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The Impact Of Artificial Intelligence On The Sustainability Of Smart Cities

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Abstract
The accelerated growth of population across the globe puts stress on the available resources and infrastructure, which makes planning the future growth of cities a difficult task. To address this, many technological solutions were devised, including the integration of artificial intelligence, or AI, to assist in setting a digital infrastructure and eventually convert urban settlements into smart cities. The purpose of this study is to evaluate how AI can be introduced to important sectors of city management and infrastructure, including transport, solid waste, managing resources like water and electricity, and the participation of citizens. For this, a total of 400 citizens of the Peruvian city of Tacna were surveyed, and 20 experts in municipal and smart technology matters were interviewed to collect their opinions and surmise the current development, possible obstacles, and perceived benefits. While both the inhabitants and specialists seem to agree the incorporation of emergent technologies could be beneficial, there are certain doubts stemming from the currently underdeveloped infrastructure and poor education on matters like the environment, road safety, and especially civil involvement in municipal decisions and regulations.

Keywords : Artificial intelligence, urban development, smart cities, resource management, mobility, waste processing, citizen participation.

1. Introduction

Across the world, there has been a very steep population growth, followed by an accelerated housing development that could compromise the stability of cities and their infrastructure. In fact, estimates claim that up to 68% of the world's population might live in urban areas by the arrival of 2050 (United Nations, 2021). Thus, one of the main concerns that arises from this quickened development is how to balance the efficiency of resource management and the quality of life inside urban areas, supporting the creation of technological tools that could aid with decision-making for choices that are both feasible within city settings and that positively impact the people and the environment.

Among these, artificial intelligence is a strong asset to plan out the sustainable growth of smart cities in areas that might not be fully urbanized yet (Schmidt et al., 2022). This is the case of Tacna, a department of Peru undergoing urban expansion, with problems in development due to its highway infrastructure, pollution, and overall limited water resources because of increased industrial demand (Bertot et al., 2019). However, despite being a potential solution for the organization and resource optimization in water and waste management (Amin et al., 2023), the use of artificial intelligence as a tool for city planning is limited by a surprising lack of a knowledge base on its effects for sustainability and decision-making, delaying the creation of supporting policies (Zhou & Liu, 2022).

This, in turn, makes it more challenging to relay the necessary information for such an effort to those involved in city planning and the population. On one hand, designing and deploying AI for smart cities requires a multidisciplinary approach, needing to take technical, social, and ethical aspects into consideration. On the other, proper communication is crucial to collect and properly set the expectations of the populace regarding the use of technology to approach issues that directly affect their lifestyle and well-being. A complementary solution to this could be the integration of monitoring and data analysis systems to achieve a greater efficiency in resource management (Mohamed et al., 2023), along with involving the local populace in both the planning for urban expansion and the creation of tools to support it, for solutions that are more adequate to their needs (Mohammed et al., 2023, Calzada & Cobo, 2020).

However, the mentioned lack of understanding might lead to poor coordination in the design and possibly disinterest or rejection from the citizens, making it more difficult to formulate a sustainable route towards smart cities (Bertot et al., 2019). This is why sustainability is not only a matter of understanding or of the environment but also includes social and economic planes that encompass quality of life, efficient resource use, and the overall well-being of the people (Brundtland Commission, 1987). Therefore, the main purpose of this paper is to estimate the impact of using artificial intelligence for the urban management of Tacna, evaluating how it improves sustainability and the population's quality of life. This helps to bridge the knowledge gap on the use of technological tools to assist in the design of smart cities and planning out the necessary infrastructure for such an effort.

For this, the presented information is arranged as follows: Section 2 presents the theories and definitions that support the research, with subsection 2.1 being dedicated to artificial intelligence, 2.2 discussing smart cities, 2.3 addressing sustainability in the context of smart cities, and 2.4 hinting at the relationship between artificial intelligence and urban sustainability. Section 3 presents the used methodology that allowed gathering and analyzing the necessary information to accomplish the set objective. Section 4 both presents the results found after the analysis and discusses their implications for the design of smart cities and the necessary tools for it, followed by Section 5, which summarily offers the final conclusions of the study.

1. Literature Review

1.1. Artificial Intelligence

Artificial intelligence, also known as AI, is a set of digital systems that attempt to emulate human cognitive processes, such as learning, decision-making, and awareness, evolving into a necessary tool for other knowledge areas like urban development, medicine, industrial automation, and education (Russell & Norvig, 2016). More precisely, it mainly comprehends computational systems that can perceive their environment and act according to a set goal to increase the odds of success, showing a focus on learning, adapting, and reacting to different stimuli within a determined context (Russell & Norvig, 2020; McCarthy, 2007). These systems or models should be able to learn from a given data set and generalize what they learn to perform tasks without human intervention, adjusting to determined activities to provide results that affect real or virtual environments (Goodfellow, Bengio & Courville, 2016; Organization for Economic Co-operation and Development, 2019).

Artificial intelligence allows the analysis of sizable data volumes in real time, making it possible to assist in activities that generate large amounts of information, such as urban mobility, energy consumption, and waste treatment (Glaeser & Berry, 2022), implying that its utilization in city planning is feasible and beneficial. In fact, within that context, it is a critical tool to automate processes like trend prediction and resource optimization (Schmidt et al., 2022). Through the usage of big data and machine learning models for real-time infrastructure management, AI enables the improvement of the operative efficiency of urban environments (Mayer-Schönberger & Cukier, 2013). This is achieved because of process automation and a lower workload for professionals of the urban sector, granting more efficiency and smaller margins for error for an increase in productivity and lower operation costs (Brynjolfson & McAfee, 2017).

Other notable mentions of the use of artificial intelligence within urban development are in the fields of transportation and environmental management. In smart cities, it is used to manage traffic in real time, reduce vehicle congestion, and increase safety on the road (Glaeser & Berry, 2022), with technologies like autonomous driving, smart traffic lights, and route optimization proving to be helpful in reducing fuel usage and accidents through prediction and data analysis algorithms (Goodall, 2016). Similarly, it benefits the environment and its sustainability through predictions on climate change, natural disasters, and a more efficient use of water and energy (Rolnick et al., 2019).

This shows the potential for artificial intelligence to assist in the urban design and expansion of Tacna with the diverse span of fields it affects. However, there are some concerns to be addressed when applying tools integrated with AI before deploying them to their fullest extent. Some of these include questions about transparency, equity, and security when handling data, particularly when people are involved.

One of the greater challenges in the use of artificial intelligence is the inherent obscurity of its mechanisms, particularly when applying deep learning on systems. This necessitates an effort to communicate the reasoning behind the decisions it takes so both users and developers can coordinate at the same level of understanding (Lipton, 2018). The importance of this lies in that artificial intelligence is already working with people by hiring personnel, giving credit, and diagnosing illnesses. Thus, the field of Explainable AI, XAI, seeks to develop more understandable and interpretable artificial intelligence with the goal of greater accessibility for humans, allowing people to audit and grasp its decisions (Doshi-Velez & Kim, 2017).

The last point on auditing systems is also relevant because of the data that needs to be provided for their development. AI programs should be carefully fed with information in such a way as to prevent potentially risky or detrimental decisions based on human biases on race, gender, or socioeconomic status. Because urban design could affect elements of security, personnel management, and legal systems, these biases could affect the lives of people if not filtered or prevented. Thus, organizations should carry out audits and set up monitoring and correction mechanisms to address this concern (Mitchell et al., 2021).

Artificial intelligence should also be secure, trustworthy, and resistant to tampering by malign actors or errors that could compromise the results (Amodei et al., 2016). This encompasses multiple factors like protecting personal data and resisting adversarial attacks to manipulate and alter results. Within the context of smart cities, this robustness is crucial to preempt failure in critical infrastructure such as traffic, energy distribution, or public security systems (Bostrom, 2014).

These factors suppose the existence and deployment of monitoring mechanisms placed by its makers to warrant an ethical, legal operation mode (Floridi et al., 2018), meaning that both companies and governments that create and employ AI should be held accountable for the decisions and outcomes adopted by these algorithms and need to offer ways to prevent, mitigate, and correct any losses caused by errors. For example, the European Union has established a law on artificial intelligence that seeks to set stricter controls on its use in sensitive sectors like health and justice (European Union, 2020). This accountability implies that AI developers should be transparent with the data they are using to create models and establish audit mechanisms that warrant a correct function of these systems.

1.2. Smart Cities

Smart cities are urban environments that incorporate advanced technology to optimize resource management, improve quality of life, and promote sustainability (Caragliu et al., 2011). However, unlike conventional city structures, they require strategic planning that can guarantee sustainability in the long term. Smart cities operate on six key factors, these being mobility, life, governance, economy, environment, and people (Giffinger et al., 2007). Ensuring their sustainability requires focusing on the last three elements by contemplating an optimal resource use, reducing carbon emissions, and securing equal access to the planned services. Specifically, the environmental dimension implies the proper management of natural resources, promoting renewable energy sources and reducing the environmental impact of human activity; the social dimension seeks to achieve inclusivity, equitable access to urban services, and public participation in decision-making; and the economic factor necessitates the efficient usage of financial resources, promoting the development of new business and work possibilities in the city.

Smart cities feature interconnected digital structures, the use of Big Data, and service automation for more efficient decision-making (Harrison & Donnelly, 2010; Batty et al., 2012). This means that different services, like transport, energy, and security, can communicate to optimize their functioning, allowing for better resource administration and more efficient public services. They also have adaptability and resilience to environmental changes, quickly responding to natural disasters, economic crises, or shifts in service using real-time data feeds. Thus, it not only depends on the use of technology but also requires public involvement and data-based governance for optimal results (Nam & Pardo, 2011), giving the citizens power and influence over important decisions through digital platforms and public consulting over the internet.

There are different types of smart cities depending on the main focus and priorities. This is not to say they only focus on these parameters, but that specific designs are geared to bettering certain public services. First is the mobility-oriented smart city, which prioritizes reducing traffic and promoting a more efficient public transport, using traffic management systems integrated with artificial intelligence (Banister, 2008) and favoring non-motorized transport and electrical vehicles. This helps to reduce carbon dioxide emissions, improves accessibility in highly dense urban areas, and assists in laying the infrastructure for less contaminant transport and automating semaphores (Wang et al., 2020), ultimately improving air quality.

Then, there are energy-focused smart cities, which concentrate on efficient energy use and delivery through smart grids, promoting the use of renewable energies and an automated, sensor-monitored resource utilization. Smart grids are essential for an optimal energy distribution that minimizes losses and is usually placed along with solar and wind energy projects, promoting clean energy production (Gellings, 2017). The use of smart sensors and prediction algorithms for energy can support the improvement of its consumption in a way that both reduces costs for the citizens and allows companies to move towards environmental sustainability (Boeing et al., 2022).

Lastly, there are smart cities with circular economies, which favor the reutilization of materials, waste reduction, and the development of sustainable business models. Firstly, they foster the reuse, recycling, and reduction of waste to lessen the environmental impact within urban environments (Ellen MacArthur Foundation, 2015), which also means reintroducing materials in a sustainable way in manufacturing and building. Smart cities also apply strategies to efficiently manage waste, digitalize secondhand markets, and recycle materials for construction, which is applied in smart buildings, adhering to the circular economy by using sustainable materials, automated energy systems, and optimized resource usage (Hernández et al., 2019). These strategies allow urban environments to notably reduce pollution and progress to better urban development.

Another important aspect of smart cities as a whole is adequate governance and management, both of which require sufficient and actualized information about the urban setting to properly take action. A tool for this is the Internet of Things (IoT), with the potential to weave a network of devices within a city to manage traffic, environmental factors, and public safety (Atzori et al., 2010), which allows for a more efficient use of resources like energy and water and a more effective urban waste management (Gupta & Degbelo, 2022). The collected information assists in making more realistic and effective decisions, promoting the implementation of efficient and transparent solutions. Similarly, the citizens can make their opinions known through citizen platforms powered by blockchain and big data (Caragliu et al., 2011).

1.3. Sustainability in Smart Cities

In the context of smart cities, sustainability as a concept encompasses a set of environmental, social, and economic factors for urban development, ensuring that the growth of a city does not negatively affect the well-being of future generations, working on an equilibrium between economic progress, social equity, and environmental preservation (Brundtland, 1987; Elkington, 1997). For the purposes of this research, sustainability can be measured with three key components. Firstly, the optimization in the use of urban resources, in which the use of artificial intelligence could help to better manage water, energy, and solid waste, allowing for a sustainable development that minimizes its environmental impact (Amin et al., 2023). In second place, there are mobility and air quality, both components of the development of urban traffic, where integrating AI has the potential to reduce vehicular congestion and improve air quality through intelligent management of semaphores and public transport (Wang et al., 2020). Lastly, there is citizen participation and governance, which benefit from digital platforms assisted by AI, easing the communication between citizens and authorities for a more transparent and inclusive governance (Calzada & Cobo, 2020).

The sustainability of a smart city combines technology and innovation with sustainable development policies to ensure a more effective utilization of natural resources, contributing to the lives of citizens and mitigating the disadvantages of an accelerated urban development. With this premise, smart cities can be defined as cities that utilize information and communication technologies, or ICT, to provide public services more efficiently whilst contributing to sustainably developing them (Caragliu et al., 2011). This not only means that cities could be technologically advanced, but also that they are resilient and eco-friendly. The modern concept of sustainability fits any development that can satisfy necessities found in the present without being detrimental to those that future generations may find (Brundtland, 1987), which, translated to the smart city, means to implement technologies and automation that can effectively use natural resources to improve the conditions of an urban area without mid- and long-term adverse effects.

Smart cities are oriented towards reducing pollution, using and optimizing renewable energies, and improving the well-being of the population by providing equal access to urban services. Academically speaking, Albino, Berardi, and Dangelico (2015) indicate three basic dimensions for sustainability. There is environmental sustainability, which focuses on clean energy, less pollution, and the preservation of ecosystems; economic sustainability, which fosters circular economy models, resource optimization, and digitalized urban management; and social sustainability, which promotes the participation of the citizens in decision-making, equal access to services, and improvements to quality of life.

The sustainable development of smart cities is deeply linked to the United Nations' 2030 Agenda and the Sustainable Development Goals (SDGs). Particularly, SDG 11: Sustainable Cities and Communities, highlights the development of cities that are inclusive, safe, resilient, and sustainable. This means the deployment of smart infrastructures that reduce their environmental mark and improve the citizens' quality of life (UN, 2015). Within that context, sustainability is bound to the ability to optimize a city's infrastructure through the use of technology. Using Internet of Things sensors, autonomous transport, and smart grids could help to minimize the waste of resources and improve the mobility of citizens within the urban setting (Angelidou, 2017).

This technological focus is key for a structured urban growth that does not create environmental complications or social exclusions. Ensuring sustainability in a smart city not only depends on technology but also on changing the mindsets of the citizens and the people responsible for urban planning. In this regard, environmental education, transparency in the management of urban information, and the implementation of sustainable public policies are necessary to effectively balance urban digitalization with social well-being (Hernández et al., 2019).

1.4. The Impact of Artificial Intelligence on Smart Cities

The relation between artificial intelligence and urban sustainability has recently emerged in the scientific spotlight, although there has been extensive research because of the potential to change how urban planning and management are done. Studies reveal several opportunities to regulate energy usage, increase the mobility in cities, optimize the collection and recycling of waste, and reinforce digital governance by using artificial intelligence (Mohammed et al., 2023). Overall, this could be helpful in the delivery of urban public services to citizens and in improving their quality of life.

Following the previous definitions of a smart city, artificial intelligence plays a critical role in automating urban services, increasing the efficiency in energy consumption, and improving public safety (Meijer et al., 2019). The integration of automated learning with smart city management systems based on Big Data allows for the analysis of sizable amounts of information, detecting patterns and trends to assist in solving problems with traffic, security, and the environment (Angelidou, 2017).

There are tangible and diverse results of the incorporation of artificial intelligence within smart cities. An example of this comes from traffic management, where automated learning algorithms find solutions to adjust traffic lights in real time (Goodall, 2016). Other notable impacts include the implementation of smart grids to ease the integration of renewable energies, the use of smart sensors to monitor losses, waste, and consumption of resources in the urban system, and systems to save water through intelligent, efficient use (Zaman & Lehmann, 2013).

Similarly, artificial intelligence has improved the development of systems for urban safety, citizen participation, and digital governance. Solutions like facial recognition, crime prediction algorithms, and real-time emergency monitoring have improved the response capacity of law enforcement and affected crime rates in cities that implemented these technologies (Nguyen et al., 2018). On the other hand, citizens can interact with public administration and report issues with public services through interactive platforms powered by artificial intelligence (Meijer & Bolívar, 2019). At the same time, public administration can use Natural Language Processing (NLP) to deploy chatbots and digital assistants to help users solve their doubts and address their complaints (Shum, He & Li, 2018). Lastly, artificial intelligence has also been used to augment mobility in urban settings, allowing for the development of autonomous vehicles, optimized public transport, and smart traffic lights (Banister, 2008), which significantly reduced transport times and pollution and improved air quality in the city (Glaeser & Berry, 2022).

As shown, the integration of artificial intelligence in smart cities has had a significant impact on a multitude of areas and has helped to create more efficient, resilient, and sustainable urban spaces. This helps to improve the quality of life of citizens as well as optimize the use of resources. However, it also presents ethical and regulatory concerns that should be addressed for more responsible and equitable city planning.

2. Method

2.1. Procedures and Sampling

The performed research is applied in type, being centered in the development of artificial intelligence for the improvement of the sustainability of smart cities, mainly in Tacna, both to create and gather knowledge that can be used in urban planning and management to improve the citizens' living conditions (Hernández, Fernández & Baptista, 2014). Its design can be described as non-experimental, since there is no direct deliberate manipulation of the elements, but an observation and analysis of their effects as they manifest (Creswell, 2014); transversal, for the determined time period used to collect necessary data (Hernández et al., 2014), which is 12 months in this case; and correlational-descriptive, as it attempts to identify and describe the relationship between artificial intelligence and the urban sustainability of Tacna. These design choices will allow the collection of details on the specific situation within the chosen timeframe, as well as finding the impact of mobility, resource management, and citizen participation.

The population for the study is mainly comprised of the inhabitants of Tacna, estimated to be 286240 people by the National Institute for Statistics and Informatics in Peru (INEI, 2022), divided into three key groups. First are the residents of Tacna, being the largest portion with 250000 inhabitants whose lives could be affected by the deployment of smart infrastructures and urban services. After this, there are the public servants, linked to urbanism and sustainability, containing approximately 2000 people, including municipal authorities, technicians on sustainable urbanism, and personnel for technology management. Finally, there are artificial intelligence and sustainability specialists, a smaller portion with up to 300 experts, including academics, digital transformation consultants, researchers, and professionals from the private sector.

To choose a sufficient and representative sample, a sampling process was performed through different strategies, ending up with samples of 400 citizens through stratified random sampling and 20 experts through intentional sampling (Etikan et al., 2016). To select adequate candidates that can provide sufficient information, it was necessary to define inclusion and exclusion criteria that allow to discern features that are acceptable for the sample. For the citizen sector, they are included in the sample if they are older than 18 years old, reside within Tacna, and have interacted with an urban infrastructure system or otherwise technologically enhanced service, while lacking any of the listed criteria makes them unable to participate. Similarly, for the public servants, it is needed from them that they have experience in urban planning, sustainability, or emergent technologies related to municipal management, being disqualified if they do not possess it. Finally, for the specialists, they should have academic formation in artificial intelligence, digital transformation, and/or sustainable urbanism, as well as having taken part in urban innovation projects. Specialists that do not have many papers or certifications or, otherwise, don't possess experience in artificial intelligence for smart cities are not considered for the procedures.

To collect valuable information from the population, a structured questionnaire geared to collect quantitative data will be used, containing closed questions to gather the citizens' opinion on sustainability and artificial intelligence. The questionnaire is validated as a collection tool through pilot tests and its examination by experts that specialize in the addressed topics (Creswell, 2014). On the other hand, a semi-structured interview will be applied to the experts and public servants to obtain information on the deployment of AI and its possible impact on sustainability, using recordings with permission of the participants and later transcribing them to analyze the data (Kvale, 2017). Lastly, a documentary revision is performed to analyze existing documents and public policies related to sustainability and artificial intelligence in Tacna to contribute to the collected information.

The topics included within these collection tools included resource management, urban mobility, solid waste, and citizen participation, all of them areas often visited by research on artificial intelligence in smart cities and sustainability. For resource management, the participants were asked about their perception of the use of resources like water, energy, and manpower, among others, to provide services and further build infrastructure. Similarly, in urban mobility, their observations about the state of public transportation and the integration of technology were collected to evaluate the state of mobility within the city of Tacna. Solid waste and its management by municipalities are relevant because they can directly affect the health of the citizens, which is the reason they are consulted for their opinions on how waste is being treated and how technologies like AI could improve it. Lastly, for citizen participation, both inhabitants and experts were asked for their experiences with participation platforms and communication technologies that could aid them in establishing communication with the respective authorities.

The methods for data analysis depend on the type of information that was collected. On the quantitative side, statistical software was used, such as SPSS and R, utilizing various methods of descriptive and correlational statistics to detect patterns and links between variables (Hernández et al., 2014). The qualitative data from the interviews is evaluated through content analysis, following through the codification and categorization stages to determine central topics regarding AI in urban planning (Cavanagh, 1997).

3. Results

The following are the results of processing a survey performed with 400 inhabitants of Tacna and interviews done with 20 experts between municipal personnel and AI specialists. The procedure consisted of sets of questions for the citizens, later averaged into 5-point scores hinting at their overall agreement with the integration and utilization of artificial intelligence and similar technologies in municipal management and other aspects of urban growth. Similarly, the experts were consulted on their opinions on these topics, which are detailed and complemented with the obtained averages. This helps to create a combined point of view between the citizens and the experts. Thus, these results not only reflect the potential of implementing smart technologies in the city but also the social, economic, and technical limitations inherent to their deployment.

3.1. Resource Management

The topics covered here included the knowledge and perceptions of the management and use of urban resources such as water, electric power, and basic urban services, like sanitation, security, communications, etcetera. The participants were consulted on their knowledge and opinions on the use of intelligent technologies to manage resources and aid in data analysis and planning future expansions.

Table 1. Perception of Tacna's citizens about AI for resource management

Answer Type (Score)	Frequency	Percentage
Negative (1)	37	9.25
Slightly Negative (2)	91	22.75
Neutral (3)	95	23.75
Slightly Positive (4)	123	30.75
Positive (5)	54	13.5

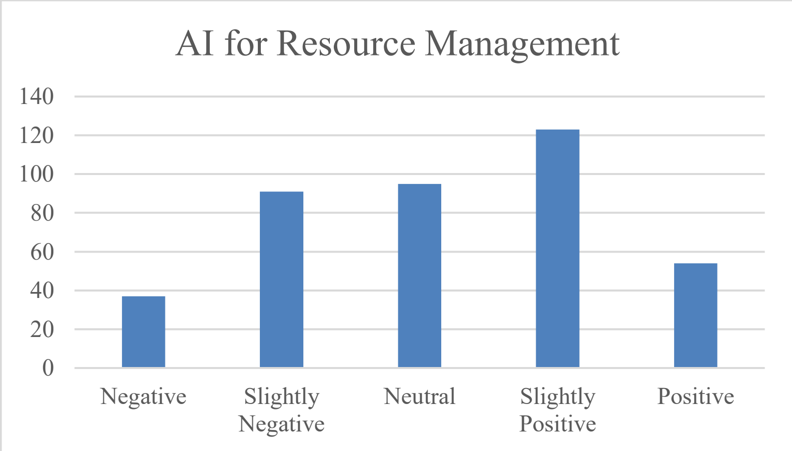

Figure 1. Frequency graph of citizens' answers for resource management

As observed in Table 1 and Figure 1, the population's opinion about the role of artificial intelligence in resource management operations tends to be more positive. The citizens are optimistic about the benefits an automated urban service system would bring to their lives and agree on the use of technology to further the development of Tacna. This is complemented by comments of the consulted experts, who mention the sanitization and delivery of clean water and the improvement of power grids for the city as critical aspects, given that there are zones of Peru with poor water processing systems and insufficient power grids. Predictive algorithms could anticipate different rates of resource consumption and adapt the output to prevent wasting water and energy.

3.2. Urban Mobility

For this subsection, the participants were asked about their perspective on the state of transportation and their general capacity to move around in the city of Tacna. Aspects like public transport, road safety, and regulations were important to have an accurate representation of the city's current position. This also correlates to the quality of the air and of life within a city such as Tacna, affecting the health of people within the urban area.

Table 2. Perception of Tacna's citizens about AI for urban mobility

Answer Type (Score)	Frequency	Percentage
Negative (1)	27	6.75
Slightly Negative (2)	89	22.25
Neutral (3)	109	27.25
Slightly Positive (4)	82	20.5
Positive (5)	93	23.25

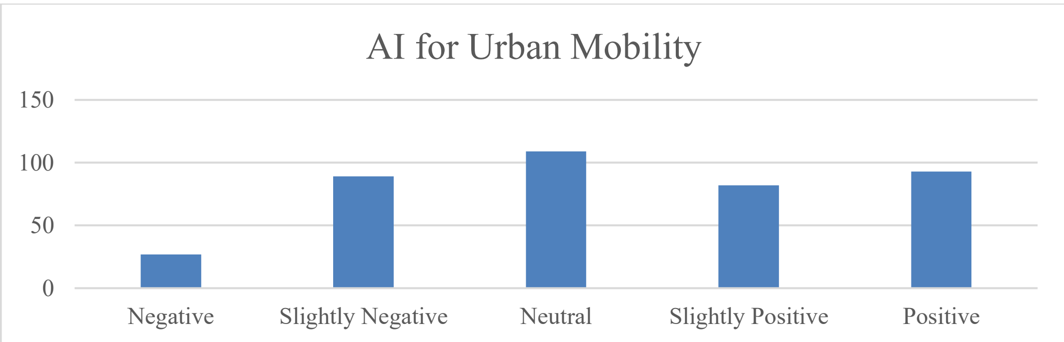

Figure 2. Frequency graph of citizens' answers for urban transport

The results displayed by Table 2 and Figure 2 show a moderately favorable pattern towards the use of intelligent technologies for urban transport, with a tendency towards a more neutral position. Although there is acceptance for the improvement of urban mobility using smart technologies, there are uncertainties and a lack of knowledge that might affect public trust and the overall deployment in a growing city. The experts complement this finding by stating that it might be related to the transport culture in Peru, which has many informal elements present, even in sectors like public transport and road construction. However, there is consensus on the negative impact of vehicular congestion on the quality of life of the inhabitants, who are optimistic about the installation of smart traffic lights and the automation of vehicle routes, as long as transparency is ensured.

3.3. Solid Waste

The citizens of Tacna were asked about the situation of the city's solid waste management, including topics like trash accumulation, public health hazards, and the existing methods to address this, like the circular economy. These are relevant because the expansion of Tacna as a city is mainly motivated by a quick growth of its population that potentially generates waste at an accelerated rhythm. Without proper infrastructure, this could overwhelm the existing systems and risk the population's health.

Table 3. Perception of Tacna's citizens about AI for solid waste management

Answer Type (Score)	Frequency	Percentage
Negative (1)	54	13.5
Slightly Negative (2)	66	16.5
Neutral (3)	107	26.75
Slightly Positive (4)	133	33.25
Positive (5)	40	10

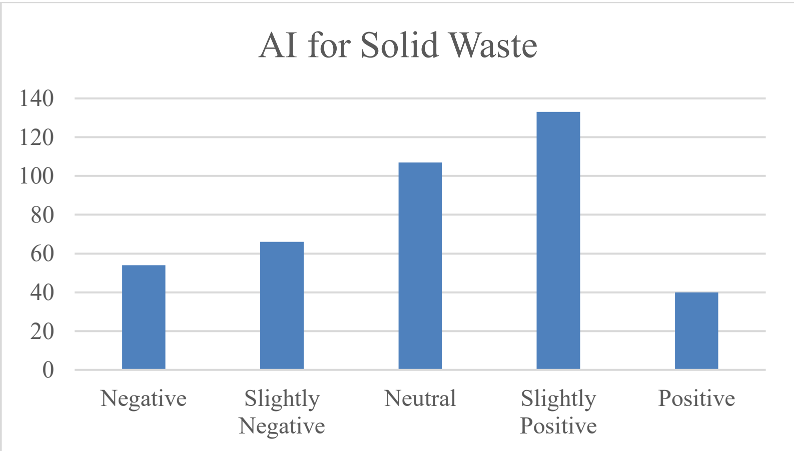

Figure 3. Frequency graph of citizens' answers for solid waste

The results shown in Table 3 and Figure 3 show a somewhat positive view, mostly tending towards neutrality. As with urban mobility, this could hint at a lack of understanding of how waste is treated in the city and an underdeveloped recycling culture, which could make the introduction of artificial intelligence in Tacna more difficult. The consulted experts also hint at the absence of active policies for intelligent waste collection, as well as poor monitoring in critical areas where waste could accumulate, indicating an insufficient infrastructure that needs reinforcement even before the introduction of newer technologies. Another critical recourse to address these issues would be environmental education, which could raise awareness and willingness to help with simple actions such as classifying waste from home, potentially maximizing the results of predictive algorithms used for waste collection and separation.

3.4. Citizen Participation

Finally, the citizens were surveyed on the available mechanisms in place to allow them to participate in decisions for the city of Tacna. Citizen participation includes elements such as communication platforms, regulations and policies, and interactions with municipal authorities. Since this affects the population's right to voice their opinions and complaints, it is crucial to consider this when developing smart cities.

Table 4. Perception of Tacna's citizens about AI for citizen participation

Answer Type (Score)	Frequency	Percentage
Negative (1)	40	10
Slightly Negative (2)	105	26.25
Neutral (3)	123	30.75
Slightly Positive (4)	107	26.75
Positive (5)	25	6.25

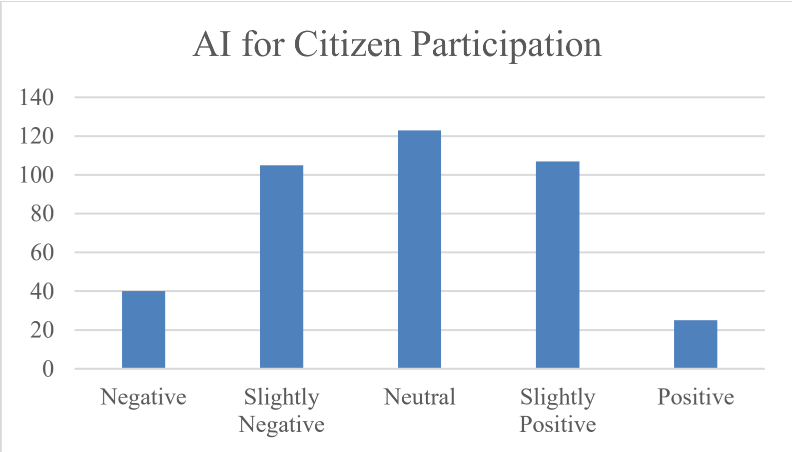

Figure 4. Frequency graph of citizens' answers for citizen participation

When asked about the use of artificial intelligence for citizen participation, Tacna's inhabitants appear undecided on the improvements it would bring, as detailed in Table 4 and Figure 4, although there is a notable interest in having tools to access information and have a stake in local decisions. This could be attributed to confusion or lack of knowledge about the available channels and tools to voice their opinions, doubts, and complaints. This is complemented by the experts, who add that the effective application of intelligent technologies to boost public participation is an area that's too little known for the common citizen, hinting at a poor digital literacy. This means that there is a critical breach of knowledge that must be addressed first through the reinforcement of public communication and digital inclusion through education.

4. Discussion

The obtained results confirm the potential of artificial intelligence to revolutionize the urban sustainability of Tacna across several areas, but they also reveal a number of concerns that should be addressed carefully. As literature on the case suggests, the success of these technologies depends on the available infrastructure and the involvement of an accepting population. Wasswa (2024) points at the fact that AI in urban environments can boost resilience as long as the data ecosystem is trustworthy and accessible to the public. However, this is still a limited aspect in Tacna, presenting a significant deviance from other contexts where proper technological infrastructure with IoT sensors is already consolidated.

In regard to the management of resources, such as water and energy, the participants acknowledged artificial intelligence as a tool that can prevent losses and optimize how they are distributed. This coincides with findings by Jakkani (2024), who proved the capacity of AI applied to smart electrical grids to significantly lower the total energy consumption and improve operative efficiency. However, the infrastructural and technological limitations present in Tacna still persist as barriers that are not found in highly developed cities. This proves that these benefits are not instantly or automatically obtained, but rather that they depend on the local conditions of implementation.

Meanwhile, in the area of mobility, results suggest a reduction of vehicular congestion through route planning and smart traffic light synchronization using artificial intelligence. This is congruent with Wang et al. (2020) and their findings, suggesting that smart transport systems enhanced with AI can improve traffic flow and lessen contaminant emissions. However, the shown data reveals some skepticism from Tacna's citizens on the complete automation of traffic, which requires a greater emphasis to strengthen the trust in technology, as signaled by Calzada & Cobo (2020) when examining the social hesitance about urban platforms for digital governance.

Another topic is solid waste management, with results showing the citizens' perception of artificial intelligence as a tool to improve collection and segregation, although there still is a weak recycling culture.

These findings coincide with Kumar et al. (2021), who highlight that artificial vision and automated learning can optimize recycling processes in urban environments, although their performance largely depends on citizen involvement. Contrasting with other Latin American cities shows that Tacna lags behind on environmental education, which limits the immediate impact of smart technologies.

On the point of citizen participation, the obtained results also reveal that there's a favorable opinion towards digital platforms that facilitate interaction with local authorities, although there are notable differences in digital literacy. This is supported by Gupta & Degbelo (2022), who indicate that artificial intelligence applied to governance processes could increase the transparency and efficiency of administration, but only if inclusive access is ensured. In the case of Tacna, there is a real risk of technological exclusion, which could reinforce existing inequalities.

Another important topic is air quality in the city, which is affected by traffic and waste management as a whole. Artificial intelligence, when integrated into transport, can help to improve air quality by promoting more efficient mobility across the city. Studies like the one performed by Boeing et al. (2022) show spatial indices on the reduction of pollution in cities with smart systems, showing an incipient but limited potential for Tacna, which still lacks accessible data in real time. This underscores the need to place urban monitoring systems that can assist with evidence-based decision-making.

In a similar vein, the results show that an analysis on the feasibility of AI in Tacna cannot be isolated but should be done within an institutional and political framework. The Economic Commission for Latin America and the Caribbean (CEPAL, 2022) underscores that successful smart cities depend on clear regulations and sustained funding for innovation. These criteria are partially achieved by Tacna in the sense that the population can acknowledge the usefulness of AI tools, but it also notices the lack of robust public policies that can back their development.

This discussion ultimately confirms the feasibility of integrating artificial intelligence in sustainable urban development, but this depends on how local limitations are addressed. The efficient management of water, energy, and waste, along with sustainable mobility and digital governance, are all achievable using smart technologies, as long as their use is complemented with citizen participation programs, infrastructure investment, and inclusive policies. Shortly put, the results obtained in Tacna could potentially reach the magnitude of that which international studies achieved with the use of AI for urban sustainability, underscoring the structural and social limitations that a city in development could face. This provides a valuable reference frame to design strategies under similar constraints.

5. Conclusions

The research performed confirms the importance of artificial intelligence to improve the urban sustainability of Tacna, as it helps to achieve a significantly higher efficacy in the management of water, energy, transport, and solid waste. The results show a positive perception of the public on predictive technologies, as long as they're transparent and accessible. This evidences that their performance depends not just on the technology used but on the available infrastructure and institutional backing to articulate lengthy projects.

On the side of urban transport and air quality, this research confirms that the effects of using artificial intelligence are critical for the improvement of the citizens' quality of life, public health, and the environment. Although this coincides with research across the globe, Tacna is particular because of the perceived skepticism in regard to the automation of transport. This means that technical know-how alone cannot warrant success, requiring building public trust in technology for better results.

The obtained results show two contrasting situations related to solid waste management. While the populace acknowledges the importance of incorporating smart technologies that can help with the collection and separation of waste, there still is a poor waste segregation culture that limits the reach of any technological solution. International research highlights this scenario, hinting at the importance of combining technological innovation with environmental education programs. The success of intelligent systems for Tacna's urban sustainability depends on surpassing this cultural breach and strengthening the relevant institutions.

Regarding citizen participation and digital governance, artificial intelligence can help the inhabitants of a city to participate in urban decisions, but issues like breaches in connectivity and digital literacy could place social exclusion as a real risk. Results show that the citizens of Tacna are interested in the use of intelligent platforms to interact with local authorities, an important aspect visited in studies about the strengthening of governance through digital technology. However, more vulnerable sectors of the Peruvian city could be exposed to existing inequalities, which requires an inclusive system design that ensures equal access and participation of all social groups.

6. References

1. Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. Journal of Urban Technology, 22(1), 3-21.
2. Amin, A., Oumer, A., & Mohammed, A. (2023). The role of artificial intelligence in sustainable urban development. Sustainable Cities and Society, 78, 103453.
3. Angelidou, M. (2017). The role of smart cities in fostering sustainability. Sustainability, 9(12), 2257.
4. Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. Computer Networks, 54(15), 2787–2805.
5. Banister, D. (2008). The sustainable mobility paradigm. Transport Policy, 15(2), 73-80.
6. Bertot, J. C., Jaeger, P. T., & Grimes, J. M. (2019). Big data and public policy: A global perspective on privacy, ethics, and accountability. Government Information Quarterly, 36(1), 72-83.
7. Boeing, G., Higgs, C., Liu, S., Giles-Corti, B., Sallis, J. F., Cerin, E., Lowe, M., Adlakha, D., Hinckson, E., Moudon, A. V., Salvo, D., Adams, M. A., Barrozo, L. V., Bozovic, T., Delclòs-Alió, X., Dygrýn, J., Ferguson, S., Gebel, K., Ho, T. P., ... Arundel, J. (2022). Using open data and open-source software to develop spatial indicators of urban design and transport features for achieving healthy and sustainable cities. The Lancet Global Health, 10(6), Artículo e907-e918. https://doi.org/10.1016/s2214-109x(22)00072-9
8. Bostrom, N. (2014). Superintelligence: Paths, dangers, strategies. Oxford University Press.
9. Brundtland, G. H. (1987). Our Common Future: The World Commission on Environment and Development. Oxford University Press.
10. Calzada, I., & Cobo, C. (2020). The role of citizens in smart cities: The case of Barcelona. Smart Cities, 3(2), 240-257. https://doi.org/10.3390/smartcities3020015
11. Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. Journal of Urban Technology, 18(2), 65-82.
12. Cavanagh, S. (1997). Content analysis: Concepts, methods and applications. Nurse Researcher, 4(3), 5-16.
13. Comisión Económica para América Latina y el Caribe (CEPAL). (2022). El camino de desarrollo de las ciudades inteligentes. CEPAL. https://www.cepal.org/es/publicaciones/47943-ciudades- inteligentes-america-latina-caribe
14. Creswell, J. W. (2014). Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.). Sage Publications.
15. Doshi-Velez, F., & Kim, B. (2017). Towards a rigorous science of interpretable machine learning. ArXiv preprint.
16. Elkington, J. (1997). Cannibals with forks: The triple bottom line of 21st century business. Capstone. Ellen MacArthur Foundation. (2015). Growth within: A circular economy vision for a competitive Europe.
17. Etikan, I., Alkassim, R. S., & Abubakar, S. (2016). Sampling and sampling methods. Biometrics & Biostatistics International Journal, 5(6), 00149.
18. Floridi, L., Cowls, J., King, T. C., & Taddeo, M. (2018). How to design AI for social good: Seven essential factors. Science and Engineering Ethics, 24(5), 1659-1680.
19. Gellings, C. W. (2017). The smart grid: Enabling energy efficiency and demand response. CRC Press.
20. Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanovic, N., & Meijers, E. (2007). Smart cities: Ranking of European médium-sized cities. Vienna University of Technology.
21. Glaeser, E., & Berry, C. (2022). Artificial intelligence and smart cities: Improving urban management through data science. Urban Studies, 59(4), 723-745.
22. Goodall, N. J. (2016). Can you program ethics into a self-driving car? IEEE Spectrum, 53(6), 28- 58.
23. Goodfellow, I., Bengio, Y., & Courville, A. (2016). Deep learning. MIT Press.
24. Gupta, S., & Degbelo, A. (2022). An empirical analysis of AI contributions to sustainable cities (SDG11). ArXiv. https://arxiv.org/abs/2202.02879
25. Hernández, R., Fernández, C., & Baptista, P. (2014). Metodología de la investigación (6th ed.). McGraw-Hill.
26. Jakkani, A. K. (2024). Incrementar la sostenibilidad urbana a partir de estrategias de eficiencia
27. Kumar, P., Venkatesh, M., & Ameer, R. (2021). Smart waste management using IoT and machine learning. Journal of Cleaner Production, 287, 125024. https://doi.org/10.1016/j.jclepro.2020.125024
28. Kvale, S. (2007). Doing interviews. Sage Publications.
29. Lipton, Z. C. (2018). The mythos of model interpretability. ACM Queue, 16(3), 31-57.
30. Mayer-Schönberger, V., & Cukier, K. (2013). Big data: A revolution that will transform how we live, work, and think. Eamon Dolan Books.
31. McCarthy, J. (2007). What is artificial intelligence? Stanford University.

32. Meijer, A., & Bolívar, M. P. (2019). Governing the smart city: A review of the literature on smart urban governance. International Review of Administrative Sciences, 85(2), 464-481.
33. Meijer, A., Rodríguez Bolívar, M. P., & Gil-Garcia, J. R. (2019). Smart governance for smart cities: A conceptual framework and Research agenda. Government Information Quarterly, 36(3), 505-512.
34. Mitchell, M., Wu, S., Zaldivar, A., Barnes, P., & Vasserman, L. (2021). Model cards for model reporting. Proceedings of the Conference on Fairness, Accountability, and Transparency.
35. Mohammed, A., Oumer, A., & Amin, A. (2023). Machine learning applications in urban sustainability. Journal of Cleaner Production, 396, 126440.
36. Nguyen, T., Rojas, F., & Lin, Y. (2018). Artificial intelligence in smart cities: Challenges and opportunities. Journal of Information Science and Technology, 25(3), 78-94.
37. OCDE. (2019). Recommendation of the Council on Artificial Intelligence. OECD Publishing.
38. Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., Lacoste, A., Sankaran, K., ... & Bengio, Y. (2019). Tackling climate change with machine learning. ArXiv preprint.
39. Russell, S., & Norvig, P. (2016). Artificial intelligence: A modern approach (3rd ed.). Pearson. Russell, S., & Norvig, P. (2020). Artificial intelligence: A modern approach (4th ed.). Pearson.
40. Shum, H. Y., He, X., & Li, D. (2018). From Eliza to XiaoIce: Challenges and opportunities with social chatbots. Frontiers of Information Technology & Electronic Engineering, 19(1), 10- 26.
41. Suha Alawadhi. Armando Aldama-Nalda. Hafedh Chourabi. J. Ramon GilGarcia. Sofia Leung. Sehl Mellouli. Shawn Walker (2019). Building Understanding of Smart City Initiatives. Lecture Notes in Computer Science. book series (LNISA,volume 7443). pp 40–53
42. Thanh, Van, Hoang. (2024). Impacto de la inteligencia artificial integrada y las tecnologías de Internet de las cosas en la transformación de las ciudades inteligentes. Tạp chí Giáo dục Kỹ thuật, doi: 10.54644/jte.2024.1532
43. European Union. (2020). Ethics guidelines for trustworthy AI. European Commission.
44. Wang, Y., Liu, Y., & Zhang, J. (2020). The application of artificial intelligence in the smart transportation system. Sustainable Cities and Society, 60, 102197. https://doi.org/10.1016/j.scs.2020.102197
45. Wasswa, Shafik. (2024). Incorporación de la Inteligencia Artificial para la Sostenibilidad de las Ciudades Urbanas e Inteligentes. Práctica, progreso y competencia en sostenibilidad, doi: 10.4018/979-8-3693-6336-2.ch002
46. Zaman, A. U., & Lehmann, S. (2013). Urban growth and waste management optimization towards 'zero waste city'. Waste Management, 32(8), 1381-1388.
47. Zhou, X., & Liu, S. (2022). The impact of artificial intelligence on urban sustainability: A review. Environmental Science & Policy, 131, 220-229.