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Article

Smart Cities' Strategies to Ameliorate Environmental Impacts of Rapid Urbanization in Beijing, China

Paulina Rodríguez Fiscal[1], Rallou Taratori[1] Marie Abigail Pacho[1], Christos S. Ioakimidis[2] and Sesil Koutra[1,3,*]

[1] Faculty of Engineering, University of Mons, 7000 Mons, Belgium; paulina.rodriguezfiscal@umons.ac.be (P.R.F.) rallou.taratori@umons.ac.be (R.T.); marieabigail.pacho@umons.ac.be (M.A.P.); sesil.koutra@umons.ac.be (S.K.); cioakim@certh.gr (C.S.I.)
[2] Center for Research and Technology Hellas/Hellenic Institute of Transport, CERTH/HIT, 6th Km Charilaou—Thermi Rd., Thermi, Thessaloniki, Macedonia, 57001 Hellas, Greece
[3] Faculty of Architecture and Urban Planning, Faculty of Engineering; Rue d'Havre 88, University of Mons, 7000 Mons, Belgium
* Correspondence: sesil.koutra@umons.ac.be

Abstract: One of the main drivers behind the urbanization process is attributed to economic fundamentals of urban growth, which boost migration from rural to urban context. This migration can be studied geographically, with increasing rates of population as the main component in developing countries, over Asia and Africa, specifically. Research has been focusing in creating models and adaptative schemes to manage and plan cities to promote sustainable development for housing large quantities of population and preserve a long-term living environment. The approach from a smart city perspective, adjusted to the rapid urbanization condition can be helpful to deal urban issues by convergence and interaction between urban agents and information technology. At academia, few works have addressed the role of Smart Cities to face the challenge of rapid urbanization. The aim of this study is to research and analyze if strategies with smart city vision can lessen environmental impacts at cases with rapid urbanization, and how can we leverage technology to promote environmental sustainability at rapid urbanization phenomena occurring at developing countries using RIAM environmental assessment method in the case of Beijing, China'.

Keywords: Developing countries; Environmental Impact Assessment; Rapid urbanization; Smart strategies

1. Introduction

According to World Population Data Sheet 2020 by the Population Reference Bureau, there is an estimated amount of 7.8 billion people worldwide in 2020, and the projections indicate that the global population could grow to around 9.9 billion in 2050 [1]. From the other side, the United Nation´s report World´s Cities, 55% of the world's population lived in urban zones in 2018, a ratio that is expected to increase to 68% by 2050 [2]. To accommodate this rapid growth, experts calculate that USD $57 trillion in global infrastructure investment is required by 2030 alone, new houses for 3 billion people and more than 1 billion people live in housing that is below minimum standards of sanitation and comfort [3]. Therefore, encouraging sustainable urban development worldwide is essential, since UN Environmental program estimates that cities are responsible for 75% of global CO_2 emissions, with buildings and transport being among the main contributors [4].

The term 'urbanization' is used to measure the increase in the percentage or share of the population settled in urban areas against to the rural areas [5]. This migration takes places for several factors that function synergetic, known as push (the causes for rural movements- and pull (city attractiveness) factors [6]. Some common push factors are: the land disagreements, landlessness, catastrophes, poverty and lack of services, while pull factors include employment potential, better services and facilities, safety and less risk of natural threats, and political security [7].

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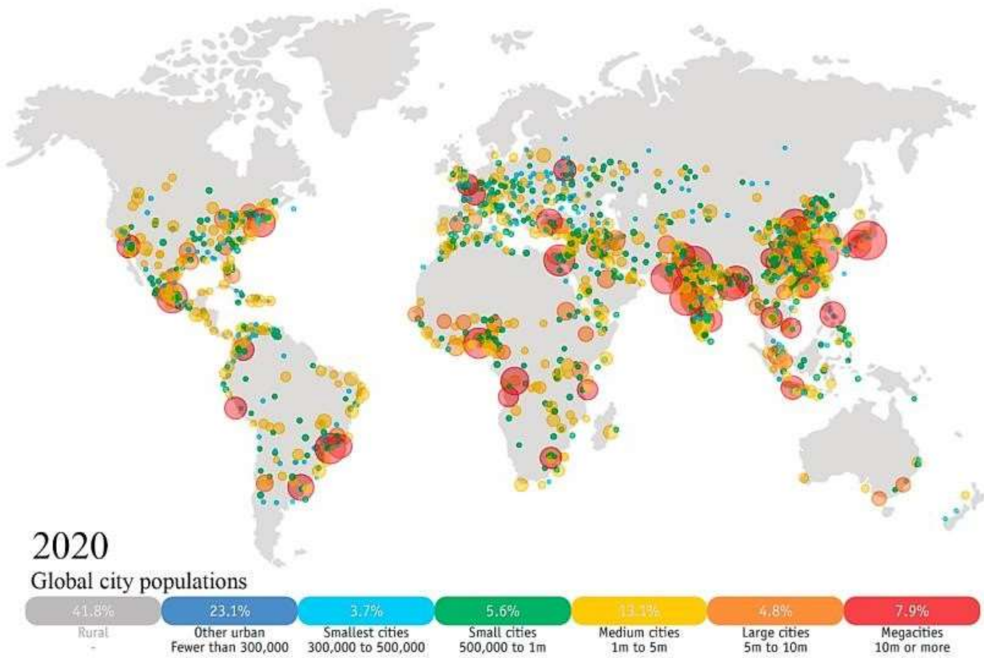

Figure 1. Urbanization worldwide in 2020 [8]

Urbanization is complex phenomena: although urbanization is linked to promote economic prosperity and QoL, it boosts issues such as high consumption of resources and energy, in addition to deterioration of the ecological environment ([9]-[10]). A lot of cities, especially across Asia and Africa, are encountering rapid urbanization, which conveys many social, economic, and environmental challenges.

1.1 Rapid Urbanization in China

China is a great example to explain the global trend towards urbanization. Since 1980, China, as the world's largest developing country, has experienced unprecedented large-scale and rapid urbanization, with the urbanization rate increasing from 17.92% in 1978 to 58% in 2017 [11]. Africa and Asia – both still comparatively less urbanized than other regions – will be the fastest urbanizing regions with the urban population projected to reach 56% in Africa and 64% in Asia by 2050, currently at 40% and 48%, respectively [12].

Between 1950 and 2010, China added more than 605 million inhabitants to its urban areas (Fig. 2), increasing its level of urbanization from 11.8% to 49.2% [13]. If the United Nations projections are accurate, China is expected to add an additional 380 million inhabitants to its urban areas between 2010 and 2050, raising the level of urbanization from 49.2% to 75.8% [14].

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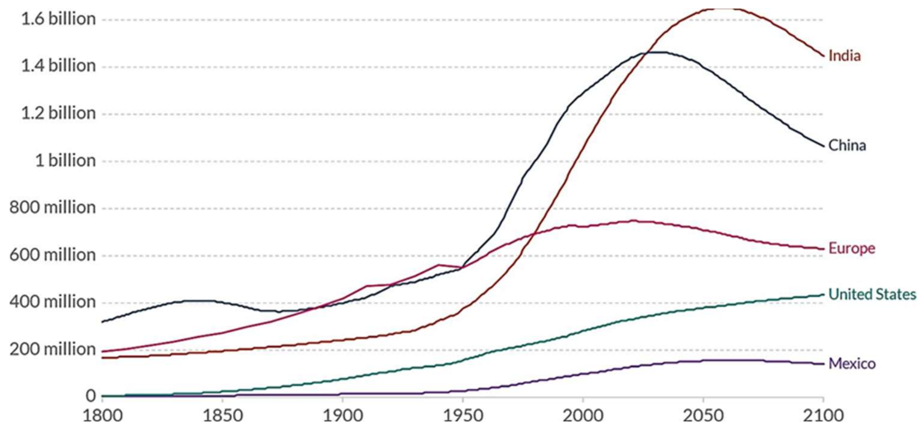

Figure 2. Historical estimates of population [14]

Furthermore, Zhang et al. [15] argue that the phenomenon occurred in Chinese territories fails to acknowledge that an important cause is a result of changes in administrative divisions since 1980s. Farrell [16] conceptualizes this multidisciplinary of the components of the urban growth as a primary mode of analysis as it is represented in Fig. 3.

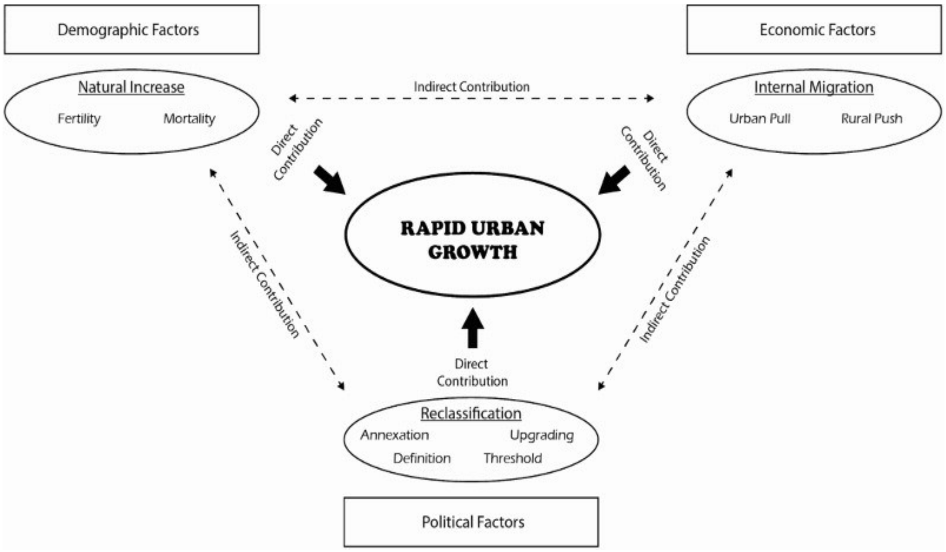

Figure 3. Rapid urban growth triad [16]

From the 20 fastest-growing cities in the world, 7 of them are located in China (Fig. 4), with Shanghai, Chongqing and Beijing as the three top cities with highest rates in that country [13].

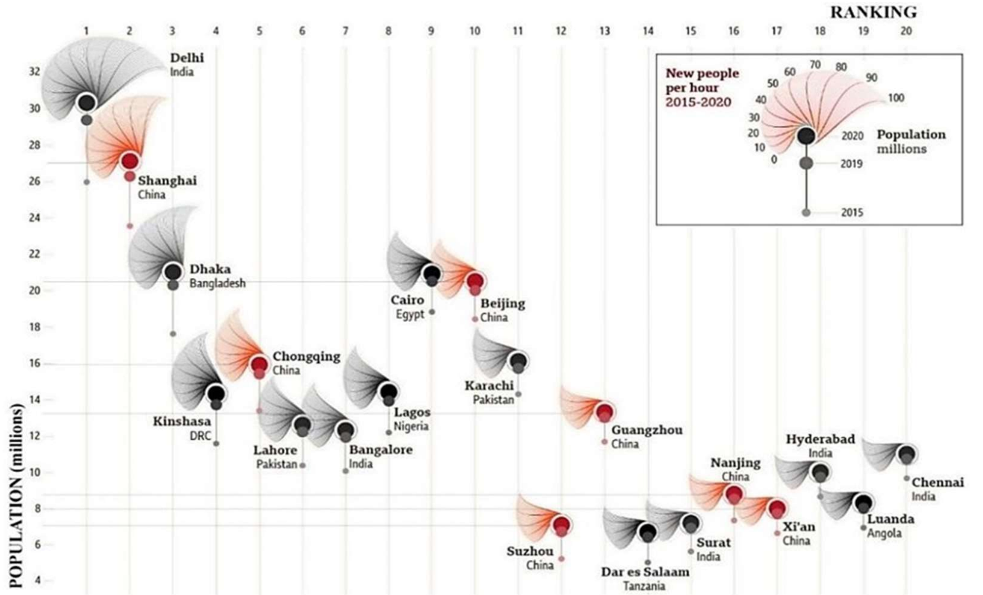

Figure 4. Top 20 fastest growing cities (2015-2020) [17]

From the other side, Beijing, the administrative center of China, has an urban history of more than 3000 years and a history as a capital of contemporary China for over 800 years [18]. The city of Beijing is located on the northern area of the North China Plain and is around 30 to 40 meters above sea level. The Yan Mountains lie along the municipality's northeastern side, and the Jundu Mountains occupy its entire western region (Fig. 5); together these form a concave arc that circles the Beijing lowland from the northeast to the southwest to form what is known to geologists as the "Bay of Beijing". The city was built at the river mouth of this bay that opens onto the great plain to the south and east, and between two rivers, the Yongding and the Chaobai, which eventually meet to flow into the Bo Hai (Gulf of Chihli) in Tianjin. municipality, about 100 miles (160 km) southeast of Beijing. South of the city, the plain stretches for about 400 miles (650 km) until it merges with the lower valley and the delta of the Yangtze River [19].

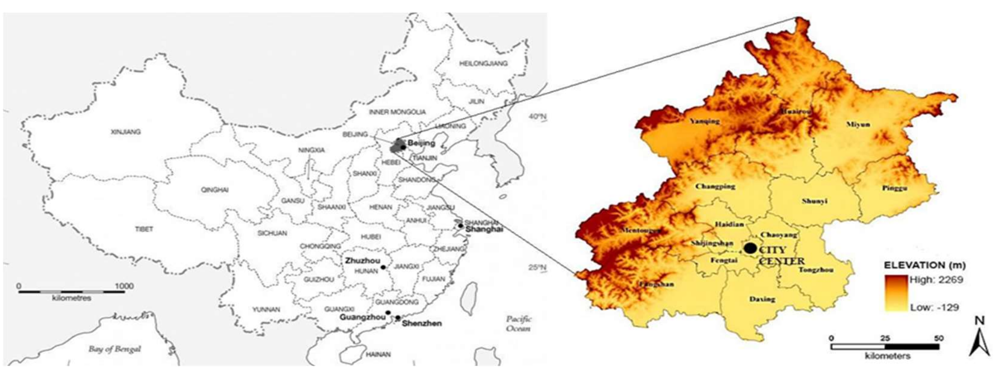

Figure 5. Location and administrative division of China. Location and topography of Beijing [20]

In Beijing, from 1978 to 2015, the area of urban land increased from 800.95 km^2 to 2,636.54 km^2 increasing annually at 3.7% (Fig. 6). Spatially, Beijing's urban expansion presents a mononuclear concentric polygon pattern, similar to its circular traffic system [21]. This pattern primarily results from its respective topographic constraints as well as urban planning and policy. Beijing suffered from the restriction of the Taihang Mountains in the west and the Yanshan Mountains in the north. Therefore, urban expansion of Beijing was mainly concentrated in the southeast of the city [19].

The urban area of Beijing was limited to the area within the Old Town before 1949, which is currently marked as the second ring road with a low urbanization rate. Beijing, which acts as the political, economic, cultural and educational center, as well as being China's most important center for international trade and communications, has expanded modestly after the founding of the People's Republic of China ([22]). Urban expansion of Beijing began to accelerate after the Chinese economic reform in 1978, bringing massive encroachment into the surrounding countryside (Figure 6) [23].

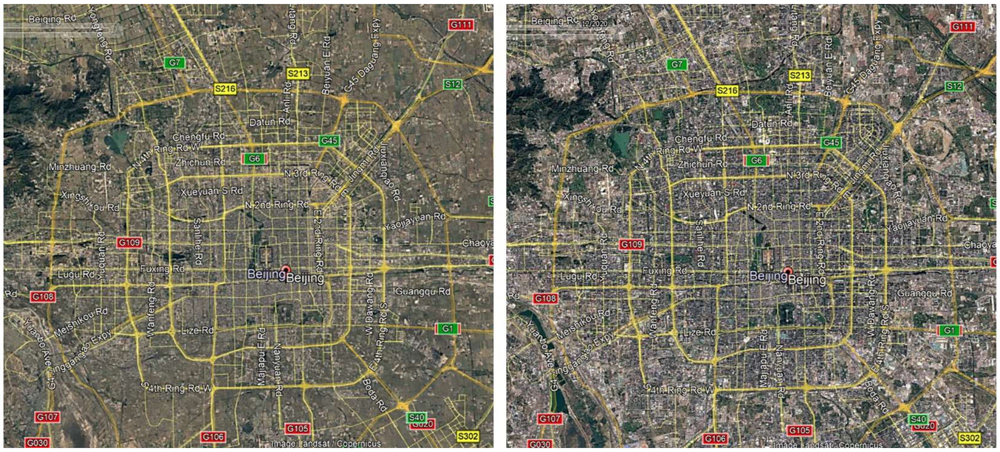

Figure 6. Satellite images of Beijing in 1984 and 2020 (Google Earth)

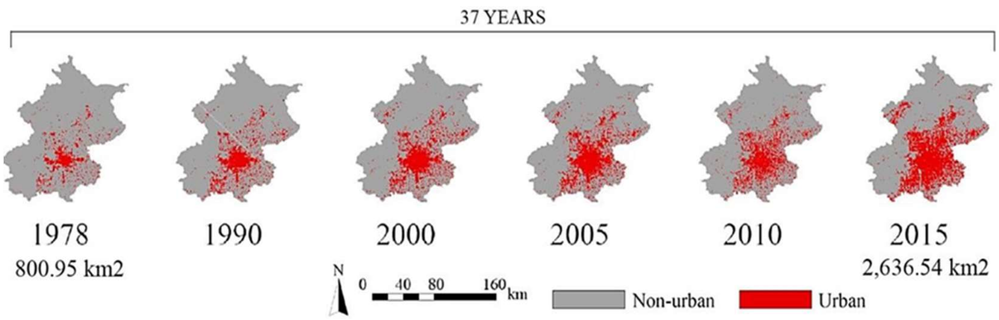

Figure 7. Change of spatial extent of urban area in Beijing from 1978 to 2015 [21]

After the 1980s, rapid urban sprawl in Beijing became one of the main forms for the development of suburban land. Industrial development on Beijing´s urban fringe was a major driving factor of urban land expansion in the early period [24]. Due to the deindustrialization process since the end of the 1990s, the city presented a remarkable increase of residential and commercial land on the city fringe of Beijing [25]. Beijing established a population target in 2000 of 18 million people by 2020. However, data showed 21.4 million people in 2016. In Beijing's Long-term Development Master Plan, a population of 23 million people was forecasted for 2030 with no growth after that. Beijing is striving to be one of the most livable cities in the world, mainly focusing on the central government district, the culture center, and its high-end service sectors [26].

In the 1990s, the Beijing government determined development targets for Beijing to become a global city comparable to London, Paris, New York, and Tokyo. With targets driving the economic restructuration since 1995, the share of industry decreased from 44.1% in 1995 to 19.1% in 2016, while the tertiary sector accounted for 80% in 2016, similar to other global cities. Within the long-term plans for Beijing, only the industries suitable for a city will remain, such as advanced electronic products, high-tech products manufacturing, and food products production [26].

China's agricultural development and economic reforms have accelerated the rate of urban expansion as they have stimulated economic growth and increased income levels.

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In this context, a key concern for policymakers is currently how to guarantee the health urban development and cope with its both direct and indirect effects such as urban populations growth, agricultural land loss, rural decay, rising unemployment, and deficiencies in public service and urban infrastructure [27]. According to data from The World Bank, in 2020 China´s urbanization rate was 63.89%, against a 5.95% of the annual GDP growth rate (Figure 7).

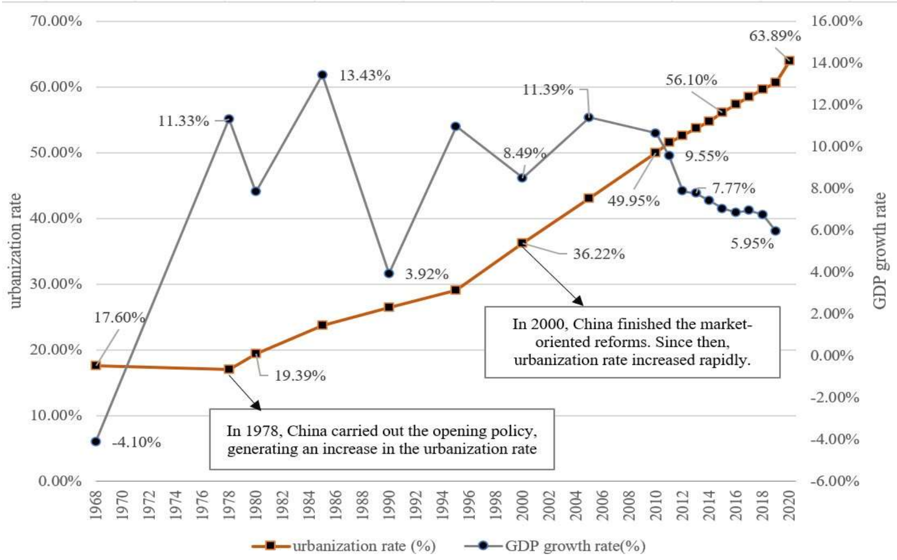

Figure 8. China´s urbanization rate vs GDP growth (1968-2020) Own authorship, data from The World Bank [28]

1.2 Research objectives

To fully understand the current state of this concept, several research questions were generated:

◎ How Smart city strategies can lessen environmental impacts at cases with rapid urbanization?

◎ How can we leverage digital technology to promote environmental sustainability at rapid urbanization phenomena occurring at developing countries?

1.3 Organisation of the Work and Structure

In this Chapter 1 of the article, a brief introduction to the concept of urbanization, and more specifically to the challenge of rapid urbanization in China, is established. In the following Chapter 2, the most typical methods (e.g., EIA, SEA) and tools (e.g., matrices, checklists, networks) available from the literature for acessing the environmental impact of processes will be explored and benchmarked against each other, to finally select the tool for the analysis of this study (i.e., RIAM). Next, in Chapter 3, the RIAM methodology allong with its assessment criteria will be presented. What is more, this chapter the collection and selection of KPIs and the assessment of impacts for this study will be discussed. Moving forward to Chapter 4, the case-study application in Beijing, China will be extensively analysed. The results, organized in a visualised table, will be presented in Chapter 5, followed by the discussion Chapter 6 and the concludory remarks in chapter 7.

2. Materials and Methods

2.1 Environmental and Impact Analysis

Impact assessment (IA) is identified as *"the process of identifying the future consequences of an ongoing or proposed action"* and it aims to promote sustainable development by providing

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scientific information on the possible impacts of a proposed action to decision-makers as well as to the public" [29]. Within environmental assessments, the need for structured handling of complex systems became increasingly clear as environmental concerns related to technical systems increase, but a sustainability approach came into consideration in these evaluations in the beginnings of 1990´s [30].

Environmental systems analysis is one branch of systems analysis used for analyzing, interpreting, simulating and communicating complex environmental issues from different perspectives and includes several methods and tools for the environmental assessment of anthropogenic systems using a systems perspective [30]. The main objective of an Environmental Impact Assessment (EIA) is to prioritize the environment in the decision-making process by assessing the environmental consequences of a proposed action, with long-term consequences, which includes almost all development activities, since sustainable development depends on the protection of natural resources, basis for further development [30].

Andersson et al. [30] propose a classification on the existing tools in: aggregated, analytical, and procedural (**Figure 9**).

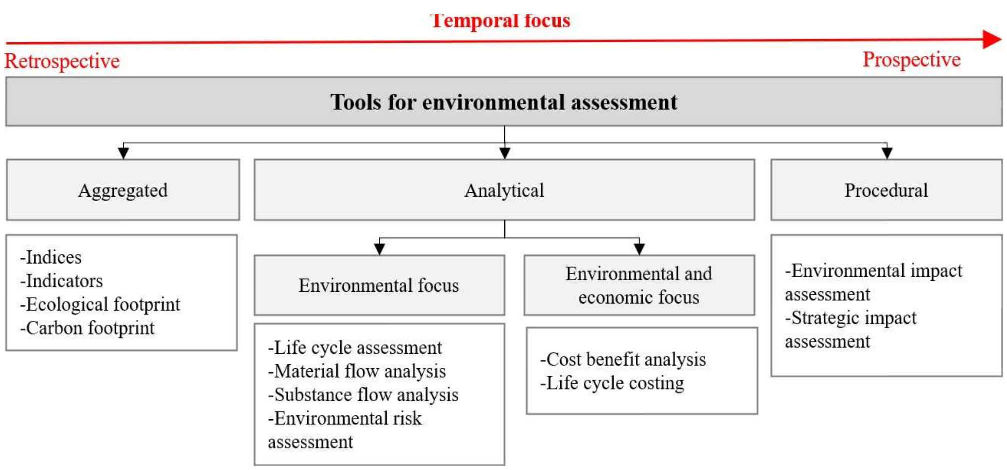

Figure 9. Categorization of existing tools for the environmental assessment [30]

The aggregated tools are necessary because they manage a format that is clear and easy to communicate; indicators and indices help to simplify, understand, and communicate complex statistical information. The analytical tools focus on the quantification of material, energy and economic flows, and these calculations are often standardized. Procedural tools involve and consider many types of criteria (including economic, environmental, and social) and define the process of conducting an assessment [31].

Andersson et. al. [30] proposed a temporal focus of these tools [32]: the arrow on the top of the framework in the temporal focus, which starts as retrospective focus (indicators/indices) moving towards prospective (integrated assessments). The temporal aspect emphasized in relation to the tool frame was whether the tools analyze previous data or work on prospective information. Due to the criteria of procedural tools (economic, environmental, and social) and the definition of its temporal focus, the approach in this thesis will be concentrated in analysis procedural tools: EIA and SEA.

The EIA is a legal and administrative tool making it possible to identify, predict and interpret the environmental impact of a project or an activity, and it was incorporated as an environmental management tool in the United States in 1970 by the NEPA [33]. In 1992, the United Nations Conference on the Environment held in Rio de Janeiro identified a way of using EIA as a tool to encourage impact assessment during installation, operation and abandonment of projects [34].

However, some limitations of a project-specific EIA have led to the creating of a new assessment tool, SEA, which ranges the assessment of EI from the project stage to the level

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of policies, programs and plans, which provide the framework for development projects [35]. Since SEA is an important environmental management tool, the most fundamental social function is to integrate environmental criteria of climate change into the definition of strategic planning and decision making [36]. EIAs and SEAs have been accepted worldwide as tools for incorporating environmental objectives, and they differ both in the level of application and in the phase of planning. In Table 1, a comparison between both tools was made.

Table 1. EIA versus SEA

Reference	EIA	SEA
[37]	*Generates more environmentally sensitive decisions*	Occurs at the earlier stages of thedecision-making cycle
[38]	Reactive approach to the development proposal	Pro-active approach to the development proposal
[38]	*Identifies specific impacts on the environment*	Identifies environmental implications of SD
[37]	*Emphasis on mitigating and minimizing impact*	Emphasis on meeting environmental objectives

For instance, EIA seeks to determine the main issues responsible for the overall environmental burden in order to plan appropriate measures to mitigate these impacts. To achieve this, the essential question to be answered is whether a project is likely to cause significant environmental change, which can then be used as a trigger for authoritative actions relating to the project [39].

For the purpose of this study, critical elements for choosing an EIA as a tool were highlighted in italic in Table 1. The EIA process characterizes, forecasts, interprets and conveys information on the impacts of a proposed project on the biophysical environment, in elements such as land, water, air, vegetation, and animals, as well as on the socioeconomic environment of the citizens affected [40]. Therefore, for the analysis of the case of Beijing, the EIA assessment was followed.

2.2 Tools and Impact Identification

Global commitment to sustainable development has made cost-benefit analysis an integralpart of EIA, triggering the expansion of factors to be taken into account in traditional cost- benefit analysis [41]. Scoping is important for two reasons. First, so that problems can be pinpointed early allowing mitigating design changes to be made before expensive detailed work is carried out. Second, to ensure that detailed prediction work is only carried out for important issues. Review of the plan or program can be carried out by various methods, which, conditionally, can be divided into two groups: methods used for assessment of impact into environment and methods used for assessment of policies and plans (Table 2).

Table 2. Tools and Impact Identification

Tool	Characteristics
Checklist	Simple to understand and use Good for site selection and priority setting
Matrices	*Commonly used method* *Good method for displaying EIA results* *Visually describe relationships between factors*

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Networks	Link action to impact Useful in simplified form for checking for secondorder impacts
Overlays	Easy to understand Used for illustrating the geographical extent of impacts
GIS and computer expert systems	Good for impact identification and analysis Requires huge amount of data

The matrices facilitate work on the interactions between environmental components and project activities. According to Kuitunen et al. [42], some of the advantages of matrices are the visual description of the relationship between two groups of factors: the expansion or contraction to meet the needs of the evaluated proposal, and the identification of the impacts of the different phases of the project, construction, operation [29]. Regardless of the layout of the matrix, some limitations need to be addressed: Unless weighted impact scores are used, comparing many project alternatives is difficult, and scaling the multitude of scores contained within, nor is a matrix a treatable proposition, as the ability to independently reproduce the method is undermined by reliance on highly subjective judgments [42]:

Table 3. Matrix of Advantages and Disadvantages of Different Tools

Source	**Tool**	**Advantages**	**Disadvantages**
[43]	Simple matrices	Short written descriptions are provided	Not a tractable proposition There is no scaling or quantification of these impacts
[42], [44]	Scaled matrices	Intersections to indicate the magnitude and the importance The impacts could each be added and compared	Measurements do not necessarily directly correlate
[42]	Component interaction matrix	Minimum the existence and length of a linkage between any two components	Structure of these linkages is exposed
[44]	*Rapid Impact Assessment Matrix*	*Efficient in terms of in handling cases with large quantities of data* *RIAM allows reanalysis and in- depth analysis of selected components in a rapid and manner*	*Inability of these assessmentsprovide a record of the judgments*

Matrix methods identify the interactions between the different actions of the project and the environmental parameters and components; together with the integration of objectives and priorities, it is reasonable to demonstrate to decision makers the indicators that present the expected changes as a result of the implementation of the plan / program to the decision makers of an easily understandable way, and offering them the possibility of following the implementation processes [42].

They are structured as a list of project activities with a checklist of the environmental components that could be affected by these activities. This application is appropriate for developing countries, but the matrices must be developed specifically for application to sectoral and national conditions. One of the main benefits of the matrix is that any information can easily be added to it during the project [37].

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As recognized before, urbanization is an inexorable phenomenon of economic and social development, and this growth has several global environmental (and other) impacts. Rapid urbanization and growth are associated with ecological decline, since it conducts complex land cover changes as well as vegetation coverage, surface roughness of the city and the surrounding areas, affecting the urban hydrological and ecological systems [45].

3. Rapid Impact Assessment Matrix (RIAM) Methodology

There is an increased discussion about the potential to apply the RIAM method with the accelerated development of the SEA methodology around the world. RIAM uses a structured matrix to allow such judgments (both subjective and based on quantitative data) to be made on a similar basis and provide a transparent and permanent record of judgments made. The RIAM computerized system allows the matrix to be displayed graphically, which greatly improves the clarity of the results produced by this method. RIAM provides a system by which development options and scenarios can be rapidly evaluated [44].

RIAM is a matrix method established to incorporate subjective judgments transparently into the EIA process. The method was developed by C. Pastakia and A. Jensen [46] in the late 1990s, and has since been extensively tested in numerous evaluations. The magnitude of the impact of RIAM is modeled as a multicriteria problem, in which the complex nature of the concept is broken down into smaller and more accessible features [39].

The RIAM tool is effective in cases with large amounts of data, which can make it difficult to get an overview of the results. RIAM's ability to provide a clear, transparent and permanent record of judgments made in an EIA is an important step forward in improving the use of EIA. Technically, the assessment process consists of four steps which must be completed in order [44]:

-Step 1: create a set of indicators

-Step 2: provide numerical value for the indicators

-Step 3: calculate environmental scores

-Step 4: evaluate the alternatives

All the criteria cannot be given the same weight, the criteria are therefore divided into two groups: those which are individually important in their impact; and those that are collectively important. The important endpoints are divided into two groups (Table 4) [46]:

(A): criteria which are important for the condition, which individually can change the score obtained

(B): criteria which are useful for the situation, but should not be able to change individually the score obtained

Table 4. RIAM Assessment Criteria

CLASSIFICATION	NAME	CRITERIA	RANGE
Criteria related to importance of the condition	A1	Importance of condition	from 4 to 0
	A2	Magnitude of change/effect	from 3 to -3
Criteria that are useful for the situation	B1	Permanence	from 1 to 3
	B2	Reversibility	from 1 to 3
	B3	Cumulative	from 1 to 3

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The assessment criteria that are usually employed in the RIAM approach are: importance of the condition (A1), magnitude of change/ effect (A2), permanence (B1), reversibility (B2), and cumulative (B3). Against these criteria, both positive and negative impacts brought about by each alternative are assessed based on the environmental, ecological, societal, and economic indicators. Scores based on these assessments are calculated as follows:

(Al) × (A2) = AT: (1)

(Bl) + (B2) + (B3) = BT: (2)

(AT) × (BT) = ES: (3)

The final result of this series of calculations, the Environmental Score (ES), is the evaluated score for a given indicator. To avoid assigning undo importance to a specific number, a more efficient scoring system was developed using ranges of values. Eleven gamut bands are used: -E, -D, -C, -B, -A, N, + A, + B, + C, + D, and + E.

RIAM is a very powerful tool to use in an EIA, especially with very complex options, and it is capable of testing different options easily, while still providing an overview of the solutions. It is easy to visualize the results of the different options, which makes the tool useful for decision makers. In addition, the combined format of the results provided by the improved RIAM method: graphical display and communication of the integrated evaluation index between decision makers and EIA experts [46], ameliorates/expands the performance/capabilities of the tool.

3.1 Collection and selection of Key Performance Indicators

The methodological approach of this study was to first select six sets of city indicators created and issued by the most important international standardization associations and relevant for evaluation of Smart sustainable cities, at two different scales: international and national level.

After gathering the data of the 15 KPIs of Beijing for the last 20 years (2000-2020, for being a timeframe of high urbanization rates), a RIAM analysis was developed. The assessment criteria (A1, A2, B1, B2 and B3) were evaluated and the environmental scores were calculated to determine the range band of each environmental component affected by the 4 planned structures EO, PC, BE, and SC. The final numerical values of the environmental scores are then converted to range bands values. As explained in Table 5, positive range band values represent significant positive changes or impacts, while negative values represent significant negative impacts.

Table 5. Conversion Table from Environmental Scores to Range Bands (adapted from [46])

Environmental Score	Range Bands	Description of Range bands
+72 to +180	+E	Major positive change/impacts
+36 to +171	+D	Significant positive change/impacts
+19 to +35	+C	Moderately positive change/impacts
+10 to +18	+B	Positive change/impacts
+1 to +9	+A	Slightly positive change/impacts
0	N	No change/status quo/not applicable
-1 to -9	-A	Slightly negative change/impacts
-10 to -18	-B	Negative change/impacts
-19 to -35	-C	Moderately negative change/impacts
-36 to -171	-D	Significant negative change/impacts
-72 to -180	-E	Major negative change/impacts

3.2 Assessing the Impacts

The implementation of a holistic approach and coordination between spatial, sectoral and environmental planning is crucial for an integrated strategy planning for sustainable

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territorial development [51]. As stated, although urban social and technical challenges should be undertaken in a holistic way, the scope of this thesis will focus on the environmental aspect of the smart city definition, with a collaborative vision of ICT enable, stakeholder collaboration and technological applications, as highlighted in the Figure 10.

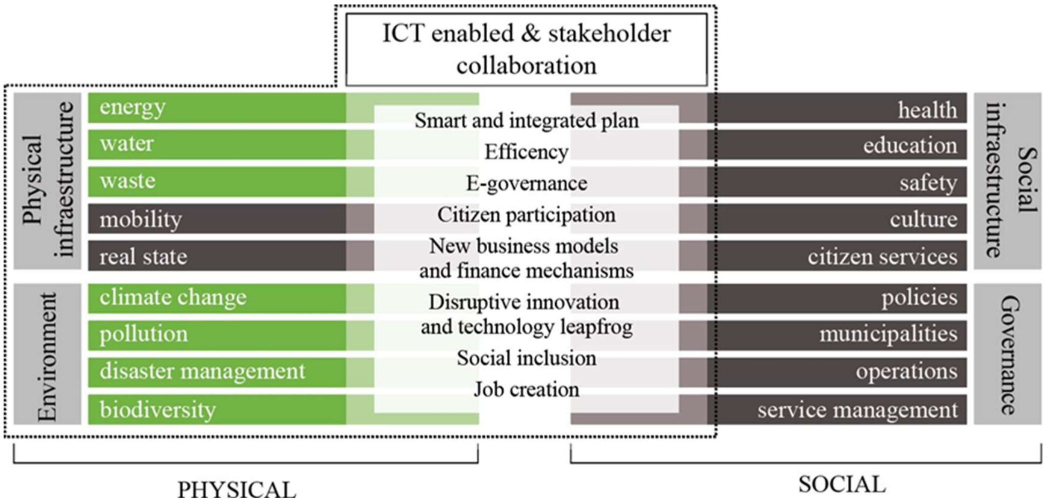

Figure 10. Relations and Methodological Approach

Global commitment to sustainable development has made cost-benefit analysis an integral part of EIA, triggering the expansion of factors to be taken into account in traditional cost- benefit analysis [41]. The EIA aims to prevent or minimize potentially negative environmental impacts and to improve the overall quality of a project. Figure 11 provides a summary of the process steps that are common to most EIA guidelines published by international organizations. The approach adopted to carry out an EIA may differ somewhat, depending on the requirements and practices of different international institutes; the legislative framework of a country; or the nature of project [38]. However, the process steps described here provide a common organizational framework for all.

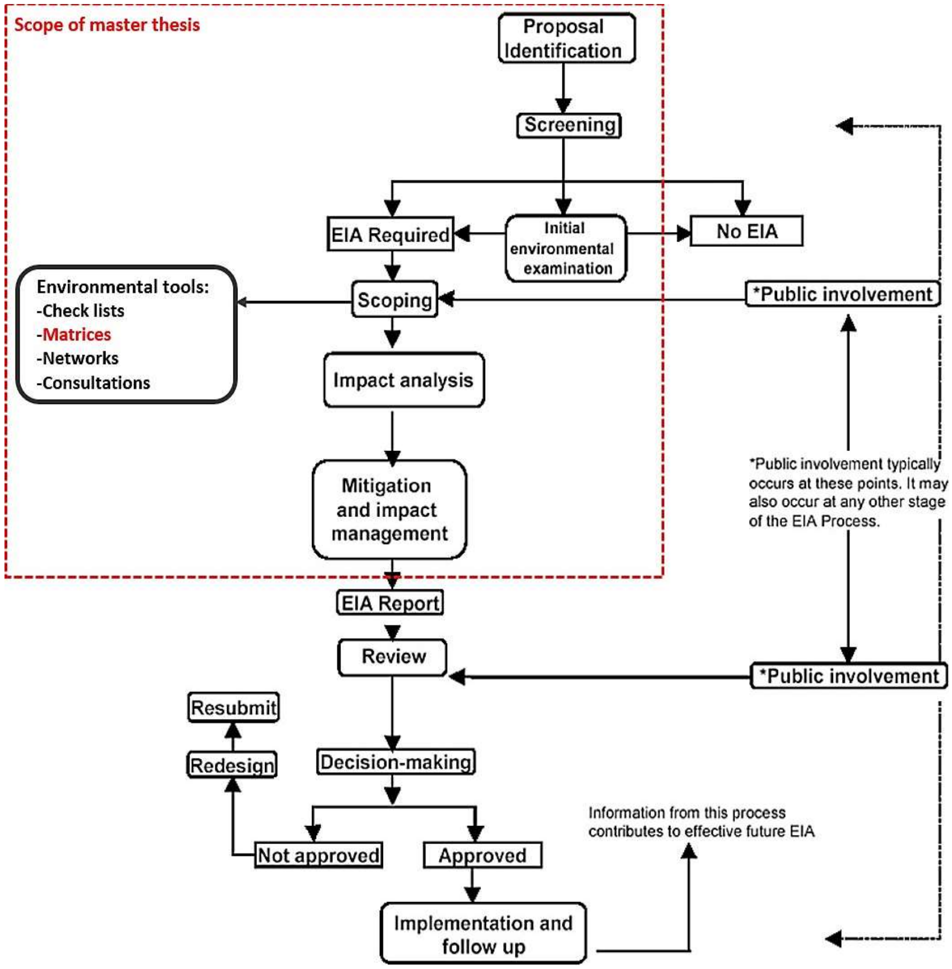

Figure 11. EIA Flowchart. (in red the limitations of the study)

3.3 Collection and Selection of KPIs

The methodological approach of this study was to first select six sets of city indicators created and issued by the most important international standardization associations and relevant for evaluation of Smart sustainable cities, at two different scales: international and national level (Table 6).

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Table 6. Indicators from International and National standards

Geographic focus	Indicator standards on Smart sustainable cities	Organization
International	ISO 37122:2019 Sustainable cities and communities (Indicators for smart cities) ITU-T Y.4903/L.1603 (10/2016)	International Organization for Standardization International Telecommunication Union
	UN- SUSTAINABLE DEVELOPMENT GOAL 11	United Nations
	United for Smart Sustainable Cities(U4SSC)	ITU, UNECE and UN-Habitat)
National (China)	The China Urban Sustain-abilityIndex 2013 Urban China Initiative	Columbia University, Tsinghua University, and McKinsey & Company

The environmental components are evaluated against the environmental impact, and are divided under four groups depending on the environmental aspect they contribute to: physical/chemical (PC), biological/ecological (BE), social/cultural (SC) andeconomics/operational (EO). For each component, a score (using the defined criteria) is determined, which provides a measure of the impact expected from the component. RIAM requires specific assessment components to be defined through a process of scoping, and these environmental components fall into one of the categories with its unique unit of measure (Table 7).

Table 7. Indicators Selected for the Assessment by RIAM

Categories	Indicators	Unit of measure	Environment sub-dimensions
PC	PC1: Fine particle matter (PM2.5) concentrationPC2: Particle matter (PM10) concentration PC3: CO_2 emissions measured in tones/ capitaPC4: NO_2 (nitrogen dioxide) concentration PC5: SO_2 (Sulphur dioxide) concentration PC6: Proportion of the city inhabitants exposed tonoise levels above international/national exposure limits	µg / m^3 µg / m^3 Tonnes CO_2/capita µg / m^{3}µg / m^3 %	Environmental and climate change
BE	BE1: Percentage of city population with regular solid waste collection (residential)	%	Solid waste
	BE2: Percentage of the city´s solid waste that isrecycled	%	Solid Waste
	BE3: Percentage of city population served by wastewater collection	%	Wastewater

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Catego-ries	Indicators	Unit of measure	Environment sub-dimensions
	BE4: Percentage of city ´s wastewater receivingcentralized treatment	%	Wastewater
	BE5: Percentage of city population with potable water supply service		
	BE6: Total water consumption per capita (litres/day)	l/day	
SC	SC1: Green area (hectares) per 100 000 population	hec/100k inh	Urban planning
EO	EO1: Total end-use energy consumption per capita EO2: Percentage of total end-use energy derivedfrom renewable sources	kWh/y %	Energy

4. Case-study Application in Beijing, China

China has impacted heavily in their environmental resources, with severe environmental pollution since the rapid economic development over the past thirty years. Environmental protection has become an important guarantee for China's sustainable economic development, which is the unavoidable alternative for building a resource-efficient and environmentally friendly civilization [47]. In China, government plays an important role in setting the policy of urbanization: to deal effectively with a series of traditional urbanization problems, the 18th National Congress of the Communist Party of China put forward a new type of urbanization development strategy characterized by a coordinated development of population, industry, space, society, resources, and environment. "The National New-type Urbanization Plan (2014– 2020)" proposed that ecology should be integrated into the whole process of urban development, stressing a new-type urbanization path that is intensive, intelligent, green and low carbon [14].

Academia and research have been increasingly gathering efforts since 2010 towards environmental impacts related specifically to rapid urbanization in Beijing, which those years are closely related to the highest rates of urbanization growth in the city. Major number of publications have been focused on water, pollution, and land-use conditions due to this phenomenon (Figure 12).

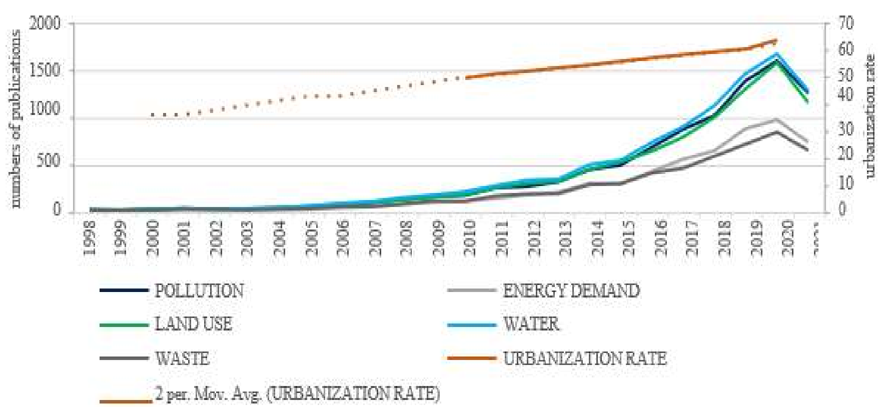

Figure 12. Number of Papers in Science Direct of Rapid Urbanization and Environmental Impacts in Beijing (1998-2020)

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4.1 Air Pollution

Because of these serious air pollution issues, Beijing implemented in 2013 a five-year air quality action plan and decided to work on controlling coal boilers, supply fuel cleaner domestic and restructure the industry [48]. By the end of 2017, PM2.5 levels had dropped 35% to 25% in the surrounding Beijing-Tianjin-Hebei region. Also in 2017, annual emissions of SO2, NO2, PM10 and volatile organic compounds in Beijing had decreased by 83%, 43%, 55% and 42% respectively (Figure 13) [49].

Some preventative measures included transforming the energy from burning coal into the use of natural gas and electricity, eliminating obsolete coal-fired boilers, tackling automobile exhaust fumes, dealing with heavy diesel vehicles, and diminishing old obsolete vehicles. Nevertheless, urban air pollution remains severe, with an average PM2.5 concentration in 2017 of 58 g m^{-3} in Beijing [50].

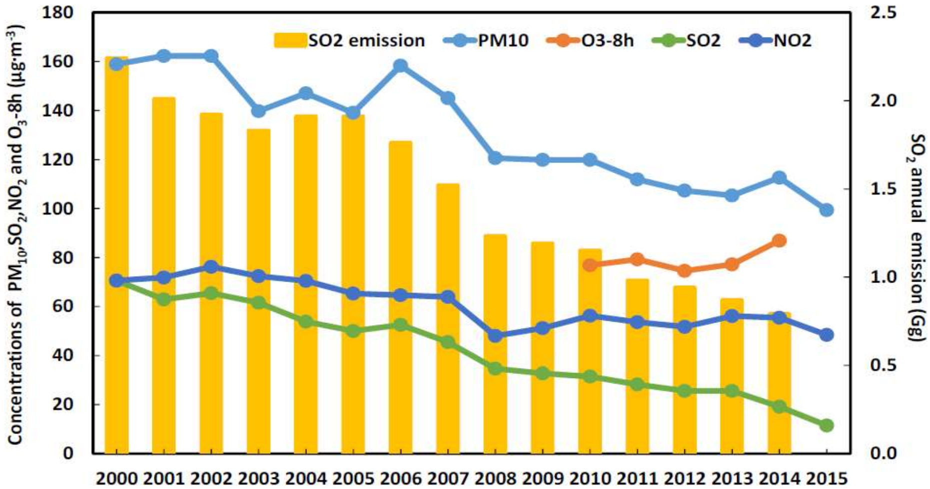

Figure 13. Annual average concentration of other main pollutants in Beijing [51]

Even though great air quality improvement has been made, Beijing and the surroundings still face pressures and challenges in future air pollution control. In 2018, PM2.5 concentration in Beijing was 66% higher than the National Ambient Air Quality Standard of China, and even higher than the World Health Organization guideline (Figure 14) (10μg/m^3 for PM2.5). In addition, ozone pollution has not been effectively controlled in recent years [52].

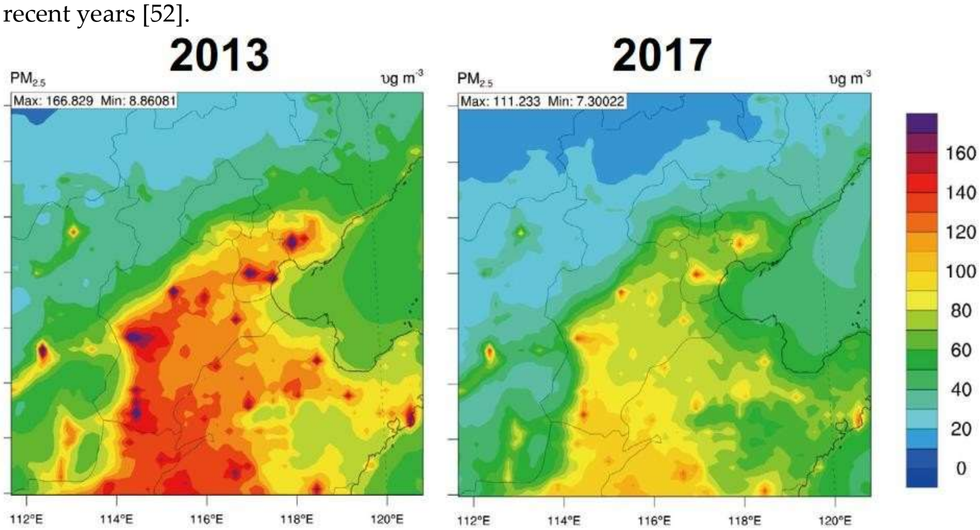

Figure 14. Spatial Distribution of Annual Average PM2.5 Concentrations in Beijing (2013 and 2017) [49]

4.2 Energy Demand

China has been putting enormous pressure on its natural resources to meet the demand for energy and other material. The contribution of natural resources to the GDP has been 5.98% (from 1970 to 2016 in average), with the leading share of coal, minerals, and oil. The abundance of natural resources reduces dependence on imported energy, and less polluting domestic energy sources, such as natural gas, are used, which mitigates environmental degradation [48]. Conversely, natural gas consumption only represented 5.9% of energy needs in 2015 [50]. Strategies should be designed and implemented to reduce reliance on conventional pollution- intensive energy sources, as fossil energy sources are the main cause of environmental degradation [51].

Nationally, urbanization in China is linked to industrial development characterized by massive energy consumption and low energy efficiency, which stimulates environmental degradation [42]. Apart from this, urbanization leads to ecological degradation by increasing the production of waste and the demand for infrastructure, food, water and other resources. Coal and charcoal were the traditional sources of energy for home consumption, but, as Beijing's population soared in the late 20th century, the use of these fuels contributed to aggravate air pollution in the city, especially during winter. A major campaign was largely successful in replacing them with natural gas and liquefied petroleum gas, which significantly reduced smoke emissions. However, many of these gains were offset by the dramatic increase in exhaust fumes from the city's large number of automobiles and trucks [52].

4.3 Water Supply and Consumption

Rapid urbanization, population growth and economic boom have also placed pressures on water resources across China. Beijing is in a warm, semi-humid and semi-arid temperate monsoon area, but the quantity of water available per capita is only about 137 m^3, much less than the world average ([53]-[54]).

Beijing's economic and environmental development has long been hampered by insufficient water resources. Beijing's water supply is greatly dependent on groundwater extraction and external water transfer, and the amount of water imported to Beijing for the year 2017 was 1.08 billion m^3, which was highly dependent to the South-North Water Diversion Project (Beijing Water Authority, 2017). In addition, within the agenda of the implementation of the national regional synergistic development strategy, the achievement of the objective of synergistic and equitable use of water resources in the Beijing-Tianjin-Hebei metropolitan area is essential (Figure 15) [54].

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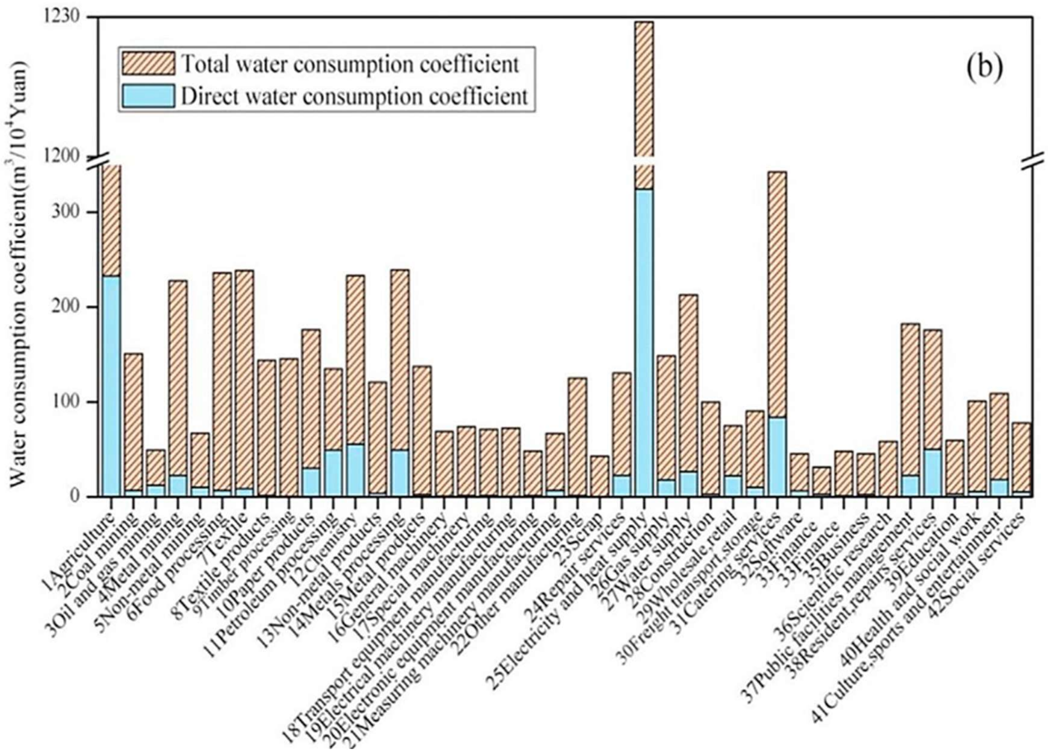

Figure 15. Direct water consumption coefficient and total water consumption coefficient of Beijing in 2012 [54]

5. Results

As presented in Table 5, indicators from the category physical/chemical (PC) are the main indicators that lead to significant or major negative environmental impacts, ranging form D- to A. The RB will define the critical components at working and proposing the framework for strategies to ameliorate environmental impacts, since it is definite to analyze by importance of the condition (A1), magnitude of change/ effect (A2), permanence (B1), reversibility (B2), and cumulative (B3). Negative impacts often require serious attention from planners and decision-makers, since these eventually become the backbone of environmental management and monitoring plans, and sometimes the basis for the acceptance or rejection of a proposed project (Table 8) [31].

Table 8. Range Band Values of RIAM Analysis

LABEL	INDICATOR	A1	A2	B1	B2	B3	AT	BT	ES	RB
EO1	Total end-use energy consumptions per capita	4	1	3	2	3	**4**	**8**	**32**	**C+**
EO2	Percentage of total end-use energy derived from renewable sources	4	2	3	2	2	**8**	**7**	**56**	**D+**
PC1	Fine particle matter (PM2.5) concentration	3	-3	2	2	1	**-9**	**5**	**-45**	**D-**
PC2	Particle matter (PM10) concentration	3	-3	2	2	1	**-9**	**5**	**-45**	**D-**
PC3	CO2 emissions measured in tons per capita	4	-3	3	3	3	**-12**	**9**	**-108**	**E-**
PC4	NO2 (nitrogen dioxide) concentration	3	-3	2	2	1	**-9**	**5**	**-45**	**D-**

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LABEL	INDICATOR	A1	A2	B1	B2	B3	AT	BT	ES	RB
PC5	SO2 (sulfur dioxide) concentration	3	-3	1	2	1	**-9**	**4**	**-36**	**D-**
PC6	Proportion of the city inhabitants exposed to noise levels above international/ national exposure limits	1	-2	2	1	1	**-2**	**4**	**-8**	**A-**
BE1	Percentage of city population with regular solid waste collection (residential)	2	1	2	2	3	**2**	**7**	**14**	**B+**
BE2	Percentage of the city´s solid waste that is recycled	3	2	2	1	1	**6**	**4**	**24**	**C+**
BE6	Total water consumption per capita (liters/day)	3	-1	1	3	1	**-3**	**5**	**-15**	**B-**
BE3	Percentage of city population served by wastewater collection	2	3	2	2	1	**6**	**5**	**30**	**C+**
BE4	Percentage of city ´s wastewater receiving centralized treatment	3	3	2	3	3	**9**	**8**	**72**	**E+**
BE5	Percentage of city population with potable water supply service	3	2	2	2	2	**6**	**6**	**36**	**D+**
SC1	Green area (hectares) per 100 000 population	1	3	2	2	3	**3**	**7**	**21**	**C+**

Rows highlighted in blue are indicators with higher values of range band, measured from E- to A-, meaning indicators PC3, PC1, PC2, PC4, and PC5 are indicators with higher values for negative impacts. Indicators with positive range bands are considered to have a positive impact (Figure 16).

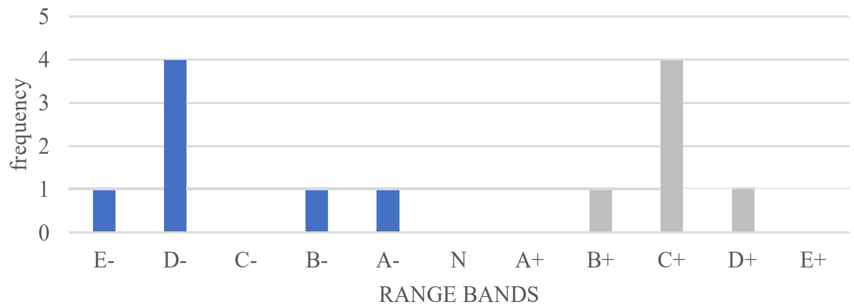

Figure 16. Summary of RIAM Analysis for Selected Indicators

Strategic planning begins to be identified as the most appropriate instrument to face the Smart transformation and with the need for it to be deployed at all levels of governance in order to achieve a better implementation and development of its proposals, from the country level and regional or territorial level, also combining other decisions of a transversal nature: housing, environment, transport and infrastructures up to the metropolitan or urban level. Under the RIAM analysis, a list of smart strategies and applications are listed in **Table 9**. These are gathered under four strategic areas: mobility, energy, water, and waste. These applications enable and promote transversal strategies linked to the Smart City and agendas correlated to the digital transformation that promotes technological development for environmental sustainability.

Table 9. Proposal of Smart Strategies and Applications for RIAM Analysis

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Strategic areas	Smart strategies and applications	KPIs involved
MOBILITY	Autonomous vehicles	E01,E02,PC1,PC2,PC3,PC4,PC5,PC6
	Intelligent traffic signals	E01,E02,PC1,PC2,PC3,PC4,PC5,PC6
	Congestion pricing	E01,E02,PC1,PC2,PC3,PC4,PC5,PC6
	Real-time public transit information	PC1,PC2,PC3,PC4,PC5,PC6
	Demand-based micro-transit	PC1,PC2,PC3,PC4,PC5,PC6
	Smart parking	PC1,PC2,PC3
	Digital public transit payment	PC3,PC6
	Predictive maintenance of transportation infrastructure	E01,PC6
ENERGY	Building automation systems	E01,E02,PC3
	Home energy automation systems	E01,E02,PC3
	Home energy consumption tracking	E01,E02,PC3
	Smart streetlight	E01,E02,PC3
	Dynamic electricity pricing	E01,E02,PC3
	Distribution automation systems	E01,E02,PC3
WATER	Water consumption tracking	BE6, BE3
	Leakage detection and control	BE3,BE4
	Smart irrigation	SC1
	Water quality monitoring	BE6, BE3
WASTE	Digital tracking and payment for waste disposal	BE1,BE2
	Optimization of waste collection routes	BE1,BE2

6. Discussion

6.1 Prioritization of Strategies for Beijing, China

Strategic planning begins to be identified as the most appropriate instrument to face the Smart transformation and with the need for it to be deployed at all levels of governance in order to achieve a better implementation and development of its proposals, from the country level and regional or territorial level, also combining other decisions of a transversal nature: housing, environment, transport and infrastructures up to the metropolitan or urban level. These are gathered under four strategic areas: mobility, energy, water, and waste. These applications enable and promote transversal strategies linked to the Smart City and agendas correlated to the digital transformation that promotes technological development for environmental sustainability.

Smart-city solutions, such as air quality monitoring, energy use optimization, and electricity, water, and waste tracking can produce results such as 10-15% fewer GHG emissions, 30-130 fewer kilograms of solid waste per person per year, and 25-80 liters of water saved per person per day [55]. SE is the most popular characteristic among EU Smart Cities, where 33% of the initiatives until 2015 where focused specifically in Smart environment [56]. The smart city environment is designed to improve sustainability, clean energy, clean air, and a clean coastline. Improving environmental conditions can help to develop a smart city, this development of sustainability and resource management can be triggered based on technology as a central concept.

Urban sustainability is achieved when social, economic and aspects of environmental sustainability have all been taken together. However, for a rapidly developing or emerging economy to become sustainable, several challenges develop: cooperation across sectors, at regional, national, and local levels, and cooperation between different stakeholders and institutions is urgently needed – not only to make the best use of finite resources, but to capitalize on synergies and ensure policy coherence to achieve systemic change. According to the UN 2020 Human Development Report, countries with higher human development tend to exert more pressure over greater scales on the planet [57]. The report

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calls for a just transformation that expands human freedoms while easing planetary pressures: if the Earth's climate has ever been characterized by abrupt change, then CO2 emissions, along with other planetary disturbances of human are this process, superimposing new instabilities on existing ones (**Figure 17**).

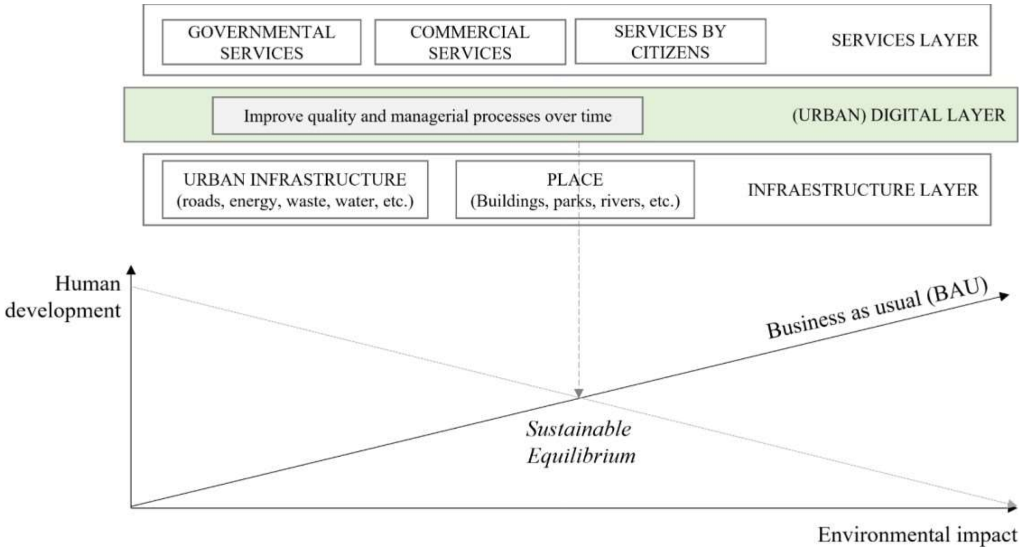

Figure 17. Schematic Representation of Sustainable Equilibrium

7. Conclusions

This study had the aim of exploring the environmental impacts related to the cities with the rapid urbanization phenomena and how SC strategies could promote environmental sustainability. The main research questions of this study were: '*How Smart city strategies can lessen environmental impacts at cases with rapid urbanization?'* and '*How can we leverage digital technology to promote environmental sustainability at rapid urbanization phenomena occurring at developing countries?'*. To answer these questions, a theoretical study was conducted. First, relevant literature was studied regarding rapid urbanization and its environmental impacts, Beijing context and definitions of smart city approaches towards smart environmental.

Secondly, an analysis of environmental impact assessments was done, and from several scoping tools, the RIAM matrix was selected as the tool for this analysis. Later a selection of KPIs was defined and data collection was done for RIAM analysis. Finally, based on the results of the RIAM analysis, a proposed conceptual framework for Beijing context was proposed. The finding of this study concluded that four main pillars should be considered in the case of Beijing´s rapid urbanization: mobility, energy, water, and waste. Several smart strategies and applications related to these pillars were proposed to lessen environmental impacts of this urban phenomena.

The study framework is a combination between a vision for four strategic areas of smartness and project management perspective and identifies applications under a prioritized order accordingly to the KPIs involved. Moreover, the study integrates the phenomena of rapid urbanization towards SC vision. In conclusion, SC around the world, and particularly at developing countries, need to create new operating roadmaps that drive innovation and collaboration to tackle the quick environmental degradation of rapid urbanization.

In particular, the broader economic, social, and political context was not studied and integrated as a whole, which is closely connected to the definition of roles and responsibilities of different stakeholders participating into the SC strategies. Governments need to step up their efforts to fulfil the basic infrastructure needs of citizens, construct clear regulatory frameworks to mitigate the technological risks involved, develop human capital, ensure digital inclusivity, and promote sustainability. This study contributes a small step

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to a deeper understanding of SC under countries with rapid urbanization. Rapid and even more uncontrolled urbanization can lead to poor urban and built environment and even to non-existing infrastructure, which reduce cities' competitiveness and citizens´ QoL.

The implementation of a 'smart city' presents several challenges in developing contexts. Infrastructure and costs are the main notions for struggling its deployment, but SC visions and strategies can empower different stakeholders involved (government, citizens, industry, and academia) for creating accurate solutions for achieving the urban sustainability and better QoL of its citizens. The ICT revolution has brought connectivity and computing power to developing countries, offering new opportunities to improve governance systems, urban management, and productivity. ICT applications are tools that can trigger government transparency and empowerment of citizens, critical characteristics of emerging economies.

SC is a concept well established and managed in developed countries, but citizens from these countries present higher carbon footprints per capita than developing countries. There is a global need and urge to develop cities that look forward for a balance between high human development and environmental costs of urban development. The crises, and more instantly in the Covid-19 pandemic, provide an opportunity for societies to reassess the rules and laws, cracking down on social and economic recovery by investing in a healthier, greener and more equitable future which extend human freedoms while relieving planetary pressures.

Future works can be focused on addressing smart city solutions in similar cases in further developing countries with rapid urbanization cities, not to only overcome environmental complications, but also economic, social, and digital complications to fulfil the basic needs of citizens and mitigate the risks involved, by a holistic approach from several different disciplines. Another axis of study can analyze and convey smart strategies with cities under environmental risks, questioning and proving if resilience can be achieved under a smart city approach, and even more specifically, under a rapid urbanization case.

Further works may include a socio-economical assessment of the deployment of smart strategies and tools, evaluation and promoting a sustainable and feasible business model. Public financing combined with the participation of the private sector in projects provides greater capacity for municipal governments in developing economies to implement their infrastructure projects. Third-party project funding can be used, and calculations of payback can be estimated, in relationship with energy, water, or operating cost savings.

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Nomenclature

EIA	Environmental Impact Assessment
ES	Environmental Score
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
IA	Impact Assessment
ICT	Information Communication Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicator
NEPA	National Environmental Policy Act
PC	Physical/Chemical
RIAM	Rapid Impact Assessment Matrix
SC	Smart City
SEA	Strategic Impact Assessment
SD	Smart Development
UN	United Nations
UNECE	United Nations Economic Commission for Europe
QoL	Quality of Life

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