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A Strategic and Smart Environmental Assessment of Rapid Urbanization in Beijing

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Abstract: One of the key challenges of developing countries is to tackle the mitigation of the impacts of rapid and uncontrolled urbanization. Assessing this phenomenon is crucial to lessen the consequences for the environment and society. 'Literature has been concentrated in planning strategies for the cities' adaptation and engagements to the principles of green development ensuring a long-term quality of life for their citizens. Hereby, smart technologies and applications consist of two of the most encouraging concepts for solutions for achieving the 2030 and 2050 horizon targets towards clean energy transition and carbon neutrality. In academia, scholars have already raised the importance of 'smartness' to define the adaptative patterns for the global pressures of climate change and uncontrolled urban growth. The mitigation of these phenomena is crucial to ensure the cities' future and lessen their impacts. This study seeks a strategic and smart-driven vision to leverage smartness on the phenomenon of rapid urbanization that occurred in the case of Beijing, China. Defining and evaluating the environmental impacts in line with the RIAM approach as one of its main targets. Future works can be focused on addressing solutions in similar cases in further developing countries to not only overcome environmental, but also economic, social, and digital complications.

Keywords: developing countries; environmental impact assessment; rapid urbanization; smart strategies

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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]. On the other side, in 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, as the 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 the rural areas (Figure 1) [5]. This migration takes place 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 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].

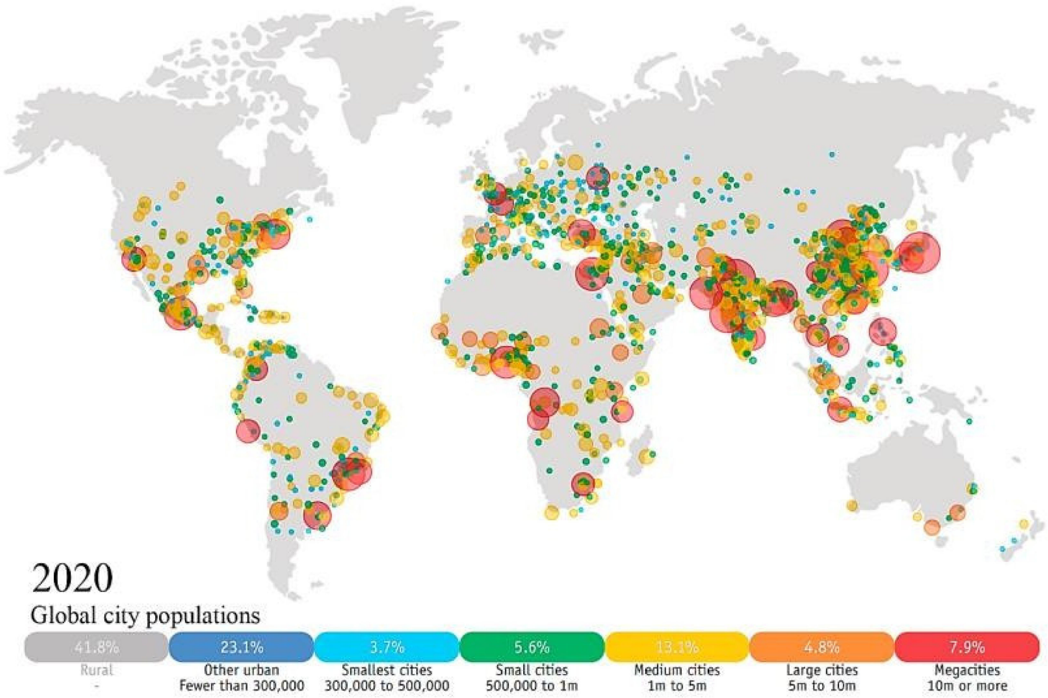

Figure 1. Urbanization worldwide in 2020 [8].

Urbanization is a complex phenomenon; although urbanization is linked to promoting economic prosperity and QoL, it boosts issues, such as high consumption of resources and energy, leading to ecological degradation [9,10]. The complexity of evaluating the impacts of this process was also one of the main challenges of this work due to its dynamic character and differences between the studies occurred in regards to the natural and human environment but also to the geographical or administrative contexts. At the same time, one additional difficulty of the study is the particularity of each case in respect to its identity and attributes. Finally, limitations are found on the data collection and the reviewing or previous works in the existing literature.

1.1. Rapid Urbanization in China

Since 1980, China, as the world's largest developing country, has experienced unprecedented large-scale and rapid urbanization, with an increasing rate from 17.92% in 1978 to 58% in 2017 [11]. Asia is considered among the fastest urbanizing regions with the urban population projected to reach 56% by 2050 (Figure 2) [12].

During the period 1950 to 2010, China recognized an unprecedented increase in its urban population from 11.8% to 49.2% [13]. In the case of these scenarios, proposed by the UN, are correct, China will face a rise of more than 300 million inhabitants to its territories accelerating the rate to approximately 75% by 2050 [14].

Furthermore, Zhao et al. [15] argue that the phenomenon that occurred in Chinese territories fails to acknowledge that an important cause is a result of changes in administrative divisions since the 1980s.

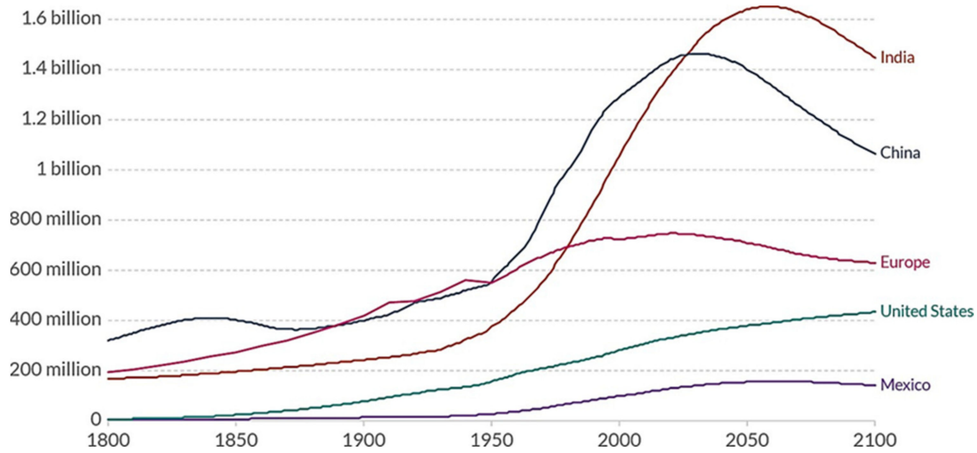

Figure 2. Historical estimates of the population [14].

Of the 20 fastest-growing cities in the world, 7 of them are located in China (Figure 3), with Shanghai, Chongqing, and Beijing as the three top cities with the highest rates in that country [13].

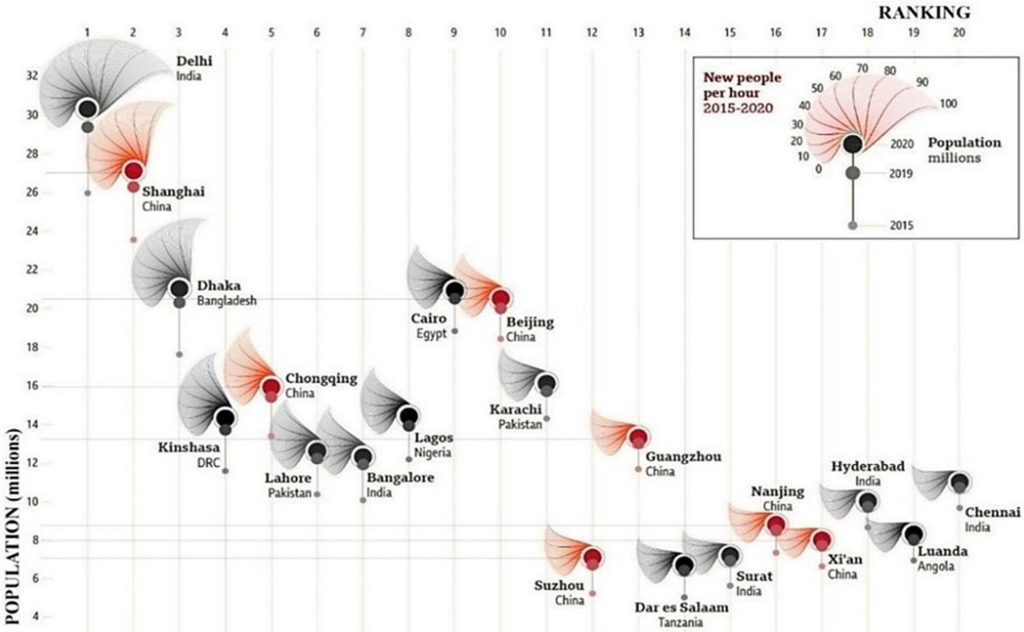

Figure 3. Top 20 fastest growing cities (2015–2020) [16].

Beijing is China's administrative center and the capital of modern China with a long urban history of more than 3000 years [16]. As Figure 4 depicts, the city is located above the sea level at approximately 30–40 m and the northern part of the China Plain, while its western part is occupied by the Jundu Mountains and the south the plain stretches for about 400 miles until it merges with the lower valley and the delta of the Yangtze River [17].

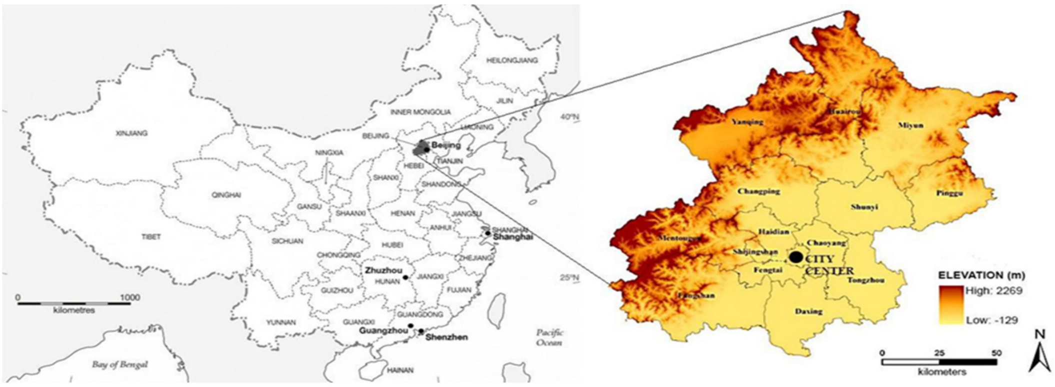

Figure 4. Location and administrative division of China. Location and topography of Beijing [18].

In Beijing, from 1978 to 2015, the area of urban land increased from 800.95 km^2 to 2636.54 km^2 increasing annually by 3.7% (Figure 5). Spatially, Beijing's urban expansion presents a mononuclear concentric polygon pattern, similar to its circular traffic system [19]. This scheme is a consequence of the limitations due to the topography, the planning, and the policies, including the Mountains of Taihang in the west and Yanshan in the north [16]. As a result of these constraints, the city expanded principally in the southeast and accelerated after the Chinese economic reform in 1978 (Figure 6) [20].

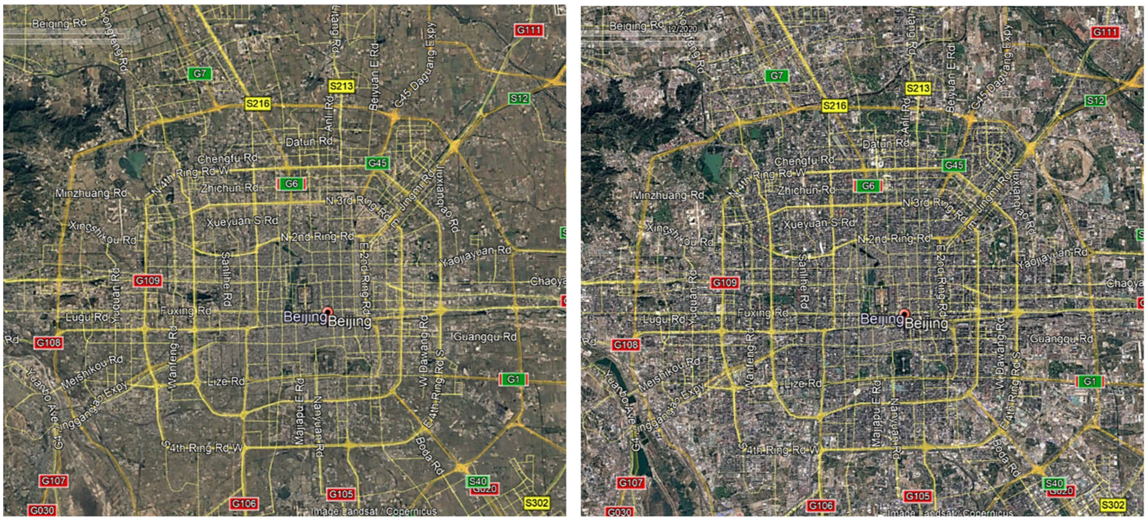

Figure 5. Satellite images of Beijing in 1984 and 2020 (Google Earth).

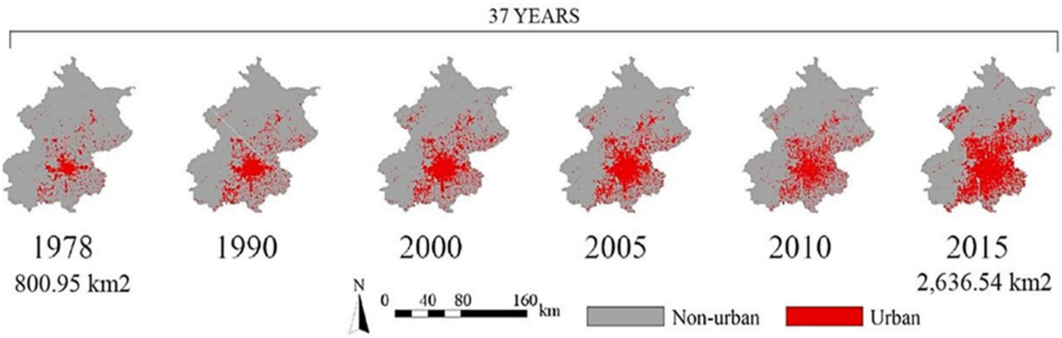

Figure 6. Change of spatial extent of urban area in Beijing from 1978 to 2015 [21].

During the 1980s, the sprawl was mainly focused on the suburban areas of Beijing, while industrialization became one of the main driving forces of the phenomenon [22]. At the end of the 1990s, the city presented a notable increase in residential and commercial use due to the deindustrialization processes [23]. Statistics of Beijing's demography explained the projections by 2020 of 18 million people and the 2030 forecast by 21.4 million people as an endpoint of this increasing rate. Nonetheless, the reality proved that already in 2016, the projection of 21.4 million people was realized, which proves the projections of uncontrolled urbanization and the complexity in the achievements of Beijing to be one of the most livable cities in the world [23].

At the same line, China's agricultural development and economic growth have accelerated the urbanization rates increasing the concerns for stakeholders to ensure the quality of life and mitigate the effects of this growth (i.e., unemployment, inequalities for the public services, and infrastructure use, etc.) [24]. According to data from The World Bank, in 2020 China's urbanization rate was 63.89%, against 5.95% of the annual GDP growth rate (Figure 7).

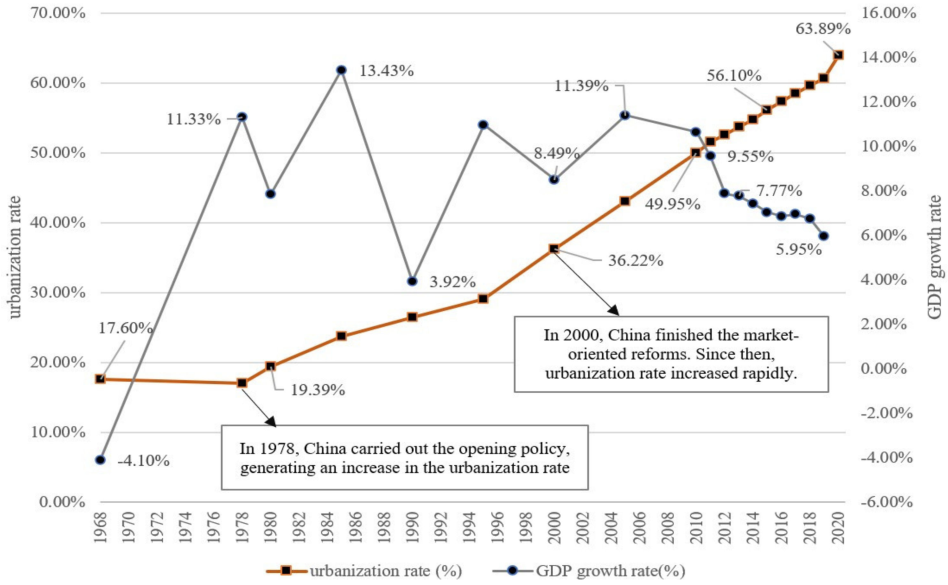

Figure 7. China's urbanization rate vs. GDP growth (1968–2020) Own authorship, data from The World Bank [25].

The phenomenon of 'city growing', is unprecedented mainly due to the transformation brought about by the shift from a rural to urban society and it consists of a major public health challenge leading to disparities. At the same time, it evokes continuous changes in the human and natural environment with massive modifications on the city's physical structure and effects on its micro-climate with higher temperatures, while the growing population puts strain on city systems and risks of urban pollution as a whole. It is reported that these challenges affect millions of people in urban areas. At the same time, promoting actions and strategies to curb pollution, congestion problems, the depletion of resources, and to improve water and air quality are prioritized.

In this work, we study the nexus of the environmental degradation in the case of Beijing, as a rapidly developing city, and we assess the impacts in line with the RIAM matrix, as it will be explained onwards, selected as a rapid but accurate method to provide the conceptualized framework of the analysis and conduct our assessment. Key features and indicators for this analysis were the water, the air or land pollution, as one of the main risks for ecosystems and severe environmental consequences, the energy demand, etc., and propose smart-driven strategies for conceptualizing a more integrated planning for urbanization.

1.2. Research Questions

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

- How can Smart city strategies lessen environmental impacts in cases of rapid urbanization?
- How can we leverage digital technology to promote environmental sustainability in developing countries experiencing rapid urbanization?

1.3. Organization of the Work and Structure

In Section 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 Section 2, the most typical methods (e.g., EIA, SEA) and tools (e.g., matrices, checklists, networks) available from the literature for assessing 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 Section 3, the RIAM methodology along with its assessment criteria will be presented. What is more, in this chapter the collection and selection of KPIs and the assessment of impacts for this study will be discussed. In Section 4, the case-study application in Beijing, China will be extensively analyzed. The results, organized in a visualized table, will be presented in Section 5, followed by the discussion in Section 6, and the conclusion in Section 7.

2. Materials and Methods

2.1. Environmental and Impact Analysis

Impact assessment 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 scientific information on the possible impacts of a proposed action to decision-makers as well as to the public"* [26]. 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 the 1990s [27].

The analysis of the environmental systems is one of the most representative branches of the literature to analyze, interpret, simulate, and communicate the complexity of the environmental impacts from different perspectives including several methods and tools for their assessment [27]. The main objective of an 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, the basis for further development [27].

Andersson et al. [27] propose a classification of the existing tools in aggregated, analytical, and procedural (Figure 8).

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 [28].

Andersson et al. [27] proposed a temporal focus of these tools [29]: 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.

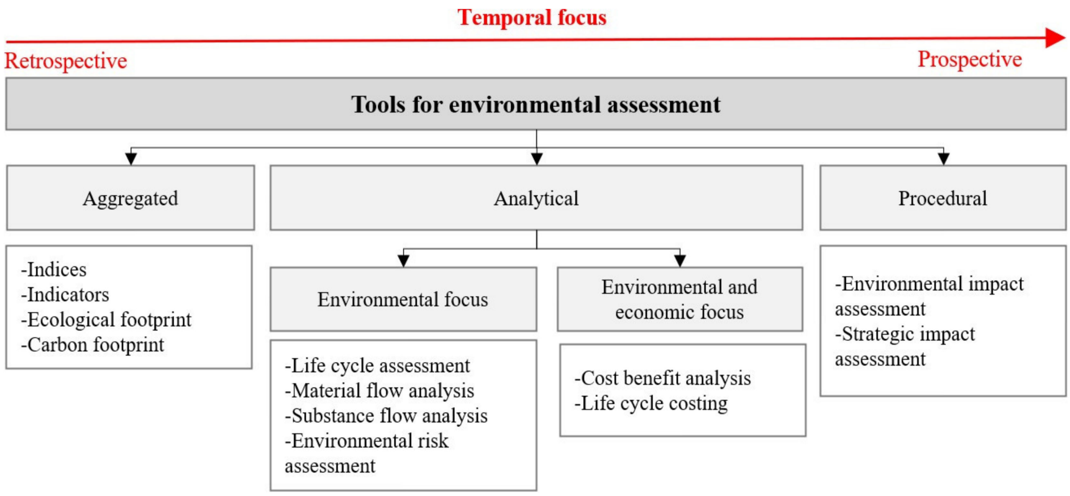

Figure 8. Categorization of existing tools for the environmental assessment [27].

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 [30]. In 1992, the UN 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 [31].

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 of policies, programs, and plans, which provide the framework for development projects [32]. As 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 [33]. 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
[34]	Generates more environmentally sensitive decisions	Occurs at the earlier stages of the decision-making cycle
[35]	Reactive approach to the development proposal	Pro-active approach to the development proposal
[35]	Identifies specific impacts on the environment	Identifies environmental implications of SD
[34]	Emphasis on mitigating and minimizing impact	Emphasis on meeting environmental objectives

One of the EIA's targets is the identification of the key issues that are harsh to the environment and can provoke negative impacts aiming to plan appropriate strategies and measures to mitigate them. To this research, it is requested to understand the time horizon of the changes' causes and impacts to proceed with their assessment [36].

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 socio-economic environment of the citizens affected [37]. 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 integral part of EIA, triggering the expansion of factors to be taken into account in traditional cost-benefit analysis [38]. Understanding the scope is essential for a twofold sense: (1) to pinpoint the problems at the design phase and avoid costs' risks and (2) to prioritize the problems in relation to their importance and smartly handle them. 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
Networks	Link action to impact Useful in simplified form for checking for second-order impacts
Overlays	Easy to understand Used for illustrating the geographical extent of impacts
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. [39], 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 [25]. 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 (Table 3) [39]:

Table 3. Matrix of Advantages and Disadvantages of Different Tools.

Source	Tool	Advantages	Disadvantages
[40]	Simple matrices	Short written descriptions are provided	Not a tractable proposition There is no scaling or quantification of these impacts
[39,41]	Scaled matrices	Intersections to indicate the magnitude and the importance The impacts could each be added and compared	Measurements do not necessarily directly correlate
[39]	Component interaction matrix	Minimum the existence and length of a linkage between any two components	Structure of these linkages is exposed
[41]	Rapid Impact Assessment Matrix	Efficient in terms of 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 assessments to provide 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 [39].

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 [34].

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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, as 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 [40].

3. 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 to be made on a similar basis and provide a transparent and permanent record of judgments made [41].

RIAM is a matrix method established to incorporate subjective judgments transparently into the EIA process. The method was developed by Pastakia and Jensen [42] 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 [36].

Technically, the assessment process consists of four steps which must be completed in order [41]:

- 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

The important endpoints are divided into two groups (Table 4) [42]:

(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

RIAM involves in fact three main categories in its assessment process:

→ A1: the conditions (existing)
→ A2: in respect to the magnitude of change
→ B1: the level of permanence
→ B2: the possibility of being reversible
→ B3: the level of being cumulative

All the above indicators are also considered in line with the sustainability indicators of social, ecological, or economic dimensions. The scores are calculated accordingly:

(Al) × (A2) = AT: (1)
(Bl) + (B2) + (B3) = BT: (2)
(AT) × (BT) = ES: (3)

The final result of this series of calculations, the Environmental Score, is the evaluated score for a given indicator. To avoid assigning undue 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.

3.1. Collection and Selection of KPI

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 the evaluation of Smart sustainable cities, at two different scales (international and national level): ISO 37122:2019_Sustainable cities and communities (Indicators for smart cities), ITU-T Y.4903/L.1603 (10/2016), UN SUSTAINABLE DEVELOPMENT GOAL 11, United for Smart Sustainable Cities (U4SSC), The China Urban Sustainability Index 2013, and Urban China Initiative. From these six standards relevant to smart sustainable cities and communities, all indicators were gathered (under the environmental category) summing a total of 61 indicators, then categorized by environmental sub-dimensions. The indicators with a frequency of 4 over 6 were selected for the final RIAM analysis, finalizing with 15 KPIs.

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 due to the data availability but also to the importance of its rise for this specific period), 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 [42]).

Environmental Score	Range Bands	Description of Range Bands
+72 to +180	+E	Major positive changes
+36 to +171	+D	Important positive changes
+19 to +35	+C	Neutral positive changes
+10 to +18	+B	Accepted positive changes
+1 to +9	+A	Limited positive changes
0	N	No change or not applicable or no available data for evaluation
−1 to −9	-A	Limited negative changes
−10 to −18	-B	Negative changes
−19 to −35	-C	Neutral negative changes
−36 to −171	-D	Important negative changes
−72 to −180	-E	Major negative changes

3.2. Assessing the Impacts

The implementation of a holistic approach and coordination between spatial, sectoral, and environmental planning is crucial for integrated strategic planning for sustainable territorial development [43]. As stated, although urban social and technical challenges should be undertaken holistically, 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 Figure 9.

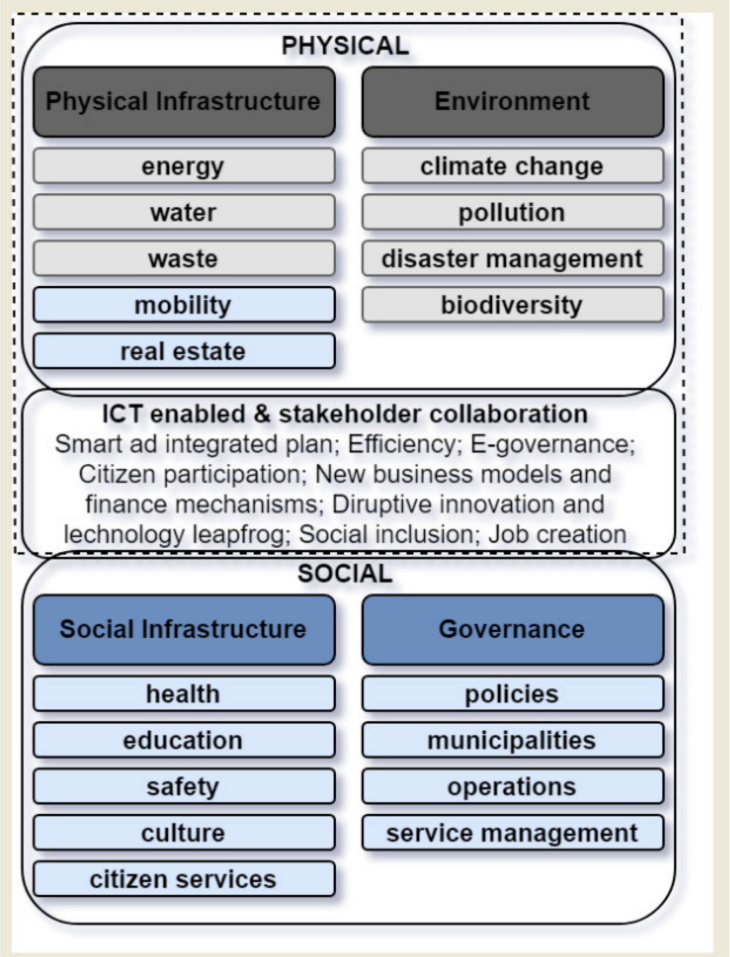

Figure 9. Relations and Methodological Approach.

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 [38]. Figure 10 summarizes the common steps to EIA guidelines as proposed and highlighted in international documents available in the existing literature. The main differences are basically found in the requirements by each institution, the policies or regulative frameworks, or even the project's identity [35].

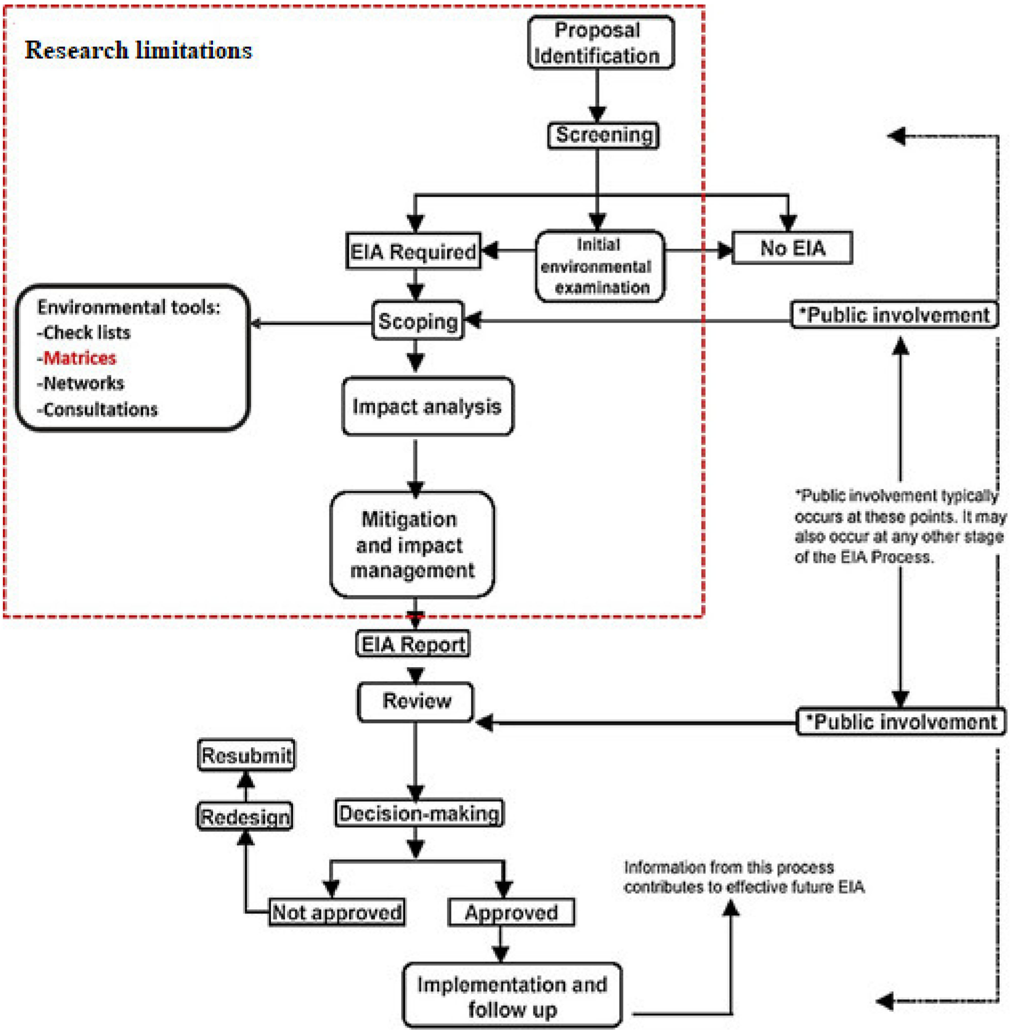

Figure 10. EIA Flowchart. (in red the limitations of the study).

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 the evaluation of Smart sustainable cities, at two different scales: international and national level (Table 6).

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) UN- SUSTAINABLE DEVELOPMENT GOAL 11 United for Smart Sustainable Cities (U4SSC)	International Organization for Standardization International Telecommunication Union United Nations ITU, UNECE and UN-Habitat)
National (China)	The China Urban Sustainability Index 2013 Urban China Initiative	Columbia University, Tsinghua University, and McKinsey & Company

From these six standards relevant to smart sustainable cities and communities, all indicators were gathered (under the environmental category) summing a total of 61 indicators, then categorized by environmental sub-dimensions. The indicators with a frequency of 4 over 6 were selected for the final RIAM analysis, finalizing with 15 KPIs. The environmental components are evaluated against the environmental impact and are divided into four groups depending on the environmental aspect they contribute to PC, BE, SC, and EO. For each component, a score (using the defined criteria) is determined, which provides a measure of the impact expected from the component (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) concentration	$\mu g/m^3$	Environmental and climate change
	PC2: Particle matter (PM10) concentration	$\mu g/m^3$	
	PC3: CO_2 emissions measured in tones/ capita	CO_2/capita	
	PC4: NO_2 concentration	Tonnes	
	PC5: SO_2 concentration	$\mu g/m^3$ μg /m^3	
	PC6: Proportion of the city inhabitants exposed to noise levels above international/national exposure limits	%	
BE	BE1: Percentage of city population with regular solid waste collection (residential)	%	Solid waste
	BE2: Percentage of the city's solid waste that is recycled	%	Solid Waste
	BE3: Percentage of city population served by wastewater collection	%	Wastewater
	BE4: Percentage of city's wastewater receiving centralized treatment	%	Wastewater
	BE5: Percentage of city population with potable water supply service		
	BE6: Total water consumption per capita (liters/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	kWh/y	Energy
	EO2: Percentage of total end-use energy derived from renewable source	%	

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 [44].

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. A major number of publications have been focused on water, pollution, and land-use conditions due to this phenomenon (Figure 11).

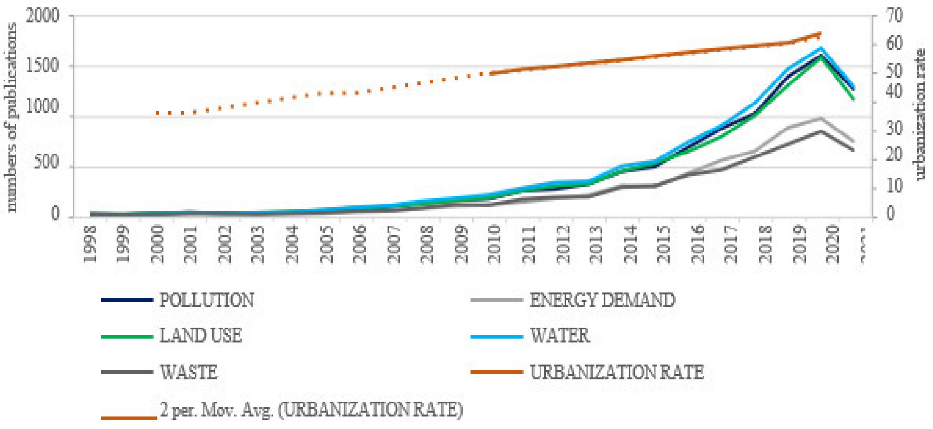

Figure 11. Number of Papers in Science Direct of Rapid Urbanization and Environmental Impacts in Beijing (1998–2020).

4.1. Air Pollution

Because of these serious air pollution issues, in 2013, Beijing implemented a five-year air quality action plan and worked on controlling coal boilers and supply fuels for domestic cleaning which eventually restructured. By the end of 2017, PM2.5 levels had dropped from 35% to 25% in the surrounding Beijing-Tianjin-Hebei region. During 2013–2017, the emissions of SO_2, NOx, VOCs, and PM2.5 decreased from 83%, 43%, 42%, and 55%, respectively (Figure 12) [45].

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 [46].

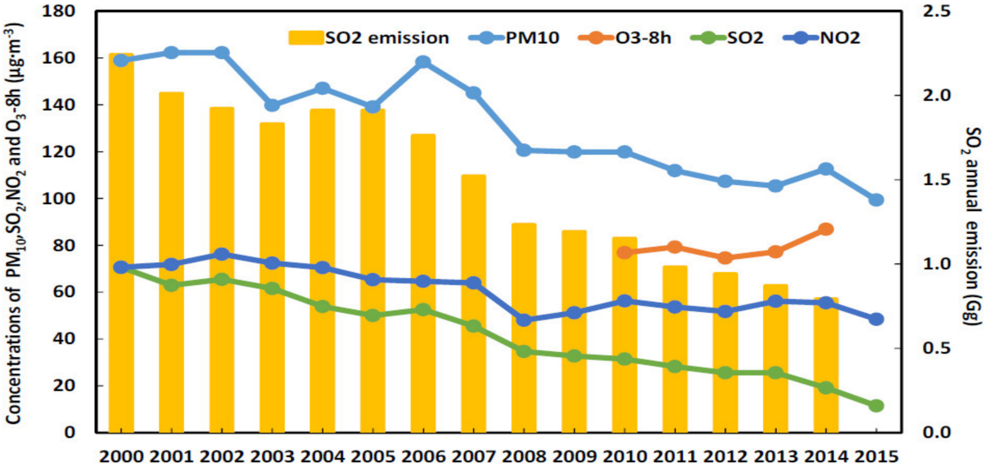

Figure 12. Annual average concentration of other main pollutants in Beijing [43].

Despite the improvements on the air quality levels, Beijing still faces stresses and challenges on this issue. The statistics from 2018 showed that PM2.5 concentrations were more than 60% higher than the National Ambient Air Quality Standards of the country and even higher than the world's levels (10 μg/m^3 for PM2.5) (Figure 13); combining with the limited control on ozone's pollution in the last years [47].

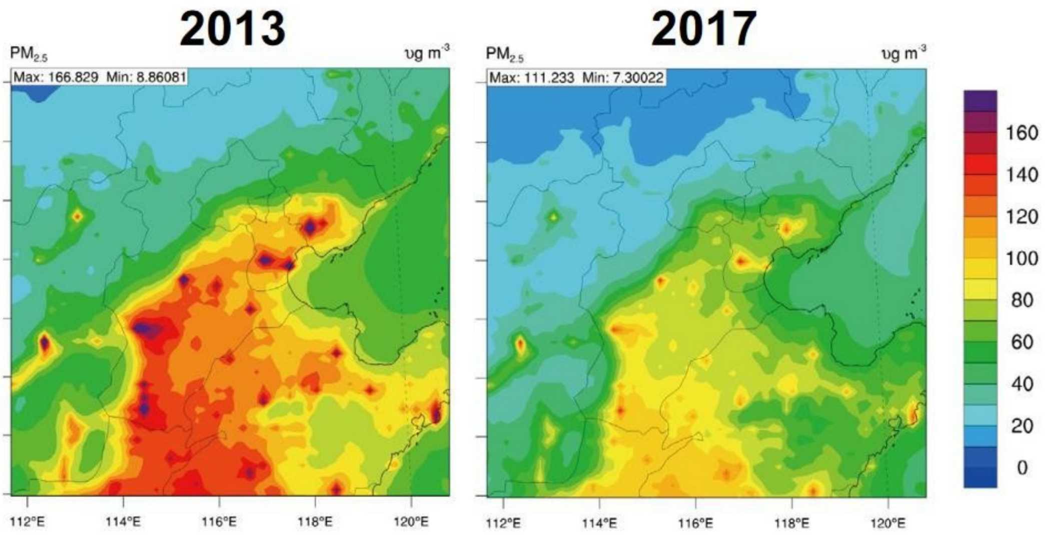

Figure 13. Spatial Distribution of Annual Average PM2.5 Concentrations in Beijing (2013 and 2017) [45].

4.2. Energy Demand

The stresses of the rapid urbanization led to an expected rise in energy demand, and consequently to the threat of scarcity of China's resources. Undoubtedly, the contribution of resources is crucial for economic growth (contribution on GDP to approximately 6% on average from 1970 to 2016) with the leading share of coal, minerals, or oil. In reality, the importance of natural resources is undeniable to reduce the dependency on imported energy and lessen environmental degradation [46].

4.3. Water Supply and Consumption

Rapid urbanization, population growth, and economic boom have also placed pressure 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 [48,49].

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 on 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 14) [49].

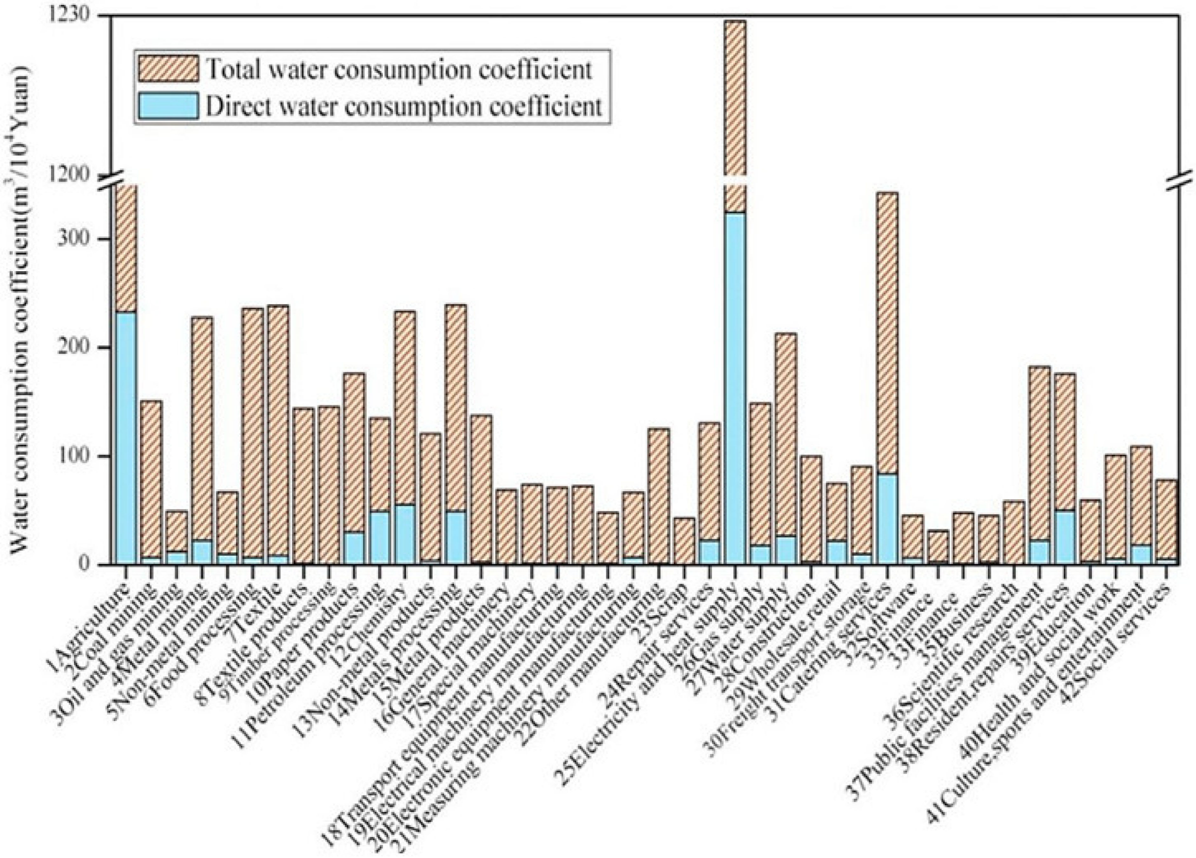

Figure 14. Direct water consumption coefficient and total water consumption coefficient of Beijing in 2012 [49].

5. Results

As presented in Table 8, indicators from the category PC are the main indicators that lead to significant or major negative environmental impacts, ranging from -D to A. The RB will define the critical components of working and proposing the framework for strategies to ameliorate environmental impacts, as it is important to analyze by the importance of the condition (A1), magnitude of change/effect (A2), permanence (B1), reversibility (B2), and cumulative (B3). Predicting and assessing the negative effects is always an important step of the planning processes to avoid failures on management and monitoring processes, which affect the acceptance and adoption of the projects [28].

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	CO_2 emissions measured in tons per capita	4	−3	3	3	3	−12	9	−108	E-
PC4	NO_2 (nitrogen dioxide) concentration	3	−3	2	2	1	−9	5	−45	D-
PC5	SO_2 (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 15).

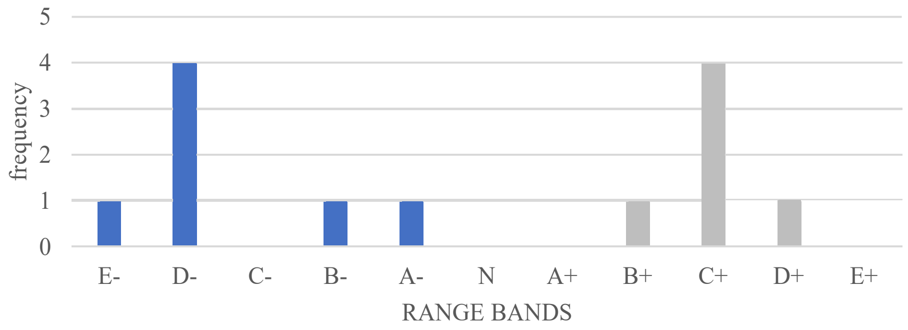

Figure 15. Summary of RIAM Analysis for Selected Indicators.

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 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.

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

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 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-driven approaches including solutions in respect to the air quality monitoring, the optimization of the energy use, the waste or water valorization, etc. are requested strategies for the prevention and assessment of consequences for environmental degradation due to the phenomenon of urbanization in developing countries [50]. SE is the most popular characteristic among EU Smart Cities, where 33% of the initiatives until 2015 were focused specifically on Smart environments [51]. Trung [52] highlights the importance of smart philosophy including digital application, intellectual systems (and sub-systems) but also intellectual processes for 'intelligent' users (citizens) of the metropolis for flexible and technological controllability.

Commitment to advanced environmental monitoring through the use of smart technologies and applications facilitates the intelligent control of incessant threats posed by climate change or by unchecked urbanization. Tracking via 'smart-driven' solutions, such as technologies for energy use optimization, energy management, and integration of alternative sources, enables the integrated and automated environmental protection of cities. Similarly, integrating building efficiency measures like advanced systems for natural lighting and temperature control contributes to the reduction of energy consumption and costs. Moreover, installing sensors or preventive systems for environmental monitoring may be included in the agenda on the improvement of air quality. Regardless of the smart technologies and/or solutions to be employed, a policy framework that ensures the incentivization of their implementation and the engagement of all stakeholders and consumers is necessary to address and overcome the barriers in the adoption of smart technologies and solutions. At the key aspects of the smart-driven strategy, we cannot neglect the importance of urban mobility; specific measures for the development of green mobility action plans contribute to the enhancement of environmental protection. Examples of these patterns can include ICT integration and the use of technology for data generation and sharing, car-sharing and car-pooling systems, or even automated electric vehicles to increase the effectiveness in the transport sector and the need for shifting from private to public means of transport in an attempt to reduce the number of accidents and global warming effects. Other digital applications complete the previous proposals with the use of sensors or even machine learning based on real-time data to assess possible traffic congestions and release the cities from pollution but also savings for their users [53]. Other digital applications complete the previous proposals with the use of sensors or even machine learning based on real-time data to assess possible traffic congestions and release the cities from pollution but also savings for their users. To this, Gorbunova and Anisimov [54] encourage the use of renewable sources to energy supply for urban infrastructure to improve their efficiency and enhance the benefits derived from the grid.

According to the UN 2020 Human Development Report, countries with higher human development tend to exert more pressure over greater scales on the planet [55].

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. Chinese urbanization, as a result of the shift from rural to urban areas, has brought several challenges due to the increased pressures on the human and natural environment and evoked questions of sustainability to preserve its resources. Forthcoming risks and concerns are the onwards threats due to the uncontrolled and complex phenomenon of rapid growth. Beyond this, the mitigation of the stress by climate change to rethink the social and economic benefits is undeniable. Top-down urbanization cannot continue to maintain growth healthily; this last point was the incentive for this work.

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 'smart-driven solutions' to promote environmental sustainability at rapid urbanization phenomena occurring in developing countries?'. To answer these questions, a theoretical study was conducted. First, the relevant literature was studied regarding rapid urbanization and its environmental impacts, Beijing context, and definitions of smart city approaches towards smart environments.

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; the selected indicators were analyzed during the period 2000–2020 as an important timeframe for the intensity of the urbanization phenomenon and the available data. The key features (indicators) for this analysis were based on the RIAM matrix proposal and lay upon the water/air quality, the energy demand, etc. Finally, based on the results of the RIAM analysis, a proposed conceptual framework for the 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 the environmental impacts of this urban phenomenon (i.e., smart grid, increase in resource use, etc.).

The study framework is a combination of a vision for four strategic areas of smartness and project management perspectives and identifies applications under a prioritized order according to the KPIs involved. Moreover, the study integrates the phenomena of rapid urbanization towards the SC vision. In conclusion, SC around the world, and particularly in developing countries, need to create new operating roadmaps, which 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 in the SC strategies. Holistic approaches towards sustainable and green principles including actions of fighting against inequalities, ensuring digital inclusivity, measures of mitigating the challenges of risks and impacts of environmental degradation are essential for long-term city planning ensuring the citizens' quality of life in a long-term horizon. This study contributes a small step to a deeper understanding of SC under countries with rapid urbanization. Rapid and even more uncontrolled urbanization can lead to poor urban and built environments and even to non-existing infrastructure, which reduces 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 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 to 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 extends 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 fulfill 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

USD	United States Dollar
UN	United Nations
QoL	Quality of Life
GDP	Gross Domestic Product
EIA	Environmental Impact Assessment
SEA	Strategic Environmental Assessment
RIAM	Rapid Impact Assessment Matrix
NEPA	National Environmental Policy Act
EI	Environmental Impact
SD	Sustainable Development
KPI	Key Performance Indicator
ISO	International Organization for Standardization
ITU	International Telecommunication Union
UNECE	United Nations Economic Commission for Europe
PC	Physical/Chemical
BE	Biological/Ecological
SC	Social/Cultural
EO	Economic/Operational
PC	Principal Component
PM	Particular Matter
NO	Nitrogen Dioxide
SO	Sulphur Dioxide
WHO	World Health Organization
GHG	Greenhouse Gas
SE	Smart Environment
EU	European Union
SC	Smart Cities
ICT	Information Communications Technology

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