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Decentralized Storage in Smart City Data Infrastructure SWOT Analysis

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ABSTRACT

The rapid growth of data volume and complexity in modern urban environments has created a critical need for storage systems that are secure, scalable, and resilient. This background emphasizes the urgency of adaptive data infrastructure to support smart city development. **This study aims** to provide a comprehensive SWOT analysis of decentralized storage in strengthening smart city data infrastructure. **A qualitative** descriptive-analytical approach is employed, using systematic literature review and document analysis to identify key internal and external strategic factors. **The findings** reveal key strengths, including enhanced data security, high resilience, and scalability. However, weaknesses such as implementation complexity, latency issues, and dependency on network stability are also noted. Opportunities lie in the integration with Internet of Things (IoT) ecosystems, growing public awareness of data privacy, and emerging collaborative economic models. Meanwhile, threats include regulatory ambiguity, lack of standardization, and evolving cybersecurity risks. **This study contributes** a strategic framework to assist policymakers, urban planners, and technology stakeholders in integrating decentralized storage systems into smart city architectures. In alignment with the **Sustainable Development Goals (SDGs)**, particularly Goal 11 (Sustainable Cities and Communities) and Goal 9 (Industry, Innovation, and Infrastructure), the research highlights the importance of secure, inclusive, and adaptive digital infrastructure in advancing sustainable urban development.

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1. INTRODUCTION

The efficient and secure management of data serves as the backbone for developing a sustainable and functional Smart City. In the vision of smart urban environments, data flows from diverse sources ranging from traffic sensors and surveillance cameras to IoT devices in households and public facilities fueling intelligent services like energy optimization, waste management, and emergency response. Without a reliable data management system, efforts to create more responsive, efficient, and livable cities will be hampered, diminishing the full potential of Smart City initiatives [1].

However, traditional approaches to Smart City data management often rely on a Centralized data model [2]. While this offers initial ease of administration, it's vulnerable to significant risks. Concentrating data in one or a few central locations makes it a prime target for cyberattacks, privacy breaches, and single points of failure [3]. Furthermore, as data volumes continuously grow, the costs associated with storing and maintaining centralized infrastructure also soar, creating substantial financial and operational hurdles [4].

Recognizing these challenges, there's an urgent need to explore more resilient and distributed data storage solutions [5]. The concept of decentralized storage, exemplified by technologies like InterPlanetary File System (IPFS) and Filecoin, offers a new paradigm [6]. These technologies allow data to be redundantly stored across numerous independent nodes within a network, rather than solely on a central server [7]. This approach inherently enhances security, censorship resistance, and cost-efficiency, while simultaneously mitigating the risk of single system failures [8].

The urgency of adopting these future proof storage solutions is becoming increasingly evident with the exponential growth of IoT data. Trillions of devices are projected to be connected in the coming years, generating unprecedented volumes of data. Smart City data infrastructure must be prepared to effectively and securely accommodate and manage this influx [9]. In line with the Sustainable Development Goals (SDGs), particularly Goal 11 on sustainable cities and communities. Decentralized storage isn't merely an alternative; it's a necessity for building a scalable and secure data foundation for future Smart Cities [10].

While the potential of decentralized storage is highly promising, there remains significant novelty in specific studies linking these technologies to smart city data infrastructure [11]. To date, there hasn't been extensive, specific SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis examining the implementation of IPFS or Filecoin within the Smart City context, especially in developing countries like Indonesia [12]. This research gap highlights the imperative for further exploration to understand the feasibility, challenges, and tangible benefits of adopting these technologies [13].

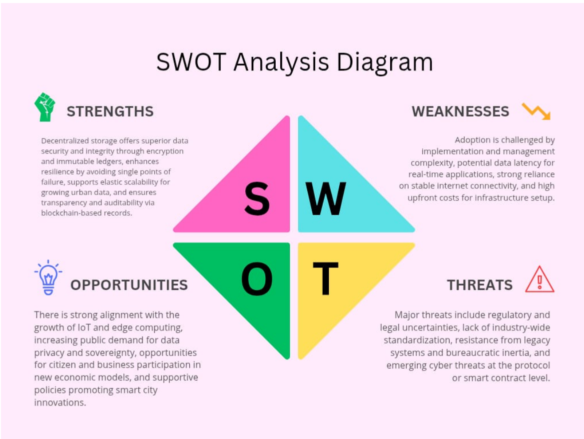

Figure 1. SWOT Analysis Diagram

Figure 1 illustrates the SWOT analysis of decentralized storage in the context of smart city data infrastructure [14]. This visual representation highlights the internal strengths such as enhanced data security, resilience, and scalability as well as the weaknesses, including implementation complexity and potential latency issues. It also outlines the external opportunities driven by the rise of IoT and data privacy concerns, alongside significant threats such as regulatory ambiguity and lack of standardization. This diagram provides a strategic foundation to understand how decentralized storage can support more robust, adaptive, and secure urban data systems.

2. LITERATURE REVIEW

The success of smart cities depends heavily on how effectively they manage the vast and ever-growing flow of urban data. As cities become more interconnected through various digital systems and sensor technologies, the demand for reliable, secure, and adaptable data infrastructure is becoming more urgent [15]. Conventional centralized storage systems are increasingly unable to keep pace with these demands, prompting a need to explore innovative alternatives. Decentralized storage has emerged as a promising solution, offering a shift in how data is stored, protected, and accessed. The following subsections provide a comprehensive discussion on the challenges of traditional smart city data infrastructure, the architectural principles of decentralized storage, its practical applications, and the key barriers that must be overcome to enable its successful implementation.

2.1. Smart Cities and Data Infrastructure Challenges

Smart cities, defined as urban ecosystems integrating information and Communication technologies (ICTs) to enhance quality of life and operational efficiency, rely heavily on robust data infrastructure. At the core of their functionality is data, continuously generated from diverse sources like IoT sensors, intelligent transportation systems, and public utilities. This data's massive volume (big data), varied formats, and rapid production present fundamental challenges for traditional ICT infrastructure. Centralized storage models, which have historically dominated data architectures, exhibit inherent limitations in coping with this scale and complexity. Vulnerabilities to cyberattacks and single points of failure, the risks of vendor lock in, and difficulties in achieving optimal scalability for exponential data growth are critical concerns. Consequently, the literature underscores the critical value of developing data storage solutions that are not only secure and efficient but also exceptionally resilient and adaptive to support the evolution of smart cities.

2.2. Concepts and Architecture of Decentralized Storage

Decentralized storage represents a fundamental paradigm shift from traditional centralized data storage models [16]. This concept involves distributing data across a network of geographically dispersed nodes, often leveraging Distributed Ledger Technology (DLT) like blockchain. This approach enables data to be encrypted, immutable, and cryptographically verifiable. Data is broken into small fragments, encrypted, and then distributed among numerous nodes in the network, ensuring redundancy and resilience against individual node failures [17]. Decentralized architectures typically include peer-to-peer (P2P) networks for data transfer, consensus mechanisms (if blockchain based) for transaction validation, and economic incentives to encourage node participation. The primary value of this architecture lies in enhanced security through data distribution and encryption, mitigation of DDoS risks, and the potential for significant cost efficiencies by utilizing dispersed storage capacity. For instance, the (IPFS) operates on a P2P protocol that stores and retrieves content based on its cryptographic hash rather than location, reducing risks of single-point failure and enhancing censorship resistance. Filecoin, as an incentive layer built on top of IPFS, introduces an economic model where participants are rewarded for providing storage capacity, thereby ensuring reliability and scalability. Together, these architectures directly address key challenges identified in the literature, such as data availability, resilience, and cost management. Furthermore, its permissionless nature on some platforms fosters innovation and broader access to storage services.

2.3. Applications and Potential of Decentralized Storage in Smart Cities

The implementation of decentralized storage holds immense transformative potential for various smart city applications. Specifically, the literature highlights its crucial role in IoT data management, where the massive data volumes from billions of devices can be stored and managed more efficiently and securely, reducing reliance on centralized clouds [18]. This supports the concept of edge computing, decreasing latency and network load. Furthermore, decentralized storage can significantly enhance citizen data security and privacy, offering more granular control and an immutable audit trail, thereby building public trust in urban data utilization. Additional added value includes facilitating secure inter departmental data sharing, enabling data collaboration with private entities, and supporting other blockchain applications like digital identity and smart contract-based public services. This promises the construction of more transparent In addition, insights from empirical case studies and pilot projects in Indonesia and the ASEAN region are reviewed to strengthen the practical relevance of the SWOT framework [19]. For instance, smart city initiatives addressing latency challenges in intelligent transportation or environmental monitoring systems provide valuable lessons on hybrid adoption strategies. By incorporating these findings, the methodology not only reflects theoretical perspectives but also demonstrates how decentralized storage solutions are being tested in practice. and censorship-resistant data infrastructure. From an interdisciplinary perspective, decentralized storage also opens pathways for innovative economic models such as citizen-incentivized storage contribution or data-sharing cooperatives. For example, cities can encourage local small and medium enterprises (SMEs) to provide unused storage capacity in exchange for economic incentives, fostering inclusive growth. Insights from urban sociology further highlight how participatory data governance can enhance social trust and encourage citizen engagement in smart city development. These examples illustrate how the concept of new economic models can be translated into practical frameworks that integrate both technological and social dimensions.

2.4. Challenges and Future Research Directions

Despite the promising potential of decentralized storage for smart cities, the literature also identifies several crucial challenges that must be addressed for widespread adoption. A primary concern is Performance and latency for real-time applications, where decentralized networks may still lag behind centralized data centers [20]. Additionally, implementation complexity and integration with existing legacy city systems present significant hurdles, requiring specialized technical expertise and substantial initial investment. Aspects of regulation and governance also require clarification, particularly concerning data sovereignty and compliance with privacy regulations like GDPR in a decentralized environment [21]. A lack of protocol standardization and interoperability among divers decentralized platforms remains a concern. Therefore, future research directions should focus on developing solutions that improve performance, simplify implementation, design adaptive regulatory frameworks, and identify optimal economic incentive models for the sustainability of city-scale decentralized storage networks [22].

3. RESEARCH METHODE

This section outlines the approach, design, and procedures used in this research to achieve its stated objective: conducting a SWOT analysis of decentralized storage within the context of resilient smart city data infrastructure[23].

3.1. Research Approach

This research adopts a qualitative approach with a focus on a descriptive-analytical study [24]. A qualitative approach is chosen because it allows for an in-depth exploration of complex phenomena such as the application of new technologies in urban environments, as well as a nuanced analysis of various factors influencing adoption [25]. The descriptive analytical nature enables the identification, collection, and interpretation of data related to the strengths, weaknesses, opportunities, and threats of decentralized storage, followed by a systematic analysis to gain strategic insights [26].

3.2. Research Design

The design of this research is a SWOT Analysis [27]. SWOT analysis is a strategic framework used to evaluate the competitive position of a project, product, or entity by identifying internal factors (Strengths and Weaknesses) and external factors (Opportunities and Threats) [28].

Figure 2 presents a concept map that outlines the key factors influencing the implementation of decentralized storage in smart city data infrastructure. These factors are grouped into internal aspects, external opportunities, and external challenges.

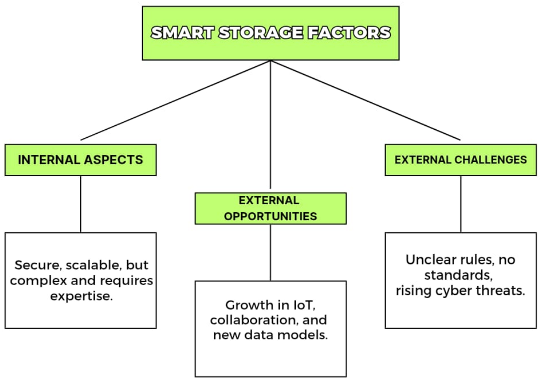

Figure 2. Smart Storage Factors

As illustrated in Figure 2, internal aspects include both strengths and limitations of decentralized storage. External opportunities reflect positive trends that support its adoption, while external challenges represent risks that may hinder its effectiveness in smart city environments.

- Strengths: Identifies favorable and relevant internal attributes of decentralized storage that support smart city data infrastructure (inherent security, resilience, scalability) [29].
- Weaknesses: Identifies unfavorable internal attributes or shortcomings of decentralized storage in this context (complexity, potential latency, expertise requirements) [30].
- Opportunities: Identifies favorable external factors that can be leveraged for the benefit of decentralized storage development in smart cities (IoT trends, potential collaborations, new economic models) [31].
- Threats: Identifies potentially detrimental external factors that could hinder the implementation of decentralized storage in smart cities (unclear regulations, lack of standardization, evolving cyber threats) [32].

3.3. Data Sources and Collection Methods

Data for this research will be collected through two primary methods:

- Systematic Literature Review: Primary data collection will involve a comprehensive literature review of academic journals, conference proceedings, technical reports, and other relevant publications discussing smart cities, data infrastructure, decentralized storage, blockchain, IoT, and cybersecurity [33]. The literature will be analyzed to identify arguments, findings, and perspectives related to each SWOT element [34].
- Document/Case Study Analysis: Secondary data will be obtained from the analysis of local and national government policy documents concerning smart city development, industry reports on storage technology trends, and case studies of implemented smart city or decentralized storage pilot projects globally [35]. This method will help identify external factors (Opportunities and Threats) and implementation contexts [36]. In addition, insights from empirical case studies and pilot projects in Indonesia and the ASEAN region are reviewed to strengthen the practical relevance of the SWOT framework. For instance, smart city initiatives addressing latency challenges in intelligent transportation or environmental monitoring systems provide valuable lessons on hybrid adoption strategies. By incorporating these findings, the methodology not only reflects theoretical perspectives but also demonstrates how decentralized storage solutions are being tested in practice.

3.4. Data Analysis Techniques

The collected data will be analyzed using Thematic Analysis within the SWOT framework[37].

- Data Extraction: Relevant information from the literature and documents will be extracted and categorized into initial themes related to the characteristics and impacts of decentralized storage [38].
- SWOT Categorization: The extracted themes will then be systematically grouped into the four SWOT categories [39]. This process involves distinguishing between internal factors (inherent to the technology itself) and external factors (originating from the external environment) [40].
- Synthesis Analysis: Once categorized, each SWOT element will be analyzed in depth to identify relationships, implications, and its relative weight in supporting or hindering resilient smart city data infrastructure. This analysis will also involve identifying potential strategies emerging from combinations of SWOT elements (SO - Strength-Opportunity, WO - Weakness-Opportunity, ST - Strength-Threat, WT - Weakness-Threat), although the primary focus will remain on the identification of the SWOT elements themselves [41].
- Validation: The findings of the analysis will be cross-referenced against the broader literature to ensure the consistency and validity of interpretations [42].

4. RESULTS AND DISCUSSION

4.1. SWOT Analysis Results

Based on the systematic literature review and document analysis conducted, the identified Strengths, Weaknesses, Opportunities, and Threats of decentralized storage in the context of smart city data infrastructure are as follows:

Table 1. SWOT Analysis of Decentralized Storage in Smart Cities

Category	**Key Points**
Strengths	Decentralized storage provides strong data security and integrity. It ensures high availability without a single point of failure, is highly scalable to accommodate urban data growth, and enables transparent and auditable recordkeeping.
Weaknesses	Implementation is complex and requires specialized technical expertise. It may cause latency for real-time applications, depends on stable internet connectivity, and involves high initial investment costs.
Opportunities	The growth of IoT and edge computing creates strong alignment with decentralized storage. Rising public awareness of data privacy and sovereignty, along with opportunities for collaborative innovation and supportive smart city policies, further enhance its potential.
Threats	There are regulatory and legal uncertainties surrounding decentralized technologies. The lack of standardization across platforms, resistance from legacy systems, and evolving cybersecurity risks at the protocol level pose significant challenges.

Table 1 provides a concise SWOT Analysis summary for implementing decentralized storage in smart city data infrastructure [43]. It details strengths like enhanced security and resilience, alongside weaknesses such as implementation complexity [44]. The table also identifies opportunities from IoT trends and increased privacy awareness, while highlighting threats like regulatory ambiguity. This strategic overview serves as a foundational understanding of decentralized storage's potential and challenges in building resilient smart cities [45]. To ensure transparency, each element of the SWOT analysis was derived through thematic synthesis of the reviewed literature and policy documents. Strengths and weaknesses were identified by tracing recurring technical attributes such as security, scalability, and implementation complexity across multiple studies, while opportunities and threats were drawn from external trends in IoT adoption, regulatory debates, and evolving cybersecurity risks. This analytical process clarifies how the summarized findings in Table 1 directly connect to evidence from prior research, thereby enhancing credibility and practical relevance for stakeholders.

4.2. Leveraging Strengths for Building Resilient Infrastructure

The intrinsic strengths of decentralized storage particularly its superior security, failure resilience, and elastic scalability directly address the core weaknesses of traditional centralized data infrastructures commonly used in cities across Indonesia and ASEAN. Amidst rising cyber threats targeting critical infrastructure, decentralization's ability to withstand centralized attacks and ensure the continuous availability of essential public services (e-government systems, digital health services) represents a crucial value proposition [46]. Its scalable flexibility is also highly pertinent for Indonesian cities experiencing rapid urbanization and exponential data growth [47]. Adopting decentralized solutions can form a foundation for urban data architectures that are not only efficient but also inherently more secure and adaptable to the dynamic pace of urban development [48].

4.3. Addressing Weaknesses for Effective Adoption

Weaknesses such as implementation complexity and potential data latency for real-time applications are critical challenges requiring careful strategies and innovation [49]. Implementing decentralized storage is highly complex and requires specialized technical expertise. This can be a significant challenge for cities with varying levels of digital literacy and tech talent, especially in developing regions such as Indonesia, where readiness and availability of human resources are not evenly distributed. Therefore, strengthening capacity building and simplifying technical frameworks are crucial to mitigate these barriers. In Indonesia, where digital literacy levels and the availability of tech talent may vary, simplifying implementation tools and enhancing local human resource capacity become paramount [50]. Regarding latency, one of the most promising solutions lies in the development of a hybrid infrastructure [51]. The system may experience latency that affects applications requiring real-time data. Before widespread adoption, latency issues for critical applications like intelligent transportation and emergency response must be addressed to ensure service reliability and public safety. A phased integration strategy that combines decentralized storage with optimized centralized systems can help mitigate these risks while gradually building trust in the technology. This would involve integrating decentralized storage for archival data, non-critical sensor data, or as a highly secure backup layer, while real-time and highly sensitive data continue to be managed by optimized local centralized infrastructure. This hybrid approach allows cities to reap the security and scalability benefits of decentralization without compromising vital performance [52]. Another crucial consideration is the reliance of decentralized storage on stable internet connectivity. In regions where network infrastructure is uneven, system performance and data accessibility may be disrupted. To overcome this challenge, cities need to invest in strengthening broadband infrastructure and explore localized edge-computing nodes that reduce dependency on constant high-bandwidth connections. However, another major barrier lies in the substantial initial investment costs required for infrastructure deployment. For many cities in developing regions, limited financial resources can delay large-scale adoption. To address this, phased implementation strategies, public-private partnerships, and integration with existing infrastructure are recommended as practical approaches to reduce financial burden while still achieving long-term resilience benefits.

4.4. Capitalizing on Opportunities for Local Innovation and Growth

Global trends in the IoT and edge computing present the most significant opportunities for decentralized storage adoption in ASEAN cities. Cities in Indonesia, for instance, are actively developing IoT ecosystems for smart transportation, waste management, or environmental monitoring. The massive data volumes generated by these IoT devices are ideally suited for decentralized storage and processing at the network edge [53]. This reduces the load on centralized clouds, minimizes latency, and maintains data sovereignty at a local level. Increasing awareness of data privacy among citizens also encourages cities to seek solutions that offer greater citizen control, a position naturally filled by decentralized storage. Furthermore, collaborative models and new economic paradigms supported by decentralization such as cities incentivizing citizens or local SMEs to provide unused storage capacity can foster a more inclusive and cost-efficient data ecosystem, driving grassroots innovation.

4.5. Managing Threats and Building Adaptive Frameworks

The most significant threats, especially in the Indonesian and broader ASEAN context, are regulatory ambiguity and a lack of industry standardization. City governments require legal clarity regarding data ownership, interoperability between decentralized platforms, and compliance with existing data privacy laws. The role of central and local governments is crucial in shaping adaptive and pro-innovation regulatory frameworks that do not stifle the development of this technology. Equally important is the establishment of standardized protocols to ensure interoperability among various decentralized platforms. Without clear technical standards, cities may face fragmentation, reduced efficiency, and limited scalability. Collaborative efforts between governments, technology providers, and international bodies are therefore essential to build a harmonized framework that supports sustainable adoption. Overcoming resistance to change within urban bureaucracies can be achieved through pilot projects that demonstrate clear success stories and a tangible return on investment. By adopting a phased implementation and focusing on risk mitigation, cities can effectively manage existing threats and fully leverage the potential of decentralized storage for truly resilient smart city data infrastructure.

5. MANAGERIAL IMPLICATIONS

5.1. Implications of Research

The findings of this research have several important implications for developing resilient smart cities, particularly in the context of data management. First, identifying the inherent strengths of decentralized storage in terms of security, resilience, and scalability suggests this technology isn't just a niche innovation. Instead, it's a potential foundation for future urban data architectures. The implication is that cities no longer need to rely entirely on vulnerable centralized models, paving the way for more effective mitigation of cyber risks and vendor lock in. Second, recognizing weaknesses and threats like implementation complexity, latency, and regulatory ambiguity implies that adoption isn't an instant or challenge-free process. This demands a strategic, phased approach, alongside investment in developing technical capabilities and supportive regulatory frameworks. The implication here is the need for well-defined pilot projects to test feasibility and build trust before full-scale adoption. Third, highlighting significant opportunities from trends like IoT, edge computing, and increased data privacy awareness implies that now is a particularly opportune moment to explore decentralized storage. Cities proactive in leveraging these opportunities can position themselves as leaders in secure, participatory data governance innovation, meeting citizens' expectations for transparency and control over their personal data. The primary implication is the potential to create new economic models and more inclusive, efficient cross-sector collaborations in managing public data assets.

5.2. City Governments and Policymakers

- Developing Adaptive Regulatory Frameworks involve Establish or adapt clear legal and policy frameworks for decentralized storage, addressing aspects like data sovereignty, privacy (GDPR or Personal Data Protection Law compliance), and legal liabilities. This will reduce uncertainty for adoption in both public and private sectors. For example, adaptive regulatory frameworks could specify clear data ownership rights in decentralized networks, outline compliance mechanisms aligned with laws such as the PDP Law in Indonesia, and establish accountability guidelines for service providers. By clarifying these aspects, governments can directly address data sovereignty ambiguities while promoting innovation-friendly policies that encourage broader adoption of decentralized storage.
- Investing in Pilot Projects: Initiate small-scale pilot projects to test the technical and operational feasibility of decentralized storage in specific smart city applications (environmental sensor data, local supply chain management). This will build proof of concept and validate return on investment.
- Promoting Standardization and Interoperability: Encourage collaboration among stakeholders to develop uniform standards and protocols, facilitating interoperability between various decentralized platforms and existing city systems.

5.3. Technology Developers and Solution Providers

- Focusing on Implementation Simplification: Develop more user-friendly tools, APIs (Application Programming Interfaces), and frameworks to simplify the implementation and integration of decentralized storage into existing city infrastructure.
- Optimizing Performance for Critical Applications: Invest in research and development to enhance the performance and reduce latency of decentralized networks, especially to meet the needs of smart city applications highly reliant on real-time data.
- Hybrid and Modular Models: Design solutions that are modular and can be integrated in a hybrid manner with existing centralized infrastructure. This will enable gradual adoption and risk mitigation.

5.4. Research Institutions and Academics

- Further Empirical Case Studies: Conduct more in-depth empirical research on actual implementations of decentralized storage in smart cities to objectively measure its impact on performance, security, and efficiency.
- Research on Decentralized Data Governance: Explore effective data governance models in decentralized environments, including incentive mechanisms for node participation and dispute resolution.
- Developing Expertise and Curriculum: Develop educational and training programs to produce talent with expertise in decentralized technologies and their applications in the smart city context.

6. CONCLUSION

The SWOT analysis of decentralized storage in the context of smart city data infrastructure reveals significant potential in strengthening urban data ecosystems. Its main strengths are enhanced security, resilience against failures, and adaptive scalability. These characteristics provide a strong foundation for building smart city systems that are more reliable and less vulnerable to cyberattacks or single points of failure.

However, the findings also highlight several challenges that need careful consideration. Technical complexity, latency issues, and high initial investment costs represent barriers to large-scale adoption. Furthermore, the absence of clear regulatory frameworks and interoperability standards creates uncertainty that must be addressed through adaptive governance and collaborative efforts among stakeholders.

Despite these challenges, decentralized storage presents substantial opportunities when aligned with emerging technologies such as IoT and edge computing. It supports data privacy, transparency, and citizen participation in smart city governance. With the right combination of supportive policies, pilot projects, and capacity building, decentralized storage can play a transformative role in creating secure, scalable, and sustainable smart city data infrastructures.

7. DECLARATIONS

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7.2. Author Contributions

Conceptualization: RN, EA, and CT; Methodology: NS; Software: IS; Validation: RN and NS; Formal Analysis: IS and CT; Investigation: EA; Resources: IS; Data Curation: RN; Writing Original Draft Preparation: RN and EA; Writing Review and Editing: NS; Visualization: CT; All authors, RN, EA, CT, NS and IS, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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