

**A City Information Model framework development for Urban
Sustainability Assessment aligning with stakeholder priorities in Astana**

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Declaration

I hereby declare that this manuscript, entitled " A City Information Model framework development for Urban Sustainability Assessment aligning with stakeholder priorities in Astana", is the result of my own work except for quotations and citations which have been duly acknowledged.

I also declare that, to the best of my knowledge and belief, it has not been previously or concurrently submitted, in whole or in part, for any other degree or diploma at Nazarbayev University or any other national or international institution.



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Abstract

Rapid urban growth and increasing sustainability pressures highlight the need for integrated digital tools that can support informed and data-driven urban governance. This study proposes a City Information Modeling (CIM) framework for assessing urban sustainability in Astana, Kazakhstan, with a focus on aligning indicators based on stakeholder-informed analysis and contextual relevance. Although existing international sustainability assessment systems provide extensive indicator sets, their practical integration into city-scale digital platforms remains limited, especially in rapidly developing urban contexts.

A mixed-methods case study approach is adopted. Initially, major international sustainability frameworks together with the national OMIR system are reviewed to identify relevant indicators based on defined selection criteria. This is followed by a systematic stakeholder mapping and power-interest analysis to connect sustainability priorities with responsible actors. The selected indicators are then organized into four main dimensions—environmental, social, economic, and institutional—alongside a set of mandatory requirements aimed at ensuring governance and infrastructure readiness. A Data Requirement Analysis (DRA) is conducted to examine the availability, quality, and compatibility of local data sources. In addition, different CIM implementation configurations, including BIM-, GIS-, and IoT-based integrations, are evaluated in terms of feasibility and governance alignment.

The study identifies 110 stakeholders representing key governance, infrastructure, and data-related roles, and compiles a total of 180 sustainability indicators, from which priority indicators are determined based on stakeholder relevance and contextual applicability. The findings indicate that institutional and economic dimensions play a central enabling role, as they underpin regulatory capacity, financial resources, and data management structures required for broader sustainability implementation. In contrast, environmental and real-time monitoring indicators are more constrained due to limited data availability and integration challenges. Significant barriers are observed in data interoperability, cross-organizational coordination, and real-time data acquisition. Indicators such as urban flood risk monitoring, district-level energy performance, and comprehensive air quality assessment are particularly difficult to operationalize without advanced digital integration.

The proposed framework conceptualizes CIM as a layered digital system that integrates spatial, infrastructural, environmental, and governance-related information into a unified platform for

sustainability assessment. While Astana demonstrates initial progress in digital infrastructure and institutional capacity, further development is required to improve data integration and coordination mechanisms. The framework offers a practical pathway for embedding sustainability indicators into a scalable city model and supports policy applications, including Green Public Procurement and broader urban digital transformation initiatives.

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List of Abbreviations & Symbols

BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CIM	City Information Modeling
EMS	Environmental Management System
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
HVAC	Heating, Ventilation, and Air Conditioning
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IoT	Internet of Things
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SDG	Sustainable Development Goal
SuDS	Sustainable Drainage Systems
TFEC	Total Final Energy Consumption
TOD	Transit-Oriented Development
TPES	Total Primary Energy Supply
UHI	Urban Heat Island
UNEP	United Nations Environment Programme
UN-Habitat	United Nations Human Settlements Programme
DT	Digital Twin
UDT	Urban Digital Twin
GPP	Green Public Procurement
TEE	Trusted Execution Environment

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Chapter 1 – Introduction

1.1. General

The thesis aim is to develop a feasible City Information Model (CIM) framework for an urban sustainability assessment with the alignment of stakeholders' preferences in Astana, Kazakhstan. The thesis proposal represents the literature review on the thesis topic, containing CIM, urban sustainability assessment tools, then suggests a tailored sustainability framework for Astana's conditions and main stakeholders. In the increasingly urbanized world, there is a strong demand for deeper analysis and a technological method helping evaluate sustainability on the urban scale. So, such a CIM framework serves to solve the sustainability concerns and assist urban planners, engineers and architects in decision-making and city management. The thesis offers an comprehensive framework for CIM to help stakeholders in Astana who can effectively integrate urban sustainability principles in the city development.

1.2 Aims & objectives

The main objectives:

1. Investigate the context of Astana, the current condition and prospectives in terms of urban sustainability and information platforms
2. By identifying the stakeholders, considering relationships between them, their influence and interest, create a stakeholder map and network analysis.
3. Evaluate and analyze the existing global urban sustainability frameworks such as BREEAM Communities, LEED for Cities and Communities and OMIR, and compliance with UN SDG 11 on urban scale, then extract applicable indicators.
4. Categorize and prioritize the parameters and indicators mentioned in the systems in accordance with stakeholder and experts' opinions and perform their evaluations
5. Perform Data Requirement Analysis (DRA) to prepare foundation to connect indicators with local data ecosystem.
6. Conduct further analysis for the feasibility of enabler tools for the CIM: e.g., GIS, BIM, IoT, using SWOT, gap analysis.
7. Demonstrate possible case studies on how to use the suggested framework in national wide implementations including the development of a urban assessment version of UMIR and supporting the Green Public Procurement system.

8. Finalize the CIM framework for the urban sustainability assessment in Astana

1.3 Methodologies and techniques

The research has a mixed-methods approach that focuses on Astana. The methodology consists of: (1) analysis of international urban sustainability assessment systems (e.g., BREEAM Communities, LEED for Cities) and national system OMIR to extract applicable indicators; (2) stakeholder identification, analysis and mapping; (3) indicator refinement through academic supervision and professional consultation; (4) Data Requirement Analysis (DRA) to evaluate local data availability and CIM integration potential; and (5) comparative assessment of CIM enabler configurations (BIM-GIS-IoT) based on feasibility, interoperability, and governance alignment. The outcome is the development of a context-adapted CIM framework for urban sustainability assessment.

1.4 Literature Review

The literature review examines the theoretical and technological foundations of City Information Modeling (CIM), including BIM, GIS, IoT, data integration, and digital twins. It further analyzes global urban sustainability assessment tools and stakeholder theory in sustainability governance. The review identifies a gap in integrating urban sustainability indicators within operational CIM frameworks, particularly in the context of rapidly developing cities such as Astana. This gap forms the basis for the proposed framework.

1.5 Thesis structure

The thesis is structured into six chapters. Chapter 1 introduces the research background, objectives, and methodology. Chapter 2 reviews literature on CIM, sustainability assessment tools, and stakeholder theory. Chapter 3 presents the method development process, including stakeholder analysis, data requirement analysis, and CIM enabler evaluation. Chapter 4 provides results and indicator projections to the urban scale and proposed CIM-based framework in the form of “indicator- formula- unit- frequency- data format- data required- enablers- data availability-data flows”. Chapter 5 contains Discussion and future implications. Chapter 6 concludes the beforementioned with key findings, limitations, and recommendations.

Chapter 2 – Literature Review

2.1. The definition of City Information Model (CIM) and the brief history

Cities represent themselves as versatile and complex systems. Therefore, there was a strong demand for appropriate concepts, enablers, and tools to be applied to resolve these complications [1-3]. In this regard, new technologies and concepts such as City Information Modeling (CIM) have been become actual to address the multiscale urban needs.

There is not a common consensus about a definite CIM definition and Table 1 summarizes the possible views of concepts on CIM. The city information modeling concept was introduced for the first time by Khemlani in 2007 [4]. Here, the well-known concept of BIM (Building Information Modeling) was extended to the urban scale. For that, an integration BIM with CIM, or an extension of Geographic Information Systems (GIS) with CIM [5-7] can be easily taken as a good definition that is related to CIM. However, recently, with the advancement of new information and data acquisition technologies, the definition developed gradually into BIM, GIS IT (information technologies), IoT (internet of things), and AI (artificial intelligence) [8,9]. As a result, one can conclude that that CIM can be defined as a three-dimensional (3D) urban model established on multi-layer urban data with a framework evolving many collaborations. CIM is the foundation for new emerged concepts like smart- cities and digital twins.

Table 1: Views on CIM concept

Perspective	Description	Reference
BIM+	CIM as an extension of BIM with bigger number of buildings and their features.	[10], [11]
BIM	CIM as a new concept but applicable to the city scale.	[10]
BIM+GIS	CIM as a consolidation of BIM and GIS	[12]
CAD+GIS	CIM as a platform that integrates CAD and GIS databases to support	[10]
3D City Models	CIM as a content enhancement or semantic annotation of 3D city models during the planning process	[12]
GIS+	CIM as an extension of GIS, based on city data model and spatial analyses	[6]
Smart Cities	CIM as a platform or Smart City realization	[10]

2.2 Data-Guided CIM Development Process

The development of a CIM follows a structured sequence of activities [10]. It is important in the beginning to set project requirements as well as to identify potential use scenarios, e.g. urban assessment. Then, data is accumulated from different channels such as municipal departments, sensor networks, satellite images, while information verifiability and integrity checked. Once collected, the data are refined undergoing format change, error rectification, duplicates removal and completion. Datasets of various origins, then, are transformed into a standardized form, that is stored within a secure system [10].

Considering different stages of data procedures, one can encounter multiple CIM related research spheres, which can be divided into main three categories: data visualization, data collection, as well as data integration categories [13].

2.2.1 Data collection

Data collection is the foundation stage in the creation of CIM. The versatile types of datasets, namely space, population, transportation, environment-related, shape the information basis for the CIM system. In the data gathering, data requirements are needed to be specified and CIM aligned with the data prerequisites. Data from areas such as transportation, energy and environment, is considered core as the CIM can be more applicable in urban needs.

During the audit of current datasets, available urban data resources and their channels (remote sensing, government, private sector) are required to be assessed. Data quality, possible gaps and shortcomings analysis make it possible thereby apply effective data gathering tactics. For smooth integration the definition of unified standards and interoperability frameworks becomes crucial. Technological tools, for example BIM and GIS serve as powerful integration ways for CIM.

In other words, standards and interoperability frameworks are essential to unify diverse urban datasets, and by integrating digital tools such as BIM for building-level detail and GIS for spatial data, cities can create a comprehensive and functional City Information Model (CIM) [10].

2.2.1.1 Collection of 3D City Model

City Information Model states its name represents a refined geometrical expression of the 3D model of an urban area, consisting of static and dynamic data. Static data exemplifies urban facilities, building structure, its type, dimensions, water bodies etc. Dynamic data may be real-time people or vehicle traffic flows [13].

The organization of both static and dynamic data gains importance to use them productively.

According to [14], [15], it is possible to classify the information in CIM into main eight modules. These include MEP (mechanical, electrical, and plumbing), terrain, building, ancillary facility transportation, grey and green infrastructures, as well as water body modules.

After urban data is collected under specific standards, CIM's capabilities are shed light on them, and then integration in many city applications are integrated [6].

Nowadays, one can meet a few methods to extract raw data for analyzing three-dimensional reconstruction modeling. The main examples of these techniques obtaining raw data for 3D model reconstruction include the following: light laser detection and ranging (LiDAR), oblique photography, as well as satellite remote sensing. Table 2 demonstrates these methods with the distinctive principles, positive and negative sides.

Table 2: The information on the important three-dimensional modeling techniques for cities [15], [16].

Method	Principle	Characteristics
Satellite remote sensing	The main principle behind satellite remote sensing technique is based on its feature that allows detecting an object with the use of electromagnetic waves (EM waves), infrared rays, as well as visible light. Then it measures the distance from the object reflected by.	Despite having low precision, satellite remote sensing method is economical to use. Therefore, one of the main characteristics of this technique is offering low cost along with being easy to implement for obtaining raw data because of the expansive measurement range.
Oblique photography	The principle behind this technique is related to its name and can be explained as: using the flying platform with sensors on it, it takes a photo of the ground object obliquely or vertically to generate high accuracy data of the object.	Moderate precision, While having moderate precision, oblique photography offers prompt and fast modeling along with highly three-dimensional models with textures. However, this method suffers from difficulties with the target identification in the model and their edition.
LiDAR	The principle of LiDAR technique to be able to create 3D models is based on the transmission of the detection signals to the selected object and compare the obtained echo with the signal was sent before.	LiDAR offers high precision. High complexity of the 3D model. Heavy workload and high costs.

2.2.1.2 Static data

Previously, the data was collected manually but now there are some new techniques. AI and Machine Learning (ML) became very effective in solving different technical challenges related to data acquisition. To illustrate, an introduced deep learning (DL) tool can classify urban areas, which in turn can be beneficial in city management, urban planning, urban analysis for city planners, engineers, and architects. Another example is a modified static database to mine urban heat island information with the assistance of satellite images and building information. It is possible to perform analyses to measure urban heat island, energy, wind flow, solar potential, mobility, shading using static data [16], [17].

2.2.1.3 Dynamic data

In order to be responsive to various scenarios as UN SDGs proposes, 3D city model needs to be updated with dynamic attributes such as energy consumption, traffic flow, CO₂ generation etc. The prominent technology that merged recently is Internet of Things. Dynamic attributes, in comparison with static attributes, extend the level of the research on sustainability [18].

2.2.2 Data integration

Data integration in CIM, refers to interoperability and systematization of the data obtained from various channels in large volumes in a one environment. Datasets from GIS, BIM, IoT and other numeric and static data are standardized and linked through common data models and spatial references to enable consistent analysis and interpretation. In the following paragraphs a summary of frameworks and methods for data integration are presented[10].

2.2.2.1 Integrated Framework

The data integration in CIM is a difficult to perform because of the huge volumes and source types. Because of that, applicable frameworks and methods for data integration are needed. They had a five layers of data in a recent CIM framework developed in China (2020) that integrates various source attributes and be of use to various scenarios [19].

2.2.2.2 Data Integration Method

Primary strategies of CIM data integration are GIS-CAD (Computer Aided Design) and GIS-BIM. GIS represents geographical information, while BIM and CAD -building information [13]. CAD, in comparison with BIM, lacks detailed building information, that lead to problems with format

conversion [7]. BIM-based models, in turn, have high-accuracy geometry so that they are more practical and appropriate for integrating with GIS. Because of that, GIS-BIM is more frequently adopted in CIM construction, using City Geography Markup Language (City GML) and Industry Foundation Classes (IFC) playing the role of data standards [18]. It can be classified as the integration of GIS-BIM into four main methods. These include the following: semantic web-technology, plug-in, direct conversion, and mapping [20], [21]. The main BIM–GIS integration approaches, along with their advantages and limitations, are summarized in Table 3.

Table 3: Integration of BIM-GIS techniques based on IFC (Industry Foundation Classes) and City GML (City Geography Markup Language) [7], [23].

Method	Positive sides	Negative sides
The possibility to convert IFC towards CityGML directly	Accessibility, comfort, simplicity, and user-friendly experience.	Negative sides include non-accessibility of data as a result of substantial conversion
IFC and CityGML, and mapping between them.	Extracting and recovering the data faster and promptly.	Difficulty in complete mapping between IFC and City GML development
Intermediate plug-in on BIM platform for GIS information import	simplicity, and user-friendly operations	There is no common and universal interface for the data's (all data types)
Semantic web technology	Bilateral conversion and proper compatibility for numerous format types.	The associated techniques and methods are of restricted scope

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2.2.3 Data visualization.

A visualization platform creates an opportunity to interact and represent data in various ways. Among widespread environments for visualization are:

- **GIS and Cartography Tools:** enable us to conduct advanced spatial analysis providing substantial support for urban management [22].
- **Digital globes:** ArcGIS Explorer, NASA World Wind, as well as Google Earth, are examples of digital globes, where one able to experience urban spaces by zooming in and out, walking and flying [23], [24].
- **Virtual simulation environments (VSE):** gives static and dynamic 3D representation of the urban landscape. Such environments allow data import and programming [25], [26].
- **BIM** gives high-geometry, detailed building models [27].

- **Gaming platforms:** due to the features such as interactivity, platform portability, connectivity, visual urban space demonstration is high-quality [28].
- **Virtual reality models** highly immersive user-oriented multi-dimensional computer interfaces.[29] Among the examples are Duisburg historic city [30], Yekaterinburg Center[31].
- **Augmented reality models:** with the support of AR one can experience an instant perspective of surroundings, augmented with virtual information [32], Urban Cobuilder [33], and ARUJI [34] serve as an example of AR.

2.3 CIM applications.

CIM is beneficial for the whole life cycle of the cities use. Among CIM applications are urban planning and management, urban facility management, flood and emergency assessment, evacuation planning, utility management, building energy analysis and management. One of the most current use is related to the assessment of urban sustainability [12].

2.4 Technology Foundation of CIM

The technological enablers such as BIM, GIS, IoT networks and others are the basis for CIM development. Each of them covers the needs of the CIM. To illustrate, BIM-GIS serves as urban representation of the urban area, IoT sensors give real time data, and AI facilitate modeling and analysis. This cross-domain integration establishes a cyber-physical infrastructure that enables the operationalization of urban digital twins in smart city development. The following paragraph demonstrates the detailed features of the enablers, roles and interconnections within CIM environment[10].

2.4.1 Building Information Modeling (BIM)

Building Information Modeling (BIM) offers parametric, object-oriented digital twins that merge structured data organization, real-time operational insights, and cross-domain semantic understanding. Through GIS-BIM integration enables urban representation beginning from individual buildings to metropolitan networks. In addition to geometry, material properties, energy performance presented in BIM serve as a rich foundation for analytics.

Despite the benefits, some deficiencies exist. Data fragmentation, inconsistent protocols, and interoperability gaps, in the case of GIS-BIM, hinder the seamless integration. Real-time updates are underused in social and environmental contexts[16].

2.4.2 Geographic Information System (GIS)

Geographic Information System offers a spatial analytics system that combines datasets, enabling

high precision and accuracy. Contemporary technologies take advantage of satellite imagery, IoT, and sensor networks that support advanced spatial and temporal 3D modeling. The positive sides mentioned have broadened GIS applications from resource and disaster management to urban monitoring. However, the management of changing data flows such as traffic or emergencies is still difficult. Real-time analytics, sensor incorporation, interoperability advancements became important to enhance the use of GIS. Programs like ArcGIS Pro, QGIS, and City Engine can be used for the visualization and analysis of spatial data [69], [70].

2.4.3 Internet of Things (IoT)

Internet of Things is another enabler in CIM construction that provides the real-time monitoring of different urban components due to sensors and smart devices network. Along with static data, CIM is enriched with dynamic one that represents essential energy components, environment changes and infrastructure. In terms of urban sustainability, for example, consumption figures gained from IoT systems contribute to better optimization.

IoT, being highly promising technology, still has some implementation obstacles. First, data security as vast amounts of sensitive data can be reached through sensors. Therefore, solid encryption, and adherence to information protection are needed. Second, the environmental conditions, hardware mistakes, and sensor problems can disrupt data accuracy. Here the solution can be sensor calibration, urgent error detection and redundant systems appliance. In addition, because IoT devices are highly diverse, achieving seamless integration is difficult. Overcoming interoperability requires standardized protocols and compatibility measures[10].

2.4.4 Big Data Analytics

Big data analytics serves as a processor and interpreter of complex urban datasets for insightful analytics. By reading patterns and trends, optimizing resource allocation, it enhances the efficiency of the urban regulation. Although Big Data analytics have potential to advance urban sustainability, challenges such as data heterogeneity, inconsistent standards, and the demands of large-scale data cleaning, processing, and storage exist. Real-time computation remains a critical hurdle because technological advances align with ethical considerations[10].

2.4.5 Artificial Intelligence (AI)

AI technology, within CIM having predictive modeling, pattern recognition, and automated decision support features, facilitates urban reception and decision-making. By taking advantage of ML, DL and data mining (DM), AI is a substantial CIM enabler that offers improved management

practices. Applications of AI-driven systems vary from congestion and emissions reduction, air quality predictions with the help of IoT and remote sensing information support to energy management and real estate analytics. Nevertheless, there are several challenges. First, AI needs vast amount of labeled (annotated) data to train properly. But collecting and using such data is often limited by privacy rules. Second, AI usually operates like “black box” —the ways results gained are not explained. This lack of interpretability makes it hard for decision-makers to trust or justify the outcomes. Potential here lies in robust data security, privacy-preserving approaches and trustworthy AI, so that it is transparent and liable part of CIM [10].

2.4.6 Integration of BIM+ GIS or CAD+GIS.

It is important to consider data integration. Usually, tools like BIM and GIS are used here. The integration is obtained by the data transformation method between industry foundation classes (IFC) and City GML [38]. Besides, the well-known tools there are some software alternatives proposed by the major companies like Autodesk and Bentley [84].

2.5 CIM: current issues and perspectives.

CIM has a substantial place as an enabler in urban management and construction. CIM can be useful in many applications, including construction, urban planning, city management etc. The huge amount of data produced on an everyday basis by many actors requires long-term support and update, which in turn improves city management, but requires new management methods [35]. The issues CIM faces in its application can be divided into technical and management problems [13]. In other classification as follows: data governance legitimization, data standardization, data integration. [10].

Despite the technological advances, the CIM still faces issues connected with data acquisition, integration and visualization. In this case, BIM and GIS integration seems the feasible solution [21]. Besides BIM and GIS, versatile data can be obtained from new technological sources such as IoT sensors, for example, that lead to the necessity of novel data integration [36], [37]. Similar challenges in the CIM development can be related with user focus, integration, openness, regulation.

Talking about the solutions, firstly, new technologies must be user-driven, so actor and stakeholder opinion and participation need to be considered. Secondly, integration of data, models, and its application is challenging. The principle of openness means open data, standards use. In order the CIM platform to be equal and transparent, the data needs to be available. Another thing to mention

is that there is lack of regulations and rules applicable to such a CIM applications [38]. Some scientists propose the following actions (Table 4). Directions for development are presented in Figure 1.

Table 4: Proposed solutions with explanation.

Solution	Explanation
Unified data standards	Use ISO 19157 Geographic Data Quality Standards and Open Geospatial Consortium guidelines in order data formats, storage ways, definitions be standardized.
Cross-departmental data sharing mechanism	Blockchain and smart contracts are useful in the regulation of access rights so that data security is provided.
Data-processing technologies	AI-driven algorithms can assist in data quality, while data flows can be optimized through ETL (Extract, Transform, Load) processes.
CIM data integration platform	While cloud computing architecture and knowledge graph technologies adopted, data storage process relieved [10].



Figure 1: Direction for development

2.6 Case studies

Many governments across the world have implemented different CIM platforms into the urban practices to support evidence-based decisions. They integrated three-dimensional spatial models and several datasets. It has been used to enhance transparency, support sustainability goals, and improve coordination between public authorities and stakeholders. Some examples of them will be discussed in the next paragraphs.

2.6.1 Berlin

The Berlin Location Center has been using a three-dimensional city model since 2009 to represent the economic potential of Berlin. The main method of model construction was to use the data from

a survey flights. The present model is established on the aerial flight from 2023 year. 3D models nowadays available for public for free as a part of the Berlin state's Open Data Initiative and encourages innovation and evidence-based urban analysis[39].

2.6.2 Singapore

The Land Authority of Singapore have developed the three-dimensional model Singapore (3D National Mapping). The information for the model was collected with the help of utilizing lidar imaging as well as scanning along with street mobile lidar scanning. The model used City GML standards and consisted of eight categories such as water bodies, bridges, transportation, etc. The level of detail (LoD) is from 0 to 2 according to the element. New methods of updating the model are under consideration (e.g. satellite images, BIM, ground laser scanning, satellite images) [40].

2.6.3 New York

The 3D New York City model was constructed based on 2014 aerial survey. The level of detail selected is from 1 to 2, where some roof attachments and little details are not modelled. The mission of the model is to serve open data for every citizen for their beneficial purposes, including personal and more analysis-oriented [41].

2.7 Urban Sustainability Assessment

The population of the world continues to grow continuously. It is expected that the numbers could exceed 1 billion by 2058, reaching about 10.5 billion people during the 2080s. Consequently, urbanization will increase with more than half of the population living in the cities [42]. Undoubtedly, the living standards, including education, the working opportunities and access to healthcare facilities have been enhanced due to urbanization process.

However, with the growth of the urban area population, the adverse effect of these phenomena such as sustainability issues has been rising. To mitigate the negative effects of urban sprawling, urban sustainability concept became critical [43]. Here, CIM could serve to effectively evaluate urban sustainability, control any changes on every stage of the city life cycle and propose recommendations for urban planner, architects and engineers. Therefore, there is need for a systematic framework to evaluate urban sustainability using CIM technology.

2.8 Urban Sustainability Assessment Tools

The feasibility of CIM 3D city model demands a deep analysis and investigating of sustainability indicators and parameters for urban sustainability assessment. One can determine the indicators of the urban utilizing different sources. These may include many sources, but not limited to, namely

LEED for Cities and Communities, the United Nations' SDG11, BREEAM Communities, CASBEE – UD (for urban development), SNTTool, SBToolPT Urban. Usually, all the indicators are within the three domains of sustainability categories: economic, social, and environmental. To understand the urban sustainability assessment and certification systems there is a need to understand such a definition as criteria and indicators, criterion, indicator, rating system, certification process. [44]

One study states that the CIM is quite promising in terms of assessing urban sustainability [45]. With the help of SBToolPT Urban, it was defined 52 calculation parameters among 41 indicators, from which 28 parameters can be ascertained through CIM, and 7 could be partially computed. Seven of the parameters, were categorized as “non-applicable”. Research is needed to enhance the application of CIM for such an assessment, and other emerging indicators. Revit and Dynamo based workflow is suggested [45].

In sustainable development the three-pillar concept exists in three constituents: economic, environmental, and social pillars. The utilization of the three pillars framework in the evaluation of urban sustainability has undergone various forms. The mentioned pillars along with concept of the triple bottom line (TBL), that include environmental quality, economic prosperity, and social equity, shape the foundation for the Sustainable Development Goals (SDGs), adopted by the United Nations Organization. Sustainable Development Goal (SDG) 11 promotes the city and environment inclusive and safe is relevant to the research, which SDG11 targets to create resilient and sustainable cities and human settlements comprise targets [46].

Sustainability grading systems and indicator (index-oriented) frameworks are popular techniques for analyzing urban sustainability [47]. Additional strategies include multi-criteria decision-making, spatial analysis and urban form, principle-based frameworks, urban carrying capacity, asset-based frameworks, impact assessment, urban metabolism, and eco-efficiency assessment [48].

Therefore, primary selection criteria for indicators are their applicability to the SDGs or sustainability pillars and their frequency of use in prior studies. Additionally, having access to annual data for a long enough duration was a crucial prerequisite for choosing indicators. Therefore, in [48] the next evaluation instruments and frameworks were chosen BREEAM for Communities, LEED for Cities and Communities, CASBEE for Cities, Sustainable Cities Index, and city KPIs performance by U4SSC as they are globally recognized and have been embraced by

numerous developing nations. AEC sector employees as well use these tools and are familiar with the proposed standards. However, the tools being one of the most effective methods of evaluation lack the applicability to the local context, cultural and technological aspects along with their common focus on the definite indicators. Further, it has been noted that these methods cannot handle the intricate interactions between different criteria and categories, and each criterion is evaluated separately even though it may influence or be influenced by other criteria [48].

Another study highlights the prevalence of various urban sustainability assessment methods in literature, with indicator- or index-oriented frameworks (25 instances) and sustainability rating systems (16 instances) being the most common, aligning with the text's note that these are the most typical approaches [9]. Principle-based frameworks (6 instances) and multi-criteria decision making (5 instances) are less frequent, reflecting the text's concern about the lack of grounding in sustainability principles [6,10]. Other methods like urban metabolism (5 instances) and eco-efficiency assessment (2 instances) support the text's call for diverse, integrative methods to address complex sustainability dimensions [9].

Urban sustainability evaluation can be used as a post-facto assessment technique, as well as a visioning method and to create aspirational aims and objectives. When used to create interventions and sustainability visions, sustainability indicators should maximize utility by identifying issues, establishing goals, and establishing management strategies. There is a vacuum in goal-oriented urban sustainability evaluations as evidenced by the current practice's lack of consensus on goals, objectives, and organizing words. Such assessments are not single-faced, comprehensive understanding requires a variety of approaches, such as governance studies, material flow analysis, and ecological services. Even though three-pillar assessments are well-recognized, mixed-methods approaches emphasize the need for integrative viewpoints, but they may make it difficult to priorities tradeoffs (such as resource conservation vs. fair access) [47].

The four categories that are most reflected in urban sustainability frameworks are environmental, economic, social and institutional [49].

2.8.1 BREEAM Communities

BREEAM, or in other words, Building Research Establishment Environmental Assessment Method, is the oldest certification system, that was founded in 1990 in the UK. After the initiation of building assessment, neighborhood one, namely BREEAM Communities, was developed in 2012 [50]. The criteria are divided into six: "Transport and Movement, Innovation, Resources and

Energy, Social and Economic Wellbeing, Land use and Ecology”, where Social and Economic Wellbeing can be classified into sub-groups. For example, Social Well-being, Environmental conditions, supporting local economy with Social and Economic Wellbeing. Aforementioned categories are also can be classified to small ones [51].

2.8.2 LEED for Cities and Communities

In the framework of LEED there are LEED-Neighborhood and LEED for Cities and Communities that are suitable for urban assessment. LEED-ND is suitable and more practical for the projects that are planned, and for the projects that will be designed and built. At the same time, LEED for Cities and Communities rating system is for the whole cities (new or existing) [52].

In 2007, US Green Building Council (USGBC) initiated Leadership in Energy and Environmental design LEED-ND rating system as a test project and extension of the LEED US assessment system. Then the upgraded version came in 2009. “Linkage and Smart Location, Design and Neighborhood Pattern, and Buildings and Green Infrastructure” are present and “Design Process and Innovative, and Regional Priority”, then divided into smaller one. The “Green Infrastructure and Buildings” is prioritized here due to points given [53]

2.8.3. CASBEE for Cities (low carbon type)

Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) for Urban Development was developed in 2006 after CASBEE (2004) in Japan by academia, industry and government. A system for thoroughly assessing cities' environmental performance, "CASBEE for Cities (low carbon type)" employs a triple bottom line approach that considers "environment," "society," and "economy."

Similar to the other CASBEE family tools, CASBEE-City applies the concept of environmental efficiency to evaluate a city from two perspectives at once: the improvement of environmental quality, activities, and quality of life (“Environmental Quality,” or “Q”) within the city, and the reduction of adverse environmental impacts (“Environmental Load,” or “L”) on surrounding areas. By determining the score for every assessment item, it enables stakeholders to understand the state of their city's environment today.

By contrasting their city with other cities around the nation, it also helps the different stakeholders understand the benefits and drawbacks of their own. It is anticipated that the 2D visualization of the assessment results will aid in raising stakeholders' environmental consciousness and advancing the goal of a sustainable, low-carbon society [54].

2.8.5. OMIR- the Kazakhstan building environmental assessment system.

The Kazakhstan building environmental assessment system OMIR was introduced by The Kazakhstan Green Building Council (Kaz GBC) under World Green Building Council (World GBC). The OMIR standard was created by experts of the construction industry with the aid of UNDP and World GBC. The OMIR system is preferred in Kazakhstan because of the adaptation to the local market and legislation, climatic, social and economic features. The OMIR managed to incorporate the best practices of well-known LEED and BREEAM building environmental assessment systems. OMIR possesses different indicators on energy efficiency, waste disposal, and building quality that meet 11 of 17 of Sustainable Development Goals [55]. OMIR does not have urban scale assessment that this research focuses on, but has office, residential, commercial building categories. It has 10 categories, 56 criteria, 110 points. The methodology is based on Mandatory requirements, Energy, Health, Management, Transport, Ecology, Waste. Water, Materials, Leadership [56].

2.8.6. Sustainable Cities Index Framework by Arcadis

With its own well-known urban sustainability assessment system, Arcadis is the world's top provider of sustainable design, engineering, and consulting services for both natural and constructed assets, that has its own well-recognized urban sustainability assessment framework: Sustainable Cities Index. By assessing and ranking cities according to the pillars of Planet, People, and Profit, Arcadis's "Sustainable Cities" initiatives—best represented by their Sustainable Cities Index (SCI)—seek to enhance urban sustainability. Recently, "Progress" pillar was added to monitor changes over time. Arcadis's primary goal is to enhance people's quality of life by developing livable, sustainable communities. Their worldwide consulting practice focusses on sustainable urbanism, which includes planning vibrant urban settings and putting creative solutions to present and upcoming urban problems into practice[57].

2.8.6. Key Performance Indicators (KPIs) for cities by United for Smart Sustainable Cities (U4SSC)

With the assistance of twelve other UN agencies and organizations, the International Telecommunications Union (ITU), the UN Economic Commission for Europe (UNECE), and the UN Human Settlement Programme (UN-Habitat) are the coordinators of the United for Smart Sustainable Cities (U4SSC) initiative. The UN Sustainable Development Goal 11: "Make cities and human settlements inclusive, safe, resilient, and sustainable" is what U4SSC aims to

accomplish[58].

To assist cities, track their progress towards becoming smarter and more sustainable, U4SSC has created a set of Key Performance Indicators (KPIs). These about hundred KPIs, which are described in the "Collection Methodology for Key Performance Indicators for Smart Sustainable Cities," encompass a number of aspects, such as the economy, society and environment[58].

2.8.7. SNTool (Sustainable Neighborhood) by iisBE (International Initiative for a Sustainable Built Environment)

SNTool for neighborhood and SBTool are an adaptable framework for evaluating sustainability performance from building to an urban scale. The tools are designed so that authorized organizations can modify it to fit specific building types, organizational requirements, or regional settings. The system can be tailored to cover a wide range of sustainability challenges, ranging from more than 100 criteria to only a few [59].

2.9 Stakeholder Priorities in Urban Sustainability

Some dictionaries propose a definition of ‘stakeholder’ as an individual or group of them owning the business and have responsibilities and interest to it [60]. In the capital of Kazakhstan, Astana, many actors and industry players exist, both governmental and non-governmental. In a broad definition, all affected and interested parties are included among stakeholders (Bryson, 2004), while in a narrower one the voices not possessing power are not considered [61].

Systematic methods for analysis and identification of stakeholders are still in need of proper development, even if the ‘stakeholders’ term is widespread [62]. Stakeholders’ engagement becomes significant in different projects, especially involved in urban context, which in turn derives from management, international development practices and public policy. Unlike the consumerist model with market demands focus, democratic model values equity and participation [63].

In sustainability assessments the broad definition is more applicable because of the complexity of sustainable development. Effective collaboration and knowledge integration is reached only when a wide range of stakeholders are engaged [64]. However, such definitions pose difficulties because of identification in a specific context. A more appropriate definition for such an assessment is “all individuals or groups who affect, are affected by, or have an interest in a project.” One of the reasons is that a narrow definition compromises some goals of sustainability such as equal participation, social learning, information diversity and conflict resolution. In this approach both

ethical base and practical need for a diverse engagement are considered. Table 5 summarizes the different objectives of sustainability assessment and highlights the implications of adopting a narrow definition of stakeholders [65].

Table 5: Different objectives of Sustainability Assessment and the implications of a narrow definition of stakeholders for each of them. Adapted from [67]

Objectives of Sustainability Assessment	Consequences of Limiting Stakeholder Definition
Integrate various forms of knowledge	Excludes local, informal, non-technical, or indigenous expertise.
Strengthen project ownership and support	Unintended users and general public may not be included, and hence not support the project
Prevent or address conflicts	External groups or activists may remain unacknowledged, leading to unresolved tensions.
Foster social capital and new collaborations	Opportunities for wider partnerships and joint initiatives are limited.
Ensure equity and fairness	Marginalized groups without influence may be excluded from consideration.
Promote social learning and consciousness	Outcomes may remain confined to technical knowledge rather than shared learning across diverse actors.
Promote participatory decision-making and empowerment	Broader democratic principles are not fully realized.

The main state institution "Department of Architecture, Urban Development and Land Relations of Astana" is a state body of the Republic of Kazakhstan that authorized body in architectural, urban development and land relations activities within the city of Astana. The objective of the institution is to implement the policy in the abovementioned relations, coordinate activities in the general plan and territories realization as well as to develop urban territories, landscaping according to environmental concerns [66].

Another important actor is Limited Liability Partnership (LLP) Research Design Institute "Astanagenplan". "Research Design Institute "Astanagenplan" specializes in the development of urban planning concepts, residential buildings, business centers, cultural and sport institutions and public areas. Besides the architectural activities, the organization has the right to conduct research on urban planning and the city, suburban territories development [67].

Also, there are non-governmental organizations, for instance Association for sustainable

development of territories Q88, that have educational, inclusive, legislative, sustainable development, green economy, urban planning initiatives. The goals that the organization pursues are the development of the documents, establishing effective connection with partners for experience exchange, accumulation of best practices for implementation [68].

2.10 Current sustainability initiatives of Astana

The concept of city sustainability became more popular in the 1990s. Considering economic, social and environmental aspects of sustainability, sustainable urban development can be defined as a harmony between extensive development and ecological protection on the city level [65]. Once the most popular urban concept, sustainability has lost ground to "smart cities" in the past decade. driven by rapid technological advancements and the increasing role of private technology companies in urban planning. While sustainability initially focused on long-term ecological, social, and economic balance, smart cities prioritize using Information and Communication Technologies (ICT) to optimize urban systems and improve efficiency[45].

This indicates that the initial notion of sustainability, which was first presented in 1987, has evolved out of date as a result of our society's need for more digitalization. Nonetheless, scholarly discourse is currently examining how intelligent solutions might contribute to balanced sustainability in urban areas. As a result, the idea of "smart sustainable cities" has emerged, which is based on combining smart technology and solutions with conventional infrastructure management techniques using data analytics, real-time monitoring, and predictive modelling[45]. The Astana smart city project focuses on digitizing the urban infrastructure, enhancing traffic management, and modernizing public services. The Kazakhstan capital will work with AI and big data firm Presight to build a digital twin of the city to improve livability, safety and community wellbeing [69]. Sustainable Initiatives Decree No. 827 authorizes the Astana Smart City 2025 project, which includes the implementation of a Digital Twin.

According to U4SSC Verification Report[70], some recommendations were provided, including improving solid waste management, public building sustainability (with the certification measures and Information and communication technology), promoting an integrated approach to urban planning, improving access to affordable housing and city governance and access and availability of urban data. From the report, it can be concluded that Astana has potential for the proper sustainability profile yet having some points of growth.

According to SWOT analysis performed (Figure 2), several strategies can be constructed. Clearer

indicators, improved monitoring and budget alignment are essential. The support of smart city projects can manage urban loads. Increased investment in public transport, including the completion of the light metro, expansion of bus and tram networks, and promotion of non-motorized mobility, is necessary to reduce congestion and emissions. Expanding green infrastructure through urban greening and nature-based solutions can enhance climate resilience, while inclusive economic growth can be promoted by supporting social enterprises and SMEs. Finally, leveraging Astana's architectural and cultural assets can strengthen tourism and contribute to sustainable economic diversification. The following indicators were categorized using the frequency within the selected frameworks[71].

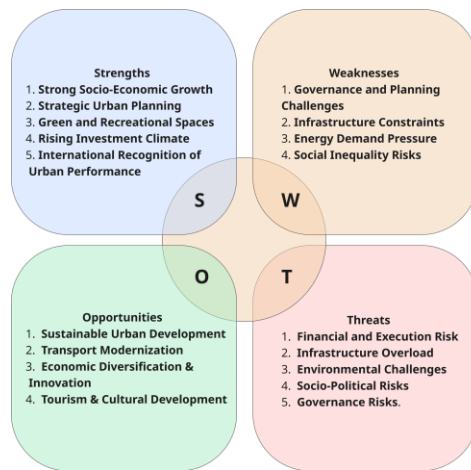


Figure 2: SWOT Analysis of Astana in terms of urban sustainability

Better urban data must also be produced to support evidence-based policy and decision-making in areas including environmental quality, waste management, housing, transportation, energy supply, air quality, innovation, and water and sanitation. Data collection and analysis skills are essential for creating successful urban solutions. and in raising the standard of living, as well as guaranteeing the equitable allocation of the financial gains from urbanization. Finally, the 2030 Agenda encourages Astana to assess the progress made in reaching the SDGs and to continue creating new policies, projects, and programs, as it lays the groundwork for cities to become the agents of change through SDG11 and other urban-related targets[70].

The Smart City Project initiated by the president aims to digitalize different urban systems and data from them such as transport, energy, security, and environmental monitoring through a unified

platform. This project is a significant step towards AI and data-driven technologies integration into urban infrastructure: smart traffic, energy-efficient meters, monitoring systems. All these improvements align with the CIM objectives, for instance, sustainability assessment. Moreover, the growing emphasis on building local technological capacity—a critical enabler for CIM implementation and long-term urban resilience—is highlighted by the national plan to train about 5,000 AI and data analytics specialists annually. Thus, inside Kazakhstan's quickly developing digital infrastructure, Astana's Smart City plan offers the perfect framework and practical basis for implementing CIM approaches to assess and improve urban sustainability metrics[72].

The public discussions on the Smart City project revealed that safety is main concern. 85 % of citizens prioritized the security of children and schools, 91 % supported centralizing video surveillance data and analytics via AI, and 46 % insisted on equitable coverage of CCTV across all neighborhoods, including outer districts.

For monitoring dangerous situations in real time, local authorities and IT specialists suggested establishing an integrated situational command center that would combine data from cameras, sensors, transportation systems, and housing-utilities infrastructure. At least 60 % of the implementation work will be performed by Kazakh IT firms, and the project includes a dedicated data processing center built with strict information-security standards [73].

Population of the country is expected to rise to 24 million, where the capital will have a substantial share. Despite the small density of 6 people per km² in the county, the situation in the capital is different: in 2017 it reached 1300 people per km². So, such urban dynamics necessitate sustainability. Today more than half of people live in cities. Astana city became the capital in 1997, when the decision about the capital relocation was accepted due to geopolitical and economic reasons. To 2001 migration flows increased so that today Astana possesses a population of over 1.4 million. In 2050 the number will rise to 70 per cent. The GDP has reached 1 billion USD.

Quality of life, public safety and infrastructure are pointed to be priorities in a Road Map in 2013. The Astana Smart City Roadmap, coordinated by Astana Innovations JSC company prioritizes six pillars of a smart city: life, mobility, people, environment, management and economy. Apart from this, some pilot projects have been implemented. In the center of them technology is. The main goal of the project is the centralization of data for the better resources management of the city. Besides the Government Fund, the Development Bank, and other investors, the important role Public Services Digitalization Department and Astana Innovations JSC play [70].

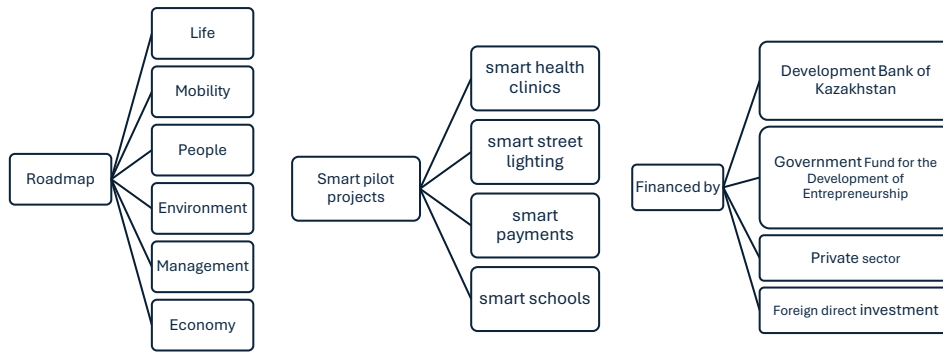


Figure 3: Astana Smart City

2.11 Geoinformation portal

The Architecture Department of Astana issued Geoportal that contains important information such as building permits, land zoning, and infrastructural plans for residents. The geoportal is available on the website of the Astana Department of Architecture, Urban Development, and Land Relations. The geoinformation portal is built on the ArcGIS platform and features a map with easy navigation and viewing of information on city features. For example, one can view planned development plans, redlines, allotments, and land parcels with cadastral numbers and designated uses without having to contact a government agency. Furthermore, all information is uploaded using high-resolution satellite imagery.

The geoportal allows to view existing buildings and structures, streets, reservoirs, roads, and administrative districts, information on urban development regulations (redlines, functional zones, buildings according to detailed planning projects, information on existing land parcels and those allocated for various purposes, utility coverage areas, assessment and tax zones. The map opens on any device with internet access and a browser installed. Map navigation is performed using either a mouse on desktop computers or gestures on mobile devices. A layer manager allows you to toggle graphic information on and off.

The geoportal has been updated with new features not found in previous versions:

1. Satellite imagery can be added to the basemap and OpenStreetMap vector data.
2. Expanded search capabilities. You can now search for information within a specific layer.
3. The map layer manager and legend with symbols are now navigable within the map window.

4. Area measurement is now available.

5. A drawing panel has been added for the first time. Previously, you had to draw on a screenshot in a third-party application.

6. A "My Location" button, which, when used on mobile devices, centers the map on the device's position on the ground, allowing for quick orientation.

7. WGS84 coordinates have appeared, which can be used in third-party GIS applications (71.424 51.164), for example, Yandex or Google maps [74]. The features can be seen in Table 6.

According to the literature[65], urban sustainability is beneficial for cities in terms of the following features: performance and progress assessment, benchmarking on the region and global, setting priorities for urban policy and investment, planning strategically, transparency and stakeholder engagement, and open data support.

Table 6: The features of Geoportal

Key points:	
Format:	Public discussions can take place in different formats, including both face-to-face meetings and online discussions.
Discussion topics:	Topics can be varied and concern, for example, the placement of new facilities, changes in the city layout, infrastructure projects.
Participants:	Both legal entities (project customers) and city residents interested in the development of the city can take part in the discussions.
Organizers:	Usually, the organizers are government agencies such as the Astana City Construction Department www.gov.kz , the Astana City Transport and Road Infrastructure Development Department www.gov.kz and others.

Chapter 3-Method development

The research aims to develop a City Information Model (CIM) framework for assessing an urban sustainability in the context of Astana. The methodology represents a mixed-methods approach, incorporating mixed-methods combining qualitative mapping and quantitative analysis of sustainability assessment tools and CIM enabler technologies. This ensures both contextual relevance and technical validity [75]. The methodology proposed and summarized in Figure 4.

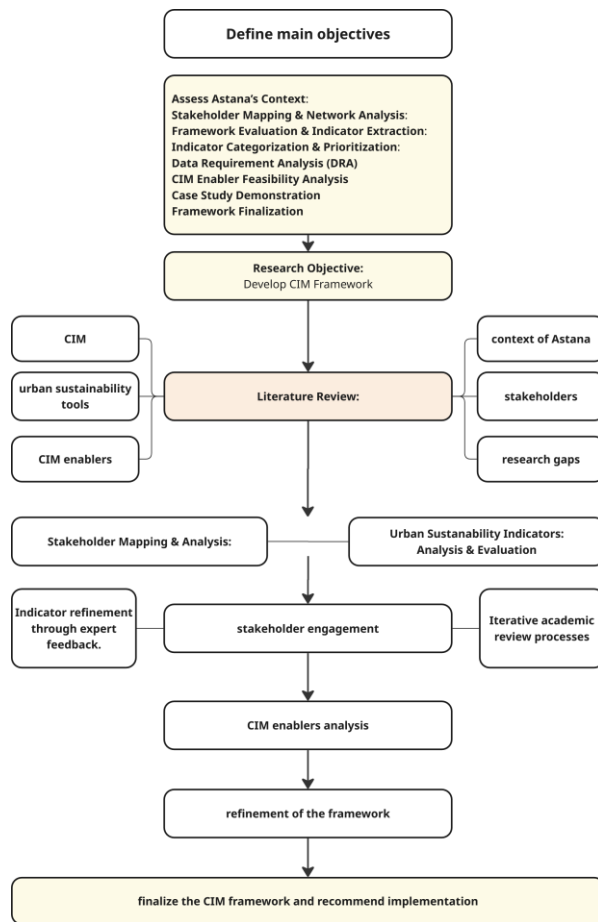


Figure 4: Methodology of research

3.1 Analysis of the urban sustainability assessment methods and their indicator selection

Globally, several world-recognized sustainability assessment methods have been developed. Among them, the most popular ones are CASBEE-UD (for urban development), LEED Cities and Communities, and BREEAM Communities. These frameworks measure the indicators in a quantitative manner and are mostly compatible with the Sustainable Development Goals (SDGs) issued by the Organization of United Nations. Despite the abundance of the approaches, there is still a necessity for an effective CIM framework to estimate sustainability on urban scale, which is essential in urban planning, city management and risk assessment.

Despite their global use, the systems were designed for specific regional conditions and may require adaptation to the context of Astana. To address this, a systematic comparative analysis is conducted. Indicators from the systems are cross-referenced and united according to three dimensions (environmental, social, and economic). Overlaps and discrepancies are identified, and terminological inconsistencies are normalized. This approach ensures that prioritized indicators are both internationally recognized and locally applicable [45]. Importantly, in this step, the criteria definition and selection are performed according to general evaluation and stakeholder preferences.

To ensure transparency and reproducibility, a semi-quantitative scoring approach was introduced. Each indicator was evaluated based on three criteria:

1. Stakeholder relevance (1–5)
2. Data availability in Astana (1–5)
3. CIM integration feasibility (1–5)

The final priority score was calculated as:

$$\text{Priority Score} = (\text{Relevance} + \text{Availability} + \text{CIM Feasibility}) / 3$$

Indicators with higher scores were classified as priority indicators.

3.2 Urban sustainability assessment methods in the context of Astana, Kazakhstan

To ensure contextual applicability, the indicators are evaluated considering urban development history, urban actors, and socio-economic conditions. Particular attention needs to be given to Astana Smart City project [76] and Kazakhstan's OMIR green building assessment system, while addressing gaps where no urban-scale framework exists. This step establishes a localized basis for integrating global sustainability criteria into Astana's context[70].

3.3 Stakeholder identification, and analysis

3.3.1 Stakeholder identification

The first is the creation of a stakeholder list. It is developed through document review, academic literature, and reports. The list included four categories of stakeholders Knowledge and Innovation, Political and Public Administration, Social, Economic and Financial with subcategories varying from municipal bodies, private sector, NGOs to academic and research institutions [77]. This provided a comprehensive inventory of potential actor for urban sustainability evaluation within CIM project.

3.3.2 Stakeholder Mapping and Analysis

Following identification, stakeholder mapping will be conducted to evaluate roles, influence, and interests. Stakeholder maps are a tool that is used to identify and visualize main actors, namely organizations, groups and individuals, and understand the relationships and complex connections between them within a defined system. Such a map helps to recognize key players, their roles and important interactions and look at the full dynamics picture of the system. Stakeholder mapping can be beneficial in system thinking in terms of context, connections, patterns and perspectives. There is a need to defect actor and roles, influence, connections [78], [79]. Table 7 summarizes the contribution of actor mapping to systems thinking.

Table 7: How can actor mapping support systems thinking and practice?[83]

Context	Understand actors, organizations and initiatives
Connections	Understand actors' roles Determine the strength of the connections between the actors Explore the nature of relationships, roles and data flows and their change
Patterns	Determine the energy core, obstacles and gaps place within the system Understand the structure changing process
Perspectives	Consider the possible actors Identify new connections opportunities

A following approach is proposed. The Power-Interest Grid method is selected as a primary tool, categorizing stakeholders into four engagement strategies: Manage Closely, Keep Satisfied, Keep Informed, and Monitor. Social Network Analysis, as a next step, is necessary to shed light on interactions between stakeholders. As a result, key brokers (actors bridging networks), central players (with strong influence), and peripheral stakeholders (with limited but potentially valuable perspectives). Network visualization gives insights into data sharing, funding and collaboration,

flows and gaps inside the connections[80].

The following stakeholder mapping are the common models: stakeholder relationship mapping, power-predictability matrix, salience model, stakeholder knowledge base chart. However, the mentioned common model has disadvantages due to the complexity of the systems. A better approach is to construct multi-dimensional actor mapping, that considers the different aspects and intensity of interactions, impact, and interest [81].

In Astana, there are many actors, that were identified during literature review, among which the “Department of Architecture, Urban Development and Land Relations of Astana”, “Astanagenplan” and large construction companies have important role.

3.4 Stakeholders involvement

Stakeholder stakeholder-informed inputs were incorporated through the following phases:

1—Indicator refinement through expert feedback. The preliminary set of urban sustainability indicators was reviewed and refined based on consultations with academic supervisors and a practitioner from the Department of Land Resources. This feedback helped validate the relevance, feasibility, and contextual applicability of selected indicators for Astana.

2-1-

3—Professional perspective integration. Practical insights from a public-sector specialist provided contextual understanding of land management practices, data availability, and institutional limitations. This ensured that the proposed CIM framework aligns with existing administrative structures and realistic data governance conditions.

4-2-

5-3- Iterative academic review processes. The framework development was continuously improved through supervisory feedback. Comments and recommendations were systematically incorporated to enhance methodological rigor and policy relevance.

Through this targeted consultation approach, stakeholder-informed adjustments were integrated into the prioritization of indicators and the conceptualization of the CIM framework, ensuring contextual validity while remaining feasible within the scope of this research.

Due to time and scope limitations, large-scale stakeholder engagement (e.g., surveys or interviews) was not conducted. Instead, stakeholder-informed insights were derived from:

- expert consultation (academic supervisor and practitioner),
- literature and policy review,

- institutional analysis of roles and responsibilities.

This approach allows the framework to remain context-aware while acknowledging limitations in empirical validation.

3.5 Data Requirement Analysis

For sustainability assessment implementation into CIM, Data Requirement Analysis (DRA) is necessary, serving to bridge global evaluation standards within local context, and to ensure that relevant indicators are both feasible and integrable within the CIM platform. The DRA involves a systematic evaluation of (i) data requires with data format, (ii) potential sources, (iii) availability in Astana, and (iv) CIM integration potential for each selected indicator.

3.6 CIM Enabler Analysis Methodology

In this step, the potential of CIM in terms of urban sustainability indicators evaluation needs to be considered and analyzed. Analysis needs to focus on the advantages and disadvantages of the tools for City Information Model (CIM) aligned with the prioritized indicator in the previous steps. There are many ways for an CIM construction such as BIM+GIS, CAD+GIS, IoT etc. that are subject for a thorough investigation. Open-source and licensed versions of the tools are considered for research progression.

Step 1 – Enabler Identification

A literature and practice review of international CIM implementations (e.g., Singapore's Virtual Singapore[19], [82], [83], China's national CIM programs, and European smart city initiatives) informed the identification of CIM enablers. Initially categorized into four technical groups (data, interoperability, analytical, and visualization), these were later synthesized into broader socio-technical enabler groups to capture governance, institutional, and stakeholder dimensions critical for implementation.

Step 2 – Evaluation Criteria Definition

Six evaluation criteria were defined: interoperability, scalability, cost and accessibility, localization to Kazakhstan's institutional context, governance and security alignment, and integration capacity with prioritized sustainability indicators. Criteria reflect Astana's implementation constraints, where localization, governance capacity, and indicator operability represent binding feasibility conditions [84], [85].

Step 3 – Comparative Analytical Assessment

CIM technological configurations (CAD+GIS, BIM+GIS, BIM–GIS–IoT integration, and digital twin platforms) were comparatively assessed using a structured qualitative framework based on the predefined criteria. Rather than a fully quantitative MCDA model, the assessment relied on literature-supported evidence, technical maturity considerations, and contextual feasibility in Astana. A contextual gap reflection identified institutional and data readiness limitations influencing configuration viability.

Step 4 – Validation

Preliminary analytical conclusions were reviewed through stakeholder consultations (academia, IT departments, private sector actors). Cross-reference with international benchmarking cases enhanced analytical robustness [82]

3.7 CIM framework development

The next important step is in the finalization of the CIM framework development for the research. Worth mentioning, there are many attempts worldwide for the CIM framework development. One of the prominent examples is China’s CIM platform that was developed with the initiative of the Ministry of Housing. Large Chinese cities’ New Areas were selected as the pilot projects for the BIM system and CIM platform [86]. However, urban sustainability assessment through CIM is unexplored topic.

Chapter 4 - Results

4.1 Stakeholder identification

A comprehensive stakeholder list, using reports, government documents, and literature is developed. As result, about 110 stakeholders are identified, the stakeholders are categorized into four main groups, each of which is divided into subgroups reflecting their role (Table 8).

The division into four groups and then subgroups is one of the methods of the stakeholder categorization that allows to develop proper engagement strategies for urban projects[77]. Besides, potential future users group is added from other methodology that divide stakeholder into those who affected and those who affects the project[87]. The whole list of stakeholders is available at Appendix A.

Table 8 : A stakeholder list Knowledge and Innovation

Subgroup	Name	Website	Description	Role/Contribution
Knowledge and innovation				

Univ ersity / resea rch	Nazarbayev University (NU)	nu.edu. kz	National research university in Astana. Houses engineering and science institutions (e.g. energy, earth sciences, architecture).	Have potential to prepare experts on urban sustainability and green technologies. Besides, NU serves as a platform to connect industry and research representatives for urban innovation projects, sustainable city planning.
	L.N. Gumilyov Eurasian National University (ENU)	enu.kz	Offers programs in architecture, engineering, ecology and regional studies. Engaged in urban studies and environmental research.	Educates planners and engineers; conducts research on ecology, geology and urban development. ENU labs may work on issues like urban flooding, water supply, and transport modeling in Astana's context.

4.2 Stakeholder mapping

The analysis identified that stakeholders naturally clustered into three quadrants: Key Players (High Power – High Interest), Keep Informed (Low Power – High Interest), Minimal Effort (Low Power – Low Interest) as given in the Figure 5. The stakeholders within (High Power – High Interest) are key players. These stakeholders have high level of authority and demonstrate interest in sustainability-related digital tools. The role is huge as the institutional power has ability to make changes in policies. The red stands for Political and Public Administration group, green for Economic and Financial group, yellow for Social and violet-Knowledge and Innovation one.

Stakeholders within (High Power – Low Interest) are needed to be keep satisfied. This section represents stakeholders that possess institutional power and can make important decisions but lacking direct interest in CIM and resilience. They act in the framework in terms of funding, collaboration and rules. In the context of Astana, they serve as context setters. The strategy connected with them can be incentive alignment, and data-sharing agreements, ensuring that they remain informed and supportive of CIM objectives without requiring intensive engagement.

Actors within (Low Power – High Interest) needs to be keep informed. This group of stakeholders lacks formal authority but has contributions through expertise and practical knowledge. These stakeholders ensure that CIM development remains participatory and contextually appropriate through active communication.

The actors within (Low Power – Low Interest) section includes actors that indirectly affected by

CIM-based initiatives and have limited influence or interest. Even though their engagement requirements are minimal, their feedback is valuable indicators of community-level satisfaction and inclusivity. For the grid the following scoring methodology is proposed: the score is accounted considering institutional responsibilities, information access, and significance to sustainability assessment.

Stakeholder Influence (Power) was assessed using a qualitative scoring system reflecting decision-making authority, resource control, and capacity to shape implementation. A score of 10 was assigned to actors with formal authority to enact laws or public policies. Scores of 8–9 represent stakeholders exercising substantial control over financial or physical resources. Actors scoring 6–7 influence outcomes primarily through advocacy, technical expertise, or advisory roles, while scores of 5 or below indicate indirect influence or limited implementation power.

Stakeholder interest was evaluated based on the degree of engagement with digital transformation and sustainability objectives. Scores of 9–10 were assigned to actors for whom digitalization or sustainability constitutes a primary institutional mandate. Scores of 7–8 reflect active involvement across at least three sustainability-related sectors, depending on project scope. Scores of 5–6 indicate peripheral engagement, such as that of supporting service providers, including telecommunications companies and trade associations.



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Figure 5: Power-Interest grid

Following the Power-Interest Analysis, Table 9 illustrates the alignment between stakeholder priorities and the proposed urban sustainability indicators in Astana. The indicators address residents' well-being and livability, support municipal and national authorities in digital governance, climate resilience, and SDG reporting, enhance regulatory transparency and efficiency for the private sector, improve reliability and monitoring for infrastructure operators, and enable data accessibility and innovation for academia, highlighting CIM's integrative role in stakeholder-aligned sustainability assessment.

Table 9 Mapping Sustainability Indicators to Stakeholder Priorities in Astana

Stakeholder Group	Key Priorities	Relevant Indicators in This Thesis	Alignment Rationale
Residents / Civil Society	Safety; housing affordability; environmental quality; accessible public spaces; mobility [73]	Crime rate; public lighting coverage; housing cost-to-income ratio; green space per capita; accessibility index; PM2.5 concentration	Addresses daily well-being, social equity, and health. Improves transparency and supports livability goals in Astana's districts [73].
Akimat & Municipal Agencies	Digital governance efficiency; operational cost reduction; climate resilience; SDG reporting; infrastructure planning	CIM maturity; interoperability level; heat island index; flood-risk exposure; energy use per capita; building permitting digitalization	Supports evidence-based decision-making, long-term planning, and compliance with national smart city strategies [72].
National Government	SDG monitoring; carbon reduction; infrastructure modernization	GHG intensity; air quality indicators; renewable energy share; recycling rate	Contributes to national sustainability commitments and international reporting.
Developers & Private Sector	Predictable regulations; transparency; reduced permitting times; improved coordination	Digital permitting; land-use clarity index; BIM-GIS integration rate	Reduces delays, prevents design conflicts, and improves investment certainty.
Utility & Infrastructure Operators	Reliability; predictive maintenance; IoT integration; real-time system monitoring	Network downtime; IoT sensor coverage; infrastructure condition index; water loss percentage	Helps prevent failures, reduces maintenance costs, and ensures service reliability.
Academia & Innovation Sector	Data accessibility; standardized formats; opportunities for modeling and testing	Open data index; metadata completeness; CIM data accessibility	Enables research, supports innovation hubs, and enhances the digital ecosystem for future development.

4.3 Projection of OMIP Criteria to Urban Scale

The study attempted to project the categories of the OMIR framework into urban scale by adjusting criteria into the urban resilience needs. There are 9 categories such as mandatory requirements, energy, water, transport, ecology, leadership and others. Each criterion retains the intent of the local building assessment system and introduces quantifiable indicators, data requirements, and evaluation parameters consistent with local statistical datasets and international sustainability frameworks.

This approach bridges national sustainability policy with data-driven, CIM-based urban assessment. The proposed criteria and indicators are designed to comply with Kazakhstan's statistical and regulatory frameworks (BNS, OMIR, Environmental Code 2021, SanPiN) while extending them to the urban and digital (CIM-based) scale, where existing national indicators remain limited. One of the sources for the formulation of credits is National Bureau of Statistics that has developed a comprehensive set of 46 environmental monitoring and assessment indicators[88].

This research focuses on developing a City Information Modeling (CIM) framework for urban-scale sustainability assessment in Astana. While building-level data (from frameworks such as OMIR) provide foundational insights, the study expands to encompass the full urban system, including infrastructure networks, mobility, environmental assets, socio-economic systems, and governance mechanisms. The CIM framework therefore integrates multi-scale data — from buildings to citywide systems — enabling holistic sustainability evaluation and data-driven urban management.

The initial indicator set, largely based on the Operational Management and Infrastructure Rating (OMIR), primarily captured sustainability at the building or facility scale. However, to align with the city-level focus of CIM, the framework has been expanded to integrate five major sustainability dimensions — Environmental, Infrastructure, Social, Economic, and Governance — each mapped to relevant CIM data layers such as GIS, BIM, IoT, and statistical databases. This broader classification ensures a more comprehensive representation of urban systems within Astana.

In reviewing the indicators provided by the Bureau of National Statistics (BNS), it became evident that although the dataset is comprehensive at the national scale, not all indicators are directly applicable to the assessment of urban sustainability or to the specific context of Astana. Many BNS indicators operate at a macro-regional or national environmental scale, which limits their

usefulness for city-level diagnosis, spatial modeling, or CIM-based integration. Therefore, the indicator set requires narrowing and contextualization. The first step is selecting only those BNS indicators that have a clear urban relevance—such as air quality, water losses, waste generation, transport demand, or energy intensity. However, even after filtering, several thematic gaps remain in areas crucial for contemporary urban sustainability, including digital infrastructure, circular material flows, urban form, green-blue networks, climate resilience, and stakeholder engagement. To address these gaps, the thesis proposes a hybrid approach: (1) adapt and refine relevant BNS indicators for city-scale application, ensuring they align with the spatial, infrastructural, and systemic realities of Astana, and (2) introduce new complementary indicators specific to urban sustainability and CIM integration, particularly those supporting circularity, resilience, and data-driven urban management. This combined approach ensures that the resulting framework remains grounded in official national statistics while advancing a more holistic and locally meaningful assessment of urban sustainability in Astana.

4.3.1 Criteria for indicators

The following Figure 6 shows seven criteria with the requirements established for urban sustainability assessment. The indicators are grouped according to thematical dimensions that serve one important issue. The criterion for indicators is being optimal to ensure manageability, clarity, and comparability.

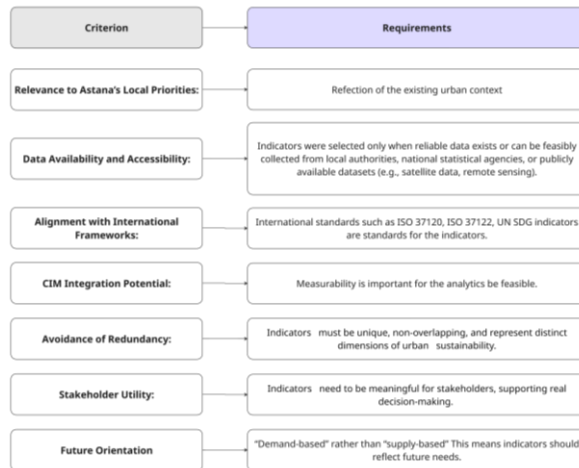


Figure 6: Criteria for indicators

4.3.2 Mandatory requirements

For urban sustainability there should be some basis such as mandatory requirements that urban area needs to implement. First requirement represents a comprehensive ecosystem assessment (MR1). It forms the informational foundation to effectively assess the condition of the natural environment. In the case of Astana, for example, natural systems such as the Taldykol lake systems, green belt and the Ishym river embankments need to be considered in terms of urban resilience and long-term monitoring. The other aspect relates to technogenic and environmental risk monitoring (MR2) that is significant in addressing hazards with the assistance of IoT sensors, early warning systems, and resilience planning. The similar requirement is on Urban Climate Resilience (MR4).

The other important point in urban sustainability is institutional capacity and governance that Municipal Sustainability Competence (MR3) criterion reflects. Sustainability centers and proficiency study programs can create the basis for structured frameworks ensuring coordination and performance. Urban Energy and resource efficiency (MR5) form another criterion, as the cities face the problem of energy overconsumption that leads to pollution and poor air quality. In addition to this, Water Access and Quality (MR6) requirement, oversee the accessibility of drinking water, wastewater treatment, and stormwater systems. In this context Resource Accounting (MR7) is a primary requirement to monitor the city-level energy and resources for better efficiency. Waste and materials disposal (MR8) in urban areas is another concern. Population needs to raise another criterion Asset and Infrastructure Management (MR9). Together, these criteria create a mandatory requirement[88].

Mandatory Requirements (MRs) represent a set of foundational urban system conditions that enable the reliable generation, interpretation, and integration of sustainability indicators. They do not measure performance, but rather verify the existence of institutional, infrastructural, and governance capacities without which indicator-based benchmarking and future projections are invalid. The representation of them can be seen in Figure 7.

The following classification of indicators is based on analysis of several frameworks. Institutional and economic one can be considered as enabling whereas environmental and social output. The reason is that institutional and fiscal preparedness serves as foundation for urban sustainability. The whole list of indicators is available in Appendix B.

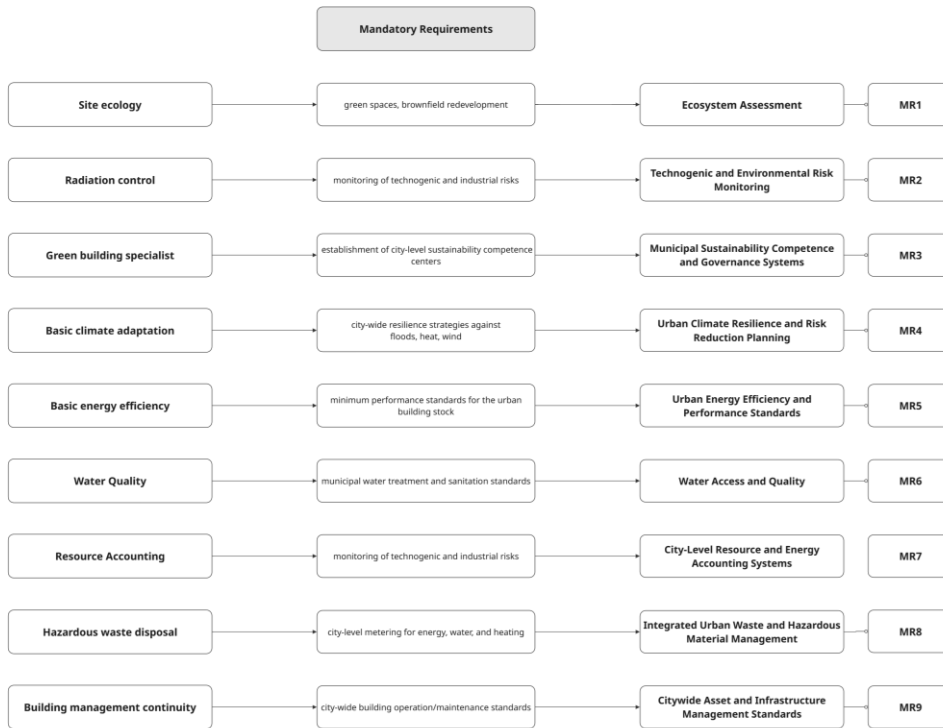


Figure 7: Mandatory requirements category

The next important point is that data and indicators assessing sustainability become meaningful in the next cases: data collected into databases needs to be implicated. To effectively understand and then apply the implications, data needs to be set side by side with the city historical data and other relevant cities, that can be set as baseline and benchmarks respectively. Such measurements allow governments to better current conditions and set trajectory.

The proposed CIM-based sustainability framework follows a prerequisite-indicator logic analogous to building-scale certification systems such as LEED. A set of Mandatory Requirements (MRs) defines non-negotiable baseline conditions related to governance capacity, data availability, environmental protection, and infrastructure management. These requirements are not scored; instead, they function as enabling conditions that determine whether indicator-based assessments can be considered reliable and comparable. Only when the mandatory requirements are satisfied does the framework proceed to indicator-level evaluation across institutional, economic, social,

and environmental domains. Figure 8 explains this logic.

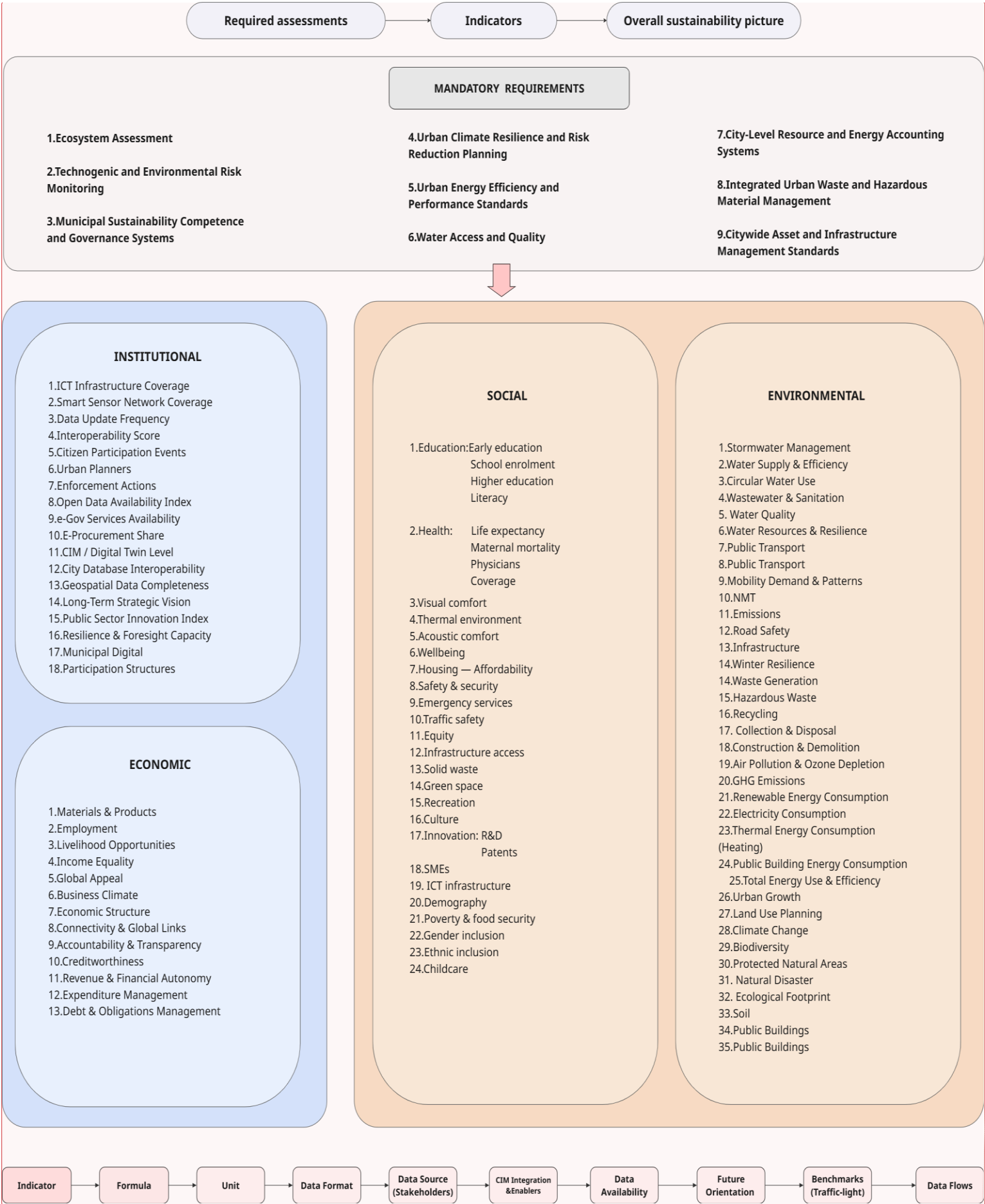


Figure 8: Indicators and assessment logic proposed

4.3.3 Economic dimensions

The economic indicators are represented in thirteen dimensions that evaluate the long-term viability of urban areas in terms of material use efficiency, cost structures, investment performance, and market dynamics. Among the most important are domestic material consumption per capita, life-cycle costs of materials and i

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infrastructure, cost premiums of sustainable solutions, and economic efficiency of resource use. They, along with assessment of economic growth, assess economic feasibility of sustainability-oriented decisions.

Within CIM environment, indicators on economic sustainability can relate to spatial data, procurement base and project-level cost information, enabling scenario analysis and comparison between conventional and sustainable alternatives. In the context of Astana growth, economic dimensions can support evidence-based decision-making in the current topics such as green public procurement, cost optimization, investments etc. that contribute to more sustainable prosperity.

4.3.4 Institutional dimensions

Indicators within institutional factors measure whether the governmental and regulatory bodies have the capacity for sustainability in urban development. About 20 dimensions include indicators related to policy implementation, regulatory compliance, data availability, inter-agency coordination, transparency, and integration of sustainability criteria into planning and procurement processes.

Within the CIM-based framework, institutional criteria play a critical enabling role. The institutional criteria play a vital role in structuring data flows between institutions, defining responsibilities for data production and use. For Astana city, in which urban data is fragmented across institutions, this dimension supports better coordination, accountability, and digital governance.

4.3.5 Social dimensions

The social dimension evaluates the quality of life, equity, well-being issues of residents inside the urban environment. The social indicators on about 25 dimensions include indicators related to housing, infrastructure and services, mobility, public spaces, environmental comfort, and social inclusiveness.

These dimensions allow spatial analysis of social disparities across districts, that in turn can be useful in underserved areas and populations identification. Social indicators within CIM environment, help in the visualization of service coverage, proximity analysis, and integration of demographic data with the built environment. In the case of Astana, where rapid urban expansion and functional zoning create uneven access to services, the social dim

ension ensures that sustainability outcomes are evaluated not only in technical or economic terms but also in terms of human-centered urban performance.

4.3.6 Environmental dimensions

The widest presented indicators are within environmental dimensions. They have about 40 categories on the physical and ecological performance of the urban system by quantifying material, energy, water, land, and emission flows associated with urban development and operation. They include indicators related to material consumption, construction and demolition waste, energy use and efficiency, greenhouse gas emissions, water use, land cover, and environmental quality.

Within the proposed workflow, environmental indicators are operationalized through variables that can be mapped spatially and monitored using CIM. The integration of GIS layers, building and infrastructure data, and environmental statistics allows identification of environmental hotspots, benchmarking and evaluation of progress toward environmental sustainability goals. In the context of Astana, these dimensions are particularly relevant due to high material intensity, extreme climatic conditions, and the need to improve resource efficiency in rapidly developing urban areas.

4.4. Data Requirement analysis

The sustainability ratings should consider the peculiarities of the national collection systems. Therefore, the existing statistical indicators of the country should be used. The main stakeholder in terms of data is the Statistics Committee of the Kazakh Ministry of National Economy is now known as the Bureau of National Statistics, and it is a department within the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. Its function is to manage and implement state statistical activities in Kazakhstan, including the formation of statistical methodology, and to provide official statistical information to the public and international community.

It is agreed that sustainable development is a composite issue with much complex information needed. One group of scientists said that information needs to be concentrated [71].

91 indicators from a variety of categories (Society, Economy, Energy, Environment, Transportation, etc.) are shown in detail in the Nur-Sultan (old name of Astana) Sustainability Assessment radar chart. Performance levels are color-coded as follows: 95%+ of the target is shown in green, 66-95% in light green, 33-66% in yellow, less than 33% in orange, no data or no target is shown in grey, and data reported but no targets are found in blue. I will concentrate on the indicators labelled "No Data or No Target" (grey) and "Data Reported - No Targets Yet

Available" (blue) to characterize the "lack in the data," highlighting any information gaps or unclear targets that exist as of the assessment date [70].

Literature showed data gaps in 8 categories Air Quality, Waste, Transport, Water and Sanitation, Innovation, Electricity Supply and Environmental Quality. In Air quality there was deficiency on data on O₃, SO₂, NO₂, PM₁₀, PM_{2.5}. In Waste the type of waste lacks data recycled, open dump, incinerated, burnt, and landfill. Transport category lacks Private Vehicles, Para Transport, Walking, Cycling. Water and sanitation, at the same manner, type is insufficient: Wastewater treated (secondary), Wastewater treated (tertiary). In Innovation category small and medium-sized enterprises number was unknown. Electricity Supply category shows no information in Electricity Supply ICT Monitoring, Electricity System Outage Time. Other category, Environmental Quality, does not have information on Exposure to Noise, EMF exposure. In Housing category there is no data on Housing expenditure. Overall, these data deficiencies are addressed through the Data Requirement Analysis conducted in this research.

The analysis searches data required, potential sources, data type, its availability and CIM Integration Potential and alignment with systems. For example, for Public Transport, sources of data are Astana LRT LLP, City Akimat (Transport Dept.), Ministry of Transport, KazHydroMet. The types of data are spatial (GIS), tabular (fleet data, service reports), time-series (operations data). The potential: CIM can integrate with GIS + Google Maps-like APIs; IoT for emissions/energy use.

Recently, scientists have employed two methods of inspecting urban quality. The first one is objective, that lies in the analysis of the secondary data such as from the official government collections. The second approach is the subjective one that utilizes social survey methods and consider the individual level, the people's perceptions and feelings towards the city life quality [89]. So, in the proposed urban sustainability assessment two approaches should be used.

4.5 CIM Enablers Analysis

This section analyzes the potential of City Information Modeling (CIM) to support the evaluation of urban sustainability indicators in Astana. Building on the prioritized indicator set defined in earlier methodological stages, the analysis focuses on how different CIM construction approaches enable or constrain indicator calculation, monitoring, and policy use. Attention is given to the advantages, limitations, and contextual suitability of alternative CIM tool configurations under Kazakhstan's institutional, data, and financial conditions.

From methodology, the CIM enabler analysis follows a four-step process. So, the enablers can be divided into six groups: Data and Information Enablers, Institutional and Governance Enablers, Human and Organizational Capacity Enablers, Technological Enablers, Stakeholder Alignment Enablers, Financial and Economic Enablers. All together they contribute to CIM framework realization. Such a grouping allows to capture the full set of conditions required for CIM implementation. Technological capacity alone is insufficient; institutional arrangements, human capital, stakeholder alignment, and financial viability critically determine whether CIM can function as a credible sustainability decision-support system.

4.5.1 Data and Information Enablers

One of the features of data enablers is they originated from various channels (GIS, BIM, IoT, crowdsourced opinion, statistics). BIM-GIS-IoT integration can provide the technical foundation, while its operationalization depends on data ownership, ethical use, security and privacy related framework. If government structures are unable to provide urban data, this may lead to data fragmentation, limited reuse, and restricted accessibility, thereby undermining the reliability of sustainability indicators and decision-support outputs. In Astana, stakeholders such as Municipality, Departments, Bureau of National Statistics and others are the main Data and Information Enablers [10].

The development of a CIM framework for urban sustainability assessment in Astana can be significantly enabled by the strategic implementation of Kazakhstan's evolving data exchange ecosystem. As outlined in the national data economy roadmap, the creation of regulated data exchanges—particularly through a hybrid model involving both government and private sector participation—ensures the availability of high-quality, certified datasets essential for dynamic urban modeling. These platforms facilitate secure and structured access to diverse data sources, including geolocation, utility consumption, and infrastructure metrics, while employing privacy-enhancing technologies (PETs) to protect sensitive information. By aligning stakeholder priorities—such as government needs for optimized public administration, business demands for monetizable data products, and public expectations for improved digital services—the CIM framework can integrate multi-sector data flows to support evidence-based sustainability planning, resilience monitoring, and participatory urban governance in Astana [90].

The realization of the CIM necessitates integration of heterogeneous datasets, including very sensitive one. However, institutional fragmentation and concerns related to data ownership, privacy, and cybersecurity significantly constrain cross-sectoral data exchange. Trusted Execution Environments (TEEs) are increasingly proposed to secure data processing in smart

city platforms and can be directly applied to CIM. A TEE is an isolated execution context inside a processor that runs code and data in protected memory (e.g., Intel SGX, ARM TrustZone, CHERI/Morello) [91]. It provides confidentiality, integrity and attestation of computations, even if OS, hypervisor or cloud provider are compromised [91]. The graphical representation is in Figure 9.

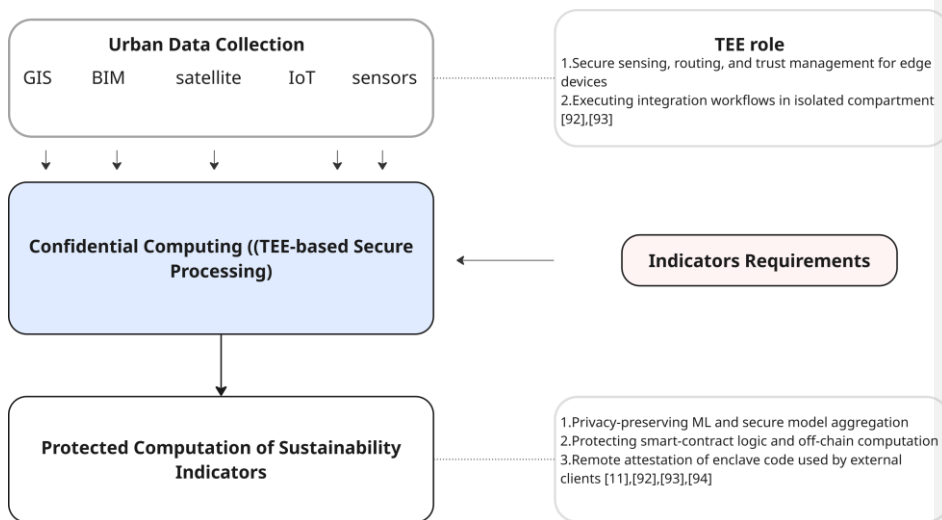


Figure 9: Mapping of TEE to CIM urban sustainability assessment workflows

Recent CIM surveys stress data security, privacy and cross-sector sharing as core challenges and point to hardware roots of trust and enclave computing as promising directions[92]. TEEs can protect sensitive layers of a CIM stack (data ingestion, identity management, analytics), enforce policy-compliant processing of personal or confidential spatial data, underpin trustworthy city digital twins and blockchain-enabled CIM by anchoring trust in hardware enclaves.

Trusted Execution Environments provide hardware-anchored isolation, attestation, and secure computation that can harden CIM platforms at IoT, edge, and cloud layers. Existing smart-city and service-integration work shows TEEs can protect data flows and analytics with manageable overhead, making them a strong candidate building block for secure, privacy-preserving City Information Modeling.

4.5.2 Institutional and Governance Enablers

Effective CIM implementation requires clear institutional arrangements and policy frameworks that define roles, responsibilities, and standardized procedures for cross-agency coordination.

Such arrangements are essential to overcome sectoral silos and enable consistent data exchange between urban planning, infrastructure management, environmental monitoring, and public service provision [93]. A detailed analysis can be seen in the section on Stakeholder Mapping. In Astana, CIM framework is developed in agenda of the national “Digital Kazakhstan 2025”, where the city functions as a pilot smart city with priorities in security, utilities, and transport[70]. However, empirical evidence indicates that institutional coordination, policy alignment, and shared ontologies remain more significant constraints than technological availability[93]. Aligning sustainability governance—particularly green and blue infrastructure targets—with CIM-supported monitoring frameworks is therefore critical to translating digital capacity into measurable sustainability outcomes.

4.5.3 Human and Organizational Capacity Enablers

Research on CIM implementation shows that that technical skills, ontology work, and organizational learning are as critical as legal/governance reforms for moving from pilots to citywide systems. Among important aspect for CIM implementation is human and institutional capacity [94], professional level of specialist [94], and knowledge hubs as an environment for growth [95].

First, talking on Human & Institutional Capacity for CIM, a municipal case study in Curitiba finds that technical capacity, infrastructure, and financial resources for CIM exist, but activation depends on political/managerial entrepreneurship and dedicated staff training policies. Lack of institutional ontologies is identified as a major barrier, more than pure technological limits[94]. Systematic reviews highlight persistent challenges around reluctance to adopt CIM, lack of standardized workflows, weak synergy between parties, and data management capacity, even when platforms exist [96].

Second, cases worldwide suggest that proper training and Change Management play a vital role as well. The Curitiba study explicitly stresses institutional ontologies as missing infrastructure for CIM institutionalization, needed to align semantics across departments and systems [94].The Lancaster CIM-UDT case lists technical training for adoption and stakeholder engagement as one of four major sociotechnical challenges for transitioning from CIM to urban digital twins [97].Transition management work on urban governance indicates that transformative digital approaches require systems thinking, communication, and learning-by-doing skills to embed new tools into routine planning practice[98].

Third, the existence of environment for the development of the staff is important. Kazakhstan’s smart-city agenda emphasizes digital and information literacy and sees libraries and universities as knowledge hubs and drivers of continuous learning, supporting smart services

and citizen competence[95].

4.5.4 Technological Enablers

Among many alternatives, BIM–GIS–IoT integration with big data, AI and cloud computing seems feasible foundation for the CIM realization [99]. Another important point is the services such as Astana Opinion Mining that implements an MLOps-based, cloud microservice architecture to collect and analyze social-media feedback, mapped to a taxonomy of sustainability criteria. It is explicitly positioned as part of a sustainability assessment and planning framework for Astana [100]. The technological enabler group was further disaggregated to reflect alternative CIM construction pathways and their implications for sustainability indicator evaluation. Rather than treating CIM as a single platform, this study evaluates competing and complementary technological stacks, considering both open-source and licensed solutions.

Combination CAD + GIS is a baseline that is commonly used in municipalities, including Astana. GIS serves as spatial querying and thematic mapping provider, while CAD supports geometric representation. Being affordable in terms of cost and access, the setup lacks interoperability and analytical capacity[101].

BIM–GIS integration significantly enhances CIM capability by linking building-level semantic data (materials, energy performance, lifecycle attributes) with city-scale spatial analysis. Open standards such as IFC and CityGML enable partial interoperability, while tools such as QGIS, ArcGIS Urban, Revit, and InfraWorks are commonly applied[11]. Such as connection is particularly applicable for energy, carbon and building stock indicators.

The addition of IoT to BIM + GIS enables dynamic indicators, temporal trend analysis, and near–real-time decision support. Open-source IoT platforms and APIs improve accessibility, but governance, cybersecurity, and data reliability have become critical constraints. This stack is highly relevant for Astana’s smart infrastructure and utility sectors[10].

City-scale digital twins integrate BIM–GIS–IoT with cloud computing, AI, and advanced simulation. Licensed platforms (e.g., city management suites) offer mature visualization and analytics, while open-source alternatives provide flexibility but require higher technical capacity. Digital twins support scenario modeling, policy testing, and indicator forecasting, making them the most comprehensive—but also the most resource-intensive—technological enabler.

Open-source solutions enhance accessibility, transparency, and local customization, aligning well with research objectives and capacity-building goals. Licensed tools, while costly, often provide superior interoperability, user support, and scalability. This study therefore adopts a

hybrid evaluation approach, recognizing that Astana's CIM implementation is likely to combine open-source GIS and analytics with selected licensed platforms for mission-critical applications.

Analysis (Table 10) shows a clear gradient from CAD+GIS to full digital twins, with increasing data richness, complexity, and governance demands [10], [94]. Recent CIM reviews recommend evaluating stacks against specific urban goals and capacities, not technology maturity alone[10]. Different toolchains optimize for cost, detail, or robustness[102]. It is concluded that there is no universally superior interoperability strategy.

Table 10 Analysis on Technological Enablers combinations

Combination	Strengths for sustainability	Key limitations / risks
CAD + GIS	Low-cost visualization, basic spatial queries; common entry point for municipalities[101].	Weak semantics, poor interoperability, limited analytics; hard to support lifecycle/energy indicators[11].
BIM + GIS (GeoBIM)	Rich building semantics + city context; strong for energy, carbon, LCA, stock and infrastructure indicators; IFC/CityGML and ontology-based integration are maturing[11].	High data harmonization effort; interoperability gaps; skilled staff needed [11].
BIM + GIS + IoT	Real-time energy, mobility, air-quality and asset-health indicators; enables dynamic monitoring and predictive maintenance[10].	Data volume, reliability, cybersecurity, and cross-department governance become critical [10].
Full Digital Twin Platforms	Integrate GeoBIM+IoT with cloud, AI, big data; best for scenario analysis, forecasting, and multi-criteria sustainability planning [10].	Highest cost, data requirements, and institutional capacity needs[10], [97].

City Information Modeling (CIM) in this research is conceptualized as an integrated framework that combines thematic urban modules with a multi-layer technical architecture to support data-driven sustainability assessment in Astana (Figure 10). CIM merges Building Information Modeling (BIM), Geographic Information Systems (GIS), and Internet of Things (IoT) technologies within a unified 3D environment. Thematic modules—including terrain (DEM), buildings, transportation, utilities (MEP), vegetation, water bodies, and green/grey infrastructure—capture the city's physical and environmental systems. Technically, the platform operates through five interconnected layers: device/sensor, data, service, application, and user layers, enabling multi-source data integration, processing, and scenario-based

applications. Using CityGML standards and Levels of Detail (LOD0–LOD4), the framework ensures scalable 3D representation from territorial to building-interior scale. In this thesis, CIM functions as a key enabler by linking indoor BIM intelligence with outdoor GIS context to support indicator evaluation and urban sustainability decision-making [12], [13].

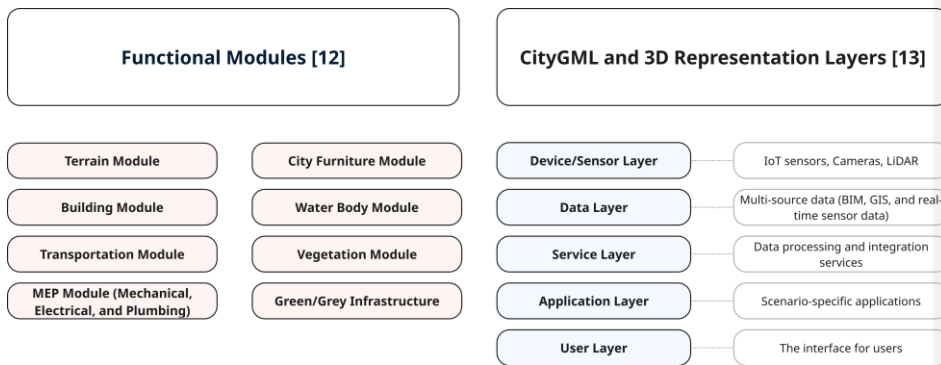


Figure 10: Structural and Technical Architecture of the CIM Framework

4.5.5 Stakeholder Alignment Enablers

Astana’s rapid infrastructure-led growth has delivered social and economic gains but also accelerated loss of green and blue spaces and resource intensity, prompting calls for broader stakeholder engagement to realign development with sustainability and ecosystem preservation. The literature stresses that such engagement must move beyond top-down planning toward inclusive, multi-stakeholder governance for sustainable infrastructure and SDGs [101].

There are several gaps in stakeholder engagement. Analysis of Astana’s infrastructure programs shows environmental costs (land use change, loss of water bodies such as Taldykol) and limited socio-economic data, concluding that future growth must involve wider stakeholder dialogue on ecosystem preservation, sprawl management, and resource efficiency [103]. Studies of sustainable construction in Kazakhstan highlight weak engagement and misaligned incentives among government, industry, and communities as barriers to sustainability adoption. Broader infrastructure and construction research finds that poorly structured engagement, late involvement, and unmanaged conflicts are common failure factors in projects [70], [100].

Another side is in the realization of CIM is so-called bottom-up smart city: crowdsourcing and citizen satisfaction. The Astana Opinion Mining service and adapted SULPiTER-based

sustainability assessment system use passive crowdsourcing (social media sentiment, online opinions) to capture resident satisfaction and concerns across transport, environment, services, and urban quality of life [103]. This approach automates data gathering and indicator computation, helping identify problem areas such as transport and mobility and environment, and is proposed as a template for other Central Asian cities [103].

Evidence supports framing Astana’s recent tools as bottom-up smart-city enablers that partially close stakeholder engagement gaps exposed by the infrastructure boom, especially around mobility, environment, and service quality—but also underlines the need to embed these digital signals into formal, multi-stakeholder governance to truly steer development toward sustainability.

4.5.6 Financial and Economic Enablers

Astana’s experience of rapid, infrastructure-led development reflects a broader pattern of resource-intensive growth in which high financial and natural resource inputs have translated into only modest sustainability gains. Empirical studies on natural resource-driven growth consistently show that, in the absence of strong governance and innovation frameworks, such development trajectories increase emissions and degrade environmental quality, ultimately weakening progress toward sustainability objectives [103]. Evidence from resource-rich economies further indicates that domestic financialization can reinforce a “resource curse” when capital allocation prioritizes expansion over performance, while targeted green finance and environmentally oriented foreign direct investment are more likely to support cleaner technologies and diversified growth pathways [103]. For Central and East Asian contexts in particular, weak oversight of domestic investment combined with resource dependence has been shown to result in inefficient and environmentally harmful projects, highlighting the need for explicit sustainability and cost-effectiveness criteria in project selection [104].

Within this context, City Information Modeling (CIM) functions as a critical enabling framework for greener investment prioritization by integrating land-use, infrastructure, energy and environmental data into unified indicator systems aligned with international standards (e.g., ISO 37120), supporting performance-based project ranking [10]. Scenario and simulation capabilities allow alternative growth pathways—such as densification versus expansion or grey versus green and blue infrastructure—to be evaluated in terms of resource consumption, emissions and service delivery outcomes [10]. In addition, CIM-supported urban analytics and pre-digital twin platforms enable both ex ante appraisal and ex post evaluation of investments, allowing projects to be ranked according to impacts on flood risk, heat stress, ecosystem services, emissions and accessibility, thereby systematically favoring green and blue

infrastructure, smart energy networks and digital public services over conventional capital-intensive expansion[10]. In this way, CIM operates not merely as a data integration tool but as a governance enabler that redirects capital toward higher-impact, environmentally resilient investments, improving both sustainability performance and long-term cost effectiveness.

4.6 Interpretation and Implications for Astana

It has been concluded that CIM implementation depends on several enabling mechanisms. Even if technological foundation seems to be the most important, other enablers are necessary. Taken together, analysis results demonstrate that no single CIM configuration is universally optimal. Instead, CIM effectiveness depends on alignment between technological capability, institutional maturity, governance readiness, and sustainability objectives. For Astana, a phased and hybrid approach—centered on BIM–GIS–IoT integration and selectively complemented by digital twin functionalities—offers the most feasible pathway for operationalizing sustainability indicators while maintaining institutional and financial realism. This integrated evaluation framework ensures transparency in tool selection and provides a defensible methodological basis for linking CIM implementation to urban sustainability governance in Astana (Table 11).

Table 11 Enablers role

Enabler Group	Operational Role in CIM-Based Sustainability Assessment	References
Data & Information	Multi-source urban data hub, lifecycle management, open & secure access	[10]
Institutional & Governance	Smart city policies, data governance, multilevel coordination	[105]
Human & Organizational	Training, leadership, ontology development, university engagement	[6]
Technological	BIM–GIS–IoT integration, AI/cloud analytics, smart infrastructures	[10], [97]
Stakeholder Alignment	Crowdsourcing, citizen indices, participatory prioritization	[97]
Financial & Economic	Sustainability-linked investment, ROI monitoring, resource efficiency	[104]

Chapter 5- Discussion and Future Implementations

The development of the proposed CIM framework and urban sustainability indicators was carried out in collaboration and negotiation with coordinators of the Kazakhstan Green Building certification system (KazGBC), incorporating stakeholder perspectives from national institutions, municipal authorities, and sustainability experts. These discussions ensured that the framework reflects not only international best practices but also national priorities, institutional realities, and implementation constraints specific to Kazakhstan. While the framework aims to align sustainability indicators with stakeholder priorities, this alignment is based on structured stakeholder analysis and limited expert consultation rather than comprehensive empirical engagement. Therefore, the results should be interpreted as stakeholder-informed rather than fully validated through participatory methods.

5.1 OMIR Projection

The OMIR is the Kazakhstan green building certification system that was the initial reference in this research as it represents the national system of green ecological assessment. However, the scope of OMIR is dominantly on the buildings of different types (residential, educational, commercial) with the neighborhood's certification in the developing stage. So, the projection method was chosen: the building-scale indicators were extended into the urban scale. The logic was that the important points are already highlighted in the building-scale OMIR, so on the urban scale it will be similar. As the scale grows other significant dimensions, such as social, institutional and economic are being involved. After the projection process not all the indicators were chosen, only part of them as compliance to the global standards is another important criterion.

So, all the urban sustainability indicators were formulated after the comprehensive review of several international urban sustainability frameworks, UN SDGs, and KPIs. The indicators were divided into social, economic, institutional and environmental. Even if the categorization can be broad, this one considered the most suitable for the local context, as such division underscore the role of the proper institutional foundation for the implementation of sustainability in the urban environment. Among them, environmental indicators, occupying substantial proportion, largely were taken from the Bureau of National Statistics (BNS), because they showed its measurability on the national level through a period. As a result, the indicator set developed in this research is not a direct extension of OMIR, but an integrated, research-driven construct designed specifically for urban sustainability assessment.

Mandatory requirements in OMIR, similar LEED structure, provide a conceptual foundation of

benchmarking urban sustainability performance. Another point in benchmarking is a traffic-light approach. The classification as green, yellow, and red, refers to acceptable, moderate, and critical conditions. Thresholds were defined based on international references, national standards where available, and Astana-specific context. This approach supports rapid interpretation, comparison across indicators, and clear communication within the CIM environment.

By projecting OMIR-related indicators to the urban scale, the framework supports more localized sustainability assessment while maintaining conceptual consistency with national monitoring objectives.

5.2 Data Requirement Analysis and National Data Limitations

Data availability: The realization of CIM framework is directly influenced by the availability and quality of data. Data Requirement Analysis showed that Kazakhstan, and Astana in particular, possesses a significant level of data lake with several problems in terms of data granularity, interoperability, and accessibility. Important operational and real-time datasets for urban sustainability analysis are available through many sources, such as national ministries, statistics agencies and many other interested parties, and often confined into statistical data without direct appliance into CIM-like environments and urban analysis. Furthermore, data on material flows, certifications, lifecycle performance are partially available or distributed across several institutions without standardized formats. The data is collected for own specific purposes, reserved in different formats, and governed by distinct institutional mandates and power, which limit their direct usability for integrated urban-scale analysis. In the same manner, integration remains limited because of institutional barriers, data-sharing restrictions, proprietary concerns, and varying levels of digital readiness. Access to such data depends on unofficial agreements and project-based collaboration rather than standardized and interoperable data pipelines.

Another important point is that data availability is uneven across thematic areas and changes depending on the type of indicators. While many social, environmental, and economic indicators rely on data that are already collected by national institutions—particularly the Bureau of National Statistics and sectoral ministries, these datasets are predominantly available in aggregated, tabular formats and often lack spatial granularity that is important within CIM. Oppositely, indicators requiring GIS layers, asset-level information, or real-time monitoring depend on municipal departments, utilities, and sensor-based systems, where data accessibility and standardization vary considerably.

As reflected in the indicator table (Appendix B), several indicators can be operationalized only through data integration, proxy use, or additional processing within CIM. This highlights that data availability is not only a question of existence, but of format compatibility, spatial resolution,

and institutional access, which together represent key limitations for full CIM-based implementation.

These national data gaps and limitations do not undermine the feasibility of the CIM framework, but they define its current boundaries. The proposed system is therefore designed to function under conditions of incomplete data, allowing incremental integration and gradual enhancement as data availability improves. CIM needs to have architecture that enables the incorporation of proxy indicators and alternative data sources, such as KPIs, project-level data, and sectoral reports. CIM here can serve as an adaptive platform within existing data constraints.

Data collection: It is suggested that data for the identified urban sustainability indicators consist of statistical, spatial, and operational datasets sourced from various institutional actors. Data required are socio-economic statistics, GIS-based land use and infrastructure layers, hydrological and meteorological records, and, where available, operational data from utilities and monitoring systems. This diversity of data types and sources highlights the need for an integrative framework such as CIM to reconcile heterogeneous datasets and support consistent indicator calculation at the urban scale.

Challenges and gaps: Reporting and benchmarking sometimes while data gaps exist become complicated. Data gaps exist in some specific thematic areas, such as emergency events preparedness, private vehicles, paratransit, walking, and cycling, secondary and tertiary wastewater treatment, and EMF exposure and others due to security considerations or incomplete monitoring mechanisms.

The benchmark thresholds used in this study are based on international frameworks (e.g., ISO, SDGs, U4SSC). However, these thresholds may not fully reflect the climatic, economic, and infrastructural conditions of Astana. Future work should focus on calculating benchmarks using: national statistical distributions, historical performance trends, expert-based local thresholds.

Therefore, the current benchmarks should be interpreted as reference values rather than strict local standards.

Next, the coverage of indicators in emerging areas such as material flow, urban biodiversity or urban heat island, remains not sufficient for comprehensive urban analysis. Even though international standards have been adopted, on the national level data quality and methodological alignment in datasets. Another factor is integration of data sources, as they are compiled by different actors, their integration into user-friendly system remains a key barrier to the development of a cohesive, user-oriented CIM platform for urban sustainability assessment.

Future developments and opportunities: One of the first efforts needs to be directed into the

enhancement of data sources: remote sensing, satellite imagery, geospatial data and others. Among other advanced data sources is the subjective with the use of social survey methods and social networks. One of the recent topics in sustainability are development of green passport for GPP, material flow accounts, also can be integrated into CIM framework.

Moreover, human resources specialized in urban statistics may positively affect data collection and analysis. Similarly, informational and technical support can be received from international projects, organizations and companies, including consultations, professional training.

5.3 Stakeholder Roles, Institutional Readiness, and Data Governance Challenges

Analysis revealed that, along with the technical capacity, stakeholder readiness influences the effectiveness of the proposed CIM framework in urban sustainability context. Kazakhstan possesses a fragmented ecosystem of actors covering governmental institutions, research and academic organizations, utilities, private sector entities, civil society, and international organizations. These main actors not only take part in the production of data from the sustainability statistics but also represent an interested party as users of the sustainability outputs and evidence-based assessments.

The research revealed that there is quite strong institutional capacity. The key stakeholders are:

- Department of Architecture and Urban Planning: controls local zoning and urban design; key user and decision-maker for CIM outputs.
- Astana Innovations JSC: city-owned innovation company coordinating Astana's Smart City development and pilot projects such as Smart Astana and Digital Twin. Developed the city's Smart City 2030 strategy and realized pilot projects related to smart health, smart schools and smart lighting, etc.
- Bureau of National Statistics (BNS): The National Committee responsible for data collection, analysis and of statistics, aligning national statistics with international standards.
- Ministry of Ecology and Natural Resources: significant provider of data on waste, forest resources, air conditions, climate etc.
- Ministry of Water Resources and Irrigation: one of the important data providers on national water resources, and water quality.
- Ministry of Industry and Construction: the Ministry regulates sectors such as industry, energy, construction, housing, mining, and defense. It has 5 Committees. Promotes urban resilience within communities by regulating urban planning, construction, and public utilities issues.
- Department of Digitalization and Public Services of Astana city: Municipal department in charge of e-government and smart-city digital initiatives. Implements AI and digital solutions (e.g. expanded citywide camera systems and digital-twin modeling) to improve public services

and urban management. One of the directions of work is the geoinformation portal of Astana. -Akimat of Astana directly manages urban development and Smart City strategies; highly interested in using CIM to improve planning and sustainability.

While there is technical expertise and data production capacity in stakeholder groups, coordination and data-sharing mechanisms remain limited. They operate and produce valuable datasets that are not integrated or standardized for urban analysis. So, the use of CIM as a unified platform is restricted by a such fragmentation. Simultaneously, the analysis unsealed the significant potential among knowledge and innovation actors, environmental consultancy, universities, and quasi-governmental institutions to support data integration, indicator refinement, and methodological advancement.

Municipal bodies and National Statistics Committee can be considered data gatekeepers: they control access to official data, define standards. Private utilities and infrastructure operators - water, energy, transport, waste- in contrast, being critical data producers of asset-level information, have varying readiness for CIM participation. In many cases, data remains underused due to interoperability, property and official data-sharing challenges. This uneven distribution of roles and capacities underscores the need for clearer governance arrangements, standardized data protocols, and institutional frameworks that facilitate collaboration among data producers, gatekeepers, and integrators within the CIM ecosystem. The findings imply that the main challenge is not the absence of data producers, but the need for defined institutional frameworks that would sustain the stakeholder's engagement and collaboration.

5.3.1 Observed Strengths in Multi-Stakeholder Interaction

The analysis identified several strength points that support stakeholder collaboration and urban sustainability data production. First, institutional framework capacity allows the realization of sustainability-related projects and data production for sustainability analysis. Second, there are coordination mechanisms that are created between interdepartmental working groups. For example, the Coordinating Council on SDGs under the Prime Minister. Third, international frameworks and standards adoption permit better comparability, enhance data consistency, and integration with international reporting. As an addition, there is of qualified and motivated professional staff with experience in sustainability-related data collection and reporting. Finally, growing demand for data from institutions, academia, and other organizations, reflect the significance of indicators in sustainable urban development and policymaking. Together, these strengths provide a solid institutional foundation upon which CIM-enabled data integration and urban sustainability assessment can be further developed.

5.3.2 Limitations and Directions for Improvement

Among all stakeholders, The Bureau of National Statistics seems to be in the center of USA framework within CIM environment, as it accumulates much important statistics on national level and provides support to all stakeholders on the methodology and dissemination of indicators. Its function is primarily statistical rather than operational, which makes it insufficient on its own for CIM-based implementation that requires the integration of municipal, utility, and spatial datasets. In this context, the primary users of CIM-based urban sustainability assessment results are municipal planning and governance bodies, particularly the Astana General Plan authority and the Akimat of Astana. Despite this, sometimes the cooperation between BNS and data sources (providers) faces some challenges: methodology on specific topics should be strengthened and collaboration needs to be formalized. CIM offers a potential mechanism for improving coordination among stakeholders by providing a shared technical environment with standardized data structures. However, successful implementation would require clear governance arrangements, defined stakeholder roles, and gradual capacity building. The framework is therefore best understood as a facilitative tool that supports collaboration rather than a fully autonomous system.

5.4 GPP: Potential Use of CIM to Support Green Public Procurement in Kazakhstan

One of the current and timely changes in the sustainability issues is that Kazakhstan is developing Green Public Procurement (GPP) to meet the goals in green economy. Among the recent initiatives are platform development for better implementation of GPP into the economy system. Kazakhstan has developed some national standards related to eco-labelling (ST RK ISO 14024), sustainable procurement (ST RK ISO 20400), and green technologies (69 standards adopted in 2023 in areas like hydrogen, waste management) [106]. But still, the immense work is needed in terms of legislation and realization of GPP, the challenges are fragmented material information, limited availability of environmental performance data, and the absence of a centralized system linking materials, standards, and certifications.

The proposed CIM framework can support the national Green Public Procurement (GPP) system in Kazakhstan serving as a centralized material information and certification database, that enables evidence-based, transparent, and verifiable green procurement decisions. By explicitly linking materials to applicable standards and available certifications, CIM helps address current verification challenges associated with green procurement claims.

The GPP projection builds upon the identified national data gaps and institutional limitations, demonstrating how the proposed CIM framework may support Green Public Procurement under existing constraints.

Chapter 6 -Conclusions

For this stage of the study, the research-initiated stakeholder mapping and identification processes, so that main strategies towards the engagements are developed. In the next step, the criteria were projected from the OMIR and completed with reference to global urban sustainability systems. This part of research results has established the basis for the next Data Requirement Analysis and CIM enabler selection. The results indicate that while Astana possesses emerging digital infrastructure and institutional initiatives such as Smart Astana and Geoportal, substantial challenges remain regarding data interoperability, access, and stakeholder collaboration.

This research set out to develop a feasible CIM framework to support urban sustainability assessment aligned with stakeholder priorities in Astana. The study contributes conceptually, methodologically, and practically to the emerging intersection of digital urban platforms and sustainability governance.

First, the research established a structured foundation through stakeholder identification and power-interest mapping. Approximately 110 stakeholders were categorized and analyzed, enabling the formulation of differentiated engagement strategies. This process demonstrated that urban sustainability assessment is not solely a technical task but a governance-driven process requiring institutional alignment and clearly defined data responsibilities.

Second, the study projected and adapted sustainability criteria from OMIR and international frameworks to the urban scale, introducing mandatory requirements that verify institutional and infrastructural readiness. By distinguishing between enabling dimensions (institutional and economic) and outcome dimensions (environmental and social), the framework ensures that sustainability indicators are supported by governance capacity rather than assessed in isolation. Third, the Data Requirement Analysis revealed both opportunities and structural constraints within Astana's data ecosystem. Although initiatives such as Smart Astana and national statistical systems provide an emerging digital foundation, significant challenges remain in data interoperability, harmonization standards, real-time integration, and cross-departmental coordination. These findings highlight that CIM implementation is not limited by technology alone but by governance architecture and institutional maturity.

Fourth, the evaluation of CIM enabler configurations (BIM, GIS, IoT) demonstrated that integrated multi-layer systems provide the greatest potential for dynamic monitoring, predictive analytics, and scenario-based urban management. However, higher integration

levels require stronger cybersecurity protocols, data governance frameworks, and skilled human capital.

Overall, the proposed CIM framework should be understood not as a fully autonomous digital twin, but as a facilitative and integrative platform that bridges sustainability indicators with spatial intelligence and stakeholder governance. It provides a scalable pathway for embedding urban sustainability assessment into operational city management systems.

From a practical perspective, the framework offers potential applications beyond assessment, including support for GPP, enhanced regulatory transparency, and evidence-based policy formulation. By linking materials, standards, and performance indicators within a structured digital environment, CIM can contribute to more transparent and verifiable sustainability decision-making at the national level. This research is limited by data availability constraints, reliance on qualitative stakeholder assessment, and the absence of full-scale pilot implementation.

Future research should focus on developing standardized interoperability protocols for national and municipal datasets, conducting pilot CIM-based sustainability dashboards for selected districts of Astana, exploring AI-driven predictive analytics within the CIM environment, assessing long-term governance models for digital urban platforms

In conclusion, this thesis demonstrates that integrating sustainability indicators within a structured CIM architecture is both technically feasible and institutionally valuable for Astana. By aligning digital infrastructure, stakeholder priorities, and sustainability assessment logic, the proposed framework contributes to advancing data-driven, transparent, and resilient urban governance in Kazakhstan.

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Appendices

Appendix A A stakeholder list

Subgroup	Name	Website	Description	Role/Contribution
Knowledge and innovation				
University researchers	Nazarbayev University (NU)	nu.edu.kz	National research university in Astana. Houses engineering and science institutions (e.g. energy, earth sciences, architecture).	Have potential to prepare experts on urban sustainability and green technologies. Besides, NU serves as a platform to connect industry and research representatives for urban innovation projects, sustainable city planning[107].
	L.N. Gumilyov Eurasian National University (ENU)	enu.kz	Offers programs in architecture, engineering, ecology and regional studies. Engaged in urban studies and environmental research.	Educates planners and engineers; conducts research on ecology, geology and urban development. ENU labs may work on issues like urban flooding, water supply, and transport modeling in Astana's context[108].
	Kazakh Agro-Technical Research University (KATRU)	kazatu.edu.kz	The Kazakh Agro-Technical Research University (KATRU) gives education in agrotechnical and engineering-focused specializations, by which have one of the leading positions in scientific and technological innovations and research advancements.	KATRU has capability to support research in climate-smart agriculture, organic food, and green practices in the country[109].
	Astana IT University	astanait.edu.kz	The university is relatively young and was founded by the Nursultan Nazarbayev Education Foundation. The institution focuses on IT, data science, and digital technologies and conducts research in smart city systems, AI, IoT, and data analytics.	The institution can have collaborations on data integration, analytics and processing and develop digital tools. Provides research and technological expertise in many data-related fields[110].
Innovation Hubs	Astana Hub (International IT Tech Park)	astanahub.com	Astana Hub is Kazakhstan's international technology park hosting startups, headquartered in Astana. Supports IT and deep-tech companies through incubation and funding.	Being platform for technologic startups, and by developing smart-city solutions, it can support innovation relevant to urban sustainability[111].
	International Green Technologies & Investment Projects Center (IGTIPC)	igtipc.org	Centre supported by the state that promotes green technologies. help investors put "green" ideas into action and keep track of green investments.	Makes condition for green financing and tech adoption. It can draw in funds for waste-to-energy plants, smart grids, or renewable installations in Astana and offer guidance to regional developers on best practices[112].
Environmental Technology & Consulting	"ECO-Astana NR" LLP	ecoastana.kz	The company provides services in different fields of environmental protection, industrial safety and engineering focusing on projects that are environmentally friendly and sustainable.	The business provides a broad range of engineering and environmental solutions along with research activities[113].
	Kazakhstan Agency of Applied Ecology (KAPE)	kapec.kz	One of the largest independent environmental consulting firms with location in Astana office.	Organizes environmental audits, clean energy projects and provide technical support to make industries meet green standards.
	Public fund "Center for Sustainable Development of the Capital"	curs.kz	The Center develops and implements innovative solutions for urban systems. Implemented solutions for smart cities and digitalization of housing and communal services and launched social initiatives that improve the quality of life.	Advises city authorities on green infrastructure, circular economy models, and SDG-aligned urban planning.
	Institution "International Academy of Ecology" (IAE)	eko-kaz.kz	IAE is a non-profit organization that is experienced in environmental consulting and produces solutions for scientific research, education and services.	By integrating contemporary information technology into the fields of ecology, hygiene, and public health, the organization seeks to address environmental problems and enhance both the environment and human health.
Research	International	isca.kz	The science complex offers expert	Science complex provides solutions for smart

ch & Consulting	Science Complex "Astana"		analysis, scientific applications, scientific education, and consulting services. It conducts top-notch research, encourages global cooperation, and provides policy advice.	cities, green technologies, and efficient resource management, thereby drives urban sustainability
	Kazakhstan Institute for Strategic Studies (KAZISS)	kisi.kz	KAZISS is a state organization in Kazakhstan dedicated to supporting the president and his administration through research and analysis. The KazISS conducts study on internal and international issues as well as Kazakhstan's social and economic advancement.	KAZISS offers policy suggestions about resilience, governance, and sustainable urban development.
	Institute of Geography and Water Security (IGWS), Kazakhstan	ingeo.kz	One of the prominent research institutes with the specialization in hydrology, environmental protection and climatology.	As a research institute, it has conducted regional studies on climate, hydro-sustainability, and land use.
Applied Urban Expertise	Kazakhstan Green Building Council (KazGBC)	kazgbc.kz	The Kazakhstan Green Building Council - KazGBC is a non-profit association of legal entities established in 2014 to promote the transition of the construction industry in Kazakhstan to the principles of sustainable development.	The main objective of KazGBC is to train the maximum number of professionals in the field of green building for the construction industry in Kazakhstan and to ensure the mass introduction of the practice of environmental certification of new and existing buildings.
	Urban Forum Kazakhstan	urbanforum.kz	Foundation has been founded in 2018 in Almaty and then started to cover the other regions of Kazakhstan. Urban Forum Kazakhstan is an independent dialogue platform which brings together stakeholders and provides research on urban environment.	The organization represents dialogue platform connecting urban stakeholders such as architects, engineers, sociologists to research and improve urban environments through policy discussions and data-driven urban planning.
	The Q88 Association	q88.kz	The association works on knowledge accumulation, pilot projects implementation, strategic documents and amendments development, and experts gathering.	Plays a vital role as brings experts together to work on the pilot projects, policy reforms for a sustainable city.
	Center for Urban Sustainability	https://uesc.kz	Work in the direction of greening of the urban environment, architecture and urbanism projects and creation of professional community to implement strategies related sustainability.	Promotes green urban environments , sustainable architecture, and urbanism by fostering a professional community to implement eco-friendly strategies in city planning and development.
	***Research and Design Institute "AstanaPlan" LLP	https://astanaplan.com.kz/	Research and Design Institute "AstanaPlan" LLP is a leading urban planning and architectural design institute in Astana that specializes in master plans development, infrastructure projects, and other urban solutions. Moreover, it provides research in the above-mentioned areas.	"AstanaPlan" implements master plan of Astana into reality thereby plays a pivotal role in shaping its sustainable development. Collaborations with government agencies and private developers help to implement innovative urban projects.
Professional bodies	Small local architectural bureaus	-	Small-scale design firms working on minor projects	May follow city standards; rarely contribute to strategic CIM
Political and Public Administration				
Municipal government	Akimat of the city of Astana city	https://www.gov.kz/memleket/entities/astana	Akimat is the city administration of Astana that in charge of urban governance and development according to budget and plans.	The administration supervises the realization of urban projects such as infrastructure and public services aiming to improve the citizens' quality of life.
Political parties	«Baytaq» The Green party of Qazaqstan	https://baytaq.kz/	The party has the slogan "Clean air, Clean water, Clean land – Clean human relations!" that reflects its goals towards flora and fauna protection, diversity preservation, and introducing global principles of sustainable use of natural resources.	They advocate the introduction of environmentally friendly, innovative technologies, digitalization of the environmental protection industry and the education of environmental awareness.
Municipal digital	Astana Innovations JSC	ain.kz	City-owned innovation company coordinating Astana's Smart City development and pilot projects such as	Developed the city's Smart City 2030 strategy and realized pilot projects related to smart health, smart schools and smart

Innovations and technologies department			Smart Astana and Digital Twin.	lighting, etc.
Municipal technical departments specialists	GIS specialists, engineers (water, electricity, roads), Environmental technicians, Smart city systems analysts, Building inspectors / technical planners, Public works technicians	-	Public-sector professionals working in city departments that provide technical expertise in urban planning, infrastructure, and service delivery. They are: GIS specialists Engineers (water, electricity, roads), environmental technicians, smart city systems analysts, building inspectors / technical planners, public works technicians	Implement and maintain urban systems (utilities, roads, buildings, data platforms); ensure sustainability standards, infrastructure functionality, and support CIM integration at the operational level.
Urban security or health services	Center for Urban Security and Video Surveillance (iKOMEK 109)	https://iko.mekastana.kz/	iKOMEK is the center that allows monitoring safety with assistance of video surveillance and emergency response systems. 24-hour reception of appeals on life-support and safety issues - Providing a unified technical infrastructure for effective operation of urban and emergency services - Analysis, identification of system problems of the city - Monitoring of quality of city services	iKOMEK is important for public safety and operational efficiency with aid of smart surveillance and real-time analytics. Key to smart and secure city infrastructure.
	Department of Sanitary and Epidemiological Control of Astana city	https://www.gov.kz/memleket/entities/dsek-astana	Department is a body responsible for sanitary norms, hygiene standards, and epidemiological safety are maintained across the city.	The Department ensures public health and hygiene in the urban environment by sanitation regulation and disease prevention. It contributes to urban sustainability goals and provides critical health-related data that can be integrated into City Information Modeling systems.
National ministries and state committees	Ministry of Ecology and Natural Resources of Kazakhstan	https://www.gov.kz/memleket/entities/ecogeo	The ministry is one of the central executive bodies responsible for regulation of natural resources and environmental policy. It consists of 2 Committees, 12 Departments, 3 directorates and 4 subordinate organizations.	The Ministry contributes to the urban sustainability and green policy by supervising water, air and waste regulations.
	Ministry of Digital Development, Innovation and Aerospace Industry of Kazakhstan	https://www.gov.kz/memleket/entities/mdai	Government ministry for state digitalization and policy in the fields of innovation, aerospace industry, public services etcf.	Main function is in the support of projects on technological and aerospace advancements along with the development of e-governmental platforms.
	Ministry of Industry and Construction of the Republic of Kazakhstan	https://www.gov.kz/memleket/entities/mps	The Ministry regulates sectors such as industry, energy, construction, housing, mining, and defense. It has 5 Committees.	Promotes urban resilience within communities by regulating urban planning, construction, and public utilities issues.
	Ministry of National Economy of Kazakhstan	https://ecconomy.gov.kz	Central body responsible for strategic planning, economic policy, and regional development.	Influences long-term urban development strategy and funding allocation; must be informed to ensure support.
	Ministry of Defense of Kazakhstan	mod.gov.kz	National military authority.	Occasionally consulted for restricted urban zones or critical infrastructure but not core to sustainability agenda.
Public entities (supra-municipal level)	Department of the Land Cadastre and Automated Information System of the State Land Cadastre	https://www.aisgzk.kz/aisgzk/en/	Department of the Land Cadastre and Automated Information System of the State Land Cadastre is a subdivision of the Directorate of the land cadastre and technical real estate survey. The aim is the maintenance and systematization of the database of the state land cadastre.	Plays a vital role because it provides foundational and accurate land information, including land parcels, ownership, and land use.

	Department of Environmental Protection and Environmental Management of Astana city	https://www.gov.kz/memleket/entities/astana-upr	Environmental protection and natural resource use is the focus of the department.	In charge of air and water quality monitoring and implementation of local environmental regulations.
	Department of Architecture and Urban Planning and Land Relations of Astana city	https://www.gov.kz/memleket/entities/astana-saulet	The city department is responsible for architecture, urban planning and land relations in Astana.	The departments regulate land relations and construction thereby plays an important role in resilient urban development
	Department of Digitalization and Public Services of Astana city	https://www.gov.kz/memleket/entities/astana-urgsa	Municipal department in charge of e-government and smart-city digital initiatives.	Implements AI and digital solutions (e.g. expanded citywide camera systems and digital-twin modeling) to improve public services and urban management. One of the direction of work is the geoinformation portal of Astana.
	Department of Emergency Situations of Astana city	https://www.gov.kz/memleket/entities/emergency-astana	In charge of overseeing the city's civil defense organizations and units is the Department of Emergency Situations of Astana, a geographical division of the Republic of Kazakhstan's Ministry of Emergency Situations.	In order to improve overall urban resilience, the Department makes ensuring that infrastructure is disaster-resilient and that environmental catastrophes are handled quickly. Additionally, it collaborates with several agencies to reduce hazards including pollution and floods, which supports Astana's long-term sustainable development objectives.
Quasi-governmental Public Entities	«International Green Technologies and Investment Projects Center» NCJSC	https://igtpc.org	The organization of the Projects center was announced during the 70th UN General Assembly in 2015. The Republic of Kazakhstan's Ministry of Ecology and Natural Resources represent the government, which is the Center's only shareholder. The center develops BAT Reference books, implements international grant programs for green projects, and provides educational awareness initiatives.	An organization supported by the government that promotes green industrialization by assisting with BAT (Best Available Techniques), providing funds for eco-projects, and increasing public awareness of sustainable industrial and urban development.
	Astana International Financial Centre (AIFC)	aifc.kz	Special financial zone (Astana-based). Develops financial and legal infrastructure, with emphasis on sustainable finance (via its Green Finance Centre).	Promotes green finance and investment. AIFC's Green Finance Centre offers ESG consulting and bonds for green projects. It can channel international capital into Astana's sustainable urban projects (e.g. green buildings, efficient transit) and support green bond issuance.
	*Green Technology Hub (under AIFC Green Finance Centre)	greentechhub.kz	AIFC-affiliated center supporting climate tech and renewable energy ventures.	Provides consulting, certification and support for carbon-neutral projects and green startups in Astana and beyond.
International Multilateral Actors	United Nations Development Programme (UNDP) Office in Astana	https://www.un.org/development/dpn/our-networks/kazakhstan/	The UNDP office has the goal to achieve UN Sustainable Development Goals (SDGs) goals, and he carries out activities to achieve them, bringing together experts from high education institutions, government, and civil society.	The contribution to urban sustainability is high as the office organizes research, brings stakeholders together and solutions for resilient urban environment.
	The Organization for Security and Co-operation in Europe (OSCE) Programme Office in Astana	osce.org/astana	OSCE field mission in Kazakhstan's capital.	Conducts programs on environmental governance, resource management and economic development in Astana and Central Asia.
Small businesses	Small private landlords / property owners	-	Own small apartment blocks or retail units	Could share data or respond to planning proposals
Construction Regulation	State Expert Review LLP (Gosexpertiza)	https://www.gosexpertiza.kz/	National authority for expert review of construction documentation.	Ensures compliance of major urban projects with regulations. Indirectly affects CIM outputs if digital models are submitted for review.
Cybersecurity	State Technical Service (STS)	sts.kz	Government cybersecurity and digital infrastructure oversight body.	Key to digital resilience and safe integration of CIM. Little engagement with sustainability modeling itself.
Statistical Authority	Bureau of National Statistics (MoNE)	stat.gov.kz	National provider of census, housing, and economic data.	Supplies key input data (population, household income, etc.) for urban sustainability modeling. Passive role in CIM usage.

Social				
Urban planners	**"Research and Design Institute "Astanagenplan" LLP	https://astanagenplan.com.kz/	Research and Design Institute "Astanagenplan" LLP is a leading urban planning and architectural design institute in Astana that specializes in master plans development, infrastructure projects, and other urban solutions. Moreover, it provides research in the above-mentioned areas.	"Astanagenplan" implements master plan of Astana into reality thereby plays a pivotal role in shaping its sustainable development. Collaborations with government agencies and private developers help to implement innovative urban projects.
	Center of urbanism of the akimat of Astana city	-	The Center makes trend analysis, develops strategic plans, consults projects and mainly improves public spaces and infrastructure according to global standards.	Implements holistic design principles, participatory planning, smart technology integration.
Citizen groups	"Let's Do It, Qazaq Eli" (Cleanup Movement)	—	Kazakh branch of the global "Let's Do It" volunteer movement.	Clean-up movement help to rise awareness among people and engage more citizens.
	"We Are for a Clean Country" (Мы за чистую страну)	—	Grassroots volunteer movement organizes clean-up actions.	Encourages citizens to participate in urban cleanups and environmental education programs, frequently collaborating with global projects to green public areas.
NGOs	The Assembly of the People of Kazakhstan		National civic platform promoting interethnic harmony and social cohesion	Has institutional power and visibility through state-backed initiatives but limited focus on digital sustainability or CIM
	Assoc. of Environmental Organizations of Kazakhstan (AEOK)	aeok.kz	Astana-based association uniting 140+ local environmental NGOs.	Coordinates different environment-related projects across Kazakhstan and mobilizes public support for green initiatives.
	Association for the Conservation of Biodiversity of Kazakhstan (ACBK)	acbk.kz	The Association leads activities in the wildlife conservation organization.	Important in biodiversity issues, so it can provide advice conservation-related initiatives, and increase public understanding of ecological issues.
	Republican public association ROO "Baytak-Bolashak"	https://ecoalliance.kz/	The association calls itself as ecoalliance that reveals activities towards biodiversity, ecosystem rebuilding and environmental stability.	The association has its own role in ecological awareness and eco-friendly projects and initiatives.
	Coalition for Green Economy and G-Global (Kazakhstan)	greenkaz.org	Public NGO that advocates for green economic development.	Promotes green economy policies and sustainability projects; has participated in EU-backed initiatives.
	Green Central Asia Initiative	https://greencentralasia.org	Initiative that works on the Central Asia green economy and environmental projects.	Has importance in transboundary collaboration on climate, water management, and sustainability strategies in the area.
	Kazakhstan Association of Regional Environmental Initiatives "ECOJER"	https://ecojer.kz/ru	Association unites local environmental groups and activists.	The power is in bringing together environmental initiatives and community-led conservation efforts.
	Earth Fund Sustainable Development	https://www.facebook.com/theearthfoundationsustainabledevelopment/	The Earth Fund "Sustainable Development" is a youth public association created with the aim of promoting sustainable development of territories and local communities through the implementation of specific projects and activities to solve environmental, social and economic problems.	Funds local initiatives in renewable energy, waste reduction, and environmental education across Kazakhstan.
	Climate Change Coordination Centre	http://www.climate.kz	Centre is one of the leaders among NGOs in the realization of the agreements, policy development and experts training.	In charge of the national mitigation efforts and ecological protection.
	Renewable Energy Association Qazaq Green	https://qazagreen.kz	Association is of supporting the development of renewable energy sources in Kazakhstan, promoting the principles of a green economy and helping to achieve carbon neutrality. The Association represents and protects the interests of	Accelerates Kazakhstan's renewable energy transition through policy advocacy, investor matchmaking, and public awareness campaigns.

			participants in the green energy sector and unites investors, developers, equipment manufacturers, international financial institutions and universities	
	Ecological Forum of Kazakhstan NGOs (EcoForum)	eco-forum.kz	National network of environmental NGOs. Coordinates campaigns on forests, water, nuclear waste and sustainable resource use.	Bridges civil society and government on environmental policy. Through workshops and projects, it can influence municipal environmental actions (e.g. anti-pollution campaigns, public input on city developments).
	Civil Alliance of Kazakhstan (GAK)	civilalliance.kz	Umbrella NGO coordinating regional and national civil society. Unites local alliances and NGOs across Kazakhstan.	Fosters community engagement in urban policy. Supports NGO projects and forums (e.g. Astana Regional Forum on gov-society partnership), enabling citizen participation in sustainability initiatives (public hearings, volunteer programs).
	KazWaste Association	http://kazwaste.kz	Professional association for the waste management industry.	Promotes circular economy practices, urban recycling solutions, and policy input.
	Aarhus Centre, Astana (Union of Aarhus Centres & Innov. Dev. Entities)	aarhus.osce.org/kazakhstan	Part of OSCE Aarhus network in Kazakhstan, based in Astana. Focuses on public participation, environmental impact assessment and green economy.	Serves as a civic-government bridge on environmental issues. Helps NGOs and citizens access information and engage in urban projects (climate change, waste management, green policies). It can guide sustainable urban development through awareness and EIA processes.
Neighborhood and citizen associations	APO (associations of property owners), or SP (simple partnerships)	-	APOs are self-governing entities formed by owners of residential buildings in Kazakhstan. Their role has grown since reforms in the Housing Relations Law (2020) , which replaced the old "condominium" model with ОСН (Объединения собственников имущества) and простое товарищество (Simple Partnerships / SP) .	Such associations help to organize people on the low level so that municipal programs and building-level sustainability upgrades are easily realized.
Media	Kazinform (3 languages)	inform.kz	Kazakhstan's official national news agency. Covers government decisions, reforms, and development programs.	State-run agency; covers govt sustainability policies, green initiatives.
	Zakon.kz	zakon.kz	Popular private online legal and political news platform. Covers laws, regulations, and public feedback.	Reports on urban development laws, environmental regulations.
	The Astana Times (English)	astanatimes.com	English-language media that covers reforms, investments, urban development.	Highlights different news related to smart-city and international partnerships
	Kapital.kz	kapital.kz	News source with an emphasis on business and the economy.	Business-focused media covers green finance and construction news.
	Khabar 24	24.kz	24/7 state television news channel. Covers government programs, policies, and public awareness topics.	National TV channel; runs segments on eco-projects (e.g., waste management).
	Astana TV	astanatv.kz	Local TV network with focus on city affairs, events, and municipal programs.	Local channel; features city planning debates and citizen feedback.
	Tengrinews (3 languages)	tengrinews.kz	One of the popular media platforms.	Highlights environmental issues.
	Lifestyle bloggers & local influencers	-	Cover daily life, food, local events; rarely urban planning	Might amplify public interest if CIM topics become trendy
Youth clubs & cultural hobby groups	Local music, art or cultural groups using public spaces	-	Local music, art or cultural groups using public spaces	Might participate in pilot events, awareness campaigns
Economic and Financial				
Urban utilities	Astana Su Arnasy (Water Utility)	astanasu.kz	Astana Su is a municipal water supply and wastewater utility in Astana.	As a provider of drinking water and sewage services, can contribute to better water treatment in the city.
	Kazakhstan Utility Systems JSC	https://www.kus.kz/	Private utility group active in electricity and heat supply.	Invests in smart grids and energy-efficient district heating systems in cities.
Telecommunications operators	Kcell	kcell.kz	One of the telecommunication operators.	IoT solutions for smart cities, such as energy conservation and traffic control, are made possible by Kcell. It intends to keep spending money on the rollout of its 3G and 4G networks in order to increase coverage and

				offer high-level services.
	Tele2 Kazakhstan	tele2.kz	One of the telecommunication operators.	Supports digital infrastructure for sustainable urban services.
	Beeline Kazakhstan	beeline.kz	One of the telecommunication operators.	Provides connectivity for smart grids and eco-friendly urban tech.
Telecommunications service companies	Kazakhtelecom	telecom.kz	Kazakhstan's largest telecommunications provider, offering broadband, data centers, cloud services, and backbone internet infrastructure . It owns or controls Kcell and Tele2 , giving it dominance across fixed and mobile networks.	National operator investing in fiber optics and 5G for smart city applications.
	Transtelecom JSC	https://www.ttc.kz	One of Kazakhstan's top telecom providers, offering cloud, cybersecurity, and ICT services. provides fiber-optic networks in cities and other parts of Kazakhstan.	facilitates the development of smart cities in Astana by making digital infrastructure, smart utility metering, high-speed internet, and urban monitoring technologies possible.
Transportation companies	City Transportation Systems LLP (Bus Operator)	cts.gov.kz	Astana's municipal public bus operator with the projects on smart public transport systems, specialists training, adaptive control system of traffic lights and similar.	Operates the city bus network and is electrifying its fleet to provide sustainable public transit.
	Astana Light Rail Transit LLP (Metro Project Authority)	—	Project company building Astana's future light-rail (metro) system.	Constructing the city's metro line (slated for 2024–25) to enable high-capacity zero-emission urban transport across Astana.
	KazAvtoZhol JSC	https://ru.qaj.kz/company/history/	Oversees national road construction and maintenance.	Controls roadway projects that may intersect with CIM data layers.
Investors and financial entities	National Bank of Kazakhstan	nationalbank.kz	Has control over monetary and macroeconomic policy.	May influence green finance tools or city investment but not engaged in technical frameworks like CIM.
	Accounts Committee for Control over Execution of the Republican Budget	esep.kz	Audits state spending including infrastructure projects.	Has influence over approval of budget for CIM-related smart city projects. Rarely engages with operational-level modeling.
	World Bank Group (Kazakhstan)	worldbank.org/kazakhstan	One of Kazakhstan's biggest international borrowing sources is the World Bank Group. backs Kazakhstan's shift to a diverse, knowledge-based economy.	In Astana, World Bank projects include waste management, water supply, energy efficiency programs, and transport and road upgrades (such as the South-West Roads Project to reduce traffic). It offers technological research for urban planning that is sustainable.
	European Bank for Reconstruction & Development (EBRD) – Kazakhstan	ebrd.com/kazakhstan	International financial institution active since 1993. Focuses on decarbonizing the economy, green energy and transport infrastructure in Kazakhstan.	Invests in Astana's green transition. For example, financing electric buses for Astana's fleet, supporting renewable energy (financed ~40% of KZ wind/solar capacity) and municipal services. Promotes policy reforms (e.g. PPP law, green city action plans) that shape sustainable urban development.
	Samruk-Kazyna Invest	https://www.skinvest.kz/	Samruk Kazyna, Kazakhstan's national wealth fund, is the only owner of this direct investment business. With a focus on green economy initiatives, localisation, and sustainable development, it was founded in 2007 and funds critical domestic projects ranging from manufacturing and IT to renewable energy and infrastructure.	offers sustained funding for digital projects, renewable energy, and urban infrastructure that promote sustainable urban development and complement CIM programs.
	Asian Development Bank (Kazakhstan)	adb.org/countries/kazakhstan	Bank for multilateral development. aims to alleviate Kazakhstan's climate vulnerabilities, increase economic resilience, and lessen inequality.	Finances infrastructure and climate projects such as renewable energy projects, public transit systems, urban flood protection, and governance enhancement.
	Otbasy Bank JSC (House Bank)	https://hcsbk.kz/ru/	Otbasy Bank specializes in financing affordable homes through savings and	It has affordable housing programs for different layers of society. The bank

	Construction Savings Bank)		mortgage programs. It owns more than 50% of the country's mortgage portfolio and provides services to more than 29% of Kazakhstan's economically active population.	participates in environmental projects including planting trees and lowering its carbon footprint, incorporates ESG principles into its operations, and supports the country's objective of becoming carbon neutral by 2060.
Energy companies	Samruk-Energy JSC	samruk-energy.kz	Samruk Energy is a state-owned national power utility that produces about 30% of Kazakhstan's electricity along with developing renewable energy portfolio.	The company makes investments in renewable energy. It is essential to the supply of clean energy and can collaborate on solar or district heating modernization projects in Astana.
	"Astana EnergoSbyt"	https://astanaenergo.sbyt.kz/	EnergoSbyt is the primary supplier of electricity in Astana is	Able to contribute significantly to urban sustainability by promoting energy efficiency initiatives and funding smart grid technologies.
	KEGOC (Kazakhstan Electricity Grid Operating Company)	https://www.kegoc.kz	Kazakhstan's national transmission grid operator. in charge of overseeing and updating the infrastructure for the transmission of power.	Incorporating renewable energy sources into urban areas, increasing energy efficiency, and deploying smart grids are essential to attaining urban sustainability. helps to stabilise and reduce the carbon footprint of Astana's power supply.
Construction and Real Estate Development Companies	BI Group (Construction & Engineering)	company.bi.group	Largest Kazakhstani developer/constructor of buildings and infrastructure. Builds residential and commercial projects and public infrastructure in Astana and other regions.	Influences urban form through construction. Incorporates energy-efficient design, green building practices and urban infrastructure projects (bridges, schools, housing). As a major builder in Astana, BI Group shapes city growth and can implement sustainable construction methods.
	BAZIS-A Corporation	https://bazis.kz/about	One of Kazakhstan's largest construction and real estate companies that creates residential, commercial, and infrastructure.	Influences urban form and energy usage in Astana through large-scale development projects.
	SVOY DOM Construction Holding	https://svoym.kz/	Real estate developer specializing in residential and mixed-use projects over the whole country.	Enhances Astana's residential landscape. A contributor to sustainable and livable neighborhoods.
	YDA Group Kazakhstan	https://www.yda.com.tr	A division of the global YDA Group, a significant Turkish infrastructure and construction company. involved in the construction of important facilities in Astana, such as smart building initiatives and medical facilities. In Astana, there is YDA Industrial Park.	As a construction firm that can influence designs so that they are more resilient and eco-friendlier.
	"Samruk-Kazyna Construction" JSC (formerly Samruk-Kazyna Real Estate Fund JSC)	https://skn.kz/en	Samruk-Kazyna focuses on real estate development and construction of public and affordable housing.	Drives green and affordable housing programs in Astana by incorporating modern construction standards.
Professional associations	Construction Workers Union	https://sskaz.kz/	The subject of the Union's activities is the coordination of the professional work of builders of the Republic of Kazakhstan and the consolidation of their efforts to implement market economic reform, the development of proposals for the approval of an optimal scheme of state regulation of the country's construction complex.	The Construction Workers Union contributes to urban sustainability by promoting green building practices , energy-efficient construction standards, and worker training in sustainable techniques, ensuring that Kazakhstan's urban development aligns with environmental and long-term resilience goals.
	Union of Architects of Kazakhstan	https://kazarch.kz	Today the Union is faced with new challenges that dictate the need to solve a different range of problems, evolve into other forms of existence and organization of the Union.	A historic professional body promoting sustainable architecture and urban design, integrating global best practices into Kazakhstan's built environment through advocacy and international partnerships.
Business associations	The National Chamber of Entrepreneurs of the Republic of Kazakhstan "Atameken"	https://atameken.kz	The National Chamber of Entrepreneurs of the Republic of Kazakhstan "Atameken" is a non-profit organization. It was created to strengthen the negotiating power of business with the Government of the Republic of Kazakhstan and government agencies. The Chamber of Entrepreneurs represents	"Atameken" , created for the purpose of coordinating and ensuring effective relationships between business entities and government agencies for the implementation of sustainable development and ESG principles in economic sectors and at the regional level.

			the interests of small, medium and large businesses, covering all areas of entrepreneurship, including domestic and foreign trade. The main task of "Atameken" is to protect the rights and interests of business and ensure broad coverage and involvement of all entrepreneurs in the process of forming legislative and other regulatory rules for business.	
Small local businesses	Cafes, small shops, services, coworking spaces, etc.	-	Locally owned shops, service providers and restaurants that operate in neighborhood centers, business streets and malls in Astana	Indirect stakeholders: their daily activity depends on urban environment quality, walkability, traffic flows, and green public spaces. CIM-supported planning can affect foot traffic, local air quality and energy infrastructure that benefits or challenges them.
Potential future users				
Startups & Innovation Ecosystem	Astana Hub (not currently focused on CIM)	-	Kazakhstan's largest tech startup ecosystem; currently more focused on IT, AI, fintech than urban data	Future collaboration possible on digital twins, smart city apps, urban IoT solutions
Real Estate Buyers (Young Families)	Youth Housing Beneficiaries (e.g., through Otbas Bank)	-	Young or first-time home buyers benefiting from affordable housing schemes	Will benefit from CIM-informed planning: access to green, safe, well-located housing
Green Startups & SMEs	Future eco-construction or recycling startups	-	Emerging or future businesses working in urban recycling, eco-design, or energy	Could become future collaborators or users of CIM for siting, infrastructure data, or permitting
Real Estate Agents / Private Brokers	Local property listing agencies (e.g. krisha.kz, olx.kz)	krisha.kz	Online real estate platforms with geolocation data	May use future open-data CIM platforms to offer better location-based filtering and sustainability data
Students & Young Professionals	University graduates in design/engineering	-	Students not yet engaged in policy but may be trained via CIM integration in urban curriculum	Could be trained to use CIM, apply for jobs in sustainable urbanism, and shape future built environments
Environmental Tech Developers	Independent developers (e.g., GIS coders, app builders)	-	Freelance developers or innovators outside current urban planning teams	May design apps that leverage open CIM datasets for mobility, air quality, public feedback

****"Research and Design Institute "AstanaGenplan"LLP-**

***Green Technology Hub (under AIFC Green Finance Centre)-**

Sources: Official government and organizational websites, plus recent news and reports, among others. Each entry above is referenced to credible, up-to-date sources indicate

Appendix B Indicators list

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency	Data Format	Data Required	Data Sources (Stakeholders)	References (Frameworks & Standards)	CIM Integration & Enablers	Astana Context& Data Availability	Future-orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Economic	Materials & Products	Domestic Material Consumption (DMC) per capita	Total material consumption of the city ÷ population	tons/person/year	Annual	Numeric (time series)	Material production, import/export, construction materials, infrastructure investment, population	Bureau of National Statistics; municipal construction & waste departments	UN SDG 8.4.2; UNEP Material Flow Accounting; EBRD Circular Economy Framework	GIS: industrial zones, construction sites, waste facilities; Data: national MFA, construction permits, infrastructure spending; CIM dashboard: DMC per capita, spatial hotspots, time-series trends; Data integration: downscale national accounts to city using land-use and population grids	DMC reported nationally; city-level values not directly available. Estimation feasible using construction statistics, industrial zones, infrastructure spending, and population data	Measures urban material efficiency and resource productivity	Green <10; Yellow 10–20; Red >20	National accounts + city activity proxies → CIM
Economic	Materials & Products	Material Circularity Rate	Secondary material input ÷ total material input × 100	%	Annual	Numeric	Secondary material volumes; total material input	Waste operators; recycling companies; municipal waste producers	ISO 59020 Circularity Indicators	GIS: recycling facilities, industrial areas; BIM: material passports, project material inputs; CIM dashboard: circularity rate by sector, trends; Data integration: link waste outputs with secondary material inputs	Recycling data exists but fragmented; reporting not standardized. Coverage improving with growing recycling sector	Core indicator for circular economy transition	Green >25%; Yellow 10–25%; Red <10%	Waste systems + recyclers + BIM → CIM
Economic	Materials & Products	Construction & Demolition Waste Recycling Rate	(Recycled C&D waste ÷ total C&D waste generated) × 100	%	Quarterly / Annual	Numeric; GIS	C&D waste quantities; recycling outputs; site locations	C&D firms; municipal waste authorities	OECD Circular Indicators; ISO 37120	GIS: demolition sites, recycling plants; BIM: project level waste quantities; CIM dashboard: recycling rate, compliance tracking, time-series; Data integration: C&D permits linked to waste reporting	High construction activity; waste volumes known, but recycling quantities inconsistently reported	Supports circular construction and waste reduction	Green >70%; Yellow 40–70%; Red <40%	C&D firms → municipal waste → CIM
Economic	Materials & Products	Share of Recycled Aggregates in Construction	Recycled aggregates ÷ total aggregates × 100	%	Annual	Numeric; BIM-based	Recycled and virgin aggregate quantities per project	Construction firms; material suppliers; permitting authorities	EBRD Green Cities; EU Circular Economy Indicators	GIS: construction projects, aggregate suppliers; BIM: quantity take-offs, material specifications; CIM dashboard: recycled vs virgin aggregates share; Data integration: link project BIM with supplier declarations	Strong reliance on virgin aggregates; recycled aggregate data is project-specific	Reduces primary resource extraction and land degradation	Green >30%; Yellow 10–30%; Red <10%	Construction firms → BIM → CIM
Economic	Materials & Products	Industrial Symbiosis Index	Number of by-product exchanges ÷ total firms in eco-industrial zones	Ratio	Annual	Numeric	By-product exchange records; firm counts	SEZ administrations; industrial clusters	UNEP Industrial Symbiosis Guidelines	GIS: industrial clusters, logistics networks; Data: by-product exchange records; CIM dashboard: symbiosis index, exchange maps; Data integration: match waste streams to industrial inputs	SEZs exist, but formal exchange data is limited	Encourages circular industrial metabolism	Green >0.20; Yellow 0.10–0.20; Red <0.10	SEZs + industrial clusters → CIM
Economic	Materials & Products	Material Productivity (GDP/DMC)	City GDP ÷ Domestic Material Consumption	USD/ton	Annual	Numeric	City GDP; estimated DMC	Bureau of National Statistics; city finance departments	UN SDG 8.4.1; World Bank WDI	GIS: economic activity zones; Data: GDP, estimated DMC; CIM dashboard: productivity ratios, decoupling trends; Data integration: align economic accounts with material flow estimates	City GDP available; DMC estimated via construction and infrastructure proxies	Tracks decoupling of economic growth from resource use	Green >120; Yellow 70–120; Red <70	Economic statistics + material flows → CIM
Economic	Materials & Products	Products with Digital Material Passports	Products/buildings with DMPs ÷ total new products × 100	%	Annual	BIM / IFC	BIM models with material composition & lifecycle attributes	Developers; manufacturers; permitting offices	EU Digital Product Passport; ISO 22095	GIS: building locations; BIM: IFC models with material metadata; CIM dashboard: DMP coverage, lifecycle indicators; Data integration: link BIM models to permitting and asset registries	BIM adoption growing; DMPs not standardized or mandated	Enables long-term material traceability and urban mining	Green >120; Yellow 70–120; Red <70	BIM + manufacturers → CIM
Economic	Materials & Products	Sustainable Procurement Rate (Public Sector)	Public tenders with circular criteria ÷ total tenders × 100	%	Annual	Text + numeric	Tender documents; procurement criteria	Public procurement authorities; Akimat departments	OECD Green Public Procurement	GIS: public project locations; Data: e-procurement tender texts; CIM dashboard: circular procurement share, policy trends; Data integration: NLP-tagged tenders linked to projects and budgets	Procurement fully digitized; circular criteria rarely applied	Drives circular market demand via public sector	Green >40%; Yellow 15–40%; Red <15%	eGov procurement platforms → CIM
Economic	Materials & Products	Urban Mining Potential Index	Value of recoverable materials ÷ population	USD/capita	3–5 years	BIM / IFC + GIS	Asset inventories; material composition; market prices	Municipal asset registries; utilities	EU Urban Mining Framework; ISO 37120	GIS: buildings, infrastructure networks; BIM: asset material composition; CIM dashboard: recoverable material value, scenarios; Data integration: combine asset inventories with market price databases	Rapid urban expansion increases embedded material stocks; BIM coverage partial but improving	Anticipates future resource availability and resilience	Green >1000; Yellow 500–1000; Red <500	BIM + asset registries + GIS → CIM
Economic	Materials & Products	Waste-to-Resource Conversion Rate	Waste converted to materials or energy ÷ total waste generated × 100	%	Quarterly / Annual	Numeric	Total waste generated; amount converted to materials or energy	Waste operators; energy utilities	UN-Habitat; EBRD	GIS: MRF locations; IoT: smart bins & sensors; CIM dashboard: conversion efficiency, trends, alerts; Data integration: link smart bins → MRF → CIM	New waste processing plant enables partial data availability and real-time monitoring	Critical indicator for circular economy transition	Green >50%; Yellow 20–50%; Red <20%	Smart bins → MRF → CIM
Economic	Employment	Unemployment Rate	Unemployed population ÷ labor force × 100	%	Quarterly	Numeric	Unemployed population; total labor force	Ministry of Labour; Bureau of National Statistics	World Bank WDI; ILO	GIS: population demographics; CIM dashboard: unemployment trends, spatial patterns; Data integration: link labor registry to census	Official quarterly data available and reliable	Core indicator of economic stability	Green <5%; Yellow 5–9%; Red >9%	Labor registry → CIM
Economic	Employment	Youth Unemployment Rate	Unemployed population (15–24) ÷ youth labor force × 100	%	Quarterly	Numeric	Youth unemployed population; youth labor force	Ministry of Labour; Statistics Agency	UN SDG 8.6; ILO	GIS: age-layered population; CIM dashboard: youth employment scenarios; Data integration: census + labor registry → CIM	Young population growing; data available	Long-term economic resilience indicator	Green <8%; Yellow 8–15%; Red >15%	Registry + census → CIM
Economic	Employment	Labor Force Participation Rate	Labor force ÷ working-age population × 100	%	Annual	Numeric	Labor force size; working-age population	Bureau of National Statistics	World Bank WDI	GIS: working-age population; CIM dashboard: participation trends; Data integration: link census & mobility layers	High workforce mobility; national data available	Measures economic engagement	Green >70%; Yellow 55–70%; Red <55%	Census → CIM
Economic	Employment	Informal Employment Share	Informal workers ÷ total employed population × 100	%	Annual	Numeric	Informal workers; total employed	Ministry of Labour; social protection agencies	ILO; UN SDG 8.3	GIS: informal worker hotspots; CIM dashboard: policy scenario modeling; Data integration: link social protection and employment data	Informality increasing; estimation required	Supports labor formalization policies	Green <10%; Yellow 10–25%; Red >25%	Social protection data → CIM
Economic	Employment	Employment Density	Number of jobs ÷ urban land area	jobs/km²	Annual	Numeric; GIS	Number of jobs; urban land area	Employers; municipal planning departments	ISO 37120	GIS: urban land & job locations; CIM dashboard: density mapping, spatial patterns; Data integration: link employment registry → land-use GIS → CIM	High density in CBD areas	Supports compact city planning	Benchmarked per ISO class	Employers → CIM
Economic	Livelihood Opportunities	Average Hourly Earnings	Average hourly income of employees (Male – Female earnings) ÷ male earnings × 100	KZT/hour	Annual	Numeric	Total wages; hours worked	Tax authority; Statistics Agency	UN SDG 8.5.1	GIS: income distribution; CIM dashboard: trends, disparities; Data integration: link tax + income data	Data available via tax/statistics agencies	Tracks income growth	OECD benchmark ranges	Tax data → CIM
Economic	Livelihood Opportunities	Gender Wage Gap	(Male – Female earnings) ÷ male earnings × 100	%	Annual	Numeric	Male and female earnings	Ministry of Labour; Statistics Agency	UN Women; UN SDG 5	GIS: gender-disaggregated income; CIM dashboard: wage gap spatial analysis; Data integration: link HR & payroll data	Persistent wage gap	Core gender equality indicator	Green <10%; Yellow 10–20%; Red >20%	Labor registry → CIM
Economic	Livelihood Opportunities	Job Accessibility Index	Average travel time to nearest employment center	minutes	Quarterly	GIS + mobility	Travel times; employment center locations	Transport authority; mobility operators	World Bank Urban Accessibility Index	GIS: transport network; CIM dashboard: accessibility maps, travel time trends; Data integration: link employment centers, transport network → CIM	Long commutes in peripheral areas	Key transport–land use indicator	Green <25; Yellow 25–40; Red >40	Transport data → CIM
Economic	Livelihood Opportunities	New Job Creation Rate	(Jobs created – jobs lost) ÷ total jobs × 100	%	Annual	Numeric	Jobs created/lost; total jobs	Business registry; Ministry of Labour	OECD Growth Indicators	GIS: employment zones; CIM dashboard: job growth, spatial visualization; Data integration: business registry → CIM	Growing economy	Tracks economic health	Higher = better	Business registry → CIM
Economic	Income Equality	Gini Coefficient	Income inequality index (0–1)	index	Annual	Numeric	Household income surveys, tax data	Bureau of National Statistics; survey agencies	UN SDG 10.1; World Bank WDI	GIS: income distribution; CIM dashboard: inequality mapping, trends; Data integration: household survey + tax → CIM	National values available; city estimation feasible	Measures income inequality	Green <0.30; Yellow 0.30–0.40; Red >0.40	Household surveys → CIM
Economic	Income Equality	Income Share of Bottom 40%	Share of total income held by bottom 40%	%	Annual	Numeric	Household income microdata	Bureau of National Statistics; social agencies	World Bank WDI	GIS: socio-economic layers; CIM dashboard: equity scenario modeling; Data integration: survey + census → CIM	City-level estimation required	Poverty reduction indicator	Green >20%; Yellow 15–20%; Red <15%	Surveys → CIM
Economic	Income Equality	Urban–Rural Income Ratio	Average urban income ÷ rural income	ratio	Annual	Numeric	Urban and rural income data	Bureau of National Statistics	GPSC	GIS: urban vs rural layers; CIM dashboard: disparity mapping; Data integration: link urban & rural datasets → CIM	Astana above national average	Captures regional inequality	Lower = better	Statistics → CIM
Economic	Income Equality	Access to Services Ratio (90th/50th)	Service access score at 90th percentile ÷ 50th percentile	ratio	Annual	Numeric	Utility & service coverage data	Utilities; transport authorities	GPSC	GIS: service coverage; CIM dashboard: inequality hotspots; Data integration: link utility + transport coverage → CIM	Relevant for utilities and transport	Reduces service inequality	Green <1.3; Yellow 1.3–1.8; Red >1.8	Utilities + transport → CIM
Economic	Global Appeal	International Visitors	Total foreign tourist arrivals per year	persons	Annual	Numeric	Border entry, visa, hotel data	Tourism authority; border services	World Bank WDI	GIS: border & airport points; CIM dashboard: visitor flows, seasonal trends; Data integration: travel + accommodation → CIM	Expo legacy supports tourism	Strengthens global economy	OECD city benchmarks	Airports → CIM

Economic dimension indicators

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency	Data Format	Data Required	Data Sources (Stakeholders)	References (Frameworks & Standards)	CIM Integration & Enablers	Astana Context & Data Availability	Future-orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Economic	Global Appeal	International Students	Enrolled foreign students	persons	Annual	Numeric	University enrollment data	Universities; Ministry of Education	GPSC	GIS: university campuses; CIM dashboard: student mobility; Data integration: enrollment + housing → CIM	NU & medical universities attract students	Builds human capital	Higher = better	Universities → CIM
Economic	Global Appeal	Foreign Direct Investment (FDI % GDP)	FDI inflow ÷ city GDP × 100	%	Annual	Numeric	FDI project data; GDP	Ministry of Economy; investment agencies	OECD FDI; IDB	GIS: economic zones; CIM dashboard: FDI trends; Data integration: link GDP + FDI inflow → CIM	Astana Hub driving tech FDI	Innovation-driven growth	Green >6%; Yellow 3–6%; Red <3%	Economy ministry → CIM
Economic	Global Appeal	International Air Routes	Scheduled international routes	count	Annual	Numeric	Airline schedules	Airport authority	GPSC	GIS: airport points; CIM dashboard: connectivity maps; Data integration: airline schedules → CIM	Astana airport as hub	Connectivity driver	Higher = better	Airport → CIM
Economic	Business Climate	Businesses per 100k Residents	Registered businesses ÷ population × 100,000	count	Annual	Numeric	Business registry; population	Business registry; tax authority	ISO 37120	GIS: business locations; CIM dashboard: enterprise density; Data integration: business registry → land-use GIS → CIM	Highest rates nationally	Entrepreneurship indicator	Higher = better	eGov → CIM
Economic	Business Climate	Days to Obtain Business License	Time from application to approval	days	Annual	Numeric	Licensing workflow data	Municipal licensing; eGov	World Bank WDI	GIS: licensing offices; CIM dashboard: process bottlenecks; Data integration: licensing workflow → CIM	Licensing digitized	Ease of doing business	Green <10; Yellow 10–20; Red >20	eGov → CIM
Economic	Business Climate	Access to Finance Index	Firms identifying finance as main constraint ÷ total firms × 100	%	Annual	Numeric	Firm surveys	SME agencies; chambers	GPSC	GIS: firm locations; CIM dashboard: financial accessibility; Data integration: survey data → CIM	SMEs face financing limits	SME growth enabler	Green <15%; Yellow 15–30%; Red >30%	Banks + SME data → CIM
Economic	Business Climate	SMEs Supported Post-Disaster	Available SME recovery mechanisms	count	Annual	Qualitative	SME recovery programs	Emergency agencies; SME bodies	City Resilience Index	GIS: SME locations; CIM dashboard: recovery simulations; Data integration: program records → CIM	Winter disruptions relevant	Economic resilience	Higher = better	Municipality → CIM
Economic	Economic Structure	Manufacturing Share in Employment	Manufacturing employment ÷ total employment × 100	%	Annual	Numeric	Sectoral employment data	Bureau of National Statistics	UN SDG 9.2	GIS: employment by sector; CIM dashboard: sectoral mapping; Data integration: employment registry → CIM	Service-dominated economy	Tracks diversification	OECD benchmark	Employment registry → CIM
Economic	Economic Structure	Sectoral GDP Breakdown	GDP share by sector	%	Annual	Numeric	GDP by sector	Bureau of National Statistics	World Bank WDI	GIS: economic zones; CIM dashboard: GDP by sector trends; Data integration: link GDP datasets → CIM	Services dominate	Structural change indicator	Higher diversity = better	Statistics → CIM
Economic	Economic Structure	Location Quotients	City sector share ÷ national sector share	index	Annual	Numeric	Sectoral employment & GDP	Bureau of National Statistics	GPSC	GIS: sector clusters; CIM dashboard: specialization patterns; Data integration: sectoral employment + GDP → CIM	Useful for logistics & finance	Reveals specialization	1 = equal; >1 specialization	Sector data → CIM
Economic	Economic Structure	Herfindahl Index	Sum of squared sectoral shares	index	Annual	Numeric	Sectoral GDP/employment	Statistics; business registries	GPSC	GIS: sectoral mapping; CIM dashboard: concentration/diversification visualization; Data integration: sectoral GDP/employment → CIM	Moderate concentration	Diversification metric	Lower = better	Business data → CIM
Economic	Connectivity & Global Links	Population Covered by Mobile Network	Covered population ÷ total population × 100	%	Annual	Numeric; GIS	Telecom coverage, population	Telecom operators; ICT regulator	UN SDG 9.c.1; ITU	GIS: geolocate coverage; CIM dashboard: coverage %, time-series trends; IoT: network readiness; Data integration: population grids → telecom coverage → CIM	Near-universal 4G; 5G emerging	Enables smart city services	Green >95%; Yellow 80–95%; Red <80%	Telecom GIS → CIM
Economic	Connectivity & Global Links	Broadband Subscriptions per 100 Inhabitants	Fixed broadband subscriptions ÷ population × 100	subs/100	Annual	Numeric	Subscription data	Telecom operators; eGov	UN SDG 17.8; WDI	GIS: subscriber distribution; CIM dashboard: subscription trends, gaps; Data integration: link telecom + population → CIM	Regional leader	Digital readiness	OECD benchmarks	Telecom → CIM
Economic	Connectivity & Global Links	National & International Air Routes	Total scheduled passenger routes	count	Annual	Numeric	Route schedules	Airport authority	GPSC; World Bank WDI	GIS: airport nodes; CIM dashboard: connectivity network; Data integration: integrate air routes with urban transport & economic networks	Astana functions as regional hub	Global integration and accessibility	Higher = better	Airport → CIM
Economic	Connectivity & Global Links	City Exports (% GDP)	Export value ÷ city GDP × 100	%	Annual	Numeric	Export data, GDP	Customs authority; Statistics agency	World Bank WDI; CRI	GIS: export-oriented sectors; CIM dashboard: trade competitiveness; Data integration: export/GDP data → CIM	Service-led exports; city-level estimation	Competitiveness indicator	Higher = better	Customs → CIM
Economic	Connectivity & Global Links	City Imports (% GDP)	Import value ÷ city GDP × 100	%	Annual	Numeric	Import data, GDP	Customs authority; Statistics agency	World Bank WDI	GIS: import-dependent sectors; CIM dashboard: supply-chain vulnerability; Data integration: imports + sectoral GDP → CIM	High import dependency for manufactured goods	Vulnerability assessment	Lower = better if balanced	Customs → CIM
Economic	Connectivity & Global Links	International Inbound Tourists	Foreign visitor arrivals per year	persons	Annual	Numeric	Visitor arrivals, visa data	Border services; Tourism authority	World Bank WDI	GIS: points of entry; CIM dashboard: seasonal & spatial demand; Data integration: border + tourism → CIM	Strong seasonality; data consistently collected	Tourism & service planning	OECD comparability	Airport + border → CIM
Economic	Connectivity & Global Links	International Outbound Tourists	Residents traveling abroad per year	persons	Annual	Numeric	Travel records	Border services	World Bank WDI	GIS: outbound flows; CIM dashboard: travel behavior analysis; Data integration: link border + transport → CIM	High outbound mobility; reliable border data	Global connectedness	Higher = better	Border service → CIM
Economic	Connectivity & Global Links	Market Accessibility Index	Composite index of travel time, connectivity, infrastructure	index	Annual	Numeric; GIS	Travel time, transport networks, land-use	Transport authority; Urban planning dept.	World Bank Urban Accessibility Index	GIS: transport & land-use layers; CIM dashboard: multimodal accessibility, scenario modeling (BRT/LRT); Data integration: transport network + land-use → CIM	BRT & LRT expansion underway; modeling feasible	Multimodal transport planning	World Bank scale	Transport + GIS → CIM
Economic	Connectivity & Global Links	Rural Access Index (RAI)	Rural population within 2 km of all-weather road ÷ total rural population × 100	%	Annual	Numeric; GIS	Road networks, rural population, satellite imagery	Ministry of Transport; Statistics agency	World Bank RAI; UN SDG 9.1	GIS: rural settlements & roads; CIM dashboard: access modeling; Data integration: road + population → CIM	Relevant for supply regions serving Astana	Improves logistics & food security	Green >80%	Transport GIS → CIM
Measurement & Assessment	Accountability & Transparency	Financial Accountability & Audit Coverage	Electronic financial tracking (Yes/No); audited accounts ÷ total accounts × 100	Yes/No; %	Annual	CSV, XLSX, API, PDF	Audit records, e-finance logs	Akimat Audit Dept.; Supreme Audit Chamber	GPSC Municipal Finance; ISO 37120	CIM dashboard: integrates audit & finance data, visualizes transparency index; Data integration: audit logs → eGov portals → CIM	Partial digitalization; no unified city audit portal	Strengthens open governance and trust	100% audited = Green	Audit logs → CIM → dashboards
Measurement & Assessment	Creditworthiness	Municipal Credit Rating	External rating of city financial sustainability	Grade / score	Annual / Biannual	PDF; CSV	Credit reports, financial statements	Rating agencies; Ministry of Finance	World Bank Creditworthiness; GPSC	CIM dashboard: simulates borrowing scenarios & fiscal risks; Data integration: link credit rating + city finance → CIM	No standalone city rating; national dependence	Enables infrastructure finance & PPPs	Investment grade = Green	Financial records → CIM
Measurement & Assessment	Revenue & Financial Autonomy	Own-source Revenue & Cost Recovery	Own-source revenue ÷ total revenue; utility cost recovery; taxes collected ÷ billed	%	Annual	CSV, XLSX, API (ERP)	Tax, utility billing, revenue data	Ministry of Finance; Akimat; utilities	IDB Municipal Finance; ISO 37120	GIS: revenue spatial patterns; BIM: utility assets; CIM dashboard: revenue & cost recovery; Data integration: ERP + tax + utility → CIM	High transfer dependency (≈70–75%)	Supports fiscal autonomy	Own-source >40% = Green	Tax ERP → CIM
Measurement & Assessment	Expenditure Management	Budget Performance & Operating Margin	(Revenue – expenditure) ÷ revenue; execution KPIs	%	Annual	CSV, XLSX, API, PDF, GeoJSON	Revenue, expenditure, project costs	Akimat Finance Dept.; Ministry of Finance	ISO 37120; GPSC	GIS: capital projects; CIM dashboard: geospatial spending dashboards; Data integration: link finance → projects → CIM	Cost overruns; limited real-time control	Ensures fiscal sustainability	Surplus >10% = Green	ERP → CIM → dashboards
Measurement & Assessment	Debt & Obligations Management	Debt Sustainability Indicators	Debt service ÷ revenue; FX debt share; debt growth	%	Annual	XLSX, CSV, PDF, API	Debt schedules, revenue, liabilities	Ministry of Finance; Debt office	IDB Debt Framework; GPSC	CIM dashboard: debt modeling, alerts for fiscal risk; Data integration: debt schedules + revenue → CIM	Local debt limited; FX risks mainly national	Prevents fiscal stress	Debt service <15% = Green	Debt data → CIM → alerts

Social dimension indicators

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency	Data Format	Data Required	Data Sources (Stakeholders)	References (Frameworks & Standards)	CIM Integration & CIM Enablers	Astana Context & Data Availability	Future-orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Social	Education — Early education	Early childhood enrolment	(Children <6 enrolled in formal early childhood education ÷ total children <6) × 100	%	Annual	Tabular; registry	Total children <6; enrolment numbers by facility & administrative unit	Ministry of Education; Municipal childcare registries; BNS	UN SDG 4.2 Metadata; UNESCO Education Indicators	GIS : geolocate schools/centers; BIM : facility info; CIM dashboard : aggregate & visualize time-series; Data integration : administrative units	Likely available from national/municipal education dept; may need aggregated extracts due to privacy; geoportal may lack facility-level coverage	Critical for long-term human capital; supports planning of childcare locations	Green: ≥70%; Amber: 40–70%; Red: <40%	Producers: Municipal Education Dept → ETL → CIM database; Consumers: planners, social services
Social	Education — School enrolment	School enrolment ratio	(Enrolled school-age population ÷ total school-age population) × 100	%	Annual	Tabular; CSV	Total school-age population; enrolment numbers by school & admin unit	BNS; Ministry of Education; School records	World Bank WDI; UN SDG 4	GIS : map schools & census tracts; BIM : school infrastructure models; CIM : dashboards & equity mapping	Enrollment counts available; disaggregation by ethnicity/wealth may be limited — use census/survey or proxy income layers	Tracks access & equity; allows targeting under-served areas	Green: ≥95%; Amber: 85–95%; Red: <85%	School info systems → municipal statistics → CIM; link with school geolocation & population raster
Social	Education — Higher education	Higher education degrees per population	(Number of tertiary degrees awarded ÷ total population) × 100,000	degrees / 100k	Annual	Tabular	Number of degrees awarded; total population by admin unit	Ministry of Higher Education; Universities	UNESCO Institute for Statistics; UN SDG 4	GIS : map university campuses & catchment areas; BIM : campus/facility data; CIM dashboards : workforce & R&D layers	Universities in Astana publish graduations; may need aggregation	Indicates skill supply and innovation capacity	Green: ≥500/100k; Amber: 200–500; Red: <200	Universities → national stats → CIM; join with labor market datasets
Social	Education — Literacy	Adult literacy rate & parity	% literate adults (15+); parity = female literacy ÷ male literacy	% ; ratio	Census / Survey	Tabular	Adult population by sex; literacy survey data	BNS; Household survey agencies	UNESCO Literacy Framework; WDI	GIS : demographic layers; CIM : literacy dashboards; Data integration : link with educational programs	Census provides baseline; household surveys may fill gaps	Essential for long-term social inclusion & targeting programs	Green: ≥98%; Amber: 90–98%; Red: <90%	Census/household surveys → statistical office → CIM demographic layer
Social	Health — Life expectancy	Life expectancy at birth	Average number of years a newborn is expected to live based on current mortality rates	Years	Annual / Biennial	Time series	Mortality counts by age & sex; birth registrations	Ministry of Health; Civil registry	WHO Life Table Methodology; WDI	GIS : mortality & population layers; IoT/sensors : hospital & environmental monitoring; CIM : vital stats dashboards	Vital registration in Astana exists but timeliness varies	Proxy for population health trends and resilience	Green: ≥78 yrs; Amber: 70–78; Red: <70	Vital stats → Health ministry → CIM vital statistics dataset
Social	Health — Maternal mortality	Maternal mortality ratio	(Maternal deaths ÷ live births) × 100,000	per 100k	Annual	Tabular	Maternal deaths by facility; live births counts	Ministry of Health; Hospitals	UN SDG 3.1; WHO MMR Guidelines	GIS : health facility mapping; IoT : maternal care monitoring devices; CIM : alerts & dashboards	Hospital reporting likely available; small counts may need smoothing	Key SDG health indicator; monitors quality of maternal care	Green: <70; Amber: 70–200; Red: >200	Hospitals → Ministry health data warehouse → CIM health dataset
Social	Health — Physicians	Physicians per 100,000	(Registered physicians ÷ population) × 100,000	per 100k	Annual	Registry; GIS	Physician registry; population by admin unit	National health registry; Ministry of Health	ISO 37120; WHO Health Workforce	GIS : geolocate providers; CIM : calculate service areas & access times	Physician registries exist; geocoding quality varies	Tracks capacity & service coverage as city grows	Green: ≥300/100k; Amber: 150–300; Red: <150	Professional registry → ETL → CIM provider layer; linked to access models
Social	Health — Coverage	Health insurance coverage	(Population covered by public health insurance ÷ total population) × 100	%	Annual	Tabular	Insurance enrolment by individual/household; total population	Ministry of Health; Social protection agencies	WHO Universal Health Coverage	GIS : overlay population & facility layers; CIM : vulnerability/poverty dashboards	Centralized insurance data likely available but may be aggregated	Important for financial protection and planning service demand	Green: ≥90%; Amber: 70–90%; Red: <70%	Social protection database → CIM attributes for population parcels
Social	Visual comfort	Public lighting performance	Composite metrics: % LED luminaires; compliant luminance share; energy use per km	% ; kWh/km	Annual / Continuous	GIS; sensor data	Luminaire type/location; energy consumption; compliance metrics	Municipal lighting dept.; Asset registries	ISO 37120; CIE Lighting Standards	GIS : street & luminaire mapping; IoT : smart sensors for luminance/energy; BIM : facility/equipment info; CIM : performance dashboards	Astana has public lighting systems; smart lighting deployment partial	Energy & safety goals; reduces light pollution and energy use	LED ≥90%; Luminance ≥95%; adaptive ≥50%; energy reduction ≥5%/yr	Asset registry & IoT → CIM street lighting layer; dashboards & KPI alerts
Social	Thermal environment	Urban thermal comfort	ΔT urban–rural; % shaded area; surface reflectance; avg indoor temp	°C ; %	Continuous / Annual	Raster; sensors	Satellite imagery; sensor data; building shade coverage	Meteorological agency; Municipal GIS	WHO Urban Climate Guidance; UN-Habitat	Remote sensing : surface temp & albedo; GIS : shade & landcover mapping; IoT sensors : indoor/outdoor temp; CIM : heat island dashboards	Continental climate; high-res urban heat & canopy data may be limited	Needed to manage heat islands and future climate adaptation	ΔT ≤2°C; shaded coverage ≥30%; SRI ≥78; indoor 20–24°C	Remote sensing & IoT → GIS processing → CIM thermal comfort layer; planning scenario modeling
Social	Acoustic comfort	Environmental noise	Average LAeq (day/night) measured & spatially aggregated	dBA	Continuous / Annual	Noise maps	Noise measurements; traffic & road data; population exposure	Municipal noise monitoring; Traffic authority	WHO Noise Guidelines; ISO 1996	GIS : map noise sources & corridors; IoT : permanent noise sensors; CIM : overlay with population density & land use	Monitoring sparse; traffic models can fill gaps	Protects health & livability; enables zoning & mitigation	Day ≤55 dBA; Night ≤45 dBA; Lden ≤70; quiet zones ≤5%	Sensors & traffic model → GIS → CIM acoustic comfort layer; alerts for noise hotspots
Social	Wellbeing	Child mortality, HIV, beds	SDG indicators: under-5 mortality; HIV incidence; hospital beds per capita	per 1k / per 100k	Annual	Tabular	Mortality by age; HIV incidence; hospital beds	Ministry of Health; BNS	UN SDG 3; ISO 37120	GIS : health facilities & population; IoT : hospital bed occupancy; CIM : disease surveillance & capacity dashboards	Hospital & mortality data available; disaggregation may be required	Direct measure of health system & disease control	Under-5 mortality: Green <10/1,000; Amber 10–25; Red >25	Hospitals → Health ministry → CIM health capacity & alerts layer
Social	Housing — Affordability	Housing affordability	Housing cost burden = housing expenditure ÷ disposable income × 100	% ; m²/person	Annual / Census	Tabular; GIS	Housing costs; household income; parcel/building data	Municipal housing dept.; Census bureau	UN SDG 11; UN-Habitat	GIS : residential parcels; BIM : building info; CIM dashboards : affordability mapping & planning	Housing registry & census/income data available; may need aggregation	Critical for social equity and urban planning	Affordable if cost ≤30% of income; Green ≤30%; Amber 30–50%; Red >50%	Housing registry & household survey → GIS → CIM housing & population layers
Social	Safety & security	Violent crime rate	(Reported violent crimes ÷ population) × 100,000	per 100k	Monthly / Annual	Tabular; GIS	Crime reports; population distribution	Police department; Interior ministry	ISO 37120; UNODC	GIS : geocode crime incidents; CIM : hotspot dashboards & trend analysis; anonymized for privacy	Police data exists; access may need negotiation	Key for policing & street improvements	Green: decreasing / low; Amber: stable; Red: increasing / high	Police CAD → ETL → CIM crime layer; overlay with urban GIS layers
Social	Emergency services	Emergency service access	Firefighters/police per 100k; avg emergency response time	per 100k ; min	Annual	Tabular; GIS	Station locations; personnel counts; historical response times	Emergency services; Municipal safety dept.	ISO 37120; UN Urban Safety	GIS : station & route mapping; IoT : dispatch logs & vehicle GPS; CIM : response time modeling & dashboards	Station locations & logs available	Measures operational readiness and perceived safety	Response time ≤8 min; satisfaction ≥80%	Dispatch logs & GIS → CIM layer; real-time routing & access analysis
Social	Traffic safety	Traffic fatalities	(Traffic deaths ÷ population) × 100,000	per 100k	Annual	Crash GIS	Crash reports; population & road data	Traffic police; Transport authority	UN SDG 3.6; WHO Road Safety	GIS : crash geolocation & road network; IoT : traffic sensors; CIM : trend analysis & risk mapping	Crash reporting exists; geocoding varies	Supports Vision Zero & urban safety planning	Green: declining trend; Amber: stable; Red: increasing / >10/100k	Police & hospital data → GIS → CIM traffic safety dataset
Social	Equity	Gini coefficient	Measure of income inequality (0 = perfect equality; 1 = max inequality)	0–1	Survey cycle	Tabular	Household income & demographic data	BNS; Household surveys	World Bank WDI; OECD	GIS : poverty & household mapping; CIM dashboards : inequality visualization	Household surveys variable; small-area estimation may be needed	Captures inequality driving social outcomes	Green: ≤0.30; Amber: 0.30–0.40; Red: >0.40	Surveys → statistical office → CIM socioeconomic layer; spatial joins with admin units

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency	Data Format	Data Required	Data Sources (Stakeholders)	References (Frameworks & Standards)	CIM Integration & CIM Enablers	Astana Context & Data Availability	Future-orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Social	Infrastructure access	Basic services coverage	(Households connected to service ÷ total households) × 100	%	Annual	Network GIS	Household connections; network GIS	Utilities; Municipal services	UN SDG 6,7,9,11	GIS: utility networks & parcels; IoT: metering & connectivity sensors; CIM dashboards: access & reliability	Utility layers exist; data access may vary	Essential for planning resilient services	Green ≥98% water/electricity; broadband depending on goal	Utilities → CIM utility network → join with household layers & service monitoring
Social	Solid waste	Waste collection coverage	(Waste properly collected & disposed ÷ total waste generated) × 100	%	Monthly / Annual	GIS routes	Waste collection & generation data; disposal site info	Municipal sanitation dept.	UN SDG 11.6; ISO 37120	GIS: collection routes & disposal sites; IoT: smart bins & weigh scales; CIM: dashboards & route optimization	Route & disposal data partially available; may require mapping	Core for urban health & sustainability	Green ≥90% regularly collected & adequately disposed	Collection logs & transfer station records → GIS → CIM waste management module
Social	Green space	Green space accessibility	Green area ÷ population; % population within 300 m of ≥5000 m² park	m²/person; %	Annual	Spatial GIS	Park polygons; population counts & spatial layers	Municipal parks dept.; Planners	UN SDG 11.7; WHO	GIS: park polygons & population overlay; Remote sensing: canopy & vegetation cover; CIM: accessibility dashboards & KPI analysis	Park inventories may be in city planning departments; canopy data may be partial	Measures liveability, health & climate resilience	Green: ≥30 m²/inhabitant & ≥70% within 300m; Amber/Red per local goals	Park polygons + population → spatial joins in CIM for accessibility analysis; dashboards & scenario modeling
Social	Recreation	Recreational facility provision	(Total public recreational area ÷ population) × 100,000	m²/100k	Annual	GIS; tabular	Facility area, location, population	Parks & sports departments	ISO 37120	GIS: facility locations & area; IoT: sensors for usage monitoring (optional); CIM: leisure infrastructure dashboards	Facility registry usually exists but quality varies	Supports healthy lifestyles & social cohesion	Green: steady increase; Amber/Red per city context	Facilities registry → CIM leisure infrastructure layer; dashboards & monitoring KPIs
Social	Culture	Cultural provision	Cultural expenditure ÷ population; institutions per 100k	currency/capita	Annual	Tabular	Cultural institutions, expenditures, population	Culture dept.; Finance dept.	UNESCO Culture Indicators	BIM: cultural facility assets; GIS: spatial distribution; CIM: cultural budgets & assets dashboards	Budget data available; private contributions harder to capture	Supports identity, tourism & resilience of cultural assets	Green: increasing per capita investment	Finance systems → CIM budget & cultural assets modules; spatial visualization of institutions
Social	Innovation — R&D	R&D expenditure share	(Total R&D expenditure ÷ city GDP) × 100	% GDP	Annual	Tabular	R&D expenditures; institution locations; GDP	National R&D agencies; Universities	OECD Frascati; ISO 37120	GIS: map R&D institutions & labs; CIM: funding & collaboration flows; dashboards for innovation capacity	City GDP estimates may be regional; university data available	Indicator of innovation capacity & future competitiveness	Green: ≥2% of GDP; Amber/Red per thresholds	Research funding agencies & universities → CIM R&D & innovation layer; dashboards & KPI monitoring
Social	Innovation — Patents	Patent intensity	(Patents granted ÷ population) × 100,000	per 100k	Annual	Tabular	Patents granted; assignee addresses; population	Patent office; IP agencies	WIPO Indicators	GIS: patent assignees locations; CIM: innovation datasets & dashboards; Data cleaning for attribution	Patent attribution to city may require assignee address cleaning	Tracks technological output & commercialization potential	Green: increasing trend year-on-year	Patent office → data cleaning → CIM innovation dataset; dashboards & trend monitoring
Social	SMEs	SME share	(SMEs ÷ total enterprises) × 100	%	Annual	Tabular	SMEs count; total enterprises; locations	Chamber of Commerce; Tax registry	World Bank SME Indicators	GIS: firm locations; CIM: link economic activity & employment layers; dashboards	Business registry likely exists; informal sector undercounted	SMEs drive local employment & resilience	Green: high share with healthy growth & productivity	Business registry → CIM economic actors network; dashboards & employment modeling
Social	ICT infrastructure	Digital connectivity	Broadband coverage; subscriptions normalized per population	% ; per 100k	Annual	Coverage GIS	Population; broadband subscriptions; coverage maps	Telecom operators; ICT regulator	ITU ICT Indicators; ISO 37122	GIS: coverage maps; IoT: connectivity sensors (optional); CIM: digital infrastructure dashboards	Broadband coverage maps may be limited; agreements needed	Enables smart city services & digital inclusion	Green: >90% coverage; household internet ≥85%	Operators → regulator → CIM connectivity layer; coverage rasters & dashboards
Social	Demography	Population & density	Density = population ÷ built-up area; dependency ratio = dependents ÷ working-age	persons/km²; ratio	Annual / Census	Raster; tabular	Population counts; built-up areas; age structure	Census bureau; Municipal planning	UN DESA; WDI	GIS: population & built-up areas; CIM: demographic & land-use models; dashboards	Population & built-up area layers exist; high-res updates may be limited	Essential for forecasting infrastructure & services	Benchmarks city-specific; track % change & density targets	Census & administrative registers → population models → CIM demographic & land-use layers
Social	Poverty & food security	Poverty & food insecurity	% below national poverty line; FIES food insecurity prevalence	%	Survey cycle	Tabular	Household surveys; income & food security data; spatial units	BNS; Social welfare agencies	UN SDG 1 & 2; FAO	GIS: spatial poverty mapping; CIM: vulnerability & social resilience dashboards	Household surveys available periodically; small-area estimation may be needed	Core social resilience indicators for targeting programs	Green: declining poverty & malnutrition trends	Surveys → statistical office → CIM socioeconomic & vulnerability maps
Social	Gender inclusion	Gender equality	Wage ratio = avg female wage ÷ avg male wage; women in office %	ratio; %	Annual / Elections	Tabular	Wage data; female/male counts in office	Labour ministry; Election commission	UN SDG 5; ISO 37120	GIS: gender distribution & workplace mapping; CIM: dashboards for planning & equity	Labour & election data available; may need cleaning	Tracks inclusion & empowerment	Green: pay ratio ≥90%; women representation ≥40%	Labour stats & election registry → CIM gender equity indicators; dashboards
Social	Ethnic inclusion	Minority representation	(Minority representatives ÷ total elected officials) × 100	%	Electoral cycle	Tabular	Minority & total elected officials	Election commission; Local govt	UN Human Rights Indicators	GIS: elected official distribution; CIM: representation dashboards; privacy-sensitive	May require ethnicity self-identification; sensitive	Reflects representation & inclusion in governance	Benchmark context-dependent; increasing proportionality	Election results → CIM governance & representation layer (privacy-aware)
Social	Childcare	Daycare availability	(Children aged 0–3 enrolled in daycare ÷ total children 0–3) × 100	%	Annual	Registry	Daycare enrolment; total children 0–3; facility locations	Municipal social services; Daycare registries	UN SDG 4.2; UNICEF	GIS: daycare locations & catchment areas; CIM: coverage & accessibility dashboards	Databases may exist at municipal level; private providers fragmented	Enables workforce participation & early development	Green: ≥60–70%	Daycare registry → CIM childcare facilities & coverage map; dashboards & planning models

Institutional dimension indicators

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency	Data Format	Data Required	Data Sources (Stakeholders)	References (Frameworks & Standards)	CIM Integration & Enablers	Astana Context & Data Availability	Data Required	Benchmarks (Traffic-light)	Data Flows (CIM)
ICT / Infrastructure	ICT Infrastructure Coverage	Level of digital infrastructure coverage	% of city area or population with adequate broadband/mobile connectivity	%	Annual / Bi-annual	GIS	Network coverage maps; population data	Akimat ICT Dept; Telecom operators; Smart City Center	UN SDG 9.c.1; ISO 37122	GIS: broadband & mobile coverage maps by district; BIM: telecom facilities as infrastructure assets; CIM dashboard: coverage %, spatial gaps, time-series trends; Data integration: link coverage to population grids & admin units	Uneven coverage, peripheral gaps	Network coverage maps; population data	<60 Red; 60–85 Yellow; >85 Green	ICT Dept → GIS → CIM Digital Layer → Dashboard
ICT / Infrastructure	Smart Sensor Network Coverage	% of city covered by IoT / environmental sensors	Sensor-covered area ÷ total area ×100	%	Continuous / Annual	IoT registry	Sensor locations, metadata	Smart City Ops Center; Env. Dept; Transport Dept	ISO 37122; UN SDG 11.7.1	GIS: sensor locations; IoT: real-time environmental & traffic streams; CIM dashboard: live maps, alerts, time-series; Data integration: sensor IDs linked to zones & road segments	Dense center, sparse periphery	Sensor locations, metadata	<30 Red; 30–70 Yellow; >70 Green	Sensors → IoT Platform → CIM IoT Layer
Data Governance	Data Update Frequency	Dataset updates per year	Number of updates per dataset	times/year	Quarterly	Metadata	Dataset IDs, timestamps	Akimat departments; Open Data Portal	OECD Data Governance; ISO 37120	Metadata layer: timestamps & versioning; CIM dashboard: dataset freshness indicators; Data integration: harmonize update cycles across departments	Irregular updates	Dataset IDs, timestamps	<2 Red; 2–4 Yellow; >4 Green	Open Data → ETL → CIM Data Lake
Data Governance	Interoperability Score	Degree of system & data interoperability	Composite index (0–100)	0–100	Annual	Metadata	System schemas, standards used	Akimat IT Dept; Data owners	ISO 37120; ISO 37123; SDG 17.18	Data integration: semantic & technical alignment; Standards: CityGML, IFC, ISO metadata; CIM dashboard: interoperability score by sector	Fragmented systems	System schemas, standards used	<50 Red; 50–80 Yellow; >80 Green	Databases → CIM Integration Layer
Participation	Citizen Participation Events	Public consultations per year	Count of events	Count	Annual	Event DB	Event records, locations	Akimat; NGOs; Public Councils	UN SDG 11.3.1; CRI	GIS: geolocate events & affected areas; CIM dashboard: participation density & trends; Data integration: link events to projects & districts	Centralized participation	Event records, locations	<5 Red; 5–15 Yellow; >15 Green	Events → CIM Participation Module
Capacity	Urban Planners per 100k	Planning staff capacity	(Planners + population) ×100,000	/100k	Annual	HR records	Staff counts, population	Akimat HR Dept	UN SDG 11.3.1; ISO 37120	GIS: planners assigned per district; CIM dashboard: staff-to-population ratios; Data integration: HR registry + population database	Shortage in growth zones	Staff counts, population	<10 Red; 10–20 Yellow; >20 Green	HR → CIM Capacity Layer
Compliance	Enforcement Actions	Violations addressed per year	Count of enforced violations	Count	Annual	Reports	Violation records, locations	Building Inspectorate; Akimat	UN SDG 11.1.1; ISO 37120	GIS: violation hotspots; BIM: link violations to buildings/permits; CIM dashboard: compliance trends; Data integration: parcels, zoning & inspection records	Informal development	Violation records, locations	<50 Red; 50–100 Yellow; >100 Green	Inspectorate → CIM Compliance Layer
Transparency	Open Data Availability Index	Coverage & quality of open datasets	Composite index (0–100)	0–100	Annual	Data catalog	Dataset inventory	eGov.kz; Open Data Portal	UN SDG 16.6.2; Open Data Charter	CIM data lake: ingest open datasets; Metadata catalog: completeness scoring; CIM dashboard: transparency index	Partial documentation	Dataset inventory	<50 Red; 50–80 Yellow; >80 Green	Open Data → CIM Data Lake
Digital Gov	e-Gov Services Availability	Share of services online	Online services ÷ total ×100	%	Annual	API	Service registry	eGov.kz; Akimat	UN E-Gov Index; SDG 16.6	API integration: eGov service registry; CIM dashboard: service availability & usage; Data integration: services linked to districts & population	High coverage	Service registry	<60 Red; 60–85 Yellow; >85 Green	eGov APIs → CIM
Digital Gov	E-Procurement Share	Digital procurement ratio	Digital contracts ÷ total ×100	%	Annual	Procurement DB	Contract metadata	Public Procurement Portal	UN SDG 16.6.1; ISO 20400	API integration: procurement platform; CIM dashboard: digital vs non-digital contracts; Data integration: link contracts to projects & budgets	Green procurement weak	Contract metadata	<40 Red; 40–70 Yellow; >70 Green	Goszakup → CIM Governance Layer
Maturity & Adoption	CIM / Digital Twin Level	CIM maturity	Ordinal scale 0–5	0–5	1–2 yrs	Assessment	System inventory	Akimat; Smart City Office	ISO 37123; Digital Twin Maturity Models	GIS: base city model; BIM: selected public assets; IoT: pilot real-time feeds; CIM dashboard: maturity roadmap	Early–Intermediate	System inventory	0–1 Red; 2–3 Yellow; 4–5 Green	Assessment → CIM Reports
Interoperability	City Database Interoperability	Degree of database integration	Composite index (0–100)	0–100	Bi-annual	Metadata	Schemas, APIs	Akimat IT; Data owners	ISO / IEC; SDG 17.18	Data integration layer: unified IDs & schemas; Standards: CityGML–IFC alignment; CIM dashboard: interoperability readiness	Siloed datasets	Schemas, APIs	<50 Red; 50–80 Yellow; >80 Green	Databases → CIM Semantic Layer
Geospatial Quality	Geospatial Data Completeness	Coverage & update frequency	% coverage	%	Annual	GIS	Base maps, 3D models	Urban Planning Dept; Geoportal	UN SDG 11.3.1; OGC	GIS: buildings, roads, utilities; BIM: detailed assets (schools, hospitals); CIM dashboard: spatial coverage indicators	Gaps in infra/buildings	Base maps, 3D models	<60 Red; 60–85 Yellow; >85 Green	GIS / BIM → CIM Spatial Layer
Vision & Strategy	Long-Term Strategic Vision	Existence of vision & KPIs	Ordinal 0–3	0–3	Plan cycle	Docs	Strategy documents	Akimat; Planning Dept	UN SDG 11.8; GPSC	Knowledge base: plans & KPIs; CIM scenario engine: future simulations; CIM dashboard: vision alignment	KPIs partly defined	Strategy documents	0 Red; 1–2 Yellow; 3 Green	Strategy → CIM Scenarios
GovTech	Public Sector Innovation Index	GovTech readiness	Composite index (0–100)	0–100	Biennial	Policy docs	Policy & funding data	Akimat; Innovation hubs	Oxford GovTech; SDG 16.6	Data integration: innovation programs & budgets; CIM dashboard: GovTech readiness; Analytics: innovation gaps	Moderate readiness	Policy & funding data	<50 Red; 50–80 Yellow; >80 Green	Policies → CIM Innovation
Planning Capacity	Resilience & Foresight Capacity	Planning resilience index	Composite	Index	Plan cycle	Reports	Risk & climate data	Emergency Dept; Planners	OECD; UN SDG 11.8	GIS: hazard & risk layers; Simulation engine: climate & disaster scenarios; CIM dashboard: resilience indicators	Partial coverage	Risk & climate data	<50 Red; 50–80 Yellow; >80 Green	Plans → CIM Simulation
Digital Skills	Municipal Digital Proficiency	Digitally skilled staff share	Trained staff ÷ total ×100 %	%	Biennial	HR surveys	Training records	Akimat HR Dept	UN SDG 4.4.1; OECD	HR systems: training records; CIM dashboard: skills index; Analytics: CIM readiness gaps	Skills gap exists	Training records	<40 Red; 40–70 Yellow; >70 Green	HR → CIM Ops Dashboard
Stakeholder Participation	Participation Structures	Civil society engagement level	Ordinal 0–3	0–3	Annual	Policy docs	Meeting records	Akimat; NGOs	UN SDG 11.3.1; CRI	GIS: stakeholder distribution; CIM participation module: meetings & feedback; CIM dashboard: inclusiveness indicators	Peripheral under-representation	Meeting records	0 Red; 1–2 Yellow; 3 Green	Policies → CIM Participation

Environmental dimension indicators

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency of Data Update	Data Format	Data required	Data Sources (Stakeholders)	Primary Source / Reference	CIM Integration & Enablers	Astana Context & Data Availability	Future Orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Environmental	Stormwater Management	Flood-Prone Area Extent	Geographic area identified as having recurrent flooding events based on hydrological and historical data	km² / % of city area	Annual / Post-event	GIS	Flood extent polygons, historical flood event locations, DEM / terrain data	Akimat of Astana (Urban Planning, Emergency Dept.), Kazhydromet, Ministry of Ecology & Natural Resources, Emergency Situations Committee	BNS, ISO 14090 (Climate Adaptation); EBRD Green City Framework; World Bank Urban Flood Risk Guidelines	GIS: flood polygons, DEM & terrain layers; IoT: water level sensors at key points; CIM dashboard: live flood maps, alerts & time-series trends; Data integration: link historical flood events, urban parcels, and drainage infrastructure	Seasonal snowmelt flooding (March–April), ponding in flat areas; historical flood polygons exist; partial satellite coverage; limited sensor data for micro-catchments; estimation feasible using DEM & past flood records	Critical for climate resilience and snowmelt adaptation	Green <5%; Yellow 5–10%; Red >10%	Satellite imagery + flood sensors → CIM
Environmental	Stormwater Management	Stormwater Runoff Volume	Total runoff generated during storm/snowmelt: $Q = C \times i \times A$	m³ / event	Seasonal / Event-based	Numeric + GIS	Rainfall & snowmelt intensity; catchment area; runoff coefficients; temperature data	kazhydromet (meteorological data); Municipal utilities (stormwater dept.), Ministry of Ecology	BNS, ISO 14090; Rational Method; EBRD Urban Resilience Guidance	GIS: catchment boundaries, impervious area layers; IoT: rainfall & snowmelt sensors; CIM dashboard: runoff volume simulations, time-series & scenario modeling; Data integration: sensor IDs linked to catchments & drainage nodes	Limited rainfall and snowmelt intensity data at micro-catchment scale; meteorological station data available; green infrastructure mapping ongoing; estimation possible using runoff coefficients & land-use data	Essential for drainage design and resilience	Context-specific (no universal benchmark)	Hydrological sensors + meteorological data → CIM
Environmental	Stormwater Management	Drainage Network Capacity Ratio	Actual drainage capacity / required capacity for design storm	%	Annual	Numeric	Pipe diameters & slopes; design storm parameters; actual flow measurements	City utility operator (Akmola Su Arnasy / municipal drainage), Akimat Infrastructure Dept.	BNS, World Bank Urban Drainage Manuals; EBRD Green Cities Action Plan (GCAP)	GIS: pipe diameters & slopes, catchment networks; IoT: flow meters, SCADA readings; CIM dashboard: network capacity visualization & predictive modeling; Data integration: pipe segments linked to real-time flow data	Many channels undersized; legacy Soviet systems; partial CAD/utility maps exist; network flow and design storm data partially digitized	Key to reducing spring flooding	Green >100%; Yellow 80–100%; Red <80%	Utility operator SCADA → CIM
Environmental	Stormwater Management	Impervious Surface Ratio	Impervious area / total urban area	%	Annual	GIS	Land-use classification; road & pavement layers; roof footprints	Akimat GIS Unit, National Bureau of Statistics (land use), Satellite data providers (Copernicus, Landsat)	BNS, ISO 37120; EBRD GCAP; UN Habitat Urban Indicators	GIS: rooftop & paved area footprints; land-use classification; IoT: optional surface imperviousness monitoring; CIM dashboard: impervious ratio maps, trends; Data integration: satellite & cadastral layers linked to urban blocks	High imperviousness in urban core roads, parking, plazas; updated satellite imagery & LiDAR available; city-wide land-use GIS exists	Drives runoff; supports urban greening decisions	Green <40%; Yellow 40–60%; Red >60%	Satellite + land-use GIS → CIM
Environmental	Stormwater Management	Time-to-Drain After Event	Time for water accumulation to disappear after storm/snowmelt	hours	Event-based	Numeric / Observed	Water depth duration; event timestamps; location-based observations	City Operations Center, Municipal road services, Emergency services, Citizen reporting platforms	BNS, City operational KPI frameworks; Smart City performance metrics (ISO 37122 – indirect)	GIS: flooded street extents; IoT: water depth sensors & CCTV streams; CIM dashboard: event-based drainage duration analytics; Data integration: sensor/CCTV IDs linked to streets & drainage nodes	Streets remain flooded hours during spring thaw; limited citizen reporting & sensor coverage; operational observations partially documented	Operational resilience and drainage efficiency	Green <2 hr; Yellow 2–6 hr; Red >6 hr	Sensors + CCTV + citizen reports → CIM
Environmental	Stormwater Management	% Drainage / Stormwater System Monitored by ICT	Proportion of drainage network with sensors, telemetry, SCADA	%	Annual	Numeric	Inventory of sensors; SCADA coverage; telemetry logs	Municipal utilities, Smart City / Digitalization Dept., Private ICT contractors	EBRD GCAP; ISO 37122	GIS: sensor & SCADA node locations; IoT: telemetry streams; CIM dashboard: real-time drainage monitoring & performance alerts; Data integration: SCADA IDs linked to drainage network	Very limited ICT deployment in drains; SCADA coverage <20%; partial telemetry data; new sensor deployments ongoing	Enables predictive maintenance	Green >60%; Yellow 20–60%; Red <20%	Utilities SCADA → CIM
Environmental	Stormwater Management	Stormwater Management Infrastructure Capacity	Ability of stormwater infrastructure to absorb design rainfall	% of design load	Annual	Numeric	Retention pond volumes; infiltration rates; pipe & channel capacity	Municipal utilities, Akimat Infrastructure Dept., Design institutes	EBRD GCAP; World Bank Climate-Resilient Infrastructure Guidelines	GIS: retention ponds, infiltration areas, pipe layouts; IoT: pond water levels & pipe flow sensors; CIM dashboard: infrastructure performance & capacity models; Data integration: ponds & pipe linked to drainage zones	Retention ponds exist in districts; insufficient in dense areas; pipe capacity metadata incomplete; infiltration capacity poorly monitored	Used for climate adaptation planning	Context-dependent	Utility operator → CIM
Environmental	Stormwater Management	Flood-Prone Area Coverage (ISO 14090)	Identified flood exposure zones according to climate adaptation standard	km²	Annual	GIS	Climate risk maps; flood hazard scenarios; land-use overlays	Ministry of Ecology & Climate Policy, Kazhydromet, Akimat Urban Planning Dept.	ISO 14090; IPCC Adaptation Frameworks; UNDRR Flood Risk Standards	GIS: flood risk overlays, land-use maps; IoT: hydrological sensors; CIM dashboard: flood coverage & risk visualization; Data integration: risk zones linked to administrative units & land parcels	Seasonal flooding zones near Ishim & lowlands; climate models available; partial flood hazard maps; adaptation scenarios not fully mapped	Supports adaptation pathways	Green <3%; Yellow 3–8%; Red >8%	Hydrology, climate models → CIM
Environmental	Stormwater Management	Drainage Network Density	Length of drainage infrastructure per km² of built-up area	km/km²	Annual	Numeric + GIS	Total drainage length; built-up area boundary	Municipal drainage operator, Akimat GIS / Cadastre	EBRD Urban Infrastructure Indicators; World Bank Urban Services Benchmarks	GIS: pipe lengths, built-up area boundaries; IoT: optional flow sensors; CIM dashboard: density heatmaps & coverage alerts; Data integration: pipe segments linked to housing blocks & roads	Density lower in new housing areas; cadastral & utility GIS partially updated; pipe inventory partially digitized	Indicates coverage and service efficiency	Green >3; Yellow 1.5–3; Red <1.5	Utility GIS → CIM
Environmental	Water Supply & Efficiency	Total Water Use (C3)	Total water use (domestic, industrial, municipal)	m³ / year	Annual	Numeric	Water consumption records; metered flows	Akimat Utilities, Industrial Departments, Construction & Municipal networks	IDB, EBRD	GIS: industrial zones, construction sites, municipal networks; IoT: flow & pressure sensors; CIM dashboard: total water use per district, spatial hotspots, time-series trends; Data integration: downscale national water accounts to district level; Data integration: link residential zones, water network pressure zones; IoT: smart meters; CIM dashboard: per capita consumption, peak-hour trends; Data integration: integrate household meter data with census & population grids	DMC reported nationally; city-level values not directly available; estimation feasible using construction statistics, industrial zones, infrastructure spending, and population data	Resource efficiency planning; monitor urban demand trends	Context-specific	Metered flows + GIS → CIM
Environmental	Water Supply & Efficiency	Household Water Use per Capita (C4)	Average household water consumption per capita	l/person/day	Annual	Numeric	Metered household water use; population data	Municipal utilities; Census & Statistical Dept.	GEF, IDB, EBRD	GIS: residential zones, water network pressure zones; IoT: smart meters; CIM dashboard: per capita consumption, peak-hour trends; Data integration: integrate household meter data with census & population grids	Metering coverage partial; city-level consumption patterns can be estimated from household connections and district population data	Support demand management & conservation	Context-specific	Meter + population data → CIM
Environmental	Water Supply & Efficiency	Population Connected to Water Supply (C5)	% of population connected to piped water supply	%	Annual	Numeric	Network maps; connection records	Municipal water utility, Akimat	IDB, EBRD	GIS: service network mapping; CIM dashboard: connectivity coverage, gaps, and equity analysis; Data integration: link population distribution to network nodes	Full municipal connection; coverage maps partially updated; network connection records available from municipal utilities	Assess service equity & expansion needs	Green >95%; Yellow 80–95%; Red <80%	Utility GIS → CIM
Environmental	Water Supply & Efficiency	Water Losses / Nonrevenue Water (C6)	% of water lost in distribution system	%	Annual	Numeric	Metered inflow & consumption; leak reports	Municipal water utility	IDB, EBRD	GIS: network topology; IoT: flow & pressure sensors; CIM dashboard: leakage hotspot mapping, trend analysis; Data integration: link meters, leak reports, and pipe segments	Legacy network; aging pipes; winter freezing increases burst risks; network losses partially monitored	Reduce system inefficiency; plan upgrades	Green <10%; Yellow 10–20%; Red >20%	Meter + SCADA → CIM
Environmental	Circular Water Use	Reuse & Recycling of Freshwater (C7)	% of reclaimed wastewater or stormwater reused in industry/landscaping	%	Annual	Numeric	Wastewater treatment records; reclaimed water flows	Municipal utilities, Industrial water users	IDB, EBRD	GIS: recycling facilities, industrial areas; BIM: material/water passports, project water inputs; CIM dashboard: circularity rate by sector, trends; Data integration: link reclaimed water & stormwater to secondary uses	Recycling data exists but fragmented; reporting not standardized; snowmelt not harvested; treated wastewater reuse minimal; estimation possible using industrial zones and irrigation requirements	Supports circular water strategies & climate adaptation	Green >30%; Yellow 10–30%; Red <10%	Utility + BIM + GIS → CIM
Environmental	Wastewater & Sanitation	Population Connected to Wastewater Treatment (C13)	% of population served by wastewater treatment facilities	%	Annual	Numeric	Sewer network & plant service areas; population	Municipal wastewater utility, Akimat	SDGs, IDB, EBRD	GIS: sewer network, plant locations; CIM dashboard: treatment load modeling & service coverage; Data integration: link population served to plant inflow	Modernizing plants; spring snowmelt increases inflow; sewer network maps partially digitized	Monitor treatment coverage; compliance with standards	Green >95%; Yellow 80–95%; Red <80%	Utility GIS → CIM
Environmental	Wastewater & Sanitation	Wastewater Treatment Facilities (C14)	Capacity & performance of wastewater treatment plants	m³/day	Annual	Numeric	Plant operational data; inflow volumes	Municipal wastewater utility, Akimat	SDGs, IDB, EBRD	GIS: plant boundaries; IoT: plant operational sensors; CIM dashboard: capacity & efficiency modeling; Data integration: link treatment capacity to served population & network	Treatment plants exist but capacity limited; operational data partially available; modernization ongoing	Infrastructure planning & climate resilience	Context-specific	IoT + GIS → CIM
Environmental	Wastewater & Sanitation	Polluted / Untreated Wastewater (C15)	% of residential/commercial wastewater untreated or discharged noncompliantly	%	Annual	Numeric	Flow & quality data; sewer network	Municipal wastewater utility, Akimat, Ministry of Ecology	SDGs, IDB, EBRD	GIS: sewer overflows, river discharge points; IoT: flow & water quality sensors; CIM dashboard: untreated wastewater mapping, scenario analysis; Data integration: link discharges to sewer network & population served	Historical untreated discharges into Ishim River; spring snowmelt increases load; monitoring limited	Compliance monitoring; reduce environmental pollution	Green <5%; Yellow 5–10%; Red >10%	IoT + GIS → CIM
Environmental	Water Quality	Drinking Water Quality (C8)	Compliance with drinking water standards	% samples meeting standards	Annual	Numeric	Lab water quality results; network zones	Municipal water utility, Ministry of Health	SDGs, IDB, WHO	GIS: water network, treatment plant boundaries; IoT: online quality sensors; CIM dashboard: quality hotspot mapping, trend analysis; Data integration: lab & sensor data linked to distribution zones	Drinking water quality generally stable; seasonal variation minimal; sampling coverage partial	Ensure safe water; public health monitoring	Green >95%; Yellow 80–95%; Red <80%	Lab + IoT → CIM
Environmental	Water Quality	BOD & Ammonium in Rivers (C9)	Biochemical Oxygen Demand & ammonium concentration	mg/L	Annual / Seasonal	Numeric	Water quality sensors; sampling stations	Ministry of Ecology, Kazhydromet	SDGs, IDB	GIS: Ishim River network; IoT: water quality sensors; CIM dashboard: pollution hotspot mapping, trend analysis; Data integration: monitoring stations linked to river segments	Moderate river pollution; peaks during spring snowmelt; station data partially available	Pollution control & river health monitoring	Green <3 mg/L; Yellow 3–6 mg/L; Red >6 mg/L	IoT + GIS → CIM
Environmental	Water Quality	Nutrients in Freshwater (C10)	Nitrate, phosphate concentrations in urban rivers/lakes	mg/L	Annual / Seasonal	Numeric	Water quality sensors; sampling stations	Ministry of Ecology, Kazhydromet	SDGs, IDB	GIS: urban rivers/lakes; IoT: nutrient monitoring sensors; CIM dashboard: nutrient concentration mapping, trend analysis; Data integration: link river/lake segments to urban catchments	Ishim River catchment; urban water bodies partially monitored; nutrient data fragmented	Pollution control & eutrophication monitoring	Context-specific	IoT + GIS → CIM
Environmental	Water Resources & Resilience	Renewable Freshwater Resources (C1)	Annual renewable freshwater resources	m³/year	Annual	Numeric	Hydrological data; river inflows; precipitation	Ministry of Ecology, Kazhydromet	SDGs, WDI, EBRD	GIS: national & local water sources; CIM dashboard: annual availability & scenario modeling; Data integration: downscale national hydrological data to city	High national availability; limited local water in Astana; city-specific data scarce	Inform water resource planning	Context-specific	National hydrology → CIM
Environmental	Water Resources & Resilience	Freshwater Abstraction (C2)	Annual freshwater withdrawals by sector	m³/year	Annual	Numeric	Abstraction points; sectoral water use	Municipal utilities, Industrial water users	SDGs, WDI, EBRD	GIS: abstraction points, river intakes, wells; CIM dashboard: abstraction volume by sector, trends; Data integration: link sectoral abstraction to urban & industrial zones	City-level abstraction relevant; some metering gaps; industrial abstraction data fragmented	Monitor sustainable use; allocation planning	Context-specific	Metered + GIS → CIM

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency of Data Update	Data Format	Data required	Data Sources (Stakeholders)	Primary Source / Reference	CIM Integration & Enablers	Astana Context & Data Availability	Future Orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Mobility	Public Transport	Population with convenient PT access (500 m / 15 min)	% of population living within 500 m of a PT stop or 15-min walk	%	Annual	GIS, GeoJSON	PT stop locations; pedestrian network; population distribution grids	Akimat transport dept., municipal PT operators, National Bureau of Statistics, GIS units	UN KPIs for Cities, SDG 11.2, ITDP accessibility guidance	GIS: PT stop buffers, pedestrian networks; CIM dashboard: catchment areas, time-series accessibility trends; Data integration: population grids linked to stop buffers	Astana sprawled; periphery poorly served; GIS layers of PT stops partially available	Key 15-min city metric for equitable mobility	Green >85%, Yellow 60–85%, Red <60	GIS layers of stops + population grid → CIM
Mobility	Public Transport	Travel Time Index (TTI)	Peak-hour travel time / Free-flow travel time	Ratio	Quarterly	Numeric	Peak-hour travel times; free-flow travel times; route speeds	Municipal transport authority; GPS providers; PT operators	GPSC; IDB urban transport indicators	GIS: road network & congestion layers; CIM dashboard: congestion maps & time trends; Data integration: vehicle GPS linked to network routes	Rush-hour congestion high on Kabanbay, Turan, Tauelsizdik corridors; GPS data partially collected	Measures congestion burden and supports transport planning	Green: <1.3, Yellow: 1.3–1.6, Red: >1.6	Real-time GPS → CIM congestion layer
Mobility	Public Transport	Jobs accessible in 30–45 min	Number of jobs reachable by public transport in 30–45 minutes	Number	Annual	Network model	PT network topology; service frequency; employment locations; travel-time matrices	Akimat urban planning; National Bureau of Statistics; PT authority	GPSC inclusive mobility; World Bank accessibility frameworks	GIS: travel-time polygons; CIM dashboard: accessibility hotspots; Data integration: travel times linked to employment data	Polycentric urban structure limits accessibility; GIS network available	Core indicator of inclusive mobility and social equity	OECD comparative benchmarks	GIS travel-time isochrones → CIM
Mobility	Public Transport	Average commuting time	Mean travel time from home to work	Minutes	Annual	Survey + GPS	Household travel surveys; GPS/mobile mobility data	National Bureau of Statistics; Akimat transport dept.; mobile operators	IDB; EBRD transport performance metrics	GIS: commute origin–destination; CIM dashboard: average travel times by district; Data integration: mobile data + surveys	Average commuting time ~34–40 minutes in winter; survey coverage partial	Assesses congestion, efficiency, and winter delay impacts	Green: <30 min; Yellow: 30–45 min; Red: >45 min	Mobile + survey data → CIM
Mobility	Public Transport	Public transport network length per 100k	Kilometers of PT routes per 100,000 population	km/100k	Annual	GIS	PT route layers; population statistics	Municipal PT operators; Akimat GIS dept.; National Bureau of Statistics	IDB transport supply indicators; GPSC	GIS: PT network mapping; CIM dashboard: coverage ratios; Data integration: population per route length	Bus-dominated system; metro absent; route data available	Evaluates service coverage and expansion needs	OECD comparisons	PT route shapefiles → CIM
Mobility	Public Transport	Bicycle path length per 100k	Kilometers of cycling lanes per 100,000 population	km/100k	Annual	GIS	Cycling infrastructure layers; population data	Akimat mobility dept.; road authority; GIS units	UN KPIs; WHO active mobility guidance	GIS: cycling network; CIM dashboard: coverage & gaps; Data integration: bike lanes linked to districts	Approx. 60+ km; network fragmented; seasonal usability	Supports active and low-carbon mobility	WHO recommendations	Cycling GIS → CIM
Mobility	Public Transport	Modal share	Share of trips by mode (PT, walking, cycling, car)	%	Annual	Survey	OD surveys; smartcard validation; mobile phone mobility	Municipal transport authority; PT operators; statistics bureau	IDB; EBRD; European benchmarks	GIS: OD flows; CIM dashboard: modal split trends; Data integration: trips linked to districts & census	High car dependency; surveys and smartcard data available	Supports transition to sustainable transport	European city averages	Smartcard + survey data → CIM
Mobility	Public Transport	Motorization rate	Number of registered vehicles per 1,000 population	Number	Annual	Numeric	Vehicle registry; population statistics	Ministry of Internal Affairs; statistics bureau	UN urban mobility; World Bank	GIS: vehicle density mapping; CIM dashboard: motorization trends; Data integration: registry linked to districts	Rapidly increasing car ownership	Key indicator for decarbonization and PT planning	Context-specific	Vehicle registry → CIM
Mobility	Mobility Demand & Patterns	Mode share (work trips)	Percentage of work trips by transport mode	%	Annual	Surveys	Work-trip surveys; employment locations	Statistics bureau; transport authority; employers	UN KPIs; EU modal split statistics	GIS: work-trip OD mapping; CIM dashboard: peak-hour modal flows	Private car use dominates peak periods	Critical for emissions reduction and PT prioritization	EU modal split benchmarks	Smartcard + surveys → CIM
Mobility	Mobility Demand & Patterns	Trip generation by district	Average daily trips per capita by district	Trips/capita	Annual	GIS + survey	District population; trip counts; land-use	Akimat planning dept.; mobile operators; statistics bureau	GPSC travel demand indicators	GIS: district heatmaps; CIM dashboard: demand intensity; Data integration: land use + population	Left-bank and right-bank demand disparities evident	Aligns transport supply with urban growth	Context-specific	Mobile + GIS → CIM
Mobility	NMT	Bicycle network	Kilometers of bike lanes per square	km/km²	Annual	GIS	Cycling infrastructure; built-up area boundaries	Akimat transport & urban design dept.	UN KPIs; Copenhagen benchmarks	GIS: cycling density maps; CIM dashboard: accessibility & safety	Summer cycling common; winter safety issues	Promotes low-carbon and healthy mobility	Copenhagen / Amsterdam	Bike network GIS → CIM
Mobility	NMT	Shared bicycles availability	Number of shared bicycles per 10,000 population	Number	Annual	Numeric	Shared bikes; docking stations; service areas	Bike-share operators; Akimat mobility dept.	World Bank; EU benchmarks	GIS: station locations; CIM dashboard: usage & coverage; Data integration: population linkage	Seasonal operation; limited coverage	Improves last-mile connectivity	EU bike-share norms	Operator API → CIM
Mobility	NMT	Pedestrian infrastructure index	Composite score of sidewalk width, continuity, safety	Score	Annual	Survey + GIS	Sidewalk audits; crossings; winter maintenance	Akimat road authority; urban design teams	World Bank walkability; Walk Score	GIS: sidewalk condition mapping; CIM dashboard: connectivity & safety	Winter-safe sidewalks lacking in many areas	Enhances walkability and public health	Walk Score-type	LiDAR + audits → CIM
Mobility	Emissions	Low-emission vehicles share	Percentage of electric and hybrid vehicles	%	Annual	Registry	Vehicle registry by fuel type; EV chargers	Ministry of Internal Affairs; Akimat energy dept.	UN KPIs; EU targets	GIS: EV distribution; CIM dashboard: decarbonization trends; Data integration: chargers + registry	EV share below 2%	Supports decarbonization strategies	EU target ~30%	Vehicle registry → CIM
Mobility	Emissions	Transport CO ₂ emissions	CO ₂ emissions from on-road transport	tCO ₂ /year	Annual	Model	Traffic counts; fleet mix; speeds; emission factors	Akimat transport dept.; statistics bureau	IPCC; EBRD	CIM: scenario modeling; emissions dashboards; Data integration: traffic + fleet	Emissions high due to car reliance	Climate action planning	IPCC factors	Traffic data → CIM
Mobility	Road Safety	Traffic fatalities	Traffic-related deaths per population	Number	Annual	Numeric	Accident records; population; locations	Traffic police; Interior Ministry	WHO; UN KPIs	GIS: crash hotspot mapping; CIM dashboard: fatality trends	Winter fatalities spike	Core safety performance indicator	WHO target <3/100k	Police reports → CIM
Mobility	Road Safety	Traffic monitoring	Percentage of roads with CCTV or ITS	%	Annual	GIS	Road network; ITS inventory	Akimat digitalization dept.; ITS operators	OMIR; ITS standards	GIS: sensor coverage; CIM dashboard: monitoring gaps	ITS expanding but incomplete	Improves enforcement and	Global ITS norms	ITS sensors → CIM
Mobility	Infrastructure	Parking supply	Parking spaces per 1,000 population	Number	Annual	GIS	Parking inventory; land-use; population	Akimat planning dept.; parking operators	OECD; OMIR	GIS: parking locations; CIM dashboard: utilization & demand	Oversupply in city center	Supports demand management	Green: 400–600; Yellow: 200–399 or 601–800; Red: <200 or >800	Parking GIS → CIM
Mobility	Infrastructure	Road quality index	Share of roads in good or satisfactory condition	%	Annual	GIS	Pavement condition surveys	Municipal road authority	SDG 9.1.1; OECD	GIS: pavement condition maps; CIM dashboard: maintenance priorities	Freeze–thaw cycles degrade roads	Asset management planning	Green >80%; Yellow 60–80%; Red <60%	Pavement surveys → CIM
Mobility	Winter Resilience	Snow/ice road coverage days	Days per year roads affected by snow or ice	Days	Winter	Sensors	Road temperature; weather; maintenance logs	Road services; Kazhydromet	Nordic benchmarks	CIM: winter condition digital twin; Data integration: sensors + logs	Over 120 icy days annually	Winter reliability planning	Green <50; Yellow 50–100; Red >100	Sensors → CIM
Mobility	Winter Resilience	Weather-related transport disruptions due to weather	Number of transport disruptions due to weather	Number	Seasonal	Logs	Incident and delay records	Transport authority; PT operators	IDB; EU norms	CIM dashboard: disruption events; Data integration: network linkage	Winter delays common	Climate adaptation planning	Green <10; Yellow 10–30; Red >30	Logs → CIM
Mobility	Winter Resilience	Freeze–thaw pavement	Potholes and cracks per km	Number/km	Annual	GIS	Road inspections	Municipal road authority	EBRD; Canadian standards	CIM: asset deterioration modeling	Severe seasonal damage	Maintenance prioritization	Green <5; Yellow 5–15; Red >15	Inspections → CIM
Mobility	Winter Resilience	Winter accident rate	Share of accidents linked to winter	%	Annual	Police data	Accident and weather records	Traffic police; insurers	WHO road safety	GIS: winter crash hotspots; CIM dashboard: seasonal risk	Icy roads elevate risk	Winter safety planning	Green <2%; Yellow 2–5%; Red >5%	Police data → CIM
Waste	Waste Generation	Municipal solid waste generated annually	Total MSW generated annually	tons/year	Annual	CSV; GIS	District waste volumes; land-use	Akimat Clean City; operators	UN SDGs; EBRD	GIS: waste intensity mapping; CIM dashboard: per-capita trends	Waste rising with population growth	Circular economy planning	Green <300; Yellow 300–500; Red >500 kg/capita	Collection data → CIM
Waste	Hazardous Waste	Hazardous waste treated	Share of hazardous waste safely treated	%	Annual	CSV; GIS	Treatment and landfill logs	Akimat Clean City; operators	EBRD; IDB	CIM: waste flow network; facility monitoring	Heavy landfilling reliance	Risk reduction	Green >80%; Yellow 20–60%; Red <20%	GPS + facility logs → CIM
Waste	Recycling	Municipal waste recycling	Share of MSW recycled or reused	%	Annual	CSV; dashboard	Recycling volumes	Akimat Clean City	UN SDGs; EBRD	CIM: recycling hotspots; smart-bin integration	Recycling ~10–12%	Circularity transition	Green >35%; Yellow 15–35%; Red <15%	Sorting data → CIM
Waste	Collection & Disposal	C&D waste management	Waste generation, service coverage, remaining landfill	kg/capita; %; years	Annual	Collection & GIS	Collection coverage; landfill capacity	Akimat Clean City	UN SDGs; IDB	CIM: routing optimization; landfill depletion modeling	Landfill nearing capacity	Long-term waste planning	Green >95% coverage; Yellow 80–95%; Red <80%	Truck GPS → CIM
Waste	Construction & Demolition	C&D waste; material passport	C&D waste generated and share of buildings with material	tons/year; %	Annual	BIM; CSV	Permits; material inventories	Akimat planning dept.; builders	ISO 37120; Circular Economy	CIM: material inventory; reuse mapping	High C&D waste; passports rare	Circular construction	Green full adoption; Yellow pilots; Red none	BIM + permits → CIM
Air Quality	Air Pollution & Ozone Depletion	Emissions of pollutants into the atmosphere	Total emissions of PM10, PM2.5, NO2, SO2, O3 precursors from stationary and mobile sources	tons/year	Annual	CSV, GIS layers	Industrial and transport emissions	Akimat, municipal transport, industrial registries	UN SDGs; WHO; ISO 37120	GIS: industrial zones, traffic routes, power plants; IoT: emission meters at key sites; CIM dashboard: spatial emission hotspots, trends, and sector breakdowns; Data integration: link emission sources with population exposure and land use	Industrial & transport emissions mapped nationally; winter emissions peak due to heating; district-level estimates feasible using traffic, building, and population data	Supports targeted mitigation, scenario modeling for emission reductions	Red: exceeding WHO limits; Amber: 50–100% of limits; Green: <50% of limits	Emission inventories + traffic/industrial GIS layers → CIM layers
Air Quality	Air Pollution & Ozone Depletion	Ambient air quality in urban areas	Measured concentration of PM10, PM2.5, NO2, SO2, O3; AQI computed	µg/m³; AQI	Daily/hourly for sensors; monthly reports	Time-series CSV; GIS	Sensor data, meteorological context	National Air Quality Monitoring, Akimat	WHO; UN SDGs	GIS: sensor locations, urban grid; IoT: air quality sensors; CIM dashboard: AQI maps, alerts, time-series; Data integration: link AQI with population density, traffic, and industrial activity	AQI worsens during winter inversion; sensors cover key districts; hotspots estimable using traffic and heating data	Enables early-warning systems, urban planning for health and traffic policy	Red: AQI >150; Amber: 100–150; Green: <100	Sensor network + population grids → CIM real-time maps
Air Quality	Air Pollution & Ozone Depletion	Consumption of ozone-depleting substances	Total CFCs, HCFCs, halons used annually	tons/year	Annual	CSV, regulatory reports	Industrial consumption records	UNEP, Akimat	UNEP; UN SDGs	GIS: industrial sites; IoT: monitoring of production units; CIM dashboard: ODS consumption trends, compliance alerts; Data integration: link industrial activity with regulatory baselines	Consumption low due to regulation; legacy equipment exists; local compliance data available	Supports regulatory compliance and ozone protection strategies	Red: >baseline allowed; Amber: 80–100% baseline; Green: <50% baseline	Industrial inventories → CIM compliance dashboards
GHG	GHG Emissions	Total city GHG emissions	CO2-equivalent emissions from energy, transport, industry, waste	tCO2e/year	Annual	CSV, GIS layers	Energy, transport, industry, waste activity	Akimat, energy utilities, transport authorities	UNFCCC; SDGs; IPCC	GIS: energy plants, traffic corridors, industrial zones; IoT: emission meters, smart grids; CIM dashboard: sectoral & spatial GHG hotspots, temporal trends; Data integration: link energy, transport, waste with population and land use	Significant emissions from heating & traffic; district-level emissions estimable using consumption & population data	Supports low-carbon strategies and carbon neutrality planning	Red: >target; Amber: 80–100% target; Green: <80% target	Energy, transport, waste datasets → CIM GHG model
Energy	Renewable Energy Consumption	Renewable energy consumption (% of total final energy)	Share of energy from solar, wind, biomass, hydro, geothermal; % gas, solar, wind	%	Annual	CSV, GIS layers	Installed capacity, generation data	Akimat energy dept., grid operator	UN SDGs; IEA; EBRD	GIS: solar/wind installations, rooftops, district energy; IoT: metering of renewable production; CIM dashboard: renewable share maps, trends, scenario analysis; Data integration: link generation with energy demand zones	High solar potential (~1,800–2,000 kWh/m²/yr); low building-level penetration; grid data available	Supports city decarbonization, SDGs, and renewable planning	Red: <5%; Amber: 5–20%; Green: >20%	PV registries + energy production → CIM energy GIS layers
Energy	Electricity Consumption	Final electricity consumption (GWh/year); per capita consumption (kWh/capita)	Total electricity consumed by residential, commercial, industrial sectors; per-person = total/population	GWh/year; kWh/capita	Monthly / Annual	CSV, smart meter, GIS	Building type, meter readings, district energy models	Akimat energy dept., utilities	UN SDGs; EBRD; ISO 37120	GIS: building footprints, energy zones; IoT: smart meters; CIM dashboard: consumption hotspots, per-capita trends, high-demand zones; Data integration: link consumption with building type, population grids, and district energy models	Peak load in winter; disparities across districts; rising due to construction & digitalization	Supports energy efficiency interventions and infrastructure planning	Red: >150% baseline; Yellow: 100–150%; Green: <100%	Smart meter + BIM → CIM energy demand maps
Energy	Thermal Energy Consumption (Heating)	Residential thermal energy consumption	Energy used for space heating and hot water per household	GJ/household	Monthly / Annual	CSV, BIM, GIS	Building envelopes, heating networks, insulation levels	Akimat energy dept., utilities	UN SDGs; ISO 37120	GIS: building footprints, heating network zones; IoT: district heat meters; CIM dashboard: per-household heating load, seasonal trends, peak alerts; Data integration: link building envelope, insulation, and network data	Astana extremely cold (Oct–Apr); heavy heating loads; high energy poverty risk	Enables heating efficiency and energy poverty mitigation policies	Red: >120% baseline; Yellow: 80–120%; Green: <80%	Heating network + BIM → CIM district heating models

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency of Data Update	Data Format	Data required	Data Sources (Stakeholders)	Primary Source / Reference	CIM Integration & Enablers	Astana Context & Data Availability	Future Orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Energy	Public Building Energy Consumption	Normalized energy consumption (kWh/m²/year)	Energy consumption per m² in schools, hospitals, government buildings	kWh/m²/year	Annual	CSV, BIM, BMS	Energy meters, building floor areas	Akimat education, health, public works	UN SDGs; ISO 37120	GIS: public building footprints; IoT: BMS meters; CIM dashboard: energy benchmarking, spatial comparison, decarbonization potential; Data integration: link BMS and BIM for monitoring	Public buildings outdated and inefficient; data available from BMS	Supports public-sector energy efficiency and decarbonization	Red: >200 kWh/m²; Yellow: 150–200; Green: <150	BMS + BIM → CIM energy dashboard
Energy	Total Energy Use & Efficiency	Final energy consumption (FEC)	Total energy consumed by all end-users (buildings, transport, industry, services)	PJ or GWh/year	Annual	CSV, GIS, BIM	Building, transport, industrial energy data	Akimat, utilities, transport	IEA; UN SDGs	GIS: land-use, industrial zones, traffic corridors; IoT: energy meters; CIM dashboard: sectoral and spatial consumption trends, scenario modeling; Data integration: integrate energy use across sectors	FEC dominated by heating and private mobility; district-level estimates feasible	Top-level indicator for city energy planning	Red: above baseline; Yellow: 90–100% baseline; Green: <90% baseline	Aggregated consumption → CIM city-level energy model
Energy	Total Energy Use & Efficiency	Total primary energy supply (TPES)	Total energy supplied including imports, local generation, transformation losses	PJ or GWh/year	Annual	CSV, GIS	Power plants, grid imports, local generation	Akimat, grid operator	IEA; UN SDGs	GIS: power plant locations, grid infrastructure; IoT: metering of supply nodes; CIM dashboard: supply flows, local generation, losses; Data integration: link energy generation, imports, and local consumption	TPES dominated by coal & gas; city-level data derived from national statistics	Supports renewable integration and supply-side planning	Red: above baseline; Yellow: 90–100% baseline; Green: <90% baseline	National supply data → CIM primary energy layer
Energy	Total Energy Use & Efficiency	Energy intensity	Energy consumed per unit of GDP	MJ/unit GDP	Annual	CSV	Energy consumption, economic output	Akimat, National Bureau of Statistics	UN SDGs; IEA	GIS: economic zones; IoT: energy meters; CIM dashboard: energy use vs economic activity; Data integration: link energy consumption to GDP by sector	Kazakhstan has high energy intensity; city-level mapping feasible using economic & energy data	Tracks efficiency improvements over time	Red: high; Yellow: medium; Green: low	Energy + GDP → CIM spatial model
Land Use	Urban Growth	Ratio of land consumption rate to population growth rate	Land consumption / population growth	Ratio	Annual	GIS, Remote Sensing	Built-up area, population	Akimat urban planning, census	SDG 11; IDB; EBRD	GIS: built-up areas, urban parcels; CIM dashboard: sprawl mapping, greenfield vs infill analysis; Data integration: link population growth and land consumption	Astana rapid urban expansion; sprawl increasing	Supports smart growth strategies, densification policies	Red: >1.5; Yellow: 1–1.5; Green: <1	Satellite imagery + population → CIM urban growth layer
Land Use	Urban Growth	Annual growth rate of built-up areas (% of total area)	Increase in built-up land area / total city area × 100	%	Annual	GIS, Remote Sensing	Built-up area	Akimat, remote sensing data	IDB; EBRD	GIS: updated urban footprint; CIM dashboard: growth hotspots, time trends; Data integration: link land-use and population density	Residential and commercial developments increasing	Enables monitoring of urban footprint and infrastructure planning	Red: >5%; Yellow: 2–5%; Green: <2%	Built-up area maps → CIM urban expansion layer
Land Use	Urban Growth	Built-up land area per person	Total built-up area / city population	m²/person	Annual	GIS, Census data	Built-up area, population	Akimat, census	GPSC	GIS: urban parcels; CIM dashboard: density mapping, per-capita land allocation; Data integration: link population to built-up area	Growth outpaces densification in some districts	Helps assess urban density, promote efficient land use	Red: >200 m²/person; Yellow: 100–200; Green: <100	Land-use + population → CIM density layer
Land Use	Urban Growth	% of urban development on existing urban land vs greenfield	Area developed on existing urban land / total developed area × 100	%	Annual	GIS, Planning data	Built-up area, land-use	Akimat, planning dept.	EBRD	GIS: land parcels, brownfield/greenfield classification; CIM dashboard: infill vs greenfield; Data integration: link development permits to parcels	Substantial new developments occur on greenfield sites	Encourages land reuse, limits sprawl, improves infrastructure efficiency	Red: <30%; Yellow: 30–70%; Green: >70%	Land-use changes → CIM greenfield/brownfield layer
Land Use	Land Use Planning	Average share of built-up area as public open space	Public open space area / total built-up area × 100	%	Annual	GIS, City planning	Parks, public spaces	Akimat, urban planning	SDG 11	GIS: open space, parks, plazas; CIM dashboard: accessibility and distribution; Data integration: link population distribution to open space	Some districts lack sufficient open space	Supports equitable access and inclusive urban planning	Red: <10%; Yellow: 10–20%; Green: >20%	Parks + building footprints → CIM open space layer
Land Use	Land Use Planning	Proportion of national population living in cities implementing	% population in cities with updated integrated land-use plans	%	Annual	GIS, Planning docs	Land-use plans, population	Akimat, planning dept.	SDG 11	GIS: planned vs implemented areas; CIM dashboard: plan adoption and compliance; Data integration: link population & plan coverage	Astana has a land-use plan; updates infrequent	Encourages long-term strategic urban planning	Red: <50%; Yellow: 50–80%; Green: >80%	Planning docs → CIM compliance layer
Land Use	Land Use Planning	Years since land-use plan updated	Number of years since last plan update	Years	Annual	GIS, Planning docs	Land-use plans	Akimat, planning dept.	GPSC	GIS: plan dates; CIM dashboard: recency and alerts; Data integration: link plans to districts	Current plan updated periodically	Supports adaptive planning and resilience	Red: >10 years; Yellow: 5–10; Green: <5	Planning documents → CIM plan update
Land Use	Land Use Planning	Density & Transit-Oriented Development (TOD)	% of land in TOD zones; average density in urban nodes	% ; persons/ha	Annual	GIS, Urban zoning	TOD zones, population, land-use	Akimat urban planning	EBRD	GIS: TOD areas, transport networks; CIM dashboard: density mapping, transit accessibility; Data integration: link land-use and PT coverage	TOD underutilized; mixed-use developments limited	Supports compact, sustainable, transit-friendly growth	Red: <30%; Yellow: 30–60%; Green: >60%	Zoning + transport network → CIM TOD & density layer
Land Use (Land & Nature, Spatial Development)	Land Use Planning	Mixed-use development promoted through zoning regulations	% of built-up area with mixed-use zoning incentives	%	Annual	GIS, Planning data	Zoning maps, building footprints	Akimat planning	EBRD	GIS: zoning + building footprints; CIM dashboard: mixed-use visualization; Data integration: link parcels, population, and land-use type	Limited in peripheral districts	Encourages functional diversity, reduces commuting, enhances circularity	Red: <20%; Yellow: 20–50%; Green: >50%	Zoning maps + building footprints + population → CIM mixed-use layer
Climate Change (Global Responsibility)	Climate Change	Air Temperature	Annual mean air temperature; urban vs. rural differences	°C	Annual	CSV, GIS	Temperature sensor data	Kazhydromet; Astana Akimat (Environmental Dept.); Ministry of Ecology RK	WMO Urban Climate Guidelines; IPCC AR6 WG I; UN SDG 13	GIS: urban/rural temperature layers; IoT: sensor network; CIM dashboard: heat maps & urban heat island modeling; Data integration: historical + real-time sensors	Rising winter & summer temperature extremes; station data available, dense IoT limited	Supports climate adaptation planning & heat-risk mitigation	Red: >+2°C; Yellow: +1–2°C; Green: <+1°C	Meteorological sensors + GIS → CIM UHI maps
Climate Change (Global Responsibility)	Climate Change	Atmospheric Precipitation	Annual precipitation totals; seasonal distribution	mm	Annual	CSV, GIS	Rainfall gauges, hydrology	Kazhydromet; Astana Su Arnasy; Ministry of Ecology RK	WMO Hydrological Practices; IPCC AR6; UN SDG 11 & 13	GIS: precipitation layers; IoT: rainfall sensors; CIM dashboard: flood-risk overlays & time-series; Data integration: drainage, flood zones, parcels	Spring snowmelt + summer rainfall drive flood risk; hydromet data reliable	Supports stormwater planning & water resource management	Red: <50% or >150%; Yellow: 50–75% or 125–150%; Green: 75–125%	Rainfall + hydrology + parcels → CIM flood maps
Climate Change (Global Responsibility)	Climate Change	Greenhouse Gas Emissions	Total city CO₂-equivalent emissions from energy, transport, industry	tCO₂e/year	Annual	CSV, GIS	Energy, transport, industry emissions	Ministry of Energy RK; Astana Akimat; KEGOC; Astana Energy	IPCC GHG Inventory Guidelines; GPC Protocol;	GIS: sectoral emission maps; CIM dashboard: hotspots & scenarios; Data integration: sectors, land-use, population	Emissions dominated by heating & transport; city-level inventory partial	Enables mitigation planning, policy evaluation & SDG tracking	Red: >baseline +20%; Yellow: ±10–20%; Green: ±10%	Energy + transport + land-use → CIM GHG layers
Climate Change (Global Responsibility)	Climate Change	Years Since Climate Strategy Update	Years since last strategic climate plan review	Years	Annual	Administrative	Strategic climate plan documents	Astana Akimat; Ministry of Ecology RK	OECD Urban Climate Governance; UN SDG 13.2; ICLEI	GIS: plan coverage; CIM dashboard: alerts for outdated strategies; Data integration: strategies → actions	Existing city strategies need stronger adaptation focus	Encourages adaptive governance & continuous review	Red: >10 yrs; Yellow: 5–10 yrs; Green: <5 yrs	Strategy docs + GIS → CIM climate module
Environment	Biodiversity	Hectares of permanent green space per 100,000	Green area / population × 100,000	ha/100k	Annual	GIS	Land-use, population	Astana Akimat (Green Economy & Landscaping); BNS RK	WHO Urban Green Space Guidelines; UN SDG 11.7; EBRD	GIS: green space mapping; CIM dashboard: density analysis; Data integration: parks + population	Peripheral districts under-served; GIS data available	Supports ecosystem services, cooling & health	Red: <50; Yellow: 50–150; Green: >150	Land-use + population → CIM green layer
Environment	Biodiversity	Share of population within 15-min	Population ≤1 km from green space / total × 100	%	Annual	GIS	Population, green space	Astana Akimat; BNS RK	UN-Habitat Public Space Indicators; WHO	GIS: accessibility analysis; CIM dashboard: equity & walkability	New districts show accessibility gaps	Supports inclusive urban design	Red: <30%; Yellow: 30–70%; Green: >70%	Population + green GIS → CIM access layer
Environment	Biodiversity	Enforcement & monitoring of biodiversity	Active enforcement programs / total regulations × 100	%	Annual	Administrative	Enforcement data	Ministry of Ecology RK; Astana Akimat	Convention on Biological Diversity;	Administrative GIS; compliance mapping; CIM dashboard: enforcement monitoring	Enforcement exists but largely centralized	Strengthens biodiversity governance	Red: <50%; Yellow: 50–80%; Green: >80%	Compliance + zoning → CIM policy layer
Environment	Biodiversity	Land-use plan with environmental	Protected zoning / built-up area × 100	%	Annual	GIS	Zoning maps	Astana Akimat (Urban Planning Dept.)	UN-Habitat Planning Framework; SDG	GIS: protection overlays; CIM dashboard: development conflict alerts	Protection zones exist; enforcement uneven	Ensures long-term conservation	Red: <10%; Yellow: 10–30%; Green: >30%	Zoning GIS → CIM protection layer
Environment	Biodiversity	Abundance of bird species (annual %	Observed species / previous year × 100	% change	Annual	Surveys, GIS	Species monitoring	Ministry of Ecology RK; NGOs; Universities	CBD Biodiversity Indicators; IUCN Urban	GIS + citizen science; CIM dashboard: trends	Data limited; monitoring fragmented	Supports habitat protection	Red: decline >5%; Yellow: ±5%; Green: >5%	Survey + GIS → CIM biodiversity trends
Environment	Biodiversity	Number of contaminated sites per 1,000	Contaminated sites / population or area	sites/1k or km²	Annual	GIS, Admin	Contaminated site registry	Astana Akimat; Ministry of Ecology RK	OECD Contaminated Land Indicators	GIS: contamination hotspots; CIM dashboard: remediation tracking	Legacy industrial sites, mainly northern districts	Prioritizes cleanup & risk reduction	Red: >5; Yellow: 2–5; Green: <2	Registry + population → CIM contamination

Dimension	Thematic Category	Indicator	Definition / Formula	Unit	Frequency of Data Update	Data Format	Data required	Data Sources (Stakeholders)	Primary Source / Reference	CIM Integration & Enablers	Astana Context & Data Availability	Future Orientation Justification	Benchmarks (Traffic-light)	Data Flows (CIM)
Environment	Protected Natural Areas	Percentage of city area protected	Protected area / total city area ×100	%	Annual	GIS	Protected area maps	Astana Akimat; Ministry of Ecology RK	IUCN Protected Area Categories; UN SDG 15	GIS: protected area mapping; CIM dashboard: encroachment monitoring	Limited protected zones within city boundary	Supports biodiversity & ecosystem services	Red: <5%; Yellow: 5–15%; Green: >15%	Zoning + land-use → CIM protected layer
Environment	Natural Disaster	Deaths, missing & affected per	(Deaths + affected) / population ×100k	per 100k	Event / Annual	Administrative	Disaster reports, population	Astana Akimat; Ministry of Emergency	Sendai Framework; UN	GIS: hazard & impact mapping; CIM dashboard: alerts	Flooding from snowmelt & extreme rainfall	Disaster preparedness & response planning	Red: >50; Yellow: 20–50; Green: <20	Disaster + population → CIM
Environment	Natural Disaster	Population living in disaster-prone	Exposed population / total population ×100	%	Annual	GIS	Population data, hazard maps	Astana Akimat; Ministry of Emergency	UNDRR Risk Exposure Metrics; UN SDG	GIS: overlay population & hazard zones; CIM dashboard: exposure & vulnerability	River-adjacent & low-lying districts exposed	Prioritizes protective infrastructure & zoning	Red: >20%; Yellow: 10–20%; Green: <10%	Population + hazard zones → CIM exposure
Environment	Natural Disaster	Resilience Plans	Existence & implementation of	Yes / No	Annual	Administrative	Resilience plan documents	Astana Akimat; Ministry of	Sendai Framework;	GIS: hazard overlays; CIM dashboard: plan compliance	City-level plans exist; community scale limited	Strengthens adaptive capacity	Red: No; Green: Yes	Plans + hazard GIS → CIM resilience
Environment	Natural Disaster	Direct economic loss due to disasters	Total economic loss from disasters / city GDP × 100	% of GDP	Event-based	Financial reports	City economic loss data, GDP	Municipal finance department; EBRD	SDG 11; EBRD	GIS: disaster-affected zones; CIM dashboard: economic loss trends and sectoral impacts; Data integration: disaster reports linked with GDP and municipal finance data	Losses historically moderate; winter floods occasionally disrupt services. GDP data available nationally, loss data fragmented.	Supports cost-effective disaster risk management and prioritization of resilience investments	Red: >1% of GDP; Amber: 0.5–1% of GDP; Green: <0.5% of GDP	Disaster reports + GDP → CIM economic impact layer
Environment	Natural Disaster	Awareness & preparedness for disasters	Percentage of population trained or informed on disaster response	%	Annual	Survey / Administrative	Population trained, campaign coverage	Emergency services; EBRD	EBRD	GIS: spatial distribution of trained population; CIM dashboard: preparedness coverage and trends; Data integration: surveys linked to districts and demographics	Public awareness campaigns limited; drills rare; surveys not systematic.	Improves community resilience, emergency response efficiency, and social preparedness	Red: <30%; Amber: 30–60%; Green: >60%	Survey data → CIM preparedness layer
Environment	Natural Disaster	Population affected by droughts, floods, extreme temperatures	Total affected population / total population × 100	%	Annual / Event-based	GIS / Administrative	Population affected, total population, hazard zones	WDI; municipal disaster office	WDI	GIS: hazard exposure and population grids; CIM dashboard: affected population hotspots and trends; Data integration: climate events linked with census and health data	Seasonal flooding most relevant; extreme heat affects some districts; partial reporting.	Enables climate adaptation planning, social protection, and emergency response targeting	Red: >10%; Amber: 5–10%; Green: <5%	Hazard layers + population data → CIM impact layer
Environment	Natural Disaster	Critical infrastructure at risk	Percentage of critical infrastructure located in high-risk zones	%	Annual	GIS / Administrative	Infrastructure GIS data, hazard maps	IDB; EBRD	IDB; EBRD	GIS: infrastructure networks over hazard maps; BIM: asset-level vulnerability; CIM dashboard: infrastructure risk levels; Data integration: hazard + asset registries	Roads, power stations, and water networks partially exposed to flood risk; incomplete overlays.	Supports resilient infrastructure planning and prioritization of retrofitting	Red: >20%; Amber: 10–20%; Green: <10%	Infrastructure data + hazard maps → CIM infrastructure risk layer
Environment	Natural Disaster	Existence of contingency plans with early warning systems	Whether the city has functional contingency and early warning plans	Yes / No	Annual	Administrative	Emergency plans, warning system coverage	IDB	IDB	GIS: coverage of warning systems; CIM dashboard: readiness status; Data integration: emergency protocols linked to monitoring systems	Plans exist but not fully integrated or digitized citywide.	Reduces response time and improves disaster preparedness and coordination	Red: No; Green: Yes	Emergency plans → CIM alert and response layer
Environment	Natural Disaster	Existence of risk maps at adequate scale	Availability of hazard and risk maps for major urban hazards	Yes / No	Annual	GIS	Hazard and risk maps	IDB	IDB	GIS: multi-hazard risk maps; CIM dashboard: risk coverage completeness; Data integration: zoning and evacuation routes	Existing maps often outdated and low resolution.	Enhances urban planning, evacuation planning, and mitigation strategies	Red: No; Green: Yes	GIS risk maps → CIM hazard mapping layer
Environment	Ecological Footprint	Financial support for sustainable construction	Share of construction or retrofit budget allocated to sustainable and resource-efficient buildings	% of total budget	Annual	Administrative / GIS	Construction budgets, sustainability allocation	Municipal finance bodies; SDG reporting	SDG 11 (adapted)	GIS: location of funded projects; BIM: sustainability attributes; CIM dashboard: green investment share; Data integration: budgets linked to permits	Limited green construction funding; sustainability tagging weak.	Encourages circular, low-carbon urban development and SDG alignment	Red: <10%; Amber: 10–30%; Green: >30%	Budget records + BIM → CIM sustainability layer
Environment	Ecological Footprint	Material footprint per capita / per GDP unit	Total material consumption divided by population or GDP	t/person or t/USD GDP	Annual	Administrative / GIS	Material consumption, population, GDP	Municipal planning agencies; SDG reporting	SDG 11; SDGs	GIS: material-intensive zones; CIM dashboard: footprint trends; Data integration: BIM quantities and waste statistics	High material intensity due to construction boom; recycling data limited.	Supports resource efficiency, circular economy planning, and long-term	Red: >15 t/person; Amber: 10–15 t/person; Green: <10 t/person	Material data + BIM → CIM material flow layer
Environment	Soil	Mercury concentration in soil	Mercury concentration measured in urban soils	mg/kg	Annual / Periodic	GIS / Lab data	Soil surveys, laboratory results	Environmental agencies; EBRD	EBRD	GIS: contaminated site mapping; CIM dashboard: contamination levels and priorities; Data integration: lab results linked to land use	Legacy industrial zones affected; surveys irregular.	Enables soil remediation, land-use safety, and public health protection	Red: >1 mg/kg; Amber: 0.5–1 mg/kg; Green: <0.5 mg/kg	Soil surveys + lab data → CIM soil contamination layer
Buildings	Public Buildings	Sustainability certification	Share of public buildings with recognized sustainability certifications	% of total public building area	Annual	Administrative / GIS	Building area, certification status	Municipal building authorities	SDGs	GIS: certified building locations; BIM: certification and performance data; CIM dashboard: certified floor area share	Few certified public buildings; data fragmented.	Supports decarbonization, energy efficiency, and sustainable operations	Red: <20%; Amber: 20–50%; Green: >50%	BIM + certification data → CIM building layer
Buildings	Public Buildings	Integrated ICT systems	Share of public buildings using ICT for automated management and monitoring	% of total public building area	Annual	Administrative / GIS	ICT systems installed, building area	Municipal ICT and building authorities	SDGs	GIS: smart building distribution; BIM: BMS and sensor metadata; CIM dashboard: ICT adoption trends; Data integration: energy and water monitoring	ICT adoption limited; legacy systems dominant.	Enables smart building operations, energy optimization, and occupant comfort	Red: <20%; Amber: 20–50%; Green: >50%	BIM + BMS data → CIM building management layer