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Designing a Sustainable ICT Infrastructure Framework for Nusantara: Enabling Smart City Governance and Environmental Resilience in Indonesia's New Capital

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ABSTRACT

This study presents a sustainable ICT infrastructure framework to support the development of Nusantara, Indonesia's new capital city, in alignment with smart and green city principles. The objective is to enable efficient urban management, environmental sustainability, and data-driven governance through technological integration and multi-level coordination. The proposed framework is structured into four levels: prerequisites, enabling technologies, strategic domains, and outcome indicators. It incorporates advanced technologies such as AI, IoT, big data analytics, and digital twins to optimize resource use, energy efficiency, and service delivery. The research methodology includes literature review, document analysis, conceptual modelling, and framework validation. Validation was conducted through alignment with the ICT ecosystem, the Smart City Management System, and the official Nusantara smart city development blueprint. Results demonstrate the framework's scalability, adaptability, and alignment with sustainability and governance goals. It supports hierarchical decision-making, real-time monitoring, and phased implementation. The study concludes with recommendations for further research, including pilot projects, network optimisation, and the creation of a virtual capital city using digital twin technology.

1. INTRODUCTION

The relocation of Indonesia's capital city from Jakarta, located on Java Island, to Nusantara on Kalimantan Island necessitates extensive and strategic planning, particularly in the development of Information and Communication Technology (ICT) infrastructure. The designated site for the new capital remains largely undeveloped, comprising expansive tropical rainforests with minimal existing physical and digital infrastructure. This transformation presents significant challenges, especially in prioritizing ICT development to ensure seamless integration with national governance systems. As Nusantara is envisioned to serve as the central hub for data and digital services supporting the administration of 38 provinces, 416 regencies, and 98 cities across Indonesia—serving a population exceeding 270 million—there is a pressing need to establish a robust and sustainable ICT foundation. The success of this relocation relies heavily on the ability to plan, implement, and manage ICT systems that align with smart city principles while maintaining ecological integrity and promoting sustainable urban development.

This study is guided by two central research questions: (1) How can the planning and design of ICT infrastructure development be effectively undertaken in the new capital? and (2) How can the staged implementation of ICT infrastructure best support the realization of a smart and green city? These questions frame the formulation of the proposed ICT infrastructure framework, elaborated in the subsequent sections.

Given the scale and complexity of this transition, the implementation of ICT infrastructure must be approached in a phased and strategic manner to ensure seamless integration with existing national and regional systems. The focus extends beyond technological innovation to include environmental sustainability, in line with the vision of Nusantara as a smart and green city [1, 2]. The deployment of advanced technologies—such as the Internet of Things (IoT), Artificial Intelligence (AI), and big data analytics—is essential to enhance public service delivery, enable efficient urban governance, and support ecological monitoring and management.

In addition, the accelerated digital transformation observed in Indonesia during the COVID-19 pandemic has underscored the increasing dependence on telecommunication technologies, including teleconferencing, digital education platforms, and remote collaboration tools. These developments present a timely opportunity to integrate next-generation systems, such as 2D teleconferencing and immersive 3D metaverse platforms, into the planning and administration of the new capital. Such innovations directly contribute to smart city governance by enabling virtual public

services, remote decision-making, and immersive planning simulations—thus enhancing administrative flexibility, citizen engagement, and efficient infrastructure design within a digital governance ecosystem. Ensuring robust digital connectivity, data protection, and cyber resilience—through secure encrypted communications and the establishment of a national intranet—will be critical in supporting the governance, transparency, and functionality of Nusantara as a technologically advanced and sustainably planned capital.

A range of emerging technologies can be utilized and further developed to support the construction and administration of Indonesia's new capital. Big data and open data platforms provide essential tools for collecting, integrating, and analyzing national-scale information to inform decision-making and public policy. Metaverse technologies, combined with advanced teleconferencing platforms, offer immersive 2D and 3D environments for conducting virtual meetings and remote collaborations [3]. In the domain of urban planning, the integration of metaverse platforms with Building Information Management (BIM) technologies facilitates comprehensive, unified, and interactive planning processes prior to real-world implementation [4, 5].

Moreover, digital twin technology provides the ability to replicate physical systems in digital environments, allowing for real-time monitoring, simulation, and management of public services [6, 7]. This facilitates continuous consistency checking and synchronization between the physical and digital realms, enhancing operational reliability.

The Indonesian government has also initiated the implementation of the Electronic-Based Government System (Sistem Pemerintahan Berbasis Elektronik, or SPBE), which is being progressively adopted from the local to national levels to support transparent, accountable, and efficient governance [8]. This initiative will be sustained and expanded as a core component of the country's broader digital transformation strategy. In this context, AI technologies serve as enablers of automation, increasing the effectiveness and efficiency of public administration processes [9].

2. METHODOLOGY

This study adopts a systematic research approach that combines literature review, document analysis, framework development, and validation to propose a sustainable ICT infrastructure framework tailored for Nusantara, Indonesia's forthcoming capital city. The research materials comprise regulatory and policy documents, smart city conceptual models, empirical case studies, and technical literature related to ICT infrastructure and sustainability principles. These sources provide a comprehensive foundation for understanding the requirements, challenges, and best practices in smart and green city planning. The research methodology is illustrated in Figure 1, which outlines the sequential stages of the study, including literature exploration, regulatory and technical document analysis, conceptual framework design, and subsequent framework validation.

2.1 Literature study

The literature study in this research examines global practices and strategies in the development of ICT infrastructure for capital cities and smart urban environments. Key areas of focus include emerging technologies such as the metaverse, digital twin systems, and the evolving work-from-anywhere (WFA) paradigm. The review aims to deepen the understanding of the technological landscape and assess the applicability of these innovations within the context of Nusantara's development as a smart and green capital. Comparative analyses of selected countries—namely Malaysia, South Korea, Estonia, and China—were conducted based on their demonstrated digital maturity, innovative approaches to smart city implementation, and contextual relevance to Indonesia's developmental goals, as shown in Table 1. These countries represent diverse geographic, political, and technological contexts, offering a broad spectrum of insights applicable to Nusantara's ICT infrastructure planning. These international perspectives serve as benchmarks to inform the formulation of a contextually relevant ICT infrastructure framework for Indonesia's new capital.

Figure 1. Research methods

Table 1. Comparison of key takeaways from each country

Country	Digital Governance Model	Key Technologies Adopted	Implementation Strategy	Key Takeaways for Nusantara
Malaysia	E-govern-ment integration in Putrajaya; dual-city model with Cyberjaya as tech hub	IoT, high-speed internet, digital identity	Government-led, public-private collaboration, long-term tech park vision	Strategic dual-city model and tech-based planning zones
South Korea	Centralized smart governance with advanced public service platforms (e.g., AR Incheon)	AR, AI, big data, smart tourism	Strong national funding, public-private innovation hubs	Use of immersive tech and central coordination platforms
Estonia	Highly digitalized public services with e-Residency and digital ID systems	Blockchain, digital ID, cloud services	Digital-first policy with citizen-centric design	User-centric design, strong legal frameworks, and interoperability
China	Top-down policy implementation with national smart city pilots (900+ cities)	IoT, AI, digital twins, 5G	Large-scale pilot programs and national standards	Scalable urban technologies with strong state coordination

2.2 Document reviews

The document review component of this study involves a critical analysis of key regulatory and planning documents relevant to infrastructure development and ICT governance in Indonesia. A qualitative content analysis approach was employed to identify recurring themes, strategic directives, and institutional arrangements. The analysis followed a guideline-based checklist adapted from smart city and ICT governance frameworks to ensure consistency and policy alignment. Primary sources include:

(1) The SPBE regulations [8];

(2) The Indonesia One Data (Satu Data Indonesia) framework [10]; and

(3) The development plans for Nusantara and its supporting buffer zones [11].

These documents are examined to identify existing policy directions, strategic objectives, and institutional arrangements pertaining to ICT implementation. The analysis highlights the gaps between current infrastructure conditions and the envisioned targets for Nusantara, thereby informing the definition of technical and institutional requirements for a sustainable ICT infrastructure framework. Furthermore, the review assesses regulatory alignment, compliance mechanisms, and governance strategies that are essential for supporting Indonesia's ongoing digital transformation agenda within the context of smart and green capital city development.

In addition to literature and policy document analysis, this study incorporated expert insights through informal consultations and policy validation meetings with stakeholders involved in the planning and development of Nusantara. These included representatives from the Ministry of National Development Planning of the Republic of Indonesia (Badan Perencanaan Pembangunan Nasional - Bappenas), the Nusantara Capital City Authority (Otorita Ibu Kota Nusantara), the Provincial Government of East Kalimantan, the Regency Government of Penajam Paser Utara, and the Indonesian Association of Urban and Regional Planners (Ikatan Ahli Perencanaan - IAP). These consultations provided contextual understanding of regulatory frameworks, practical implementation considerations, and alignment with the national vision for Nusantara as a smart and green capital.

2.3 Framework design

The ICT infrastructure development framework is designed to guide planning and implementation in alignment with smart and green city principles. The design process integrates:

(1) Insights from literature and document reviews.

(2) Lessons learned from case studies of other countries.

(3) Emphasis on sustainability, including energy efficiency, environmental monitoring, and disaster management using technologies such as IoT, AI, and big data analytics.

The framework aims to address the complexity and scalability of ICT systems while ensuring adaptability to future technological advancements.

To support practical understanding, the framework design also incorporates conceptual examples to illustrate potential applications. For instance, the integration of IoT sensors and AI algorithms for smart water management can enable real-time monitoring, leakage detection, and predictive maintenance. Similarly, digital twin technology can simulate disaster response scenarios to support early warning systems and infrastructure resilience planning. These illustrative use cases demonstrate how each layer of the framework—from prerequisites to outcomes—can guide structured implementation in the context of Nusantara's development as a smart and green capital.

The framework also incorporates feedback loops to ensure adaptive and responsive governance. This is achieved by embedding real-time data collection systems—such as IoT-based environmental sensors and digital twin platforms—that continuously monitor key indicators (e.g., air quality, water levels, or energy consumption). Insights generated from these systems are fed back into decision-making processes at various levels, enabling dynamic policy adjustments, early interventions, and continuous improvement across strategic domains such as environmental management, public safety, and infrastructure resilience.

2.4 Framework validation

The validation process assesses the feasibility, applicability, and functional robustness of the proposed ICT infrastructure framework through targeted case-based analysis. The validation was conducted internally by the research team, drawing on interdisciplinary expertise in smart city planning, ICT systems, and urban governance. In addition, the process was supported by informal consultations with institutional stakeholders, including representatives from the Ministry of National Development Planning (Bappenas), the Nusantara Capital Authority (Otorita IKN), and the Provincial Government of East Kalimantan. Their input helped ensure contextual relevance and policy alignment in evaluating the framework's practical applicability. Validation materials include:

1) the ICT infrastructure ecosystem,
2) smart city management systems, and
3) alignment with the Nusantara Capital Development Masterplan [11].

Table 2. Summary of validation criteria for each component

Component	Validation Focus	Key Indicators / Aspects Evaluated
ICT Infrastructure Ecosystem	Structural feasibility and readiness	Network architecture, data centers, digital platforms, human capital
Smart City Management System	Functional capacity and technological integration	Real-time monitoring, operational efficiency, use of IoT, AI, and analytics
Blueprint Alignment	Policy and strategic coherence with national development goals	Conformity with Nusantara Smart City Blueprint, sustainability targets, digital governance objectives

Given the long-term and large-scale nature of Nusantara's development, the validation does not involve full-scale implementation but instead employs theoretical evaluation and small-scale simulations. These simulations were scenario-based rather than model-driven, focusing on conceptual applications of the framework—such as smart water management and disaster response—under assumed operational conditions to evaluate its functionality, scalability, and policy alignment. The results provide insights into the framework's adaptability, scalability, and potential integration

with existing governance and planning systems, ensuring its relevance for guiding the digital transformation of Indonesia's new capital.

To enhance clarity and provide a structured overview of the validation process, Table 2 summarizes the validation focus and key indicators used to assess each of the three core components: the ICT infrastructure ecosystem, the smart city management system, and alignment with the Nusantara Smart City Blueprint. This summary helps to illustrate how the proposed framework was evaluated in terms of technical feasibility, functional robustness, and policy coherence.

3. RESULTS AND DISCUSSION

3.1 Literature study and document reviews

The concept of a smart city has been widely examined as a transformative approach that integrates digital technologies across multiple urban sectors, including infrastructure, energy, housing, public safety, and mobility [12-17]. Giffinger et al. [18] identify six key dimensions of a smart city: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. These dimensions serve as both conceptual pillars and performance indicators for evaluating smart city implementation. Within the context of Indonesia's planned capital, Nusantara, located in Kalimantan—a region recognized for its ecological richness and critical role as one of the world's "lungs"—the smart city vision must be grounded in principles of environmental sustainability [19, 20].

Among the most promising digital innovations is the metaverse, which merges physical, augmented, and virtual realities within a shared digital space [21]. Mystakidis [22] classifies the metaverse into four key dimensions: affordances, technologies, challenges, and principles. Technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) underpin metaverse development, while its guiding principles emphasize openness, interoperability, and user-centered design. Despite challenges related to well-being, privacy, and ethics, the metaverse has shown significant potential in improving education, remote interaction, and collaborative work environments [23].

Complementing the metaverse is the concept of digital twins, which enable the creation of virtual replicas of physical entities for real-time simulation and monitoring [24-28]. These technologies have expanded into city-scale applications known as digital twin cities [29-31], which collect real-time data through IoT and other sensors to support dynamic urban planning and decision-making [32, 33]. Digital twin systems contribute to cost efficiency, environmental optimization, and sustainable infrastructure development. Furthermore, they integrate seamlessly with metaverse platforms to support design testing, operational validation, and performance analysis [34-36].

The global work-from-anywhere (WFA) movement has also underscored the need for adaptable and resilient ICT infrastructure. Catalysed by the COVID-19 pandemic, WFA has influenced how governments and organizations structure their operations. Indonesia's Ministry of Finance, for instance, adopted Business Continuity Plans and Flexible Working Arrangements to ensure operational resilience through digital tools [37-39]. This shift signals a long-term structural transformation in how digital infrastructure is leveraged for governance, productivity, and public service delivery.

Comparative international experiences offer critical insights for planning Nusantara's ICT infrastructure. In Malaysia, the relocation of administrative functions to Putrajaya and the parallel development of Cyberjaya as a technology hub exemplify how capital relocation can be strategically aligned with ICT development and smart city initiatives [40-44]. In South Korea, augmented reality platforms like AR Incheon have been employed to promote smart tourism and immersive digital experiences [45]. Estonia, a global leader in digital governance, has implemented comprehensive e-citizenship frameworks, facilitating online public services and digital elections [46-48]. The United Arab Emirates, through the establishment of a Ministry of Artificial Intelligence, is advancing AI-driven public services in line with its national innovation strategy [49, 50]. Meanwhile, China has launched over 900 pilot smart cities, with Shanghai emerging as a global benchmark through the integration of digital twin technologies in urban planning and service delivery [51-55].

Finally, a review of national regulatory frameworks provides the institutional context for developing ICT systems in Nusantara. The SPBE [8] outlines the structural reforms needed to digitize public administration across all levels of government, emphasizing transparency, efficiency, and data integration. In parallel, the Satu Data Indonesia (One Data Policy) initiative [56] aims to standardize data governance and interoperability across public institutions. These frameworks form the foundation upon which a sustainable, secure, and integrated ICT infrastructure for Nusantara can be designed and validated.

3.2 Framework

The proposed framework for ICT infrastructure development in Indonesia's new capital, Nusantara, is structured to align with the principles of smart and green city development. The framework is conceptualized as a multi-layered model, comprising four interrelated levels that reflect the progression from foundational enablers to desired strategic outcomes. As illustrated in Figure 2, each level addresses a distinct area of focus, encompassing infrastructure readiness, technological integration, service delivery mechanisms, and sustainability goals. This layered approach is intended to ensure that the ICT infrastructure is not only scalable and adaptable to emerging technologies, but also capable of supporting long-term environmental and governance objectives within the context of Nusantara's development as a smart and ecologically responsible capital city.

The four levels of the proposed framework—prerequisites, technology enablers, strategic scope, and outcome indicators—are designed to be interdependent and mutually reinforcing. The prerequisites provide foundational readiness that enables the adoption of key technologies; these technologies, in turn, support strategic domains such as digital government, economy, and society. The outcomes reflect the impact of these domains and feed back into earlier levels, enabling iterative planning, policy refinement, and system upgrades. This structure ensures coherence, adaptability, and continuous improvement in line with the evolving needs of Nusantara's smart and green city vision.

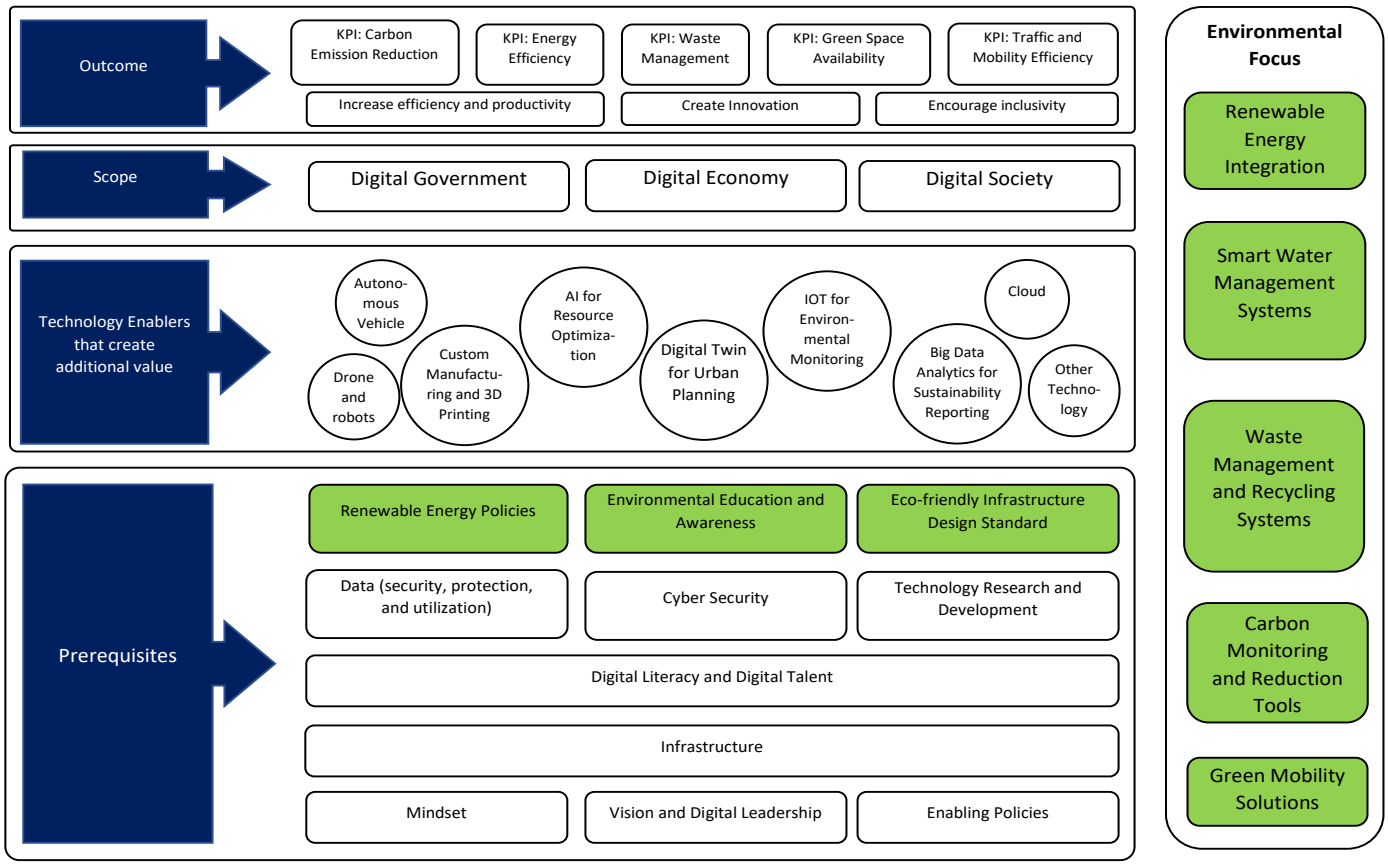

Figure 2. The ICT infrastructure development framework for the new capital [57]

3.2.1 Prerequisites level

The Prerequisites Level serves as the foundational layer of the proposed ICT infrastructure framework, encompassing the essential elements required to initiate and support the development of a sustainable, smart, and green digital ecosystem in Nusantara. This level comprises the following key components:

Mindset, Vision, and Digital Leadership: Establishing a shared national vision that emphasises digital transformation, environmental sustainability, and long-term innovation. Strong and inclusive leadership is essential to drive cross sectoral alignment and policy coherence.

Enabling Policies: Developing and harmonising regulatory frameworks that facilitate the integration of ICT with smart and green city objectives. This includes provisions for open data, interoperability, digital governance, and environmental standards.

Infrastructure Development: Building the necessary physical and digital infrastructure, including national data centres, high-speed communication networks, smart grids, and renewable energy systems to support ICT deployment.

Digital Literacy and Talent Development: Strengthening human capital through education, vocational training, and digital upskilling programmes to ensure the availability of a competent and future-ready workforce.

Data Management and Cybersecurity: Establishing robust mechanisms for data governance, privacy protection, and cybersecurity to ensure trust, resilience, and the responsible use of data assets across sectors.

Research and Development (R&D): Promoting innovation ecosystems that advance the adoption of frontier technologies, including AI, the IoT, and big data analytics, tailored to Indonesia's urban development priorities.

3.2.2 Technology enablers level

The Technology Enablers Level of the proposed ICT infrastructure framework identifies critical digital innovations that serve as catalysts for transformation and directly support the implementation of smart and green city principles in Nusantara. These technologies not only enhance the efficiency and responsiveness of urban systems but also contribute to long-term environmental sustainability. The key enabling technologies include:

AI: Facilitates data-driven decision-making, automates administrative and operational processes, and improves resource allocation and efficiency across various public service domains.

IoT: Enables continuous, real-time monitoring of environmental parameters, supports smart energy distribution systems, and allows for automated waste and water management, thereby promoting ecological balance and efficient service delivery.

Big Data Analytics: Provides powerful analytical capabilities to extract actionable insights from large volumes of structured and unstructured data. This supports predictive modelling, resource optimisation, and evidence-based policy formulation.

Cloud Computing: Offers scalable, flexible, and secure platforms for data storage, computing, and service deployment. It supports interoperability among government agencies and enhances digital resilience.

Digital Twins and Metaverse: Serve as immersive and interactive platforms for simulating urban planning, testing public policy scenarios, and visualising development outcomes. These technologies enable optimisation of design processes and reduce ecological risks through virtual validation before physical implementation.

Drones and Autonomous Vehicles: Improve urban mobility, logistics, and public safety through smart traffic management and remote monitoring. These technologies also contribute to carbon emission reductions by promoting cleaner transport alternatives.

Custom Manufacturing and 3D Printing: Enhance precision in construction and infrastructure development, reduce material waste, and support decentralised, on-demand production models that align with sustainable development goals.

Collectively, these technologies form the operational backbone of Nusantara's ICT infrastructure and enable the transition toward a more intelligent, efficient, and environmentally conscious capital city.

3.2.3 Scope level

The Scope Level defines the contextual pillars and primary focus areas guiding the development of ICT infrastructure in Nusantara. These domains reflect the broader functional outcomes that ICT systems are expected to enable and support within the framework of a smart and green capital city. The strategic domains are as follows:

Digital Government: Refers to the establishment of electronic governance (e-governance) systems that facilitate efficient, transparent, and accountable public administration. This includes integrated service portals, digital identity systems, and real-time data sharing across government agencies, enhancing decision-making and citizen access to services.

Digital Economy: Encompasses the promotion of economic transformation through digital innovation, entrepreneurship, and technology-enabled commerce. Digital platforms are leveraged to support start-ups, creative industries, financial inclusion, and smart logistics, driving inclusive and sustainable economic growth.

Digital Society: Focuses on building an inclusive and participatory society through the application of smart technologies. This includes enhancing digital literacy, improving citizen engagement in governance processes, and fostering sustainable urban living through the deployment of smart city applications in areas such as health, education, mobility, and public safety.

Together, these domains define the overarching purpose and societal impact of ICT infrastructure development in Nusantara, ensuring alignment with national priorities for innovation, equity, and sustainability.

3.2.4 Outcome level

The Outcome Level represents the final tier of the proposed ICT infrastructure framework, focusing on the intended goals and measurable impacts that reflect the success of implementation in the context of Nusantara as a smart and green capital. These outcomes serve as key performance indicators (KPIs) to evaluate the effectiveness, inclusiveness, and sustainability of the ICT systems. The primary outcome dimensions include:

Efficiency and Productivity: Demonstrated through streamlined administrative and operational processes, reduced resource consumption, and improved quality and timeliness of public service delivery. Digital automation and integration are leveraged to optimise workflows and reduce redundancy.

Innovation: Encompasses the continuous development, adoption, and diffusion of emerging technologies and digital practices. The framework supports dynamic innovation ecosystems that foster research, experimentation, and entrepreneurship.

Inclusivity: Ensures equitable access to digital infrastructure, services, and opportunities across all segments of society, including vulnerable and marginalised populations. Bridging the digital divide between urban and rural areas is prioritised to promote social equity.

Sustainability Metrics: Utilises quantifiable indicators to assess environmental performance, including reductions in energy consumption, carbon emissions, and waste generation. These metrics provide feedback for adaptive planning and support alignment with national and global sustainability targets.

These KPIs will be measured using quantifiable indicators such as electricity and water consumption levels, real-time public service response times, the adoption rate of digital platforms, and reductions in carbon emissions. Data will be collected through smart city monitoring systems and evaluated periodically to ensure alignment with national targets for sustainability, digital governance, and inclusive development.

This outcome-oriented level reinforces the framework's commitment to creating a digitally empowered, environmentally sustainable, and socially inclusive capital city that serves as a model for future urban development in Indonesia and beyond.

3.2.5 Environmental focus

Environmental sustainability is a central pillar of the proposed ICT infrastructure framework for Nusantara, reflecting the broader vision of developing a capital city that is both smart and ecologically responsible. In alignment with national and global climate agendas, the Environmental Focus element complements all levels of the framework—from prerequisites to outcomes—by embedding sustainability principles and eco-centric practices throughout ICT development.

This cross-cutting component consists of six key focus areas:

Renewable Energy Integration: ICT infrastructure is designed to operate on clean and renewable energy sources such as solar, wind, and hydro. This reduces reliance on fossil fuels and contributes directly to the reduction of greenhouse gas emissions. Integration with smart energy grids also ensures efficient energy use and distribution.

Smart Water Management Systems: The deployment of IoT-enabled water systems allows for real-time monitoring, leak detection, and water usage optimisation. These systems improve efficiency in water supply and contribute to the conservation of critical natural resources.

Waste Management and Recycling Systems: Digital technologies such as smart bins, data analytics, and automation support efficient solid waste management and promote circular economy practices. These systems enable better segregation, collection, and recycling of waste materials across urban environments.

Carbon Monitoring and Reduction Tools: Real-time data collection platforms and analytics engines are deployed to track carbon emissions across sectors. These tools support transparency and data-driven policymaking for emission reduction targets and sustainability reporting.

Green Mobility Solutions: Environmentally friendly transportation technologies such as electric vehicles, autonomous shuttles, smart public transit, and shared mobility platforms are integrated into the urban system. These solutions

reduce traffic congestion, minimise air pollution, and support low-carbon mobility.

Eco-Friendly Infrastructure Design Standards: The framework adopts green construction standards and sustainable architectural practices that reduce energy use, promote the use of environmentally friendly materials, and protect the surrounding ecosystem. Building Information Modeling (BIM) and digital twin technologies are employed to assess and optimise environmental performance before physical implementation.

By embedding these environmental focus areas into the broader ICT infrastructure framework, Nusantara's development can move beyond traditional digital transformation efforts to achieve climate-resilient, low-carbon, and ecologically integrated urban governance. These measures reinforce the role of ICT as not only an enabler of efficiency and innovation but also as a driver of environmental stewardship and long-term sustainability.

Several elements of this environmental focus have been successfully implemented in other global smart cities. For example, Singapore's Smart Water Grid uses IoT sensors to monitor water pressure and detect leaks in real time, reducing water loss and improving supply efficiency. In Seoul, the city's integrated green mobility system combines electric buses, autonomous shuttles, and real-time traffic management to reduce emissions and improve air quality. These international experiences serve as practical references that support the applicability of similar initiatives in Nusantara.

3.3 Ecosystem

The ICT ecosystem envisioned for Nusantara is structured into three interrelated components—Foundation, Resource, and Target—which collectively support the realisation of a smart and green capital city. This ecosystem-based approach ensures coherence across technological, institutional, and functional layers, enabling efficient integration and long-term sustainability. The structure of the ecosystem is depicted in Figure 3 and described as follows.

3.3.1 Foundation

The Foundation component represents the core principles guiding ICT development, positioning the new capital as a symbol of national identity that adheres to modern, international, and sustainable standards. It emphasises effective governance through the implementation of enabling regulations, sovereignty in digital infrastructure, robust information security, and institutional integration. These elements form the structural basis for ensuring legal compliance, operational stability, and long-term institutional resilience. The foundation aligns ICT development with the broader vision of Nusantara as a capital that reflects national pride, modernisation, and ecological responsibility.

3.3.2 Resource

The Resource component encompasses the infrastructure, technologies, and human capital required to support the ecosystem. It includes:

Network Infrastructure: Comprising public telecommunications networks for citizen access and intra-governmental networks for secure, high-integrity communications among government agencies.

Data Centers: Structured into three categories:

(1) *Green Data Centers*, which prioritise energy efficiency and environmental sustainability;

(2) *National Data Centers* for centralised data governance and policy enforcement; and

(3) *Peripheral Data Centers* to ensure redundancy, reliability, and disaster recovery capacity.

Digital Platforms: Integrate core functions of government administration, public services, business operations, academic collaboration, and city-wide sensor management. These platforms support interoperability and facilitate data-driven governance aligned with smart city and sustainability objectives.

Human Capital: Includes stakeholders from government, industry, academia, and civil society. Emphasis is placed on capacity building through continuous training, digital literacy initiatives, and environmental awareness campaigns to foster responsible use of green technologies and inclusive digital governance.

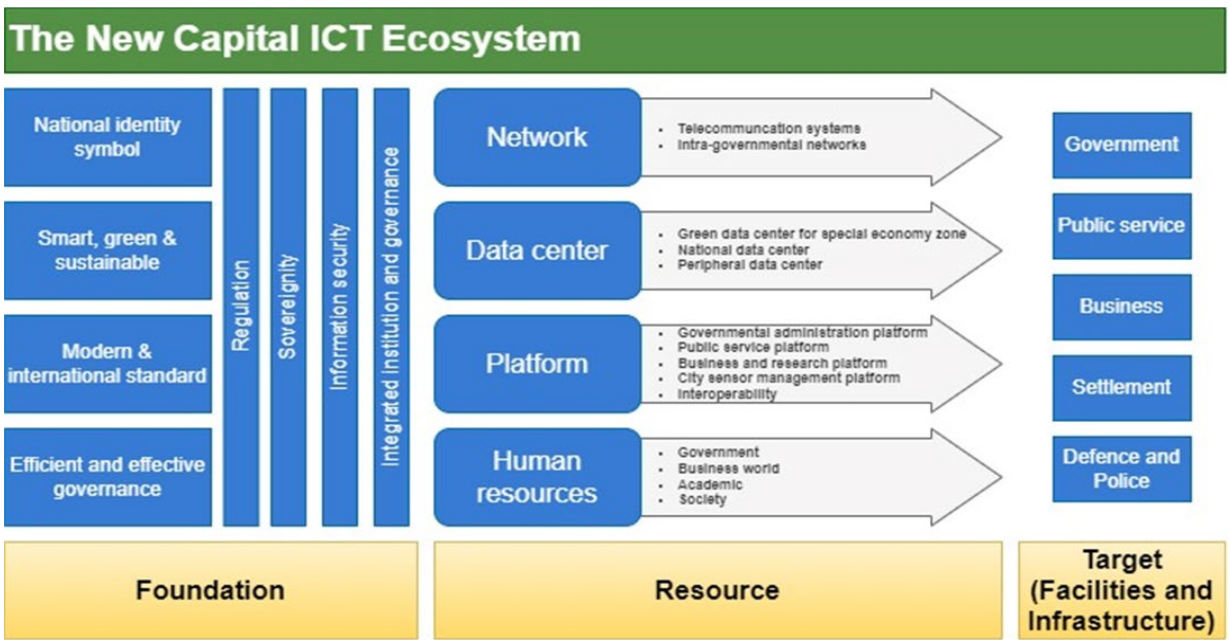

Figure 3. The new capital ICT ecosystem [57]

To ensure consistency and resilience across all layers of the ICT ecosystem, data governance and cybersecurity will be coordinated through a unified regulatory framework. This includes the implementation of secure, tiered national and peripheral data centers, standardized encryption protocols, and interoperable data-sharing policies. These mechanisms are designed to support sovereignty, reliability, and accountability in handling critical information throughout the infrastructure lifecycle.

To better anticipate challenges and guide risk mitigation strategies, a SWOT analysis was conducted for the proposed ICT ecosystem. This analysis provides a structured overview of internal and external factors that could affect successful implementation, as shown in Table 3.

Table 3. SWOT analysis of the proposed ICT ecosystem

Strengths	Weaknesses
- Strong alignment with national digital vision	- High dependency on reliable energy and connectivity infrastructure
- Multi-layered governance and regulatory integration	- Limited digital literacy in remote areas
- Scalable architecture and modular design	- Initial high investment and operational costs
Opportunities	**Threats**
- Potential for international collaboration and smart city pilots	- Cybersecurity risks and data breaches
- Acceleration of local innovation and digital economy	- Policy fragmentation across sectors and regions
- Environmental sustainability leadership at national level	- Resistance to change and institutional inertia

3.3.3 Target

The Target component outlines the functional areas where ICT is applied to achieve tangible societal, environmental, and economic benefits. These focus areas include:

Government Administration: Implementation of e-governance systems that promote transparency, efficiency, and accountability.

Public Services: Deployment of ICT to enhance healthcare, education, transportation, and utility services through smart applications.

Business and Economy: Facilitation of digital entrepreneurship, research collaboration, and smart infrastructure to support economic resilience and innovation.

Urban Settlements: Integration of green building practices, energy-efficient housing, and environmentally conscious planning tools.

Defense and Security: Application of AI-based surveillance and disaster management systems to strengthen urban resilience and emergency responsiveness.

Each target area supports environmental monitoring, energy conservation, and disaster preparedness while promoting digital inclusivity and equitable growth. The alignment of these components reinforces the role of ICT as both a technological enabler and a driver of sustainable urban transformation.

3.4 Smart city management system

The Smart City Management System proposed for Nusantara is structured to integrate advanced digital technologies with a hierarchical governance framework, thereby ensuring efficient urban management and long-term sustainability. This system plays a central role in coordinating urban functions, enhancing public service delivery, and enabling responsive governance.

As illustrated in Figure 4, the system comprises two main components, namely Smart City Administration and National Control.

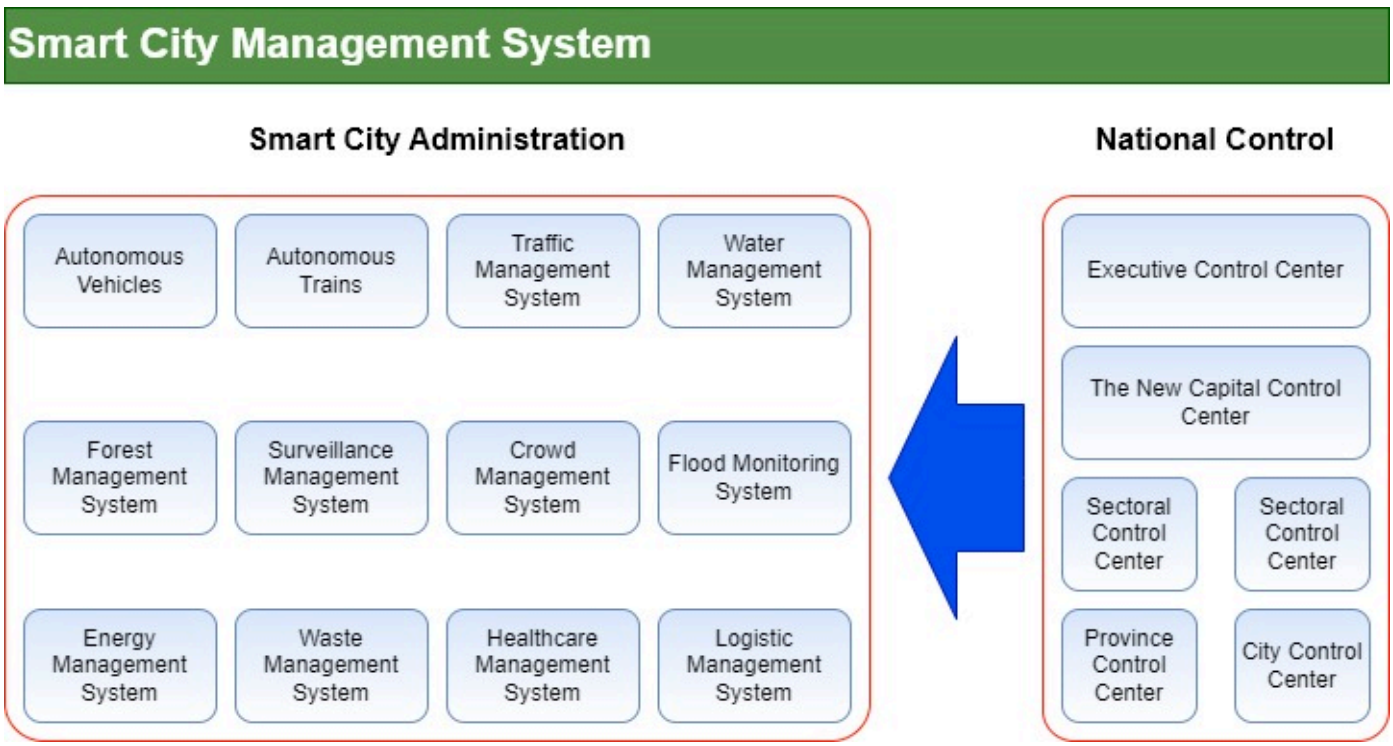

Figure 4. Smart city management system [57]

The Smart City Administration component is responsible for managing core urban functions and public services through the application of advanced technologies such as AI, the IoT, and big data analytics. It integrates a range of digital systems to enhance operational efficiency, environmental sustainability, and public welfare. Key features include:

Smart Mobility Systems: Integration of autonomous vehicles and autonomous rail systems to support efficient, low-emission transportation. A centralised traffic management system optimises traffic flow and reduces urban congestion and carbon emissions.

Water Management: Real-time monitoring and control of water distribution ensure optimal usage and conservation of water resources, contributing to sustainability goals and climate resilience.

Environmental and Forest Management: Utilisation of sensor networks and satellite data for biodiversity monitoring, forest conservation, and land-use planning to preserve ecological integrity.

Surveillance and Public Safety: Deployment of smart surveillance systems and urban monitoring tools to enhance security and enable proactive management of public spaces.

Crowd and Event Management: Real-time analytics and control systems are used to manage public gatherings, major events, and emergency evacuations.

Disaster Risk Reduction: Flood monitoring systems and predictive analytics enhance the city's disaster preparedness and adaptive capacity.

Energy and Waste Management: Implementation of smart energy systems to monitor consumption and efficiency, coupled with waste management systems that facilitate recycling, segregation, and waste reduction.

Healthcare and Logistics: Digital platforms streamline healthcare delivery and logistics management, ensuring inclusivity, service continuity, and supply chain resilience.

The National Control Center provides a hierarchical governance architecture for city-wide and national-level coordination. It comprises several operational layers:

Executive Control Center: Positioned at the national level, it oversees strategic governance, inter-ministerial coordination, and national emergency response.

New Capital Control Center: Manages city-wide ICT functions and ensures alignment with urban development policies and infrastructure integration.

Sectoral Control Centers: Monitor and regulate specific domains such as transportation, public health, waste management, and energy services.

Provincial and City Control Centers: Facilitate regional and local-level operations, enabling decentralised monitoring, rapid response, and adaptive service delivery.

Data flows in the Smart City Management System follow a hierarchical yet integrated architecture. For instance, real-time data from edge devices such as autonomous vehicles—collected through IoT sensors—is first transmitted to local aggregation nodes or Sectoral Control Centers (e.g., Transportation). This data is then filtered, processed, and relayed to the New Capital Control Center for further analysis and coordination. Critical summaries and strategic insights are forwarded to the National Control Center through secure cloud-based platforms and encrypted inter-agency networks. This multi-tiered data pipeline ensures real-time responsiveness, interoperability, and central oversight while maintaining data integrity and cybersecurity across levels.

These interconnected layers enable seamless communication, interoperability, and data-driven governance across multiple administrative levels, thereby enhancing operational resilience and policy alignment.

The Smart City Management System contributes not only to efficiency and productivity but also directly supports sustainability objectives. The use of KPIs—such as traffic flow efficiency, water recycling rates, waste reduction percentages, and energy savings—provides measurable metrics for evaluating the system's performance and its alignment with smart and green city principles.

To conceptually validate specific subsystems, a hypothetical simulation of the Advanced Traffic Management System (ATMS) is presented as shown in Figure 5. In this scenario, real-time data on traffic volume, speed, and travel time is captured via IoT sensors and autonomous vehicles across Nusantara's main corridors. The data is processed at the Transportation Sectoral Control Center to detect traffic offenses (e.g., speeding or illegal stopping) and generate violation records.

Figure 5. Overview of the advanced traffic management system (ATMS) features in Nusantara [58]

The system applies Origin-Destination matrix analysis and traffic simulation algorithms to reroute vehicles during congestion or incidents. Virtual violation data is forwarded to law enforcement systems via Electronic Traffic Law Enforcement (ETLE) integration, while summary reports are relayed to the National Control Center for policy coordination. The entire process is supported by unified ticketing systems, predictive analytics, and real-time dashboards, demonstrating how hierarchical data flow and decision-making occur within the Smart City Management System.

3.5 Framework validation

The validation of the proposed ICT infrastructure framework was carried out to assess its relevance, applicability, and alignment with the requirements for supporting smart and green city development in Nusantara. The validation process focused on three core components: the ICT Ecosystem, the Smart City Management System, and its consistency with the Nusantara Smart City Blueprint [11].

3.5.1 Ecosystem validation

The ecosystem validation assessed the framework's ability to support foundational requirements, including enabling policies, digital sovereignty, information security, and governance architecture. Infrastructural readiness—comprising network infrastructure, data centres, digital platforms, and human resource capacity—was evaluated to determine its effectiveness in supporting smart and sustainable technologies. The results indicated that the proposed ecosystem is well-structured, integrating renewable energy systems, green technologies, and environmentally conscious design standards. This integration demonstrates compatibility with long-term sustainability objectives and aligns with international smart city frameworks.

3.5.2 Smart city management system validation

Validation of the Smart City Management System involved conceptual assessments and scenario-based simulations to evaluate its capacity to manage essential urban systems using advanced digital technologies. The system was tested in relation to key operational domains, including traffic management, energy optimisation, waste recycling, and disaster response. These evaluations confirmed that the system facilitates real-time monitoring, enhances resource efficiency, and supports adaptive governance. The findings validate the system's capacity to deliver responsive and integrated smart city services while upholding environmental goals.

3.5.3 Alignment with Nusantara Smart City Blueprint

The final stage of validation compared the framework against the strategic objectives outlined in the Nusantara Smart City Blueprint [11], particularly those related to digital governance, sustainable infrastructure, and inclusive urban growth. The review confirmed that the proposed framework aligns with the national vision, ensuring compatibility with policy directions and development priorities. Its modular design ensures scalability and adaptability, making it suitable for long-term implementation and integration into broader national development strategies.

3.5.4 Summary of validation outcomes

The validation process confirms that the proposed ICT infrastructure framework is practical, scalable, and aligned with the strategic vision of developing Nusantara as a smart and green capital city. It offers a structured and adaptable approach to integrating digital innovation with sustainability, while addressing governance, resilience, and inclusivity. The framework supports proactive urban planning and policy implementation, enabling the new capital to respond effectively to future challenges and opportunities. While the validation was largely qualitative, selected quantitative indicators—such as traffic flow efficiency, service response time, and projected environmental impact—were referenced to strengthen the conceptual assessment.

To consolidate the findings, Table 4 summarizes the validation outcomes for each core component of the framework, highlighting their alignment with technical feasibility, operational robustness, and national development objectives.

Table 4. Summary of validation outcomes by component

Component	Validation Outcome
ICT Infrastructure Ecosystem	Proven scalability and readiness; aligned with national digital transformation goals
Smart City Management System	Functional architecture supports real-time monitoring and adaptive coordination
Alignment with Smart City Blueprint	Strong coherence with policy direction, implementation roadmap, and development targets

3.6 Discussion

The relocation of Indonesia's capital city to Nusantara presents a unique set of challenges, particularly in the development and integration of ICT infrastructure. In response, the proposed ICT framework offers a comprehensive and structured solution that incorporates smart technologies, sustainability principles, and multi-level governance into the planning and implementation processes.

This framework is designed to facilitate the efficient deployment of ICT systems that enable real-time monitoring, data-driven decision-making, and resource optimisation. By integrating technological, environmental, and institutional components, the framework supports a coordinated and adaptive approach to infrastructure development, essential for managing a city of national significance.

The staged implementation strategy emphasises the importance of central-to-local government coordination, as articulated in the Smart City Management System. This hierarchical governance model ensures the scalability, flexibility, and resilience of the ICT infrastructure, supporting sustainable urban development over time.

Validation results confirm the framework's alignment with three critical components: the ICT Ecosystem, the Smart City Management System, and the Nusantara Smart City Blueprint [11]. These evaluations demonstrate the framework's suitability for guiding the digital transformation of Nusantara, ensuring coherence with national goals and international best practices.

To support the realisation of smart and green city objectives, the framework incorporates environmentally conscious technologies such as energy-efficient systems, renewable energy integration, and sustainable waste management. These features are designed to ensure compliance with environmental targets and contribute directly to climate

resilience and ecological sustainability.

Overall, the proposed ICT infrastructure framework provides a robust foundation for Nusantara's development as a forward-looking capital city—one that is intelligent, inclusive, and environmentally sustainable.

4. CONCLUSIONS

The relocation of Indonesia's capital city from Jakarta to Nusantara necessitates extensive planning, particularly in the development of ICT infrastructure that aligns with smart and green city principles. This study has underscored the pivotal role of ICT in enabling efficient urban management, environmental sustainability, and integrated connectivity to support Nusantara's transformation into a technologically advanced and resilient capital.

This paper contributes to the field of smart city planning and ICT governance by proposing a context-sensitive, multi-level infrastructure framework specifically designed for Indonesia's new capital. The framework integrates technological, regulatory, and institutional dimensions to guide the sustainable and adaptive development of a smart and green city.

The proposed ICT infrastructure framework offers a scalable and sustainable roadmap for development. It integrates advanced technologies—including AI, the IoT, and big data analytics—to optimise resource utilisation, enhance energy efficiency, and improve the delivery of public services. Furthermore, the framework supports critical domains such as cybersecurity, economic development, education, and healthcare, ensuring an inclusive and future-proof urban ecosystem.

Validation of the framework against the ICT Ecosystem, the Smart City Management System, and the Nusantara Smart City Blueprint [11] confirms its coherence with national development strategies, sustainability objectives, and multi-level governance structures. The use of hierarchical control systems and digital twin simulations enables real-time monitoring, disaster response, and adaptive decision-making, thereby strengthening the framework's practicality and implementation readiness.

The development of ICT infrastructure should be approached in phased stages, incorporating strategic budget planning, execution oversight, and continuous evaluation. Once operational, the infrastructure is expected to catalyse physical development, support digital transformation, and facilitate the adoption of flexible work models, including work-from-anywhere schemes. To further enhance urban efficiency and scenario planning, the creation of a virtual capital city using digital twin technologies is recommended to simulate urban growth, infrastructure needs, and resource optimisation.

Further research should focus on:

Optimising network architectures to ensure seamless connectivity and system interoperability.

Integrating AI-driven solutions for real-time urban monitoring, traffic control, and environmental forecasting.

Expanding IoT applications for climate-sensitive areas such as water resource management, air quality monitoring, and energy distribution.

Enhancing cybersecurity frameworks and data protection mechanisms to safeguard critical infrastructure against evolving digital threats.

Conducting pilot implementations and scenario-based simulations to evaluate the framework's scalability, adaptability, and performance in real-world conditions.

In terms of implementation priorities, immediate policy action is required to establish enabling regulations, strengthen data governance and cybersecurity frameworks, and accelerate the development of core digital infrastructure such as data centers and broadband networks. These foundational steps are essential to support early-phase deployment. In contrast, more advanced initiatives—such as AI-based urban analytics, digital twin simulations, and integration of metaverse platforms—can be staged over time as the ecosystem matures and technical capacity increases.

By addressing these areas, future work can contribute to the refinement and advancement of sustainable ICT infrastructure models, ensuring that Nusantara evolves as a resilient, intelligent, and environmentally responsible capital city.

As a concrete next step, a pilot implementation of the proposed framework is recommended in a specific functional area of Nusantara—such as traffic management or smart utility systems. This initiative could be carried out in collaboration with the Otorita IKN to assess technical feasibility, infrastructure integration, and operational readiness, serving as a foundation for broader scaling and refinement.

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