenges is the adaptation of emotion models trained for a given user, emotion, scenario, to another set of those parameters. To respond to this challenge, transfer learning techniques will be applied for applying the developed solutions (as those are expressed in terms of features selected and model parameters) to real-life situations [287].

4.2 IoT as intelligent assets

Internet of Things (IoT) are network of physical devices, like smart phones, vehicles, homes, home devices, etc., that hold a unique identifier and can transfer data without requiring the human factor. The contribution of IoT is very important, since the use of it makes many aspects of the everyday life simpler. The number of connected IoT devices tends to be increased making this technology very popular. It seems that IoT devices will grow to 26 billion by 2020, which are 30 times the estimated number of devices deployed in 2009 and it is far more than the 7.3 billion smartphones, tablets and PCs that are expected to be in use by 2020 [288].

Currently, most IoT solutions rely on centralized server-client systems that offer cloud servers solutions connected through Internet. Even though, this approach works properly, there is need for improvement. Regarding this popularity, the number of vulnerabilities and attacks is increasing that are exploiting the flaws, the complexity and the heterogeneity of IoT networks. This fact arises the need of protecting these networks by applying cyber security methods. A proposal for the improvement of IoT networks is the application of Blockchain technology. Blockchain can execute transactions, track, and apply strong cryptographic techniques to protect the records that are stored on the ledger. For this reason, why, applying Blockchain over IoT could be a solution for the improvement of it.

IoT architecture consists of three layers, the Perception Layer, the Network Layer and the Application Layer. The Perception layer includes devices that are connected to the Internet and can concentrate and exchange information through the Internet communication networks. These devices may be smart cameras, Wireless Sensors, Radio Frequency Identification Devices- RFIDs, GPS, etc. The data is collected from these devices and forwarded to the application layer [289]. IoT systems use a combination of short-range communication networks technologies, like Bluetooth and ZigBee, for the transmission of information from the perception layer to a nearby gateway. For longer distances, IoT systems use internet technologies like Wi-Fi, 2G, 3G, 4G etc., regarding the application. Application layer includes smart homes, smart vehicles, smart cities, and is where the information is received and processed [290].

4.2.1 Crowdsourcing and crowdsensing

Crowdsourcing is a source model where humans or companies can contribute to wide problem solving faster through Internet. Linux, Wikipedia and Yahoo could be considered as crowdsourcing examples. Crowdsourcing has been characterised *the wisdom of crowds* by James Surowiecki, as he was amazed about the fact that a group of Internet users can find solutions to sophisticated problems. Mainly, it divides and allocates tasks of the same work between users in order to achieve faster the solution to the problem [291]. During crowdsourcing process, many ideas are concentrated together, filtered and give the final solution to each problem [292].

There is a misconception that crowdsourcing and outsourcing are the same thing. The major difference between crowdsourcing and outsourcing is that the first is applied over abstract, public groups, where outsourcing is relevant with more specific, named groups. Some of the advantages of crowdsourcing models include not high cost, quality, faster solutions, flexibility, scalability, etc. [291] and it can be either virtual or real. Moreover, crowdsourcing process is typically a man-to-machine process.

Crowdsensing or mobile crowdsensing term is referred to a technique where large group of people who obtain personal, smart devices, like phones, tablets, watches, laptops, etc., which are equipped with sensors in order to collect and exchange data with intention of extracting information to measure, map, analyse, estimate or predict processes of common interest. In other words, crowdsensing means data sensing from mobile devices in order to help public. Crowdsensing is a subset of crowdsourcing and it replaces the traditional techniques of gathering information in big range environments like a city. Moreover, it is an alternative way of gathering information as it is not necessary to have and maintain stable sensors around a city or a region in order to have data about air quality and traffic as people are able to do the same thing in a faster and cheaper way. A use case of crowdsensing process is a project with the name Air-Cloud, which is a system that monitors the concentration of $PM_{2.5}$ in China. Crowdsensing approach includes two components, the mobile component for the data gathering and the central server for data storage and processing [293].

4.3 Big Data

Apart from IoT networks, Big Data is another technological enabler for smart circular cities. The usage of IoT devices that generate, gather and exchange data can lead to the concertation of huge amount of it. This amount of data generated by smart devices that are part of an IoT network in a smart city can be considered as big data. The storage and analysis of this data can produce useful patterns, which are helpful for various applications, sectors of a smart circular city, services, integrated ICT approaches, etc. Some use cases of big data analytics application could be public healthcare sector, transportations, public services, energy efficiency, waste management, security and emergency management, and many others. It is common for these services that data needs acquisition, storage and processing on either local smart city's servers or on cloud computing platforms.

Big data is stored, processes and mined in a smart city in order to enhance services of it and to produce helpful information for different smart city sectors. Furthermore, big data can help with decision making plans for the expansion of those cities.

The usage of big data technology can contribute to the upgrade of smart cities services using the right tools and methods for fruitful data analysis. This kind of analysis will enhance and contribute to the communication and the creation of new services that will help citizens, make the urban environment more friendly and provide better customer experience.

As it has been mentioned above, the key enabler of smart cities is Internet of Things networks technology that produces and collects a vast amount of data using a big number of sensors and smart devices, which are equipped with cameras and sensors as well. Big data that is produced and concentrated must be kept stored, be processed when it is necessary and be analysed in order to mine useful information. Data mining and analytics on the collected data would be performed either on the cloud or near the edges, where the information is relevant.

Another challenge related to big data is low degrees of automation in quick queries and the retrieval of big data. In cases where the data retrieval is essential the process should be fast enough to handle an emergency. The traditional information systems perform only simple data acquisition and storage. The atomisation of these systems regarding data retrieval and fast queries response should be taken into consideration. Applying these automatisation processes, it will be possible to retrieve data when in cases of conducting prior warning and effectively deterring criminal activities, for example. The automatisation will allow actions of prevention, emergency cases where the fast insertion is necessary and post-event measurements [294].

Big data technology is essential for smart cities, however, as it is bounded with the availability of other technological enablers and tools, like IoT networks and cloud computing, the maintenance of its flow it is necessary. Big data generation, analysis and storage depend on other tools and technologies and the availability of them [295].

Finally, mining for knowledge from big data is difficult. Mining of big data should be an in depth process in order to obtain useful information when it is necessary. However, the major characteristics of big data make the mining difficult. For example, it is difficult to conduct data mining from datasets that include spatial information [294].

4.4 Artificial Intelligence

Artificial Intelligence- AI is a subfield of computer science the application of which covers a big range of other applications, like scientific research tools, games, robots control, medical tools, etc. Furthermore, many modern services are based on Artificial Intelligence.

Smart environments need modern technological tools that can deal with the everyday life. One of the mains ways that this concept can be achieved is through the usage of many sensors that are placed around a smart city and generate vast amount of data. In these cases, the generation of this data can be helpful for educating AI –based systems in order to be able to provide many other services, like incidents' prediction. In general, AI-based systems should be able to educate themselves from users' behaviour, i.e., when users interact with a smart city using the services that the last provides and its infrastructures. When these interactions have been recorded, the system must be able to detect them, recognise them and be ready to perform the learned actions autonomously when it is necessary [296].

4.4.1 Machine Learning

As being type of Artificial Intelligence, machine learning is another subfield of computer science that studies algorithms and statistical models in order to provide the ability of learning to machines without explicit programming [296]. A set of information samples is used as input to learning algorithms in order that algorithm to be trained. This set of information samples is called training set. In machine learning, there are three main categories of learning, the supervised, the unsupervised and the reinforcement. The supervised learning category refers to the learning category where the training set includes labels, which are the corresponding appropriate targets vectors apart from the input vectors samples. The unsupervised learning does not include the labels, only the input vectors samples. The reinforcement learning category is related to the problem of learning the most suitable action or sequence of actions to be taken for a given situation in order to maximize payoff [297].

In smart cities use cases, where the amount of data produced is huge, there is need for recycling processes regarding the handle of it. Machine learning algorithms should be used and be able to extract knowledge and useful information from data to reduce the amount of digital waste.

There are some smart city characteristics from machine learning perspective. The first one is related to the interaction of citizens with the infrastructures of the city in order to provide feedback. Another characteristic is that smart devices and sensors produce big amount of data that is used in order to "train" the system more and more. Furthermore, smart cities need a dynamic and continuous learning system that will be evolved more and more over the time. Finally, the data that a smart city produces is not always "clear". In some cases, this data is noisy. This fact means that the system should be able to keep the useful part of this data and discard the non-useful part of it.

Regarding the above-mentioned characteristics of smart cities and the data that they produce, there are many opinions, which support that the interaction of DNNs, reinforcement learning and unsupervised learning can bring a solution to those issues.

As the architecture of a smart city concept could be considered that it includes three levels, the IoT level, where the city is and the IoT devices have been placed, the Edge Computing level, which is placed above IoT networks and interacts with the IoT devices and the Cloud computing level, where the data generated from IoT devices of the city is stored. The adoption of machine learning approaches can be beneficial for each level.

Machine learning algorithms can be used over IoT devices, which gather the necessary data in order to keep only the information that is useful for the system, as the nature of IoT is very constrained. Moreover, machine learning can be applied over the second level as well, where the data from the first level is aggregated and transmitted to the cloud computing level. At the cloud computing level, machine learning and data mining algorithms can integrate in order to extract useful patterns from the generated smart city's data.

Furthermore, there are use cases where machine learning techniques have been applied in order to reduce the consumption of water and energy. In 2017, California had used big data analytics in order to secure water for drought periods. It has been achieved using smart water meters and an intelligent system based on DRL. The results helped to the reduction of water consumption during the summer months and which hours during the day [297].

4.5 Decentralised smart contracts

This kind of technology was first proposed in 1994 and the most well-known applications of it is over the Ethereum cryptocurrency. The tem smart contract refers to a set of software functions which is stored in distributed ledger and is executed when there is a request for a new transaction in the Blockchain. These software functions are executed inside the ledger. This means that there is a real-time execution by all the nodes that are members of the distributed ledger network, regarding the consensus rules that have been applied and agreed by all the participants. Generally, smart contracts can be considered as digital, legal agreements between two or more parties in order to protect digital assets. A blockchain can store more than one smart contract regarding the needs of users/parties. Smart contract technologies have some advantages. The main one is that it can combine many different rules for multiple users/parties [298].

4.6 3D Printing

3D printing is considered among the latest revolutions and disruptive technologies in manufacturing. 3D printing, also known as additive manufacturing is a process where three dimensional objects are built from a digital file. The creation of a 3D printed object is achieved using additive processes.

In an additive process, in order to achieve the creation of a new object, layers of material are necessary to be laid down successfully until the object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of eventual object.

Even though many specialists around the world believe that 3D printing is unable to replace established manufacturing methods, there are many applications where it can be applied in order to deliver a very accurate design, faster than these methods using functional materials.

3D printing starts with a 3D model. There are many 3D models online, however, everyone is able to design their own model [299], [300]. Some of the main advantages of this technology are presented below.

Speed

Speed is one of the main advantages of 3D printing compared to traditional manufacture. In additive manufacture, even complex models can be uploaded from a computer-aided design- CAD model and printed in a few hours. In this way, the ability to produce more functional end products in a few hours drives to a huge time-saving advantage and bigger profit comparing with traditional manufacturing techniques.

Cost

The cost of 3D printing is divided into three categories, the machine operation cost, the material cost and the labour cost. Regarding the machine operation cost, the average amount of power that a 3D printer uses is equal to a laptop computer power. Industrial additive manufacturing technologies consume a high amount of energy to produce a single functional object. However, there is the ability to produce complex models in a single step. The result of this fact is the higher efficiency of production and profit. This type of cost is the lowest contributor to the overall cost of 3D printing.

The material cost for 3D printing varies significantly by the type of the printer. For example, the cost of material in a desktop FDM printer that is uses filament coils may cost around $25 per kg when SLA printer uses resin which costs $150 per litre. This means that the cost of additive manufacturing is relevant to the material cost that is the biggest contributor to the whole process.

Finally, the labour cost, which is low and this fact is one of the advantages of additive manufacture. The 3D printing is almost automated process in order to produce functional objects. On the other hand, traditional manufacturing needs highly skilled mechanists and operators, whose cost is bigger that in additive manufacturing.

Complexity

In traditional manufacturing, there are some restrictions regarding the production of complex designs, something that there is not exist in additive manufacture. Since components are constructed one layer at a time, design requirements such as draft angles, undercuts and tool access do not apply, when designing parts to be 3D printed. Since the objects are accurately printed by a 3D printer, there are not restrictions regarding the design. This fact gives to designers a large amount of design freedom and enables them to design and produce more complex models.

Customisation

Another advantage of 3D printing is customisation. As it has been mentioned above, there is a freedom regarding the design that a 3D printer can produce. This feature is very helpful in case where the products should be customised, for example, in cases of medical and dental industry, where every patient has different needs.

Sustainability

Maybe the most important advantage of additive manufacture, as there are many 3D printers that can use only the amount of material that they need in order to produce a design. Most processes use raw materials that can be recycled and reused in more than one design. As a result, 3D printing process produces very little waste [300].

3D printing is a core and substantial enabler of circular economy. The plastic waste of a big city can be used as input-material for the creation of plastic objects that this city needs. An example of this use of this technology is the Coca Cola project in Greece, “Zero Waste Future”. The purpose of this project is to minimise the plastic waste of cities. This project starts from Thessaloniki, Greece with the name “Print your City”, where citizens collect their plastic waste and place them in blue bins in order to recycle and convert it into useful objects that will be placed around the city. This will be done with the contribution of 3D printing technology. In this way, citizens will be an active part of the city and they will be able to manage and decide the future of their plastic waste [301].

This project can inspire many others to recycle, especially plastic waste, in order to recreate useful objects without wasting new materials and achieving the ultimate circularity.

It should be noted that 3D printing does not necessarily involve man made materials; Carlo Ratti Associati designed and built an 11-feet tall aesthetically pleasing device which combines a 3D printer and a juicer [302]. The printer-juicer can hold 1,500 oranges. As the oranges make their journey through the device to produce juice, the rest of the fruit is directed through an oven in order to be transformed into the cup to hold the juice.

4.7 Infrastructure

4.7.1 SDN and NFV

Software Defined Networks (SDNs) and Network Functions Virtualisation (NFV) constitute key infrastructural technologies for managing efficiently resources, applications and data at prescribed and required service levels. SDN offers capabilities to dynamically configure network topologies, which together with the 5G technologies can create an environment for efficient data forwarding and processing capable of meeting all potential requirements of the underlying smart city projects and use cases. Through SDN and NFV the network can elastically scale up or down, allowing a city to respond to the varying needs and cover for eventualities. For example, similar to allocating dedicated lanes for emergency vehicles to handle accidents or life and time critical incidents, in an event of an emergency during say a concert, the network communications will be reconfigured to guarantee bandwidth for the emergency services and will reduce the throughput allocated to the ordinary “crowd” users but allowing them to only send short messages rather than capabilities for bandwidth consuming video streams.

4.7.2 Cloud computing

The term Cloud Computing refers to the on-demand availability of computer system resources, especially data storage and computing power, without direct data active management by users. Generally, Cloud Computing describes the data centres that are spread over the Internet and are available to users.

Some of the basic characteristics of Cloud Computing are presented below.

- *On-demand self-service:* It is a service that is provided by cloud computing and enables the provision of computing capabilities when it is necessary without requiring human interaction with each service provider.
- *Broad network access:* The Cloud Computing services are available over the network and accessed through Internet using traditional mechanisms that support various clients' platforms, like laptops, mobile phones, workstations, etc.
- *Resource pooling:* The ability of Cloud platforms to serve multiple customers using a multi-tenant model that assigns dynamically physical and virtual resources to clients regarding their demands.
- *Rapid elasticity:* The Cloud Computing services can be elastically provisioned and released, automatically in order to be adapted to the demands of customers.
- *Measured service:* Cloud Computing services are automatically controlled and readopt when it is necessary by leveraging a metering capability at some level of abstraction appropriate to the type of service. The usage of the resources of the Cloud can be monitored and controlled in order to keep the transparency for the provider and user of Cloud Computing service.

There are several service models of Cloud Computing. The main service models are the Software as a Service (SaaS), the Platform as a Service (PaaS) and the Infrastructure as a Service (IaaS). The first one refers to the services that are provided to the customers of cloud infrastructures in an application form that either is accessible through Internet Interface via a web browser or in a program interface. The clients interact only with the application of the provided service without configuring the cloud platform. The Platform as a Service (PaaS) term is used to describe the Cloud Computing solutions that are tailored-made regarding the demands of each client. Again, users are not able to manage or configure the cloud infrastructure, however, they are able to configure the settings of their application. Finally, the Infrastructure as a Service (IaaS) service model of Cloud Computing where the consumer can deploy, run and use software that may include operating systems and applications. In this service model, consumer is not able to manage and control the underlying cloud infrastructure, however, he/she can control the operating system and the applications over it [303].

4.7.3 Edge computing

Edge computing refers to the technologies that enable computations at the edge of the network. As "edge" of the network is defined as any computing and network resources between data sources and cloud services. It is a new cloud-based technology and it uses the Radio Access Network (RAN). The main goal of Edge Computing technology is to enhance the performance of the network reducing its latency, increasing the efficiency of the network and providing a better experience to its users by being closer to them. Some basic characteristics of Edge Computing are low latency, proximity, high bandwidth and real-time insight into radio network information and location awareness, as data is collected and processed closer to customers. Implemented applications on Edge Computing require high bandwidth and low latency environments. For this reason, distributed data centres service providers are located at the Edge Computing. Users can have access to Edge Computing in multiple ways, like using wireline. Edge Computing is the evolution of mobile base stations and one of the fundamental technologies behind 5G networks, apart from Network Functions Virtualisation (NFV) and Software-Defined Networking (SDN). It contributes to the demanding requirements regarding throughput, latency scalability, and automation of 5G and it helps to improve the mobile broadband network into a programmable world [304].

4.7.4 Cloudlet

Cloudlet is a virtualised architecture that spans between mobile devices and a remote cloud, which allows the storage and processing of certain types of data of mobile users without going to the remote cloud. The main goal is to reduce the response time in order to meet the needs of some latency-sensitive application. Note that the Cloudlet has the advantages of being close to the user but does not have the same capabilities as those of the central or remote cloud. Thus, its computing capacities are limited for certain services. In addition to its proximity to the users, Cloudlet also has the advantage of being exploited by mobile users who do not even have an Internet connection [305].

4.7.5 Fog computing

Fog Computing is another Edge Computing architecture system. Fog computing reduces the amount of data that should be proceed and stored on the cloud. Fog is an extension of cloud technologies, however, placed closer to the actors and devices that produce data, users and IoT devices. In Fog, IoT devices are called fog nodes. Every device with computing, storage and network connectivity can be fog node. These nodes are spread everywhere inside a network [305].

4.7.6 Multi-access edge computing

Multi-access Edge Computing is the latest version of Edge Computing that was developed back to 2014 by European Telecommunications Standards Institute (ETSI) as the key enabler for 5G networks. It enables the resources provision through cloud servers close to users via the Radio Access Networks (RAN) tickets. According ETSI, MEC achieves essential latency reduction and permits the user’s location detection in a better way by the operator. The main goal of MEC is to increase the bandwidth and decrease the latency improving the quality of services for mobile applications.

Edge computing provides storage and computation services at the edge of a network. The usage of edge computing provides better experience to network users, as it provides better quality of services, reducing latency and bandwidth, and it is located closer to the users. The last fact has as impact data of users be more protected as closer to its owners. Furthermore, data that is stored in MEC instead of cloud environments could be considered as more secured, because it is kept by a reliable server, where security and privacy techniques have been applied, and not by a server service provider, who is located away [304].

There are three layers in the Multi-access Edge Computing architecture, namely Networks, the ME Host Level and the ME System Level. There are no specific MEC entities that should be used in order for several networks to have access to Edge Computing. The second level of the architecture includes the ME host and ME host level Manager. The ME host consists of the ME platform, the ME application and the Virtualisation Infrastructure, and provides storage, network and computing resources to ME applications. The ME platforms can communicate between each other over an Mp3 reference point. In this way, several ME platforms can be grouped and create a communication grids. ME application interact with ME host using a Mp1 reference point. The ME platform manager, which is part of ME host, is dived into several groups, the ME platform element management, the ME application lifecycle management and the ME application rules and requirements management functions.

Edge Computing environment will improve many existing services and IT systems, as it can provide services that rely on low latency, accurate location data, high bandwidth and available throughput. In terms of IoT networks, Edge Computing can provide different services that are able to improve the performance of IoT networks. Analytic applications of data that IoT devices exchange can be hosted at Edge Computing and provide results in real time. Analytics regarding improvement of performance of the network, prevention of situations and alerts, identification of other devices, humans, objects, etc., creation of behaviour rules, security solutions and many other can be performed and extracted very fast locally [306].

4.7.7 5G

As the wireless communication has gained more and more ground and has become an important part of the society, the evolution of it is essential. Since satellite communication, television and radio transmission has advanced to pervasive mobile telephone, wireless communication has transformed the style in which society runs. As the wireless technologies are growing, the data rate, mobility, coverage and spectral efficiency increases. The main difference between last generation and next generation networks is the method of implementing a telecommunication network that they use. For example, 1G and 2G use circuit switching, while 2.5G and 3G use both circuit and packet switching. In this case, the new networks generation, 5G uses packet switching.

5G networks are the next generation of mobile internet connectivity. It offers faster speeds and more reliable connections on smartphones and other devices that ever before. The 5G networks operate in high frequency band, between 28GHz and 60GHz, which range is known as millimetre wave spectrum.

5G is one of the key enablers in smart cities cases, where, as it has been mentioned above, IoT network devices will produce and exchange information/data via 5G networks and Internet. 5G can significantly contribute to IoT by connecting billions of smart devices to create massive networks of IoT without human factors [307].

4.7.8 Machine to Machine- M2M communication

Machine-to-machine-M2M communication is a technological enabler of smart cities that enables connectivity and communication between two or more autonomous devices with small human contribution or without. M2M communication is the basic feature for supporting data transfer among IoT devices, like sensors and cameras to facilitate various smart city applications. Furthermore, there is possibility of supporting massive number of machine type communication, however, this comes with a challenge that is related to the multiple access in the network and to the minimisation of network overload. M2M communication allows not only sensors and cameras to exchange data between each other, but, mobile devices, like phones, tablets, smart watches, etc. Many smart city applications can be supported with the use of machine to machine communication. Some examples of these applications could be smart meters, security and resilience, smart parking systems for drivers, e-health applications and many others. In M2M communication, devices are connected to the infrastructure in a wired or wireless way. Wireless access method can be either capillary or cellular. Wired connection has many benefits, like high reliability, high rates and small delay, in many cases, it is not suitable for smart city's applications because of the high cost and the lack of scalability and mobility. On the other hand, the wireless solution is less expensive, low power and more scalable, however, it comes with some disadvantages as well, like low rate and weak security. The last-mentioned case is about capillary wireless solution. There is another wireless solution that is cellular, which has overcome the problem of capillary M2M solution and is more suitable for smart city's applications [308].

4.7.9 Human to Machine - H2M communication

Human-to-machine- H2M is a form of communication where humans interact with a variety of devices, like smart devices, sensors, etc. This kind of communication can contribute to the improvement of everyday life in a smart city concept, as users will have the opportunity to be updated with the latest news and useful details when it is necessary regarding the living in a big city (traffic in main highways, faster access to hospitals for emergencies, etc.). Some of the benefits of H2M communication include the easier and faster alarming users, the flexibility of the ways in which users can be informed from the system, and the immediate incidence response to emergencies [309].

4.7.9.1 Robotics

Robotics is another technological enabler of smart cities, as the collaboration between human and robots can provide great contribution to many sectors of a smart city concept in the future. The adoption and the integration of robots with urban facilities and environments can transform a city to smart very fast. Some big cities that have adopted robotics in order to become smarter are Tokyo, Singapore and Dubai.

There are two questions that we should take into consideration when we would like to adopt robotics in such cases. The first question is related to how robots will work and interact with humans. A use case of it could be the adoption of robotics by Japan in 2020 regarding the Olympic Games. Robot taxis will drive the people who will visit the country for the Olympic Games, Smart chairs will serve disable people in airports and smart robots will interact with tourists in 20 different foreign languages, make their trip easier.

Another use case is Dubai's smart cities projects that include robots working in public services. The same happens in Rotterdam, in the Netherlands. Furthermore, police officer robots are in plan for the future.

Also, Singapore's national government plans are about introducing robots as physical extension for management and city control of existing systems. Moreover, hotels have adopted robots to clean rooms and provide services to clients [310].

Some application of robotics in smart cities include fully automated trash removal, self-guiding drones and public transportation.

Fully automated trash removal will be featured of future smart cities concepts. The concept of fully automated trash removal starts with a self-driving garbage truck, which will be able to communicate with sensors. Through these sensors, it will be able to track routes to garbage points around cities. Furthermore, an automated drone will scan the area and let the truck know about hurdles between the truck and garbage points, making the process easier. When the truck collects garbage, will return to the garbage truck, a camera will be ready to give instructions about the next step, which is the collection of rubbish from the second truck without the contribution of human factor. The name of this project is ROAR- Robot based Autonomous Refuse Handling and it has been tested and applied in Sweden by Volvo groups, Malardalen University, Penn State University, Chalmers University of Technology and Renova.

Another example of robotics applications in a smart city concept is drones. As it has been mentioned above, the use and

Finally, robotics is applied on public transportation as well. Apart from autonomous vehicles and self-driving cars, this application includes subway trains, buses, boats and all transportation infrastructures of a city. An example of this case is the Sidewalk Labs, which tries to transform Toronto's Quayside waterfront neighbourhood into a smart city, where driverless cars will play a huge role [311].

5 Digital strategies for service business models

5.1 Evaluation criteria

Following the analysis conducted in the earlier chapters it can be established that cities not only have different goals and agendas fuelled by their pains and challenges, but can also be on a different maturity level in their journey to become smart and ultimately, circular. Following this study, a list of measures and factors is produced, as shown in Table 11 that describe a Responsive City. The sources of the information will be endogenous to the city or external.

Table 11 Responsive City - metrics and factors

Dimension - Factor	Description – metric	source
Environmental		
CO_2 emissions	CO_2 emissions from the burning of fossil fuels (kilotons)	IoT sensor (real-time) World Bank
Methane emissions	emissions that arise from human activities such as agriculture and the industrial production of methane.	IoT sensor (real-time) World Bank
Air quality index	PM2.5, PM10, O3, NO2	waqi.info (real-time) IoT sensor (real-time)
UV Index	UV index values on the ground	IoT sensor (real-time)
Noise pollution	db. levels	IoT sensor, mobile device/crowd
Environmental performance index (EPI)	Monitors the environmental trends and effects of policymaking. Scale 1 (poor) – 100 (good)	epi.envirocenter.yale.edu
Future climate	Percentage of the rise in temperature in the city during the summer forecast for 2100 if pollution caused by carbon emissions continues to increase.	climatecentral.org
Access to the water supply	Percentage of the population with reasonable access to an appropriate quantity of water	World Bank
Renewable water sources	Total renewable water sources (per capita)	Food and Agriculture Organization
Solid waste	Average amount of municipal solid waste generated annually per person (kg/year)	Council’s waste management service
Transportation		
Traffic index rate	Traffic Index is a composite index of time consumed in traffic due to job commute, estimation of time consumption dissatisfaction, CO2 consumption estimation in traffic and overall inefficiencies in the traffic system.	numbeo.com

Inefficiency index	An estimation of inefficiencies in the traffic. High inefficiencies are usually caused by the fact that people drive a car instead of using a public transport or long commute times. It can be used as a traffic component measurement in economies of scale.	numbeo.com
Index of traffic commuting to work	Index of time that takes into account how many minutes it takes to commute to work.	numbeo.com Crowdsensing (real-time)
Bikes per household	Percentage of bikes per household	Euromonitor IoT/crowdsensing (real-time)
Bike sharing	This system shows the automated services for the public use of shared bicycles that provide transport from one location to another within a city. The indicator varies between 0 and 8 according to how developed the system is.	Google – bike-sharing world map Local providers (real-time)
Vehicles	Number of vehicles in city (thousands)	Euromonitor Traffic management sensors (real-time)
Roadway Congestion index	A measure of vehicle travel density on major roadways in an urban area. An RCI exceeding 1.0 indicates an undesirable congestion level, on an average, on the freeways and principal arterial street systems during the peak period.	Smart road sensors (real-time)
Vehicle ownership per household	Percentage of vehicles per household	Vehicle registration authority
Passengers per trip	Average number of passengers in a private vehicle	Crowdsensing & traffic management sensors (real-time)
Autonomous to human driven vehicles ratio	This measure is for future use, to measure the transition to autonomous vehicles	City transport ICT infrastructure
Peer to peer vehicle renting	This measure correlates to the utilisation of private vehicles.	Crowdsourcing application – city's ICT infrastructure, smart contracts
Energy		
Energy consumption	MWh	Local energy providers and stakeholders
Renewable Energy generation	This includes the energy produced by the citizens (kWh)	Smart grid (real-time)

Energy efficiency index	This is the rate of energy generation by consumption. The closer to 1 the more efficient.	Energy providers through analytics and smart meters
Healthcare		
Citizens physical activity	Steps per day or similar measure	Crowdsensing through the smart devices
Citizens wellbeing	Objective (e.g. employment) and subjective factors (e.g. how we feel)	Self-reported data and data mined from smart devices
Health incidents	Personal and collective measures	Data from smart devices and sensors installed in future healthcare devices (e.g. ambulances, defibrillator)
Incident response time	Mean, 90th centile, target, Deviation	Data from health providers
Outpatient treatment	Number of outpatients' appointments vs. in patient treatment per category	Hospital episodes statistics
Technology		
5G coverage	Percentage of 5G area coverage	Mobile Network Operator
Integrated infrastructure	Percentage of intelligent assets available to city's API	City APIs
Software Defined Network	Percentage of networked components that are fully SDN enabled	City's network asset register
Service availability	ratio of total time-outages by total time.	Service provider
Open Data	Ratio of data decoupled from applications and vendor lock-ins.	
Incident response	Mean time to recover from security incidents	Security and safety service provider
People and communities		
DARE Index	The Digital Accessibility Rights Evaluation (DARE) Index is used to measure compliance with the Convention of Rights with People with Disabilities.	g3ict.org
Happiness index	An index that measures the level of happiness of a country. The highest values correspond to countries that have a higher degree of overall happiness.	worldhappiness.report
Citizen's Engagement	Engagement measures the interaction and participation of citizens through local crowdsourcing applications	happyplanetindex.org

5.2 Human aspects

5.2.1 Persuasive interventions

Technology can be designed to influence behaviour. This goes beyond the mechanics included in digital media to increase user retention and engagement. It can indeed be designed to lead to a lifestyle and real-world behaviour change. Technology-assisted behaviour change solutions are on the rise. Examples of that include gamification and persuasive technology and serious games. For example, persuading citizens to adhere to a speed limit is usually done through fines and penalties. However, solutions around showing the driver a smiling face on a street panel are a way to reward positive behaviour. Persuasive solutions can also be implemented in a social style, e.g. by comparing behaviour to others, e.g. in some smart cars which show a person how they compare to other drivers in being eco-friendly as a way to encourage taking the public transport and the bikes.

Digitally-assisted persuasion centres on the use of software solutions to increase the will of people to follow certain behaviours and prevent others [312]. For example, it is used to encourage adherence to fitness programs [313] and to assist smoking cessation [314]. Such digital motivation solutions build on the well-established motivation theory, widely defined as the “psychological processes that cause the arousal, direction, and persistence of behaviour” [315]. The element which facilitates an increase in the will of a person to follow certain behaviours is called a “motive” [316]. Gamification [317] and persuasive technology [318] are examples of paradigms that employ DM and use software-based motives.

Current gamification design methods inherit elements and characteristics from game design methods [319] ,[320] and are mainly focused on the implementation and testing stages, e.g. with limited tools and concepts that suit the analysis and requirements stages [321]. However, as gamification is a secondary system, i.e. operating on top of a serious business objective such as learning and answering customers calls, its design shall consider both the underlying system and the game mechanics augmenting that system. Omitting the nature of that primary system, the intentions and capabilities of personnel, as well as the social structure of the organisation in terms of roles and hierarchy, introduces risks of inefficiency and determinability. It can also lead to game mechanics that conflict with the primary goals and preferences of their subjects. This introduces severe side effects on citizens work style and well-being [322], [323], [324]. The approach proposed in another work provides constructs and mechanisms to detect these potential risks early in the development life cycle and filter the space of alternatives at the strategic level of goals and recommend viable design options which are consistent with their socio-technical systems [325]. This includes the detection of a conflict of interest and potential for social loafing when a gamification technique is introduced to a task performed by individual actors.

Emotions and their formalisations have been another topic of research in systems analysis and design. Sometimes referred to as affective computing [326], emotions have been little if at all, discussed in the process of elicitation and specification of citizens requirements from digital systems [327]. However, emotions can usually have a direct relation with intrinsic motivations, i.e. activities which are conducted through intrinsic motivations can often lead to emotions such as fun and enjoyment [328]. Such emotions can also affect the work patterns of employees of an organisation, e.g. when a new software system is introduced in their workplace [329]. Therefore, some scholars have tried to incorporate the elicitation and specification of emotions into the citizens requirements engineering practices via specific tools, such as the one proposed in [330].

Persuasive interventions are delicate issue to deal with and test carefully before application. For situations where competition or collaboration is encouraged (either between individuals or groups), the effectiveness of a reward will depend on the individual personalities of citizens and group factors (e.g. the cohesiveness of groups within an organisation). Yee similarly categorised ways to motivate video game-players into interpersonal and intrapersonal factors [331]. Interpersonal motivation related to the role of social factors (in game design) to motivate players. Such as group strategies (e.g. players motivated other group members and encouraged group loyalty) and encouraging player interaction as a key motivation to continue playing. Intrapersonal motivation related to personal achievement and immersion. A sense of personal control can enhance self-esteem by gaining respect. Similarly, DM has been used to motivate individual student engagement in learning using digital games [332]. In both contexts, entertainment and education, incorrect use of DM can lead to negative results. Therefore, it needs to be incorporated based on psychological research and understanding of motivation within the socio-cultural framework of society and without neglecting personality and individuals' contexts.

5.2.2 Citizen inclusion

To achieve citizen inclusion in smart cities, it is important for citizens to participate in the planning and renewal programmes. Arnstein [333] established the 'Scaffold of Smart-Citizen Participation' conceptual tool, to define the methods in which smart cities can include citizens. The concept consists of a conceptual ladder with eight rungs which correspond to the extent that citizens can influence the development of a smart city. The lowest rung refers to non-participation, where citizens do not participate in the planning stages and are manipulated by the planners. The next level of participation is defined as, 'tokenism', where citizens have some influence in the planning, but are not able to influence design decisions. The highest three rungs refer to, 'citizen power', where citizens can take an active participative role in the planning of a smart city. There has been some criticism of this technique, where it is suggested that empowerment and participation by the citizens may not achieve the intended aim for society [334]. However, it is argued that the conceptual tool is the most appropriate way to design a smart city, to enable discussions with the citizens throughout the planning process [335]. There is evidence that smart city strategies are often implemented without considering that up to 25% of citizens may not have access to digital, as well as Information and Communications Technology (ICTs) [336]. Therefore, planning of smart cities can only be 'smart' when it considers the potentially excluded citizens and methods are implemented to tackle digital exclusion, ensuring participation of the whole community.

Citizen inclusion can be achieved through the reliance on technology and digital media to satisfy their personal and social needs, such as enhancing their self-esteem and maximising their social capital [337] and to provide support through the use of assistive technology [338]. Such reliance can become problematic (i.e., over-reliant), leading to negative impacts on one's wellbeing due to the peer pressure and lower self-esteem as a result of comparing themselves unfavourably to others or believing that someone's online material is always a true reflection of reality [339]. Moreover, the over-reliance on digital media can result in the obsessive and excessive use of them, which is often associated with undesirable life experiences, such as reduced creativity, increased anxiety, and a neglect of the reality of life [340], [341]. Despite increasing awareness of the possible negative effects of excessive digital exposure and usage, certain individuals still seem to have strong feelings about, and intimate engagement with, digital devices and tend to ignore the associated risks.

Excessive and pathological Internet use has been recognised widely [342], [343], [344], [345] and is described using different terms, such as Internet addiction, digital addiction, and cyber addiction. The problematic relationship with technology is associated with a set of harmful consequences, such as negative emotions, destructive psychological states, and over-dependence. Originating from the attachment theory [346], problematic attachment to technology denotes an interaction style between users and the digital spaces when the former overly rely on the latter to satisfy their social needs for relatedness and popularity with gratification while interacting with others online [347].

Recent studies have discovered similarities between the symptoms of digital media use and those of classic addiction [348], [349]. These symptoms include withdrawal (feeling anxiety when unable to connect as desired), tolerance (increasing online presence, interaction and accounts), relapse (after attempting to minimize or adjust one's current usage habits), conflict (using social media despite having other priorities), and mood modification (feeling better when receiving likes and comments). Moreover, when people disconnect from or are asked to spend less time on social media and online interactions than desired, they become anxious, despite the lack of a clear and justified purpose for that online presence [350]. A report conducted in the United Kingdom shows that approximately 15 million Internet users (about 34% of the national population of Internet users) attempted a "digital detox" in 2016 [351]. However, when they went offline, 33% of participants reported having an increased feeling about productivity, 27% felt a sense of liberation, and 25% reported that they were enjoying life more. The report also noted that 16% of participants had a strong fear of missing out (FoMO), 15% felt lost, and 14% felt neglected.

It is argued that interventions should be proposed to help people take control of their social media usage, e.g., [352] and [353], and more importantly, social media should be designed to accommodate diverse techniques for the self-regulation of problematic attachment styles to improve digital wellbeing [354]. However, it remains unclear how such an intervention method should be designed when a relationship with digital media can exhibit intimacy and become a second nature for citizens to satisfy their social-emotional needs [355]. Most research on social media addiction, online identity, and online attachment only relied on offline data collection methods, which are subject to recall bias and limitations on ecological validity. For example, interviews [356], [357] surveys [358] [359], and focus groups [360] were used to capture hindsight feelings and experiences from participants without considering their as-is experiences to do with as-is scenarios.

The use of technology can lead to inclusion of citizens who have disabilities by providing assistance with daily tasks within smart cities that would otherwise be challenging. An example is the integration of automated door technologies to assist citizens in wheelchairs to negotiate buildings. Opening and closing doors has been previously identified as a common challenge for a wheelchair user. This difficulty is the result of the weight of the doors, particularly with external doors, and simultaneously having to open the door and operate the wheelchair [361].

5.2.2.1 Persuasive Tech and gamification for all types of users

Despite the benefits of persuasive interventions and their digital version, e.g. gamification, its application has potential risks. For example, the way of calculating, assigning, and displaying feedback, behaviour analytics and rewards may increase the chance for adverse ethics including lack of group cohesion, reduced self-esteem, and workarounds and cheating [322]. While gamification risks are a recognised issue, there is a lack of reference models and systematic methods to evaluate and mitigate these risks [362]. These risks have a peculiar nature due to their intermingled relation with human factors such as motivation, personality, enterprise culture and group dynamics as well as business requirements, such as increasing efficiency and quality. The work by Algashami et al. in [363] is the first step towards a design of persuasive interventions that are inclusive and sensitive to the risks they may lead to.

To accommodate diversity, Shahri et al.[322] proposed the notion of personas for digital motivation solutions. The personas were built around several factors. The first is the concerns people have around privacy and this may affect what is feasible to gamify. The second is around their preferences and ability to set goals and behavioural targets. The third is the collaborative nature of the individual which would affect whether gamification shall be based on personal or collective performance and behaviour. The fourth is around feedback on the actions and the behaviour change as some might require more frequent and timely feedback than others. The last one is about the difference in preferences around the incentives, their value and chance of winning and nature.

5.2.2.2 System design to be compatible with all users' requirements to be captured in this basis

As citizens are diverse in personality, culture values and aspiration, it is advised that technology is adapted to that diversity rather than expecting a human adaptation to one-size-fits-all technological solutions. This means that the diverse goals and motivations, as well as activities of people, should be captured as part of the early analysis stages of a system. The work by Rodrigues et al. [367] recognises such differences and propose the use of Personas to capture user models together with the other analysis artefact of a system so that users diversity are accommodated early in the systems development. The personas are used to be used in tandem to the other systems analysis tools, particular goal modelling, and act as a reference point to measure the fitness and adaptability of systems to the diversity of people who are expected to use them.

5.2.3 Accessibility

The World Bank estimates that approximately one billion people worldwide, almost a third of the population, have a disability that affects their daily interactions with society [368]. The accessibility of smart cities can enable the urban environments to provide greater opportunities for all communities. However, this can only be achieved through integration with existing assistive technologies, including screen readers, hearing aids and braille displays [369]. These technologies can assist with overcoming daily obstacles and addressing the systematic inequalities that adversely affect the quality of life for people with disabilities.

Assistive technologies are developed to assist with numerous challenges and improve quality of life [369] in a variety of locations, including the home environment and education. However, there is less use of assistive technologies in urban environments, resulting in inaccessible travel and tourism services [369]. There is a growing concept of accessible tourism that aims to make destinations, particularly cities, accessible to the entire population independent of any physical limitations, disabilities or age reference. This can result in enhancing the social and economic values of society through equal access of information, accommodation, shopping, transportation and dining [369] for the entire population.

Smart city technologies have the potential to assist individuals to overcome daily obstacles and promote equality. The Internet of Things (IoT) platform can be used to improve accessibility of cities by providing useful information to all citizens in cities, including those with disabilities. For example, a Case Study on the city of Cagliari in Sardinia, discusses the development of a mobile application, Tour Planner, which assist tourists arriving on cruise ships [370]. The Tour Planner provides detailed information about accessible routes within the city, in order for tourists to reach Points of Interest, including museums, botanical gardens and restaurants. The application can be optimised to suit specific mobility needs and provide itineraries containing accessibility information for each Point of Interest. Due to the natural and geographical features of Cagliari, tourists with disabilities are often restricted to visiting the areas around the port. However, using Tool Planner enables more tourists to reach all the attractions of interest using accessible routes and obtain a greater experience from their visit.

Technologies in smart cities can also be used to integrate public services, to provide greater financial inclusion for people with physical disabilities to navigate. For example, London’s Oyster Card provides a pre-loaded contactless smart card and therefore a ticketless payment system to reduce transaction time [371]. It is realised that people with disabilities encounter greater barriers to employment and employment within cities can be a challenge. Technologies can be used to provide greater telecommuting opportunities to enable people to work remotely, but there are also other technologies to assist people with disabilities who commute into work. The Vodafone Foundation in Spain developed a series of custom mobile applications, supported with augmented reality, to overly digital material onto physical environments. One application, ‘Follow my Steps’, utilises the user’s current location to deliver step by step audio and 3D graphics to assist with their commute [372].

For smart cities to become accessible to the entire community, technology must be adopted and therefore it is important for 7 Principles of Universal Design [373] to be followed during the development, with Smart Cities for All [2] being an important initiate for the dissemination of universal design. The initiative aims to reduce the division between people with disabilities and the elderly with the rest of the population. The strategy is collaborating with Information Communication Technology (ICT) companies, to develop more inclusive smart cities. To conform to the 7 Principles of Universal Design, smart city technologies must be useful for people with diverse abilities to avoid segregation and ensure that the design is appealing to all users. The services provided within smart cities should accommodate a wide range of individual references and abilities, as well as being simple and intuitive to use, regardless of their knowledge. Information should be communicated to the user effectively in all conditions and provide compatibility with other technologies, e.g. alternative methods of interaction.

Smart cities have great potential to reduce the barriers to full participation experienced by people with disabilities and the elderly. However, this can only be achieved with detailed consideration of usability and accessibility requirements, during the development of smart cities.

5.3 Value Chains

Cities are data-generating spaces where complex societal challenges arise, and interaction between sectors takes place, and where new solutions are possible [374]. Now, life is marked by digital technology that is transforming the relationship of individuals with cities and their urban spaces. The access to data is also transforming the global economy, positioning the supply chain under disruptive pressure. One innovation of IDEAL-CITIES is a circular-aware value chain which is formed by coordinating standardized, smart services that implement the technological enablers and where all links must cooperate to make the transition to a circular economy and circular-aware value chains.

It is also essential that all stakeholders within the economic system participate in the entire implementation process of change, finding synergies, creating new opportunities for partnerships, collaborations throughout the entirety of the value chain and cross-borders, and transforming data into value [375]

5.3.1 Ideal-Cities Value Chain Framework

The coordination of the services in IDEAL-CITIES is realized using a platform that supports the development, integration, and operational management of IoTPS applications. It is based on high impact use cases: 1) the assistance on the movement of the visually impaired and; 2) the increase on citizen safety through lifelogging. The platform will enable the capture and exchange of real contextualized information of the city; the approach of the decision-making process to facts; thus, more transparency in governance; the incorporation of a citizen-centric approach. Citizens themselves are essential for the improvement of the urban environment, and harness the power of their own smart mobile devices that already include sensors encouraging participation and resilience to the provision of open-data and Cloud technologies. Better analysis of the information will make it possible to provide efficient inter-connected and well-adapted services; finally, stakeholders will be able to share resources and reduce costs.

The business of collecting and exploiting all types of data, whether personal, machine or system generated data, can be analysed with reference to a Smart City value chain framework shown in figure 30. This emerging data value chain consists of several steps that requires assess on how value is created at each step and what types of business models are employed to do so.

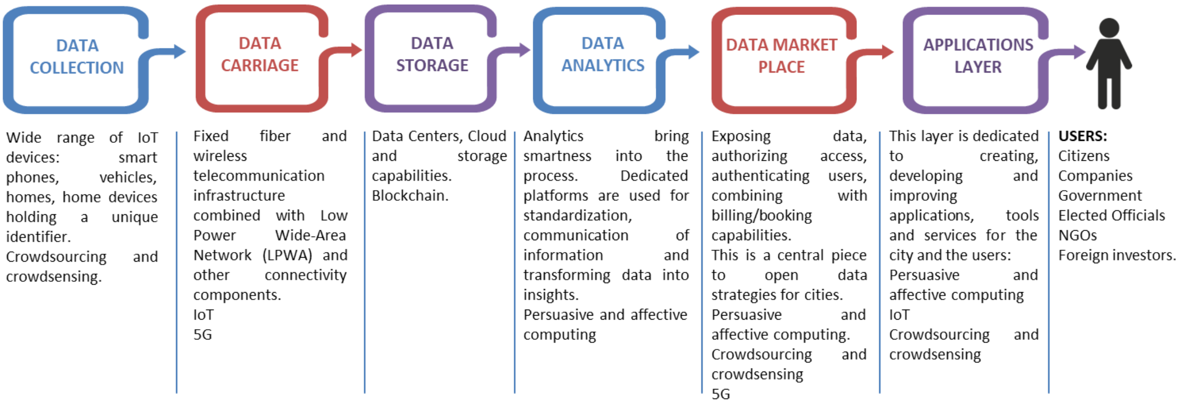


Figure 34 Smart City Value Chain. Adapted from White Paper e-madina (2016) Smart City Value Chain [376]

Moreover, the overview of the data value chain in IDEAL-CITIES shown in Figure 35, will help to envision a way to aggregate all collected information using common infrastructure and technology.

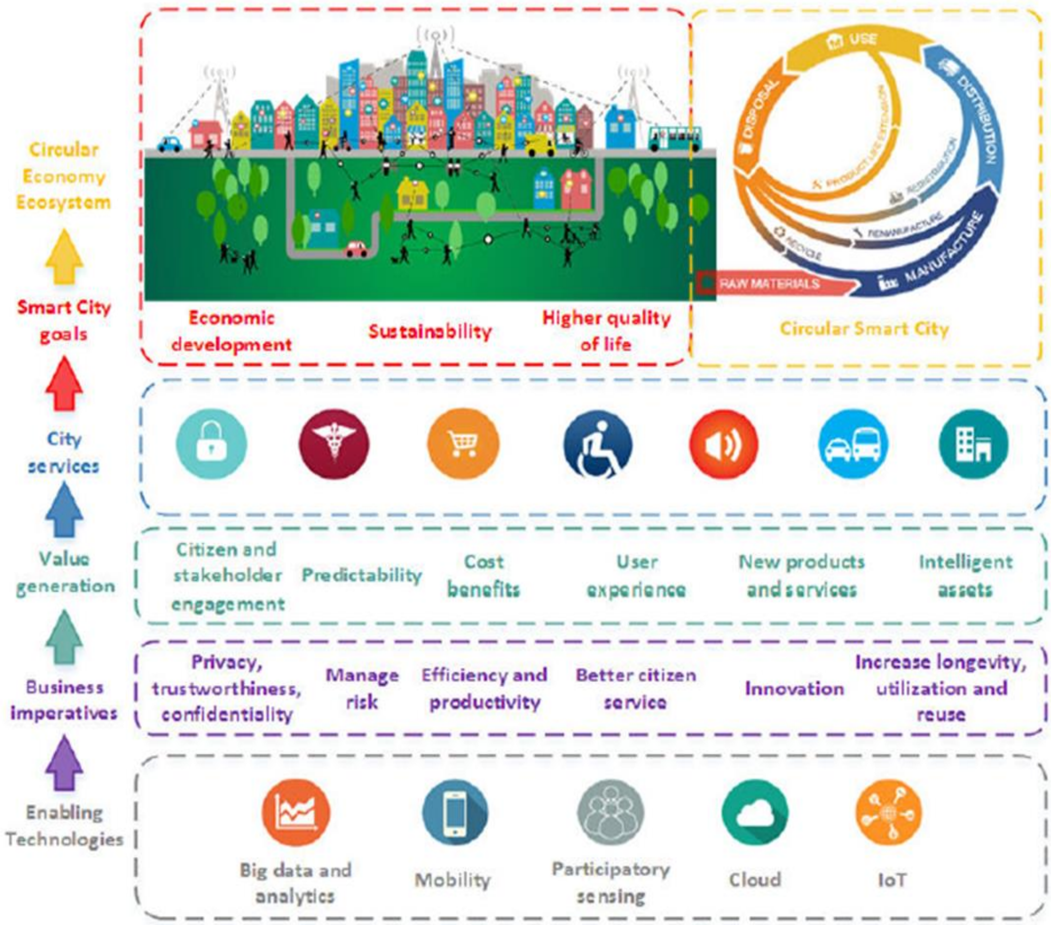


Figure 35 IDEAL-CITIES Value Chain

IDEAL-CITIES aims to develop demonstrate and evaluate an open modular platform for building adaptive Internet of Things and Participatory Sensing (IoTPS) based Smart City applications, supported by Big Data analytics and Cloud services. Big Data is a vast and complex data sets arriving from different sources, thus with a great variety, and Big Data Analytics is necessary to collate, organize, analyse the information and finally make decisions.

5.3.2 Technological Enablers for value generation

We make decisions based on data, and now there is more data collected every minute than most businesses had for a year in the 1950s. This large and complex data or datasets have different sources, and if combined with rapid increases in the scale of computer processing power and innovative technologies can enhance decision making and new business models that integrate circular economy. Technology can improve remote visibility and control of assets which are essential for business models. Some examples are the Sharing Platform business model (e.g. cars an asset sharing), the Product Life-Extension model (e.g. maintenance, repair and remaking activities) or Product as a Service (e.g. products performance basis) mentioned in section 1.3 of this report.

Technology is now included in the value chain performing activities that in the past weren't considered because of manual labour requirement or different collaborations related to the exchange of information, position tracking, schedule organization, etc. Now, with the automatization of some processes companies improve logistics implementing remote control software, white-label software platforms, etc. Indeed, digital technologies allow real-time information exchanges among users, machines, and management systems.

The design of value chains including circular business models can revolutionize services and flexibility fostered by technology. Merging physical and digital worlds, enabling dematerialization and different ways to interact with physical and digital assets. Digital technologies can transform value chains and eliminate the need of additional resources to grow.

Against all the technological enablers outlined earlier, the IDEAL-CITIES platform is composed of big data analytics, mobility, participatory sensing, cloud and IoT that are illustrated in Figure 36. These technologies are especially effective in connecting physical and digital channels, and in connecting people with the internet of things.

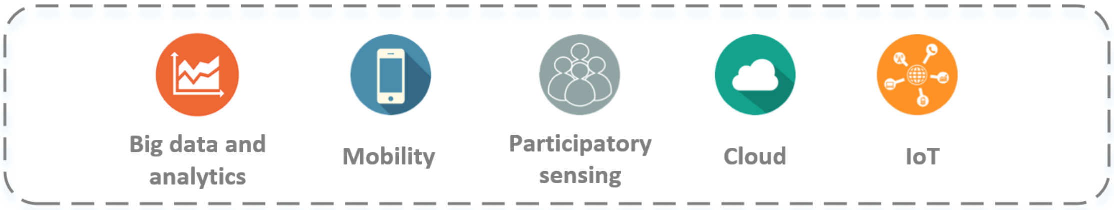


Figure 36 IDEAL-CITIES Technological Enablers

5.3.3 Data Value Chain Framework & Value Creation

After collection, data can be mined for different purposes. The need to collect substantial amounts of data to be able to find the right subset or combination of data to commercialize can also lead to vertical integration enabling companies to expand the scope of data they collect, this is especially true on platform type services [377] like IDEAL-CITIES. Figure 37 identifies five stages in the data value chain.

Figure 37 Data Value Chain Adapted from: GSMA, (2018), "The Data Value Chain."

5.3.3.1 Generation

The first step is generating the data and capturing it in digital format. A few keystrokes represent a significant volume of data and the repetition over time represents a significant dataset from which value can be created in such ways that are not easy to replicate, enabling players to gain a competitive advantage (scale and exclusivity of the data) — the more granular the information about an individual, the greater the potential value for advertisers. Thus attracting more users has many positive impacts in the form of returns from scale and scope, and the cross-group benefits of a larger user community, increasing the utility and value of the service.

There is a highly competitive market for data-generating applications and devices in many areas and any company wanting to collect new data is likely to be able to find a supplier of the necessary hardware, software and if needed a service provider to collect data.

5.3.3.2 Collection

Data collection is a preparatory event that uses a networking infrastructure to transmit and consolidate multiple sources of data before integration into an intelligible dataset. The ability to connect and transmit data between devices and storage locations is an essential function in the operation of the data value chain. It allows collating data and ensuring that the data received is accurate, that it comes from a verified source or user, that the sensor providing it is functioning correctly (quality)for the analytical stage.

As part of the process, primary data is combined with other associated data (from other locations, sources, periods, etc.) increasing the scale, scope, and frequency of data available for analysis. Reach into remote areas can be a source of value creation. A great amount of value is created by curating a robust and reliable dataset to be used in other steps, including analytics. It is, however, difficult to build a distinctive position at this stage of the value chain.

5.3.3.3 Storage

Data storage allows the organization of the collected information in a convenient way for fast access and analysis.

There is a highly competitive market for the provision of resilient cloud storage and data networks based on open standards in almost all countries, the market has become competitive in terms of price evolution. The unit cost of storing and securing data has drastically reduced and it continuous to fall each year as operators build increased scale. Thus, companies of any size have access to almost limitless storage capacity on a 'virtual' basis without the need for major upfront investment. A clear driver of growth for many data-centric businesses is the exponential growth of smartphones and other devices which allows data collection in most places at very low cost. Therefore, economics also improves.

However, there has been a gradual concentration of suppliers, where only the largest and most efficient can compete: Google Cloud, Amazon Web Services, and Microsoft Azure are now the major suppliers in the global storage market. There are also restrictions which prevent companies making full use of such scale. Many countries have data localization requirements that require companies in certain sectors, e.g. banking and telecoms, to store and process data within the country, and data storage is also arguably less secure since it is primarily dependent on the quality of the infrastructure (including physical building, redundancy, back-up, and disaster recovery facilities) rather than the geographic location of the storage.

5.3.3.4 Analytics

Data analytics allow the processing of the data through the use of different technologies and put to use to generate insights and valuable information and patterns in the data which are trades with an end-user. The raw input data is clearly an important component and mining uses sophisticated mathematical algorithms to segment the data and establish links between pieces making predictions, understanding actions and behaviours.

The most value can be created at this stage since it is the stage with the most potential for companies to innovate, develop and deploy their intellectual property and by so doing, build up more attractive, defensible and higher-margin businesses. A new entrant with innovative software algorithms but no access to relevant data would struggle to monetize this directly and might prefer to sell its software (or the entire company) to companies holding the data. In general, the market for analytics functions effectively with many providers and a constant flow of innovation in tools and applications. The ability to engage in data activities across multiple segments can lead to greater value creation opportunities. The comprehensiveness of analytic insight about a specific target could become a barrier to entry, as it would be difficult to replicate.

5.3.3.5 Data Exchange

Data exchange is the final step in the value chain; it consists in putting the insights and knowledge generated to commercial use. At this stage, the data by the end-user may be used and then reused or repurposed, perhaps several times, at least until the data becomes out-dated and then part of a historical trend which still has value. Maximizing the value thus relies on a company’s ability to develop commercially attractive services based on the insights they have developed, or to use the insights effectively to refine their existing business and marketing efforts.

In the sale of data, value is derived from the quality, volume and uniqueness of the data service provided. A key component is the supplier’s reputation for quality and integrity in terms of the source and accuracy of the data. Companies can also trade on insights, with packaged insights and information to sell services to other companies, without actually selling the underlying data. The value comes from the breadth and depth of insights a company can offer to buyers.

At date, there is not a strong trade or open market for raw data. Where data can be aggregated and anonymized, it has more potential to be collected and sold, and there are emerging marketplaces facilitating the buying and selling of data. It was observed through the existence of such services that generally the market for data exchange works according to normal commercial trading rules and principles and, in most cases, there are various competing companies offering similar services, so buyers have a reasonable choice of competing alternatives. Nevertheless, there is not a general, liquid market for data outputs. It is possible that as markets mature and technology advances, such trading will become more feasible and the barriers to trade overcome.

5.3.4 Mobility

As cities become bigger and busier, navigating around the complex and congested network of city roads becomes extremely challenging in terms of safety. IDEAL-CITIES in this sense develop a use case focus on visually impaired or otherwise mobility-challenged. Citizens requiring assistance (people with a disability, elder or injured). In such circumstances, they can greatly benefit from an IoT and participatory sensing enabled infrastructure, which in collaboration with a smartphone or wearable can enable them to arrive at their destination safely. The data generated and collected by Mobile network operators has the potential to be used for societal benefits by providing insights into the movements and actions of very large populations, given the majority of people in most countries now has a mobile device. Data from mobile networks also has potential to be used in other “smart city” applications.

Mobile operators have an important role since they are active in all parts of the data value chain. As providers of data connectivity they are important players in the collection step, providing the coverage and bandwidth for all human and machine interactions. They are the primary means of connection for smartphones which are a major source of data, in many cases they act as the conduit for data but will often not know the source or destination of encrypted data.

Moreover, mobile technology is an enabler for the adoption of circular business models allowing low-cost access to data and applications. For Circular models as Sharing Platform and Product Life Extension, mobile devices play a major role enabling a smart management of physical products.

The development and deployment of 5G mobile networks will create the opportunity for operators to increase the scope of their activities by building new services that require a high density of devices or specific low latency networks for real-time interactions.

5.3.5 Participatory Sensing

Participatory Sensing in the case of visually impaired or otherwise mobility-challenged, in addition to alerts notifications and activation of structural devices, the platform could infer the presence of ad-hoc obstacles on footpaths such as potholes, signs, parked cars or debris by observing walking patterns via participatory sensing of other (non-impaired) citizens. Thus, a visual impaired person equipped with a smartphone and a headset can navigate obstacles by following the same safe route as other citizens via listening to timely audio instructions.

The second scenario in IDEAL-CITIES is aimed at creating an IoTPS Smart City application, as part of a wider IoT infrastructure, which will be able to collect and exchange different types of lifelogging citizen information, visualize it, and provide different types and levels of alerts. Through lifelogging, for example, citizens will be able to report security and safety incidents in different city areas (e.g., broken lights or suspicious activities in certain areas, attacks to themselves or other people, or other incidents).

At the same time, additional information gathered from body sensors as, for example, the user's stress level or speed of walking can provide additional indicators of real or perceived security risks. Such information can activate smart structural devices, e.g. increase the lighting provided by lampposts or trigger alarms and help from fellow citizens who use the same IoTPS application and are in the vicinity of the user at risk. Based on such information, an IoTPS application will also be able to adapt and focus on designated city areas to collect additional data (e.g., data from video surveillance cameras), which can help authorities to investigate citizen reports and act on them. Depending on the severity of an event, for example, the whole IoT enabled infrastructure of the city could be activated (e.g., notify emergency responders, activate the video surveillance system of and area etc.). Overall, the aim of this scenario is to empower the participation of citizens in the development of a secure urban environment and to enable authorities and first responders to be instantly notified and updated with field information depending on the level of alerts. Furthermore, city authorities will be able to notify citizens of specific security incidents. They will also be able to record information of such incidents that is communicated to them for future analysis or even legal use.

6 Conclusions

A number of cities are already embracing the Circular Economy paradigm. For some of the cities, their transformation and transition commenced over a decade ago when CE was an implicit term, with a limited focus on waste and materials management. Nowadays however, true value generation is seen to stem from a data-driven economy: a digitally connected economy that realizes significant value from connected, large scale data that can be rapidly analysed by technology to generate insights and innovation [378].

In this context**,** data-driven Circular Economy has been identified as an emerging paradigm cross-cutting several verticals as it refers not only on assets but also services and knowledge. 5G infrastructures, including IoT and Software Defined Networks are considered as the enabling technologies to realize data driven Circular Economy concepts.

In order for cities to become "CE-enabled", transformation will need to happen at all levels; cities that attempted to invest only on technology managed to attain a smart city status. However, in order to achieve sustainability, the city would need to be a *responsive city***,** a city capable of adapting to the continuously changing environment by optimising the use of its finite resources, a city that respects its resources and assets; a city that can *listen, understand and respond* to the changes, both proactively and reactively. The two key ingredients for achieving this is data and people. A direct consequence of recognising that no smart city can involve their citizens solely as recipients of its inventions, is the requirement for the city to be fully inclusive. Technological advances often introduce barriers which affect inclusion and accessibility; The IDEAL-CITIES project studies outlier use cases, in order to establish how *all* citizens will enjoy a high quality of life. Participation, inclusivity, accessibility, safety and happiness are the non-negotiable hard requirements driving the transition to a sustainable city.

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