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Geospatial Technology Integration in Smart City Frameworks for Achieving Climate Neutrality by 2050: A Case Study of Limassol Municipality, Cyprus

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Abstract

This study investigated the integration of geospatial technologies within smart city frameworks to achieve the European Union's climate neutrality goals by 2050. Focusing on rapid urbanization and escalating climate challenges, the research analyzed how smart city frameworks, aligned with climate neutrality objectives, leverage geospatial technologies for urban planning and climate action. The study included case studies from three leading European cities, extracting lessons and best practices in implementing Climate City Contracts across sectors like energy, transport, and waste management. These insights highlighted the essential role of EU and national authorities in providing technical, regulatory, and financial support. Additionally, the paper presented the application of a WEBGIS platform in Limassol Municipality, Cyprus, demonstrating citizen engagement and acceptance of the proposed geospatial framework. Concluding with recommendations for future research, the study contributed significant insights into the advancement of urban sustainability and the effectiveness of geospatial technologies in smart city initiatives for combating climate change.

Keywords

Smart Cities, Geospatial Technologies, Smart City Frameworks, Geospatial Integration

1. Introduction

Urbanization, a defining characteristic of the modern era, has led to cities becoming hubs of population and economic activity. However, this growth presents significant environmental challenges, especially in the context of climate change. Cities, while occupying just 4% of the European Union's land area, are home to 75% of its population and are substantial contributors to carbon emissions, accounting for over 70% of global CO_2 emissions. This situation highlights a critical need to rethink urban planning and development for sustainability and environmental stewardship [1]

In response, the European Union has embarked on an ambitious mission to transform urban landscapes. Central to this initiative is the goal of establishing 100 climate-neutral and smart cities by 2030, a stepping stone towards achieving climate neutrality for all cities by 2050. This mission is part of the larger European Green Deal [2] which seeks to significantly reduce emissions by 2030, charting a course towards a sustainable future. The EU's strategy transcends mere environmental impact mitigation, aiming also to enhance urban life quality through cleaner air, safer transport, and reduced urban congestion and noise.

Addressing these challenges requires a multifaceted approach, involving local authorities, citizens, businesses, investors, and regional and national governments. It calls for innovative solutions that bridge technological advancement with urban planning. This study explores the integration of geospatial technologies within smart city frameworks to address these challenges. By examining the application of these technologies in three European cities, the paper seeks to understand their role in aiding cities to meet the EU's climate neutrality objectives. The study not only highlights the importance of these technologies in urban sustainability but also identifies the gaps in current approaches and proposes solutions for enhancing their efficacy in urban planning. The findings offer valuable insights into the integration of advanced geospatial technologies in smart city initiatives, providing a roadmap for cities worldwide in their quest to fight climate change.

The novelty of this work lies in its detailed examination of the intersection between geospatial technologies and smart city frameworks, particularly in the context of the EU's climate goals. This research presents new findings on the practical challenges and opportunities of technology integration in urban planning, contributing significantly to the scientific discourse on urban sustainability. By the conclusion of this introduction, it is evident that this research not only fills a crucial gap in urban planning literature but also provides a strong scientific justification for the broader application of geospatial technologies in smart city development for climate neutrality.

2. Literature: Climate-Neutral Smart Cities and Geospatial Frameworks

Smart cities represent a modern combination of urban planning, technology, and policy, aimed at improving and enhancing the quality of urban life [3] [4]. They leverage advanced Information Communication and Technology to optimize city functions, engage citizens, and promote sustainable urban development. A smart city is characterized by its ability to integrate physical, digital, and human systems in a built environment, enhancing the overall efficiency, responsiveness, and livability of urban spaces [5].

2.1. Overview of Smart City Frameworks

The concept of smart cities [6] [7] has evolved to include a diverse range of frameworks [8] [9] [10] each reflecting unique regional priorities and challenges. Initially focusing on the integration of digital technologies to enhance urban functionality, these frameworks have gradually included broader objectives, notably climate neutrality. Modern smart city frameworks now increasingly align with climate goals integrating strategies for energy efficiency, sustainable resource management, and emission reduction. They represent a combination of technological innovation and environmental stewardship, acknowledging the critical role urban areas play in fighting against climate change.

2.2. The EU's Approach

The European Union's approach to developing climate-neutral smart cities is distinct in its cross-sectoral and demand-led nature. As part of the Cities Mission [11] this approach emphasizes creating cooperation between various urban sectors such as energy, transport, and waste management, while ensuring that the development strategies are directly responsive to the specific needs of each city. This method recognizes that effective and sustainable urban transformation requires not just top-down policy implementation but also bottom-up localized solutions that address the unique challenges and opportunities of individual cities.

2.3. Climate City Contracts and Geospatial Technologies

A pivotal element of the EU's strategy is the development of Climate City Contracts [12]. These contracts represent a commitment by cities to achieve climate neutrality including comprehensive plans across multiple sectors such as energy buildings, waste management, and transport. The integration of geospatial technologies in these contracts is vital. These technologies can provide cities with the tools to analyze and monitor urban dynamics accurately, facilitate data-driven decision-making, and ensure efficient resource allocation. Geospatial technologies can be used in creating detailed urban models that can forecast the impacts of various climate actions, thereby enabling cities to strategize and implement effective climate-neutral initiatives.

3. Geospatial Technologies in Urban Planning and Climate Action

3.1. Defining Geospatial Technologies

Geospatial technologies, which include Geographic Information Systems (GIS), Global Positioning Systems (GPS) and remote sensing, are fundamental in urban planning for acquiring, analyzing, and managing spatial data. GIS integrates various data types [13] [14] [15], such as demographic and environmental, allowing for a multi-layered view of urban landscapes. GPS provides precise location data crucial for navigation and emergency services, while remote sensing, through satellite or aerial imagery is vital for monitoring urban expansion and environmental factors. Data for these technologies come from high-resolution satellite programs like Landsat and the Copernicus Sentinel series. The processing of this data is carried out using advanced GIS software like ArcGIS or QGIS, including steps from image correction to spatial analysis and thematic mapping. This data is often enhanced with field surveys for a comprehensive urban understanding.

The accuracy and reliability of geospatial data are ensured through validation techniques like cross-referencing with ground data and statistical analysis. These technologies enable city planners to visualize urban trends, assess land use, and monitor environmental changes, facilitating effective urban management. Applications in urban planning are diverse, ranging from visualization of urban growth and land use changes to environmental monitoring and efficient management of urban resources like water, energy, and transportation systems [16] [17]. As urban areas continue to evolve, the role of geospatial technologies in shaping sustainable and resilient urban environments becomes increasingly crucial, offering a robust framework for data-driven decision-making and urban management strategies.

3.2. Applications in Climate-Neutral Cities

In the context of climate-neutral cities, geospatial technologies play a critical role in various urban planning domains. Their applications are diverse and with immerse impact:

- Zero-Emission Mobility [18] [19]: Geospatial tools help in designing efficient public transportation networks and cycling paths, optimizing traffic flow and planning electric vehicle charging infrastructure. By analyzing traffic patterns and mobility data, cities can reduce congestion and lower transportation-related emissions.
- Clean Energy Districts [20]: GIS and remote sensing are used to identify optimal locations for renewable energy installations like solar panels and wind turbines. They assist in mapping out energy consumption patterns, contributing to the development of smart grids and clean energy districts.
- Urban Greening [21] [22]: Geospatial technologies assist in urban greening efforts by identifying suitable areas for parks, green roofs, and urban farms. These tools help in monitoring vegetation health, urban heat islands and the overall impact of greening initiatives on the urban microclimate.

4. Case Studies: European Cities Leading the Way

4.1. Examples of Implementation

This chapter examines three European cities that are among the pioneers in the

100 climate-neutral cities initiative, showcasing their innovative use of geospatial technologies in achieving climate neutrality.

Barcelona's GIS-Driven Cycling Paths and Routes [23] [24]: Barcelona stands out as an excellent case where Geographic Information System (GIS) technology has been pivotal in transforming urban mobility. The city's authorities used GIS to design and develop a comprehensive cycling network. This involved analyzing various data layers, including existing road infrastructure, traffic patterns, population density and urban topography. By strategically planning cycling routes and bike-sharing stations, Barcelona enhanced accessibility and safety for cyclists. This GIS-driven approach contributed significantly to reducing transportation emissions by encouraging cycling as a sustainable and efficient alternative to motorized transport, showcasing the potential of technology in fostering eco-friendly urban mobility solutions.

London's Geospatial-Driven Smart Renewable Energy: London serves as a leading example in the implementation of smart energy grids, reliant on geospatial data. The city utilized GIS technology to map out energy consumption patterns, identify optimal locations for renewable energy sources, and integrate them into the existing grid. This geospatial approach enabled London to efficiently manage energy distribution, reduce waste, and incorporate renewable energy sources like solar and wind power more effectively [25] [26] [27]. By leveraging geospatial data, London has made significant progress in transitioning towards renewable energy, demonstrating a model approach for other cities aiming to enhance energy efficiency and sustainability.

Amsterdam's Remote Sensing for Urban Greening [28] [29] [30]: Amsterdam's use of remote sensing technologies for urban greening initiatives offers a compelling case study. The city employed satellite imagery and aerial photography to assess and monitor urban green spaces, contributing to better planning and management. This technology helped in identifying underutilized areas suitable for greening, monitoring the health of existing green spaces, and understanding their impact on air quality and urban biodiversity. Amsterdam's approach demonstrates how remote sensing can provide important data for enhancing urban ecosystems, making significant contributions to environmental sustainability and quality of urban life.

4.2. Lessons Learned and Best Practices

The case studies of Barcelona, London, and Amsterdam reveal several key lessons and best practices in employing geospatial technologies for smart city initiatives:

Integrated Planning: Cross-Departmental Collaboration: These cities demonstrated that successful geospatial technology integration requires collaboration across various city departments and stakeholders, ensuring cohesive and efficient planning and execution.

Community Engagement Involving Citizens: The effectiveness and acceptance of urban projects were significantly enhanced by engaging citizens in the planning process. Geospatial tools facilitated this engagement by making complex data more accessible and understandable to the public.

Scalability and Adaptability—Flexible Strategies: The strategies implemented were scalable and adaptable, addressing the specific needs and challenges of each city while also providing models that could be tailored to different urban contexts.

Data-Driven Decision Making—Dependance on Accurate Data: All three cities emphasized the importance of data accuracy and accessibility in their decision-making processes. The precision and reliability of geospatial data were crucial in developing effective urban strategies.

From these case studies, valuable insights lead to the best practices for integrating geospatial technologies in urban planning, highlighting the need for integrated planning, community engagement, scalability, and data-driven decision-making.

4.3. Barriers to Implementation

Technical Challenges [31]: Cities often face technical barriers in their effort to keep up with the geospatial technological evolution and the integration of geospatial technologies with other systems, including the need for high-level expertise, advanced infrastructure, and interoperability among various systems.

Regulatory Obstacles: Navigating the complex regulatory environment, especially regarding data privacy and security, has significant challenges. Ensuring compliance while leveraging the full potential of geospatial data can be a challenging endeavor.

Financial Constraints: The financial aspect, including initial investment and ongoing maintenance costs of sophisticated geospatial systems, can be prohibitive, particularly for smaller municipalities or those with limited budgets.

4.4. Opportunities for Innovation

Enhanced Urban Planning [18] [32]: Geospatial technologies offer unique opportunities for innovative urban planning, allowing for more accurate and efficient resource allocation, urban development, and environmental management.

Climate Action: These technologies are instrumental in driving effective climate action initiatives, from monitoring emission hotspots to planning sustainable urban infrastructure.

Citizen Engagement and Transparency [33] [34]: Enhanced data visualization and accessibility can foster greater citizen engagement and transparency in urban governance, leading to more inclusive and responsive city planning.

5. Methodology

As part of this research, the identified gap, which relates to the absence of a standardized methodology for the development and integration of geospatial solutions for neutral climate-smart cities, led to the design of a smart city integrated geospatial framework. The primary objective of this framework is to aid and guidance to the 100 climate-neutral smart cities in the European Union (EU) for the development and integration of geospatial solutions that align with their Smart City Climate Neutrality initiatives. The framework is designed to aid and guide city officials through all phases of their geospatial enterprise development, encompassing conceptual and technical guidelines and implementation procedures. This approach enables all cities to establish their enterprise geospatial infrastructure and systems using a consistent and standardized methodology while allowing for the configuration of individual parameters on an ad-hoc basis.

6. Research Results: Implementation of a Novel Geospatial Framework for the Limassol Municipality in Cyprus

By applying the integrated geospatial framework under the Limassol municipality initiative for the EU Mission, an integrated geospatial system for citizen engagement was designed and developed, following the Smart City Integrated Geospatial Framework guidelines. This has produced the following results:

- Citizen's engagement interactive Web application.
- WebGIS Dashboard analytics application, demonstrated in Figure 1.
- Workflow scripts for automating data processing steps.
- Integration with additional geospatial data through web services.

As an integrated component of the proposed framework and following the framework's stages, an interactive and responsive 5 stages survey application, as well as an integrated WebGIS Dashboard, were developed to collect citizens' perceptions within the context of the Limassol Municipality initiatives aimed at achieving EU 100 Climate Neutrality in Cities by 2030. Both applications were designed following the guidelines set by the proposed framework, from the gathering of requirements to the final implementation.

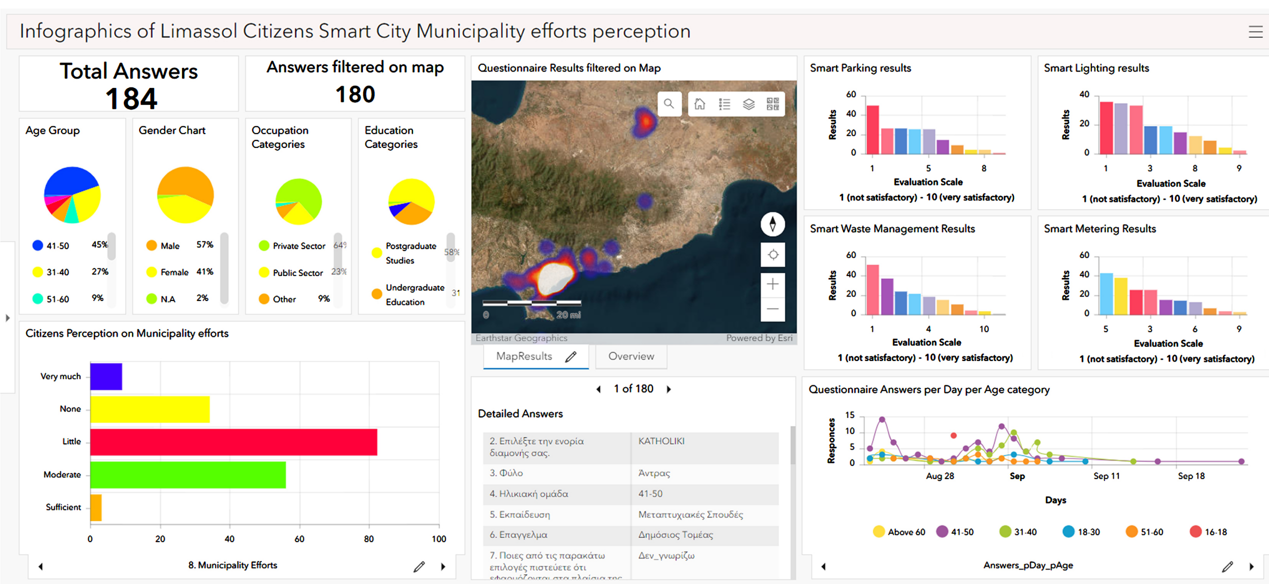

Figure 1. WebGIS dashboard analytics.

Further to the development and deployment of the Survey and WebGIS applications, the following results were produced through this pilot phase:

An additional layer was populated through spatial analysis, the Quarter Choropleth layer shown in **Figure 2**, effectively showing the concentration variations across quarters as submitted by participants.

The integration of Waste Bins Data through Rest services, sourced from the Cyprus University of Technology's various initiatives for data capture and collection, played a pivotal role in enhancing the understanding of smart waste management. This data was correlated as demonstrated in **Figure 3** with the responses obtained from participants in the smart waste management-related questions.

The correlation analysis revealed an intriguing contradiction within the data. Specifically, participants from certain areas provided feedback suggesting significantly further actions on waste management, where in those areas a high number of waste bins already existed. This variation raised a notable concern—it indicated that despite the apparent abundance of waste bins, citizens might still face challenges, implying a potential lack of information or awareness regarding the exact locations of waste bins. This contradiction highlighted the possibility that citizens may not be sufficiently informed about the waste bin locations, leading to a perception of inadequate communication by the municipality. This insight underscores the importance of not only having the infrastructure in place but also effectively communicating relevant information to the residents using effective ways.

The analysis of waste bins data and participant responses underscored another aspect of smart waste management. It emphasized the need for municipalities to ensure effective communication with citizens and awareness initiatives, thereby fostering more informed and actively engaged citizens.

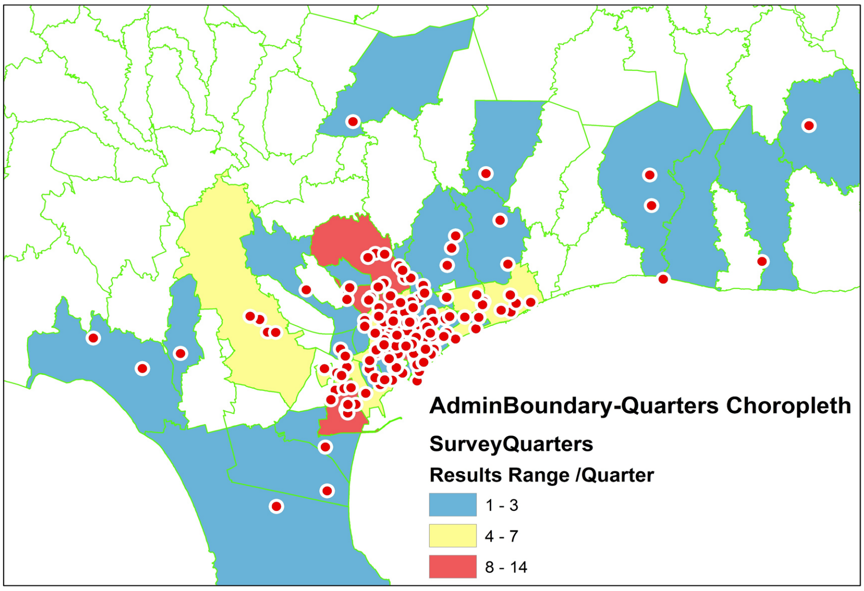

Figure 2. Overview of the submitted results.

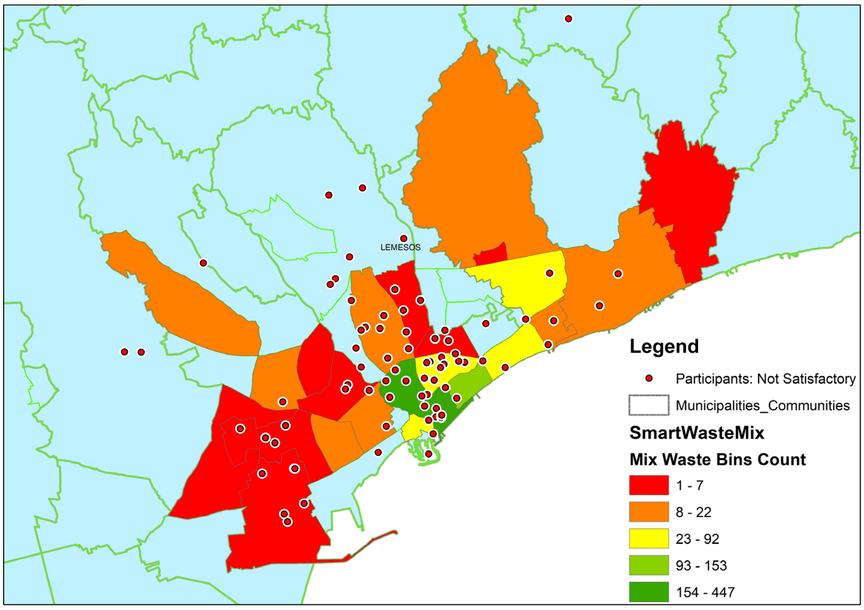

Figure 3. Overview of the submitted results.

The combination of demographic data as shown in **Table 1** unviel that the majority of participants' age is between 30 and 50, whereas their occupation is Private Sector. This group of participants leans to believe that the Municipality efforts are Little to Moderate.

7. Discussion

The integration of geospatial frameworks in smart city development is essential for achieving climate neutrality by 2050, primarily due to their ability to provide accurate and real-time data crucial for informed urban planning and resource management. These technologies are key in monitoring environmental impacts and are alinged with sustainable urban development goals. Survey results based on location and further data analytics have significantly reinforced citizen acceptance of the proposed geospatial framework. Demonstrating the tangible benefits and user-friendly interface of the survey and dashboard applications, these outcomes have shown how the framework can enhance urban living, leading to location based feedback and higher adoption rates among citizens.

An informed citizenry is pivotal in municipal initiatives, as this research highlights. The Citizens Engagement through geospatial applications can lead to creating citizens profiles and target citizens needs more accurately and target specific areas with different landscapes and demographics. When citizens are well-informed and engaged in decision-making processes, the likelihood of successful urban project implementation increases. This is particularly evident when citizens are familiar with technology, a factor this research suggests is prevalent among urban populations. Such familiarity is crucial for the smooth adoption and integration of new technologies in urban planning, as it encourages citizens to utilize and interact with systems they comprehend.

Table 1. Submitted results analytics per age group.

Results	Effort Level					
Groups	Sufficient	None	Little	Moderate	Very Much	Total
16 - 18		1	2	6		9
Other		1	1	4		6
Private Sector				1		1
Student			1	1		2
18 - 30	1	3	8	3		15
Other		1	1			2
Private Sector	1	1	5	2		9
Public Sector			1			1
Student		1	1	1		3
31 - 40	2	6	24	16	1	49
Other		1	1			2
Private Sector		5	18	13		36
Public Sector	2		5	3	1	11
41 - 50	5	16	37	24		82
Other			1			1
Private Sector	3	9	24	21		57
Public Sector	2	7	12	3		24
51 - 60		5	5	5	1	16
Other					1	1
Private Sector		2	3	4		9
Public Sector		3	2	1		6
Above 60	1	1	6	2	1	11
Other		1	2	2		5
Private Sector			4		1	5
Public Sector	1					1
Don't want to answer		2				2
Don't want to answer		2				2
Total	9	34	82	56	3	184

a. The submitted results table shows analytical categorizations.

The proposed smart city integrated geospatial framework stands out for its dynamic and adaptable nature, able to meet the unique needs of different urban environments. This flexibility is key to its effectiveness, allowing for customization and scalability to address diverse urban challenges. Smart city initiatives, as the research concludes, represent a convergence of innovation, environmental management, and community engagement. This integration is vital for holistic urban development, blending technological advancements with sustainable practices and active citizen participation to create more resilient and livable cities.

Furthermore, the proposed framework aligns with the EU Mission towards climate-neutral cities, addressing key challenges such as efficient resource utilization and emission reduction. Its potential lies in offering scalable and adaptable solutions applicable across various urban contexts within the EU. The transformational potential of smart city frameworks and geospatial technologies in creating sustainable, climate-resilient urban areas is underscored in the research. These technologies are not merely tools for urban management but catalysts for a paradigm shift towards more sustainable, efficient, and citizen-centric urban environments, paving the way for a future that is technologically advanced, environmentally responsible, and socially inclusive.

7.1. Support from EU and National Authorities

The European Union and national authorities play a critical role in supporting cities towards climate neutrality. Through initiatives like the EU Mission [11] cities receive essential technical, regulatory, and financial assistance. This support is crucial for the development and implementation of innovative solutions using geospatial technologies. The EU's Horizon Europe program allocates significant funds for research and innovation actions linked to the mission and sets an example for comprehensive support structures that can drive urban transformation. Horizon Europe, with its budget of around €95.5 billion for the period 2021-2027, focuses on fostering scientific excellence, boosting innovation capacity, and delivering impactful solutions to societal challenges, particularly those related to climate change and sustainability.

One of the major outcomes of the Horizon Europe program is the promotion of collaborative research and innovation projects that span across multiple European countries, integrating diverse expertise to tackle complex urban challenges. The program has been instrumental in advancing sustainable urban development, with projects exploring innovative approaches to energy efficiency, waste management, and sustainable transportation. These projects not only contribute to the theoretical understanding of sustainable urban systems but also provide practical, scalable models for city planners and policymakers. Furthermore, Horizon Europe's emphasis on citizen engagement and social innovation ensures that the solutions developed are holistic, inclusive, and responsive to the needs of urban communities. This approach sets a precedent for comprehensive support structures that can drive effective and inclusive urban transformation toward climate neutrality.

7.2. Future Research and Development

Future work could involve enhancing the survey applications to accommodate multiple initiatives and integrating them within smart city portals. Further development of the Dashboards should include additional geospatial data and functionality, such as reporting tools.

Integration of Emerging Technologies: Future research should focus on the integration of emerging technologies such as Blockchain, AI, Virtual Reality, and IoT with geospatial systems to enhance their capabilities in urban planning.

Data Accessibility and Interoperability: Researchers should investigate solutions for improving data accessibility and interoperability among different urban systems and technologies.

Impact Assessment Models: Sophisticated models should be developed to assess the long-term impact of geospatial technologies on urban sustainability and climate action.

Citizen-Centric Approaches: Research should also explore citizen-centric approaches, examining how geospatial data can be used to enhance citizen engagement and participation in urban planning.

8. Conclusions

In conclusion, this research contributes valuable insights into the necessity of geospatial frameworks integrated into smart cities, by proposing a novel smart city integrated geospatial framework. This framework, while adaptable to the unique needs of each city, adheres to established standards and principles. The proposed smart city integrated geospatial framework can be applied in all EU Neutral Climate Smart Cities, aiming for a unified standardized methodology for designing and implementing a smart city enterprise geospatial infrastructure.

The submitted responses and the data analytics showed that this survey was commonly accepted and embraced by citizens, since the sample of 184 submitted questions within a period of one month can be considered sufficient, as shown in **Figure 4**.

The results also showed that citizens no matter the age group, **Table 2**, want and need to be informed about the municipality's initiatives. The methodology chosen in this research showed that citizens are familiar with technology.

Suggestions for future research aim to enhance the generalizability of results and explore emerging technologies' integration into the smart city integrated geospatial framework. With continuous collaboration with local authorities, and

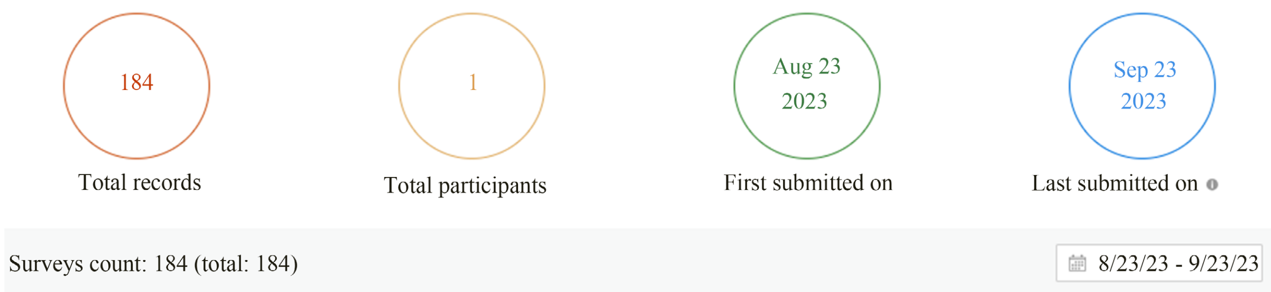

Figure 4. Overview of the submitted results.

Table 2. Submitted results totals per age group.

Age	Sufficient	None	Little	Moderate	Very Much	Total
16 - 18		1	2	6		9
18 - 30	1	3	8	3		15
31 - 40	2	6	24	16	1	49
41 - 50	5	16	37	24		82
51 - 60		5	5	5	1	16
Above 60	1	1	6	2	1	11
Don't want to answer		2				2
Total	9	34	82	56	3	184

a. Total submitted results per age group.

stakeholders, and a commitment to ethical considerations, this framework stands as a dynamic and evolving solution for the ever-changing landscape of urban environments.

This research has underscored the vital role of geospatial technologies in the realm of smart city frameworks, demonstrated in **Table 3**, particularly in advancing the agenda of climate neutrality. Through the examination of the European city case studies of Barcelona, London and Amsterdam, it becomes evident that the integration of geospatial technologies is not just beneficial but essential for effective urban planning and climate action. The challenges, while significant, are outweighed by the immense opportunities these technologies present, especially in enhancing urban sustainability, optimizing resource management, and facilitating informed decision-making.

The way towards climate-neutral cities, as guided by the EU Mission, is both challenging and promising. Smart city initiatives, strengthened by the strategic use of geospatial technologies, are at the forefront of this transition. They represent a convergence of innovation, environmental aspects management, and community engagement. Looking forward, the potential of these initiatives to transform urban landscapes and meet ambitious climate goals is crucial. Continues support from EU and national authorities, along with focused research and development in this field, will be crucial in realizing the full potential of smart city frameworks in achieving a sustainable and climate-resilient future.

Concluding, this research offers significant insights into the integration of geospatial technologies within smart city frameworks, in alignment with the European Union's ambitious goals for achieving climate neutrality by 2050. The study's examination of several European cities demonstrates how these technologies are pivotal in enhancing urban sustainability and combatting climate change. Key findings reveal that geospatial technologies are not only instrumental in improving urban planning and operational efficiency but are also crucial in fostering citizen engagement and informed decision-making.

Table 3. Geospatial framework's key role.

	Smart City Geospatial Framework in Urban Development.		
Transformative role of the Smart City Geospatial Framework in urban development	Crucial tool, empowering city authorities to optimize critical urban infrastructure elements, amplify public services, and enhance emergency response mechanisms	Plays an instrumental role in traffic management, environmental sustainability	Efficient and effective development of diverse applications and platforms
Citizens Engagement Framework	Improving the overall quality of life for residents	Innovative geospatial methodology designed to evaluate citizen feedback	Fosters citizen engagement

a. Smart city geospatial framework contribution.

The case studies from Barcelona, London, and Amsterdam and the specific implementation for Limassol Municipality illustrate practical applications of these technologies. They highlight the importance of collaborative efforts between local authorities, citizens, businesses, and the EU. This synergy is vital for the successful transition to climate-neutral smart cities.

Challenges such as technical complexities, regulatory hurdles, and financial constraints were identified, yet the opportunities presented by advanced geospatial technologies in urban planning significantly outweigh these challenges. The study underscores the need for ongoing support from EU and national authorities, not only in technical and regulatory aspects but also in financial and strategic planning.

This research contributes to the broader discourse on urban sustainability, offering a roadmap for cities worldwide to leverage geospatial technologies towards climate neutrality. Future research should focus on exploring the integration of emerging technologies like AI and IoT with geospatial systems, improving data interoperability, and developing citizen-centric approaches in urban planning.

In summary, the strategic integration of geospatial technologies within smart city frameworks is essential for achieving the EU's climate neutrality goals. This approach provides a model for urban areas worldwide to enhance their sustainability, resilience, and overall quality of urban life.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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