Innovation and Technology in Urban Transformation: An Analysis of Frameworks, Stakeholders, and Key Performance Indicators for the Development of Smart Cities

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Abstract. Urban development has become increasingly complex due to rapid population growth and the demand for sustainable practices. Implementing smart city solutions offers a potential approach to address these challenges. This study advances the understanding of the smart city concept, its essential elements, and its specific applicability within the Mexican context. We define smart cities by distinguishing them from sustainable cities, and We explore the most common frameworks created by the International Telecommunications Union (ITU) and the International Standardization Organization (ISO). We review the Mexican standards (NMX) for smart cities. Additionally, we analyze different smart city approaches, and the roles of stakeholders involved in planning and implementing these initiatives. Based on this analysis, we outline adaptable frameworks for potential application in Mexican cities, identifying priority areas and criteria for selecting and prioritizing key performance indicators (KPIs) like technology use, energy efficiency, and social inclusion. This work lays a preliminary foundation for practical approaches to smart city development, offering a framework that supports informed decision-making and structured evaluation of progress toward urban intelligence.

1 Introduction

According to World Bank statistics [1], more than half of the world's population (57%) lives in urban areas. Demographic projections indicate that this trend will persist in the future, since it is estimated that urban population will double by 2050 [2]. In Mexico this percentage is even higher, with more than 80% of the population living in urban areas nowadays [3].

Urban areas management objectives should focus on providing equal access to the infrastructure and services like housing, public infrastructure, transportation, energy, education and health to the population [4].

Seminal work by Giffinger *et al* [5] defined the characteristics that confer intelligence to a city; moreover, it introduced a first hierarchical structure with indicators that made it possible to evaluate the degree of 'intelligence' of a city.

The International Telecommunications Union (ITU) and the International Standardization Organization (ISO) have developed international standards [6-9]. Taking up the ideas of Giffinger *et al* [5], among others, these organizations have enabled the standardization of the definitions and the metrics to compare and evaluate the degree of intelligence between cities throughout the world.

Considering these models and frameworks we introduce an initial set of proposals towards the establishment of criteria and quantitative indicators that enable the evolution of the Mexican cities as smart cities. This initial exploration allows the comprehension of the contexts, their complexity, and their relation to the priority areas of our socio-economic conditions.

2 Objective

This work contributes to the comprehension of the smart city concept, its elements and its applicability at the national level, throughout an exploration of the Mexican context in international indexes related to smart cities, the identification of initiatives for the transition towards smart and sustainable cities at the federal and municipal levels, the national standardization efforts, as well as the analysis and identification of national priority issues, associated with international reference frameworks, which lay the basis for proposing criteria for their attention.

3 Problem statement

In a broad context, a smart city has key elements: it is sustainable, inclusive and transparent, generates wealth, and is designed for the citizens. The common denominator for these key elements is technology, which is used to reduce costs, optimize resource consumption, operate with open data, provide adequate infrastructure, and improve people's quality of life by offering faster and more efficient public services [10].

While there is no single model for the description of a smart city, there are convergences among the criteria used to determine how close or far a city is from achieving this status. Various organizations have implemented indices to monitor these aspects using different methodologies. One of these is the IESE Cities in Motion Index (ICIM). The ICIM index evaluates nine dimensions: economy, human capital, technology, environment, international projection, social cohesion, mobility and transportation, governance, and urban planning. These dimensions are integrated into a single indicator. The 2022 edition of the ICIM index includes 183 cities worldwide and provides a calculator for inputting data from any city to determine its ranking in the index [11].

The IMD Smart City Index (IMD stands for International Institute for Management and Development) is another index whose methodology evaluates the perceptions of city inhabitants regarding available infrastructures and technological applications in areas such as health and safety, mobility, activities, opportunities, and governance. In its 2023 edition it ranks 141 cities worldwide, capturing the perceptions of 120 inhabitants per city. The final score is calculated using the perceptions from the last three years of the survey, with a weight of 3:2:1 for 2023:2021:2020 [12].

The only Mexican city considered in both indices is Mexico City. In the IESE Cities in Motion Index, it is ranked 115th out of 183, while in the IMD Smart City Index it holds the 121st position out of 141 (queries conducted on July 18, 2023). Although Mexico City has been the subject of more detailed and specific analysis in terms of its progress towards urban intelligence, it is evident that it still faces challenges in advancing towards greater development as a smart city. Additionally, there is a need to analyze other Mexican cities that are taking initiatives in this direction.

In Mexico, to date, only one proposal from the governmental sphere related to smart cities has been identified. This initiative was presented in 2016 by Senator Andrea García García and aims to create a special commission on smart cities [13]. However, this initiative has not progressed, and its status is reported to be with the Political Coordination Board of the Mexican Congress; there is no information about its approval as of the consultation date.

Still within the governmental sphere, according to the list of related initiatives in the field of smart/sustainable cities provided by the Economic Commission for Latin America and the Caribbean (ECLAC) [14], there is the Emerging and Sustainable Cities (ESC) program of the Housing and Urban Development Division, launched in 2012 by the Inter-American Development Bank (IDB). This was a non-reimbursable technical assistance program aimed at providing direct support to central and local governments in the development and implementation of urban sustainability plans (IDB, n.d.) [15]. Eight Mexican cities participated in this program: Campeche, Coatzacoalcos, Hermosillo, La Paz, Lázaro Cárdenas, Salina Cruz, Tapachula, and Xalapa. Through their municipal governments, Banobras (Mexican Governmental Bank for Development), and the IDB, these cities worked on defining and implementing specific action plans based on the recommendations and methodology of the ESC program [16].

The most recent known evaluation of these actions was conducted by the IDB's Office of Evaluation and Oversight in 2016. It highlights that in Mexico, information is only broken down for three cities: Xalapa, La Paz, and Campeche, which were visited during the evaluation. Although the document mentions annexes as case studies for each evaluated country, these chapters are not available in the online document [17].

While the development of methodologies aimed at the sustainability of cities is a meritorious effort for the modernization of cities and the improvement of citizens' quality of life, in a global scenario where technological innovation and increasing competition are predominant, standardization becomes an essential tool for economic development and global trade [18].

The international standards related to smart cities established by the International Organization for Standardization (ISO) address the need to evolve towards sustainable communities and cities. The primary standard is ISO 37122 [6], which, in combination with ISO 37120 [7], establishes the methodologies and indicators for measuring cities.

Furthermore, since the intelligence of a city inherently relies on the use of information and communication technologies (ICT), the International Telecommunication Union (ITU) issued the recommendation ITU-T Y.4900/L.1600 [8], which has recently been complemented by the recommendation ITU-T Y.4903:2022 [9], defining a set of performance indicators for smart cities.

In Mexico, two standards have been developed: a) “Information Technologies - Conceptual Model of Smart City - Guide to Establish a Model for Data Interoperability” (NMX-I-30182-NYCE-2020); and b) “Key Performance Indicators Related to Smart and Sustainable Cities to Assess the Achievement of Sustainable Development Goals” (NMX-I-4903-NYCE-2021), both shown in Table 1. Contrary to Mexican Official Standards (NOM), the Mexican Standards (NMX) are primarily voluntary and are promoted by the Secretary of Economy and the private sector through the National Standardization and Certification Organization NYCE.

Even though an international and national standardization framework exists; and municipal governments make isolated efforts to develop smart or sustainable cities, they lack a systematic approach to define the key indicators that would establish a starting framework for such development under conditions like those of other cities in the world. Therefore, this work aims to define those key indicators.

Table 1. Mexican standards for Smart City initiatives [19-20].

Current code and title	Objective and scope	Alignment with international standards
NMX-I-30182-NYCE-2020 *Tecnologías de la información-Modelo conceptual de ciudad inteligente-Guía para establecer un modelo para la interoperabilidad de datos.* Standard Status: FINAL Date of Publication in DOF: May 25, 2020 Effective Date: July 25, 2020	A defining characteristic of smart cities is the ability to interoperate. This Mexican Standard defines a conceptual model and provides guidance to decision-makers to promote the interoperability of data created, used, and maintained by a city across all sectors, on behalf and in collaboration with its citizens.	This Mexican standard is identical (IDT) to the International Standard: ISO/IEC 30182:2017-05 Smart city concept model - Guidance for establishing a model for data interoperability.
NMX-I-4903-NYCE-2021 *Telecomunicaciones- Indicadores clave de desempeño relacionados con las ciudades inteligentes y sostenibles, para evaluar el logro de los objetivos de desarrollo sostenible.* Standard Status: FINAL Date of Publication in DOF: February 8, 2022 Effective Date: April 9, 2022	This Mexican Standard describes key performance indicators (KPIs) in the context of smart and sustainable cities (SSC) used to assess the achievement of sustainable development goals (SDGs). Evaluating these indicators can help cities and their stakeholders understand to what extent they can be perceived as smart and sustainable.	This standard is modified (MOD) from the International Standard: Recommendation ITU-T Y.4903:2016 Key performance indicators for smart sustainable cities to assess the achievement of Sustainable Development Goals (SDG).

3.1 The Concepts of Sustainable City and Smart City

In the context of this research, the goal is to discern the concepts and particularities that distinguish sustainable cities from smart cities. A precise understanding of these notions is fundamental for exploring how they converge and contribute to the well-being of their populations.

Sustainable cities emerge from the combination of sustainable development and urbanization. Traditionally, the concept of sustainable cities has focused on infrastructure related to sewerage, water, energy, and waste management [21].

The concept of a "smart city" has not yet been fully standardized, but it refers to a city that systematically employs digital technologies to promote sustainability, reduce resources consumption, and improve the quality of life for its inhabitants. These cities rely on smart solutions applied to infrastructure, energy, housing, mobility, services and security, based on integrated sensor technology, connectivity, data analysis, and functional and independent processes [22].

Under the approach of Höjer & Wangel [21], it is not redundant to speak of "sustainable smart cities," given that in the literature not all definitions of smart cities explicitly include sustainability.

In this regard, the International Telecommunication Union, in its Recommendation ITU-T Y.4900/L.1600 [8], defines a smart and sustainable city as “an innovative city that uses information and communication technologies (ICT) and other means to improve quality of life, the efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental, and cultural aspects.”

In this work, we refer to smart cities as those that rely on the use of ICT to achieve their social, environmental, economic, and socio-cultural objectives.

Having delineated the fundamental concepts of sustainable and smart cities, it is imperative to explore the theoretical frameworks that underpin their development and implementation.

3.2 Theoretical Foundations of Smart and Sustainable Cities

Understanding the development of smart cities necessitates the integration of foundational theories in urban governance and socio-technical systems. Urban Governance Theory underscores the pivotal role of collaborative governance among diverse actors—including governmental bodies, the private sector, and civil society—in the effective management of urban resources and the implementation of sustainable policies [23]. This framework highlights the importance of multi-stakeholder engagement and participatory decision-making processes in fostering resilient and adaptable urban environments. Complementing this, Socio-Technical Systems Theory emphasizes the interdependent relationship between social dynamics and technological infrastructures, advocating for holistic approaches that consider both human and technological factors in the design and deployment of smart city solutions [24]. Furthermore, Resilience Theory introduces the capacity of urban systems to absorb shocks and adapt to evolving conditions, which is essential for sustainable urban development [25]. By synthesizing these theoretical perspectives, our framework delineates the distinctions between sustainable and smart cities while establishing a robust foundation for examining how collaborative governance and socio-technical dynamics collectively contribute to sustainable urban development within the Mexican context. This integrated approach aligns

technological innovation with social equity and environmental sustainability, supporting the development of resilient and inclusive urban environments.

4 Methodology

4.1 Research Design

This study conducted a literature review to analyze smart city frameworks, methods, and standards in both national and international contexts. The objective was to identify best practices and emerging trends in smart city development.

4.2 Data Collection

The literature review included academic publications, governmental documents, and reports from relevant organizations. Scopus was utilized to source academic materials, while official websites of governmental bodies and international organizations provided access to pertinent reports and policy documents.

4.3 Data Analysis

Smart city standards were examined to identify key practices and emerging trends. A comparative analysis was conducted to assess their applicability within the Mexican context.

4.4 Development of Proposals

Based on the literature review findings, proposals were developed to guide the implementation of smart city concepts, standards, and stakeholder engagement in Mexico. These proposals provide general recommendations for advancing smart city initiatives and should be adapted to the specific needs and contextual characteristics of individual Mexican urban environments.

5 Elements in Smart City Development

In the evolution process towards a smart city, three fundamental elements exist [5, 26, 27]: the stakeholders involved in decision-making and the development and implementation of the process; the reference frameworks and the city model chosen to be implemented; and the indicators that will allow for an initial evaluation to set a starting point, as well as subsequent evaluations. These three elements are discussed in this section as a starting point for understanding them as the minimum components of a structured framework that enables the development of proposals based on the specific needs of each community.

5.1 Stakeholders

The implementation of a smart city constitutes a collective project, a shared administration with a high degree of self-management. Those involved must be aware of the project's scope and the responsibilities they assume. A prominent level of commitment is required when agreeing to a protocol like this, which aims to cultivate pathways for the construction of smart communities.

Smart cities must be based on noticeably clear and relevant regulatory platforms to ensure their success. It is necessary for the different stakeholders to have a roadmap and a definition of responsibilities regarding their participation in the project. The governance mechanisms, forms of involvement, and commitments of the various participants must be clear to maximize the benefits of the technologies and mechanisms implemented.

Van Der Hoogen *et al* [26] propose a stakeholder classification model based on Mayangsari & Novani [28] according to the roles they assume. The roles are a) enabler, b) provider, c) utilizer, and d) user. The enabler is responsible for creating the vision, finding the resources, providing leadership strategies, and fostering collaborations. The provider coordinates the efforts of academics and innovators to promote innovation methods and development, generate knowledge, and manage it systematically. The utilizers create products and services, set small-scale objectives based on the vision, learn new practices to produce accessible knowledge, and innovate. Meanwhile, the users participate in the experiments and provide on-site experiences of the products and services of smart cities.

In a broader framework, Ibrahim *et al* [27] propose a stakeholder participation model in eight stages: 1) identification of stakeholders, 2) prioritization of stakeholders, 3) information sharing with stakeholders, 4) stakeholder mapping, 5) collaboration among stakeholders, 6) stakeholder management, 7) engagement, and 8) monitoring and evaluation.

This model provides a series of recommendations to those planning the implementation of a smart city, as well as to decision-makers on how to ensure effective and efficient engagement of the different types of stakeholders in their city transformation projects.

In this work, we propose using the approach of Van Der Hoogen *et al* [26] for identifying key stakeholders in Mexico as the first step in implementing Ibrahim *et al*'s participation model [27] (see Table 2). This approach is then complemented by outlining the subsequent stages, providing guidance for setting priorities, assessing potential impact levels, and identifying the relative importance of project activities, all with the aim of fostering the commitment of key stakeholders in the process of transforming a city into a smart city.

Table 2. Stage 1: Identification of stakeholders and roles in the Mexican context.

Stakeholder roles	Stakeholders
Enablers	Federal Government State Government Municipal Government
Providers	Research Centres Higher Education Institutions Research Networks Business Incubators, Think Tanks
Utilizers	Nonprofit Organizations Private Sector Suppliers
Users	Citizens Investors Civil Society Organizations

Source: Adapted from [26].

Stage 2. Prioritizing Stakeholders: Mexico's complex governmental structure, with responsibilities distributed across federal, state, and municipal levels, requires careful prioritization of stakeholders based on their direct influence over the issues being addressed. This approach ensures that resources and efforts are allocated to those actors who can have the most significant impact on the progress towards a smart city.

Stage 3. Information Sharing with Stakeholders: In the Mexican context, platforms such as *Datos Abiertos de México* can be utilized to keep stakeholders informed about project developments. Transparency is essential; public institutions can leverage forums and social media to keep citizens updated.

Stage 4. Mapping Stakeholders: The diverse range of stakeholders in Mexico, from local NGOs to large multinational corporations, necessitates a clear visual mapping that specifies each actor's role and relationships within the project. This mapping should account for each actor's capacity to influence key areas, such as infrastructure, financing, and public awareness, while also identifying potential synergies and conflicts.

Stage 5. Collaboration and Partnerships: Public-private partnerships are a common mechanism in Mexico for infrastructure and technology development. A key example is *Proyectos México* an investment platform, which promotes private investment in public service sectors.

Stage 6. Managing Stakeholders: To foster the continuity of projects in Mexico, where changes in administration may affect the stability of initiatives, it is advisable to establish long-term collaboration agreements and governance mechanisms that institutionalize these projects. This contributes to ensuring that commitments made by key stakeholders remain robust and sustainable across administrative transitions.

Stage 7. Involvement in Project Monitoring and Evaluation: Entities such as the *Auditoría Superior de la Federación* (ASF) and citizen observatories could play a role in project evaluation and accountability. Involving these actors in the evaluation process promotes transparency and builds public trust in the project outcomes.

Stage 8. Monitoring and Evaluation of Stakeholder Commitment: Implementing specific indicators, such as those outlined in the Mexican standard NMX-I-4903-NYCE-2021, can support the effective fulfillment of key stakeholders' roles by measuring progress toward Sustainable Development Goals in the context of smart cities. This continuous monitoring facilitates strategic adjustments in collaboration and enhances a focus on achieving measurable results.

While the identification and engagement of stakeholders are essential to project success, defining their roles across each phase of a large-scale lifecycle is equally critical. The World Economic Forum's smart city implementation methodology [29] provides a foundational framework, from which this work develops context-specific actions for Mexico by aligning Urban Infrastructure Life-Cycle Stages with tailored stakeholder engagement strategies, as outlined in Table 3.

Table 3. Lifecycle Stages and Stakeholder Engagement: Proposed Actions for Mexico

Urban Infrastructure and Corresponding Stakeholder Engagement Stages	Proposed Strategic Actions for the Mexican Context
1. Strategic Planning, Funding, and Partnerships *Identification, Prioritization, Collaboration*	Involve key entities to align with strategic objectives, prioritize stakeholders by influence across government levels, and use *Proyectos México* to attract public-private investment.
2. Design and Procurement *Information Sharing, Mapping*	Employ *Datos Abiertos de México* to ensure transparency and stakeholder alignment with sustainability standards. Establish a detailed stakeholder role mapping to optimize synergies and minimize conflicts, especially between technology firms and NGOs.
3. Commissioning and Delivery *Management, Collaboration*	Establish robust governance frameworks to ensure project stability and continuity across administrative cycles. Integrate public-private partnerships to distribute risk equitably and to foster innovative approaches in project delivery.
4. Operations and Maintenance *Monitoring and Evaluation, Commitment Assessment*	Reinforce transparency. Employ NMX-I-4903 indicators to rigorously evaluate stakeholder commitment, enabling responsive strategic adjustments.
5. Repurposing and End-of-Life *Commitment Assessment, Management*	Continuously assess project adaptability with a focus on circular economy, maintaining agreements to secure stakeholder engagement in repurposing and decommissioning.

Source: Source: Own elaboration, based on [29].

This approach offers an initial guideline for defining stakeholder roles across each stage of the smart city lifecycle. While it provides structured guidance for governance and alignment with project goals, the diverse conditions across Mexican cities suggest that further adaptations may be necessary to effectively address local needs and evolving urban challenges.

5.2 Frameworks and Smart City models

Establishing a unified reference framework for smart cities poses challenges, given the distinct and complex attributes of each urban environment. Nevertheless, a well-defined framework is crucial for aligning stakeholder efforts and guiding cities toward the transformative vision of smart urbanism [26]. Such a framework provides the foundation for prioritizing indicators, identifying critical areas for improvement, and implementing strategies tailored to the unique context of each city.

Building on the seminal work of Giffinger *et al* [5], which delineated six defining dimensions of a "smart" city—economy, people, governance, urban mobility, environment, and lifestyle—these dimensions have evolved into pillars for contemporary smart city models (e.g., Khatoun & Zeadally [30]; Prabowo & Rosalinda [31]).

The Inter-American Development Bank framework [32] offers an exemplary model for Latin American contexts, focusing on social inclusion, economic resilience, and environmental sustainability. By structuring assessment criteria around these pillars, this framework enables cities to calibrate their efforts based on local priorities, directing resources toward impactful areas.

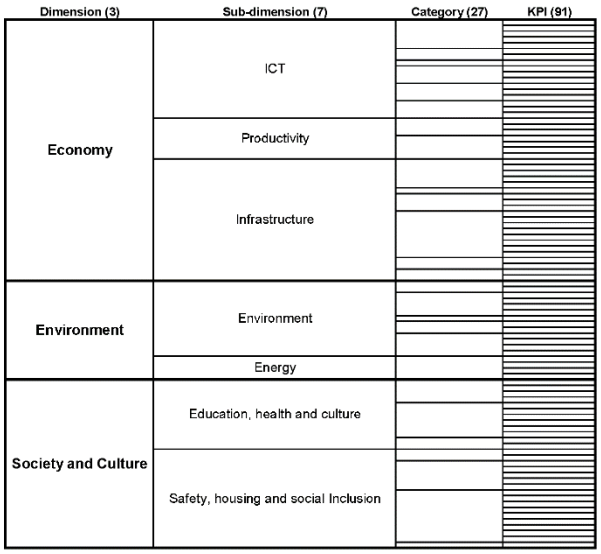
For Mexican cities, this approach holds particular significance. With a diverse range of urban challenges and opportunities across regions, a flexible framework supports tailored applications of smart city principles. Such adaptability is essential for addressing Mexico's urban priorities—mitigating infrastructure disparities, advancing social equity, and enhancing climate resilience.

5.3 Indicators

In the literature, there are various elements under which indicators emerge to assess how smart a city is. Among the elements commonly assessed are economy, society, environment, infrastructure, governance, energy, transportation, health, and lifestyle [5, 21, 33].

The ISO 37122 standard [6] defines 20 indicators for smart cities, while the ITU-T Y.4903 standard [9] provides 91 key performance indicators (KPIs) grouped into 27 categories, which correspond to 7 sub-dimensions of 3 dimensions: economy, society and culture, and environment.

Figure 1 illustrates the hierarchy of KPIs in the ITU-T Y.4903 standard. There is a mechanism to quantify each of them and eventually evaluate the degree of a city's smartness. The names of the KPIs are not specified in the graphic because the intention is to illustrate the classification hierarchy, where aspects such as the use of ICT, infrastructure, or security, housing, and social inclusion are measured with greater precision.



Source: Own elaboration, based on [9].

Fig. 1. Hierarchical scheme of the ITU-T Y.4903 standard.

Table 4 shows an association between the indicators of the ISO 37122 standard and the number of KPIs and the dimension with which these indicators are addressed in the ITU-T Y.4903 standard. While this association is not formally established between the two organizations, it helps illustrate the complexity of information processing and the definition of prioritization criteria when starting the evaluation of a city's status at the beginning of a conversion process into a smart city.

To systematically address KPI selection and prioritization in the context of Mexican smart cities, this study adopts the framework outlined in Prabowo & Rosalinda [31]. This structured approach centers on three strategic objectives: enhancing quality of life, promoting sustainable social and economic growth, and fostering environmental sustainability. These categories allow KPIs to be selected based on relevance, measurability, and alignment with each city's specific priorities, addressing the need for adaptable and context-sensitive indicators.

a) Enhancing Quality of Life. For Mexican cities. KPIs in this category focus on improving access to essential services and economic opportunities. Indicators evaluate accessibility, efficiency, and affordability of urban services, emphasizing ICT solutions that lower costs and enhance daily efficiency, particularly in underserved areas. These KPIs are essential for equitable urban development, where basic infrastructure remains a priority.

b) Sustainable Social and Economic Growth. Economic growth through smart infrastructure is crucial in Mexico, where public-private partnerships (PPPs) significantly impact service delivery and local economies. KPIs should assess job creation, social capital, and the effectiveness of PPPs in reducing informality and supporting SMEs. Strengthening human capital is key to maximizing the long-term benefits of smart city initiatives.

c) Clean and Sustainable Environment. Environmental sustainability is critical for Mexican cities, facing urban pollution and energy challenges. KPIs here measure resource efficiency, carbon reduction, and municipal efforts in sectors like transport and waste management. Given Mexico's climate vulnerability, these indicators are vital for assessing resilience and adaptability.

By integrating these strategic goals, this framework provides a clear, adaptable methodology for selecting KPIs that align with local priorities and measurable outcomes, directly addressing the need for tailored, goal-oriented indicators.

Table 4. Relationship between indicators, dimensions, and number of KPIs in the ISO 37122 and ITU-T Y.4903:2022 standards.

ISO 37122 Indicator	ITU-T Y.4903:2022 Standard	
	Dimension	**KPIs**
Economy	Economy	45
Education	Society and Culture	4
Energy	Environment	4
Environment and Climate Change	Environment	13
Finance	--	--
Governance	Society and Culture	--
Health	Society and Culture	6
Housing	Society and Culture	2
Population and Social Conditions	Environment	5
Recreation	Society and Culture	4
Security	Environment	9
Solid Waste	Society and Culture	1
Sports and Culture	Economy	2
Telecommunications	Economy	17
Transportation	Society and Culture	8
Local/Urban Agriculture and Food Security	Environment	1
Urban Planning	Economy	2
Drainage	Economy	2
Water	--	3
Documentation and Records Maintenance	Economy	--

Source: Own elaboration, adapted from [6,9].

A continuous monitoring and evaluation framework is essential to effectively support smart city initiatives across Mexico's diverse urban contexts, considering each city's unique priorities and needs. The proposed strategies include:

a) Real-Time Monitoring and Citizen Feedback. Implementing real-time data dashboards enables immediate KPI tracking and strategic adjustments. Digital surveys can further capture shifting public needs, creating a responsive feedback loop. Although this approach enhances adaptability, it may face challenges with data integration and citizen engagement, especially in cities with varying technological infrastructures.

b) Quarterly Audits. Quarterly audits can bolster transparency and accountability, ensuring KPIs align with sustainability objectives across distinct urban settings. This method allows early identification of necessary adjustments; however, its feasibility may vary due to interagency coordination demands and administrative capacities across cities.

c) Application of the Mexican Standard NMX-I-4903-NYCE-2021. Applying this standard to measure progress toward sustainable development goals enables alignment with Mexico's 2030 Agenda. Given the evolving urban challenges, periodic reviews of these KPIs may be required to maintain their relevance across different cities.

These strategies lay a foundation for adaptive urban management in Mexican smart cities, yet their success depends on overcoming limitations related to data quality, resource allocation, and the diverse socio-economic and technological landscapes of Mexican cities.

6 Smart City Priorities in Mexico

Building on the methodology outlined in Section 4 and the analysis of stakeholders, frameworks, and indicators in Section 5, this section delineates key priorities essential for advancing smart city initiatives in Mexico. Focusing on critical areas such as citizen well-being, public service optimization, urban mobility, and sustainable infrastructure, these priorities are tailored to address the nation's unique socio-economic challenges. Aligned with international standards (ISO 37122 and ITU-T Y.4903:2022), they ensure coherence with global best practices in smart city development.

6.1 Enhancing Citizen Care

Citizen care emerges as a paramount priority in Mexico, where significant portions of municipal budgets are allocated to public safety and healthcare services. By leveraging Information and Communication Technologies (ICT), smart cities can augment justice systems, enhance public safety through intelligent surveillance, and expand healthcare access via telemedicine and e-health solutions. This priority involves stakeholders such as federal and municipal governments (enablers), technology providers and research institutions

(providers), and the citizenry (users). ISO 37122 Indicators: Health and Safety; ITU-T Y.4903:2022, 15 KPIs involved.

6.2 Optimizing Public Service Management

Optimizing public services through technological innovation holds the potential to reduce operational costs and enhance efficiency in critical areas such as water management, electricity distribution, transportation systems, and administrative processes. The implementation of e-governance platforms, smart grids, and IoT-enabled infrastructure necessitates collaboration between governmental entities (enablers), academia and research centers (providers), and private sector stakeholders (utilizers). ISO 37122 Indicators: Economy, Energy, Governance, Water, Sewerage; ITU-T Y.4903:2022, 54 KPIs involved.

6.3 Advancing Urban Mobility

Addressing urban congestion is critical for improving quality of life and fostering economic vitality. Smart mobility solutions—including real-time traffic management, intelligent public transportation systems, and the promotion of sustainable transport modes—can substantially enhance travel efficiency and reduce environmental emissions. Key stakeholders include municipal governments and transportation authorities (enablers), technological innovators (providers), and commuters (users).. ISO 37122 Indicators: Environment and Climate Change, Transportation, Urban Planning; ITU-T Y.4903:2022, 23 KPIs involved.

6.4 Streamlining Production and Distribution of Goods

Enhancing the efficiency of production and distribution networks is essential for reducing transaction costs and stimulating economic growth. By adopting advanced technologies such as Artificial Intelligence (AI) and data analytics, smart cities can optimize supply chains and logistics, thereby improving competitiveness. Stakeholders encompass private sector companies (utilizers), research institutions (providers), and consumers (users). ISO 37122 Indicators: Economy, Urban Planning, Local/Urban Agriculture, and Food Security; ITU-T Y.4903:2022, 48 KPIs involved.

6.5 Implementing Sustainable Waste Management

Transitioning towards sustainable waste management practices is integral to developing a circular economy within smart cities. Introducing intelligent waste collection systems, recycling initiatives, and waste-to-energy technologies requires the participation of municipal sanitation departments (enablers), environmental organizations (providers), and residents (users). ISO 37122 Indicators: Environment and Climate Change, Solid Waste, Sewerage; ITU-T Y.4903:2022, 6 KPIs involved.

6.6 Enhancing Educational Infrastructure and Mobility

Although educational policy is predominantly managed at the federal level, municipal governments significantly influence the maintenance and development of educational facilities and the safety and mobility of school communities. Smart city strategies can optimize the spatial distribution of educational institutions and improve access routes through data-driven urban planning. Stakeholders include municipal authorities (enablers), educational institutions (providers), and students and families (users). ISO 37122 Indicators: Transportation, Urban Planning; ITU-T Y.4903:2022, 10 KPIs involved.

6.7 Developing Smart General Infrastructure

Advancing general infrastructure through smart technologies promotes efficient land use, energy conservation, and resource management. The integration of smart buildings capable of generating renewable energy and autonomously managing operational functions contributes significantly to sustainability objectives. Collaboration is needed among government agencies (enablers), construction and engineering firms (utilizers), and technology providers. ISO 37122 Indicators: Governance, Urban Planning; ITU-T Y.4903:2022, 2 KPIs involved.

These priorities delineate a strategic framework for smart city development in Mexico, directly addressing key socio-economic challenges. By focusing on critical sectors and aligning with international standards, this approach facilitates effective implementation through coordinated stakeholder engagement and measurable outcomes.

7 Conclusions

This study has established an initial framework for advancing smart city initiatives in Mexico, highlighting the necessity of tailoring strategies to the diverse conditions of individual cities. By integrating stakeholders, reference frameworks, models, and indicators, the proposed methodology offers flexibility and adaptability, enabling measurable progress toward smart city objectives.

Recognizing that a uniform approach is impractical due to the varying needs, resources, and infrastructural capacities across Mexican cities, this framework allows each city to customize strategies according to its unique context. External factors such as budget constraints, infrastructural disparities, residents' lifestyles, the digital divide, and potential resistance to change must be carefully considered to ensure realistic and sustainable implementation.

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References

1. Banco Mundial, Población urbana (% del total), [Internet]. Available: https://datos.bancomundial.org/indicador/SP.URB.TOTL.IN.ZS.Accessed: July 20, 2023.
2. Banco Mundial, Desarrollo urbano, panorama general [Internet]. Available from: https://www.bancomundial.org/es/topic/urbandevelopment/overview. Accessed: July 12, 2024.
3. Banco Mundial, Población urbana (% del total) - México [Internet]. Available from: https://datos.bancomundial.org/indicator/SP.URB.TOTL.IN.ZS?locations=MX. Accessed: July 12, 2024.
4. United Nations, World Urbanization Prospects 2018 Highlights [Internet]. Available from: https://population.un.org/wup/Publications/Files/WUP2018-Highlights.pdf. Accessed: July 12, 2024.
5. R. Giffinger, C. Fertner, H. Kramar, R. Kalasek, N. Pichler-Milanovic, and E. Meijers. (2007). Smart cities: Ranking of European medium-sized cities. Available from: https://www.smart-cities.eu/download/smart_cities_final_report.pdf. Accessed: July 12, 2024.
6. ISO, Sustainable cities and communities — Indicators for smart cities (ISO 37122:2019), (2019). https://www.iso.org/standard/69050.html
7. ISO, Sustainable cities and communities — Indicators for city services and quality of life (ISO 37120:2018), (2018). https://www.iso.org/standard/68498.html
8. ITU-T, Overview of key performance indicators in smart sustainable cities (ITU-T Rec. Y.4900/L.1600), (2016). https://www.itu.int/ITU-T/recommendations/rec.aspx?id=12627
9. ITU-T, Key performance indicators for smart sustainable cities to assess the achievement of sustainable development goals (ITU-T Y.4903:2022), (2022). https://www.itu.int/rec/T-REC-Y.4903-202203-I/
10. M. Bouskela, M. Casseb, S. Bassi, La ruta hacia las Smart Cities: Migrando de una gestión tradicional a la ciudad inteligente (2016). http://dx.doi.org/10.18235/0012831
11. P. Berrone, J. Enric Ricart, Índice IESE Cities in Motion (2022). https://www.iese.edu/media/research/pdfs/ST-0633.pdf
12. IMD, IMD Smart City Index 2023 (2023). https://imd.cld.bz/IMD-Smart-City-Index-Report-20231
13. A. García García, Gaceta del Senado. Documento No. LXIII/2PPO-42-1990/66944. En Gaceta del Senado (2016). https://www.senado.gob.mx/65/gaceta_del_senado/documento/66944
14. CEPAL, Ciudades inteligentes / sostenibles. Iniciativas y Proyectos Regionales y Mundiales [Internet]. Available from: https://biblioguias.cepal.org/c.php?g=159524&p=1044499. Accessed: July 12, 2024.
15. BID, Programa Ciudades Emergentes y Sostenibles [Internet]. Available from: https://www.iadb.org/es/quienes-somos/topicos/desarrollo-urbano-y-vivienda/iniciativas-de-desarrollo-urbano/programa-de Accessed: July 12, 2024.
16. Proyectos México, Desarrollo regional [Internet]. Available from: https://www.proyectosmexico.gob.mx/por-que-invertir-en-mexico/desarrollo-regional. Accessed: July 12, 2024.
17. Oficina de Evaluación Supervisión, Evaluación de la Iniciativa Ciudades Emergentes y Sostenibles del BID (2016). https://publications.iadb.org/es/publicacion/17206/evaluacion-de-la-iniciativa-ciudades-emergentes-y-sostenibles-del-bid
18. Secretaría de Economía, Unidad de Normatividad, Competitividad y Competencia [Internet]. Available from: https://e.economia.gob.mx/unidad-de-normatividad-competitividad-y-competencia/. Accessed: July 12, 2024.
19. NYCE, Acervo normativo NYCE. Catálogo normativo [Internet]. (2022). Available from: https://nyce.org.mx/catalogodeestandaresnyce/. Accessed: July 12, 2024.
20. Secretaría de Economía, Sistema Integral de Normas y Evaluación de la Conformidad (SINEC) [Internet]. Available from: https://e.economia.gob.mx/servicios/sistema-integral-de-normas-y-evaluacion-de-la-conformidad-sinec/. Accessed: July 12, 2024.
21. M. Höjer, J. Wangel, Smart sustainable cities: Definition and challenges. In L.M. Hilty, B. Aebischer (Eds.), ICT Innovations for Sustainability. Adv. Intell. Syst. Comput. **310**,

(Springer, Cham, 2015). https://doi.org/10.1007/978-3-319-09228-7_2
22. O. Gassmann, J. Böhm, M. Palmie, Smart Cities: Introducing Digital Innovation to Cities (Emerald Group Publishing, 2019).
23. P. Healey, Collaborative Planning: Shaping Places in Fragmented Societies. (Macmillan Press Ltd, London, England, 1997). https://doi.org/10.1007/978-1-349-25538-2
24. Orlikowski, Wanda J. "The Duality of Technology: Rethinking the Concept of Technology in Organizations." Organization Science 3, no. 3 (1992): 398–427. http://www.jstor.org/stable/2635280.
25. S. Meerow, J.P. Newell, and M. Stults. "Defining Urban Resilience: A Review." Landscape and Urban Planning, **147** (2016): 38-49. https://doi.org/10.1016/j.landurbplan.2015.11.011.
26. A. Van Der Hoogen, B. Scholtz, A. Calitz, A Smart City Stakeholder Classification Model. 2019 Conference on Information Communications Technology and Society (ICTAS), 1-6 (2019). https://doi.org/10.1109/ICTAS.2019.8703633
27. M. Ibrahim, A. El-Zaart, C. Adams, Stakeholders Engagement in Smart Sustainable Cities: A Proposed Model. 2017 International Conference on Computer and Applications (ICCA). 342 (2017). https://doi.org/10.1109/COMAPP.2017.8079773
28. Mayangsari L, Novani S, Multi-stakeholder co-creation Analysis in Smart city Management: An Experience from Bandung, Indonesia. Procedia Manuf. **4**, 315–321 (2015). https://doi.org/10.1016/J.PROMFG.2015.11.046
29. World Economic Forum. Implementing a life-cycle approach to infrastructure: A policy roadmap for cities. World Economic Forum. (2024). https://www3.weforum.org/docs/WEF_Implementing_a_Life_Cycle_Approach_to_Infrastructure_2024.pdf
30. R. Khatoun, S. Zeadally, Smart cities. Commun. ACM, **59**(8), 46–57 (2016). https://doi.org/10.1145/2858789
31. W. A. Prabowo, A. T. Rosalinda, Development of Smart City Sustainable Key Performance Indicators in line with IT Infrastructure Library. 2022 International Conference on ICT for Smart Society (ICISS), 1–7 (2022). https://doi.org/10.1109/ICISS55894.2022.9915091
32. Inter-American Development Bank (IDB). Aplicación de la metodología para evaluación, identificación e implementación de proyectos Ciudades Inteligentes ("Smart Cities") en América Latina y el Caribe, 2021. https://github.com/EL-BID/Plantilla-de-repositorio
33. A. Abu-Rayash, I. Dincer, Development and application of an integrated smart city model. Heliyon, **9**(4), e14347 (2023). https://doi.org/10.1016/j.heliyon.2023.e14347